UNIT III LINEAR BEAM TUBES

Limitations and losses of conventional tubes:

The Efficiency of **Conventional Microwave Tube** is largely independent of Frequency upto a certain limit, when frequency increases beyond a certain limit efficiency drastically decreases.

Conventional low frequency tubes like triodes fail to operate at microwave frequencies (MF) because the electron transit time from cathode to grid becomes do large that it cannot produce microwave oscillations. In order for an amplifier to work efficiently at the desired frequency the propagation times must be insignificant. And we see conventional tubes have a significant propagation times and hence cannot be used at microwave frequencies.

The device parameters for this tubes starts taking a dominating part in circuit and hence successful oscillations aren't met. There are also other limitations attached to them:

There are few important points that need to be noted when Microwave frequency is increased

1. Interelectrode capacitance
2. Dielectric losses
3. Lead inductance effect
4. Effects due to radiation losses and radio frequency(RF) losses
5. Skin effect(*which is is the tendency of an alternating current (AC) to become distributed within a conductor such that the current density is largest near the surface of the conductor, and decreases with greater depths in the conductor)*
6. Gain-bandwidth limitations

Interelectrode Capacitance

The Interelectrode capacitance in vacuum tubes at low or Medium frequency produce large Capacitive reactance with no serious effect.

The Capacitive reactance become so small when the frequency drastically increased

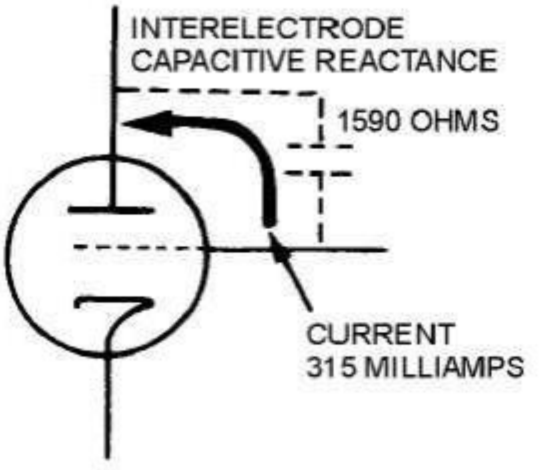


Figure —Interelectrode capacitance in a vacuum tube at 100 MHz

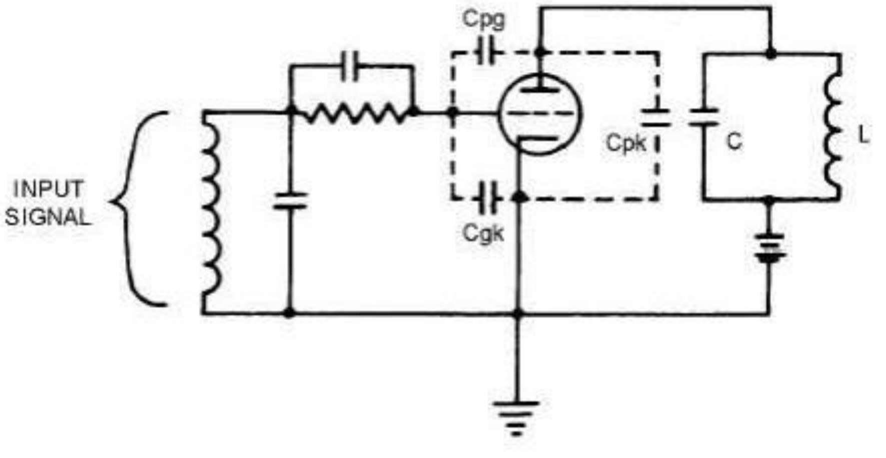


Figure —Interelectrode capacitance in a vacuum tube.

A good point to remember is that the higher the frequency, or the larger the interelectrode capacitance, the higher will be the current through this capacitance. The circuit in figure 2-1C, shows the interelectrode capacitance between the grid and the cathode (Cgk) in parallel with the signal source. As the frequency of the input signal increases, the effective grid-to-cathode impedance of the tube decreases because of a decrease in the reactance of the interelectrode capacitance. If the signal frequency is 100 megahertz or greater, the reactance of the grid-to-cathode capacitance is so small that much of the signal is short-circuited within the tube. Since the interelectrode capacitances are effectively in parallel with the tuned circuits, as shown in figures

Lead Inductance

Another frequency-limiting factor is the LEAD INDUCTANCE of the tube elements. Since the lead inductances within a tube are effectively in parallel with the interelectrode capacitance, the net effect is to raise the frequency limit. However, the inductance of the cathode lead is common to both the grid and plate circuits. This provides a path for degenerative feedback which reduces overall circuit efficiency.

Lead Inductance within the tube are effectively in parallel with the interelectrode capacitance, the net effect is to raise the frequency limit, However the inductance of the positive cathode lead is common to both the Grid plate Circuit.

This provide the path for Regenerative Feed back which reduces overall Circuit efficency.

Transient Time

Transient time is the time required for electrons to travel from the Cathode to the plate, this time time is insignficant at lower frequency .

However at the higher frequency the transient time become and appreciable portion of signal cycle and begins to hinder effeciency.

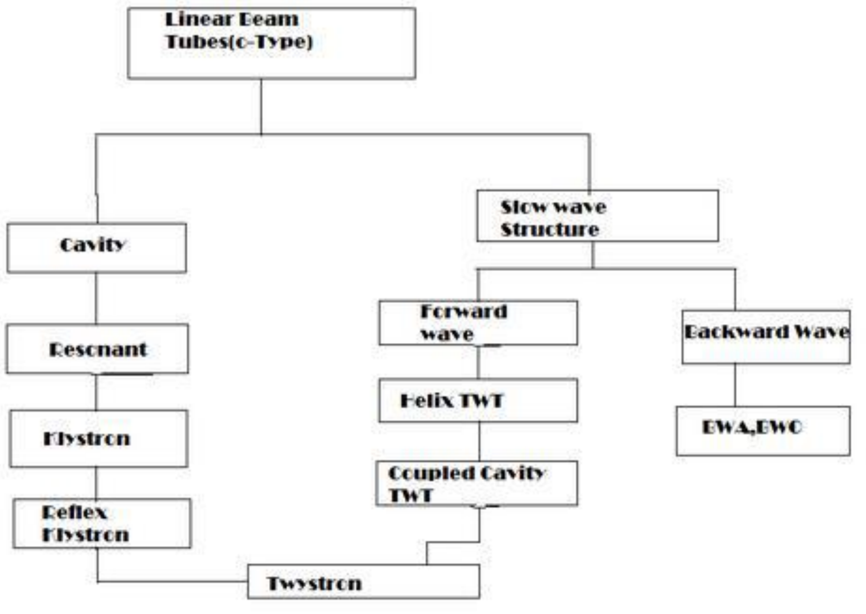
CLASSIFICATION OF MICROWAVE TUBES:

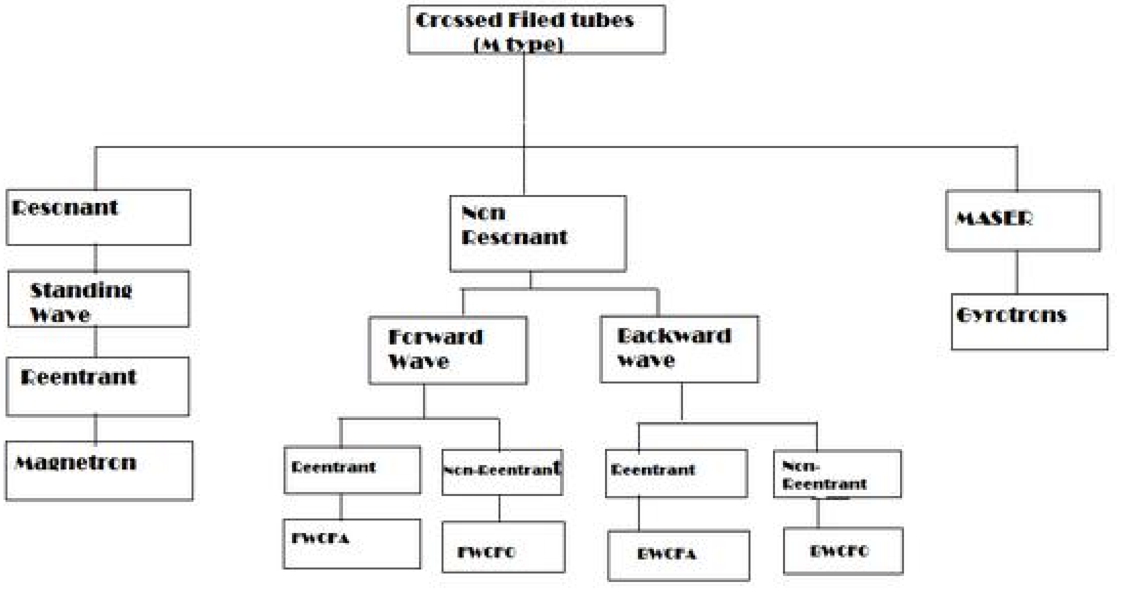
Microwave tubes can be broadly classifies into two categories

1.**O-TYPE L inear 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 togetheras it travels the length of the tube

2.**M-TYPE Tubes** *(Magnetrons and cross field devices)*





Basically there are only main two types of microwave tubes

1. Tubes with electromagnetic cavity*(klystrons and magnetrons)*
2. Tubes with slow wave circuits*(traveling wave tubes)*

KLYSTRON

A **klystron** is a specialized linear-beam vacuum tube (evacuated electron tube). The pseudo-Greek word *klystron* comes from the stem form κλυσ- (*klys*) of a Greek verb referring to the action of waves breaking against a shore, and the end of the word *electron*.

The brothers Russell and Sigurd Varian of Stanford University are generally considered to be the inventors of the klystron. Their prototype was completed in August 1937. Upon publication in 1939,[1] news of the klystron immediately influenced the work of US and UK researchers working on radar equipment. The Varians went on to found Varian Associates to commercialize the technology (for example to make small linear accelerators to generate photons for external beam radiation therapy). In their 1939 paper, they acknowledged the contribution of A. Arsenjewa-Heil and O. Heil (wife and husband) for their velocity modulation theory in 1935.[2]

During the second World War, the Axis powers relied mostly on (then low-powered) klystron technology for their radar system microwave generation, while the Allies used the far more powerful but frequency-drifting technology of the cavity magnetron for microwave generation. Klystron tube technologies for very high-power applications, such as synchrotrons and radar systems, have since been developed.

The klystron is a linear-beam device that overcomes the transit-time limitations of a grid-controlled tube by accelerating an electron stream to a high velocity before it is modulated. Modulation is accomplished by varying the velocity of the beam, which causes the drifting of electrons into bunches to produce RF space current. One or more cavities reinforce this action at the operating frequency. The output cavity acts as a transformer to couple the high-impedance beam to a low-impedance transmission line. The frequency response of a klystron is limited by the impedance-bandwidth product of the cavities, but may be extended through stagger tuning or the use of multiple-resonance filter-type cavities.

The klystron is one of the primary means of generating high power at UHF and above. Output powers for multicavity devices range from a few thousand watts to 10MW or more. The klystron provides high gain and requires little external support circuitry. Mechanically, the klystron is relatively simple. It offers long life and requires minimal routine maintenance.

INTRODUCTION

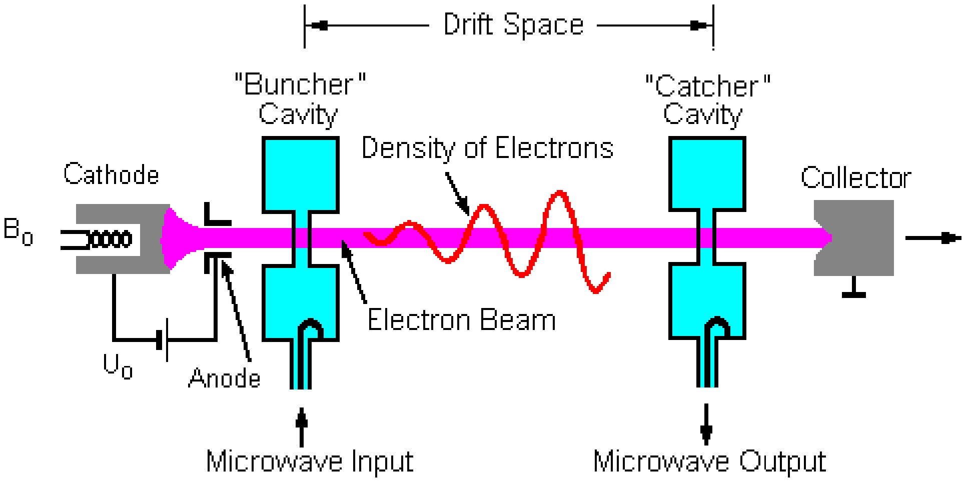
Klystrons are used as an oscillator (such as the reflex klystron) or amplifier at microwave and radio frequencies to produce both low-power reference signals for superheterodyne radar receivers and to produce high-power carrier waves for communications and the driving force for linear accelerators.

All modern klystrons are amplifiers, since reflex klystrons have been surpassed by alternative technologies. Klystron amplifiers have the advantage (over the magnetron) of coherently amplifying a reference signal so its output may be precisely controlled in amplitude, frequency and phase.

Many klystrons have a waveguide for coupling microwave energy into and out of the device,

Explanation

Klystrons amplify RF signals by extracting energy from a DC electron beam. A beam of electrons is produced by a thermionic cathode (a heated pellet of low work function material), and accelerated to high voltage (typically in the tens of kilovolts). This beam is then passed through an input cavity. RF energy is fed into the input cavity at, or near, its natural frequency to produce a voltage which acts on the electron beam. The electric field causes the electrons to bunch: electrons that pass through during an opposing electric field are accelerated and later electrons are slowed, causing the previously continuous electron beam to form bunches at the input frequency. To reinforce the bunching, a klystron may contain additional "buncher" cavities. The electron bunches excite a voltage on the output cavity, and the RF energy developed flows out through a



In the two-chamber klystron, the electron beam is injected into a resonant cavity. The electron beam, accelerated by a positive potential, is constrained to travel through a cylindrical *drift tube* in a straight path by an axial magnetic field. While passing through the first cavity, the electron beam is velocity modulated by the weak RF signal. In the moving frame of the electron beam, the velocity modulation is equivalent to a plasma oscillation, so in a quarter of one period of the plasma frequency, the velocity modulation is converted to density modulation, i.e. bunches of electrons. As the bunched electrons enter the second chamber they induce standing waves at the same frequency as the input signal. The signal induced in the second chamber is much stronger than that in the first.

TWO-CAVITY KLYSTRON OSCILLATOR:

The two-cavity amplifier klystron is readily turned into an oscillator klystron by providing a feedback loop between the input and output cavities. Two-cavity oscillator klystrons have the advantage of being among the lowest-noise microwave sources available, and for that reason have often been used in the illuminator systems of missile targeting radars.

The two-cavity oscillator klystron normally generates more power than the reflex klystron—typically watts of output rather than milliwatts. Since there is no reflector, only one high-voltage supply is to cause the tube to oscillate, the voltage must be adjusted to a particular value.

This is because the electron beam must produce the bunched electrons in the second cavity in order to generate output power. Voltage must be adjusted by varying the velocity of the electron beam to a suitable level due to the fixed physical separation between the two cavities. Often several "modes" of oscillation can be observed in a given klystron.

REFLEX KLYSTRON :

The reflex klystron is a single cavity variable frequency time-base generator of low power and load effiency.

The reflex klystron uses a single-cavity resonator to modulate the RF beam and extract energy from it. The construction of a reflex klystron is shown in Figure In its basic form, the tube consists of the following elements:

- A cathode
- Focusing electrode at cathode potential
- Coaxial line or reentrant-type cavity resonator, which also serves as an anode
- Repeller or
- reflector electrode, which is operated at a moderately negative potential with respect to the cathode.

APPLICATION:

- It is widely used as in radar receiver
- Local oscillators in microwave receiver
- Portable microwave rings

CONSTRUCTION:

Reflex cavity klystron consists of an electron gun , filament surrounded by cathode and a floating electron at cathode potential

The cathode is so shaped that, in relation to the focusing electrode and anode, an electron beam is formed that passes through a gap in the resonator, as shown in the figure,and travels toward the repeller. Because the repeller has a negative potential with respect to the cathode, it turns the electrons back toward the anode, where they pass through the anode gap a second time.

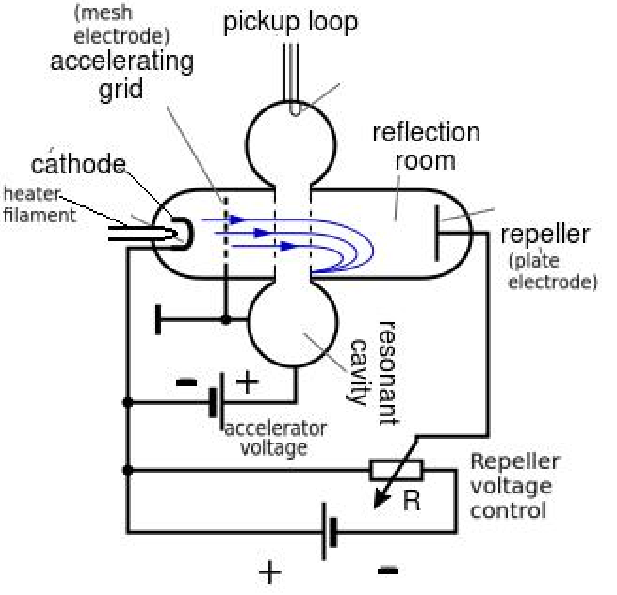
$$\frac{1}{2}m\upsilon^2=qVa$$

$$V=\sqrt{\frac{2qVa}{m}}\ m/s$$

OPERATION:

The electron that are emitted from cathode with constant velocity enter the cavity where the velocity of electrons is changed or modified depending upon the cavity voltage.

The oscillations is started by the device due to high quality factor and to make it sustained we have to apply the feedback.



Hence there are the electrons which will bunch together to deliver the energy act a time to the RF signal.

Inside the cavity velocity modulation takes place. Velocity modulation is the process in which the velocity of the emitted electrons are modified or change with respect to cavity voltage. The exit velocity or velocity of the electrons after the cavity is given as

$$V' = \sqrt{\frac{2q\,(Va + Vi \sin(\omega t))}{m}}$$

In the cavity gap the electrons beams get velocity modulated and get bunched to the drift space existing between cavity and repellar.

Bunching is a process by which the electrons take the energy from the cavity at a different time and deliver to the cavity at the same time .

Bunching continuously takes place for every negative going half cycle and the most appropriate time for the electrons to return back to the cavity ,when the cavity has positive peak .So that it can give maximum retardation force to electron.

It is found that when the electrons return to the cavity in the second positive peak that is 1 whole ¾ cycle.(n=1π).It is obtained max power and hence it is called dominant mode.

The electrons are emitted from cathode with constant anode voltage Va, hence the initial entrance velocity of electrons is

$$V = \sqrt{\frac{2qVa}{m}} \text{ m/s}$$

$$V = \sqrt{\frac{2q\,(Va + Vi \sin(\omega t))}{m}}$$

$$V = \sqrt{\frac{2qVa}{m} + \frac{2qVaKaVi \ \sin \omega t}{Vam}}$$

$$V = \sqrt{Vo^2 + \frac{Vo^2 KiVi \sin \omega t}{Va}}$$

$$V = Vo\sqrt{1 + \frac{KiVi \ \sin \omega t}{Va}}$$

$$V = \sqrt{1 + \frac{Vo^2 iVi \sin \omega t}{Va}}$$

When, $\frac{kivi}{Va}$ =Depth of velocity

$$V=Vo\left(1+\frac{Vo^{2}iVi\sin\omega t}{2Va}\right)$$

TRANSIENT TIME:

Transit time is defined as the time spent by the electrons in the cavity space or, time taken by the electrons to leave the cavity and again return to the cavity.
If $t1$ is the time at which electrons leave the cavity and $t2$ is the time at which electrons bunch in the cavity then, transit time

$$tr=t1-t2$$

During this time the net displacement by electrons is zero. That the potential of two point A and B is VA and VB(plate) as known in figure,then,

$$VAB= VA-VB$$
$$= VA+ Vi\sin wt+ VR$$

$=VA+VR+Vi\sin wt$ Neglecting
the AC compoment, $VAB= Va$
$+ VR$

$$E=\frac{\partial V_{AB}}{\partial x}=\frac{-V_{AB}}{s}=\frac{-(V_a+V_R)}{s} \quad \text{-------(a)}$$

The force experienced on an electron

From equations a and b we get

$$F=qe=\frac{-q\,(V_a+V_R)}{s}$$

$$F=\frac{m\,\partial^2 x}{\partial t^2} \quad \text{-------(b)}$$

$\frac{m\,\partial^2 x}{\partial t^2} = \frac{-q\,(V_a+V_R)}{S}$

Integrating both sides we get,

$\int \frac{m\,\partial^2 x}{\partial t^2} = \frac{-q\,(V_a+V_R)}{S}$

$\int m\,\partial x^2 = \frac{-q\,(V_a+V_R)}{S} \{_{t1}^{t} \partial t$

$m\frac{\partial x}{\partial t} = \frac{-q\,(V_a+V_R)}{S}\,{}_{t1}^{t}t$

$\frac{\partial x}{\partial t} = \frac{-q\,(V_a+V_R)}{mS}$ (t-t_1)+ k_1

$\therefore$ $k_1$is called velocity constant and assumed to velocity at (t-t_1)

$\frac{\partial x}{\partial t} = \frac{-q\,(V_a+V_R)}{mS}$ (t-t_1)+$V(t1)$

$$\int \partial x = \frac{-q(V_a+V_R)}{mS}\int (t - t_1)\,\partial t + V(t1)$$

$$X = \frac{-q\,(V_a+V_R)}{mS}\,{}_{t1}^{t}[\tfrac{t^2}{2}] - t_1\,{}_{t1}^{t}[t] + \int V(t1)\ \partial t$$

$$= \frac{-q\,(V_a+V_R)}{mS}\left[\left[\frac{t^2 - t1^2}{2}\right] - (t_2 - t_2)t_1\right] + \int V(t1)\ \partial t$$

$$= \frac{-q\,(V_a+V_R)}{mS}\left[\frac{t^2 - t1^2 - 2t_2t_1 + 2t_2{}^2}{2}\right] + \int V(t1)\ \partial t$$

$$= \frac{-q\,(V_a+V_R)}{mS}\left[\frac{t^2 + t1^2 - 2t_2t_1}{2}\right] + \int V(t1)\ \partial t$$

$$= \frac{-q\,(V_a+V_R)}{mS}\left[\frac{(t - t1)^2}{2}\right] + \int V(t1)\ \partial t$$

$$= \frac{-q\,(V_a+V_R)}{mS}\left[\frac{(t - t1)^2}{2}\right] + \int V(t1)\ (t - t1) + k_2$$

Where,k2 is displacement constant at t=t2,x=0 .In practice k2=the cavity width which is negligible with respect to cavity space s. Here we can neglect k2 in the expression of x

At t=t2,x=0

$$0 = \frac{-q\,(V_a+V_R)}{mS}\left[\frac{(t - t1)^2}{2}\right] + V(t1)\ (t - t1)$$

- ➢ $\frac{-q\,(V_a+V_R)}{mS}\left[\frac{(t_2 - t1)^2}{2}\right] = V(t1)\ (t_2 - t1)$
- ➢ $(t_2 - t1) = \frac{2V(t1)ms}{q\,(V_a+V_R)}$

TRANSIT ANGLE:

$$\omega t_{r} = \omega(t_2 - t1) = \omega \frac{2V(t1)ms}{q(V_{a+}V_R)}$$

$$\omega t_{r} = \omega \frac{2V(t1)ms}{q(V_{a+}V_R)}$$

We know,

n=+3/4, for n=0,1,2,3,4…..

n-1/4. for n=0,1,2,3,4…..

$$2\times \pi(t_2 - t1) = \left(n - \tfrac{1}{4}\right) 2\pi \times \mathrm{T}$$

$$2\times \pi \times f(t_2 - t1) = \left(2n\pi - \tfrac{\pi}{2}\right)$$

$$\omega t_{r} = \left(2n\pi - \frac{\pi}{2}\right) = \omega \frac{2V(t1)ms}{q(V_{a+}V_R)}$$

OUTPUT POWER:

The beam current of Reflex klystron is given as

$$\mathrm{Ib}=\mathrm{I_O}+ \sum_{n=1}^{\infty} (2\mathrm{I_0}\mathrm{I_n}(\mathrm{x}') \cos(\mathrm{n\omega t} - \varphi)$$

I0 is dc current due to cavity voltage is given by

$$P_{dc=}V_a I_o \text{ -------(1)}$$

The ac component of the current is given by

$$\mathrm{I_{ac}}= \sum_{n=1}^{\infty} (2\mathrm{I_0}\mathrm{I_n}(\mathrm{x}') \cos(\mathrm{n\omega t} - \varphi))$$

For (n=1),we have fundamental current component ie,

$$\mathrm{If}\ (2\mathrm{I_0}\mathrm{I_1}(\mathrm{x}') \cos(\mathrm{n\omega t} - \varphi)$$

$$\text{For n=2; } \cos(\mathrm{n\omega t} - \varphi) = 1$$

$$I_2=2I_oK_iJ_i(X_i)$$

$$\text{Power}=\frac{v_i I_2}{2}=\frac{v_i}{2}(2I_o k_i Ji(Xi))$$

$$\omega(t_2-t1)=\ \omega\frac{2V(t1)ms}{q(V_{a+}V_R)}$$

$$\omega t_2=\omega t_1+\frac{2V_0 ms\omega}{q(V_{a+}V_R)}[1+\frac{k_i v_i}{2v_a}\sin\omega t_1]$$

$$\therefore [\frac{2V_0 ms\omega}{q(V_{a+}V_R)}]=\alpha$$

$$\rightarrow \omega t_2=\omega t_1+\alpha[1+\frac{k_i v_i}{2v_a}\sin\omega t_1]$$

$$\rightarrow \omega t_2=\omega t_1+\alpha+\frac{k_i v_i \alpha}{2v_a}\sin\omega t_1]$$

Where , $\frac{k_i v_i \alpha}{2v_a}$=x, bunching parameter

$$V_i=\frac{2v_a x}{\alpha k_i}=\frac{2v_a x}{(2n\pi-\frac{\pi}{2})k_i}$$

$$P_{o/p}=\frac{2v_a x I_0 \times J_i(x)}{(2n\pi-\frac{\pi}{2})}$$

Efficiency: $\eta\%=\frac{P_{output}}{P_{input}}\times 100\%$

$$=\frac{2v_a x I_0 \times J_i(x)}{(2n\pi-\frac{\pi}{2})v_a x I_0}$$

$$=\frac{2\times J_i(x)}{(2n\pi-\frac{\pi}{2})}\times 100\%$$

Electronics admittance of reflex klystron
It is defined as the ratio of current induced in the cavity by the modulation of electron beam to the voltage across the cavity gap.

TRAVELING-WAVE TUBE :

A **traveling-wave tube (TWT)** is an electronic device used to amplify radio frequency signals to high power, usually in an electronic assembly known as a **traveling-wave tube amplifier** (TWTA).

The TWT was invented by Rudolf Kompfner in a British radar lab during World War II, and refined by Kompfner and John Pierce at Bell Labs. Both of them have written books on the device.[1][2] In 1994, A.S. Gilmour wrote a modern TWT book[3] which is widely used by U.S. TWT engineers today, and research publications about TWTs are frequently published by the IEEE.

Cutaway view of a TWT. (1) Electron gun; (2) RF input; (3) Magnets; (4) Attenuator; (5) Helix coil; (6) RF output; (7) Vacuum tube; (8) Collector.
The device is an elongated vacuum tube with an electron gun (a heated cathode that emits electrons) at one end. A magnetic containment field around the tube focuses the electrons into a beam, which then passes down the middle of a wire helix that stretches from the RF input to the RF output, the electron beam finally striking a collector at the other end.

A directional coupler, which can be either a waveguide or an electromagnetic coil, fed with the low-powered radio signal that is to be amplified, is positioned near the emitter, and induces a current into the helix.

The helix acts as a delay line, in which the RF signal travels at near the same speed along the tube as the electron beam. The electromagnetic field due to the current in the helix interacts with the electron beam, causing bunching of the electrons (an effect called *velocity modulation*), and the electromagnetic field due to the beam current then induces more current back into the helix (i.e. the current builds up and thus is amplified as it passes down). A second directional coupler, positioned near the collector, receives an amplified version of the input signal from the far end of the helix. An attenuator placed on the helix, usually between the input and output helicies, prevents reflected wave from travelling back to the cathode.

The bandwidth of a broadband TWT can be as high as three octaves, although tuned (narrowband) versions exist, and operating frequencies range from 300 MHz to 50 GHz. The voltage gain of the tube can be of the order of 70 decibels.
A TWT has sometimes been referred to as a traveling-wave amplifier tube (TWAT),[4][5] although this term was never really adopted. "TWT" is sometimes pronounced by engineers as "TWIT".[6]

MULTICAVITY KLYSTRON

In all modern klystrons, the number of cavities exceeds two. A larger number of cavities may be