Electrical Engineering Department
Electromagnetics Lab

Expt #7: Mode characteristics of a Klystron

Objective: To study the mode characteristics of a reflex klystron and hence to determine mode number, transit time and electronic tuning sensitivity (ETS)

Components/Apparatus:

Klystron power supply, Reflex klystron with mount and cooling fan, Variable attenuator, Frequency meter/wavemeter, Waveguide detector mount with detector, SWR meter or microammeter, Waveguide stands and accessories (or Microwave Test bench with Klystron source)

Introduction:

At high frequencies, the performance of a conventional vacuum tube is impaired due to transit time effects, lead inductance and inter-electrode capacitance. Klystron is a microwave vacuum tube employing velocity modulation and transit time in achieving its normal operation. The most common klystron tube, which is used as an amplifier, is two cavity klystron. The other klystron tube is single cavity klystron. It is known a reflex klystron. It has been the most used source of microwave power in laboratory (Fig. 6.1). It consists of an electron gun producing a collimated electron beam. The electron beam is accelerated towards the reflector (repeller) by a DC voltage V_0 while passing through the positive resonator grids.

Fig. 6.1: Cross-sectional view of a typical reflex klystron tube.

Theory:

To understand the operation of this device, assume that the resonator cavity is oscillating slightly, causing an ac potential, say V_1sinωt in addition to V_0 to appear across the cavity grids. These initial oscillations could be caused by any small disturbance in the electron beam. In the presence of the r.f field V_1sinωt, the electrons which traverse towards the repeller will acquire the velocity

$$v = v_0 \left\{1 + \frac{V_1}{V_0} \sin \omega t\right\}^{1/2}$$

Thus we have a velocity modulated beam travelling towards the repeller, having velocities between $v_0 \sqrt{(1 + V_1/V_0)}$ and $v_0 \sqrt{(1 - V_1/V_0)}$ i.e., electrons leaving the cavity during the positive half-cycle are accelerated while electrons leaving the cavity during negative half-cycle are decelerated. Obviously the electrons traversing towards the repeller with increased velocity, *i.e.*, faster ones, shall penetrate farther into the region of the repeller field (called drift space) as compared to the electrons traversing towards the repeller with decreased velocity, *i.e.*, slower ones. But the faster electrons leaving the cavity take longer time to return to it and the faster electrons, therefore, catch up with slow ones. As a result the returning electrons group together in bunches. The bunching action is shown in Fig. 6.2.

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As the electron bunches recross the cavity, they interact with the rf voltage between the cavity grids. If the bunches pass through the grids at the time when the grids potential is such that the electrons are severely decelerated, the decelerated electrons give up their energy and this energy reinforces oscillations within the cavity. Hence under these conditions, sustained oscillations are possible. The electrons having spent much of their energy are then collected by the positive cavity wall near the cathode. Thus, it is clear that in its normal operation the repeller electrode does not carry any current and, indeed, this electrode can severely be damaged by electron bombardment. To protect the repeller from such damage, the repeller voltage V_R is always applied before the accelerating voltage V_0

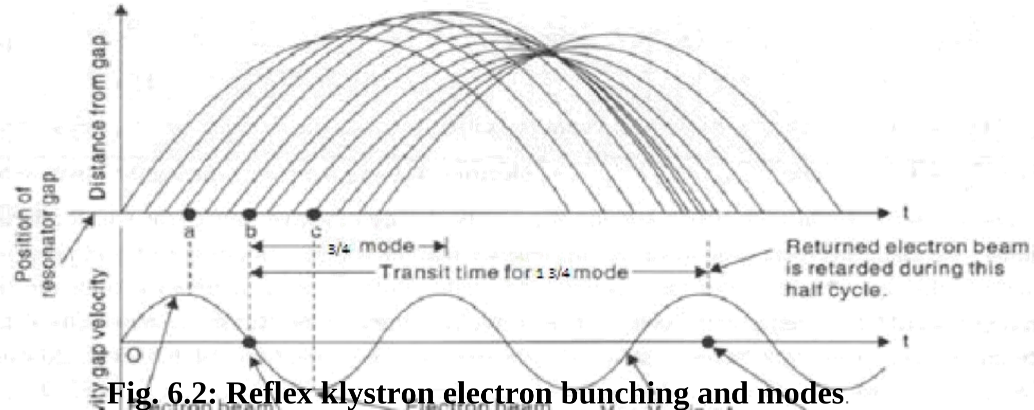

Fig. 6.2: Reflex klystron electron bunching and modes.

From the above discussion, it is obvious that electron bunch should reach the resonator cavity at a time when the r.f field has retarded the bunch and forced it to give up energy to reinforce the oscillations within the cavity *i.e.*, it should have proper transit time. From Fig. 6.2 it is clear that optimum transit time for bunch to arrive at the cavity is *(n* + 3/4) cycles after the beam initially left the cavity.

Hence, transit time T_0' is related to the frequency by the relation:

$$T_0' = \frac{n + 3/4}{f} = \left(n + \frac{3}{4}\right) T$$

where T = 1/f (time period of r.f voltage across the gap) and n = 0, 1, 2, 3……

Thus reflex klystron can be operated at different drift times (round trip transit time), which correspond to different values of *n.* These different transit times are referred to as *modes* and are labelled to values of *n, i.e.*

Mode number $N = (n + 3/4)$,

where $n = 0$ is known as 3/4 mode, $n = 1$ is known as 1 3/4 mode and so on.

For fixed value of anode voltage *Vo* and resonant frequency the relationship between repeller voltage and mode number is

$$\frac{(|V_{R_1}| + V_0)}{(|V_{R_2}| + V_0)} = \frac{N_2}{N_1} = \frac{n + 1.75}{n + 0.75}$$

for two adjacent modes of operation described by N1 and N2.
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Fig. 6.3 shows the variation of power output and frequency versus repeller voltage ($-V_R$). These are known as mode curves. For $n = 0$ (i.*e., $T_0' = ¾ T$),* the gain mechanism is usually not strong enough to overcome system losses. Hence, higher order modes *(n*> 1) are present at lower voltages.

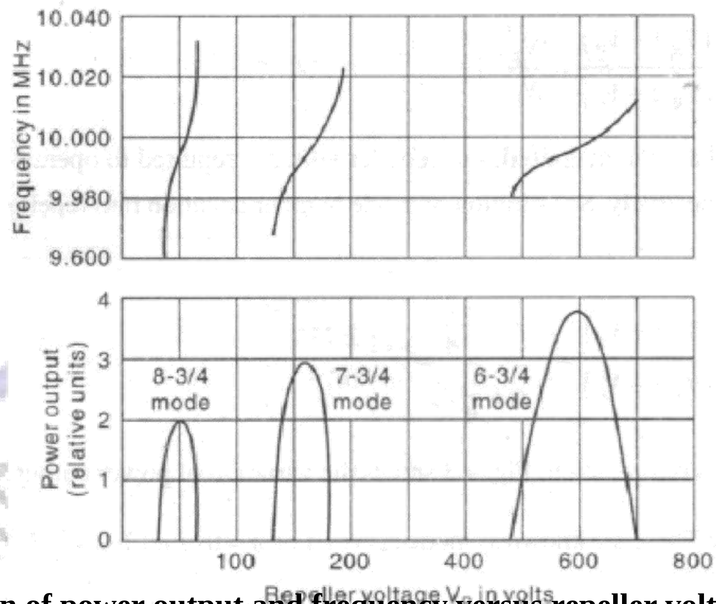

Fig. 6.3: Variation of power output and frequency versus repeller voltage (mode curves)

In addition to mechanical tuning, the oscillator frequency can be adjusted by reflector voltage variations. The maximum power output point is referred to as the 'top' of the mode. If the reflector voltage is set to any other voltage, the transit time is changed; as a result the klystron oscillates at a different frequency with decreased power output. *Electronic tuning sensitivity (ETS) (*usually measured in Mega Hertz/volt of repeller voltage change) , is defined as

$$\text{ETS} = \frac{f_2 - f_1}{V_2 - V_1} \text{ MHz/volt}$$

where f_2 and f_1 are frequencies in MHz at which mode power falls to half of its value at the 'top'. It is clear from the power-frequency characteristics (Fig. 6.3), that ETS is higher for higher modes though power output is small. Thus for low power requirements, klystron operates for wider range of frequency.

Procedure:

- Assemble the equipment as shown in Fig. 6.4 with Micro-ammeter as indicating meter.
- Switch on klystron power supply for 1000 hz square wave modulation of the signal.
- Fire the klystron correctly as per instructions.
- Adjust the modulation voltage and repeller voltage to obtain peak reading in meter.
- Adjust the repeller voltage to maximum negative value and increase it in steps of I V (repeller negative voltage to be decreased in steps of 1 V) and record output power and frequency in Table 6.1. The frequency is measured by tuning the frequency meter to have a dip in the output each time.

Table 6.1 Beam Voltage = ____ V

S. No.	Repeller Voltage (in volts)	Micro-ammeter reading (power)	Frequency meter reading (in Ghz)
1. 2.			

- The frequency meter should be detuned each time while measuring power
- Plot power/frequency versus repeller voltage to get mode curves
- Compute various parameters from the graph

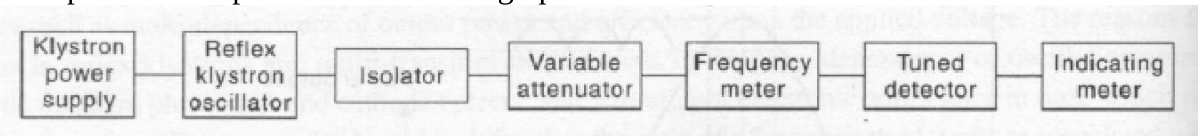

Fig. 6.4: System setup

Calculations and Results:

- Knowing mode top voltage of two adjacent modes, for a fixed value of anode voltage mode, number of the modes may be computed from

$$\left(\frac{|V_{R_1}| + V_0}{|V_{R_2}| + V_1}\right) = \frac{(n+1) + 3/4}{n + 3/4}$$

- Knowing mode number, transit time of each mode may be calculated from

$$T_0' = \frac{n + (3/4)}{f_{01}} = \frac{N_1}{f_{01}} \text{ seconds}$$

- ETS may be calculated from

$$\text{ETS} = \frac{f_2 - f_1}{V_2 - V_1} \text{ MHz/V}$$

f_2 and f_1 being half power frequencies in GHz, and V_2 and V_1 are corresponding repeller voltages for a particular mode. At the end of the experiment, various operating modes of the Reflex klystron should be understood and mode number, transit time and electronic tuning sensitivity (ETS) be calculated.