Important Relations in Two-cavity klystron Amplifier

① Initial Electron Velocity,

$$v_0 = \sqrt{\frac{2eV_0}{m}} = 0.593 \times 10^6 \sqrt{V_0} \text{ m/s}$$

$e \rightarrow 1.6 \times 10^{-19}$ C

$V_0 \rightarrow$ Beam Voltage. $m \rightarrow 9.1 \times 10^{-31}$ kg.

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② At Cavity Gap,

Gap transit time $(\tau) = \dfrac{d}{v_0}$

Gap transit angle $(\theta_g) = \dfrac{\omega d}{v_0} = \omega\tau$

$d \rightarrow$ ~~distance between~~ Cavity gap space.

$\omega \rightarrow 2\pi f$

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③ DC transit time $(T_0) = \dfrac{L}{v_0}$

DC transit angle $(\theta_0) = \omega T_0 = \dfrac{\omega L}{v_0}$

$L \rightarrow$ Space between two cavities.

Input Cavity

Output Cavity

④ Beam Coupling Coefficient, $\boxed{\beta_i = \beta_0}$

when cavities are identical.

$$\beta_i = \frac{\sin\left(\frac{\theta_g}{2}\right)}{\frac{\theta_g}{2}}$$

(5) Input Voltage, [Maximum]

(7)

$$V_{1(max)} = \frac{2V_0 X}{\beta_i \theta_0} \quad ; \quad X = 1.84 \quad J_1(X) = 0.58$$

(6) Voltage Gain,

(10)

$$A_v = \frac{V_2}{V_1} = \frac{\beta_0^2 \theta_0 J_1(X)}{[R] X} [R_{sh}]$$

$R_{sh} \rightarrow$ Shunt impedance

$R \rightarrow$ ~~Input impedance~~ dc beam resistance $\rightarrow \frac{\text{Beam Voltage}}{\text{Beam Current}} = \frac{V_0}{I_0}$

→ Maximum ~~Amplitude~~ Voltage Value obtained at

$J_1(X) = 0.582$ for $X = 1.841$

from Bessel function i.e, first fundamental Value.

(7) Equation of Velocity Modulation:

(5)

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

(or)

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

⑧ Output Power :-

$$P_{out} = \frac{\beta_0 I_2 V_2}{2}$$

$\boxed{2 I_0 J_1(X) = I_2}$ → Current at Catcher gap (Output cavity)

$\boxed{\beta_0 I_2 R_{sh} = V_2}$ → RF signal voltage at Catcher gap (Output cavity)

⑨ Input Power & efficiency :-

$$P_{in} = I_0 V_0$$

$$\eta = \frac{P_{out}}{P_{in}} = \frac{\beta_0 I_2 V_2}{2 I_0 V_0}$$

→ The efficiency is about 58%.
But, in practice efficiency of Klystron amplifier is in range of 15 to 30%.

⑩ Mutual Conductance of Klystron Amplifier :-

⑪ $G_m = \frac{2 \beta_0 I_0 J_1(X)}{V_1}$; $V_1 = \frac{2 V_0 X}{\beta_0 \theta_0}$; $\frac{1}{R} = \frac{I_0}{V_0}$

⇒ $\boxed{A_V = (G_m)(R_{sh})}$

(11) Bunching Parameter of klystron Amplifier,

(6)

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

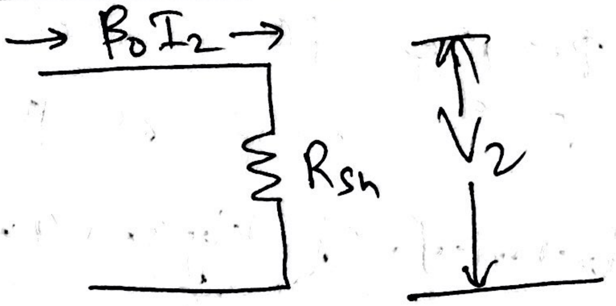
→ If coupling is perfect, $\beta_0 = 1$, $V_0 = V_2$

& $I_{2max} = 2 I_0 (0.582)$.

→ Then the maximum efficiency is about 58%.

→ But in practice, it is in the range of 15 to 30%.

Output equivalent circuit:-



→ R_{sh} → effective shunt resistance

$$V_2 = \beta_0 I_2 R_{sh}$$

$P = IV$

$V = IR$

→ A two-cavity Klystron amplifier has following parameters:

$V_0 = 1000V$, $I_0 = 25mA$, $f = 3GHz$,

$d = 1mm$, $L = 4cm$, $R_{sh} = 30k\Omega$

find maximum input gap Voltage, — (a)

(b) Voltage gain

(c) efficiency of amplifier.

$v_0 \rightarrow 1.88 \times 10^7$ m/s

$\theta_g \rightarrow 1 rad$

$\beta_i \rightarrow 0.952$

$\theta_0 \rightarrow 40 rad$

$V_{1max} = 96.5 V$

$A_V = 8.595$

$\eta = 46.2\%$

Important Relations in Reflex-Klystron Oscillator :-

① Round-trip in dc transit time of center of the bunch electron,

$$\boxed{T_0' = \frac{2mLv_0}{e(V_R+V_A)}}$$

$$v_0 \rightarrow \sqrt{\frac{2eV_A}{m}} = 0.593\times10^6\sqrt{V_A} \text{ m/s.}$$

$V_A \rightarrow$ Beam Voltage

$V_R \rightarrow$ Repeller Voltage.

$L \rightarrow$ Repeller space.

② Round-trip dc transit angle,

$$\boxed{\theta_0' = \omega T_0'}$$

③ Bunching parameter of Reflex klystron,

$$X' = \frac{\beta_i V_1 \theta_0'}{2V_A}$$; $V_1 \rightarrow$ RF voltage signal.

$\beta_i \rightarrow$ Beam coupling coefficient

④ DC power supplied by beam voltage (V_A) is

$$\boxed{P_{dc} = V_A I_A}$$

$I_A \rightarrow$ Beam current.

(5) AC Power delivered to load is given by

$$P_{ac} = \frac{V_1 I_2}{2}$$

Where, $\boxed{I_2 = 2 I_A \beta_i J_1(x')}$ & $\boxed{V_2 = 2 I_A J_1(x') R_{sh}}$

$$\Rightarrow P_{ac} = V_1 I_A \beta_i J_1(x')$$

(6) Power Output,

from (3) $V_1 = \frac{2 V_A X'}{\beta_i \theta_0'}$

$$\Rightarrow \boxed{P_{ac} = \frac{2 V_A X' I_A J_1(x')}{\theta_0'}}$$

→ for maximum energy transfer, in reflex klystron,

$$\theta_0' = 2\pi N = 2\pi\left(n - \frac{1}{4}\right) = 2\pi n - \frac{\pi}{2}$$

$N \rightarrow n - \frac{1}{4} \rightarrow$ number of modes.

$n \rightarrow$ positive integer for cycle number

$$\Rightarrow P_{ac} = \frac{2 V_A I_A X' J_1(x')}{2\pi n - \pi/2}.$$

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7. Efficiency of Reflex Klystron oscillator.

$$\eta = \frac{P_{ac}}{P_{dc}}$$

$$\Rightarrow \eta = \frac{2x' J_1(x')}{2\pi n - \pi/2}$$

→ ~~amplitude~~ maximum Voltage Value obtained at $J_1(x') = 0.52$ with.

$x' = 2.408$

8. In practice, the mode of $n = 2$ (or) $1\frac{3}{4}$ ~~mode~~ has most power output.

for $n = 2$ (or) $1\frac{3}{4}$ mode

$$\text{efficiency}_{max} = \frac{2(2.408)(0.52)}{2\pi(2) - \frac{\pi}{2}}$$

$$\simeq 22.7\%$$

→ Theoretically, efficiency of reflex Klystron ranges from 20 to 30%.

9. In general, the optimum transit time is given as $T = n + 3/4$; where 'n' is any integer.

(11) The Relationship between ~~Beam Voltage (V_0)~~ cycle number(n) & repeller voltage (V_R),

W.K.T,

$$\rightarrow T_0' = \frac{2mL v_0}{e(V_R+V_A)}$$

$$\rightarrow v_0 = \sqrt{\frac{2eV_A}{m}}$$

$$\rightarrow \theta_0' = 2\pi n - \frac{\pi}{2}$$

$\rightarrow$ Also, $\theta_0' = \omega T_0'$

$$\omega T_0' = \frac{\omega\, 2mL}{e(V_R+V_A)} \cdot \sqrt{\frac{2eV_A}{m}}$$

$$\theta_0' = \frac{\omega\, 2\sqrt{2}\, \sqrt{m}\, L \sqrt{V_A}}{\sqrt{e}\,(V_R+V_A)}$$

$$2\pi n - \frac{\pi}{2} = \frac{2\omega L}{(V_R+V_A)} \cdot \sqrt{\frac{2mV_A}{e}}$$

Squaring on b.s.

$$\left(2\pi n - \frac{\pi}{2}\right)^2 = \frac{8\omega^2 L^2 m V_A}{(V_R+V_A)^2 \cdot e}$$

$$\Rightarrow \boxed{\frac{V_A}{(V_R+V_A)^2} = \frac{\left(2\pi n - \frac{\pi}{2}\right)^2}{8\omega^2 L^2} \cdot \frac{e}{m}}$$

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(12) The power output in terms of repeller Voltage V_R.

W.K.T

$\Rightarrow P_{ac} = \dfrac{2V_A I_A X' J_1(X')}{\theta_0'}$; $\Rightarrow \theta_0' = \omega T_0'$

$\rightarrow T_0' = \dfrac{2mL v_0}{e(V_R+V_A)}$

$\rightarrow v_0 = \sqrt{\dfrac{2eV_A}{m}}$

Now, (*) $\theta_0' = \omega T_0' = \dfrac{\omega 2mL v_0}{e(V_R+V_A)} = \dfrac{\omega 2mL}{e(V_R+V_A)} \cdot \sqrt{\dfrac{2eV_A}{m}}$

$$P_{ac} = \frac{2V_A I_A X' J_1(X') \cdot e(V_R+V_A) \cdot \sqrt{m}}{\omega 2mL \cdot \sqrt{2eV_A}}$$

$$P_{ac} = \frac{V_A I_A X' J_1(X') \cdot \sqrt{e}\,(V_R+V_A)}{\omega \sqrt{m}\, L \cdot \sqrt{2V_A}}$$

$$P_{ac} = \frac{V_A I_A X' J_1(X') \cdot (V_R+V_A)}{\omega L} \cdot \sqrt{\frac{e}{2mV_A}}$$

→ A Reflex klystron oscillator has following specifications:

V_0 (or) $V_A = 600V$, $L = 1mm$, $R_{sh} = 15 k\Omega$, $f_r = 9 GHz$.

~~The~~ ~~tube~~ It is oscillating at f_r at peak value $n = 2$

(or) $N = 1\frac{3}{4}$ mode.

(i) Find value of V_R.. $V_R = 250V$

(ii) Find ~~the~~ direct current necessary to give a microwave gap voltage of 200 V. (I_A) (or) (I_0)

$$\rightarrow V_2 = 2 I_A J_1(x') R_{sh}.$$

$I_A = 12mA$.

$$\Rightarrow I_A = \frac{V_2}{2 J_1(x') R_{sh}}.$$

(iii) Find dc transit angle. $\theta_0' = 10.74$ rad

$$\rightarrow \frac{V_A}{(V_R+V_A)^2} = \frac{\left(2\pi n - \frac{\pi}{2}\right)^2}{8\omega^2 L^2} \cdot \frac{e}{m}$$

$$\rightarrow \theta_0' = \omega T_0'$$

$$\rightarrow T_0' = \frac{2mL\nu_0}{e(V_R+V_A)}$$

$$\rightarrow \nu_0 = 0.593 \times 10^6 \sqrt{V_A} \text{ m/s.}$$