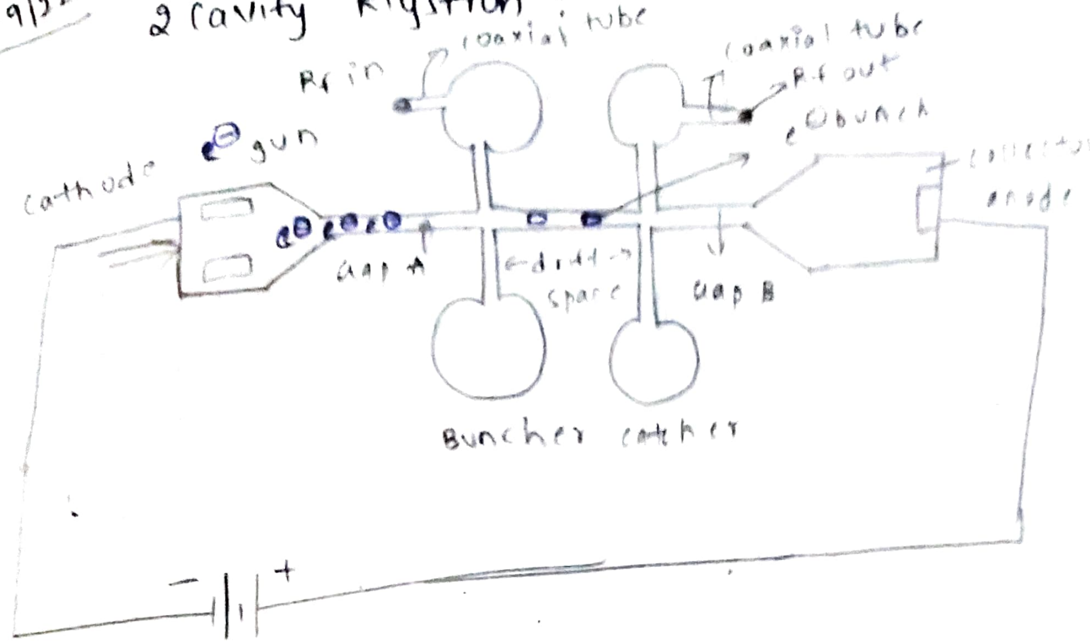
07/09/22 2 cavity klystron :



→ There are 2 cavities, Buncher & catcher.

→ 2 cavity klystron used as amplifier.

→ e⊖ gun emit out electrons, e⊖s moves out,

→ As the e⊖ gun is connected to negative the e⊖s starts emitting.

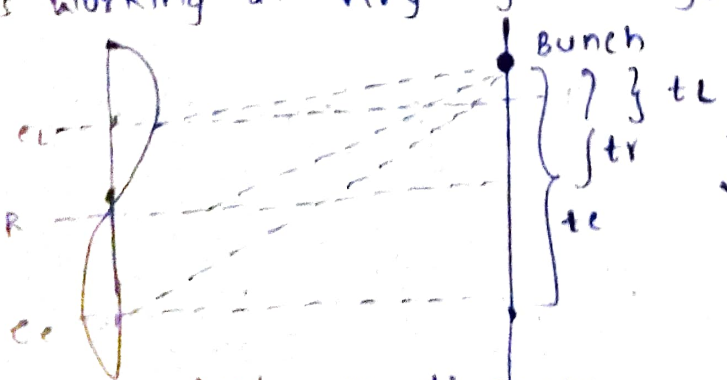
→ first electron coming from e⊖ gun, is early electron

→ Deacceleration occurs as the potential is ⊖

→ for +ve RF signal, the polarity changes the e⊖s accelerates and there is more acceleration

→ Reference is neither +ve nor -ve, it remains/moves with constant velocity with which it had started

→ It is working at very high voltage



$t_e > t_r > t_L$

$V_L < V_r < V_e$

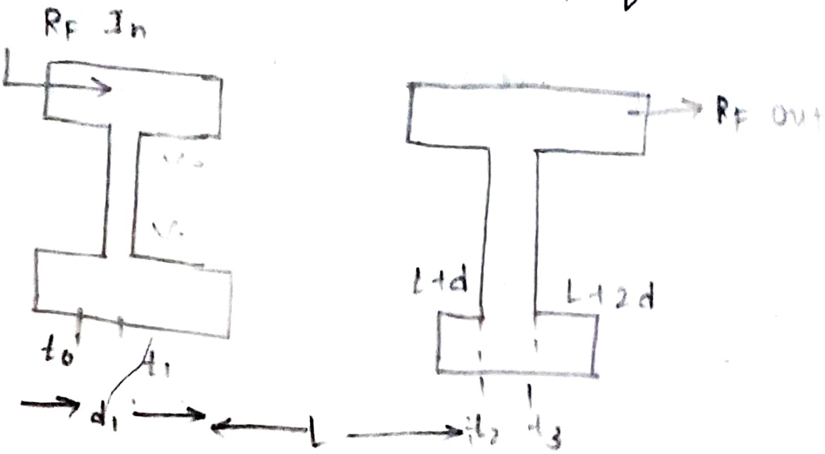
$V_r = \frac{2e}{m}$

Applegate diagram

12/09/22

2 Cavity klystron amplifier :

Relation b/ween o/p power & η :



Buncher cavity

catcher cavity

Let the dc voltage b/w anode & cathode is V_0, v_0 is velocity of electron, L is length of drift space (where bunching occurs), RF input signal to be amplified by the klystron be V_s

$$v_0 = \sqrt{\frac{2eV_0}{m}} = 5.92 \times 10^5 \sqrt{V_0}$$

$$V_s = V_1 \sin \omega t \rightarrow \text{i/p signal from buncher Cavity}$$

After V_0 distance, the electron is taken from V_1, then

$$\frac{1}{2} m v_1^2 = e(V_0 + V_1 \sin \omega t)$$

$$v_1 = \sqrt{\frac{2e(V_0 + V_1 \sin \omega t)}{m}}$$

$$v_1 = \sqrt{\frac{2eV_0}{m}} \sqrt{1 + \frac{V_1}{V_0} \sin \omega t} = \left(1 + \frac{V_1}{V_0} \sin \omega t\right)^{1/2}$$

$$v_1 = v_0\left(1 + \frac{V_0}{2V_0}\sin\omega t\right) \rightarrow \text{Velocity modulation}$$

$$\omega t_1 = \omega t_0 + \frac{\theta_g}{2}$$

θ_g is the phase angle of RF input voltage during which electron is accelerated.

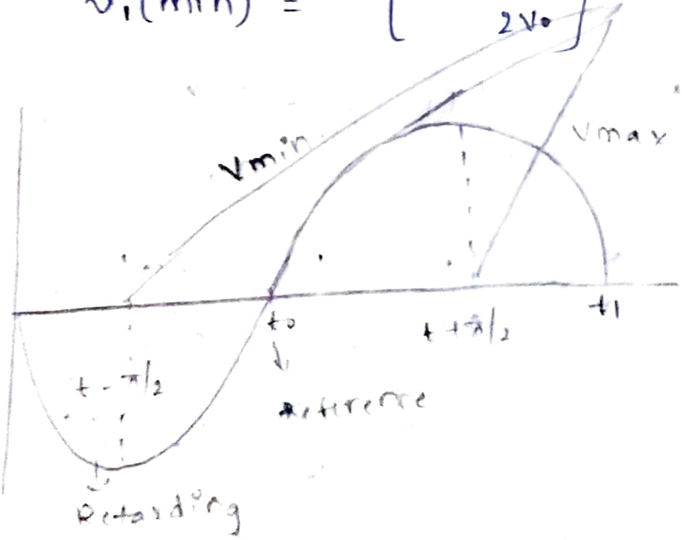
→ Maximum Velocity occurs at $\pi/2$, so that Voltage will be maximum

$$\theta_g = (\omega\{t_1 - t_0\})$$

$$v_1(max) = V_0\left[1 + \frac{V_1}{2V_0}\right]$$

→ minimum velocity occurs at $\pi/2$, so that voltage will be minimum

$$v_1(min) = V_0\left[1 - \frac{V_1}{2V_0}\right]$$



→ If the distance in the drift space at which bunching occurs from the buncher grid at time t_1 is L_1

$L_1 = V_0(t_1 - t_0)$

L_1 at $t - \pi/2 = V_{min}(t_1 - t - \pi/2)$

L_1 at $t + \pi/2 = V_{max}(t_1 - t + \pi/2)$

$t - \pi/2 = t_0 - \frac{\pi}{2\omega}$

$t + \pi/2 = t_0 + \frac{\pi}{2\omega}$

L_1 at $t - \pi/2 = V_0\left(1 - \frac{V_1}{2V_0}\right)\cdot\left(t_1 - t_0 + \frac{\pi}{2\omega}\right)$

L_2 at $t + \pi/2 = V_0\left(1 + \frac{V_1}{2V_0}\right)\left(t_1 - t_0 + \frac{\pi}{2\omega}\right)$

$$\therefore \boxed{L_1 = V_0(t_1 - t_0) + V_0\left[\frac{\pi}{2\omega} - \frac{V_1}{2V_0}(t_1 - t_0) - \frac{V_1}{2V_0}\frac{\pi}{2\omega}\right]}$$

If the distance has to be same for $-\pi/2, 0, +\pi/2$ bunches the L_1 for all 3 should be equal to $V_0(t_1 - t_0)$

$$\frac{\pi}{2\omega} - \frac{V_1}{2V_0}(t_1 - t_0) - \frac{V_1\pi}{2V_0 \cdot 2\omega} = 0$$

neglect

$$\cancel{\frac{\pi}{2\omega} = \frac{V_1(t_1 - t_0)}{2V_0} + \frac{V_1\pi}{2V_0 2\omega}}$$

$$\cancel{= \frac{2\omega V_1(t_1 - t_0) + V_1\pi}{2V_0 2\omega}}$$

$$\cancel{\frac{V_1}{2V_0}(t_1 + t_0) = \frac{V_1\pi}{2V_0 2\omega}}$$

$$\cancel{(t_1 - t_0) = \frac{\pi}{2\omega}}$$

$$\frac{\pi}{2\omega} - \frac{V_1}{2V_0}(t_1 - t_0) - \frac{V_1 \pi}{2V_0 2\omega} = 0$$

$$\frac{\pi}{2\omega} - \frac{V_1 \pi}{2V_0 2\omega} - \frac{V_1}{2V_0}(t_1 - t_0) = 0$$

$$\frac{\pi}{2\omega} - \frac{V_1}{2V_0}(t_1 - t_0) = \frac{V_1 \pi}{2V_0 2\omega}$$

$$t_1 - t_0 = \frac{2V_0}{V_1} \cdot \frac{\pi}{2\omega} - \frac{2V_0}{2V_1} \cdot \frac{V_1 \pi}{2V_0 2\omega}$$

$$= \frac{2V_0}{V_1} \cdot \frac{\pi}{2\omega} - \frac{\pi}{2\omega}$$

$$\therefore \boxed{(t_1 - t_0) = \frac{\pi}{2\omega} - \frac{\pi}{\omega} \cdot \frac{V_0}{V_1}}$$

Bunching occurs as the RF signal changes from $\left(-\frac{\pi}{2} \text{ to } +\frac{\pi}{2}\right)$ for a value of π, we are taking 3.682, so optimum bunching occurs

$$L_1 = V_0 \left(\frac{\pi V_0}{\omega V_1}\right)$$ → Voltage is very high

$$L_1 = 3.682 \frac{v_0 V_0}{\omega V_1}$$

→ If the Beam coupling coefficient of i/p cavity is β_1, where $\beta = \frac{\sin(\theta_g/2)}{(\theta_g/2)}$ $\left(\therefore \theta_g = \frac{\omega d}{v_0}\right)$

$$L_{max} = 3.682 \frac{v_0 V_0}{\omega \beta V_1}$$ $\left[\eta = \frac{P_{out}}{P_{in}}\right]$

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

Performance Characteristics for 2 cavity klystron

→ frequency, works on 250MHz - 200GHz

→ power, (10kW - 500kW) CW - 30MW (pulse)

→ power gain (15dB - 70dB)

→ Band width (10 - 60MHz)

→ Noise figure (15 - 20dB)

→ theortical frequency (58%)

Applications:

→ It is used as power out tubes

a) In ultra high frequencies as TV transmitter

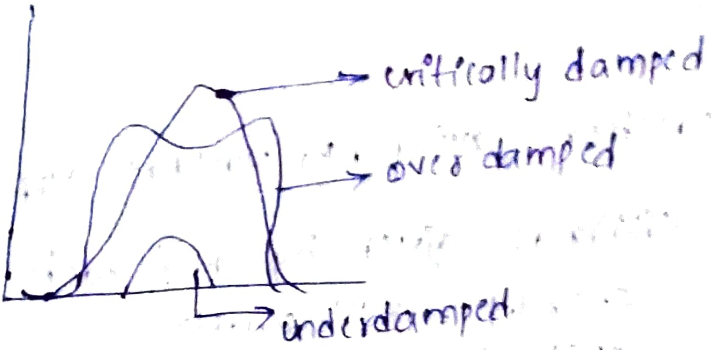
~~In TV transmitter~~

b) In troposphere scatter transmitter

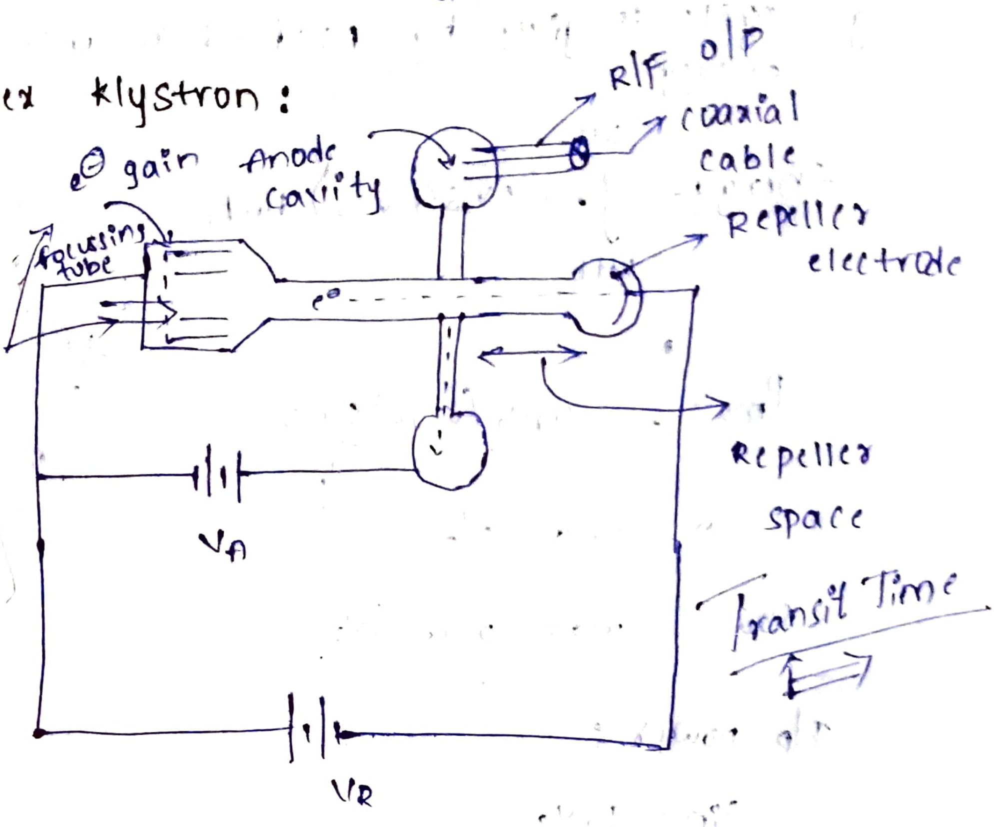
c) satellite communications, Ground station

d) Rador transmitters

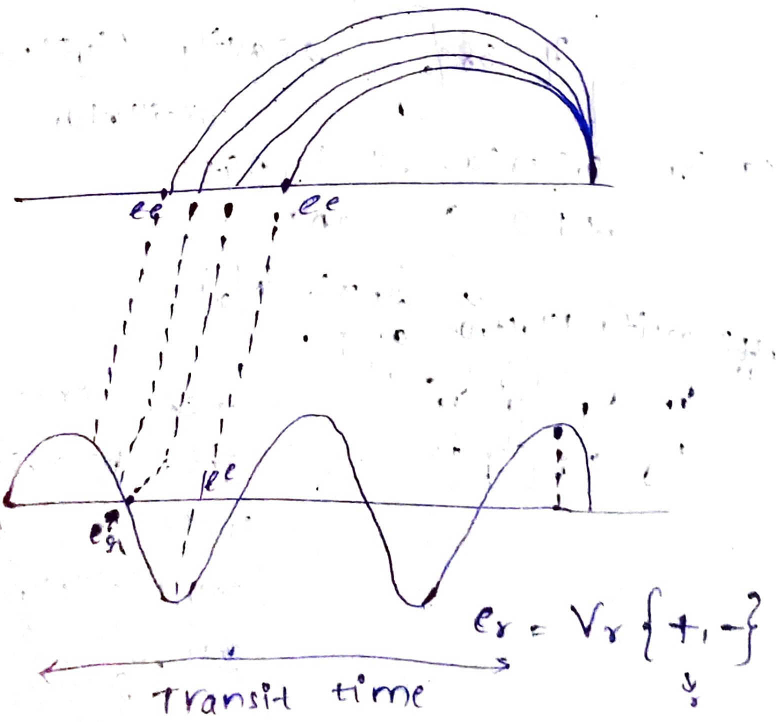
→ It is used as power oscillator (5 - 50GHz) if used as klystron.



Reflex klystron :



⊙ If focussing tube is not connected then all e⊖ will move in separate paths.



⊙ Bunching : occurs at different parts (Modulation & demodulation) occurs

$e_e \Rightarrow V_e \rightarrow acc \rightarrow V \uparrow$

$e_r \Rightarrow V_r \rightarrow x \rightarrow v$ (conducting)

$e_{\pi} = V_{\pi} \rightarrow -ve \rightarrow$ deacc

$e_e \rightarrow t_e$

$e_r \rightarrow t_r$

$e_{\pi} \rightarrow t_r$

$t_e > t_r > t_l$

$V_e > V_{\pi} > V_r$

$\forall\ d_e > d_r > d_e$

Transit time $t = n + 3/4$

↓

Time taken by the $e^{\ominus}$ to travel from the $e^{\ominus}$ back to the repeller point to

→ Always Transit time should be $+90^{\circ}$

→ Low efficiency and power though we are using only single Cavity.

- No Bunching.
- Sustained Oscillations

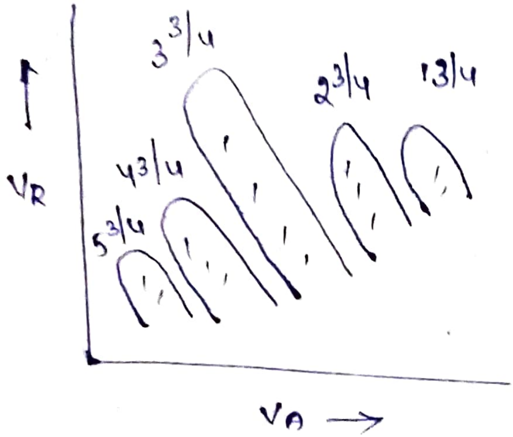
↓

occurs at fixed intervals of time

→ If more no of $e^{\ominus}$ are deaccelerating, then more energy is released resulting in more power

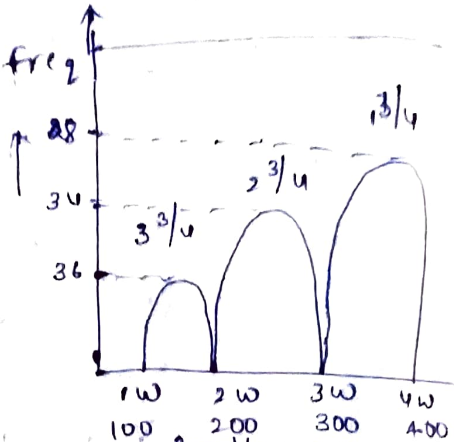
→ Low freq, low efficiency, low power device

Reflex klystron Oscillator



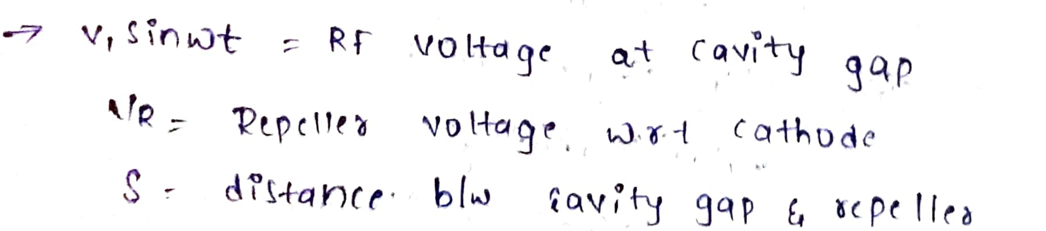
Voltage characteristics

$T = n + 3/4$



o/p ~~power~~ freq power characteristics

Mathematical Analysis of Reflex klystron:



→ $V_1 \sin \omega t$ = RF voltage at cavity gap

V_R = Repeller voltage w.r.t cathode

S = distance b/w cavity gap & repeller electrode

v_0 = Velocity of $e^{\ominus}$ in gun

V_1 = velocity due of RF voltage in additional to the $e^{\ominus}$ accelerating voltage V_0

t_0 = time for $e^{\ominus}$ entering cavity gap at $x=0$

t_1 = time for same $e^{\ominus}$ leaving cavity gap at $x=d$

t_2 = time for same $e^{\ominus}$ return by the retarding field at $x=d$

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

$V_R - (V_0 + V_1 \sin \omega t_1)$

$= V_R - V_0$

$$v_1 = v_0 \sqrt{\frac{1+V_1}{V_0} \cdot \sin \omega t}$$

$\therefore V_0 + V_1 \sin \omega t_1 \; \{V_1 << V_0\}$

→ retarding electrostatic field b/w repeller & anode is,

$$E = \frac{-V}{d} \; \{V = Ed\}$$

$$= \frac{-(V_R - V_0)}{s}$$

$$F = \frac{+e(V_R - V_0)}{s}$$

$$ma = \frac{md^2x}{dt^2} = \frac{e(V_R - V_0)}{s}$$

$$\int \frac{d^2x}{dt^2} = \int \frac{e(V_R - V_0)}{ms}$$

$$\boxed{\frac{dx}{dt} = \frac{e(V_R - V_0)t}{ms} + C}$$

At $t = t_1$,

assume $\frac{dx}{dt} = v_1$

$$v_1 = \frac{e(V_R - V_0)t_1}{ms} + C$$

$$C = v_1 - \frac{e(V_R - V_0)t_1}{ms}$$

$$\therefore \frac{dx}{dt} = \frac{e(V_R - V_0)t}{ms} + V_1 - \frac{e(V_R - V_0)t_1}{ms}$$

$$\boxed{\frac{dx}{dt} = \frac{e(V_R - V_0)(t - t_1)}{ms} + V_1}$$

$$\int \frac{dx}{dt} = \int \frac{e(V_R - V_0)(t - t_1)}{ms} + V_1$$

$$\therefore \boxed{x = \frac{e}{2ms}(V_R - V_0)(t - t_1)^2 + V_1 t + C_1}$$

At $x = 0$, at point of return from the repeller space assume $t = t_2$

$$0 = \frac{e}{2ms}(V_R - V_0)(t_2 - t_1)^2 + V_1 t_2 + C_1$$

$$C_1 = \frac{-e}{2ms}(V_R - V_0)(t_2 - t_1)^2 - V_1 t_2$$

$$\therefore x = \frac{e}{2ms}(V_R - V_0)(t - t_1)^2 + V_1 t - \frac{e}{2ms}(V_R - V_0)(t_2 - t_1)^2 - V_1 t_2$$

$$\therefore \boxed{x = \frac{e}{2ms}(V_R - V_0)\left[(t - t_1)^2 - (t_2 - t_1)^2\right] + V_1(t - t_2)}$$

$$(t^2 + t_1^2 - 2tt_1 - (t_2^2 + t_1^2 - 2t_1 t_2)$$

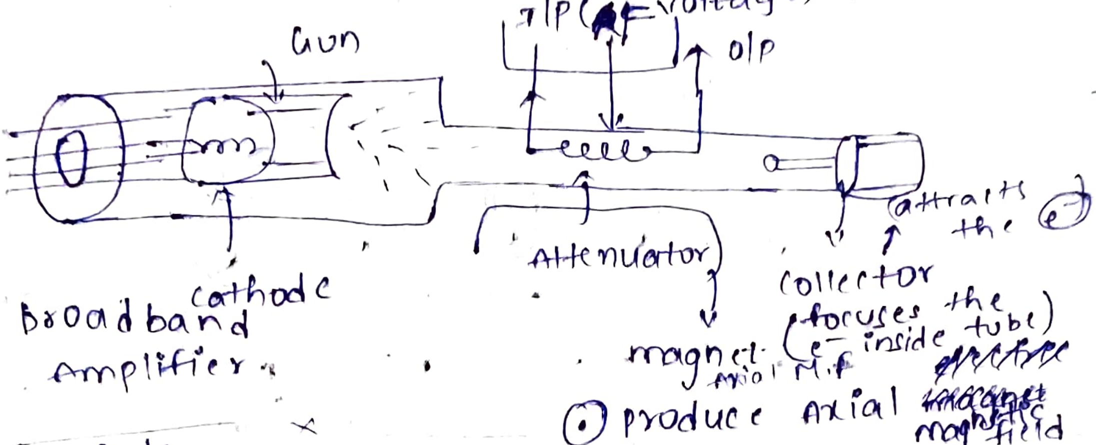
At $x = 0$, $t = t_1$

$$0 = \frac{e}{2ms}(V_R - V_0)\left[-(t_2 - t_1)^2\right] + V_1(t_1 - t_2)$$

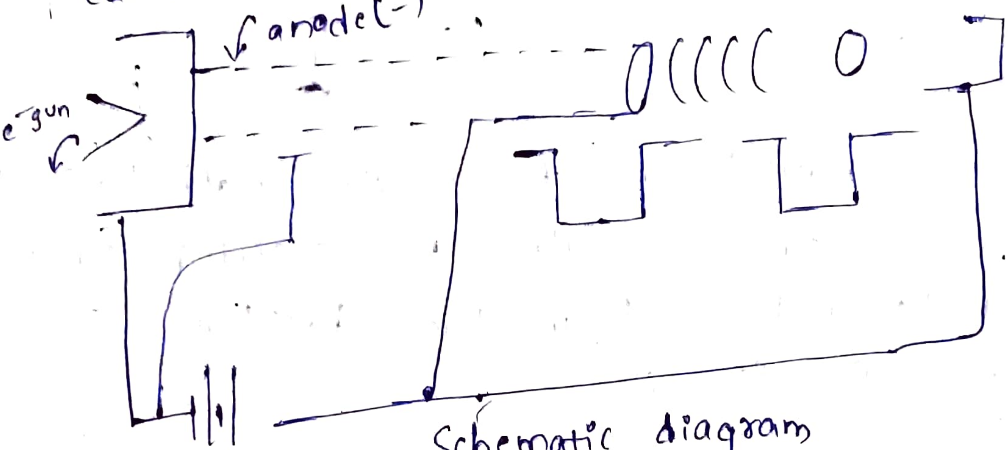
$$\frac{e}{2ms}(V_R - V_0)(t_2 - t_1)^2 = V_1(t_2 - t_1)(-1)$$

$$\therefore \boxed{t_2 - t_1 = \frac{-V_1 2ms}{e(V_R - V_0)}}$$

27/09/23 TWTA : Travelling wave Tube Amplifier



Cathode



Schematic diagram

here only we give dc voltage

helical structure : slow wave structural helix.

= 0.1 v_c (velocity of light)

bunching effect :

$$V_n = V_c \left[\frac{\text{pitch of helix}}{\text{circumference of helix}} \right]$$

(distance from one helix to other helix)

$2\pi r$

- due to reduce of electric field.
- interaction of e^- which are in high position

only they interact

→ As we are using broadband amplifier it should be modulate.

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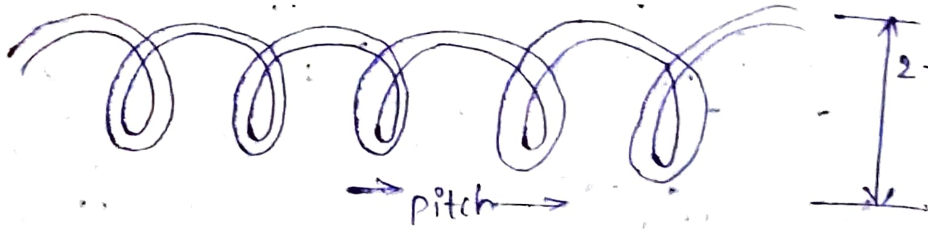
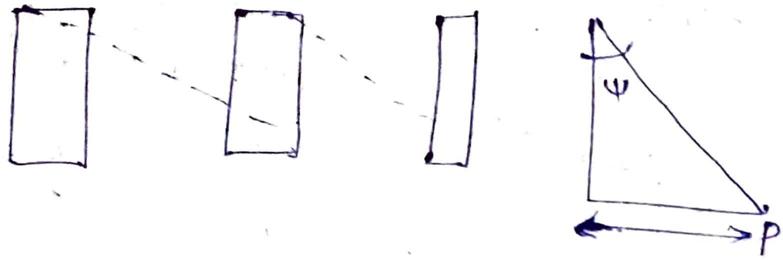
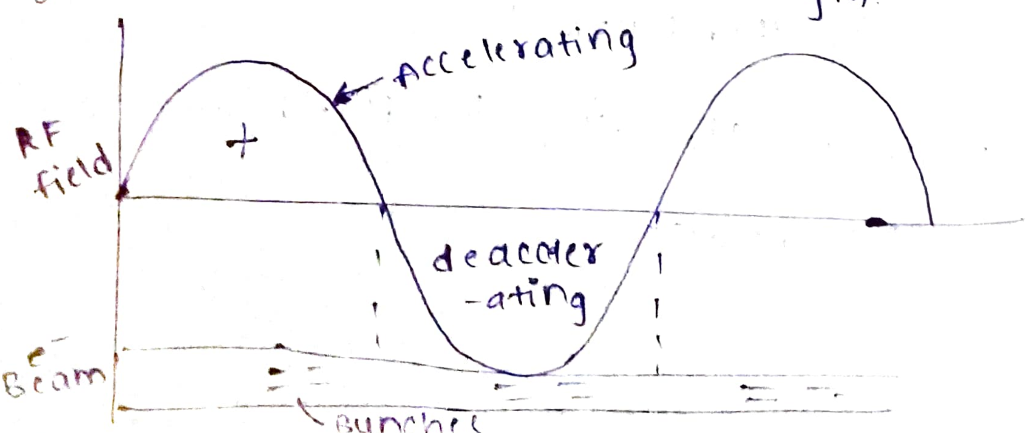
Mathematical Analysis :





- The conductivity of smooth sheath helix in direction of helix wire is specified to be infinite and that in the direction ⊥^{lr} to helix wire is '0'.
- helix support a slow wave with an axial phase velocity $v_p = V_c \sin\psi$, where 'ψ' is the helix angle, $\psi = \tan^{-1}(P/2\pi r)$.
- The wave travelling along helix has a longitudinal component of electric field which causes velocity modulation of electron beam (v). this velocity modulation causes bunching of elec at regular interval of one wavelength.



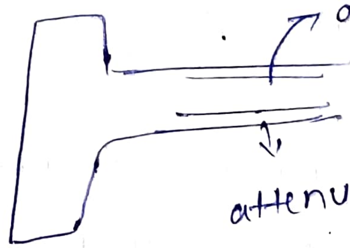
- Gain of TWT $\left[\begin{array}{l} G = -9.54 + 47.3\,CN \text{ (dB)} \\ C = \text{gain parameter} = k\left(\frac{I_0}{V_0}\right)^{1/3} \end{array} \right]$

N = helix length in wavelength = $\frac{L}{\lambda_g}$

$$\lambda_s = \frac{v_p}{f}$$

Here 'k' is constant, v_p is axial phase velocity, I_0 is dc beam current, V_0 is dc beam voltag

- The Gain will be maximum when beam voltage is approximately in synchronism with the axial ~~wave~~ phase ~~axial~~ velocity (v_p)

- 

Performance characteristics of TWT :

- frequency of operation : (0.5 GHz - 95 GHz)
- power output : (5 mW - low power TWT)

250 kW : ~~CW~~ CW (high power)

10 MW : pulsed.

3 GHz : continuous wave

- Efficiency : (5-20%)
- Noise figure (4-6 dB) - low power

25 dB - high power at 40 GHz

Applications of TWT :

- Low noise RF amplifier in broadband amp
- Repeater amplifier in wide band communication links & coaxial cables
- Due to long tube life TWT is used as power output tube in communication satellite.
- continuous wave high power TWT's are used in ~~tpr~~ Tropo scatter links.
- Air borne & ship borne pulsed high power radars
- GBR (Ground Based radar) used in ECM. (broad band TWT)

Eg: A Reflex klystron operates at peak mode of $N = 2$, with beam voltage $V_0 = 300V$, beam current $I_0 = 20mA$, signal voltage V_1 is $40V$.

Determine
i, Input power in watts
ii, o/p power in watts
iii, efficiency.

Eg: i, Input power $= V_0 I_0$

$= 300 \times 20 \times 10^{-3}$

$P_{dc} = 6 wts.$

ii o/p power $= \dfrac{2 V_0 I_0 \times \overbrace{J_1(x')}^{1.25}}{2n\pi - \pi/2}$

$= \dfrac{2(300)(0.02) \times 1.25}{2(2)\pi - \pi/2}$

$P_{ac} = \dfrac{12 \times 1.25}{4\pi - \pi/2} = 1.364$ wts iii efficiency $= \frac{P_{dc}}{P_{ac}}$

$= \frac{1.36}{6}$

$= 22.7\%$

Eg:(2):- A Reflex klystron operates at the peak N=1 on 3/4, The dc power i/p 40mw, Ratio of V_1 over V_0 is 0.278 i determine efficiency of Reflex klystron

ii, Total power o/p in mw

iii If 20% of power delivered by electron beam is dissipated in cavity walls. find the power delivered to the load

Sol:- i $\eta = \frac{2x'J_1(x')}{2n\pi + \pi/2}$, n = 1 $\quad 2\pi + \pi/2 = 5\pi/2$

$= \frac{2(125)}{100(5\pi/2)} = \frac{\cancel{5250} \times 2}{\cancel{100}(5\pi)} = 1/\pi$

$\eta = 0.318 \Rightarrow 31.8\%$

ii o/p power = 2