OBJECTIVE

To study the characteristics of the reflex Klystron tube and to determine its electronic tuning range.

EQUIPMENTS

Klystron power supply, Klystron with mount, Isolator, Frequency meter, Variable attenuator, X-band detector, BNC-to-BNC cable and Oscilloscope.

THEORY

Reflex Klystron is one of the most commonly used microwave (low power) generators. It converts D.C. power into microwave power.

*Reflex Klystrons Oscillator:*

The schematic diagram of a reflex klystron tube is shown in Fig. 4.1, which uses only a single re-entrants microwave cavity as resonator. The electron beam emitted from the cathode K is accelerated by the grid G and passes through the cavity anode A to the repeller space between the cavity anode and the repeller electrode.
**Mechanism of Oscillation:**
Due to dc voltage in the cavity circuit, RF noise is generated in the cavity. This electromagnetic noise field in the cavity becomes pronounced at cavity resonant frequency. The electrons passing through the cavity gap experience this RF field and are velocity modulated in the following manner. The electrons as shown in Fig. 4.2 which encountered the positive half cycle of the RF field in the gap will be accelerated, those (reference electrons) which encountered zero RF field will pass with unchanged original velocity, and the electrons which encountered the negative half cycle will be retarded on entering the repeller space.

![Fig. 4.2 Bunching action of a reflex klystron](image)

All these velocity modulated electrons will be repelled back to the cavity by the repeller due to its negative potential. The repeller distance $L$ and the voltages can be adjusted to receive all the velocity modulated electrons at a same time on the positive peak of the cavity RF voltage cycle. Thus the velocity modulated electrons are bunched together and lose their kinetic energy when they encounter the positive cycle of the cavity RF field. This loss of energy is thus transferred to the cavity to conserve the total power. If the power delivered by the bunched electrons to the cavity is greater than the power loss in the cavity, the electromagnetic field amplitude at the resonant frequency of the cavity will increase to produce microwave oscillations. The RF power is coupled to the output load by means of a small loop which forms the center conductor of the coaxial line. When the power delivered by the electrons becomes equal to the total power loss in the cavity system, a steady microwave oscillation is generated at resonant frequency of the cavity.

**Mode of Oscillation:**
The bunched electrons in a reflex klystron can deliver maximum power to the cavity at any instant which corresponds to the positive peak of the RF cycle of the cavity oscillation. If $T$ is the time period at the resonant frequency, $t_o$ is the time taken by the reference electron to travel in the repeller space between entering the repeller space at $b$ and the returning to the cavity at positive peak voltage on formatting of the bunch, then
Thus by adjusting repeller voltage for given dimensions of the reflex klystron, the bunching can be made to occur at \( N = \frac{1}{4} \), \( \frac{3}{4} \), \( \frac{2}{4} \), \( \frac{3}{4} \), etc. for modes \( n = 0, 1, 2, 3, \ldots \), respectively. It is obvious that the lowest order mode \( 3/4 \) occurs for a maximum value of repeller voltage when the transit time \( t_0 \) of the electrons in the repeller space is minimum. Higher modes occur at lower repeller voltages. Since at the highest repeller voltage the acceleration of the bunched electrons of return is maximum, the power output of the lowest mode is maximum.

**Modulation:**

By varying the reflector voltage about a d.c. value, Klystron can be frequency and amplitude modulated simultaneously. For proper square wave modulation with 100% modulation index, the reflector voltage and amplitude of the square wave should be set as shown in Fig. 4.3. If the square wave peak to peak amplitude is \( V_m \) and \( V_o \) is the reflector d.c. voltage, the total reflector voltage will switch between \( (V_o+V_m) \) and \( (V_o-V_m) \).

We have to choose \( V_o \) and \( V_m \) such that \( (V_o+V_m) \) is in the mode center and \( (V_o-V_m) \) is the non-oscillating region for proper square wave modulation.

**PROCEDURE**

1. Equipments are connected as shown in the Fig. 4.4 and study the operation of each equipment.
2. Set the variable attenuator to maximum and Klystron cathode power supply to minimum and reflector voltage to maximum.
3. Apply beam voltage and adjust reflector voltage (-ve) to have mode top displayed on Y-axis of the oscilloscope (see Fig. 4.3(a)). Record the amplitude of mode top and corresponding reflector voltage. Manipulate reflector voltage to obtain 15mA cathode current (Set the oscilloscope to x-y mode).
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4. Now, set modulation to AM which applies an internal 1 KHz square wave to the reflector along with D.C. reflector voltage approximately 150 volts. Adjust modulation amplitude and reflector voltages to obtain a good square wave on the oscilloscope. If the output is small, tune the detector and also reduce the attenuation. (Equipments are connected as shown in the Fig. 4.5).

5. Adjust the repeller voltage to maximum negative value and increase it in steps of 1volt (repeller –ve voltage to be decreased in steps of 1volt) and record output power and frequency in table 1.0.

6. Frequency measurement—adjust the frequency meter till a dip appears on the display. The frequency meter directly gives the frequency.

7. Klystron modes- measurement of Klystron characteristics.
   a) Set the oscilloscope to x-y mode. Connect the detector output to y input and sawtooth output of the klystron of power supply to x-input of scope (Fig. 4.5).
   b) Set the Klystron to FM and adjust the amplitude of modulation and reflector voltage slightly to obtain one mode on the scope display.
   c) Vary the dc reflector voltage to obtain one mode at a time. Scan through all the modes one by one. Normally 3 to 4 modes are obtainable with the reflector voltage range available with the Klystron power supply.
   d) Adjust the reflector voltage to get the first mode on scope display. Tune the frequency meter till a dip appears at the display peak of the mode as shown in Fig. 4.3(a). When the display is centered as shown in Fig. 4.3(a) the frequency reads the cavity center frequency and reflector voltage at that mode center. The Y-axis can be treated as the measure of power provided the detector is operated at low input power level as at low power level detector V-I curve characteristics is square law dependent.

   Vary the reflector voltage to get the display as shown in Fig. 4.3(b) and note down the reflector voltage at the starting and ending of oscillations. Display 4.3(c) and 4.3(d). Note down the reflector voltage and frequency for each display which are half power point reflector voltages and frequency. Record all the values of voltage and frequencies in tabulated form as per the format shown. Repeat the procedure for all the power modes.

8. Plot the mode characteristics on a graph paper giving reflector voltage versus power output frequency.

9. Calculate the mode number n for each mode using the equation

\[
\frac{V_{O1}}{V_{O2}} = \frac{(n+1)+3/4}{n + 3/4} \quad \text{(at constant frequency)} \quad \frac{N2}{N1}
\]

where \(V_{O1}\) and \(V_{O2}\) are reflector voltages for two successive modes at maximum power points.
Fig. 4.1. Square wave Modulation

Fig. 4.2 Modes of klystron

Fig. 4.3. Oscilloscope displays
Fig. 4.4 Microwave setup for measurement of wavelength & Frequency
Fig. 4.5. Setup of equipment for mode study of Klystron

Table 1.0

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Repeller Voltage (in volts)</th>
<th>SWR reading (in power)</th>
<th>Frequency meter Reading (in GHz)</th>
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CALCULATIONS

(i) Knowing mode top voltage of two adjacent modes, mode number of the modes may be computed from Equation below:

\[
\frac{\frac{N_2}{V_2}}{\frac{N_1}{V_1}} = \frac{(n+1) + \frac{3}{4}}{n + \frac{3}{4}}
\]

(ii) Knowing mode number, transit time of each mode may be calculated from Equation below:

\[
t_1 = \frac{n + \frac{3}{4}}{f_{01}} = \frac{N_1}{f_{01}} \text{ sec}
\]

(iii) Calculate electronic tuning range, i.e., the frequency band from one end of the mode to another.

(iv) ETS may be calculated from equation below:

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

\(f_2\) and \(f_1\) being half power frequencies in GHz, and \(V_2\) and \(V_1\) are corresponding voltages for a particular mode. A practical example is given below.

(i) \[
\frac{N_1}{N_2} = \frac{n + \frac{3}{4}}{(n+1) + \frac{3}{4}} = \frac{V_2}{V_1} \quad \text{Or,} \quad \frac{n + 0.75}{n + 1.75} = \frac{-64}{-105.5} \quad \text{Or,} \quad n = \frac{32.9}{40.5} \approx 1
\]

(ii) Hence, \(N_1 = 1.75\) and \(N_2 = 2.75\) are the respective mode numbers.

Corresponding transit times are:

\[
t_1 = \frac{N_1}{f_{01}} = \frac{1.75}{9.465} \times 10^{-9} = 1.8 \times 10^{-8} \text{ s}
\]

\[
t_2 = \frac{N_2}{f_{02}} = \frac{2.75}{9.47} \times 10^{-9} = 2.9 \times 10^{-8} \text{ s}
\]

(iii) ETR for 1.75 mode = \((9.488-9.435) \times 10^9 \text{ Hz} = 53 \text{ MHz}\)

ETR for 2.75 mode = \((9.482-9.425) \times 10^9 \text{ Hz} = 57 \text{ MHz}\)

(iv) ETS for 1.75 mode = \(\frac{9.485 - 9.39}{(111.5 - 98)} \times 10^9 \text{ Hz/V} = \frac{46}{13.5} = 3.4 \text{ MHz/V}\)

ETS for 2.75 mode = \(\frac{9.482 - 9.487}{(69 - 57.5)} \times 10^9 \text{ Hz/V} = \frac{45}{11.5} = 3.9 \text{ MHz/V}\)

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