Experiment - 1: Study of Microwave Bench

1. **Aim:** To study the Microwave Bench and its components.

2. **Requirements:** Klystron power supply. Klystron tube with klystron mount isolator, circulator, frequency meter (direct and indirect-reading type), fixed and variable attenuator, detector mount, matched termination, movable short circuit, waveguide junctions, directional coupler, slotted line carriage, pyramidal horn antenna and waveguide stand.

3. **Pre-experiment Exercise**

   Brief Theory

4. Laboratory Exercise

4.1 Procedure:

Explanation of bench

4.2 Observations:

Block Diagram of the Microwave Bench

5. Post Experiment Exercise:

5.1 Conclusion/Comments

5.2 Questions:

1. What are microwaves? List IEEE band designations with one application of each band.

2. Explain the advantages, disadvantages and applications of microwaves.

3. Explain in brief the various components used in microwave bench. (Attach an image for each component).

4. Microwave test bench is used in which band of the electromagnetic spectrum? Which rectangular waveguide is used in the microwave bench and what are the dimensions and its cut-off frequency?

Experiment - 2: Impedance Matching Network Design

1. Aim: To design impedance matching network by the means of stubs using Smith chart and V-Smith tool

2. Requirements

- Smith Chart (Z)
- V-Smith software v4.1

2. Pre-experiment Exercise

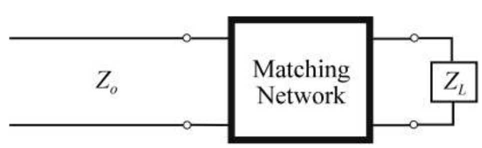
Brief Theory

One of the most important aspects of high-frequency circuit design and microwave engineering is the problem of impedance matching. Impedance matching is the design of a circuit to be inserted between a source and a load (both used in the general sense) so as to provide maximum power transfer between them.

Impedance Matching and Transformation

Matching the source and load to the transmission line or waveguide in a general microwave network is necessary to deliver maximum power from the source to the load. In many cases, it is not possible to choose all impedances such that overall matched conditions result. These situations require that matching networks be used to eliminate reflections

T-line or waveguide to termination matching network



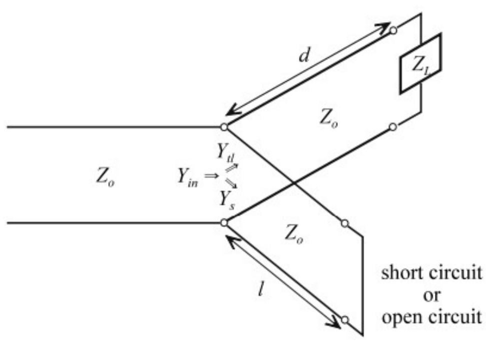
T-line or waveguide to t-line or waveguide matching network

Depending on the application, matching may be required over a band of frequencies such that the bandwidth of the matching network is an important design parameter. If the load impedance varies over a given range, a matching network which can be adjusted or tuned as necessary. In general, matching networks are constructed with reactive components only so that no loss is added to the overall network.

Single Stub Tuners

Given that we can obtain any value of reactance or susceptance with the proper length of short-circuited or open-circuited transmission line, we may use these transmission line stubs as matching networks.

Shunt Stub

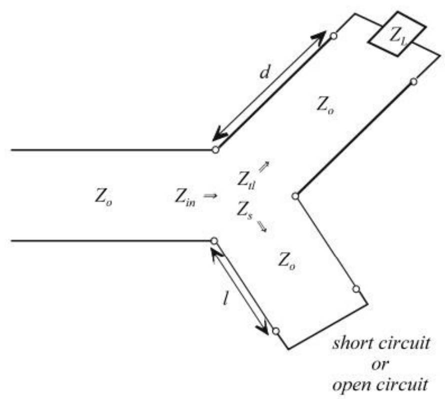


$Y_{tl} = Y_o + jB$ [Input admittance of the terminated t-line section]

$Y_s = -jB$ [Input admittance of the stub (short or open circuit)]

$Y_{in} = Y_{tl} + Y_s = Y_o$ [Overall input admittance]

Series Stub



$Z_{tl} = Z_o + jX$ [Input impedance of the terminated t-line section]

$Z_s = -jX$ [Input impedance of the stub (short or open circuit)]

$Z_{in} = Z_{tl} + Z_s = Z_o$ [Overall input impedance]

4. Laboratory Exercise

<u>Single Shunt Stub Tuner Design Procedure</u>

1. Locate normalized load impedance and draw VSWR circle (normalized load admittance point is 180 from the normalized o impedance point).
2. From the normalized load admittance point, rotate CW (toward generator) on the VSWR circle until it intersects the r = 1 circle. This rotation distance is the length d of the terminated section of t-tline. The nomalized admittance at this point is 1 + jb.
3. Beginning at the stub end (rightmost Smith chart point is the admittance of a short-circuit, leftmost Smith chart point is the admittance of an open-circuit), rotate CW (toward generator) until the point at 0 - jb is reached. This rotation distance is the stub length l.

<u>Single Series Stub Tuner Design Procedure</u>

1. Locate normalized load impedance and draw VSWR circle.
2. From the normalized load impedance point, rotate CW (toward generator) on the

VSWR circle until it intersects the r = 1 circle. This rotation distance is the length d of the terminated section of t-tline. The nomalized impedance at this point is 1 + jx.

3. Beginning at the stub end (leftmost Smith chart point is the impedance of a short-circuit, rightmost Smith chart point is the impedance of an open-circuit), rotate CW (toward generator) until the point at 0 ! jx is reached. This rotation distance is the stub length l.

4.1 Procedure:

1. Transform the given impedances and design the matching network using lumped elements using the V-Smith tool.
2. For a given load and characteristics impedance design a matching network with stubs (Short circuit/Open circuit) using the Z-chart. Provide both the solutions.
3. Verify the networks obtained in step 3 using the V-Smith tool.

4.2 Observations:

Sr. No	**Specifications**	**Approach**	**Design elements/parameters using V-Smith (Practical)**	**Design elements/parameters using Smith Chart (Theoretical)**
1	**VSWR**	--		
2	**Reflection Coefficient**	--		
3	**Impedance Matching Network**			
			Solution 1	**Solution 1**
	Z_L = ________ Zo = ________	Connection:___________ Termination:__________	d1:	d1:
			l1:	l1:
			Solution 2	**Solution 2**
			d2:	d2:
			l2:	l2:
4		Connection:___________ Termination:__________	**Solution 1**	**Solution 1**
			d1:	d1:
			l1:	l1:
			Solution 2	**Solution 2**
			d2:	d2:
			l2:	l2:

4.3 Results:

Impedance matching network circuit (Theoretical)

Connection:	**Termination:**
Solution 1	**Solution 2**
Connection:	**Termination:**
Solution 1	**Solution 2**

5. Post Experiment Exercise:

5.1 Conclusion/Comments

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5.2 Questions:

1. What is meant by impedance matching and state its importance in microwave engineering?
2. A single stub tuner is to be matched to a lossless line of 400 Ω to a load of 800 – j300 Ω. The frequency is 3GHz. (Use Smith Chart)

i. Find the distance in meters from the load to the tuning stub.

ii. Determine the length in meters of the short circuited stub.

Experiment 3

Vector Network Analyzer

Aim: To study Vector Network Analyzer and measure the S-parameters of any port(s) network.

Requirements: Vector Network Analyzer/Internet, any-port network prototype (For. eg: Antenna (1 pot), MIMO antenna(2-port), Bandpass Filter etc.).

Theory:

What is vector network analyzer and why is it required?

Block diagram of VNA (To be drawn)

Fig.1 Block diagram of VNA

Observations:

Sr. No	Parameters	Results
1	Ports for which VNA Calibration was done	
2	VNA Support Frequency	
3	Type of network(s)	
4	Operating Bandwidth	

Conclusion:

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Post Experiment Exercise

Questions

1. List the different kinds of terminations available?
2. Write the input impedance of a transmission line for
   a. Short circuit termination and b. Open circuit termination
3. Explain with a diagram how microwave power is measured using a Bolometer.
4. Explain with the help of block diagrams different methods to measure impedance
5. Describe the methods to measure high and low VSWR.

Experiment - 4: Design of Rectangular Waveguide using EM Simulation Software

1. **Aim:** To design, simulate and analyze a WR-90 Rectangular Waveguide using Ansys 2022 R1
2. **Objectives:**
   a) To implement and simulate an air filled WR-90 Rectangular Waveguide in HFSS.
   b) To study field pattern for the first three modes (TE10, TE20, TM11).
   c) To generate β vs. frequency graph for each mode.
3. **Requirements**
   ANSYS Software

4. Pre-experiment Exercise

Brief Theory

5. Laboratory Exercise:

5.1 Procedure

1. Implement a WR-90 Rectangular waveguide in HFSS.
2. Simulate the designed waveguide and observe field patterns for the dominant mode.
3. Observe the S11 and S12 graph
4. For first three modes in a rectangular waveguide, plot Beta/ko vs frequency response and obtain the cutoff frequency for each mode using the plot.
5. Compute the cutoff frequencies for the modes using the analytical approach.
6. Compare the results obtained from step 3 and step 4.

5.2 Observations

Sr. No.	Type of Modes	Simulation	Theoretical
1.	Mode1(TE10)	f_{cTE10} = ________	f_{cTE10} = ______________
2.	Mode 2 (TE20)	f_{cTE20} = ________	f_{cTE20} = ________
3.	Mode 3(TM11)	f_{cTE01} = ________	f_{cTE01} = ________

Other Observations:

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Post Experiment Exercise:

6.1 Conclusion/Comments

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6.2 Questions

1. Define a dominant mode and which mode is a dominant in rectangular waveguide? Give reason? Which modes are not possible in a rectangular waveguide and why?
2. Derive field equations for TE and TM modes in rectangular waveguides
3. A rectangular waveguide is designed to propagate the dominant mode at 5 GHz. The cut-off frequency is 0.8 of the signal frequency. The ratio of the guide height to width is 2. The time average power flow through the waveguide is 1kW. Determine the magnitudes of electric and magnetic fields inside the guide and indicate where these occur in the guide.
4. A rectangular waveguide operating at 3.5 GHz in the dominant TE10 mode has inside dimensions a=7 cm b=3.5 cm. Calculate cut-off frequency, phase velocity and guided wavelength.

Experiment – 5: Microstrip Transmission Line

1. **Aim:** To design and analyze a 50-Ω transmission line at 5 GHz using a FR4 substrate with the help of simulation software.
2. **Requirement:** ANSYS R2022 software.
3. **Theory:**

Transmission Line

- In general, a transmission line is a medium or structure that forms a path to direct energy from one place to another.
- Transmission lines are specialized cables and waveguides designed to carry alternating current (AC) and electromagnetic waves of radio frequency → the currents with frequency high enough that its wave nature has to be taken onto account.
- RF transmission lines "enclose" electromagnetic waves, preventing them from being radiated off the line, which would cause power loss.
- The transmission lines are characterized using the Scattering parameters or S-parameters which describe the behavior of linear microwave networks.
- S-parameters are widely used in RF/microwave measurements as they formulate the transformation properties in terms of incident and reflected waves and use matched loads. S-parameters can be directly measured with network analyzers.

4. **Procedure:**

i. **Design theoretically the microstrip line using the given specifications and compute L and W.**

ii. **Getting started using simulation:**

• Microsoft **Start > Programs > Ansys**

• After program initialization, click on the blue icon for (**Insert HFSS Design**)

• Select the menu item **HFSS>Solution Type**, choose **Driven Terminal** click **OK**

• Select the menu item **3D Modeler>Units**, choose **mm** and click **OK**

• Select the menu item **3D Modeler>Grid Plane > XZ**

iii. **Draw the Structure:**

- Select the menu item **Draw > Rectangle (ground)** with the dimensions of 20 x 40 in mm and name the rectangle as a **ground.**
- Select the menu item **Draw > Box (substrate)** with the dimensions of 20 x 40 x 1.6 in mm above ground and name the box as **substrate** also select the material as **"FR4_epoxy".**

- Select the menu item **Draw > Rectangle (line)** with the dimensions of 3 x 40 in mm above and at the center of the substrate and name the rectangle as a **microstrip.**
- Select **ground plane**, right click on it and choose **Assign Boundaries > Perfect E** then click **OK.**
- Select **microstrip line**, right click on it and choose **Assign Boundaries > Perfect E** then click **OK.**
- **Assign Excitations** to port 1 and port 2 on either sides of the line
- To draw Radiation Box, select the menu item **Draw > Box** with dimensions such that microstrip patch is equidistance from all the sides of the Radiation Box.

iv. Analysis:

• **HFSS > Analysis Setup > Add Solution Setup**
In the **General** view:
Frequency = 5 GHz
Maximum number of passes = 10
Maximum Delta S = 0.02
Click **OK**

• **HFSS > Analysis Setup > Add Sweep Discrete** type of sweep from 2 GHz to 10 GHz with the step of 0.1GHz

• Check the validity by **HFSS>Validation Check** and if there is no error go ahead and run the simulation **HFSS > Analyze All**. Wait a few minutes for the simulation to be done.

v. View Results:

- **Result > create modal solution data report > rectangular plot**
- In **Category** select **S-parameters** and in **Function** select **dB,** now select all the four S-parameters and click on **New Report.**
- **Similarly get the Z-plot under results**

5. Observations:

Sr. No	Parameter	Values	Interpretation
1	S11		
2	S22		
3	S12		
4	S21		
5	Z		

Conclusion:

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Post Experiment Exercise:

1. Differentiate between a microstrip and a stripline
2. Draw and explain the equivalent circuit diagram of a two-conductor transmission line
3. With respect to the transmission line define and explain the following parameters
   a. VSWR
   b. Reflection Coefficient
   c. Characteristic Impedance
   d. Propagation Constant
4. What does the characteristic impedance of the transmission line depend upon? In the experiment why did we prefer designing a 50-ohm transmission line?
5. List and prove the properties of S-parameters.

Experiment - 6: Characteristics of Reflex Klystron

1. Aim: To study the characteristics of Reflex Klystron tube.

2. Requirements

- Klystron Power Supply.
- Klystron Tube with Klystron Mount
- Isolator
- Frequency Meter
- Variable Attenuator
- Detector Mount
- VSWR meter or CRO
- Waveguide Stand and BNC cable.

3. Pre-experiment Exercise

Brief Theory

The Reflex Klystron makes use of velocity modulation to transform a continuous electron beam into microwave power. It contains a reflector plate refer to as the repeller, instead of the output cavity used in other types Klystrons. The electron beam is modulated by passing it through an oscillating resonant cavity. The feedback required to maintain oscillations within the cavity is obtained by reversing the beam and sending it back through the cavity. The electrons in the beam are velocity modulated before the beam passes through the cavity the second time and will give up the energy required to maintain oscillations.

The electron beam is turned around by the negatively charged electrode that repels the beam. This negative element is the repeller mentioned earlier. This type of Klystron oscillator is called a Reflex Klystron because of the reflex action of electron beam.

The frequency is primarily determined by the dimensions by the resonant cavity. Hence by the changing volume of resonator, mechanical tuning of Klystron is possible.

Also, a small frequency change can, be obtained by adjusting the reflector voltage. This is called electronic tuning range.

4. Laboratory Exercise

Procedure:

1. Set up the components and equipments as shown in Fig.2
2. Keep position of variable attenuator at minimum attenuation position
3. Set mode selector switch to AM –MOD position.
4. ’ON’ the Klystron Power Supply and Oscilloscope
5. ’ON’ beam voltage switch and set beam voltage to 300 V on beam voltage control knob.
6. By changing the reflector voltage and amplitude of FM modulation any mode of Klystron tube can be seen on Oscilloscope

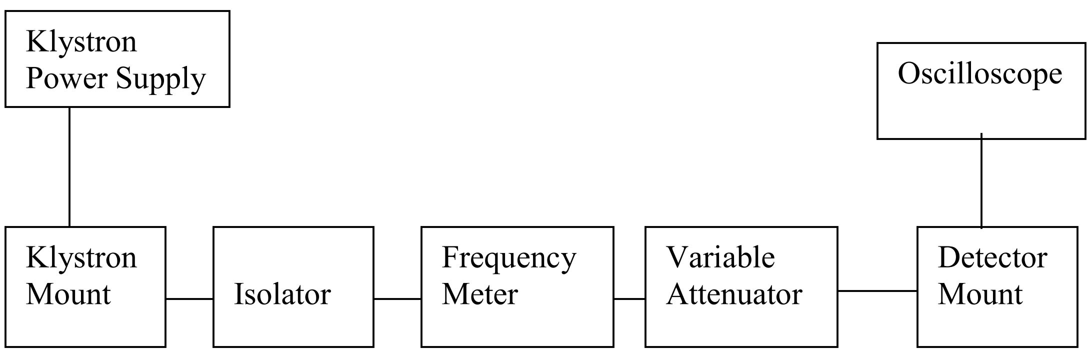

Fig.1. SET UP FOR STUDY OF KLYSTRON TUBE

4.2 Observations:

1. **Power Supply Settings:**
   Beam Voltage = ___________
   Beam Current = ___________
   Initial Reflector Voltage = ____________
   Assume R = 1 ohm

2. Characteristics of Reflex Klystron

<table>
<tr><th>Mode No.</th><th>Repeller voltage (V)</th><th>Voltage Amplitude (mV)</th><th>Power (mW)</th></tr>
<tr><td rowspan="3">1</td><td></td><td></td><td></td></tr>
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5. Post Experiment Exercise:

5.1 Results:

1. Plot Repeller voltage v/s Power on a graph paper.

5.2 Conclusion/Comments

5.3 Questions:

1. Describe basic principle of O type and M type devices in brief.
2. Explain the principle of operation of Reflex Klystron with a labelled diagram.
3. Explain the bunching process in Reflex Klystron.

Experiment - 7: Microwave Measurements

1. Aim: To measure the microwave frequency, guided wavelength and VSWR

2. Requirements

- Klystron Power Supply.
- Klystron Tube with Klystron Mount
- Isolator
- Frequency Meter
- Variable Attenuator
- Detector Mount
- VSWR meter or CRO
- Waveguide Stand and BNC cable

3. Pre-experiment Exercise

Brief Theory

The measurement of frequency is often a necessary part of microwave investigations. Direct reading type frequency meter is used to measure the frequency. The heart of this frequency meter is the resonant cavity and for any particular cavity size, a single frequency resonance will be “supported”. The cavity has a small window such allow some energy to enter. The energy is often said to be absorbed by the cavity, and hence the name “Absorption Type”.

Maximum absorption takes place when the cavity is tuned exactly to the frequency of the energy to be measured. For greatest accuracy, Q of the cavity is made very high, often as high as 10,000. It indicates that the tuned circuit is extremely sharp, absorbing a maximum of the energy at the exact frequency and much less at slightly different frequencies. At exact dial setting, where the maximum or peak absorption takes place, an accurate frequency measurement can be made. The indicating meter in the circuit indicates the energy level and shows a drop in energy level the moment energy is absorbed by the frequency meter cavity.

A frequency measurement would therefore, consist of tuning the cavity of the frequency meter until maximum "dip" occurs on the indicating meter and then reading the corresponding frequency from the frequency meter.

The wavelength of microwaves varies from medium in which it travels. Similarly the guided wavelength depends upon its internal dimensions. The guided wave length and free space wavelength are related by the equation,

$$\left(\frac{1}{\lambda_g}\right)^2 - \left(\frac{1}{\lambda_0}\right)^2 = \left(\frac{1}{2a}\right)^2 \qquad (1)$$

where

λ_g = guided wavelength, λ_0 = free space wavelength, a = width of the waveguide

Frequency f can be obtained using the Direct reading type frequency meter. Thus we can find operating wavelength λ_0 using $\lambda_0=c/f$. Now substituting λ_0 in equation (1), we can find λ_g, where the longest dimension a of the waveguide is known to us. Also, λ_g can be practically determined by the following method. If the distance d between the two minimas on the standing wave pattern is measured, then $\lambda_g / 2 = d$.

For measurement of low VSWR, we use the detector probe carriage to determine the minimum and maximum standing wave voltage along the waveguide. The waveguide is assumed to be terminated appropriately. VSWR is determined as

$$VSWR = \frac{V_{\max}}{V_{\min}} \qquad (2)$$

4. Laboratory Exercise

Precautions: Before firing the reflex klystron, the following points should be borne in mind:

1. During the operation of reflex klystron, the repeller does not carry any current and as such it may be severely damaged by electron bombardment. To protect the repeller from such damage, *the repeller negative voltage is always applied before anode voltage*. Also, the repeller voltage should be varied in one direction to avoid hysteresis in reflex klystron.
2. Switch ON the cooling fan before firing the reflex klystron.
3. While measuring power, the frequency meter should be *detuned* each time because there is a dip in the power when frequency meter is tuned.

Procedure:

1. Set up the components and equipments as shown in Fig.1
2. Keep position of variable attenuator at min.attenuation position
3. Set mode selector switch to AM –MOD position.
4. 'ON' the Klystron Power Supply and Oscilloscope
5. 'ON' beam voltage switch and set beam voltage to 300 V on beam voltage control knob.
6. By changing the reflector voltage and amplitude of FM modulation any mode of Klystron tube can be seen on Oscilloscope
7. Now adjust the direct reading frequency meter till you observe a dip in power on VSWR meter on CRO The position on the frequency meter indicates the microwave frequency. Measure and record this frequency.
8. Calculate λ_0 using the relation $\lambda_0 = c/f$.
9. Calculate λ_g using equation (1) where a = 2.286 cm.
10. Verify the above value of λ_g by the following experimental procedure.
    a. Move the plunger on the slotted line till you get minimum deflection on the VSWR meter or minimum voltage on CRO. Note down this reading in cm. Let it be X.
    b. Now move the plunger further till you get second minimum. Let it be Y. Now, $\lambda_g/2$ = X-Y = d. Therefore, $\lambda_g = 2d$.
11. Record the maximum and minimum voltage along the guide and determine the VSWR using equation (2).

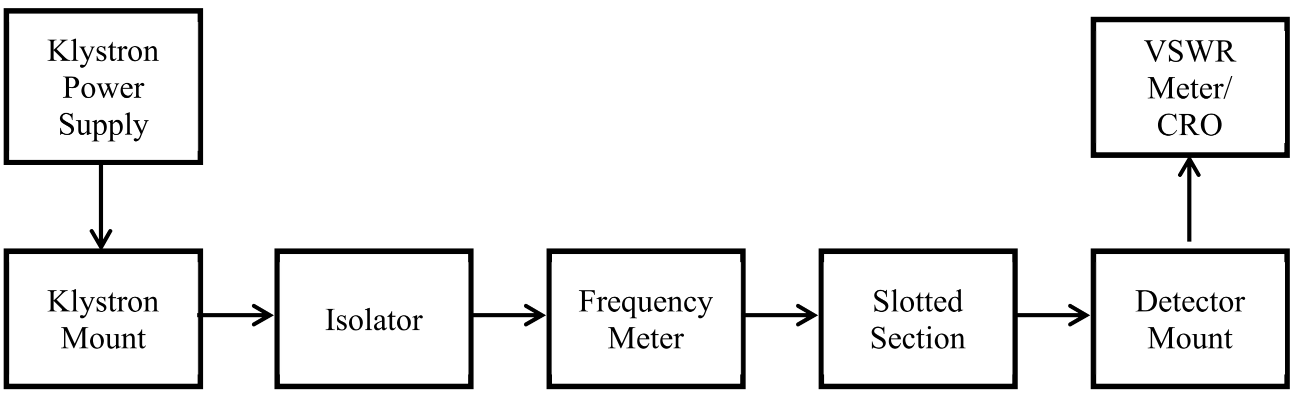

Fig.1. Set-up for Measurement of Guide Wavelength

4.2 Observations:

Sr. No.	Parameter	Measured values	Calculated values	$\%\text{Error} = \left\lvert \dfrac{\text{Experimental Value} - \text{Theoretical Value}}{\text{Theoretical Value}} \right\rvert \times 10$
1.	Frequency			
2.	Free space wavelength			
3.	First min/max position X		–	
4.	Second min/max position Y		–	
5.	Third min/max position Y (if any)		--	
6.	Guide wavelength			
7.	$V_{\max}$		–	
8.	$V_{\min}$		–	
9	VSWR		–	

5. Post Experiment Exercise:

5.1 Conclusion/Comments

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5.2 Questions:

1. Explain the operation of Two cavity Klystron with a neat labelled diagram.
2. Derive the expression for velocity modulation in two cavity Klystron
3. Define guided velocity and phase velocity.

Experiment -8: Gunn diode

1. Aim : To study V-I characteristics of Gunn diode.

2. Requirements

- Gunn Power Supply.
- Gunn Oscillator
- Pin Modulator
- Isolator with termination
- Detector Mount
- Oscilloscope(CRO) or VSWR meter with probe

3. Pre-experiment Exercise

Brief Theory

A Gun diode, also known as a transferred electron device (TED) is a form of diode used in high –frequency electronics. It is somewhat unusual in that it consists only

Of N-doped semiconductor material, whereas most diodes consist of both P and N-doped regions. In the Gunn diode, three regions exist: two of them are heavily N-doped on each terminal, with a thin layer of lightly doped material in between. When a voltage is applied to the device, the electrical gradient will be largest across the thin middle layer. Eventually; this layer starts to conduct, reducing the gradient across it, preventing further conduction. In practice, this means a Gunn diode has a region of negative differential resistance.

4. Laboratory Exercise

4.1 Procedure:

1. Set the components and Equipments as shown in Fig.1

2.Keep the control knob of Gunn Power Supply as below

Meter switch -off

Gunn Bias Knob -Fully anti clockwise

PIN bias knob -Fully anti clockwise

PIN Mode frequency -Any position

3. Set the micrometer of Gunn Oscillator for required frequency of operation.

4.'ON' the Gunn Power Supply

5. Turn the meter switch of Gunn Power Supply to voltage position.

6.Measure the Gunn diode current corresponding to the various voltage controlled by Gunn bias voltage below 10 Volts.

7. Plot the voltage and current readings on the graph as shown in fig.2.

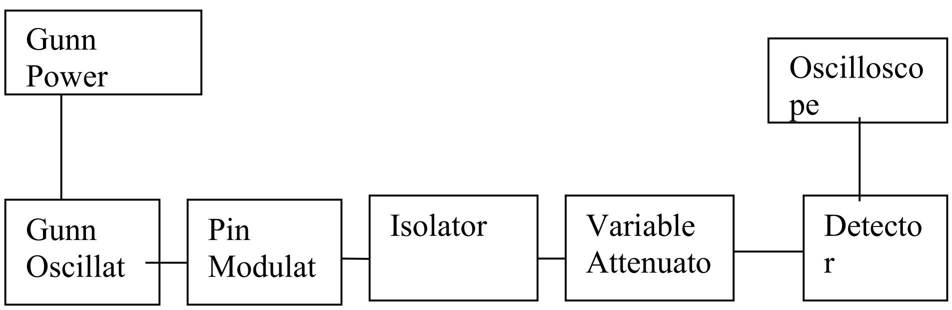

Fig.1. SET UP FOR STUDY OF GUNN OSCILLATOR

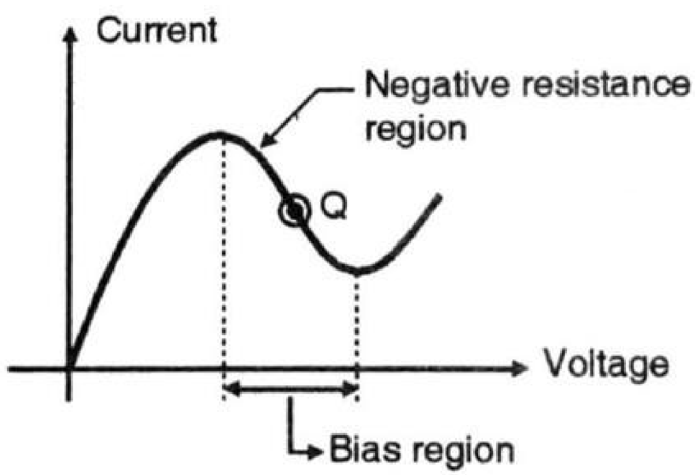

Fig.2. V-I Characteristics of Gunn Diode

4.2 Observations :

Sr.No.	Gunn Voltage(V)	Gunn Current(mA)
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		

5. Post Experiment Exercise :

5.1 Results :

1. **Plot Gunn v/s current in a graph paper.**

5.2 Conclusion/Comments

5.3 Post Experiment Exercise

Questions:

1. Describe different modes of oscillation of Gunn diode.
2. Differentiate between Transit time devices and Transferred electron devices.
3. Explain the working of a negative resistance parametric amplifier.
4. Explain any two avalanche transit time devices