Helix TTs :- (O-type traveling-wave tube)

↳ It is a specialized vacuum tube used to amplify RF signals in microwave range.

Significance :- ↳ Can amplify a wide range of frequencies, a wide bandwidth

→ In 1944, Kompfner invented helix traveling wave tube.

↳ Helix TWTs are used for broadband applications.

→ Operating freq. → 300 MHz to 50 GHz, power gain → 40 to 70 dB, o/p power → few watts to mega watts.

→ For high-average-power purposes, such as radar transmitters, the coupled-cavity TWTs are used.

↳ In TWT, the microwave circuit is nonresonant and the wave propagates with same speed as the electrons in the beam.

→ The initial effect on the beam is a small amount of velocity modulation caused by the weak electric fields associated with the travelling wave.

→ The interaction of electron beam and RF field in TWT is continuous over the entire length of the circuit. whereas in klystron it occurs only at cavity gap.

The wave in TWT is a propagating wave, the wave in klystron is not.

→ The

↳ A helix traveling-wave tube consists of an electron beam and a slow-wave structure.

→ The electron beam is focused by a constant magnetic field along the slow-wave structure.

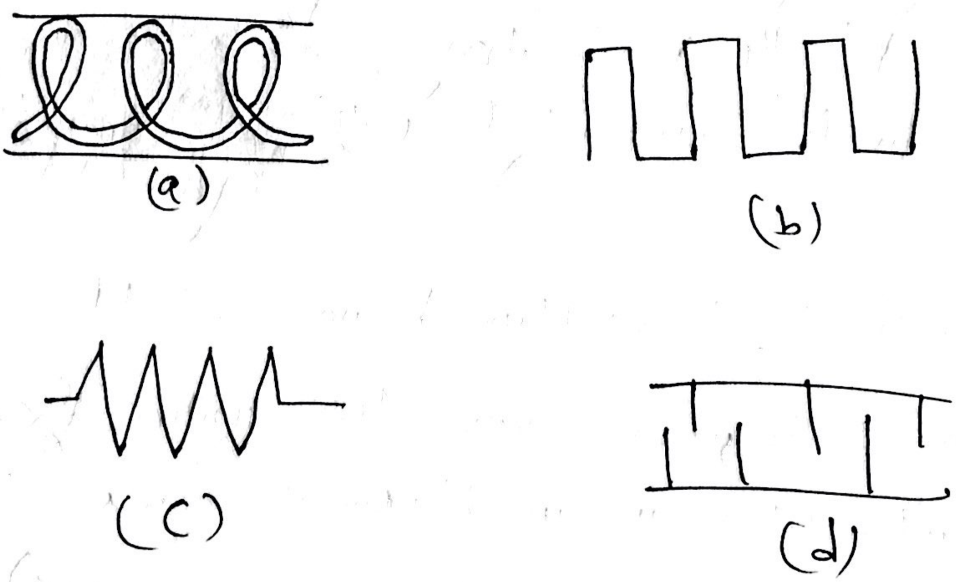
→ The slow-wave structure is helical type.

→ The applied signal propagates around the turns of helix and produces an electric field at the center of helix, directed along ~~the~~ helix axis.

Slow-wave structure :-

(1) → It is a nonresonant periodic circuit designed to produce large gain over a wide bandwidth.

→ (3)



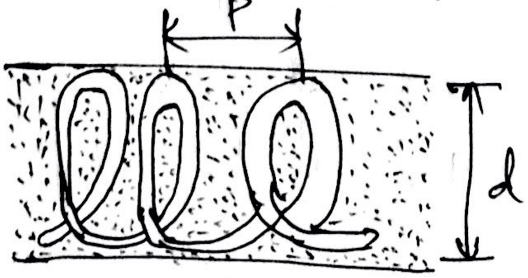
(a) helical line (b) Folded-back line

(c) Zigzag line (d) Interdigital line.

→ Types of slow wave structures.

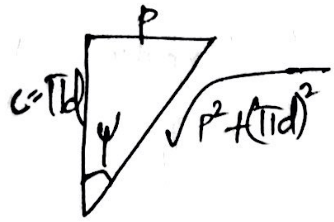
→ Commonly used slow wave structure is a helical coil with a concentric conducting cylinder. (2)

(4)



(a)

Helical Coil



(b)

one turn of helix

(2) → Slow wave structures are special circuits that are used in microwave tubes to reduce the wave velocity in a certain direction so that the electron beam and the signal wave can interact. In TWT, the phase velocity of microwave signal can keep pace with that of electron beam velocity for effective interactions.

(5) → As we know that, the ratio of phase velocity v_p along the pitch to the phase velocity along the coil is given by

$$\frac{v_p}{c} = \frac{p}{\sqrt{p^2 + (\pi d)^2}} = \sin\psi \quad \text{—(1)}$$

Where, $C = 3 \times 10^8$ m/sec is the velocity of light in free space.

p = helix pitch

d = diameter of the helix

ψ = pitch angle.

→ In general, the helical coil may be with in a dielectric-filled cylinder. so, the phase velocity in the axial direction is expressed as.

$$\vartheta_{p\varepsilon} = \frac{p}{\sqrt{\mu\varepsilon\left[p^2+(\pi d)^2\right]}} \quad \text{—} \; (2)$$

→ for a very small pitch angle, the phase velocity along the coil in free space is approximately represented by $\vartheta_p \approx \frac{pc}{\pi d} = \frac{\omega}{\beta}$ — (3)

→ The helix ω-β diagram is shown in figure and is useful in designing helix slow wave structure.

→ The group velocity of the wave is calculated by measuring slope of the curve.

$$\vartheta_{gr} = \frac{d\omega}{d\beta} \quad \text{—} \; (4)$$

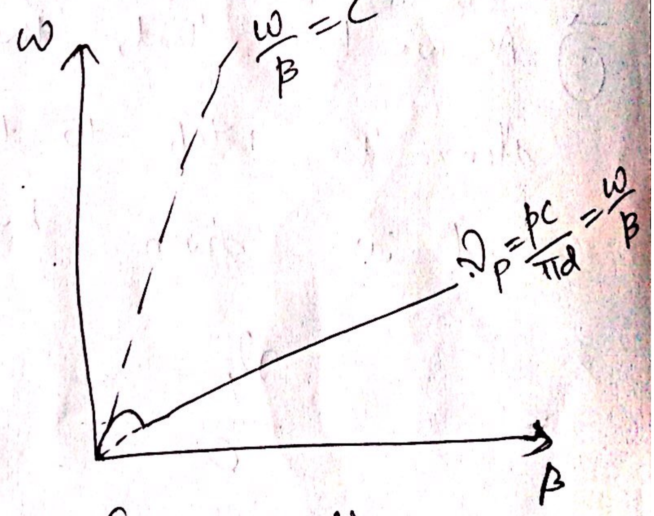
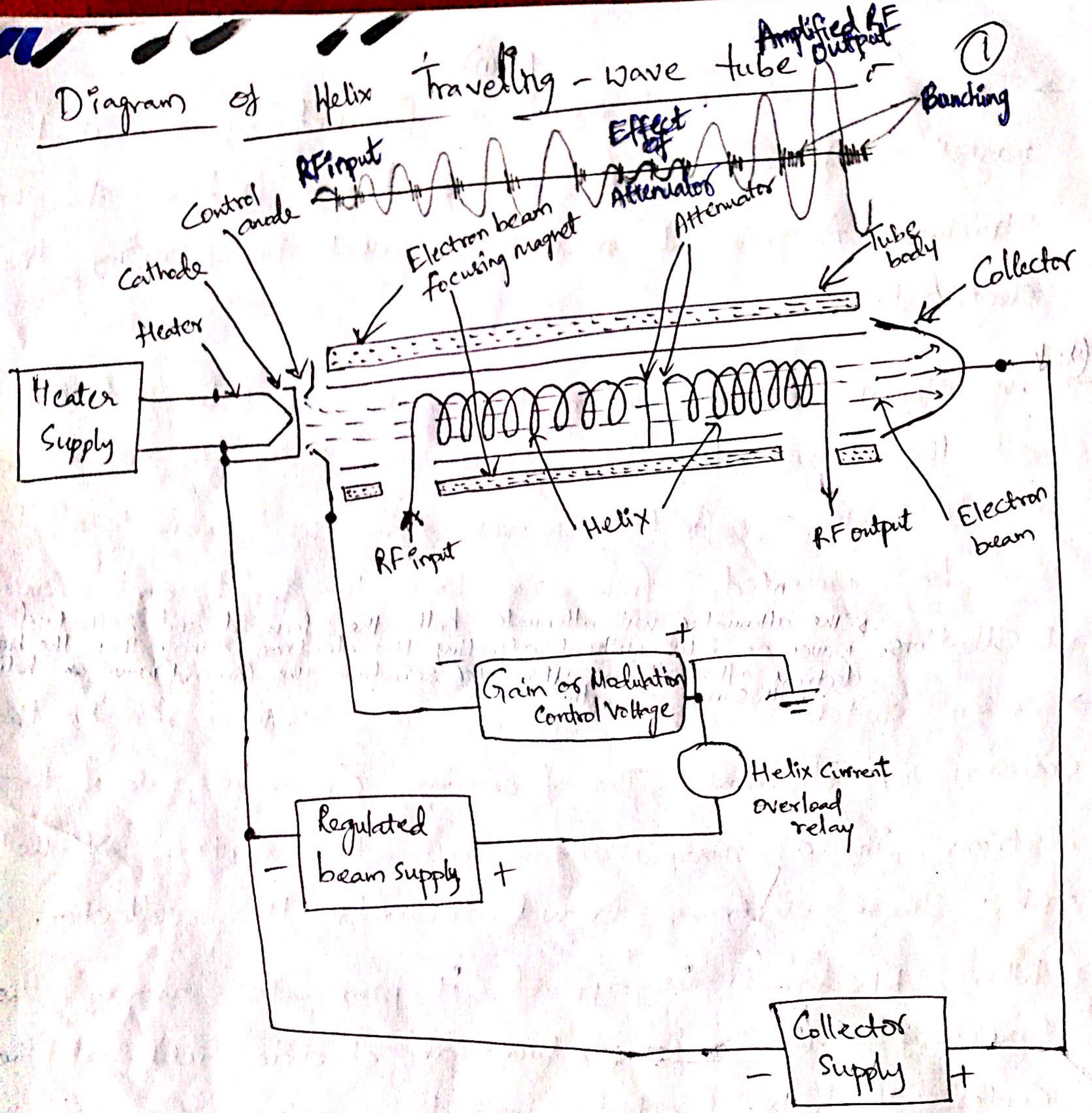
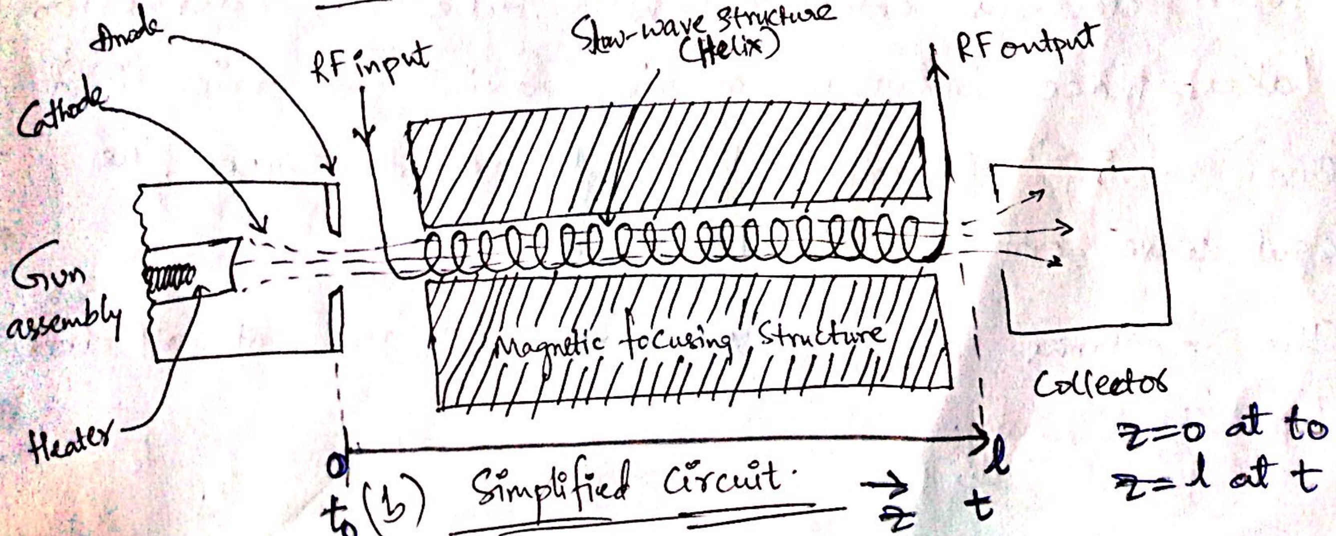


Fig. ω-β diagram for a helical structure

① Diagram of Helix Travelling-wave tube



(a) Schematic diagram of helix TWT



(b) Simplified circuit

(gun)

→ It consists of an electron beam focused by a constant magnetic field along the electron beam and a slow-wave structure. A permanent magnet is used for focusing the electron beam.

(*) → An attenuator placed near the center of helix reduces all the waves traveling along the helix to nearly zero so that the reflected waves from the mismatched loads can be prevented from reaching the input and causing oscillations. → The attenuator will attenuate both the forward and reflected waves on helix without affecting the electron beam. Thus, the bunched electrons after exit from attenuator reinduce the forward wave on helix with same strength.

→ When switch on the circuit, the cathode starts the emission of electrons. The focussing electrodes focus these electrons in a narrow beam at the centre of the tube. These electrons travel towards the collector.

→ When RF signal is applied, it propagates around the turns of helix and produces an electric field at the center of helix, directed along helix axis.

→ When electrons enter the helix tube, an interaction takes place between moving axial electric field and moving electrons. This interaction causes the signal wave on helix to become larger.

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

→ Those electrons entering the helix at the accelerating field are accelerated, and those at the retarding field are decelerated.

→ As a result, the electrons will be formed in bunches and travel towards collector with in the helix.

→ The volume of bunch become stronger and stronger as the electrons appraches collector.

i.e.,

→ As the electrons travel further along the helix, they bunch at ~~collector~~ output end of the helix.

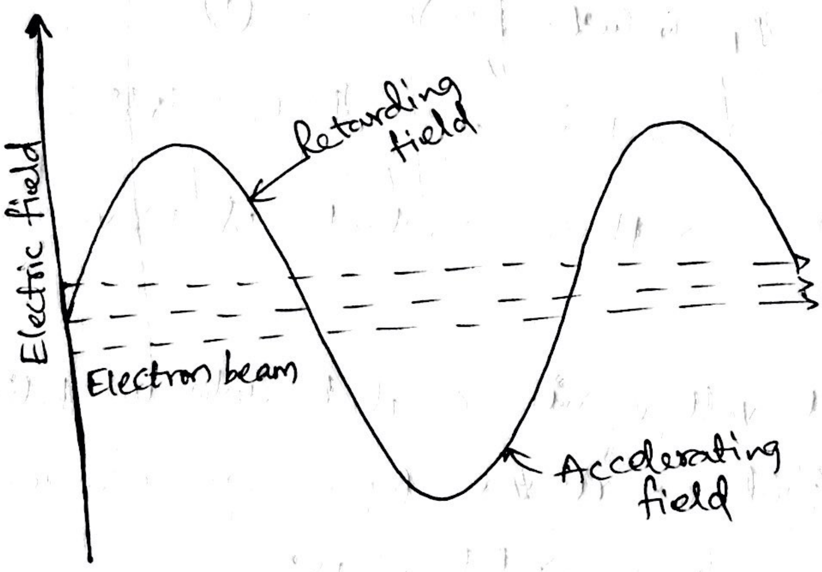


fig. Interactions between electron beam and electric field.

→ Then the microwave energy of the electrons is delivered by the electron bunch to the wave on the helix, resulting the amplification of signal wave.

→ The energy from the bunches increases the amplitude of the travelling-wave along the length of TWT.

→ The characteristics of traveling-wave tube are:

Bandwidth → about 0.8 GHz

Efficiency → 20 to 40%.

Mathematical Analysis of TWT:

→ The motion of electrons in the helix-type TWT can be analyzed in terms of axial electric field.

→ If the traveling wave is propagating in the z-direction, then the z component of electric field can be expressed as

$$E_z = E_1 \sin(\omega t - \beta z) \quad -①$$

Where, E_1 is magnitude of electric field in z-direction

$\rightarrow \beta = \dfrac{\omega}{v_p}$ → phase constant of wave.

→ When a signal voltage is coupled into the helix, the axial electric field exerts a force on electrons as a result of following relationships:

i.e., $F = ma$

$F = -eE$

$\Rightarrow ma = -eE$

$$m\frac{dv}{dt} = -e\left[E_1 \sin(\omega t - \beta z)\right] \quad -②$$

→ Assuming that the velocity of electron (v) is

$$v = v_0 + v_e \cos(\omega_e t + \theta_e) \quad — (3)$$

where, v_0 = dc electron velocity $= \sqrt{\frac{2eV_0}{m}}$

v_e = magnitude of velocity fluctuation in the velocity-modulated electron beam.

ω_e = angular frequency of velocity fluctuation

θ_e = phase angle of fluctuation.

Differentiating eq. (3) w.r.t 't'

$$\frac{dv}{dt} = 0 - v_e \omega_e \sin(\omega_e t + \theta_e) \quad — (4)$$

Sub. (4) in (2)

$$m\left[-v_e \omega_e \sin(\omega_e t + \theta_e)\right] = -e\left[E_1 \sin(\omega t - \beta z)\right] \quad — (5)$$

→ For effective interactions between the electrons and the electric field, the velocity of the velocity-modulated electron beam must be approximately equal to the dc electron velocity. This is

$$v \approx v_0 \quad — (6)$$

→ Hence the distance 'z' traveled by electrons is

$$z = v_0(t - t_0) \quad — (7)$$

Sub. (7) in (5)

$$m v_e \omega_e \sin(\omega_e t + \theta_e) = eE_1 \sin[\omega t - \beta v_0 (t - t_0)] \quad -(8)$$

Comparison of left and right-hand sides of Eq. (8):

(i) $m v_e \omega_e = eE_1$

$$\Rightarrow v_e = \frac{eE_1}{m\omega_e} \quad -(9)$$

(ii) $\omega_e = \omega - \beta v_0$

$$\omega_e = v_p \beta - \beta v_0 \quad \left(\because v_p = \frac{\omega}{\beta}\right)$$

$$\Rightarrow \omega_e = \beta(v_p - v_0) \quad -(10)$$

(iii) $\theta_e = \beta v_0 t_0 \quad -(11)$

→ It can be seen that the magnitude of velocity fluctuation of electron beam is directly proportional to the magnitude of the axial electric field.

Supression of oscillations:-

Refer to (A) → @ previous page

Gain of TWT :-

→ Output power gain in decibels is defined as

$$A_p = 10 \log \left| \frac{V(l)}{V(0)} \right|^2 = -9.54 + 47.3 NC \text{ dB}$$

Where, $V(l)$ → output voltage

$V(0)$ → input voltage.

$N \rightarrow \frac{l}{\lambda_e}$ → circuit length (N)

$$\lambda_e = \frac{2\pi}{\beta_e}.$$

l → length of helix structure.

β_e → phase constant of velocity modulated electron beam

C → gain parameter of TWT.

$$C = \left(\frac{I_0 Z_0}{4 V_0} \right)^{1/3}$$

I_0 → Beam Current

Z_0 → Characteristic impedance of helix

V_0 → Beam voltage.

→ A TWT operates under the following parameters;

Beam current = 25 mA

Beam Voltage = 2.5 KV

Characteristic impedance of helix = 10 Ω

Circuit length = 40

frequency = 9.5 GHz.

phase constant of wave = 2.01×10^3 rad/m

Determine (i) phase velocity of wave.

(ii) gain parameter of TWT

(iii) Output power gain.

(i) $v_p = \frac{\omega}{\beta}$ (ii) 'C' (iii) Ap.

→ In an O-type traveling tube, beam voltage is 4KV & the magnitude of axial electric field is 4 V/m. The phase velocity on the slow-wave structure is 1.1 times ~~greater~~ of ~~than~~ d(electron beam velocity. The operating frequency is 2 GHz. Find the magnitude of velocity fluctuation.

$$\rightarrow v_e = \frac{eE_1}{m\omega_e} \qquad \rightarrow \omega_e = \beta(v_p - v_0)$$

$$\rightarrow \beta = \frac{\omega}{v_p} \qquad \Rightarrow v_0 = \sqrt{\frac{2eV_0}{m}}$$

$V_0 = 4KV$

$E_1 = 4V/m$

$f = 2GHz$.

$\Rightarrow v_p = 1.1\, v_0$

1.6×10^{-19}

9.1×10^{-31}

$= 0.593 \times 10^6 \sqrt{V_0}$