MICROWAVE TUBES-KLYSTRON

3.1 INTRODUCTION

O-TYPE Linear Tubes (Travelling tube amplifiers, Klystrons) .In O-Type tube , a magnetic field whose axis coincides with the electron beam is used to hold the beam together as it travels the length of the tube

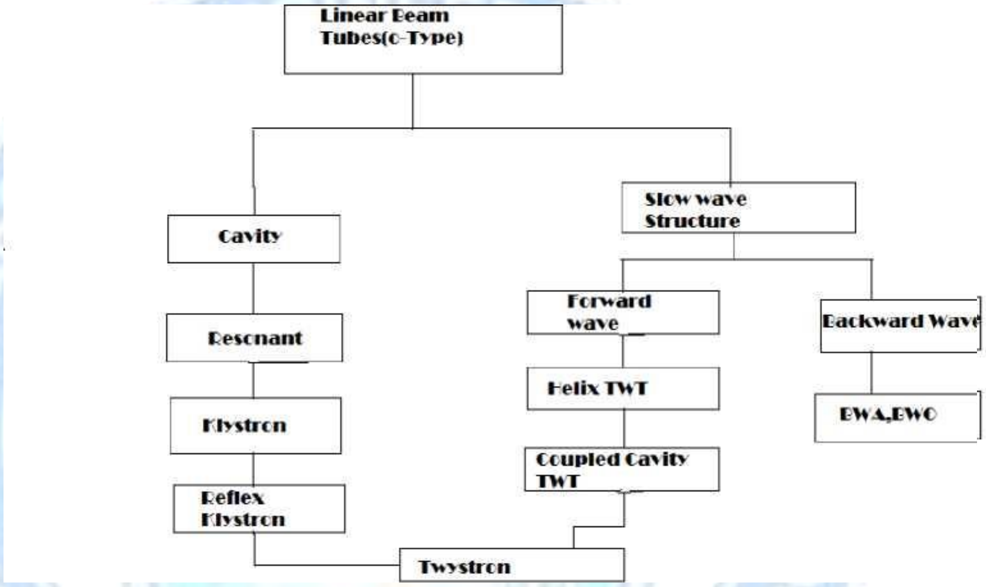

Figure 3.1 Classification of microwave tubes

Velocity-modulated Tubes

Velocity-modulated tubes are microwave tubes using transit time in the conversion of dc power to radio-frequency power. The interchange of power is accomplished by using the principle of electron velocity modulation and low-loss resonant cavities in (or near the electron beam of) the microwave tube.

Velocity modulation is then defined as that variation in the velocity of a beam of electrons caused by the alternate speeding up and slowing down of the electrons in the beam. This variation is usually caused by a voltage signal applied between the grids through which the beam must pass. The direction of the electron beam and the static electrical field goes to each other parallelly (linearly) into linear beam tubes. Against this the fields influencing the electron beam stand vertically by the electron beam at the cross field tubes.

The following table compares with characteristic quantities of the velocity- modulated tubes used in radar technology. Although the planar tube isn't a velocity- modulated tube, it was included into this table for comparison purposes. The grid of the density controlled tube (like the planar triode) regulates the number of electrons on the path to the anode. The different speeds of the electrons by additional accelerating due the microwave voltage are annoying in this case. The cut-off frequency of density controlled tubes is relatively low. Higher frequencies need the use of velocity- modulated tubes, as shown in the table:

Table 3.1 Comparison between microwave tubes

	Klystron	Traveling Wave Tube	Magnetron	Carcinotron	EIK/EIO	planar tube
frequency	up to 35 GHz	up to 95 GHz	up to 95 GHz	up to 5 GHz	up to 230 GHz	up to 1.5 GHz
bandwidth	2-4%	10-20%	any megahertzes	2 GHz	0.5...1%	30 - 50%
power output	up to 50 MW	up to 1 MW	upto 10 MW	1 W	up to 1 kW	up to 1 MW
amplification	up to 60 dB	upto 50 dB	-	-	40...50 dB	up to 20 dB
function as	small-band power amplifier	wide-band, lownoise voltage amplifier	high power oscillator at one frequency	frequency-controlled oscillator (VFO)	microwave amplifier/ oscillator	amplifier, oscillator

3.2 Klystron Amplifier

Klystron amplifiers are high power microwave vacuum tubes They are used in some coherent radar transmitters as power amplifiers. Klystrons make use of the transittime effect by varying the velocity of an electron beam. A klystron uses special resonant cavities which modulate the electric field around the axis of the tube modulating the electric field around the axis the tube. In the middle of these cavities, there is a grid allowing the electrons to pass the cavity. Due to the number of the resonant cavities klystrons are divided up into Two- or Multicavity klystrons, and Reflex or Repeller Klystrons.

3.2.1 Two-Cavity Klystron

As the name implies, this klystron uses two cavities. The first cavity together with the first coupling device is called a “buncher”, while the second cavity with its coupling device is called a “catcher”. The direction of the field changes with the frequency of the “buncher” cavity. These changes alternately accelerate and decelerate the electrons of the beam passing through the grids of the buncher cavity. The area beyond the cavities is called the “drift space”. The electrons form bunches in this area when the accelerated electrons overtake the decelerated electrons.

The function of the “catcher” cavity is to absorb energy from the electron beam. The “catcher” grids are placed along the beam at a point where the bunches are fully formed. The location is determined by the transit time of the bunches at the natural resonant frequency of the cavities (the resonant frequency of the catcher cavity is the same as the buncher cavity).The air-cooled collector collect the energy of the electron beam and change it into heat and X radiation.

Klystron amplification, power output, and efficiency can be greatly improved by the addition of intermediate cavities between the input and output cavities of the basic klystron. Additional cavities serve to velocity-modulate the electron beam and produce an increase in the energy available at the output.

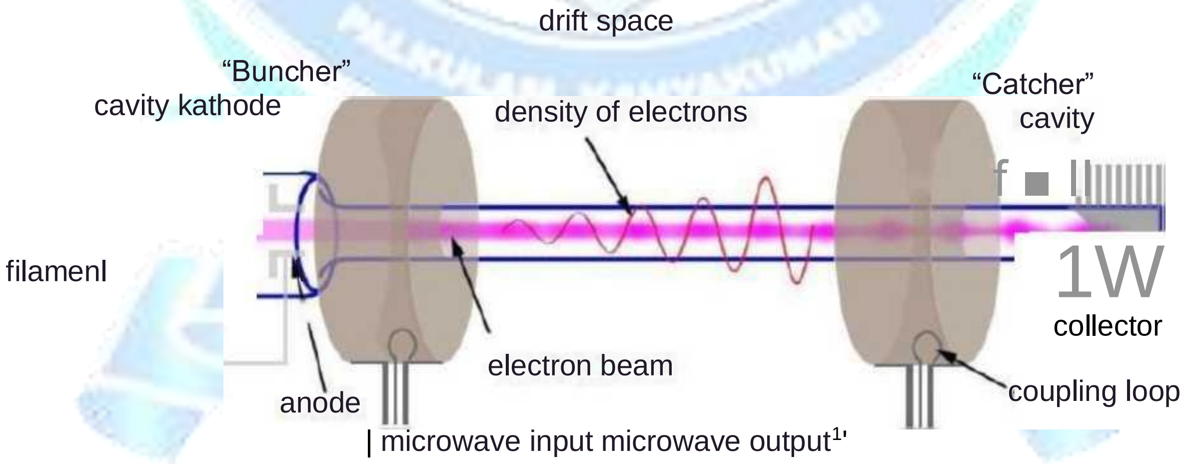

Figure 3.2: Physical construction and mode of operation of a two-cavity klystron

As indicated in the introduction this voltage will produce velocity modulation on the beam.

Let the Z' axis be taken in the direction of electron flow with grid position Z=0.

As the electron in between grids experiences a force due to the RF electric field

(1)

Where,V1 is the amplitude of the signal and V1 << V0
By considering either time to or the exiting time t1,te modulated velocity in the buncher cavity can be determined.The average microwave voltage in the buncher gap needs to be determined in below figure 3.2

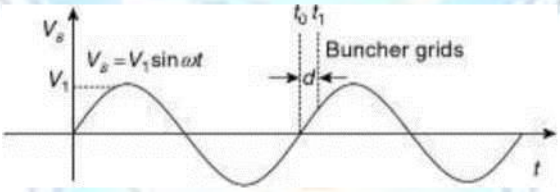

Figure3.2 Signal Voltage in the Buncher gap

As V1<<V0 ,the average transit time all the way through the bunchergap of distance d is

$$\tau = \frac{d}{v_0} = t_1 - t_0$$

(2)

The phase delay caused during transit time across the gap is referred to as gap transit angle g and can be given as

n , s wd
9„ =d)T = (D(t. -rh> = —
‘ 13)

Eventually, The average microwave voltage in the buncher gap can be given as

$$V_s = \frac{1}{\tau}\int_{t_0}^{t_1} V_1 \sin(\omega t)dt = \frac{-V_1}{\omega\tau}[\cos(\omega t_1) - \cos(\omega t_0)]$$

(4)

$$V_s = \frac{V_1}{\omega\tau}\left[\cos(\omega t_0) - \cos\left(\omega t_0 + \frac{\omega d}{v_0}\right)\right]$$

_(5)

let

(•)/,. + -— - (i>tn + — = A and ---- - — - B
2v(1 " 2 2v0 2
(6)

By using trigonometric relations ie cos(A-B)-cos(A+B)=2sinAsinB Eq 5 can be written as

$$V_s = V_1 \frac{\sin[\omega d / 2v_0]}{\omega d / 2v_0} \sin\left(\omega t_0 + \frac{\omega d}{2v_0}\right)$$

7)

(M
= l\fi} sin | mi,t + y

Where Pi the beam coupling coefficient of the input cavity gap and is given as

$$\beta_1 = \frac{\sin[\omega d / 2v_0]}{\omega d / 2v_0} = \frac{\sin(\theta_g / 2)}{\theta_g / 2}$$

We can observe that when the gap transit angle increases the coupling between the electron beam and buncher cavity reduces which means for a given microwave signal the velocity modulation decreases.The exit velocity modulation,can be instantly calculated as

$$v(t_1) = \sqrt{\frac{2e}{m}(V_0 + V_s)}$$

-(9)

Substituting Eq 7 in Eq 9

$$v(t_1) = \sqrt{\frac{2e}{m} V_0 \left[1 + \frac{\beta_1 V_1}{V_0} \sin\left(\omega t_0 + \frac{\theta_g}{2}\right)\right]}$$

(10)

Where, the fector P1V1/V0 is called the depth of velocity modulation

$$v(t_1) = v_0\sqrt{1+\frac{\beta_1 V_1}{V_0}\sin\left(\omega t_0+\frac{\theta_g}{2}\right)} \qquad (11)$$

Where p1 the beam coupling coefficient of the input cavity gap and id given as assuming that piV1<<V0 and by means of binomial expansion the Eq 11 is modified as

$$v(t_1) = v_0\left[1+\frac{\beta_1 V_1}{2V_0}\sin\left(\omega t_0+\frac{\theta_g}{2}\right)\right] \qquad (12)$$

This is called the velocity modulation equation,this equation can also be written as,

$$v(t_1) = v_0\left[1+\frac{\beta_1 V_1}{2V_0}\sin\left(\omega t_1 \quad \frac{\theta_g}{2}\right)\right] \qquad \underline{(13)}$$

Applegate diagram:

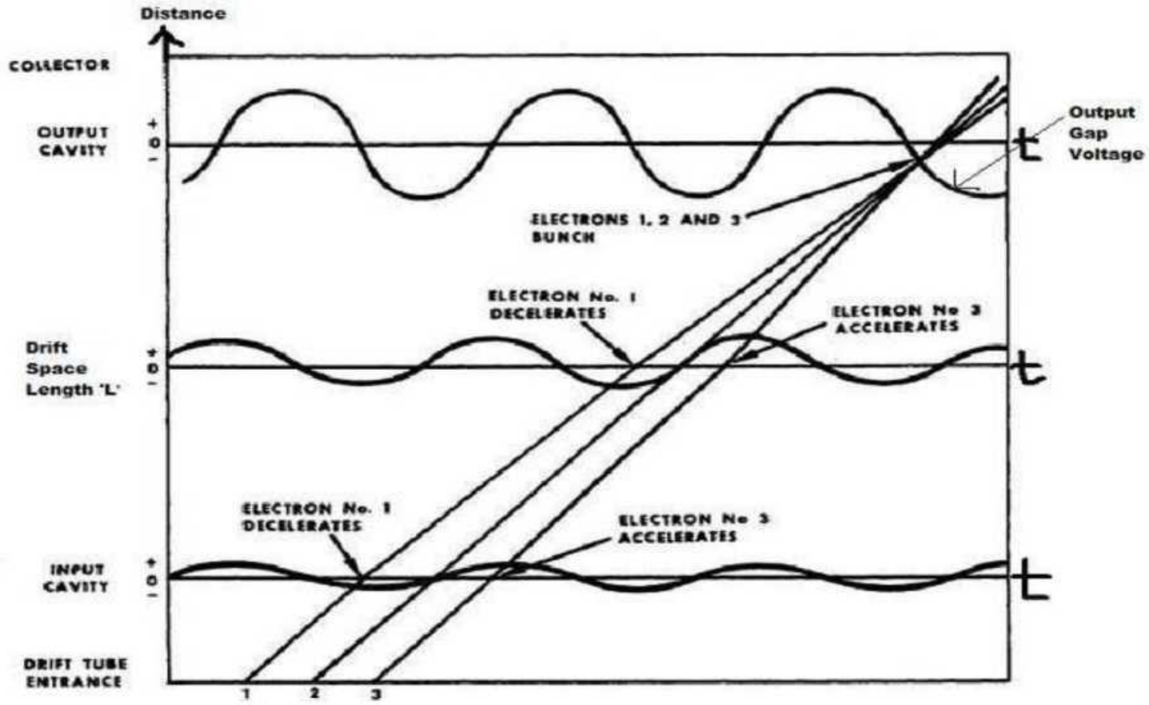

Figure 3.3: Applegate diagram

In a quarter of one period of the plasma frequency, the velocity modulation is converted to density modulation, i.e. bunches of electrons. Now let's see this procedure with the help of Applegate diagram hus the electron beam is velocity modulated to form bunches or undergoes density(Current modulation) with input RF signal. This current modulation of beam produces amplification of RF signal input at the catcher cavity. Thus what we obtain finally is the amplification of RF input signal. One important observation is that the phase of output signal is opposite to that of input signal. Also many harmonics are generated during amplification. One way to remove this harmonics is to tune the catcher cavity to the fundamental frequency or any other harmonic desired.

Bunching process:

The Electrons from the bunching centre they pass through at Vs=0 with an unchanged velocity Vo.During the Positive half cycles of the microwave input voltage Vs the electron passes the gap faster compared to the electrons that pass the gap at Vs=0.The electrons that enter buncher cavity during neagative half cycle of Vs are slow compared to that pass the gap at Vs=0.

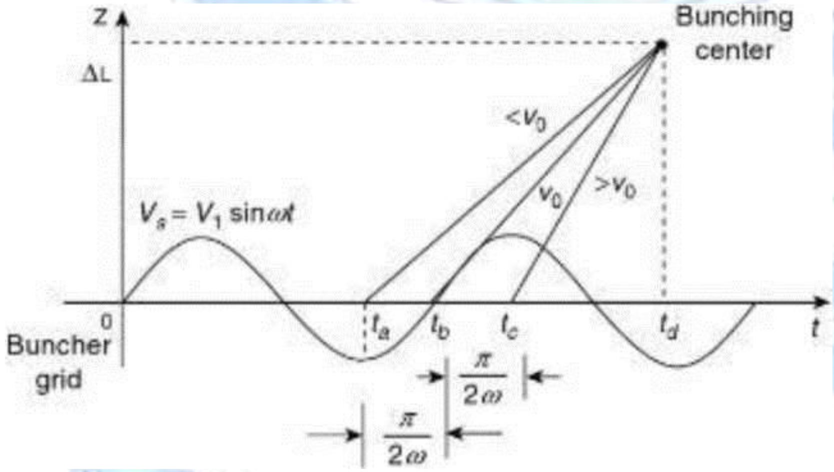

Figure 3.4: Bunching process

AL $^{=v}$**o(G ~)** ______ **1**

Similarly, the distances for the electrons at ta and tc are

$$\Delta L = v_{\min}(t_d - t_a) = v_{\min}\left(t_d - t_b + \frac{\pi}{2w}\right) \quad (2)$$

$$\Delta L = v_{\max}(t_d - t_c) = v_{\max}\left(t_d - t_b - \frac{\pi}{2w}\right) \quad (3)$$

From **the velocity modulation**

Maximum velocity occurs at n/2,so that

$$v_{\max} = v_0\left(1 + \frac{\beta_1 V_1}{2V_0}\right)$$

---4

Minimum velocity occurs at -n/2,so that

$$v_{\min} = v_0\left(1 - \frac{\beta_1 V_1}{2V_0}\right)$$

--- 5

Substituting Eqs 5 and 4 in 3 and 2

$\Delta L = v_0(t_d - t_b) + v_0$ *κ p.V.* *v Pf. n*

2(0 2l'ƒ) J **2K0** *2(0*

-------------6

The necessary condition for those electrons at ta,tb,and tc to meet at the same distance AL is

JL *K}.^L2L.a*

2(0 **2^ d h 2K0** *2(0* ------------------------- *7*

** , Wi* fl/i *

2(0 **2K0** $(t_d - t_b) +$ *2V. 2(0*

--------------------------------8

Consequently

$$t_d - t_b \approx \frac{\pi V_0}{\omega \beta_1 V_1}$$ -- **9**

$$\Delta L =$$ -- **10**

The transit time for velocity-modulated electrons to travel at a distance L is given by above eqs

$$T = (t_2 - t_1) = \frac{L}{v(t_1)} = \frac{L}{v_0\left[1 + \frac{\beta_1 V_1}{2V_0}\sin\left(\omega t_0 + \frac{\theta_g}{2}\right)\right]}$$ ------------- **11**

$$= \frac{L}{v_0}\left[1 + \frac{\beta_1 V_1}{2V_0}\sin\left(\omega t_0 + \frac{\theta_g}{2}\right)\right]^{-1}$$ ------------------------------------ **12**

Multiplying by oob both sides of the above equation,We get

$$\omega T = \omega t_2 - \omega t_1 = \frac{\omega L}{v_0}\left[1 - \frac{\beta_1 V_1}{2V_0}\sin\left(\omega t_0 + \frac{\theta_g}{2}\right)\right]$$ ------------- **13**

In the above equation,L/v0=T0 is the transit time

15

$$\omega T = \omega(t_2 - t_1) = \theta_0 \left[1 - \frac{\beta_1 V_1}{2V_0} \sin\left(\omega t_0 + \frac{\theta_g}{2} \right) \right]$$

---------------- 14

$$\theta_0 = \frac{\omega L}{v_0} = 2\pi N$$

Where '0=dc transit angle between cavities
N= number of electron transit cycle in the drift space

By expanding 14,we get the value of the bunching parameter

Where

$$\omega T = \omega(t_2 - t_1) = \theta_0 - \theta_0 \frac{\beta_1 V_1}{2V_0} \sin\left(\omega t_0 + \frac{\theta_g}{2} \right)$$

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$$X = \frac{\beta_1 V_1}{2V_0} \theta_0$$

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