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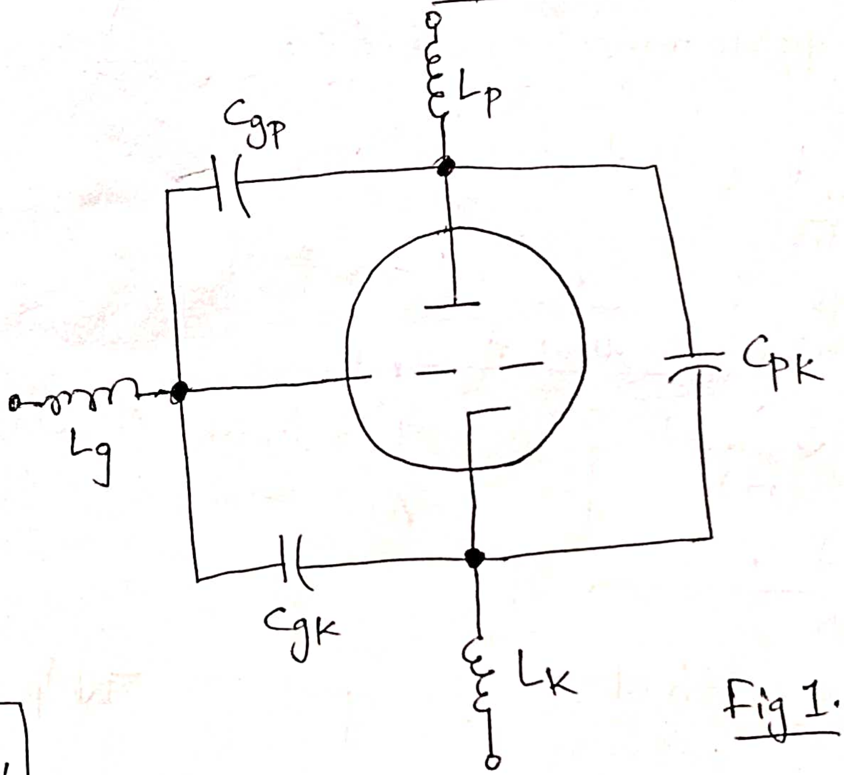
Limitations of Conventional Tubes at Microwave frequencies :-

→ Conventional Tubes such as triodes, tetrodes and pentodes are useful only at low frequencies.

→ They have certain limitations at high frequencies. Some of them are as follows:-

1) **Inter electrode Capacitance effect** :- (IEC).



g → grid
p → plate (anode)
k → cathode.

Fig 1. Triode

$\boxed{f\uparrow, X_c\downarrow}$

→ As frequency increases, the reactance $\boxed{X_C = \frac{1}{2\pi f C}}$, decreases and at higher frequencies X_c becomes almost short due to which the output voltage decreases. (from figure 1. C_{gp}, C_{pk} & C_{gk} are IEC's. The distance between electrodes decreases as X_c becomes short.). $\boxed{X_c\uparrow, C\downarrow}$

$C\downarrow, A\downarrow$ (or) $C\downarrow, d\uparrow$

→ To minimize the IEC effect, by using $\boxed{C = \frac{\varepsilon_0 \varepsilon_r A}{d}}$ we have to decrease the area of electrodes (or) increase the distance between them.

2) Lead Inductance (LI) effect:-

→ $\boxed{X_L = 2\pi f L}$

$\boxed{f\uparrow \text{ \& } X_L\uparrow}$ (reactance).

↳ Which results in reduced Voltage gain of tube. i.e., ratio of output voltage to input voltage.

from fig. 1 L_p, L_g, L_k are the lead inductances which limit the performance of tube.

→ $\boxed{X_L\downarrow, \; L\downarrow}$

from, $\boxed{L = \dfrac{l}{\mu_0 \mu_r A}}$

$\boxed{\begin{array}{c} L\downarrow, \; l\downarrow \\ \text{(or)} \\ L\downarrow \; A\uparrow \end{array}}$

l → length of Coil
A → area of Coil.

3) Transit time effect:-

→ Transit time is the time taken for the electron to travel from Cathode to anode as shown in figure 2

i.e., Transit time, $\boxed{\tau = \dfrac{d}{v_0}}$ —(1)

d → distance b/w anode & cathode
v_0 → Velocity of electrons.

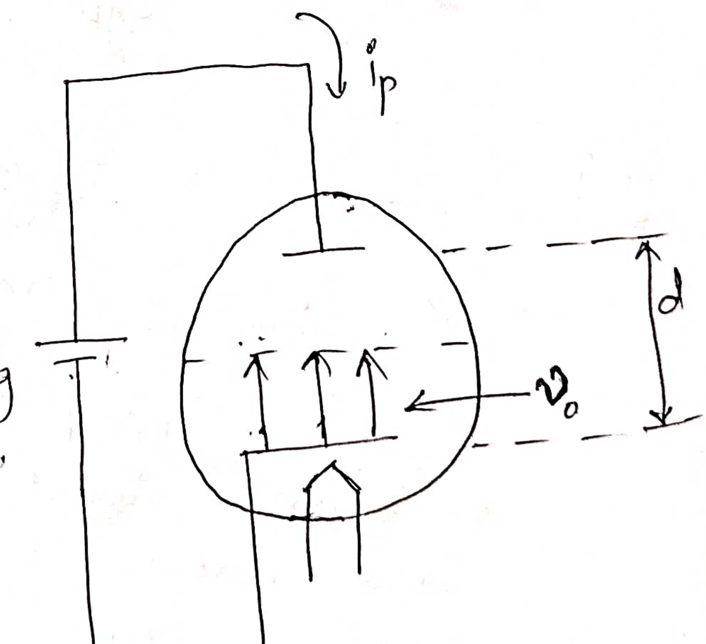


figure. 2

W.K.T. Static energy of electron = eV_0 (2)

Kinetic energy $= \frac{1}{2} m v_0^2$

Under equilibrium, Static energy = kinetic energy.

$$eV_0 = \frac{1}{2} m v_0^2$$

$$\boxed{\begin{array}{l} e = 1.6 \times 10^{-19} C \\ m = 9.1 \times 10^{-31} kg \end{array}}$$

$$v_0 = \sqrt{\frac{2eV_0}{m}} \quad -(2)$$

from (1) & (2) $$\boxed{\tau = \frac{d}{\sqrt{2eV_0/m}}}$$

→ At low frequencies, the transit time is negligible i.e, for the change in input voltage V_g, the plate current i_p responds immediately. Where as at high frequencies, the plate current i_p responds after some delay with change in V_g. due to which the transit time is not negligible & it will be in some nano-seconds delay. [i.e, electrons take some time to travel from cathode to anode at high freq. than at low freq.].

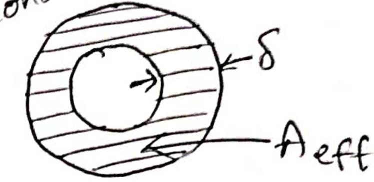
→ To minimize $\boxed{\tau \downarrow, \quad d \downarrow}$ [distance b/w electrodes can be decreased.]

④ Effect due to RF losses :-

(a) Skin effect losses (or Conductor or I^2R losses)

W.K.T Skin depth $\delta = \sqrt{\frac{2}{\omega\mu\sigma}}$

$\omega \to 2\pi f$
$\mu \to$ permeability
$\sigma \to$ Conductivity



i.e., $\delta \propto \frac{1}{\sqrt{\omega}}$ & $\delta \propto A_{eff}$.

$\delta \propto \frac{1}{\sqrt{f}}$ where, $A_{eff} \propto \frac{1}{\sqrt{f}}$

$A_{eff} \to$ effective area over which current flows.

& $R = \frac{\rho l}{A_{eff}}$ $\Rightarrow R \propto \sqrt{f}$

Resistance

→ As $f\uparrow$ $R\uparrow$., Hence losses will increase at higher frequencies. These losses can be reduced by increasing the size of conductors.

(b) Dielectric losses :-

These losses occur due to the type of insulating materials used in the devices such as spacers, glass envelope, silicon or plastic encapsulations etc.,

⑤ Radiation Losses :-

Whenever the dimensions of wire approaches the wavelength, it will emit radiation, i.e.,
As frequency increases, the amount of radiation loss also increases.

$$\delta = \sqrt{\frac{1}{\pi f \mu\sigma}}$$

$\sigma = \frac{1}{\rho}$ → resistivity

$$\delta = \sqrt{\frac{\rho}{\pi f \mu}}$$