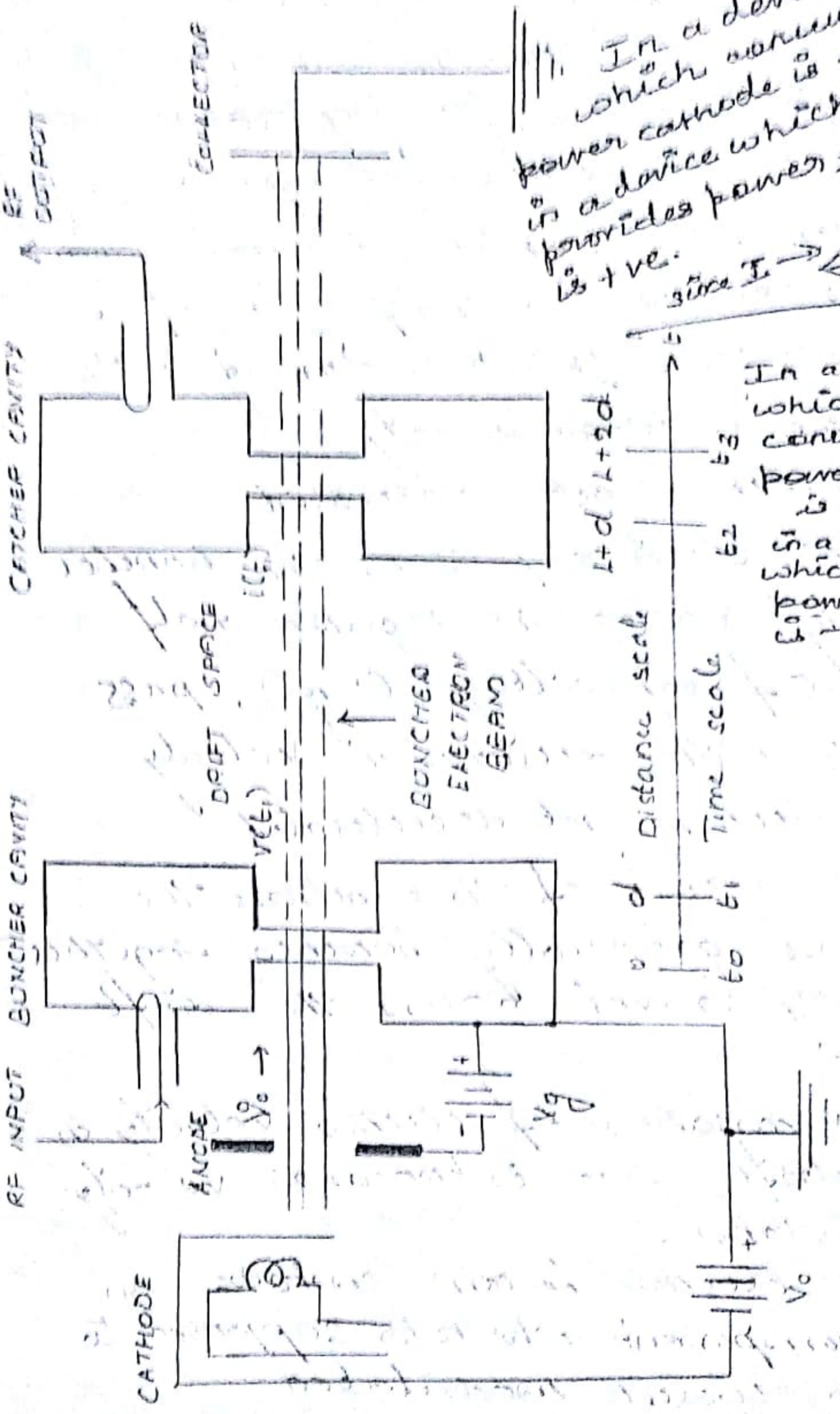
UNIT-II

MICROWAVE TUBES

TWO CAVITY KLYSTRON AMPLIFIER



In a device which consumes power cathode is -ve, in a device which provides power, cathode is +ve.

since I → ← e

In a device which consumes power anode is +ve, in a device which provides power anode is -ve.

→ It is widely used microwave amplifier operated by velocity & current modulation.

→ All electrons injected from the cathode arrive at the buncher cavity with uniform velocity

→ The electrons passing the buncher cavity at zeros of gap voltage V_g, pass through with unchanged velocity.

→ Electrons passing the buncher cavity during the positive half cycle of gap voltage (V_g), pass through with increase in ~~rotta~~ velocity.
i.e., electrons get accelerated.

→ The electrons passing the buncher cavity during the negative half cycle of gap voltage (V_g), pass through with decrease in velocity
i.e., electrons get decelerated.

→ As a result of these actions, the electrons gradually bunched together as they travel blocers the drift space.

→ The variation of electron velocity in the drift space is known as velocity modulation.

→ The electron beam contains an a.c component which is supposed to be a current modulated.

→ The maximum bunching should occur approximately midway between the catcher cavity.

→ Thus kinetic energy is transferred from electrons to the field of catcher cavity.

→ The electrons with reduced velocity finally terminated at the collector.

→ The cavity close to the cathode is known as buncher (or) i/p cavity which velocity modulates the i/p wave.

→ The other cavity known catcher cavity (or) o/p cavity catches energy from bunch electrons.

→ Characteristics of 2 cavity klystron amplifier as follows:

* efficiency - 40%
* power o/p ≃ 500kw
* power gain ≃ 30°

<u>Velocity Modulation Process</u>: When the electrons are first accelerated by high DC V_0 before entering the buncher cavity.

$$v_0 = \sqrt{\frac{2eV_0}{m}} \quad \text{— (1)}$$

V_0 → voltage

$$\text{velocity} = \sqrt{\frac{2 \times 1.63 \times 10^{-19} V_0}{9.109 \times 10^{-31}}} \quad \frac{J}{kg}$$

$$v_0 = 0.593 \times 10^6 \sqrt{V_0} \ m/s \quad \text{— (2)}$$

V_0 → applied voltage

→ In equn (5) it is assumed that electrons leave the cathode with zero velocity.

→ When a microwave signal is applied to the i/p terminal, the gap voltage b/w buncher cavity appears as,

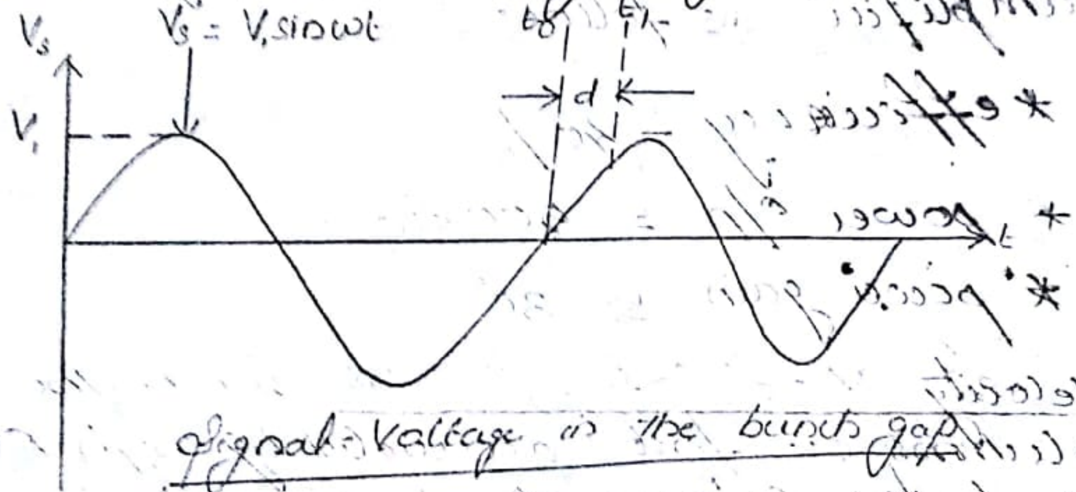
$$V_s = V_1 \sin\omega t \quad —⑤$$

V_s → signal voltage

V_1 → amplitude of the signal and

V_1 very much less than V_0 is assumed.

→ Inorder to find the modulated velocity in the buncher cavity in terms of either the entering time t_0 or the exit time t_1 and the gap transit angle θ_g as shown in the following figure,



Signal voltage in the bunch gap

→ The average transit time through the buncher gap distance 'd' is given by

$$\to \tau = \frac{d}{V_0} = t_1 - t_0 \quad —④$$

→ The average gap transit angle can be expressed as,

$$\theta_g = \omega\tau = \omega(t_1 - t_0) \quad \text{--- (5)}$$

$$\boxed{\theta_g = \omega \frac{d}{V_0}} \quad \text{------ (6)}$$

→ The average microwave voltage in the buncher gap can be found using.

$$V_s = \frac{1}{\tau}\int_{t_0}^{t_1} V_1 \sin\omega t \, dt \quad \text{--- (7)}$$

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

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

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

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

→ let $\omega t_0 + \dfrac{\omega d}{2V_0} = \omega t_0 + \dfrac{\theta_g}{2} = A$ ------ (9)

and $\dfrac{\omega d}{2V_0} = \dfrac{\theta_g}{2} = B$ ---- (10)

1/07/11 Expanding equa (10) using the following identity $\cos(A-B) - \cos(A+B) = 2\sin A \cdot \sin B$.

$$\cos\left(\omega t_0 + \frac{\theta_g}{2} - \frac{\theta_g}{2}\right) - \cos\left(\omega t_0 + \frac{\theta_g}{2} + \frac{\theta_g}{2}\right)$$

$$= 2\sin\left(\omega t_0 + \frac{\theta_g}{2}\right) \cdot \sin\left(\theta_g/2\right)$$

$$\cos(\omega t_0) - \cos(\omega t_0 + \theta_g) = 2\sin\left(\omega t_0 + \frac{\theta_g}{2}\right)\sin\left(\frac{\theta_g}{2}\right)$$

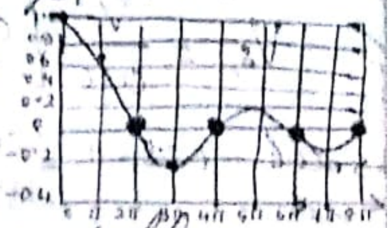
$$\therefore V_s = \frac{V_1}{\omega\tau}\left[2\sin\left(\omega t_0 + \frac{\theta_g}{2}\right)\cdot\sin\left(\frac{\theta_g}{2}\right)\right]$$

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

$$= \frac{V_1 \sin\left(\frac{\omega d}{2v_0}\right)}{\left(\frac{\omega d}{2v_0}\right)}\cdot\sin\left(\omega t_0 + \frac{\omega d}{2v_0}\right)$$

$$= \left[\frac{V_1 \sin(\theta_g/2)}{(\theta_g/2)}\cdot\sin(\omega t_0 + \theta_g/2)\right] \quad -(11)$$

where $\frac{\sin\left(\frac{\theta_g}{2}\right)}{(\theta_g/2)} = \beta_i$ where β_i is the Beam coupling coefficient — (12)



→ from equa (12), there are 2 different observations.

Observation (1): If the gap transit angle θ_g increases, the beam coupling coefficient β_i decreases.
i.e., Velocity modulation for a given microwave signal is decreased.

→ Observation ②: If the gap transit angle θ_g decreases, the beam coupling coefficient β_i ~~decreases~~ increase

ii, Velocity modulation for a given microwave signal is increased.

→ Immediately after velocity modulation, the exit velocity ~~from~~ the buncher gap is given by,

$$v(t_1) = \sqrt{\frac{2e}{m}\left[V_0 + \beta_i V_1 \sin\left(\omega t_0 + \frac{\theta_g}{2}\right)\right]} \quad (13)$$

$$= \sqrt{\frac{2e}{m} V_0 \left[1 + \beta_i \frac{V_1}{V_0} \sin\left(\omega t_0 + \frac{\theta_g}{2}\right)\right]} \quad (14)$$

where $\beta_i \frac{V_1}{V_0}$ is called as depth of velocity modulation.

→ On the assumption, $\beta_i V_1 << V_0$, equ ⑭ becomes,

$$v(t_1) = \sqrt{\frac{2e}{m} V_0 + \frac{2e}{m} V_0 \beta_i \frac{V_1}{V_0} \sin\left(\omega t_0 + \frac{\theta_g}{2}\right)} \quad (15)$$

$$= \sqrt{\frac{2e}{m} V_0} \left[1 + \beta_i \frac{V_1}{V_0} \sin\left(\omega t_0 + \theta_g/2\right)\right]^{1/2} \quad (16)$$

→ Using Binominal expansion & from equa⑤, equa ⑯ can be reduced to, under the assumption $\beta_i V_1 << V_0$

$$v(t_1) = v_0 \left[1 + \frac{\beta_i V_1}{2V_0} \sin\left(\omega t_0 + \frac{\theta_g}{2}\right)\right] \quad (17)$$

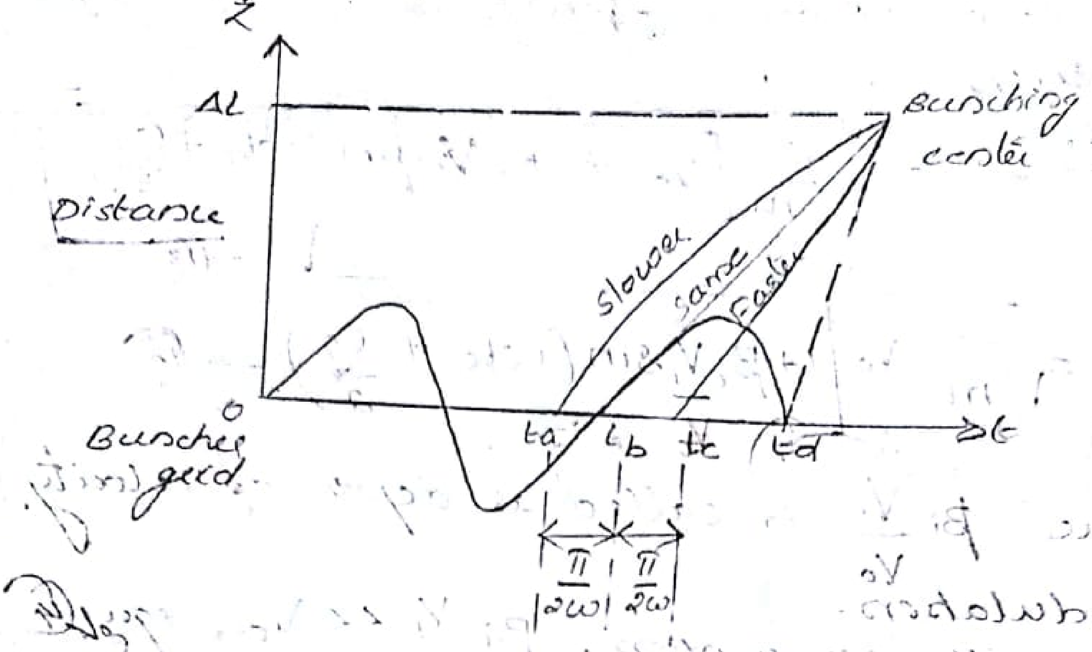
(or)

$$= v_0 \left(1 + \frac{\beta_i V_1}{2V_0} \sin\left(\omega t_1 - \theta_g/2\right)\right) \quad (18)$$

where equa (17) & (18) jointly forms the equation of velocity Modulation.

<u>Bunching Process</u>: Once the electrons leave the buncher cavity. They drift with the velocity given by equa (17) & (18).

<u>Bunching distance</u>:



→ The effect of velocity modulation produces bunching of electron beam.

→ The electrons that move with same velocity form the bunching centre.

→ The electrons that pass through the buncher cavity during positive half cycle of microwave input voltage travel faster than electrons with same velocity.

→ The electrons that pass through the buncher cavity during ~~positive~~ negative half cycle of microwave i/p voltage band flower that electrons with same velocity.

→ The above figures show the trajectories of minimum, zero & maximum electron acceleration.

→ The distance from the buncher grid to the location of dense electron bunching for the electron at time t_b is given by.

$$\Delta L = V_0 (t_d - t_b) \quad \text{--- (19)}$$

$$\Delta L = V_0 (t_d - t_a) \quad \text{--- (20)}$$

$$= V_{min} (t_d - t_b + \pi/2\omega) \quad \text{--- (21)}$$

$$\Delta L = V_0 (t_d - t_c) \quad \text{--- (22)}$$

$$= V_{max} (t_d - t_b - \pi/2\omega) \quad \text{--- (23)}$$

The minimum and maximum velocities can be obtained from equations of velocity modulation as follows,

$$V_{min} = V_0 \left[1 - \frac{\beta_i V_1}{2 V_0}\right] \quad \text{--- (24)}$$

$$V_{max} = V_0 \left[1 + \frac{\beta_i V_1}{2 V_0}\right] \quad \text{--- (25)}$$

sub (24) in (21)

$$\therefore \Delta L = V_0 \left[1 - \frac{\beta_i V_1}{2 V_0}\right] (t_d - t_b + \pi/2\omega).$$

$$= \left[V_0 - \frac{\beta_i V_1 V_0}{2 V_0}\right] (t_d - t_b + \pi/2\omega) \quad \text{(26)}$$

$$= V_0 t_d - V_0 t_b + V_0 \pi/2\omega - \frac{\beta_i V_1 V_0 t_d}{2 V_0} + \frac{\beta_i V_1 V_0 t_b}{2 V_0} - \frac{\beta_i V_1 V_0}{2 V_0} \cdot \pi/2\omega$$

$$\therefore \Delta L = V_0 (t_d - t_b) + \left[V_0 \frac{\pi}{2\omega} - V_0 \frac{\beta_i V_1}{2V_0} (t_d - t_b) - V_0 \frac{\beta_i V_1}{2V_0} \cdot \frac{\pi}{2\omega} \right] \quad \text{—— (26)}$$

Sub equa (25) in (23).

$$\Delta L = V_0 \left[1 + \frac{\beta_i V_1}{2V_0} \right] (t_d - t_b - \pi/2\omega)$$

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

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

$$\therefore \Delta L = V_0 (t_d - t_b) - V_0 \frac{\pi}{2\omega} + V_0 \frac{\beta_i V_1 t_d}{2V_0} - V_0 \frac{\beta_i V_1 t_b}{2V_0} - V_0 \frac{\beta_i V_1}{2V_0} \cdot \frac{\pi}{2\omega}$$

$$\Delta L = V_0 (t_d - t_b) + \left[- V_0 \frac{\pi}{2\omega} + V_0 \frac{\beta_i V_1}{2V_0} t_d - V_0 \frac{\beta_i V_1}{2V_0} t_b - V_0 \frac{\beta_i V_1}{2V_0} \cdot \frac{\pi}{2\omega} \right] \quad \text{—— (27)}$$

The necessary conditions for those electrons at t_a, t_b, t_c to meet the same distance Δ_1 by equating to zero.

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

$$V_0 \frac{\pi}{2\omega} - V_0 \frac{\beta_i V_1}{2V_0}\left[t_d - t_b + \frac{\pi}{2\omega}\right] = 0 \quad \text{—— (29)}$$

$$\cancel{V_0} \frac{\pi}{\cancel{2}\omega} = \cancel{V_0} \frac{\beta_i V_1}{\cancel{2}V_0}\left[t_d - t_b + \frac{\pi}{2\omega}\right]$$

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

$$t_d - t_b = \frac{\pi V_0}{\beta_i V_1 \omega} - \frac{\pi}{2\omega} \quad (18)$$

$$\beta_i V_1 << V_0$$

$$t_d - t_b \simeq \frac{\pi V_0}{\beta_i V_1 \omega} \quad \text{—— (30)}$$

→ Product equa (30) in (27)

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

$$= V_0(t_d - t_b) + \left[-V_0 \frac{\pi}{2\omega} + V_0 \frac{\cancel{\beta_i V_1}}{2\cancel{V_0}} \times \frac{\pi V_0}{\cancel{\beta_i V_1}\omega} - V_0 \frac{\beta_i V_1}{2V_0} \cdot \frac{\pi}{2\omega}\right]$$

$$= V_0 \times \frac{\pi V_0}{\beta_i V_1 \omega} + \left[-V_0 \frac{\pi}{2\omega} + V_0 \frac{\pi}{2\omega} - V_0 \frac{\beta_i V_1}{2V_0} \frac{\pi}{2\omega} \right]$$

$$= \frac{\pi V_0^2}{\beta_i V_1 \omega} + V_0 \frac{\pi}{2\omega} \left[-\frac{\beta_i V_1}{2V_0} \right]$$

$$= V_0 \cdot \frac{\pi V_0}{\beta_i V_1 \omega} \cancel{+} \cancel{V_0} \cdot \frac{\pi \beta_i V_1}{4\omega \cancel{V_0}}$$

$$\boxed{\Delta L = V_0 \frac{\pi V_0}{\omega \beta_i V_1}} \longleftarrow (31)$$

(or)

$$\Delta L = V_0 (t_d - t_b)$$

$$\boxed{\Delta L = V_0 \frac{\pi V_0}{\beta_i V_1 \omega}} \longleftarrow (31) \quad t_d - t_b \simeq \frac{\pi V_0}{\beta_i V_1 \omega}$$

$\beta_i V_1 << V_0$

<u>What should be the spacing between Buncher and Catcher Cavities inorder to achieve maximum degree of Bunching :-</u>

→ The transit time T is given by,

$$T = t_2 - t_1 \longleftarrow (32)$$

$$\rightarrow T = \frac{L}{V(t_1)} \longleftarrow (33)$$

(57)

$$T = \frac{l}{v_0\left[1 + \frac{\beta_i V_1}{2V_0}\sin(\omega t_1 - \theta_g/2)\right]}$$

$$T = T_0\left[1 - \frac{\beta_i V_1}{2V_0}\sin\left(\omega t_1 - \frac{\theta_g}{2}\right)\right] \quad \text{— (57)}$$

→ The above equations can be expressed in radians as,

$$\omega T = \omega t_2 - \omega t_1$$

$$\omega T = \omega T_0 - \frac{\beta_i V_1}{2V_0}\omega T_0 \sin\left(\omega t_1 - \frac{\theta_g}{2}\right) \quad \text{— (58)}$$

$$\theta = \theta_0 - X\sin(\omega t_1 - \theta_g/2) \quad \text{— (59)}$$

where X → Bunching Parameter

$$X = \frac{\beta_i V_1}{2V_0}\omega T_0$$

$$\boxed{\theta_0 = \omega T_0 = \frac{\omega L}{v_0}} \quad \text{— (58)}$$

→ θ_0 is DC transit angle b/w cavity's.

28/07/11 At buncher cavity gap, a charge dQ_0 passing through a time interval dt_0 is given by

$$dQ_0 = I_0\,dt_0 \quad \text{— (59)}$$

where I_0 is the DC current

→ From the principle of conservation of charges, the same amount of charge dQ_0 also passes the catcher cavity at a later time interval dt_2 is given by.

$$dQ_0 = i_2 dt_2 \quad \text{--- (40)}$$

where i_2 is the current at catcher cavity.

$$T = t_2 - t_1$$

$$t_2 = T + t_1$$

$$t_2 = T + t_0 + \tau \quad \text{--- (41)}$$

sub (35) in (41),

$$t_2 = t_0 + \tau + T_0\left[1 - \frac{\beta_i V_1}{2V_0}\sin\left(\omega t_0 + \theta_g/2\right)\right] \quad \text{--- (42)}$$

(in terms of t_0).

→ Expressing the equa in terms of radians

$$T = t_2 - t_1$$

$$\omega T = \omega t_2 - \omega t_1$$

where X → Bunching Parameter

$$\theta_0 - X\sin\left(\omega t_0 + \frac{\theta_g}{2}\right) = \omega t_2 - \omega t_1$$

$$\omega t_1 = \omega t_0 + \theta g$$

$$= \omega t_0 + \frac{\theta g}{2} + \frac{\theta g}{2}$$

$$= \omega t_2 - \left(\omega t_0 + \frac{\theta g}{2} + \frac{\theta g}{2}\right)$$

$$\theta_0 - X\sin\left(\omega t_0 + \frac{\theta g}{2}\right) = \omega t_2 - \omega t_0 - \frac{\theta g}{2} - \frac{\theta g}{2}$$

$$\left(\omega t_0 + \frac{\theta g}{2}\right) - X\sin\left(\omega t_0 + \frac{\theta g}{2}\right) = \omega t_2 - \theta_0 - \frac{\theta g}{2}$$

$$\left(\omega t_0 + \frac{\theta g}{2}\right) - X\sin\left(\omega t_0 + \frac{\theta g}{2}\right) = \omega t_2 - \left(\theta_0 + \frac{\theta g}{2}\right)$$

$\left(\omega t_0 + \theta g/2\right)$ → buncher cavity departure angle

$\omega t_2 - \left(\theta_0 + \frac{\theta g}{2}\right)$ → catcher cavity arrival angle.

$$\frac{dt_2}{dt_0} = 1+0+0 - \tau_0 \frac{\beta_i V_1}{2V_0} \cos\left(\omega t_0 + \frac{\theta_g}{2}\right) \cdot \omega$$

$$= 1 - \theta_0 \frac{\beta_i V_1}{2V_0} \cos\left(\omega t_0 + \frac{\theta_g}{2}\right)$$

$$\frac{dt_2}{dt_0} = 1 - x \cos\left(\omega t_0 + \frac{\theta_g}{2}\right)$$

$$dt_2 = dt_0 \left[1 - x \cos\left(\omega t_0 + \theta_g/2\right)\right] \quad \text{--- (44)}$$

→ By equating equ (39) & (45).

$$I_0 \, dt_0 = i_2 \, dt_2$$

$$I_0 \, \cancel{dt_0} = i_2 \cdot \cancel{dt_0} \left[1 - x\cos\left(\omega t_0 + \theta_g/2\right)\right]$$

$$I_0 = i_2 \left[1 - x\cos\left(\omega t_0 + \theta_g/2\right)\right]$$

$$\boxed{i_2 = \frac{I_0}{\left[1 - x\cos\left(\omega t_0 + \theta_g/2\right)\right]}}$$

→ The current arriving at the catcher cavity is given by,

$$i_2(t_0) = \frac{I_0}{1 - x\cos\left(\omega t_0 + \frac{\theta_g}{2}\right)} \quad \text{--- (46)}$$

→ In terms of t_2, the current arriving at catcher cavity is given by,

$$i_2(t_2) = \frac{I_0}{1 - x\cos\left(\omega t_2 - \theta_0 - \frac{\theta_g}{2}\right)} \quad \text{--- (47)}$$

→ Assuming that the beam current at the catcher cavity to be a periodic waveform, i_2 can be expanded in Fourier Series as follows.

$$i_2 = a_0 + \sum_{n=1}^{\infty} \left[a_n \cos(n\omega t_2) + b_n \sin(n\omega t_2) \right] \quad \text{—— (48)}$$

→ The series co-efficient a_0, a_n & b_n are given by,

$$a_0 = \frac{1}{2\pi} \int_{-\pi}^{\pi} i_2 \, d(\omega t_2) \quad \text{—— (49)}$$

$$a_n = \frac{1}{\pi} \int_{-\pi}^{\pi} i_2 \cos(n\omega t_2) \, d(\omega t_2) \quad \text{—— (50)}$$

$$\boxed{b_n = \frac{1}{\pi} \int_{-\pi}^{\pi} i_2 \sin(n\omega t_2) \, d(\omega t_2)} \quad \text{—— (51)}$$

$$a_0 = \frac{1}{2\pi} \int_{-\pi}^{\pi} I_0 \, d(\omega t_0)$$

$$\boxed{a_0 = I_0} \quad \text{—— (52)}$$

$$a_n = \frac{1}{\pi} \int_{-\pi}^{\pi} I_0 \cos\left[(n\omega t_0 + n\theta_g + n\theta_0) + n X \sin\left(\omega t_0 - \theta_g/2\right) \right] \quad \text{—— (53)}$$

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$$b_n = \frac{1}{\pi}\int_{-\pi}^{\pi} I_0 \sin\left[(n\omega t_0 + n\theta_g + n\theta_0) + nX\sin(\omega t_0 + \theta_g/2)\right] d\omega t_0 \quad (54)$$

→ By using a trigonometric functions, $\sin(A+B)$ & $\cos(A+B)$ & using a Bessel function. a_n & b_n is given by,

$$a_n = 2I_0 J_n(nX)\cos(n\theta_g + n\theta_0) \quad (55)$$

$$b_n = 2I_0 J_n(nX)\sin(n\theta_g + n\theta_0) \quad (56)$$

where $J_n(nX)$ is n^{th} order Bessel function

sub equa (52), (55) & (56) in (48). yields beam current i_2

$$i_2 = I_0 + \sum_{n=1}^{\infty} 2I_0 J_n(nX)\cos\left[n\omega(t_2 - \tau - T_b)\right] \quad (57)$$

→ The magnitude of beam current is given by,

$$I_f = 2I_0 J_1(X)$$

→ Assuming that I_f has its maximum amplitude at $X = 1.841$ — (59)

→ The optimum distance 'L' at which the maximum fundamental component of current occurs is computed from equations

$$\theta_0 = \frac{\omega L}{V_0}, \quad X = \frac{\beta_i V_1 \theta_0}{2V_0}$$

→ from above equations, sub..

$$1.841 = \frac{\beta_i V_1 \theta_0}{2V_0}$$

$$= \frac{\omega L}{V_0} \frac{\beta_i V_1}{2V_0}$$

$$L = \frac{1.841 \times 2 V_0 v_0}{\omega \cdot \beta_i V_1}$$

$$\boxed{L_{optimum} = \frac{3.682 V_0 v_0}{\beta_i \omega V_1}} \quad \text{—— (66)}$$

Output Power & Beam Loading

Induced current in Catcher Cavity

Since the current induced by the electron beam in the walls of the catcher cavity is directly proportional to amplitude of microwave input voltage V_1

→ Therefore, the fundamental component of induced microwave current in the catcher cavity is given by,

$$i_2\, ind = \beta_0 i_2 \quad \text{—— (61)}$$

→ sub (61) in (57)

$$i_2\, ind = \beta_0 \left[I_0 + \sum_{n=1}^{\infty} 2 I_0 J_n(nX) \cos[n\omega(t_2 - \tau - T\right.$$

sub $n = 1$,

$I_{2ind} = \beta_0 2 I_0 J_1(x) \cos[\omega(t_2 - \tau - T_0)]$ — (62)

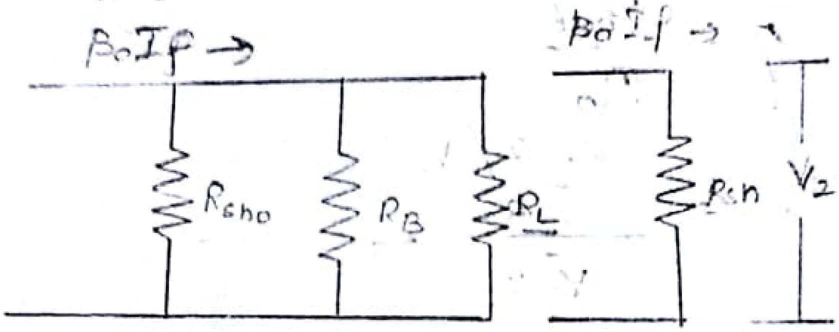
where $\beta_0 \rightarrow$ Beam coupling coefficient in catcher cavity,

→ If buncher and catcher cavities both are identical $\beta_i = \beta_0$.

→ Therefore, the fundamental component of the current induced in the catcher cavity has a magnitude.

$$I_{f,ind} = \beta_0 I_f \quad \text{— (63)}$$

$$I_{f\,ind} = \beta_0 2 I_0 J_1(x) \quad \text{— (64)}$$



where $R_B \rightarrow$ Beam coupling Resistance

$R_L \rightarrow$ ~~Ef~~ External Load "

$R_{sh} \rightarrow$ Effective shunt ,

$R_{sho} \rightarrow$ wall resistance of catcher cavity

∴ The o/p power delivered to the catcher cavity and load is given by

$$P_{in} = V_0 I_0 \quad \text{— (65)}$$

$$P_{out} = \frac{V^2}{2} \cdot R_{sh}$$

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$$P_{out} = \left(\frac{\beta_0 I_f}{2}\right)^2 R_{sh}$$

$$= \frac{\beta_0^2 I_f^2 R_{sh}}{2}$$

$$P_{out} = \frac{\beta_0 I_f}{2} \cdot \beta_0 I_f R_{sh}$$

$$\boxed{P_{out} = \frac{\beta_0 I_f}{2} V_2} \quad \text{--- (66)}$$

→ The efficiency of the two cavity klystron amplifier is,

$$\eta = \frac{P_{out}}{P_{in}}$$

$$= \frac{\frac{\beta_0 I_f V_2}{2}}{V_0 I_0}$$

$$\boxed{\eta = \frac{\beta_0 I_f V_2}{2 V_0 I_0}} \quad \text{--- (67)}$$

→ Maximum electronic efficiency of a 2 cavity klystron amplifier is about 58%.

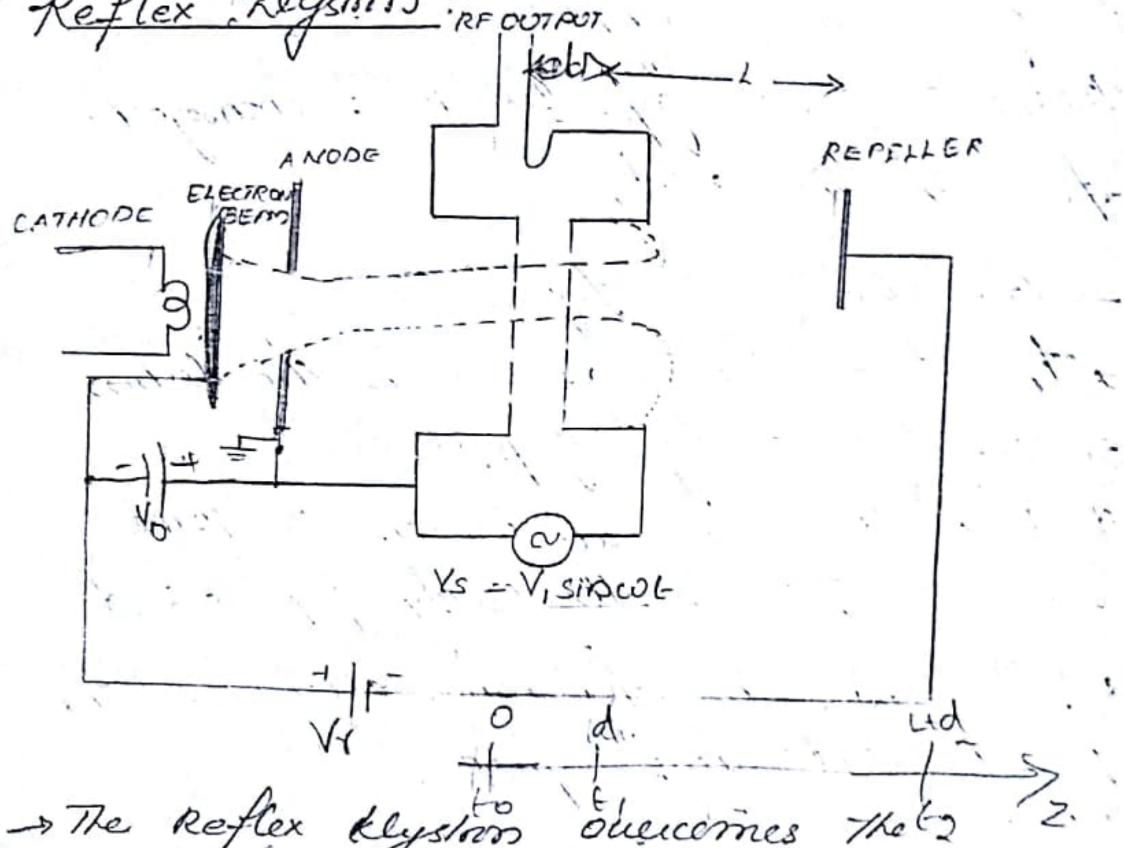
→ In practice the electronic efficiency of klystron amplifier is in the range of 15-30%.

Disadvantage :

→ The reflected wave will produce a positive feedback where as the oscillator should produce a negative feedback. as the reflected wave changes its resonant frequency of the buncher & resonant cavity.

→ The reflected waves will affect the 2 cavities, due to this positive feedback will not be produced instead the oscillator will produce negative feedback.

Reflex Klystron :



→ The Reflex klystron overcomes the disadvantage 2 cavity klystron amplifier.

→ It is a low power generator of 10-500mW in the frequency range of 1-25 GHz.

→ The electron beam injected from the cathode is velocity modulated by cavity gap voltage.

→ Some electrons are accelerated by the accelerating field, enter the repeller space with increased velocity.

→ Some electrons decelerated by the according speed enter the repeller speed with decrease in volt velocity.

→ All electrons turned around by the repeller voltage passed through the cavity gap in bunches.

→ When the electrons are reflected, the bunched electrons pass through the gap during the retarding phase and give up their kinetic energy ~~through~~ electromagnetic field in the cavity.

→ from the above figure,

* t_0 is the time at which the electron enters the cavity gap, at $z=0$.

* t_1 is the time at which the same electron reaches the cavity gap at $z=d$.

* t_2 is the time for same electron returned by the retarding speed.

→ The electron entering the cavity gap at $z=0$ and time t_0 is, assumed to have uniform velocity.

→ where $v_0 = 0.593 \times 10^6 \sqrt{V_0}$ m/s —— (68)

v_0

→ The same electron leaves the cavity gap at $z=d$ at time t_1 with velocity $v(t_1)$ is given by,

$$v(t_1) = v_0\left[1 + \frac{\beta_i V_1}{2V_0}\sin\left(\omega t_1 - \frac{\theta_g}{2}\right)\right] \quad \text{—— (69)}$$

→ The same electron is forced back to the cavity at $z=d$ and time t_2 by the retarding electric field E is given by.

$$E = \frac{V_0 + V_r + V_1\sin\omega t}{L} \quad \text{—— (70)}$$

→ assuming retarding electric field to be constant in z direction.

$$m\frac{d^2z}{dt^2} = -eE \quad \text{—— (71)}$$

Sub (70) in (71).

$$\rightarrow m\frac{d^2z}{dt^2} = -e\left[\frac{V_0 + V_r + V_1\sin\omega t}{L}\right]$$

$$V_1\sin\omega t << (V_r + V_0)$$

$$\rightarrow m\frac{d^2z}{dt^2} = -e\left[\frac{V_r + V_0}{L}\right] \quad \text{—— (72)}$$

$$\frac{d^2z}{dt^2} = -e\left[\frac{V_r + V_0}{mL}\right] \quad \text{—— (73)}$$

→ On integrating we get,

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

$$= \frac{-e(V_r + V_0)}{mL} \int_{t_1}^{t} dt$$

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

$$\boxed{\frac{dz}{dt} = -e \frac{\left[V_r + V_0 \right]}{mL} \left[t - t_1 \right] + k_1} \quad \text{— (14)}$$

at $t = t_1$, $\frac{dz}{dt} = v(t_1) = k_1$

$$\therefore \frac{dz}{dt} = -e \frac{(V_r + V_0)}{mL} \left[t - t_1 \right] + v(t_1) \quad \text{— (15)}$$

→ On integrating again,

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

$$z = \frac{-e(V_r + V_0)}{mL} \int_{t_1}^{t} (t - t_1)\, dt + v(t_1) \int_{t_1}^{t} dt$$

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

$$z = \frac{-e(V_r + V_0)}{2mL} (t - t_1)^2 + v(t_1)(t - t_1) + k_2 \quad \text{— (16)}$$

at $t = t_1$, $z = d = k_2$

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

On the assumption that electron leaves the cavity gap at $z=d$ at time t with a velocity $v(t_1)$ and returns to the gap at $z=d$, and time t_2 then $t=t_2$.

Substituting these assumption in (17),

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

$$\frac{-e(V_r+V_0)}{2mL}(t_2-t_1)^2 + v(t_1)(t_2-t_1) = 0$$

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

$$\boxed{(t_2-t_1) = T' = \frac{2mL\,v(t)}{e(V_r+V_0)}} \quad \text{— (78)}$$

where $T' = T_0'\left[1 + \frac{\beta_i V_1}{2V_0}\sin\left(\omega t_1 - \frac{\theta_g}{2}\right)\right]$

Round trip transit time — (79)

where.

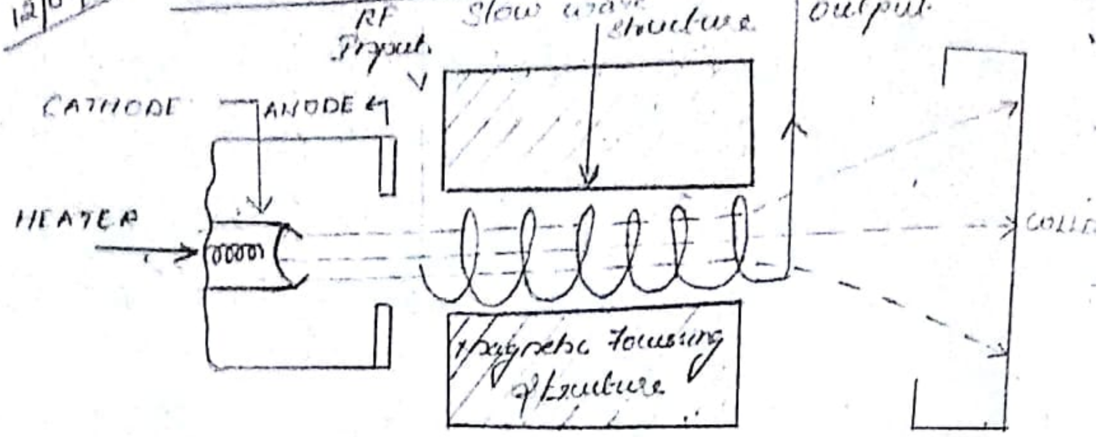
$$\boxed{T_0'' = \frac{2mL\,v_0}{e(V_r+V_0)}} \quad \text{— (80)}$$

$$\omega T' = \omega T_0'\left[1 + \frac{\beta_i V_1}{2V_0}\sin\left(\omega t_1 - \frac{\theta_g}{2}\right)\right].$$

$$\omega(t_2-t_1) = \theta_0' + \theta_0'\frac{\beta_i V_1}{2V_0}\sin\left(\omega t_1 - \theta_g/2\right)$$

$$\boxed{X'' = \theta_0' \frac{\beta_i V_1}{2V_0}} \quad \text{— (81)}$$

12/07/11 HELIX TRAVELLING WAVE TUBE



→ A mechanical wave is a disturbance which is created by an vibrating object and subsequently travels through a medium from one location to another, transporting energy as it moves.

→ The mechanism by which by a mechanical wave propagates itself through a medium involves particle interaction, one particle applys a push (or) pull on its adjacent neighbour, causing a displacement of that neighbour from ~~its~~ equilibrium (or) rest position.

→ As a wave is observed through a travelling medium, a crest is seen moving along from particle to particle.

→ The crest is followed by a trough which is inturn followed by a crest

→ The sine wave pattern continues to move in a uninterrupted fashion until it encounters a boundary (or) another wave along the medium.

→ (The type of wave pattern which is observed travelling through a medium is referred to as travelling wave.)

→ A Travelling Wave tube (TWT) was invented by Rudolf Kompfner in the year 1942

→ A TWT is an electronic device used to amplify RF signals to high power.

→ It operates in the frequency range from (300 MHz - 50 GHz).

Construction:

→ TWT is contained within a glass vacuum tube

→ Within the TWT, the first element is the electron gun comprising primarily of a heated cathode and anode. This produces and then accelerates a beam of electrons that travel along the length of the tube.

→ In order that the electrons are made to travel as a tight or narrow beam along the length of the TWT, a magnetic focussing structure is included.

→ The field from the magnet keeps the beam as narrow as required. The Helix TWT consist of an electron gun and slow wave structure

→ A slow wave structure is nothing but a special circuit that are used in microwave tube to reduce the wave voltage in a certain direction so that the electron beam and the signal can interact. ✓

→ The applied signal propagates around turns of the helix and produces an electric field at the center of the helix

→ The axial electric field propagates through the center of the helix

→ When the electrons enter the helix tube, an interaction takes place b/w moving axial electric field and the moving electrons

· The electrons transfer kinetic energy of the wave on the helix

→ The electrons entering the helix at zero field are not affected by the wave

→ Electrons entering the helix at accelerating speed are accelerated.

→ Electrons entering the helix at the retarding speed are decelerated

→ As the electrons travel further along the helix they bunch at the collector, then the microwave energy of the electrons is delivered by the electron bunch to the wave on the helix.

→ The current produced by the axial electric field is convection current.

Amplification Process in TWT: When a signal voltage is coupled to the helix, the axial electric field exerts a force on the electrons yields following results

$$F = -eE \quad \text{--- (8.2)}$$

$$E = -\nabla V \quad \text{--- (8.3)}$$

e → charge of electron

E → Electron field

The electrons entering the retarding field are decelerated and those in accelerating field are accelerated because in retarding field more electrons are formed and hence more interaction leading to amplification of signal

→ Since the velocity of electron is slightly greater than wave velocity, more electrons are in the retarding field so more amount of energy is transferred from the beam to the electromagnetic field

→ The microwave signal voltage is thus amplified by the amplified field

characteristics of TWT

→ frequency range 3GHz ↑

→ efficiency 20-40%

→ Power Gain – upto 60dB

→ o/p power in kW

→ Bandwidth in GHz range

Applications:

→ Microwave Radar systems

→ Electronic Missiles

→ Satellite Transponders

→

13/07/11 Magnetron :- [microwave oven]

Microwave Cross field Tubes [M-Type]

Cross field Tube derieve their name from the fact that, dc electric field and DC magnetic field are perpendicular to eachother.

→ In a crossed field Tube, the electrons emitted by the cathode are accelerated by the electric field and gain velocity, greater the velocity, more their path is bent by the magnetic field.

→ If a RF field is applied to the anode circuit, those electrons entering the circuit during the retarding phase are decelerated and given up their kinetic energy to the RF field with reduced velocity. Thereby increasing the efficiency of magnetron.

→ Commonly used Magnetron oscillators are

* cylindrical Magnetron
* Coaxial Magnetron
* Voltage tunable Magnetron
* inverted Magnetron.

Magnetron Oscillators

→ Magnetron is a self oscillating device requires no external elements

→ It was invented by Hall in 1921

→ All magnetron oscillators consist of anode & cathode operated in dc magnetic field normal to the d.c electric field.

If the dc magnetic field is strong enough the electrons will return back to cathode. In order to prevent this Hull cut off condition is derived as follows:

Steps:

i) Define the motion of electron?

ii) Obtain the angular frequency ω_c.

$$\omega_c = \frac{e}{m}$$

iii) Angular velocity $= \frac{1}{2}\omega_c\left[1 - \frac{a^2}{r^2}\right]$

where $a \rightarrow$ radius of the cathode.

iv) Hull cut off magnetic equation is obtained as follows:

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

$B_{oc} \rightarrow$ Magnetic flux density

$b \rightarrow$ Radius from the center of the cathode.

$a \rightarrow$ Radius of the cathode.

→ Finally the voltage equation i.e, HATREE condition is obtained as a function of phase velocity.

$$V_{on} = \frac{\omega\beta_0 d}{\beta_i} - \frac{m}{2e} - \frac{\omega^2}{\beta^2}$$

where ω/β is the phase velocity.

Construction and Operation:

Microwaves are generated using interaction of electrons with magnetic field.

→ When a high voltage is applied to the cathode, the electron beam starts generating stream of electrons.

→ The cavities are opened along their length as electrons pass through the openings, they induce a resonant high frequency radio field in the cavity which in turn cause the electrons to bunch into groups.

→ Waveguide directs the extracted RF energy to the load.

Characteristics:

→ Efficiency varies from 40 to 70%.

[accelerated by the electric field and [illegible] by the magnetic field]