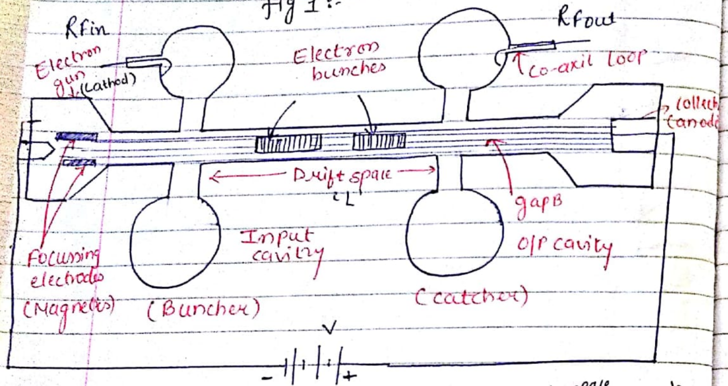
* Two Cavity Klystron Amplifier

fig 1:-



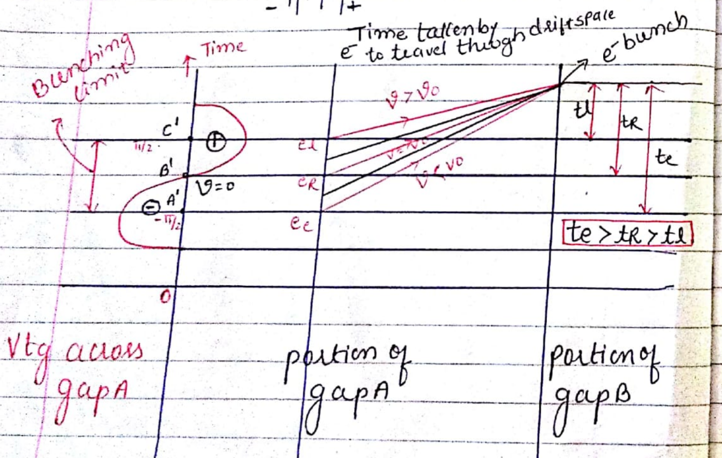
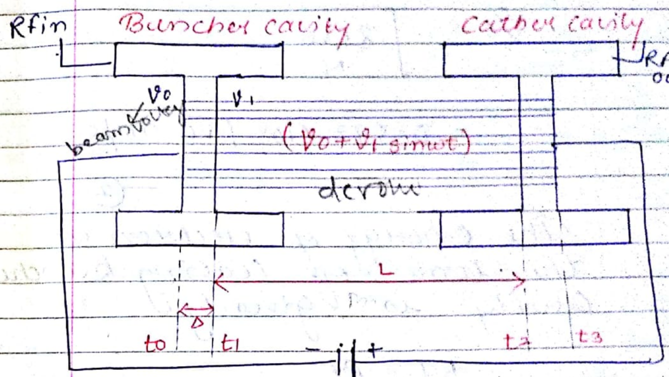


fig 2 Applegate diagram of Klystron amplifier

* Mathematical Analysis of Klystron Amplifier:



*part 1:- Let the dc voltage between cathode and anode the V_0 also called the beam voltage

v_0 = Velocity of electrons before Modulation

v_1 = Velocity of electron after Modulation.

L = Drift space length and the Rf i/p signal to be amplified by the Klystron

$$V_s = V_1 \sin \omega t \quad \text{—(1)}$$

V_1 = amplitude of Rf signal

The velocity of electron v_0 is given by.

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

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

The energy of electron at the time of leaving buncher cavity is given by

$$KE = PT$$

$$\frac{1}{2} m v_1^2 = e(V_0 + V_1 \sin\omega t_1)$$

$$v_1^2 = \frac{2e}{m}(V_0 + V_1 \sin\omega t_1)$$

$$v_1 = \sqrt{\frac{2e}{m}(V_0 + V_1 \sin\omega t_1)}$$

$$= \sqrt{\frac{2eV_0}{m} + \frac{2eV_1}{m}\sin\omega t_1}$$

$$v_1 = \sqrt{\frac{2eV_0}{m}\left(1 + \frac{V_1}{V_0}\sin\omega t_1\right)}$$

$$= \sqrt{\frac{2eV_0}{m}} \sqrt{1 + \frac{V_1}{V_0}\sin\omega t_1}$$

$$v_1 = v_0 \sqrt{1 + \frac{V_1}{V_0}\sin\omega t_1}$$

$$\boxed{v_1 = v_0\left(1 + \frac{V_1}{V_0}\sin\omega t_1\right)^{1/2}}$$

Expanding binominal and neglecting higher powers of $\sin\omega t_1$ we get

$$\boxed{v_1 = v_0\left(1 + \frac{V_1}{2V_0}\sin\omega t_1\right)} \quad — (3)$$

Velocity of electron after Modulation

Part 2

(2) Transit Time :- (T_0)

The product of period of one cycle and number of cycle require during the transit

$T_0 = T \cdot N$

$T = \frac{1}{f}$

$T_0 = \frac{1}{f} \cdot N$

$\omega = 2\pi f$

$f = \frac{\omega}{2\pi}$

$= \frac{1}{\frac{\omega}{2\pi}} \cdot N$

$$\boxed{T_0 = \frac{2\pi}{\omega} \cdot N}$$

Multiply both sides by ω

$\omega T_0 = 2\pi N$

we know that

$T_0 = \frac{d}{v_0}$

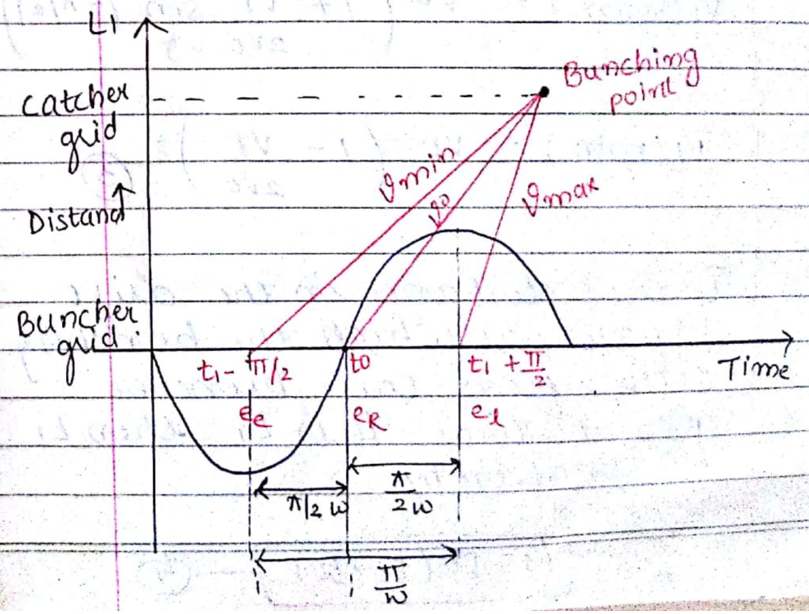
$$\boxed{\theta_g = \omega T_0 = \frac{\omega d}{v_0} = 2\pi N}$$

with RF field (AC) * θ_g = Transit angle with RF field

without RF field (DC) * $\theta_0 = \frac{\omega L}{v_0}$ = dc transit angle without RF field

Part 3:

Bunching process of Electron beam



Velocity of electron after Modulation is given by

$$v_1 = v_0 \left(1 + \frac{V_1}{2V_0} \sin \omega t_1\right) \quad \text{—} (1)$$

max velocity occurs at $+\pi/2$
min velocity occurs at $-\pi/2$

$$v_{1max} = v_0 \left(1 + \frac{V_1}{2V_0} \sin\frac{\pi}{2}\right)$$

$$V_1(max) = V_0 \left(1 + \frac{V_1}{2V_0}\right) \quad \text{—} (2)$$

$$V_1(min) = V_0 \left(1 + \frac{V_1}{2V_0} \sin(-\pi/2)\right)$$

$$V_1(min) = V_0 \left(1 - \frac{V_1}{2V_0}\right) \quad \text{—} (3)$$

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

$$\boxed{L_1 = v_0 (t_1 - t_0)} \quad \text{—} (4)$$

$(t - \pi/2)$

At $\left(t + \frac{\pi}{2}\right)$

$$L\left(t - \frac{\pi}{2}\right) = V_{min}\left\{t_1 - \left(t - \frac{\pi}{2}\right)\right\} \quad (5)$$

At $\left(t + \frac{\pi}{2}\right)$

$$L\left(t + \frac{\pi}{2}\right) = v_{max}\left\{t_1 - \left(t + \frac{\pi}{2}\right)\right\} \quad \text{—} (6)$$

From figure

$$t - \frac{\pi}{2} = t_0 - \frac{\pi}{2\omega} \quad \text{—} (7)$$

$$t + \frac{\pi}{2} = t_0 + \frac{\pi}{2\omega} \quad \text{—} (8)$$

Sub the value of eq (3) & (7) in eq (5)

$$L\left(t - \frac{\pi}{2}\right) = v_0\left(1 - \frac{V_1}{2V_0}\right)\left\{t_1 - \left(t_0 - \frac{\pi}{2\omega}\right)\right.$$

$$= \vartheta_0 - \frac{\vartheta_0 V_1}{2V_0}\left\{(t_1 - t_0) + \frac{\pi}{2\omega}\right\}$$

Multiply the term

$$= V_0(t_1 - t_0) + \frac{\vartheta_0 \pi}{2\omega} - \frac{\vartheta_0 V_1}{2V_0}(t_1 - t_0)$$

$$- \frac{V_0 V_1}{2V_0}\left(\frac{\pi}{2\omega}\right)$$

$$\boxed{L\left(t + \frac{\pi}{2}\right) = \vartheta_0(t_1 - t_0) + \vartheta_0\left\{\frac{\pi}{2\omega} - \frac{V_1}{2V_0}(t_1 - t_0) - \frac{V_1}{2V_0}\left(\frac{\pi}{2\omega}\right)\right\}} \quad -(9)$$

Sub eq (2) & (8) in eq (6)

$$L\left(t + \frac{\pi}{2}\right) = \vartheta_0\left(1 + \frac{V_1}{2V_0}\right)\left\{t_1 - \left(t_0 + \frac{\pi}{2\omega}\right)\right\}$$

$$= \vartheta_0 + \frac{\vartheta_0 V_1}{2V_0}\left\{(t_1 - t_0) - \frac{\pi}{2\omega}\right\}$$

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

$$\boxed{L\left(t + \frac{\pi}{2}\right) = V_0(t_1 - t_0) + V_0\left\{-\frac{\pi}{2\omega} + \frac{V_1}{2V_0}(t_1 - t_0) - \frac{V_1}{2V_0}\left(\frac{\pi}{2\omega}\right)\right\}} \quad -(10)$$

If the distance has to be same for $-\pi/2$, 0, $+\pi/2$ bunches L_1 for all 3 should be equal to $v_0(t_1 - t_0)$

$$L\left(t - \frac{\pi}{2}\right) = v_0(t_1 - t_0) + v_0\left(\frac{\pi}{2\omega} - \frac{v_1}{2v_0}(t_1 - t_0) - \frac{v_1}{2v_0}\left(\frac{\pi}{2\omega}\right)\right)$$

$$\frac{\pi}{2\omega} - \frac{v_1}{2v_0}(t_1 - t_0) = \frac{v_1}{2v_0}\left(\frac{\pi}{2\omega}\right)$$

$$\frac{-v_1}{2v_0}(t_1 - t_0) = \frac{v_1}{2v_0}\left(\frac{\pi}{2\omega}\right) - \frac{\pi}{2\omega}$$

$$-(t_1 - t_0) = \frac{2v_0}{v_1} \times \frac{\cancel{v_1}}{\cancel{2v_0}}\left(\frac{\pi}{2\omega}\right) - \frac{2v_0}{v_1}\left(\frac{\pi}{2\omega}\right)$$

$$-(t_1 - t_0) = \left(\frac{\pi}{2\omega}\right) - \frac{2v_0}{v_1}\left(\frac{\pi}{2\omega}\right)$$

$$(t_1 - t_0) = \frac{\cancel{2}v_0}{v_1}\left(\frac{\pi}{\cancel{2}\omega}\right) - \frac{\pi}{2\omega}$$

$t_1 - t_0 = \frac{v_0}{v_1}\left(\frac{\pi}{\ }\right)$ $\frac{v_0}{v_1} >> \frac{\pi}{2\omega}$, neglect it

$$\boxed{t_1 - t_0 = \frac{v_0}{v_1}\left(\frac{\pi}{\omega}\right)}$$

put in eq ④

$$\boxed{L_1 = v_0 \frac{v_0}{v_1}\left(\frac{\pi}{\omega}\right)}$$

$-\frac{\pi}{2}$ to $+\frac{\pi}{2}$ i.e π

for $\pi = 3.682$ max bunching take place [from smith chart]

$$\boxed{L_1 = 3.682 \frac{v_0 v_0}{\omega v_1}}$$

Since bunching occur between $-\frac{\pi}{2}$ to $\frac{\pi}{2}$

$3.68 \frac{v_0 V_0}{\beta\omega V_1}$

$L_1 = 3.68 \frac{V_0 V_0}{\beta\omega V_1}$

* Efficiency of 2-cavity Klystron Amplifier

$$\% \eta = \frac{P_{out}}{P_{in}} \times 100 \quad -(1)$$

catcher cavity

The RF signal is available at catcher cavity is $V_2 \sin \omega t_2$

Energy given by electron to the bunch is given by

$$(-e) V_2 \cdot \sin \omega t_2$$

average energy given to the RF field in a cycle

$$P_{avg} = \frac{1}{2\pi} \int_{\omega t_1 = 0}^{2\pi} (-e V_2 \sin \omega t_2)\, d\omega t_1 \quad -(2)$$

In a field free space transit time is given by

$$T = \frac{L}{v_1} = (t_2 - t_1)$$

Put eq (3) in above equation

$$T = \frac{L}{v_0 \left\{1 + \frac{V_1}{V_0} \sin \omega t_1\right\}^{1/2}}$$

$$T = \frac{L}{v_0} \left\{1 + \frac{V_1}{V_0} \sin \omega t_1\right\}^{-1/2}$$

$$= \frac{L}{v_0} \left\{1 - \frac{V_1}{2V_0} \sin \omega t_1\right\}$$

Multiply by 'ω' on both sides

$$\omega T = \frac{\omega L}{v_0} \left\{1 - \frac{V_1}{2V_0} \sin \omega t_1\right\} \quad -(A)$$

$$\omega T = \omega t_2 - \omega t_1 \quad -(B)$$

$$\omega T_2 - \omega T_1 = \frac{\omega L}{V_0} \left\{1 - \frac{V_1}{2V_0} \sin \omega t_1\right\}$$

$$\boxed{\omega t_2 = \omega t_1 + \theta_0 \left\{1 - \frac{V_1}{2V_0} \sin \omega t_1\right\}} \quad -(3)$$

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Put eq ③ in eq ②

$$\boxed{P_{avg} = \frac{-eV_2}{2\pi}\int_0^{2\pi} \sin\left\{\omega t_1 + \theta_0\left(1-\frac{V_1}{2V_0}\sin\ldots\right)\right\} d\omega t_1}$$

This is a Bessel function & its solution is given by

$$\boxed{P_{avg} = -eV_2 \cdot J_1(x)\sin\theta_0}$$

where, $J_1(x)$ is the bessel function of first order for argument x

for n electron transit cycle energy transferred is given by

$N \cdot P_{avg}$

$$P_{avg} = -\underbrace{N \cdot e}_{I_0} \cdot V_2 \sin\theta_0 \cdot J_1(x)$$

$\because$ O/P current, $I_0 = N \cdot e$

$$P_{avg} = -I_0 V_2 \sin\theta_0 \cdot J_1(x)$$

For Max energy transfer

$(J_1(x) = 0.58$ at $x = 1.84)$

from bessel function chart/table

$$P_{avg} = -I_0 V_2 \sin\theta_0 (0.58)$$

Put $\boxed{\sin\theta_0 = -1}$ for $\theta_0 = 2\pi n - \frac{\pi}{2}$

where $n = 0, 1, 2$

$\therefore P_{avg} = -I_0 V_2 (-1)(0.58)$

$P_{out} = P_{max} = I_0 \cdot V_2 \times 0.58$ — ④

Input power is basically DC input given by

$P_{in} = V_0 \cdot I_0$ — ⑤

Substitute eq ④ & ⑤ in eq ①

$$\boxed{\eta = \frac{I_0 V_2 \times 0.58}{V_0 I_0}}$$

If $V_2 \cong V_0$

$$\eta = \frac{I_0 V_0 \times 0.58}{V_0 I_0} \times 100$$

$$\boxed{\eta = 58\%}$$

Bunching parameter of klystron is define by

$$\boxed{X = \frac{V_1}{2V_0}\theta_0}$$

$$\omega T = \theta_0\left(1 - \frac{V_1}{2V_0}\sin\omega t_1\right)$$

$$= \theta_0 - \left(\frac{\theta_0 V_1}{2V_1}\right)\sin\omega t_1$$

Which is dimensionless Quality and proportional to i/p power

Also, for max power transfer electron gain anode voltage required is given by

$$X = \frac{V_1}{2V_0}\theta_0$$

$$\left(\frac{V_1}{V_0}\right)_{max} = \frac{2X}{\theta_0}$$

$$= \frac{2 \times 1.84}{2\pi n - \pi/2}$$

$$\boxed{\frac{V_1}{V_0} = \frac{3.682}{2\pi n - \pi/2}}$$

* Beam coupling co-efficient

In a circuit the generation of alternating current between the two gap with is known as beam coupling.

In order to find average microwave signal is given by

$$V_S = \frac{1}{T_0}\int_{t_0}^{t_1} V_1 \sin\omega t \, d\omega t$$

$$= \frac{V_1}{T_0}\left(\frac{-\cos\omega t}{\omega}\right)_{t_0}^{t_1}$$

$$= \frac{-V_1}{\omega T_0}\left(\cos\omega t_1 - \cos\omega t_0\right)$$

$$V_S = \frac{V_1}{\omega T_0}\left[\cos\omega t_0 - \cos\omega t_1\right] \quad -①$$

$$T_0 = \frac{d}{V_0} = (t_1 - t_0)$$

Multiply by ω.

$$\omega T_0 = \frac{\omega d}{V_0} = \omega t_1 - \omega t_0$$

$$\therefore \boxed{\omega t_1 = \omega t_0 + \frac{\omega d}{V_0}}$$

Put in eq ①

$\cos(A-B) - \cos(A+B) = 2\sin A \sin B$

Let $A = \omega t_0 + \frac{\omega d}{2V_0}$

$B = \frac{\omega d}{2V_0}$

$$A-B = \omega t_0 + \frac{\omega d}{2V_0} - \frac{\omega d}{2V_0}$$

$$\boxed{A-B = \omega t_0}$$

$$A+B = \omega t_0 + \frac{\omega d}{2V_0} + \frac{\omega d}{2V_0}$$

$\frac{1}{2}+\frac{1}{2}=1$ $\therefore \frac{\omega d}{V_0}$

$$\boxed{A+B = \omega t_0 + \frac{\omega d}{V_0}}$$

. Using the formula

$$\cos(A-B) - \cos(A+B) = 2\sin A \cdot \sin B$$

$$V_s = \frac{V_1}{\omega T_0}\left\{2\sin\left(\omega t_0 + \frac{\omega d}{2V_0}\right) \cdot \sin\left(\frac{\omega d}{2V_0}\right)\right\}$$

$$\boxed{\frac{\theta g}{2} = \frac{\omega d}{2V_0} = T\omega}$$

$$V_s = \frac{2V_1}{\omega T_0}\left\{+\sin(\theta g/2) \cdot \sin\left(\omega t_0 + \frac{\omega d}{2V_0}\right)\right\}$$

$$V_s = \frac{V_1}{\frac{\omega T_0}{2}}\left\{\sin(\theta g/2) \cdot \sin\left(\omega t_0 + \frac{\omega d}{2V_0}\right)\right\}$$

$$= \frac{V_1}{\theta g/2}\left\{\sin(\theta g/2)\sin\left(\omega t_0 + \frac{\omega d}{2V_0}\right)\right\}$$

$$= V_1\left\{\frac{\sin(\theta g/2)}{(\theta g/2)} \cdot \sin\left(\omega t_0 + \left(\frac{\omega d}{2V_0}\right)\right)\right\}$$

$$= \boxed{V_s = V_1 \beta \sin\left(\omega t_0 + \frac{\omega d}{2V_0}\right)}$$

Where $\boxed{\beta = \frac{\sin(\theta g/2)}{\theta g/2}}$ $\rightarrow$ Beam coupling co-efficient.

Formula:-

* Two Cavity Klystron Amplifier

(1) Electron velocity, $v_0 = \sqrt{\frac{2eV_0}{m}} = 0.593 \times 10^6 \sqrt{V_0}$

(2) Gap transit angle, $\theta_g = \frac{\omega d}{v_0}$

(3) Beam coupling coefficient,

$$\beta_L = \frac{\sin(\theta_g/2)}{(\theta_g/2)}$$

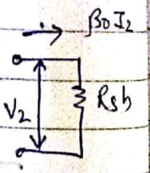
(4) DC transit angle, $\theta_0 = \frac{\omega L}{v_0}$

(5) Bunching parameter, $X = \frac{\beta_1 V_1 \theta_0}{2V_0}$

(6) Input voltage, $V_1 = \frac{2V_0}{\beta_1 \theta_0} \cdot X$

(7) $V_2 = \beta_0 \cdot I_2 R_{sh}$

$[J_1(X) = 0.58 \text{ for } X = 1.84]$



(8) $I_2 = 2 I_0 \cdot J_1(X)$

(9) $A_V = \left(\frac{V_2}{V_1}\right) = \frac{\beta_0 I_2 \cdot R_{sh}}{V_1}$

OR

Rox

(10) Efficiency $\eta = \frac{P_{out}}{P_{in}}$

$$= \frac{\beta_0 I_2 V_2}{2 I_0 V_0}$$

$$= \frac{0.58 V_2}{V_0}$$

(11) Electron gain anode voltage for max power transform

$$\left(\frac{V_1}{V_0}\right) = \frac{3.682}{2\pi n - \frac{\pi}{2}}$$

(12)

Q) A two cavity Klystron amplifier has the following characteristics

Voltage gain (A_V) = 15dB

Input power (P_{in}) = 5mW

R_{sh} of I/P cavity (R_{sh1}) = 30kΩ

R_{sh} of O/P cavity (R_{sh2}) = 40kΩ

R_L (R_L) = 40kΩ

Find

(i) I/P RMS voltage (V_1)

(ii) O/P RMS voltage (V_2)

(iii) power delivery to load (P_{out})

Sol (1) $P_{in} = \frac{V_1^2}{R_1}$

$5\times10^{-3} = \frac{V_1^2}{30\times10^3}$

$\sqrt{5\times10^{-3} \times 30\times10^3}$

$\boxed{V_1 = 12.25\,V}$

(2)

$V_2 = ?$

$A_V = 15\,dB$

$A_V = 20\log_{10}\left(\frac{V_2}{V_1}\right)$

$15 = 20\log_{10}\left(\frac{V_2}{12.25}\right)$

$15 = 20\log_{10}\left(\frac{V_2}{V_1}\right)$

$15 = 20\log_{10}\left(\frac{V_2}{12.25}\right)$

$P_{in} = \frac{V_1^2}{R_1}$

$\boxed{V_2 = 68.89\,V}$

(3) $P_{out} = \frac{V_2^2}{R_{sh_2}}$

$P_{out} = \frac{(68.89)^2}{40\times10^3}$

$P_{out} = 0.118$

$\boxed{P_{out} = 118.6\,mW}$

(4) $\eta = \frac{P_{out}}{P_{in}}$

$= \frac{118.6\,m}{5\,m}$

$\boxed{\eta = 23.72\,\%}$

Q2 Two cavity klystron amplifier has the following specification

Beam voltage, $V_0 = 900V$

Beam current, $I_0 = 30mA$

frequency $= 8\,GHz = 8\times10^9\,Hz$

Gap spacing $d = 1mm = 1\times10^{-3}m$

Spacing between two gap

$L = 4cm = 4\times10^{-2}m$

$R_{sh} = 40K\Omega$

(a) Electron velocity

(b) DC transit time of electron

(c) i/p voltage for max o/p voltage

(d) voltage gain in dB

* Multicavity Klystron

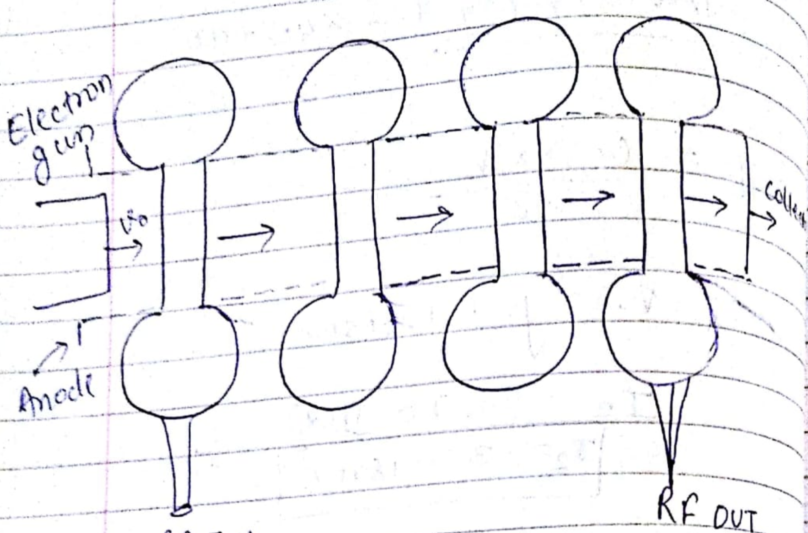
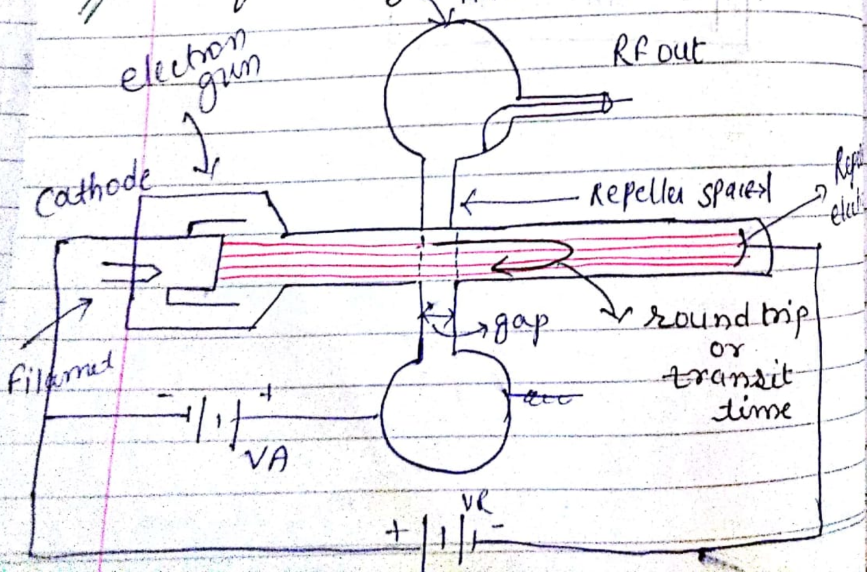


fig (a) 4-Cavity Klystron

sem * Reflex Klystron



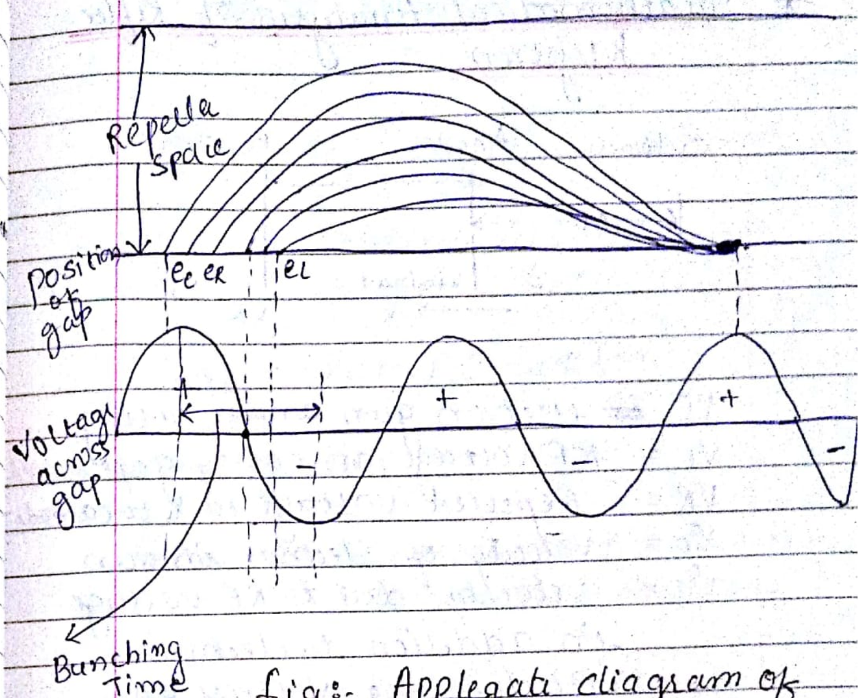


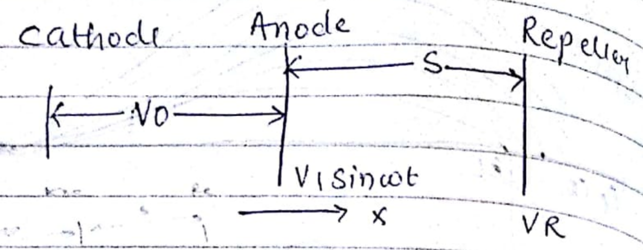
fig:- Applegate diagram of Reflex Klystron

eR ref

ee max positive vtg (max velocity)

el late e⊖ max -ve vtg (min velo)

* Mathematical Analysis of Reflex Klystron.



V0 = electron gun anode voltage
V1 = RF voltage at cavity gap
VR = Repeller voltage w.r.t to cavity
ϑ_0 = Velocity of electron in gun
ϑ_1 = velocity due to RF voltage in addition to electron accelerating voltage V0

t_0 = Time for electron entering cavity gap and $x=0$

t_1 = Time for same electron leaving cavity gap

t_2 = Time for same electron return by retarding field.

S = Distance between cavity gap and Repeller electrode

$$\vartheta_0 = \sqrt{\frac{2eV_0}{m}} \quad — (1)$$

$$\vartheta_1 = \vartheta_0 \left(1 + \frac{V_1}{2V_0} \sin\omega t\right) \quad — (2)$$

Voltage between repeller and anode is given by

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

As $V_0 \gg V_1$

Voltage b/w R&A = $V_R - V_0$ —— (3)

Retarding electrostatic field between Repeller and Anode is

$$E = -\frac{(V_R - V_0)}{S} \quad — (4)$$

Force on electrons $-eE$

$$= -e\left[-\frac{(V_R - V_0)}{S}\right]$$

$$= \frac{e(V_R - V_0)}{S} \quad — (5)$$

Force $= m \times a$

$$= m \cdot \frac{d^2x}{dt^2} \quad — (6)$$

where $x \rightarrow$ displacement

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

$$\therefore \frac{d^2x}{dt^2} = \frac{e}{ms}(V_R - V_0) \quad \text{--- (7)}$$

Integrating equation (7) w.r.t. t

$$\frac{dx}{dt} = \frac{e}{ms}(V_R - V_0)t + c \quad \text{--- (8)}$$

$$t = t_1, \frac{dx}{dt} = v_1$$

Let $t = t_1$, velocity mod^n & $\frac{dx}{dt} = \vartheta_1$

$$\vartheta_1 = \frac{e}{ms}(V_R - V_0)t_1 + c$$

$$\boxed{C = \vartheta_1 - \frac{e}{ms}(V_R - V_0)t_1} \quad \text{--- (9)}$$

Put eq^n (9) in eq^n (8)

$$\frac{dx}{dt} = \frac{e}{ms}(V_R - V_0)t + \vartheta_1 - \frac{e}{ms}(V_R - V_0)t_1$$

$$\frac{dx}{dt} = \frac{e}{ms}(V_R - V_0)[t - t_1] + \vartheta_1 \quad \text{--- (10)}$$

Again integrating eq (10) we get

$$x = \frac{e}{ms}(V_R - V_0)\frac{(t - t_1)^2}{2} + v_1 t + c_1$$

$$x = \frac{e}{2ms}(V_R - V_0)(t - t_1)^2 + \vartheta_1 t + c_1 \quad \text{--- (11)}$$

At $x = 0$ i.e. at the point of return from repeller space $t = t_2$

$$x = 0, t = t_2$$

$$0 = \frac{e}{2ms}(V_R - V_0)(t_2 - t_1)^2 + v_1 t_2 + c_1$$

$$c_1 = \frac{-e}{2ms}(V_R - V_0)(t_2 - t_1)^2 - \vartheta_1 t_2$$

put in eq (11)

$$x = \frac{e}{2ms}(V_R - V_0)(t - t_1)^2 + \vartheta_1 t - \frac{e}{2ms}(V_R - V_0)(t_2 - t_1)^2 - \vartheta_1 t_2$$

$$x = \frac{e}{2ms}(V_R - V_0)\left[(t - t_1)^2 - (t_2 - t_1)^2\right] + \vartheta_1(t - t_2) \quad \text{--- (12)}$$

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

$$0 = \frac{e}{2ms}(V_R - V_0)\left[-(t_2 - t_1)^2\right] + \vartheta_1 (t_1 - t_2)$$

$$\frac{e}{2ms}(V_R - V_0)(t_2 - t_1)^2 = -\vartheta_1 (t_1 - t_2)$$

$$\frac{e}{2ms}(V_R - V_0)(t_2 - t_1)^{\cancel{2}} = -\vartheta_1 (t_2 - t_1)$$

$$\frac{e}{2ms}(V_R - V_0) \cdot (t_2 - t_1) = -\vartheta_1$$

$$\boxed{(t_2 - t_1) = \frac{-2ms\,\vartheta_1}{e(V_R - V_0)}}$$

$$\frac{e}{2ms}(V_R - V_0)(t_2 - t_1) = -\vartheta_1$$

$$t_2 - t_1 = -\frac{\vartheta_1 2ms}{e(V_R - V_0)} = -\frac{2ms}{e(V_R)} \quad (13)$$

where $t_2 - t_1$ is the round trip transit time

Transit angle $= \omega(t_2 - t_1)$

The transit angle $\omega(t_2 - t_1)$ is define as the transit angle at time $(t_2 - t_1)$

$$\omega t_2 = \omega t_1 = \frac{-2ms\,\vartheta_1 \omega}{e(V_R - V_0)}$$

$$\omega t_2 = \omega t_1 - \frac{2ms\,\vartheta_1 \omega}{e(V_R - V_0)} \quad (14)$$

$$\vartheta_1 = \vartheta_0\left(1 + \frac{V_1}{2V_0}\sin\omega t\right)$$

put in eq (14) ϑ_1

$$\omega t_2 = \omega t_1 - \frac{2ms\omega}{e(V_R - V_0)}\left(1 + \frac{V_1}{2V_0}\sin\omega t\right)$$

θ_0'

where $\boxed{\theta_0' = \frac{-2ms\,\omega\vartheta_0}{e(V_R - V_0)}} = \omega T_0'$

round trip dc that transit angle centre of electron bunch

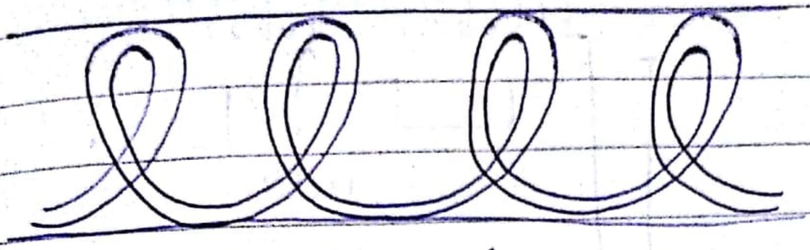
$$\omega t_2 = \omega t_1 + \theta_0'\left(1 + \frac{V_1}{2V_0}\sin\omega t\right)$$

$$\omega t_2 = \omega t_1 + \theta_0' + \underbrace{\frac{\theta_0' V_1}{2V_0}}_{X'}\sin\omega t$$

$\boxed{X' = \frac{V_1}{2V_0}\theta_0'}$ → Bunching parameter

Sem

* Slow wave structure



(1) Helical

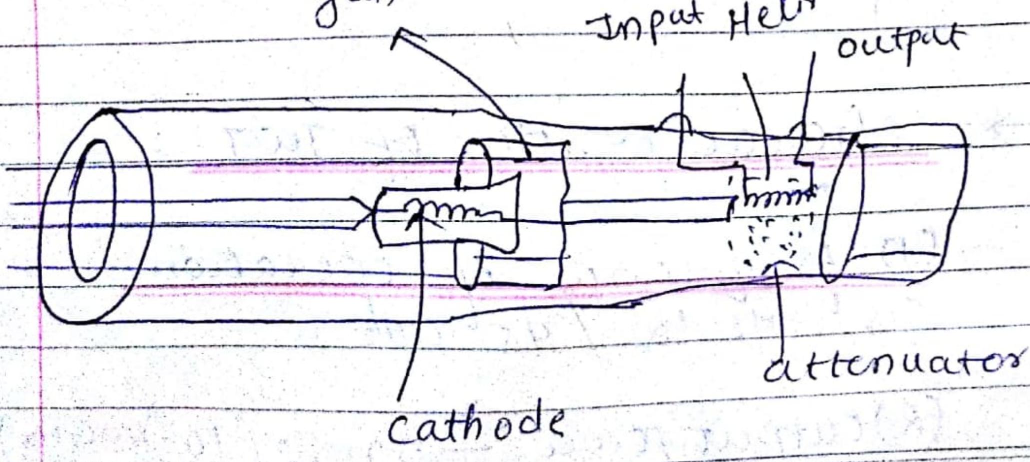
(2) Folded back

(3) zigzag lines

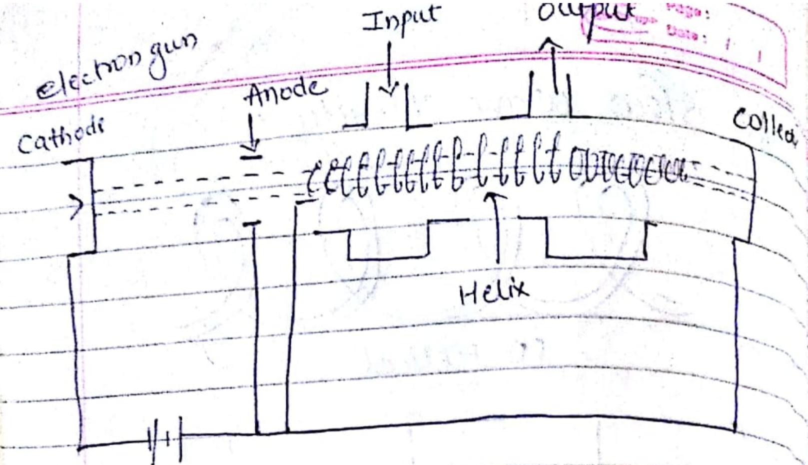
Sem

* Travelling wave Tube (TWT)

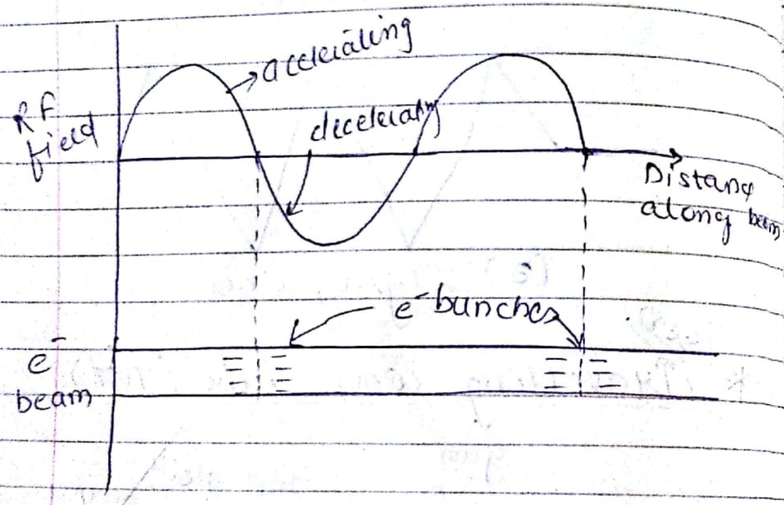
gain



(4) Attenuator



(b) Schematic Electrode Arrangement.



* Characteristics of TWT

(1) frequency of operation:
0.5 GHz to 95 GHz

(2) output power — 5mW (10-40GHz)
low power TWT

+250kW at 3GHz
(High power TWT)

(3) Efficiency — 5 to 20%.

* Applications

(1) Low noise RF amplifier in Broad-band microwave receivers.

(2) Repeater amplifier in white band communication link.

(3) Due to long tube life (50000 hr) against $\frac{1}{4}$th for other types)
TWT are used as power o/p tubes in communication satellites.

(4) Air borne and ship borne high power radars, ground base radar use a TWT.

Numerical

(1) A Helical TWT has diameter of 2mm with 50 ~~turns~~ turns/cm. calculate
(i) axil phase velocity and anode voltage at which TWT can be operated for useful gain. Standard = $m = 9.1 \times 10^{-31}$

Sol $v_p = v_c \left(\frac{Pitch}{2\pi r} \right)$

$$Pitch = \frac{1}{turns/cm} = \frac{1}{50} = 0.02 = 2 \times 10^{-4} m$$

$$Circumference = 2\pi r = d\pi = 6.28 \times 10^{-3} m.$$ $\boxed{2\pi r = d\pi}$

$$v_p = 3 \times 10^8 \left(\frac{2 \times 10^{-4}}{6.28 \times 10^{-3}} \right)$$

$$\boxed{v_p = 9.54 \times 10^6 m/s}$$

(b) $P.E = K.E$

$$eV_0 = \frac{1}{2} m v_p^2$$

$$V_0 = \frac{m \cdot v_p^2}{2e}$$

$$= \frac{9.1 \times 10^{-31} \times (9.54 \times 10^6)^2}{2 \times 1.6 \times 10^{-19}}$$

$$\boxed{V_0 = 258.81 V}$$

sem

* Backward wave Oscillator:

Backward wave oscillator is a microwave continous wave oscillator with excellent tunning capability and freq coverage range. It is similar in construction and operates on the same principal of RF electron beam RF wave oscillators generaly employing a helical slow wave structure since BWO does not have an attenuator there will be oscillation due to reflection from an imperfectly terminated collector end of the tube. The Reflected wave results in a backward wave hence the name backward wave oscillators

* Performance characteristics of BWO

(1) frequency range – 1GHz to 1000GHz

(2) Power o/p → 10mw to 150mw (cw) continuous
20w (at high freq)
250kw (pulsed)

(3) Tunning range → upto 40GHz.

* Applications:

(1) BWO can be used as signal sources in instrument and transmitter.

(2) Broadband noise source.

(3) A noiseless oscillator with good bandwidth in the frequ range 3 to 9GHz

* Magnetrons :- oscillator
very useful in radar

O type	M-type
(1) Linear beam tube	Cross field tubes
(2) Ex:- * Klystron * amp * reflex Klystron * TWT, BWO	Ex:- * Magnetron.
(3) Electric & Magnetic are $\parallel^{al}$	Electric & Magnetic $\perp$ to eachother

Magnetrons provides microwave oscillations of very high peak power. There are three types of magnetrons

+ (1) Negative Resistance Type (f<500)
+ (2) Cyclotron frequency type (f>100)
** Imp (3) ** Cavity Magnetron
OR
Travelling wave Magnetron
only in syllabus

* Cavity Magnetrons

Cavity Magnetrons depend upon interaction of electrons with rotating ~~electron~~ electro magnetic field of constant velocity this provide oscillation of very high peak power and hence are very useful in radar application.

Int e^- & rotating e.m.f (MF) const vel.

Performance charateristics:

(1) Power output = in excess of 2501kw (pulsed m...)

10mw (UHF band)
2mw (X band)
8kw (at 95 GHz)

(2) Frequency = 500 MHz to 12 GHz

(3) Efficiency = 40% – 70%

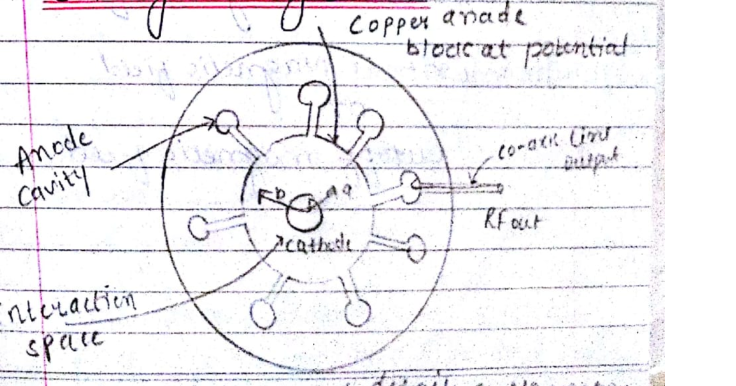
* Application :-

(1) pulse radar is the single most important application with large pulse power.

(2) Voltage-tunable magnetrons are used in oscillators and in missile application.

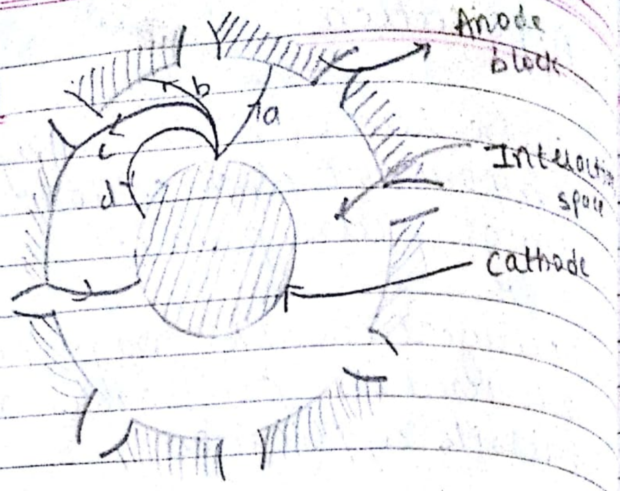
(3) Fixed frequency : continous wave magnetron are used for industrial heating and microwave oven (500 MHz – 2.5 GHz) (300w to kw power) (η of 50%)

* Cavity Magnetron



(a) constructional details of Magnetron

Rf signal is not available



fig(b) Electron trajectories in the process of crossed electrical and magnetic fields

(a) No magnetic field
(b) small magnetic field
(c) Magnetic field = Bc
(d) Excessive magnetic field

Bc = Critical Magnetic field
or
Cutoff magnetic field

The correct minimum phase shift 45° (45 × 8) = 360°. Therefore $\phi_v \rightarrow$ relative phase change of the electrical field across adjacent cavity

$$\boxed{\phi_v = \frac{2\pi n}{N}}$$

where
$n = 0, \pm 1, \pm 2 \ldots \pm \frac{N}{2}$

N = Number of cavity (N=8)

$$\phi_v = \frac{2\pi n}{8}$$

$$\boxed{\phi_v = \frac{\pi n}{4}}$$

If $n = \frac{N}{2}$, $\phi_v = \frac{2\pi \cancel{N}}{\cancel{N}2} = \pi$

$\boxed{\phi_v = \pi} \rightarrow \pi$ mode

This mode of resonance called π mode.

If $\boxed{n = 0,\ \phi_v = 0}$

This is the zero mode meaning there will be no RF electric field between anode and cathode called fringing field

In absence of ~~electric~~ magnetic field electron travels straight from cathode to the anode due to the radial electric field force acting on it (integrated by trajetary A in fig b)

If the Magnetic field strength is increased slightly it will exert the lateral force binding the path of the electron as shown by path B. The radius of path is given by

$$R = \frac{mv}{eB}$$

That varies directly with velocity of electron and inversely with magnetic field strength

$$R \propto v$$

$$R \propto \frac{1}{B}$$

If the strength of magnetic field is make sufficiently high so has to prevent the electrons from reaching the anode (Path c). The magnetic field require to return electrons back to cathode just grazing the surface on the anode is called the critical magnetic field (BC) all the cut off magnetic field.

If the magnetic field is made larger then the critical magnetic field $\therefore B > B_c$ the electron experiences a greater rotational force and may returns back to cathode quite faster all such electron because back heating of the cathode