MICROWAVE ENGINEERING LABORATORY MANUAL

Subject code: ECC309

Subject name: Microwave Engineering Lab

Course: B.Tech

Winter Sem., 2021-2022

DEPARTMENT OF ELECTRONICS ENGINEERING

General Instructions

Do's

1. Connections must be made according to the block diagram given in the respective experiment and all the connection should be tight.
2. Devices like Klystron power supply, VNA, Power meter, GUNN power supply should be handled carefully.
3. Take observations carefully.

Don'ts

1. Do not switch **ON** the power supply unless you have made the tuned connections.
2. While doing the experiment do not change any component. This may lead to damage other devices.
3. While leaving the lab don't forget to switch **OFF** all electrical points.

CONTENT

Sl. No.	Name of Experiment	Page No.
1	Study of I-V Characteristics of Gunn diode.	
2.	Study the propagation of wave in X-band waveguide & draw the $\omega - \beta$ plot.	
3.	Determine experimentally the propagation characteristics of Directional Coupler operating at X-band using microwave test bench	
4.	Determine experimentally the propagation characteristics of Magic Tee operating at X-band using microwave test bench	
5.	Determine the standing wave ratio and reflection coefficient	
6.	Determine the unknown impedance of the device at a spot frequency in X-band and also verify by using smith chart.	
7.	1. Study rectangular waveguide 2. Find cut-off wavelength equation for rectangular waveguide. 3. Determine experimentally the broader dimension of rectangular waveguide using microwave test bench at X-band of microwave frequency.	
8.	1. Study the microstrip filter 2. Study the Frequency Response of various Microstrip filter 3. Analyze the response in C- band using SICO microstrip trainer kit.	
9.	To conduct the experiment to obtain: 1. The far field distance between the transmitting and receiving antennas. 2. The radiation pattern of Horn antenna in X-band using microwave test bench.	
10.	To conduct the experiment to obtain: 1. The far field distance between the transmitting and receiving antennas. 2. The gain of Horn antenna in X-band using microwave test bench.	

11.	1. Study the sample. 2. Find dielectric constant of sample. 3. Analyze using two point method.	
12.	Determine experimentally the S-parameters of reciprocal device with the help of slotted line in X-Band of microwave frequencies using microwave test bench.	

EXPERIMENT – 1

OBJECTIVES:

Study I-V Characteristics of Gunn diode in X-band.

Outcomes: Students are able to

1. Analyze the characteristics curve of GUNN DIODE.

EQUIPMENTS:

Gunn power supply, Gunn oscillator, Isolator, PIN modulator, Frequency meter, Variable attenuator, Detector with tunable mount, Waveguide stands, SWR meter, Matched load terminations, Cables and Accessories.

THEORY:

GUNN Diodes (Transferred Electron Device)

Gunn diodes are negative resistance devices which are normally used as low power oscillator at microwave frequencies in transmitter and also as local oscillator in receiver front ends. **J B Gunn** (1963) discovered microwave oscillation in Gallium arsenide (GaAs), Indium phosphide (InP) and cadmium telluride (CdTe). These are semiconductors having a closely spaced energy valley in the conduction band as shown in Fig. 1.1(a) for GaAs. When a dc voltage is applied across the material, an electric field is established across it. At low **E**-field in the material, most of the electrons will be located in the lower energy central valley. At higher **E**-field, most of the electrons will be transferred in to the high-energy satellite L and X valleys where the effective electron mass is larger and hence electron mobility is lower than that in the low energy valley. Since the conductivity is directly proportional to the mobility, the conductivity and hence the current decreases with an increase in **E**-field or voltage in an intermediate range, beyond a threshold value V_{th} as shown in Fig. 1.1(c). This is called the transferred *electron* effect and the device is also called 'Transfer Electron Device (TED) or Gunn diode'. Thus the material behaves as negative resistance device over a range of applied voltages and can be used in microwave oscillators.

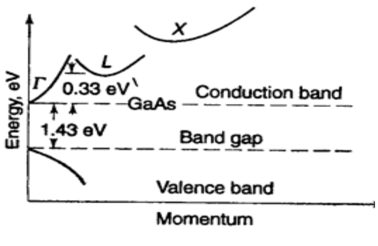


Fig 1.1(a) Multi-valley conduction band energies of GaAs

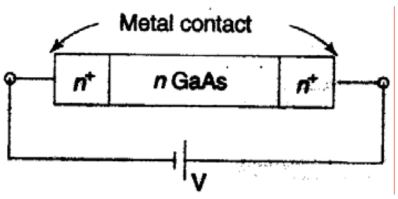


Fig 1.1(b) Gunn Diode configuration

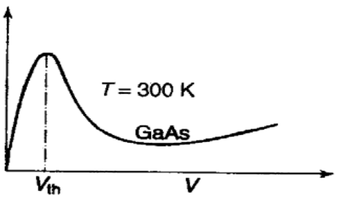


Fig 1.1(c) Current-voltage characteristics of GaAs

The basic structure of a Gunn diode is shown in Fig. 1.2 (a), which is of n-type GaAs semiconductor with regions of high doping (n+). Although there is no junction this is called a diode with reference to the positive end (anode) and negative end (cathode) of the dc voltage applied across the device. If voltage or an electric field at low level is applied to the *GaAs,* initially the current will increase with a rise in the voltage. When the diode voltage exceeds a certain threshold value, V_{th} a high electric field (*3.2 KV/m for GaAs*) is produced across the active region and electrons are excited from their initial lower valley to the higher valley, where they become virtually immobile. If the rate at which electrons are transferred is very high, the current will decrease with increase in voltage, resulting in equivalent negative resistance effect. Since *GaAs* is a poor conductor, considerable heat is generated in the diode. The diode will be bonded into a heat sink (Cu-stud).

The electrical equivalent circuit of a Gunn diode is shown in Fig. 1.2 (b), where C_j and $-R_j$ are the diode capacitance and resistance, respectively, R_S includes the total resistance of lead, ohmic contacts, and bulk resistance of the diode, C_p and L_p are the package capacitance and inductance, respectively. The negative resistance has a value that typically lies in the range –5 to –20 ohm.

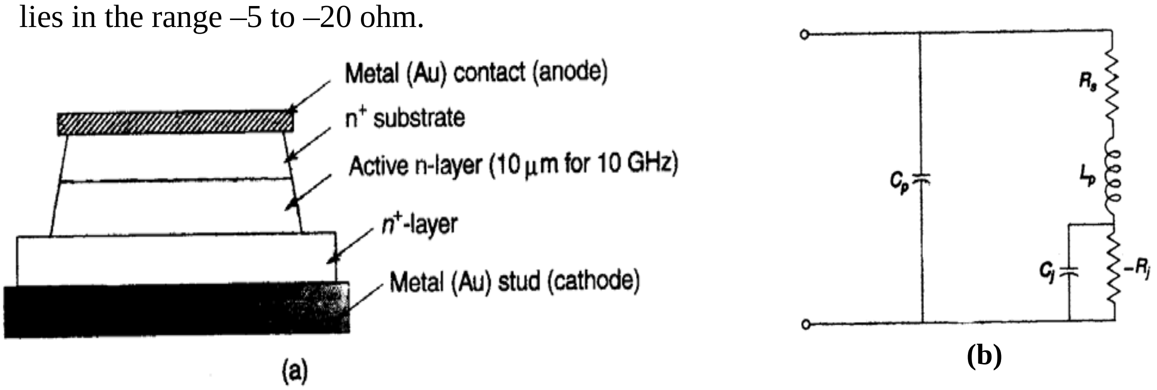


Fig.1.2 Constructional details and electrical equivalent circuit of Gunn Diode.
(*MICROELECTRONICS AND VLSI, 4January 2013, http://mmicroelectronics.blogspot.com/2013/01/gunn-diode.html*)

Gunn Oscillator:

In a Gunn Oscillator, the Gunn Diode is placed in a resonant cavity. In this case the oscillation frequency is determined by cavity dimension than by the diode itself. Although Gun Oscillator can be amplitude-modulated with the bias voltage, we have used separate PIN modulator through *PIN diode for square wave modulation*

PROCEDURE:

1. Set the components and equipment as shown in the Fig. 1.3.
2. Initially set the variable attenuator for maximum attenuation.
3. Keep the control knob of Gunn Power Supply as below:
   Meter Switch - 'OFF'
   Gunn bias knob - Fully anticlockwise
   Pin bias knob - Fully anticlockwise
   Pin Mod Frequency - Any Position
4. Keep the control knob of VSWR meter as below:
   Meter Switch - Normal
   Input Switch - Low Impedance

Range dB Switch - 40 dB
Gain Control Knob - Fully clockwise.

5. Set the micrometer of Gunn Oscillator for required frequency of operation.
6. 'ON' the Gunn Power Supply, VSWR meter and Cooling fan.

Voltage-current characteristics:

1. Turn the meter switch of 'Gunn power supply to voltage position.
2. Measure the Gunn diode Current Corresponding to the various voltage controlled by Gunn bias knob through the panel meter and meter switch.
3. Plot the voltage and current readings on the graph as shown in Fig.1.4.
4. Measure the threshold voltage from the graph which corresponds to maximum current.

NOTE: DONOT KEEP GUNN BIAS KNOB POSITION AT THRESHOLD POSITION FOR MORE THAN 10-15 SECONDS. READING SHOULD BE OBTAINED AS FAST AS POSSIBLE. OTHERWISE, DUE TO EXCESSIVE HEATING, GUNN DIODE MAY BURN.

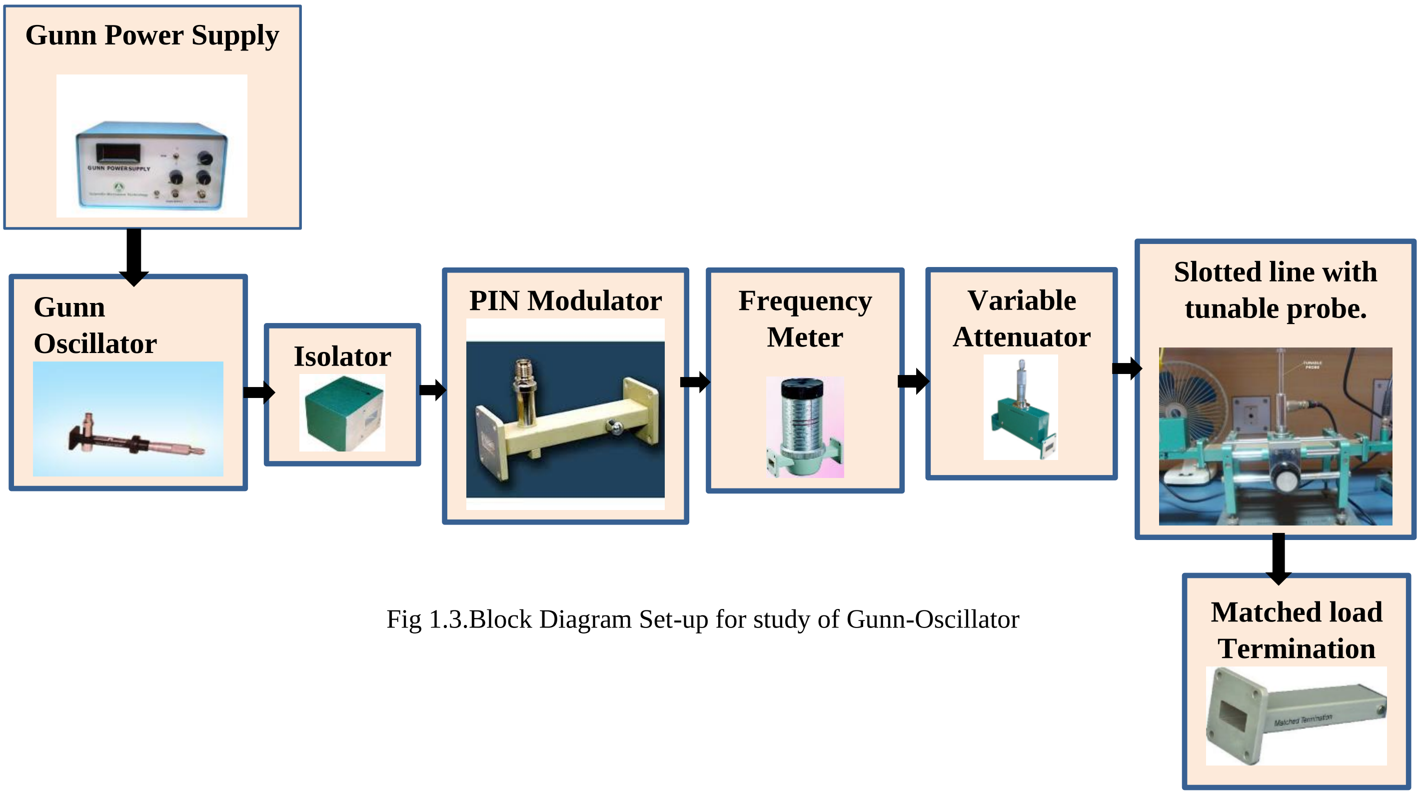


Fig 1.3.Block Diagram Set-up for study of Gunn-Oscillator

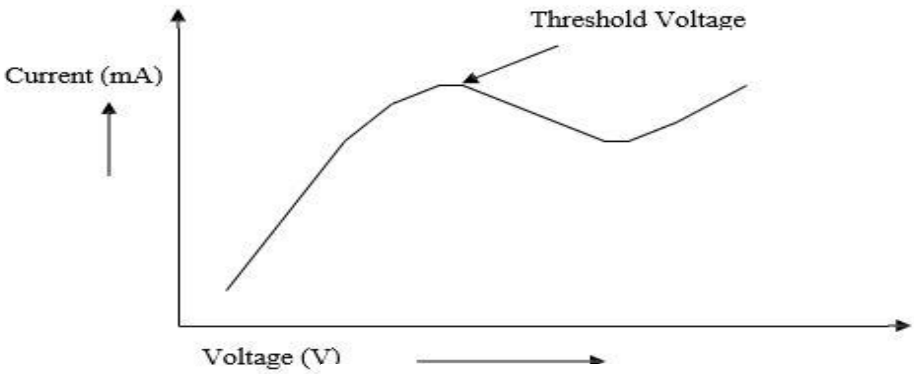


Fig 1.4. V-I Curve of Gunn Oscillator

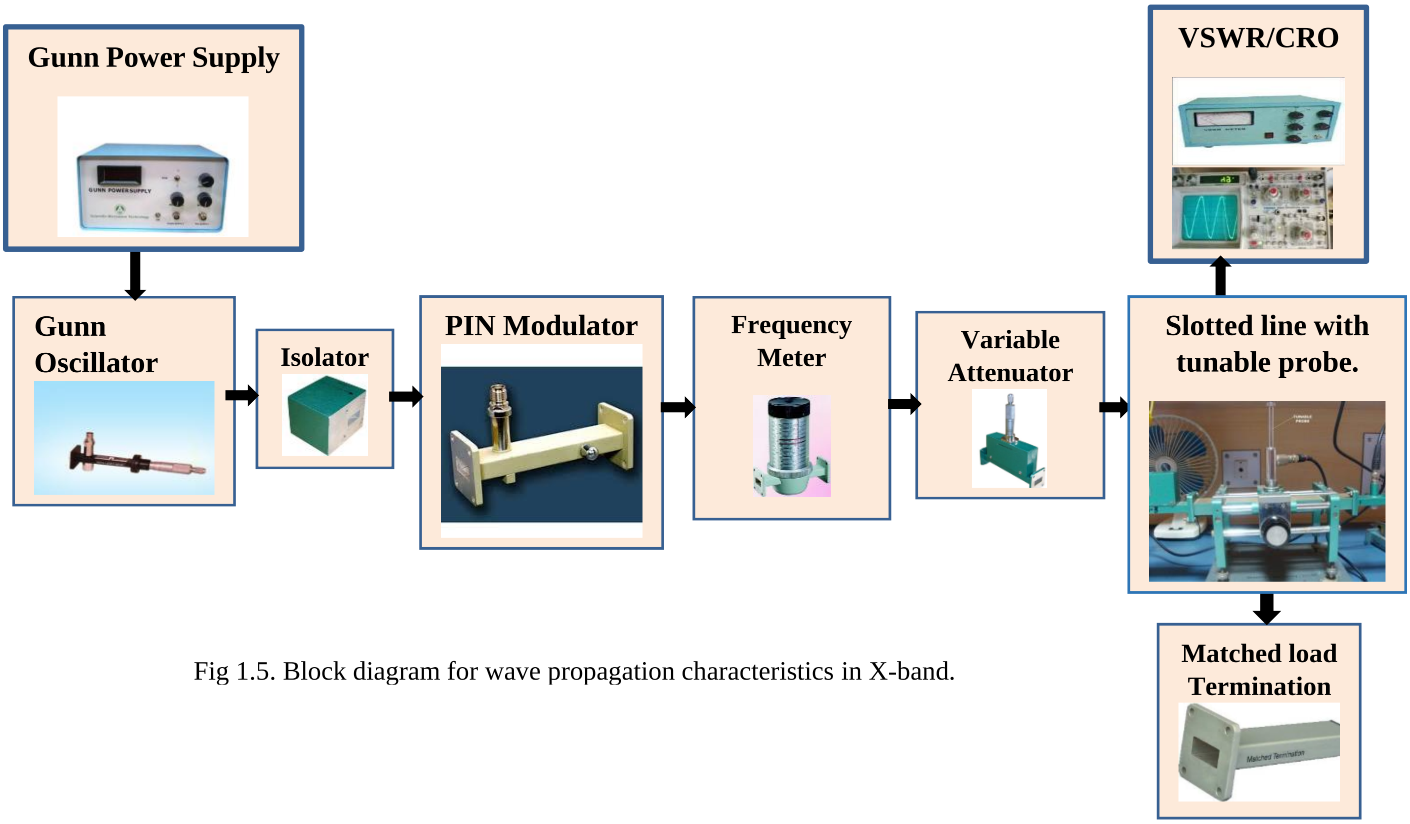


Fig 1.5. Block diagram for wave propagation characteristics in X-band.

OBSERVATION TABLE:

V-I Characteristics curve:

Change Gunn biasing voltage in step of 0.5V and note the current readings. The biasing voltage range is 0-10V

S.No.	Voltage (volts)	Current (mA)	Threshold voltage (from graph)

RESULTS & DISCUSSION:

PRECAUTIONS:

1. The Gunn power supply should be handled carefully.
2. Detector should not be exposed to power > 15mW.
3. VSWR readings and frequency adjustments should be done properly.
4. All elements should be properly tuned.

ViVa Question:

1. What is threshold voltage of a Gunn Diode?
2. What is –ve resistance region?
3. Why it is named as Gunn diode?

EXPERIMENT – 2

OBJECTIVES:

Study the propagation of wave in X-band waveguide & draw the $\omega - \beta$ plot.

Outcomes: Students are able to

1. Analyze the characteristics curve of $\omega - \beta$ plot.
2. Calculation of phase velocity and group velocity from the $\omega - \beta$ plot.

EQUIPMENTS:

Gunn power supply, Gunn oscillator, Isolator, PIN modulator, Frequency meter, Variable attenuator, Detector with tunable mount, Waveguide stands, SWR meter / CRO, Matched load terminations, Cables and Accessories.

THEORY:

$\omega - \beta$ Characteristics:

For guided modes propagating along a perfectly straight line path, we may assume that all components of the electromagnetic wave can be represented in the form

$$f(u,v)e^{-j\beta z}e^{j\omega t}$$

in which 'z' is chosen as the propagation direction, (u, v) are generalized orthogonal coordinates in the transverse plane, 'β' is the propagation constant, and 'ω' is the angular frequency of the wave. Field solutions for a given guiding structure must satisfy the appropriate boundary conditions which yields a transcendental equation in 'ω' and 'β' for the guided modes.

How the propagation constant, 'β', of a given guided mode varies as a function of frequency is obtained by solving the governing transcendental equation. The ω-β diagram is simply a way of displaying the behavior of 'β' vs. 'ω'. From this diagram one may obtain $\beta, \partial\beta/\partial\omega$, and $\partial^2\beta/\partial\omega^2$, as a function of frequency. These values specify the dispersion characteristics of a given mode. For example, the phase velocity is ω/β for that mode, the group velocity is $\partial\beta/\partial\omega$ for that mode, and the pulse broadening factor for that mode is related to $\partial^2\beta/\partial\omega^2$.

PROCEDURE:

1. Set the components and equipment as shown in the Fig. 1.2.
2. Initially set the variable attenuator for maximum attenuation.
3. Keep the control knob of Gunn Power Supply as below:
   - Meter Switch - 'OFF'
   - Gunn bias knob - Fully anticlockwise
   - Pin bias knob - Fully anticlockwise
   - Pin Mod Frequency - Any Position
4. Keep the control knob of VSWR meter as below:

Meter Switch - Normal
Input Switch - Low Impedance
Range dB Switch - 40 dB
Gain Control Knob - Fully clockwise.

5. Set the micrometer of Gunn Oscillator for required frequency of operation.
6. 'ON' the Gunn Power Supply, VSWR meter and Cooling fan.

A. Wave propagation ($\omega - \beta$) characteristics:

1. Again check the connections as shown in Fig 1.2.
2. At a particular frequency adjust the shorting plunger so that there is no loss due to insertion.
3. Move the slotted line section and check VSWR meter for two consecutive minima and note the readings from scale.
4. The difference between the 2 minima gives the half guided wavelength ($\lambda_g/2$).
5. From λ_g and λ_c , λ_o can be calculated hence $'\beta'$ can be calculated. Similarly for the adjusted value of frequency $'\omega'$ can be found.
6. Repeat the steps 2-6 for different frequency values for X-band (in the difference of 0.2-0.4 GHz) and find the different values of $'\omega'$ & $'\beta'$.
7. Plot the graph between $'\omega'$& $'\beta'$ and verify the wave propagation characteristics from Fig 1.1.

NOTE: DONOT KEEP GUNN BIAS KNOB POSITION AT THRESHOLD POSITION FOR MORE THAN 10-15 SECONDS. READING SHOULD BE OBTAINED AS FAST AS POSSIBLE. OTHERWISE, DUE TO EXCESSIVE HEATING, GUNN DIODE MAY BURN.

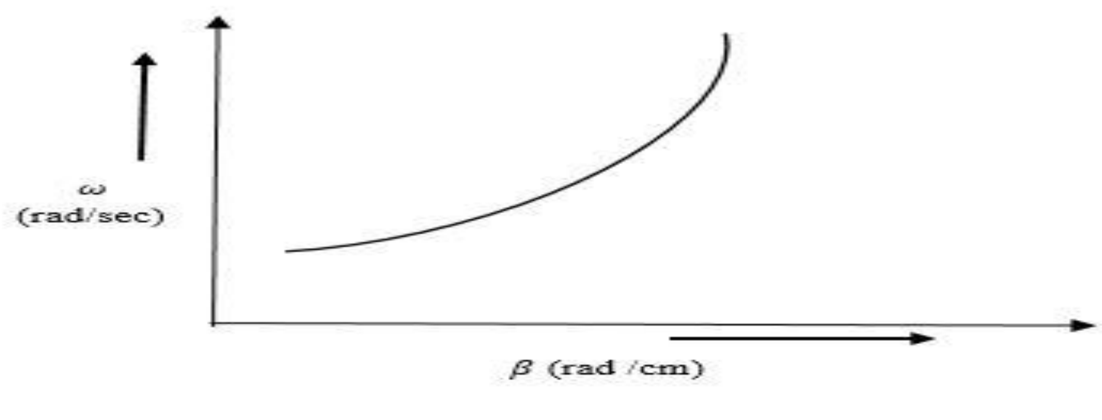


Fig 1.1. Wave propagation characteristics curve

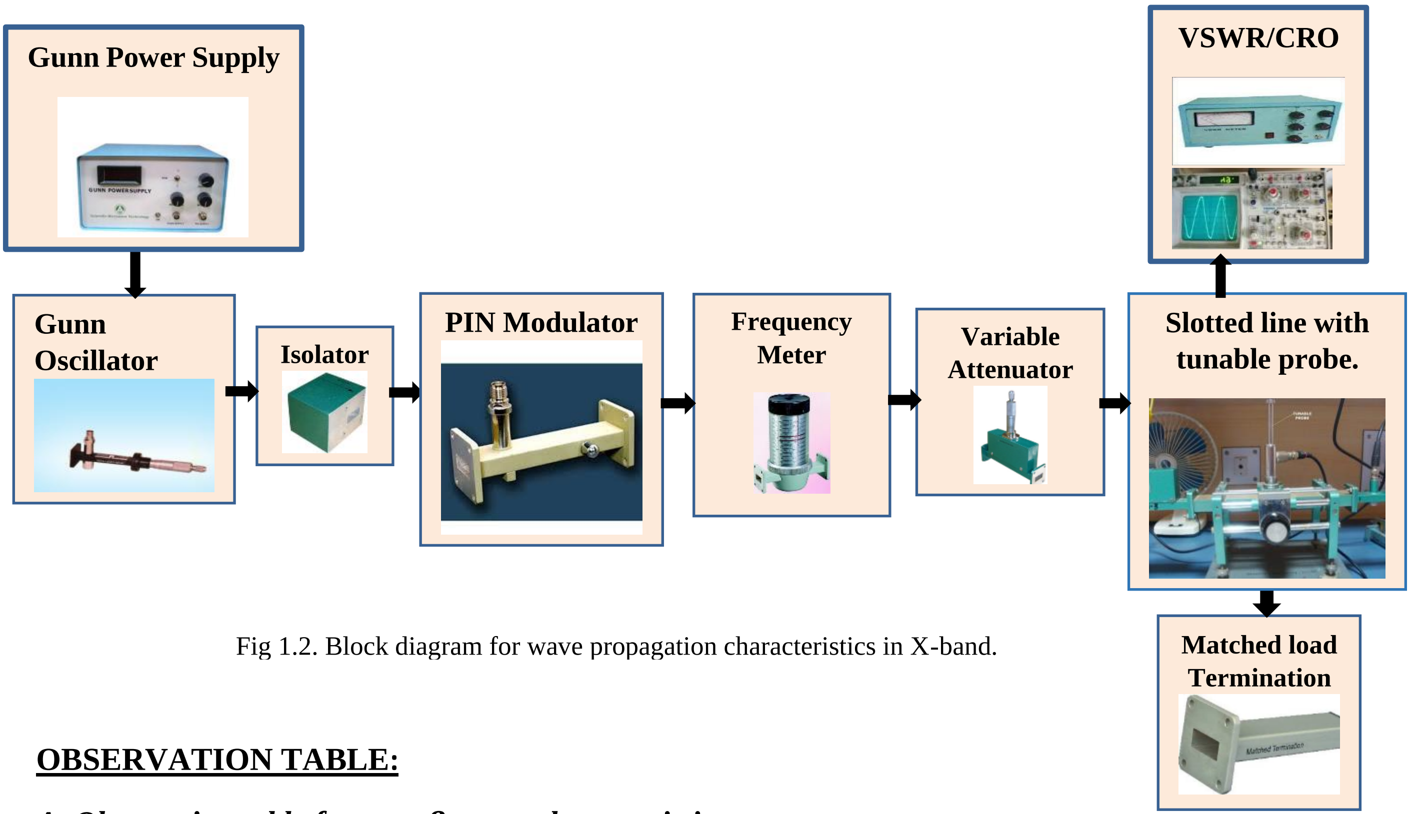


Fig 1.2. Block diagram for wave propagation characteristics in X-band.

OBSERVATION TABLE:

A. Observation table for $\omega - \beta$ curve characteristics:

S.No.	1st Minima			2nd Minima			Frequency (GHz)	λ_g (cm)	λ_o (cm)	$\beta = 2\pi/\lambda$
	Main Scale	Vernier scale	Total	Main Scale	Vernier scale	Total				
1.										

CALCULATIONS:

1. Using group velocity ($V_g = \frac{d\omega}{d\beta}$) and phase velocity ($V_p = \frac{\omega}{\beta}$), the relation between $\omega - \beta$ is given by

$$\frac{\omega^2}{c^2} = \beta^2 + \frac{{\omega_c}^2}{c^2} \quad => \quad \frac{1}{{\lambda_o}^2} = \frac{1}{{\lambda_g}^2} + \frac{1}{{\lambda_c}^2}$$

2. For TE_{10} mode in rectangular waveguide , cutoff wavelength $\lambda_c = 2a,$ $where\ 'a' is\ the\ broader\ dimension\ of\ the\ rectangular\ waveguide.$

RESULTS & DISCUSSION:

PRECAUTIONS:

5. The Gunn power supply should be handled carefully.
6. Detector should not be exposed to power > 15mW.
7. VSWR readings and frequency adjustments should be done properly.
8. All elements should be properly tuned.

ViVa Question:

1. Explain phase velocity?
2. Explain group velocity?
3. What do you understand by pulse broadening factor?

EXPERIMENT - 3

OBJECTIVES:

Determine experimentally the propagation characteristics of Directional Coupler operating at X-band using microwave test bench

Outcomes: Students are able to measure the coupling factor and directivity of the coupler

EQUIPMENTS:

Microwave Source (Klystron), Isolator, Frequency Meter, Variable Attenuator, Directional Coupler, Waveguide Stand, Cables and Accessories, Power meter, Matched Termination.

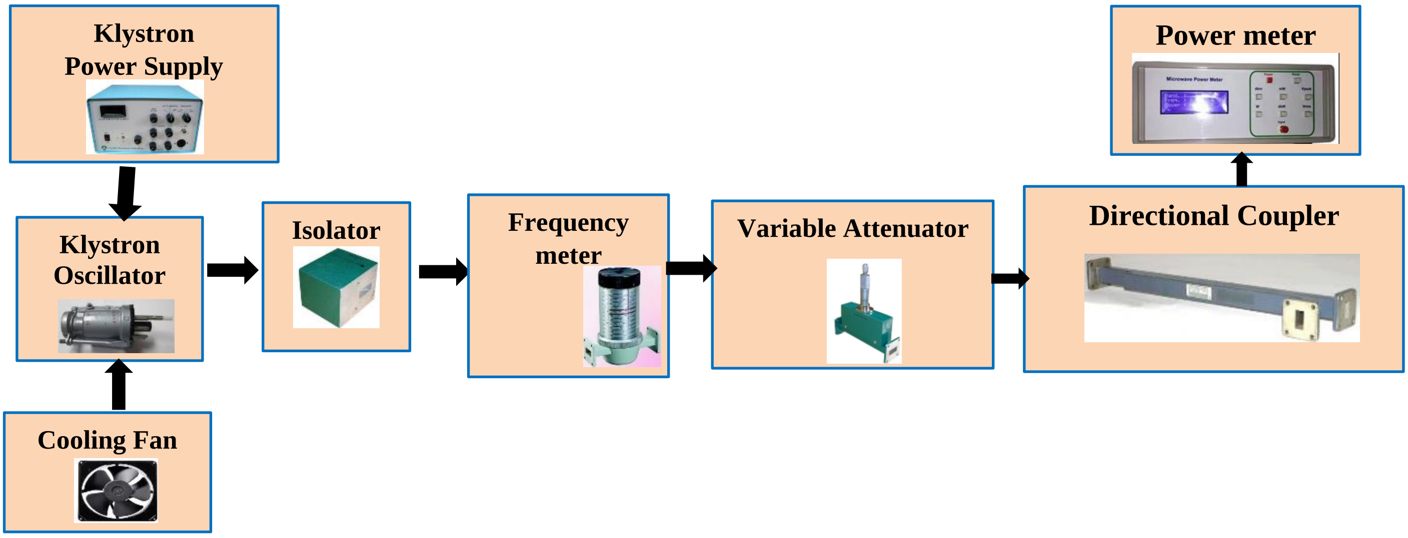


Fig.3.1 Experimental set-up to study the characteristics of Directional coupler and Magic Tee

THEORY:

A. *Directional Coupler:*

Directional Coupler (DC) is a passive, reciprocal, four-port device, where one port is isolated from the input port. A directional coupler is a device with it is possible to measure the incident and reflected wave separately. It consists of two transmission line, the main arm and auxiliary arm, electromagnetically coupled to each other. Refer to the fig. The power entering port 1 the main arm gets divided between port 2 and 3 and almost no power comes out in port 4. Power entering port 2 is divided between port 1 and port 4.

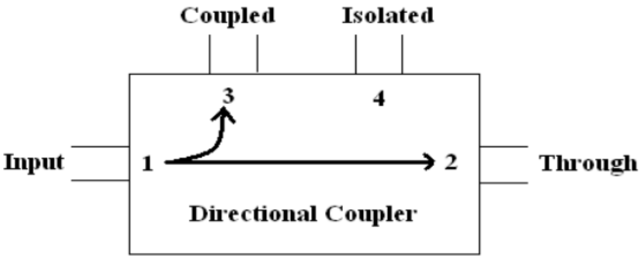


Fig. 3.2. Schematic Diagram of Direction Coupler

The three characteristic parameters of a DC are defined as follows:

Coupling (C) = $10\ log\frac{P_1}{P_3}$ …….(3.1)

Directivity (D) = $10\ log\frac{P_3}{P_4}$ ..……(3.2)

Isolation (I) = $10\ log\frac{P_1}{P_4}$ …….(3.4)

Insertion Loss (IL) = $10\ log\frac{P_1}{P_2}$ ……(3.5)

Here P_i denotes the power measured (in linear scale) at the ***i^th^ (i=1, 2, 3 and 4)*** port of the directional coupler. Since practically the powers at different ports are measured in *dBm* using power meters, we can use the following relations for calculation of coupling (C), directivity (D) and isolation (I) in dB scale:

C (dB) = P_1 (dBm) - P_3 (dBm) ………….(3.6)

D (dB) = P_3 (dBm) - P_4 (dBm) ………….(3.7)

I (dB) = P_1 (dBm) - P_4 (dBm) = C (dB) + D (dB) …….(3.8)

PROCEDURE:

For Directional Coupler characteristics:

1. Set the equipment's as shown in Fig. 3.1
2. At first measure the power output at the input side.
3. To measure the power at the output of the waveguide. The input from where power needs to be delivered is connected to the waveguide.
4. Set minimum attenuation in the variable attenuator.
5. Measure the input power with the help of power meter.
6. Now connect the multi-hole directional coupler as shown in Fig. 3.1.
7. Connect power meter to the different output port while keeping all remaining ports connected to matched termination
8. Measure the power at each port with the help of power meter.
9. To measure the power at port-4, place the directional coupler in reverse and calculate the power.
10. Calculate the directivity, isolation and coupling and note down in the table.

OBSERVATION TABLE:

A. For Directional Coupler characteristics:

I/P at port 1	O/P at port 2	O/P at port 3	O/P at port 4	Insertion Loss	Isolation	Coupling factor	directivity

CALCULATIONS:

Calculate the coupling factor in dB

Compute insertion loss in dB

Compute the isolation in dB

Now Directivity = Isolation - Coupling

ERROR CALCULATION:

RESULTS & DISCUSSION:

PRECAUTIONS:

1. Use fan to keep the klystron temperature low.
2. Ensure tight connection of the apparatus.
3. Avoid tight connection to the threads.
4. Beam voltage should be minimum and repeller voltage should be normal before switch ON/OFF the Klystron PSU.

Viva Questions:

1. What is the primary purpose of a directional coupler?
2. How far apart are the two holes in a simple directional coupler?
3. In a directional coupler that is designed to sample the incident energy, what happens to the two portions of the wavefront when they arrive at the pickup probe?

EXPERIMENT - 4

OBJECTIVES:

Determine experimentally the propagation characteristics of Magic Tee operating at X-band using microwave test bench

Outcomes: Students are able to measure the isolation and coupling coefficient of the magic tee.

EQUIPMENTS:

Microwave Source (Klystron), Isolator, Frequency Meter, Variable Attenuator, Magic Tee, Waveguide Stand, Cables and Accessories, Power meter, Matched Termination.

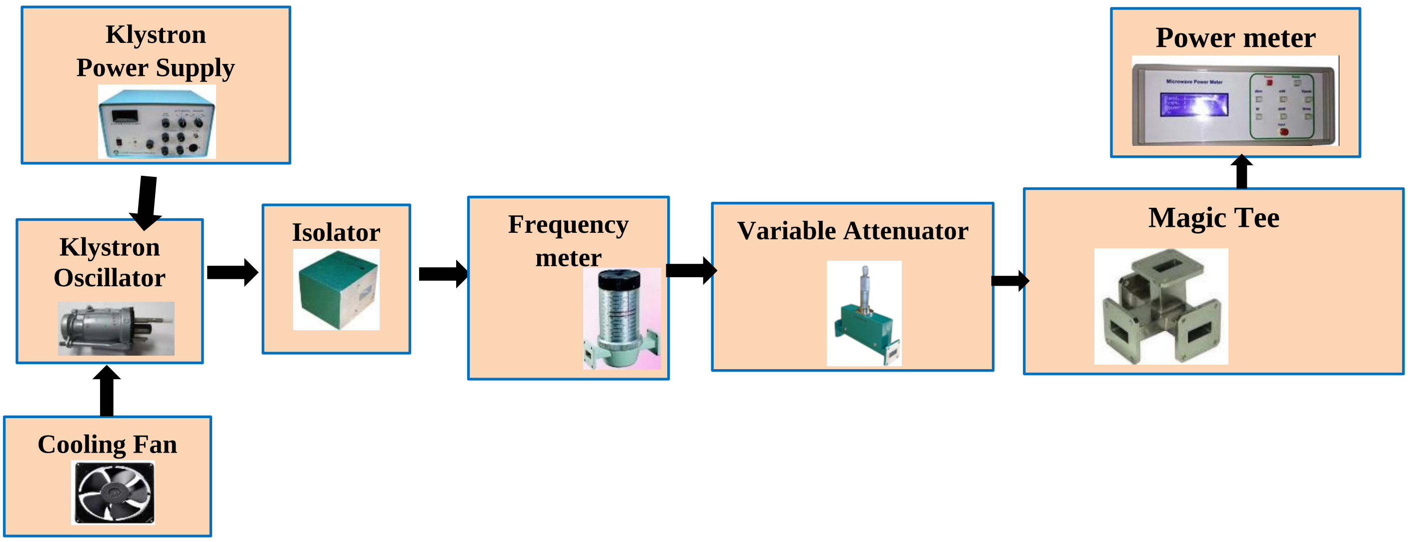


Fig.4.1 Experimental set-up to study the characteristics of Directional coupler and Magic Tee

THEORY:

B. *Magic Tee:*

The Magic Tee is a four port device & it is a combination of the E & H plane Tee. If the power is fed into arm 3 (H- arm), the electric field divides equally between arm 1 and 2 with same phase, and no electric field exists in arm 4. If the power is fed in arm 4 (E- arm), it divides equally into arm 1 and 2 but out of phase with no power to arm 3. Further, if the power is fed from arm 1 and 2, it is added in arm 3 (H-arm), and it is subtracted in E-arm, i.e., arm 4.

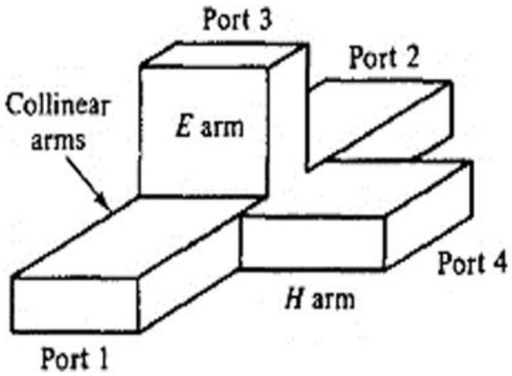


Fig.4.2 Schematic diagram of Magic Tee

The basic parameters to be measured for magic Tee are defined below:

Isolation: The isolation between E and H arms is defined as the ratio of the power supplied by the generator connected to the E-arm (port 4) to the power detected at H-arm (port3) when side arms 1 and 2 are terminated in matched load. Hence,

$$Isolation\ 3\text{-}4 = 10 \log_{10} (P4 / P3)$$

Coupling Coefficient: It is defined as $Cij = 10^{-\alpha/20}$, Where 'α' is attenuation / isolation in ***dB*** when ***'i'*** is input arm and '*j*' is output arm. Thus $\alpha = 10 \log Pi / Pj$, Where ***'Pi'*** is the power delivered to arm i^{th} and ***Pj*** is power detected at j^{th} arm.

In the case of magic tee, there are total 12 coupling coefficient. One for each of the arm as input and each of the other three arm as output. However, if we connect perfectly matched detector and generator then, ***Cij= Cji.***

PROCEDURE:

1. Set the equipment's as shown in Fig. 1
2. Measure the power at the output of the waveguide. The input from where power needs to be delivered is connected to the waveguide.
3. Calculate the input power with the help of power meter.
4. The output port of the magic tee from where power needs to be detected is connected to the power meter.
5. The remaining two ports of the magic tee are terminated with the matched termination.
6. Reverse one by one and connect one arm to the generator side and one arm to the detector side. The remaining port is connected by matched load.
7. Repeat this process for every port and measure the power from each port.
8. Determine the coupling coefficient from the equation mentioned above.
9. Determine the isolation between port 3 and 4 as $P_3 - P_4$ in db.

OBSERVATION TABLE:

For Magic Tee:

	O/P at port 1	O/P at port 2	O/P at port 3	O/P at port 4	Coupling coefficient	Isolation
I/P at port 1	-----------					
I/P at port 2		--------				
I/P at port 3			--------			
I/P at port 4				----------		

CALCULATIONS:

ERROR CALCULATION:

RESULTS & DISCUSSION:

PRECAUTIONS:

5. Use fan to keep the klystron temperature low.
6. Ensure tight connection of the apparatus.
7. Avoid tight connection to the threads.
8. Beam voltage should be minimum and repeller voltage should be normal before switch ON/OFF the Klystron PSU.

Viva Questions:

1. What are the two basic types of T junctions?
2. Why is the H-type T junction so named?
3. The magic-T is composed of what two basic types of T junctions?
4. What are the primary disadvantages of the magic-T?
5. What type of junctions is formed where the arms of a hybrid ring meet the main ring?

EXPERIMENT - 5

OBJECTIVE:

Determine the Standing Wave-Ratio and Reflection Coefficient.
Outcomes: Students are able to measure the low/high voltage standing wave ratio and also reflection coefficient by using the microwave test bench setup.

EQUIPMENTS:

Klystron power supply, Klystron oscillator, Isolator, Frequency meter, Variable attenuator, Slotted line, Tunable probe, VSWR meter/ CRO, Short circuit load, S-S tuner, Matched termination.

THEORY:

It is a ratio of maximum voltage to minimum voltage along a transmission line is called VSWR, as ratio of maximum to minimum current. SWR is measure of mismatch between load and line.

The electromagnetic field at any point of transmission line may be considered as the sum of two traveling waves: the 'Incident Wave' propagates from generator and the reflected wave propagates towards the generator. The reflected wave is set up by reflection of incident wave from a discontinuity on the line or from the load impedance. The magnitude and phase of reflected wave depends upon amplitude and phase of the reflecting impedance. The superposition of two traveling waves, gives rise to standing wave along with the line.

The maximum field strength is found where two waves are in phase and minimum where the line adds in opposite phase. The distance between two successive minimum (or maximum) is half the guide wavelength on the line. The ratio of electrical field strength of reflected and incident wave is called reflection between maximum and minimum field strength along the line.

Hence VSWR denoted by S is

$$S = \frac{E_{max}}{E_{min}}$$

$$= \frac{|E_I|+|E_R|}{|E_I|-|E_R|}$$

Where, E_I = incident voltage

E_R = reflected voltage

Reflection Coefficient, ρ is

$$\rho = \frac{E_R}{E_I} = \frac{Z-Z_0}{Z+Z_0}$$

Where, Z is the impedance at a point on line,

Zo is characteristic Impedance.

The above equation gives following equation

$$|\rho| = \frac{S-1}{S+1}$$

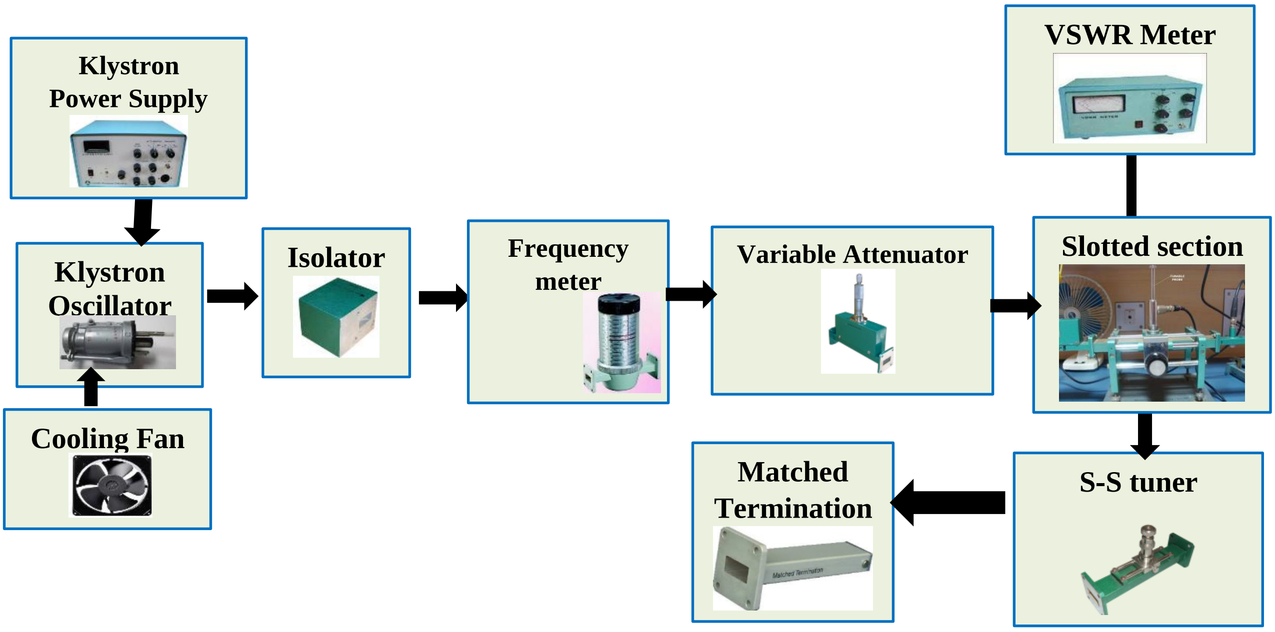


Fig.5.1.Experimental set-up for measuring voltage standing wave ratio and refection coefficient.

PROCEDURE:

1. Set up the equipments as shown in the above figure.
2. Set the variable attenuation at no attenuation position.
3. Keep the control knobs of klystron power supply as below:
   Meter switch - 'Off'
   Mod switch - AM
   Beam voltage knob - Fully anticlockwise
   Reflector voltage - Fully clockwise
   AM-Amplitude knob - Around fully clockwise
   AM-Frequency knob - Around mid-position
4. Keep the control knob of VSWR meter as below;
   Range dB - 40dB/50dB position
   Input switch - Crystal low impedance
   Meter switch - Normal
   Gain (Coarse & Fine) - Mid position
5. Switch 'ON' the klystron power supply, VSWR meter and cooling fan.
6. Set beam voltage at 290 V and repeller voltage at -60 V.
7. Tune the probe for maximum deflection in VSWR meter.
8. Move the probe along with slotted line, the reading will change.
9. For low SWR set the S.S tuner probe for no penetration position.
   a. Measurement of low and medium VSWR

i. Move the probe along with slotted line to maximum deflection in SWR meter in dB.
ii. Adjust the SWR Meter gain control knob or variable attenuator until the meter indicates 0.0 dB on normal mode SWR for 0.0 dB is 1.0 by keeping switches at SWR we can read it directly.
iii. Keep all the Control knobs as it is, move the probe to next minimum position. Keep SWR /dB switches at SWR position.
iv. Repeat the above step for change of S.S. Tuner probe path & record the corresponding SWR. Read SWR from display & record it.
v. If the SWR is greater than 10, follow the instructions that follow.

b. Measurement of High SWR (Double Minimum Method)

i. Set the depth of S.S tuner slightly more for maximum SWR.
ii. Move the probe along with slotted line until a minimum is indicated.
iii. Adjust the SWR meter gain control knob and variable attenuator to obtain a reading of 3 dB (or any other reference) at SWR meter.
iv. Move the probe to the left on slotted line until maximum reading is obtained i.e. 0 dB on scale. Note and record the probe position on slotted line. Let it be d1. (Or power should be increased by 3 dB).
v. Move the probe right along with slotted line until maximum reading is obtained on 0 dB scale. Let it be d2.
vi. Replace the S.S tuner and terminator by movable short.

Result and analysis:

vii. Measure the distance between two successive minima position or probe.

Twice this distance is waveguide length.

$$\lambda g = 2(d1-d2)$$

viii. Now calculate SWR using following equation

$$SWR = \lambda g/\Pi\ (d_1-d_2)$$

ix. For different SWR, calculate the refection coefficient.

$$|\rho| = \frac{S-1}{S+1}$$

OBSERVATIONS:

1. Measurement of low and medium VSWR:

VSWR =

2. Measurement of High SWR (Double Minimum Method):
Case-I:
d_1 = cm

$d_2 =$ cm

Case-II (short circuit load) :

$d_1 =$ cm

$d_2 =$ cm

CALCULATIONS:

1. Guided wavelength (λg):

$$\lambda g = 2(d1-d2) = ?$$

2. Voltage standing wave ratio:

$$VSWR = \lambda g/\Pi\,(d_1-d_2) = ?$$

3. Reflection Coefficient:

$$|\rho| = \frac{S-1}{S+1} = ?$$

RESULTS & DISCUSSION:

PRECAUTIONS:

1. The exhaust fan should be kept always ‘ON’.
2. The direction of isolator should be correct.
3. All the connection should be tightly fixed.
4. Repeller voltage must be applied before beam voltage.
5. The knob of slotted line should be moved very slowly.

Viva Questions:

1. What does standing wave ratio mean?
2. What is the difference between VSWR and ISWR?
3. What causes high VSWR?
4. Why VSWR is infinite in short condition?
5. What affects VSWR?

EXPERIMENT - 6

OBJECTIVE:

Determine the unknown impedance of the device at a spot frequency in X-band and also verify by using smith chart.

Outcomes: Students are able to measure the impedance of a device or unknown load by using the microwave test bench setup.

EQUIPMENTS:

Klystron power supply**,** Klystron oscillator, Isolator, Frequency meter, Variable attenuator, Slotted line, Tunable probe, VSWR meter/ CRO, Short circuit load, Unknown load.

THEORY:

The figure below shows the standing wave patterns for both a "short-circuit" and a load. Depending on the load impedance, the load minima may shift towards the generator or towards the load. The magnitude of the mistermination reflection coefficient is determined from the VSWR reading taken when the slotted line is misterminated. Knowing the magnitude and angle of the reflection coefficient, we can determine the normalized load impedance. Multiplying the normalized impedance by the characteristic impedance of the line gives you the impedance of the mistermination.

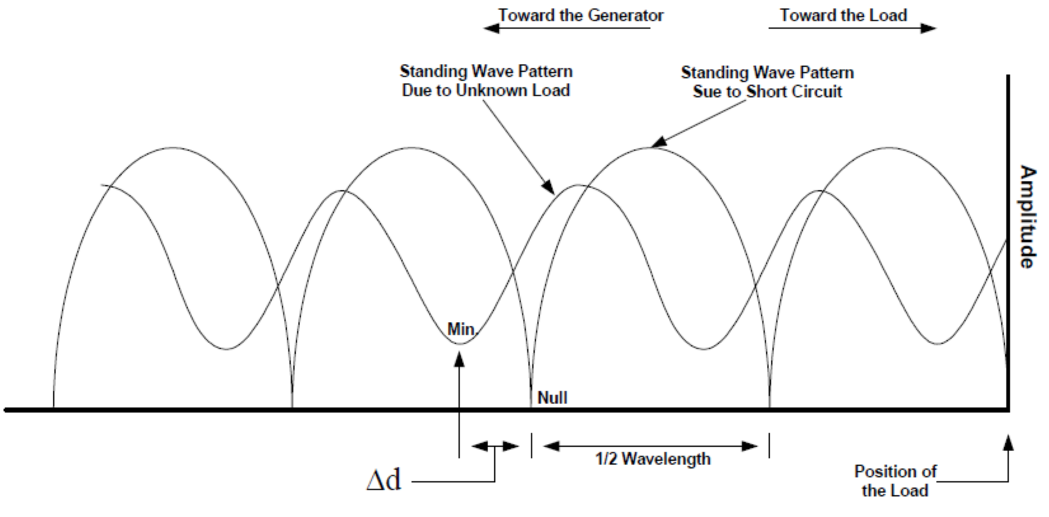


Fig 6.1. Standing wave at two different cases, (short circuit load, unknown load)

Compute normalized impedance using the formulas below:

$$ZL = Zo\cdot[1 - j(SWR)(\tan X)] / [SWR - j(\tan X) \qquad \ldots\ldots\ldots\ldots(6.1)$$

$$\text{Where: } X = [(180°)(+\Delta d)] / (\lambda g/2) \qquad \ldots\ldots\ldots\ldots(6.2)$$

Δd is the displacement distance of the load minimum a short circuit Null in cm.
Δd is positive when the Null is closer to the load than the Minimum (as above)
Δd is negative when the Null is further from the load than the Minimum
λg/2 is one-half of line wavelength (distance between Nulls or Minima)

By microwave power supply using klystron oscillator a wave of unknown frequency can be generated through the microwave bench setup. This unknown frequency can be calculated by frequency meter equipped with the microwave bench setup. To do this, make sure that no wave should be passed through the slotted waveguide. At this position VSWR meter will show highest reading.

Microwave bench setup consists of isolator, frequency meter, attenuator and detector respectively in sequence. Isolator allows the waves to propagate into one direction by blocking the reflected waves. Frequency meter is used to block the amplitude of propagating wave so that it can be measured by probe detector in VSWR meter.

VSWR meter is used to measure the maxima and minima points of electric field in waveguide. The guided wavelength of propagating wave is measured by calculating the distance between two successive maxima or two successive minima points. The guided wavelength can be given by-

$$\frac{\lambda_g}{2} = D_{null1} - D_{null2} \qquad \ldots\ldots\ldots\ldots\ldots(6.3)$$

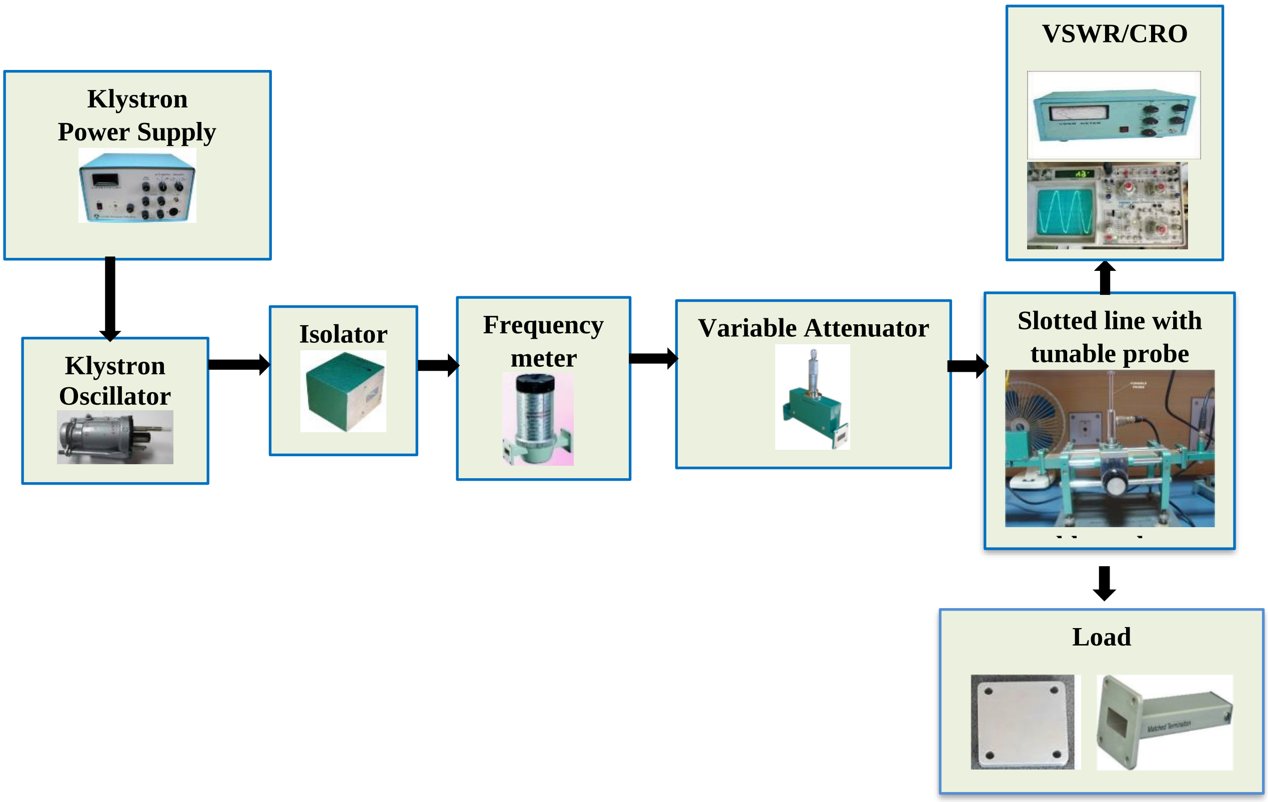


Fig 6.2 Experimental set-up to determine the unknown impedance at a spot frequency.

PROCEDURE:

10. Set up the equipments as shown in the above figure.
11. Set the variable attenuation at no attenuation position.
12. Keep the control knobs of klystron power supply as below:

    Meter switch - 'Off'
    Mod switch - AM

Beam voltage knob - Fully anticlockwise
Reflector voltage - Fully clockwise
AM-Amplitude knob - Around fully clockwise
AM-Frequency knob - Around mid-position

13. Keep the control knob of VSWR meter as below;
    Range dB - 40dB/50dB position
    Input switch - Crystal low impedance
    Meter switch - Normal
    Gain (Coarse & Fine) - Mid position
14. Switch 'ON' the klystron power supply, VSWR meter and cooling fan.
15. Set beam voltage at 290 V and repeller voltage at -60 V.
16. Tune the probe for maximum deflection in VSWR meter.
17. Tune the frequency meter knob to get dip in the VSWR scale and note down the frequency (*f*) directly from the frequency meter. Now you can detune the meter from dip position.
18. Move probe along with the slotted line, the deflection in VSWR meter will vary. Move the probe to a minimum deflection position, to get accurate reading; it is necessary to increase the VSWR meter range dB switch to higher position. Note and record the probe position.
19. Move the probe to next minima position and record the probe position again.
20. Calculate the guided wavelength (λ_g) as twice the distance between two successive minimum positions obtained as above.
21. Calculate the cutoff wavelength (λ_c) by using formula;

$$\frac{1}{\lambda^2} = \frac{1}{{\lambda_c}^2} + \frac{1}{{\lambda_g}^2} \text{ (where, } \lambda = \frac{free\ space\ velocity\ (c)}{f}\text{)} \quad \text{……….(6.4)}$$

22. Calculate the cutoff frequency (f_c).
23. Replace the short circuit load by unknown load.
24. Record the position of minima and measure the VSWR from VSWR meter.
25. Find the difference of minima positions of short circuit load and unknown load.

    Let say, P_1 = Position of minima by using short circuit load
    P_2 = Position of minima by using unknown load
    $Q = P_1 - P_2$

26. Calculate the characteristics impedance (Z_0) using the formula;

$$Z_0 = \frac{120\,\pi}{\sqrt{1-\left(\frac{f_c}{f}\right)^2}} \quad \text{…………….(6.5)}$$

27. Calculation of unknown load impedance (Z_L) by using formula

$$Z_L = Z_0 \left[\frac{1-j\,(\text{SWR})\tan(X)}{(\text{SWR})-j\tan(X)}\right], \quad \text{..…………(6.6)}$$

Where, $X = \frac{180^{\circ}\,(Q)}{\lambda_g/2}$ ……………(6.7)

28. Calculation of unknown load impedance using smith chart

1. Calculate Q/λ_g.
2. Take a smith chart taking '1' as a center and draw a circle of radius equal to the VSWR value (constant VSWR circle).
3. Make a point on circumference of chart towards load side (if 'Q' is positive) or towards generator side (if 'Q' is negative) at a distance equal to " Q/λ_g ".
4. Join the center with this point.
5. Find the point where it cut the drawn circle. The coordination of this point will show the normalized impedance of load.
6. Multiply normalized load impedance with the calculated characteristics impedance to obtain the value of unknown load impedance.

OBSERVATIONS:

1. Resonant frequency from frequency meter:

   f = GHz

2. For short circuit termination:

   Position of first minima = d_1 = cm = P_1
   Position of second minima = d_2 = cm

3. For unknown load termination:

   Position of first minima = P_2 = cm
   Standing wave ratio (SWR) =

CALCULATIONS:

1. Free space wavelength = $\lambda = \frac{c}{f}$ = ?
2. Distance between two successive minima = d_1-d_2 = $\frac{\lambda_g}{2}$

   $$\lambda_g = ?$$

3. Relation between free space wavelength, cutoff wavelength and guided wavelength;

$$\frac{1}{\lambda^2} = \frac{1}{{\lambda_c}^2} + \frac{1}{{\lambda_g}^2}$$

$$\lambda_c = ?$$

4. Cutoff frequency = f_c = ?
5. Q = difference of minima positions of short circuit load and unknown load = $P_1 - P_2$ = ?
6. Characteristics impedance = $Z_0 = \frac{120\,\pi}{\sqrt{1-\left(\frac{fc}{f}\right)^2}} = ?$

$$X = \frac{180^\circ\,(Q)}{\lambda_g/_2} = ?$$

7. Unknown load impedance = $Z_L = Z_0 \left[\frac{1-j\,(\text{SWR})\tan(X)}{(\text{SWR})-j\tan(X)}\right] = ?$
8. Unknown load impedance using smith chart = Z_L = ?
9. Error percentage = ?

RESULTS & DISCUSSION:

PRECAUTIONS:

6. The exhaust fan should be kept always ‘ON’.
7. The direction of isolator should be correct.
8. All the connection should be tightly fixed.
9. Repeller voltage must be applied before beam voltage.
10. The knob of slotted line should be moved very slowly.

Viva Questions:

1. For what purpose is a slotted line used?
2. Why do we use Smith chart?
3. What is normalized impedance?
4. Why is impedance matching needed?
5. What do the arcs on a Smith chart represent?

EXPERIMENT-7

OBJECTIVE:

4. Study rectangular waveguide
5. Find cut-off wavelength equation for rectangular waveguide.
6. Determine experimentally the broader dimension of rectangular waveguide using microwave test bench at X-band of microwave frequency.

EQUIPMENTS:

Microwave test bench, Matched and short terminations, CRO/VSWR meter.

THEORY:

A waveguide is a structure that guides waves, such as electromagnetic waves or sound, with minimal loss of energy by restricting expansion to one dimension or two. In a waveguide that can support more than one propagation mode, the mode that propagates with the minimum degradation, i.e., the mode with the lowest cutoff frequency is called as dominant mode. Below the cut-off frequency, total reflection will happen in the waveguide. So, operating frequency must be above cut off frequency of dominant mode and below cut off frequency of next higher order mode. Designations for the dominant mode are TE_{10} for rectangular waveguides and TE_{11} for circular waveguides.

Cut-off wavelength equation for rectangular waveguide is given below:

$$\lambda_c = \frac{2}{\sqrt{\left(\frac{m}{a}\right)^2 + \left(\frac{n}{b}\right)^2}} \qquad \text{……………..(7.1)}$$

Where,

m = number of half-wave along broad-side dimension,

n = number of half-wave along the shorter side,

For dominant mode TE_{10} case, m = 1 and n = 0.

Hence, λ_c = 2(broad dimension) = 2a

Formula Used: $$\frac{1}{\lambda_0{}^2} = \frac{1}{\lambda_c{}^2} + \frac{1}{\lambda_g{}^2} \qquad \text{……………….(7.2)}$$

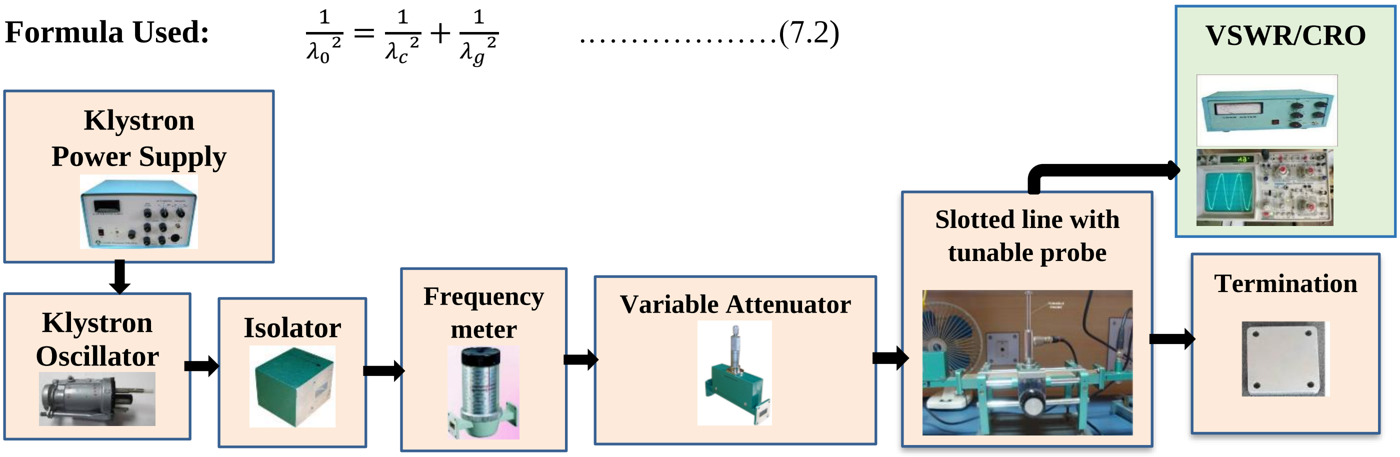


Fig.7.1. Experimental set-up to calculate broader dimension of waveguide

PROCEDURE:

1. Make the connections as required according to the setup given.

2. Set the variable attenuator at maximum position.
3. Keep the control knobs of Klystron power supply as below:
   Meter switch - 'Off'
   Mod-switch - AM
   Beam voltage knob - Fully anticlockwise
   Reflector voltage - Fully clockwise
   AM-Amplitude knob - Around fully clockwise
   AM-Frequency knob - Around mid-Position
4. If you are using VSWR meter in place of CRO, keep the control knobs of VSWR meter below:
   Range dB - 50 dB position
   Input switch - Crystal low impedance
   Meter switch - Normal position
   Gain (coarse & fine) - Mid Position
5. Switch 'ON' the Klystron power supply, VSWR meter/CRO and cooling fan.
6. Rotate the meter switch of power supply to beam voltage position and set beam voltage at 300 V (you should not make beam voltage higher than 300V) with help of beam voltage knob (you should not touch this knob till the end of the experiment).
7. From here, the procedure can be discussed as two cases: one is using CRO and another one using VSWR meter.

A. Using CRO:

1. Observe a waveform in CRO.
2. Tune the frequency meter so that the amplitude of the wave in CRO slightly reduces, note down that frequency in frequency meter.
3. Move probe along the slotted line and observe the change in amplitude of the wave in CRO from minimum to maximum or maximum to minimum.
4. Calculate the distance between two minima's or two maxima's
5. Calculate guided wavelength using this distance and finally find out the cutoff wavelength and then broader dimension of waveguide.

B. Using VSWR meter:

1. Adjust the reflector voltage to get some deflection in VSWR meter.
2. Maximize the deflection with AM amplitude and frequency control knob of power supply.
3. Tune the reflector voltage knob for maximum deflection.
4. Tune the probe for maximum deflection in VSWR meter.
5. Tune the frequency meter knob to get a 'dip' on the VSWR scale and note down the frequency directly from the frequency meter.
6. Move probe along with the slotted line, the deflection in VSWR meter will vary. Move the probe to a minimum deflection position, to get accurate reading; it is necessary to increase the VSWR meter range dB switch to higher position. Note and record the probe position.
7. Move the probe to next minimum position and record the probe position again.
8. Calculate the guided wavelength as twice the distance between two successive minimum positions obtained as above.
9. Finally, calculate the cutoff wave length and broader dimension of the waveguide.

OBSERVATIONS:

1. Resonant frequency from frequency meter;

   f = GHz

2. For short circuit termination;

   Position of first minima = d_1 = cm
   Position of second minima = d_2 = cm
   Position of third minima = d_3 = cm
   Position of fourth minima = d_4 = cm

CALCULATIONS:

1. Take average = A = $(d_2-d_1) + (d_4-d_3) / 2$
2. Now λ_g can be calculated as 2*A
3. Calculate λ_o from f.
4. From λ_g and λ_o, calculate λ_c.
5. From λ_c, calculate the broader dimension of waveguide.

RESULTS & DISCUSSION:

PRECAUTIONS:

1. The exhaust fan should be kept always ‘ON’.
2. The direction of isolator should be correct.
3. All the connection should be tightly fixed.
4. Repeller voltage must be applied before beam voltage.
5. The knob of slotted line should be moved very slowly.

Viva Questions:

1.What is dominant mode of rectangular waveguide.
2.What is cut-off frequency.
3.What are the mode exist in rectangular waveguide.

EXPERIMENT - 8

OBJECTIVE:

1. Study the microstrip filter

2. Study the Frequency Response of various Microstrip filter

3. Analyze the response in C- band using SICO microstrip trainer kit.

EQUIPMENTS:

Advanced Microstrip Trainer Kit, Power Supply, C Band Solid State Source, Test Jig, Detector, Active Filter, CRO, Microstrip filter (Low pass, Band pass, Band stop filter), Co-axial cable, Vector Network Analyser

THEORY:

Microstrip: It is a type of electrical transmission line which is fabricated using printed circuit board technology and it is used to convey microwave frequency signal. It consist of conducting strips separated form a ground plane by a dielectric known as substrate. Microwave component such as antenna coupler, filter and power divider can be formed from microstrip. It has advantages over waveguide because of light weight and less expensive. Microstrip transmission shown in Fig.5.1 consists of a dielectric substrate with bottom surface completely covered with metallization and serving as a ground plane. The top surface consist of metallization of width ***'w'***. The design of microstrip basically involves choosing the substrate material, the thickness and calculating the width ***'w'*** for given impedance. The dominant mode in the microstrip is the transverse electromagnetic type of mode usually known as quasi-TEM mode.

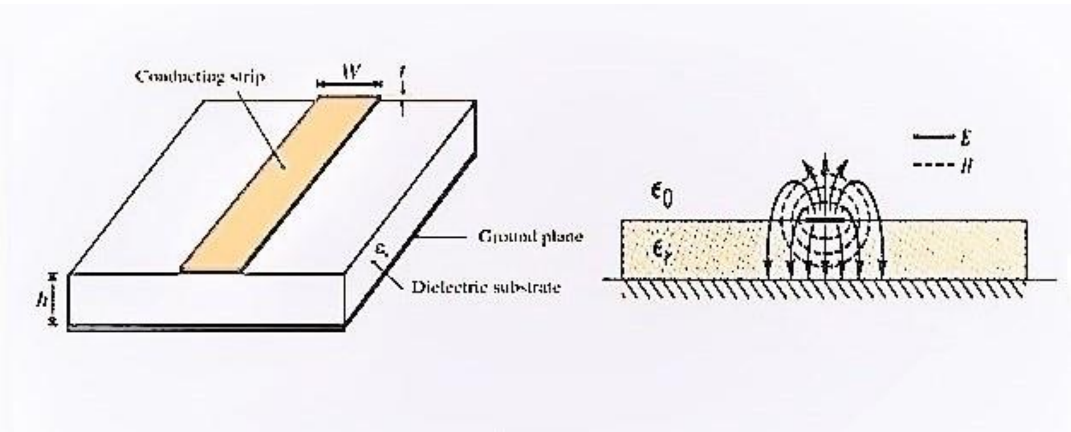


Fig.8.1 Microstrip Line Geometry and Electric (E) and magnetic (H) field lines in microstrip

Fig.8.1 shows the electric field and magnetic field lines for the dominant mode in the microstrip. The strip and the ground plane in Fig.8.1 from a transmission line that guides electromagnetic energy in the quasi-TEM mode. The substrate thickness is usually a very small fraction of a wavelength. As long as the physical dimensions and the dielectric constant remains constant, virtually no radiation occurs.

Microstrip filter: A filter is a two port network used to control the frequency response at a certain point in a system by providing transmission within the pass band of the filter and attenuation in the stop band of the filter. Various type of filter can be design using microstrip line with different construction features. Three different filter's Fig.8.2 and their scattering parameter ***(S11 & S21)*** responses are given below. It is important to take care of various scattering parameter (***S11 and S21***) for the microstrip filters.

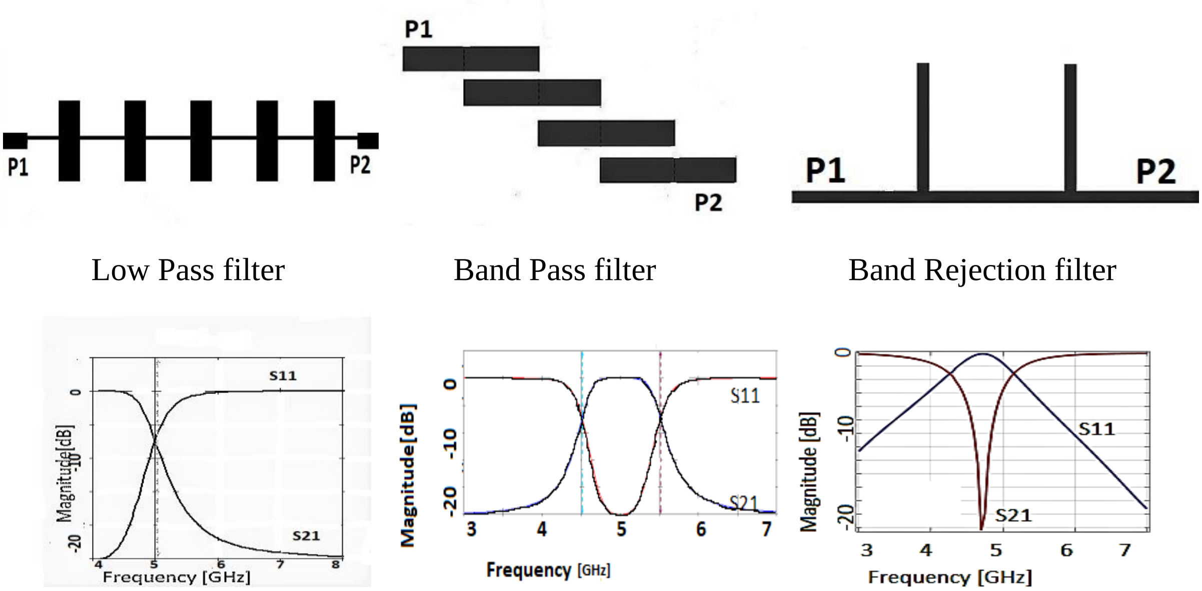


Fig.8.2 Microstrip filters and their frequency responses

The low-pass filter has a gain response with a frequency range from zero frequency (DC) to $\boldsymbol{\omega_c}$. Any input that has a frequency below the cut-off frequency $\boldsymbol{\omega_c}$. gets a pass, and anything above it gets attenuated or rejected. The gain approaches zero as frequency increases to infinity.

The input signal of the filter shown in Fig.5.3 here has equal amplitudes at frequencies $\boldsymbol{\omega_1}$ and $\boldsymbol{\omega_2}$ after passing through the low-pass filter, the output amplitude at $\boldsymbol{\omega_1}$is unaffected because it's below the cut-off frequency $\boldsymbol{\omega_c}$. However, at $\boldsymbol{\omega_2}$, the signal amplitude is significantly decreased because it's above $\boldsymbol{\omega_c}$.

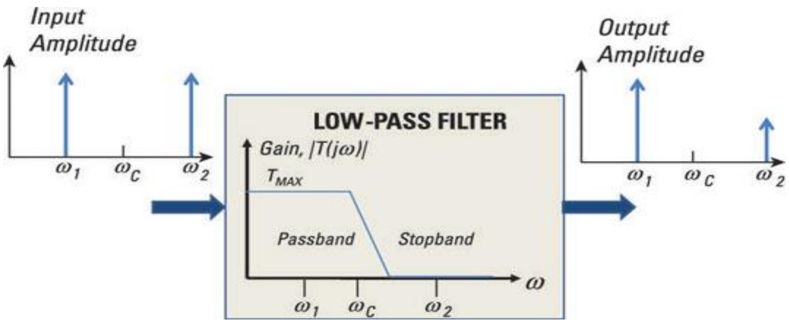


Fig.8.3 Low pass filter frequency response

The band-pass filter as shown in Fig.5.4 has a gain response with a frequency range from $\boldsymbol{\omega_{c1}}$ to $\boldsymbol{\omega_{c2}}$. Any input that has frequencies between $\boldsymbol{\omega_{c1}}$ and $\boldsymbol{\omega_{c2}}$ gets a pass, and anything outside this range gets attenuated or rejected.

The input signal of the filter shown here has equal amplitude at frequencies $\boldsymbol{\omega_1}$, $\boldsymbol{\omega_2}$ and $\boldsymbol{\omega_3}$. After passing through the band-pass filter, the output amplitudes at $\boldsymbol{\omega_1}$and $\boldsymbol{\omega_3}$ are significantly decreased because they fall outside the desired frequency range, while the frequency at $\boldsymbol{\omega_2}$ is within the desired range, so its signal amplitude passes through unaffected.

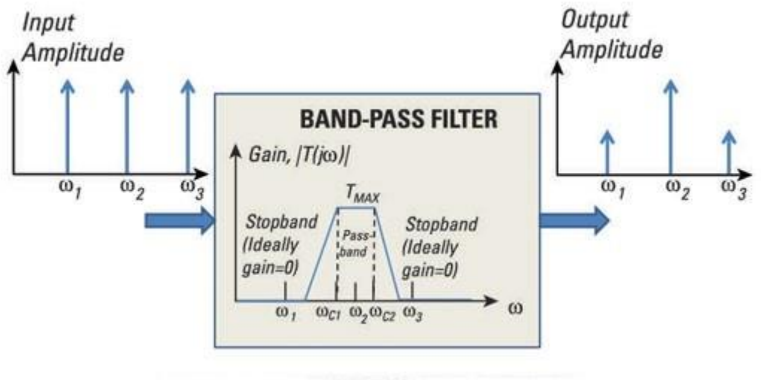


Fig.8.4 Band pass filter frequency response

The band-reject filter, or band stop filter, has a gain response with a frequency range from zero to $\boldsymbol{\omega_{C1}}$ and from $\boldsymbol{\omega_{C2}}$ to infinity. Any input that has frequencies between $\boldsymbol{\omega_{C1}}$ and $\boldsymbol{\omega_{C2}}$ gets significantly attenuated, and anything outside this range gets a pass.

The input signal of the filter shown here has equal amplitude at frequencies $\boldsymbol{\omega_1, \omega_2}$, and $\boldsymbol{\omega_3.}$ After passing through the band-reject filter, the output amplitude at $\boldsymbol{\omega_1}$ and $\boldsymbol{\omega_3}$is unaffected because those frequencies fall outside the range of $\boldsymbol{\omega_{C1}}$ to $\boldsymbol{\omega_{C2}}$. But at $\boldsymbol{\omega_2,}$ the signal amplitude gets attenuated because it falls within this range.

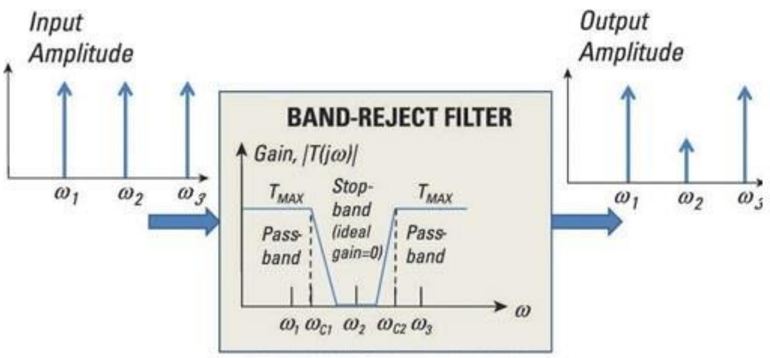
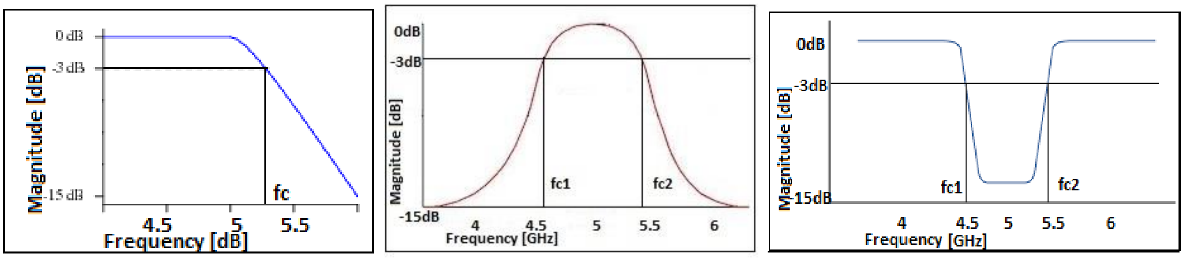


Fig.8.5 Band stop filter frequency response

The cut-off frequency is defined as the frequency where the amplitude of frequency response is $1/\sqrt{2}$ times the maximum amplitude (i.e.$-3db$, half power point). Frequency response graph of all three different filters are plotted in Fig.8.6 between magnitude ($20\log{(V_0/V_{in})}$ or $10\log{(P_0/P_{in})}$) and frequency and their cut-off frequencies are shown. The points intersecting the $-3dB$ line with the frequency response curve gives the cut off frequencies of the respective filter.



(a) Low pass filter (b) Band pass filter (c) Stop band filter

Fig.8.6 Frequency response for calculation of cut-off frequency and

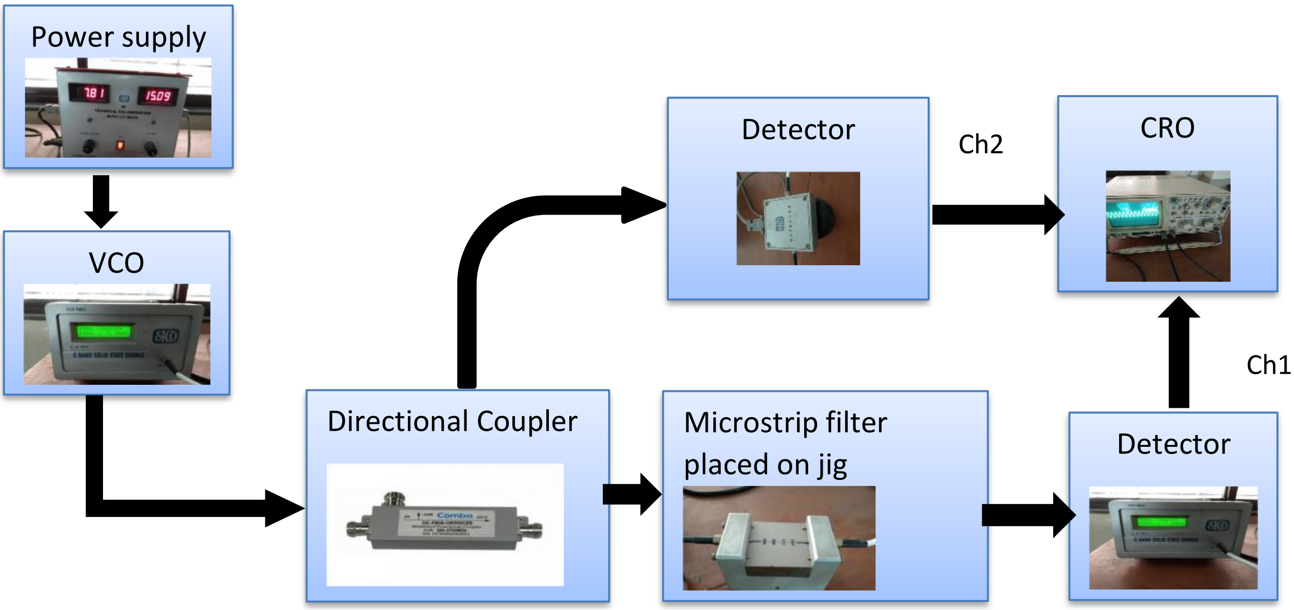
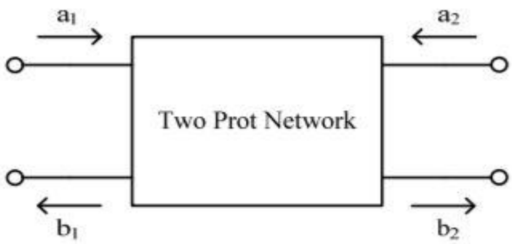


Fig.8.7 Experimental set-up based on VCO

Fig.8.8 Measurement setup based on Network analyzer

Scattering parameter: -

[S]- Parameter relates the incident wave and reflected wave at different ports.



$$S = \frac{V^-}{V^+} = \frac{V^- \big/ \sqrt{Z_{on}}}{V^+ \big/ \sqrt{Z_{on}}} = \frac{b_n}{a_n} \qquad \begin{bmatrix} b_1 \\ b_2 \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix} \cdot \begin{bmatrix} a_1 \\ a_2 \end{bmatrix}$$

$$S_{11} = \left.\frac{b_1}{a_1}\right|_{a_2=0} \qquad S_{12} = \left.\frac{b_1}{a_2}\right|_{a_1=0}$$

$$S_{21} = \left.\frac{b_2}{a_1}\right|_{a_2=0} \qquad S_{22} = \left.\frac{b_2}{a_2}\right|_{a_1=0}$$

S_{11}= Input Reflection co-efficient
S_{12}= Reverse transmission co-efficient
S_{21}= Forward transmission co-efficient
S_{22}= Output reflection co-efficient

If the network is reciprocal

$$S_{12} = S_{21}$$

If the network is symmetric

$$S_{11} = S_{22}$$

These parameter depends on frequency as well as physical dimension of the conductor strip by suitable choice of dimension, various filters can be designed as shown in figures.

PROCEDURE:

A. ***Using the VCO***

1. Set up the system as show in figure 3.
2. Measure the input power fed to the microstrip filter circuit at a selected VCO frequency.
3. Measure the reflected the power by noting the reading of the detector connected to the directional coupler and the forward power by noting the reading of the detector connected to the microstrip filter circuit at the same frequency setting of the VCO.
4. Repeat the above two steps after each 100MHz in C Band by tuning the VCO.
5. Plot the return loss and transmission loss of the microstrip filter circuit.
6. From the plot, determine the cut off frequency of the microstrip filter circuit and minimum and maximum return loss and insertion loss.
7. Set the VCO frequency +500MHz more than the cut off frequency and measure transmission loss.

B. Using the Network Analyzer

1. Pick up the microstrip filter circuit board from the AMTK and mount the substrate in the test jig.
2. From the front panel of the Network Analyzer, select the lower, upper frequencies and number of frequency points.
3. Calibrate the Network Analyzer.
   - i) Press Tools→ Calibration kit→Load→Select kit→Press Open→Apply→Exit
   - ii) Click Calibration
   - iii) Select two port calibration
   - iv) Select open (port 1)
   - v) Insert open end of the calibration tool into port 1.
   - vi) After completion press finish
   - vii) Select short(port 1)
   - viii) Insert short end of the calibration tool into port 1.
   - ix) After completion press finish
   - x) Select load(port 1)
   - xi) Insert load end of the calibration tool into port 1.
   - xii) After completion press finish
   - xiii) Repeat the steps from ‘iv’ to ‘xii’ for port 2.
   - xiv) Select through
   - xv) Connect port 1 with port 2 through cable provided in the VNA kit.
   - xvi) After completion, press finish
4. Connect the test jig with the circuit between the two ports of the Network Analyzer.
5. Select dual channel option for the display.
6. Press the channel selector 1. On the parameter panel press the button S11.
7. Press the channel selector 2. On the parameter panel press the button S21.
8. Set reference value in both the channels to 0.0 dB and scale to 10.0 dB/div.
9. Using a marker, determine the cut-off frequencies for microstrip filters.
10. Determine the minimum and maximum return loss in pass band.
11. Determine minimum and maximum transmission loss in the pass band.
12. Using a marker, determine the attenuation at 500 MHz away from the cut-off frequencies of the microstrip filter.

OBESEVATION:

Measurement Table

SL NO:	Frequency (GHz)	Through CRO			S11(dB)	S21(dB)	Through VNA	
		a1(V)	b1(V)	b2(V)			S11(dB)	S21(dB)

CALCULATION (IF ANY):

RESULTS & DISCUSSION:

PRECAUTION:

1. All the connection should be tightly fixed.
2. Repeller voltage must be applied before beam voltage.
3. The knob of slotted line should be moved very slowly.

Viva Questions:

1. What is S- Parameter.
2. Describe the frequency response of various filter.
3. Calculate cut off frequency of various filter.

EXPERIMENT - 9

OBJECTIVE: To conduct the experiment to obtain:

1. The far field distance between the transmitting and receiving antennas.

2. The radiation pattern of Horn antenna in X-band using microwave test bench.

EQUIPMENTS:

Signal generator, Two Pyramidal horn antennas, Spectrum analyzer or power meter, Cables, connectors and Accessories, Antenna tripod stands.

EXPERIMENT SETUP:

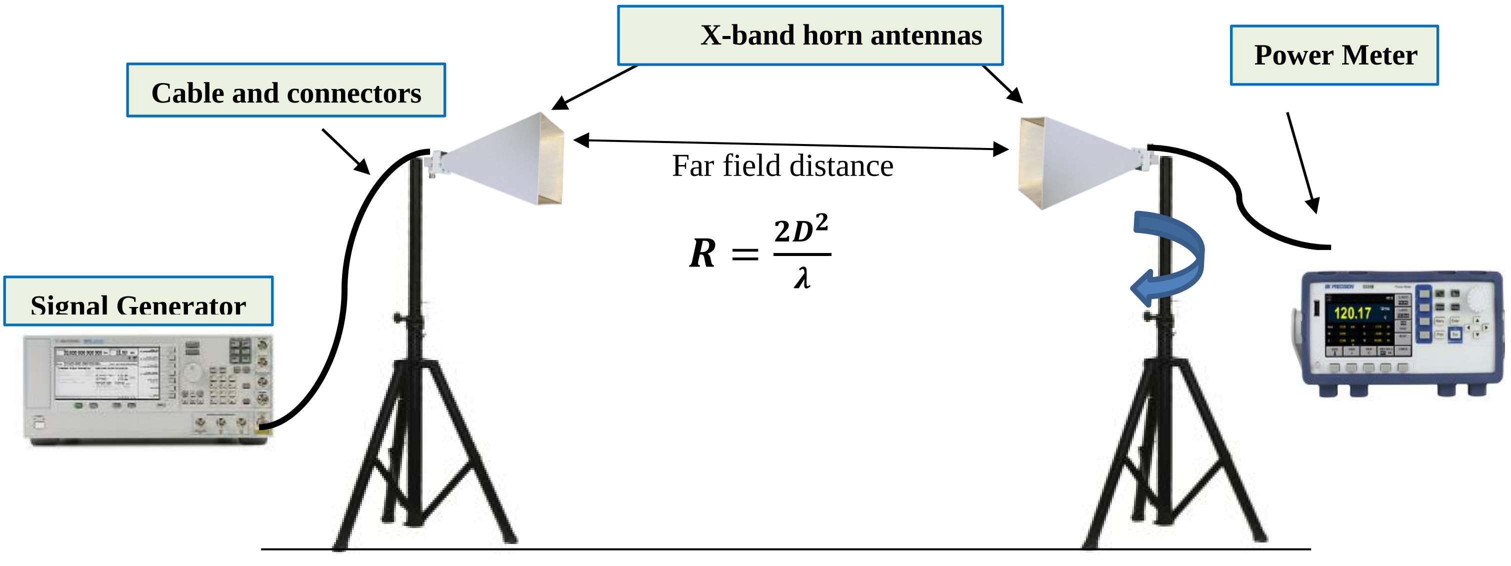


Fig. 9.1. Experimental set-up to measure the radiation pattern of an antenna.

THEORY:

The radiation pattern is a graphical representation of the strength of radiation of an antenna as a function of direction. The strength of radiation is usually measured in terms of field strength although sometimes radiation intensity (power radiated per unit solid angle) is also used. For the purpose of radiation pattern, one considers the given antenna to be located at the origin of a spherical polar coordinates systems (r,θ,φ) and the variation in the field strength at different points on an imaginary concentric spherical surface of radius r is noted. For sufficiently larger r, the field variation or the pattern is independent or r and also the fields are tangential to the hypothetical spherical surface. In general, separate patterns are plotted for θ and φ polarization.

Usually the radiation pattern is shown in principal planes of interest. Further, for linearly polarized antennas, patterns may be plotted in E – plane or H – plane E- plane is defined as the plane passing through the antenna in the direction of beam maximum and parallel to the far field E – vector. One defines the H – plane similarly. It is quite common to plot the pattern by normalizing the field values with respect to the field strength in the direction of maximum radiation.

The radiation pattern of typical microwave antennas consists of a main lobe and a few minor or side-lobes. Beam-width of an antenna is defined as the angular separation between 3 dB points with respect to the maximum field strength. Side lobes represent a loss and leakage of information in the transmit mode. In the receive mode, side lobes may cause an uncertainty in determining the angle of arrival of a signal. However, side lobes are very sensitive to the surroundings in which the radiation pattern is measured.

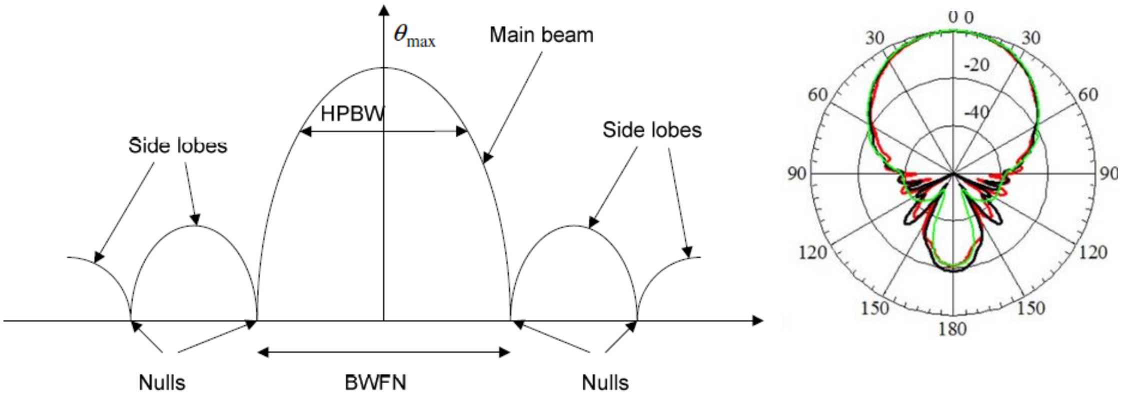


Fig. 9.2. Cartesian and Polar plot of radiation pattern

A receiving antenna is considered to be in the far-field of the test antenna if the wavefronts across it is practically plane. Most measurements are carried out in the far field region.

PROCEDURE:

1. Set the component and equipment's as shown in Fig.9.1
2. Set the amplitude and frequency in the signal generator, and keep the frequency fix throughout the measurement of radiation pattern.
3. Set the RF switch as ON.
4. In the first step, same type (identical) of horn antennas are used as transmitter and receiver antennas, keeping the axis of both the antenna in same axis line (Co-arrangement).
5. Place both the antennas (Test antenna and reference antenna) at far field distance.
6. Align the antennas at 0° direction, now note down the value of power received in power meter and write down in observation table 1.
7. Initially, keep the test antenna at E-Plane and rotate the test antenna from 0° to 90° with the step size of 5° and then 0° to -90° and note down the respective values in the observation table.
8. Change the aperture of test horn antenna 90° to measure the cross component and repeat the above steps.
9. Repeat the step 7 and 8 by keeping the in H-plane.

Note: For cable losses calculations, directly connect the cables used between signal generator and Power meter

OBSERVATION:

Table 1. For Radiation Pattern Measurement

Angle (degree)	**Power received (dBm)**		**Angle (degree)**	**Power received (dBm)**	
	E-Plane			**H-Plane**	
	Co-Polar	Cross-polar		Co-Polar	Cross-polar
0			0		
5			5		
10			10		
15			15		
20			20		
25			25		
30			30		
35			35		
40			40		
45			45		
50			50		
55			55		
60			60		
65			65		
70			70		
75			75		
80			80		
85			85		
90			90		
-5			-5		
-10			-10		
-15			-15		
-20			-20		
-25			-25		
-30			-30		

-35			-35		
-40			-40		
-45			-45		
-50			-50		
-55			-55		
-60			-60		
-65			-65		
-70			-70		
-75			-75		
-80			-80		
-85			-85		
-90			-90		

CALCULATION:

Calculate the normalized power and plot the radiation pattern in linear scale and polar form.

RESULTS & DISCUSSION:

PRECAUTIONS:

1. Check the far distance properly
2. Make the connections properly.
3. Avoid any kind of obstacles between the test antenna and reference antenna.

Viva Questions:

1. Define radiation pattern of the antenna.
2. What are the Antenna field Zones?
3. What are the different types of horn antennas?

OBJECTIVE: To conduct the experiment to obtain:

1. The far field distance between the transmitting and receiving antennas.

2. The gain of Horn antenna in X-band using microwave test bench.

EQUIPMENTS:

EXPERIMENT - 10

OBJECTIVE: To conduct the experiment to obtain:

1. The far field distance between the transmitting and receiving antennas.

2. The gain of Horn antenna in X-band using microwave test bench.

EQUIPMENTS:

Signal generator, Two Pyramidal horn antennas, Spectrum analyzer or power meter, Cables, connectors and Accessories, Antenna tripod stands

EXPERIMENT SETUP:

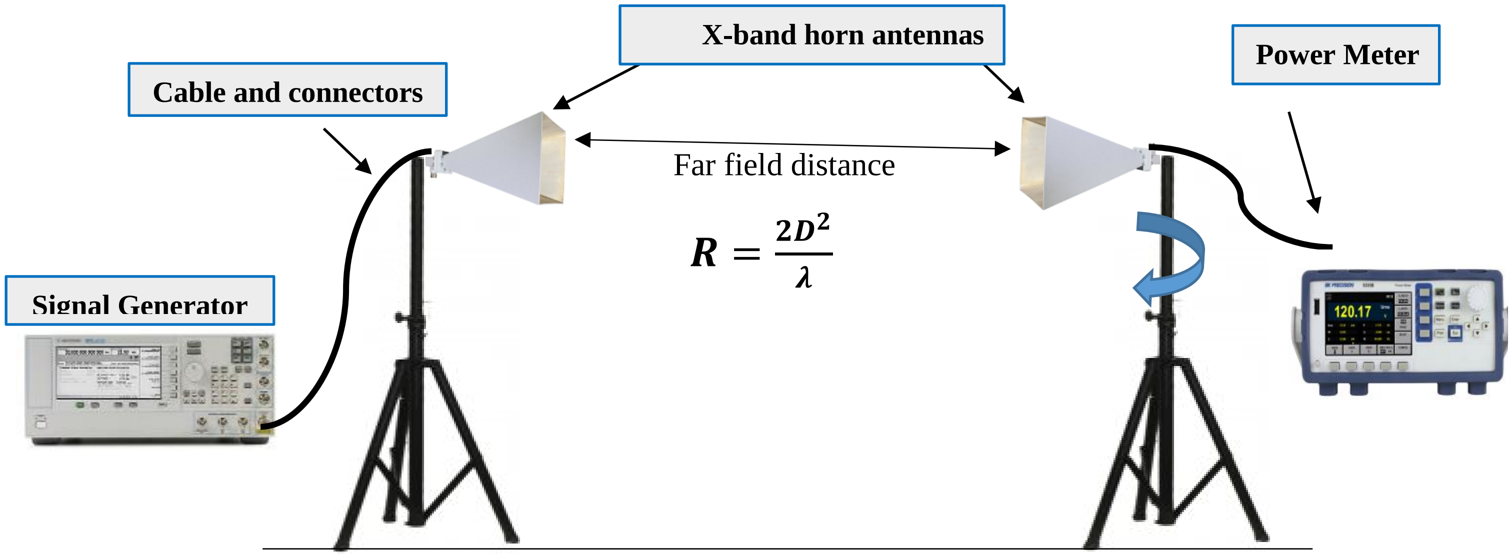


Fig. 10.1. Experimental set-up to measure the gain of an antenna.

THEORY:

The term Antenna Gain describes how much power is transmitted in the direction of peak radiation to that of an isotropic source. A transmitting antenna with a gain of 3 dB means that the power received far from the antenna will be 3 dB higher (twice as much) than what would be received from a lossless isotropic antenna with the same input power.

We can measure the gain of given using the Friis Transmission Equation given below

$$P_r = P_t G_t G_r \left(\frac{\lambda}{4\Pi R}\right)^2 \qquad \text{…………… (10.1)}$$

P_r = Power received by test antenna.

P_t = Power transmitted by reference antenna.

G_r = Gain profile of test antenna.

G_t = Gain profile of reference antenna.

λ = operating wavelength.

R = antenna separation

PROCEDURE:

1. Set the component and equipment's as shown in Fig.10.1
2. Set the amplitude and frequency in the signal generator, and change the frequency throughout the measurement of gain.
3. Set the RF switch as ON.
4. Same type (identical) of horn antennas are used as transmitter and receiver antennas, keeping the axis of both the antenna in same axis line (Co-arrangement).
5. Place both the antennas (Test antenna and reference antenna) at far field distance.
6. Align the antennas at 0° direction, now note down the value of power received in power meter and write down in observation Table 1.
7. Unlike radiation pattern, keep the test antenna at 0° and change the frequency in signal generator and note down the power detected in Power meter at different frequency.
8. Calculate the gain of the antenna using Friis equation.

Note: For cable losses calculations, directly connect the cables used between signal generator and Power meter

OBSERVATION:

Table I

Frequency (GHz)	Transmitted Power (fixed)	Received power	Operating wavelength	Cable Loss

CALCULATION:

Use Friis transmission formula to calculate the gain of test antenna and also include cable loss.

RESULTS & DISCUSSION:

PRECAUTIONS:

1. Check the far distance properly
2. Make the connections properly.
3. Avoid any kind of obstacles between the test antenna and reference antenna.

Viva Questions:

1. Define gain of the antenna.
2. What is 2 antenna method?
3. What are the sources of error in antenna measurement?

EXPERIMENT - 11

OBJECTIVE:

1. Study the sample.

2. Find dielectric constant of sample.

3. Analyze using two point method.

EQUIPMENTS:

Klystron power supply, Klystron mount, Isolator, Cooling fan, Frequency Meter, Variable Attenuator, Slotted Section, VSWR meter, Empty Waveguide, Matched Termination, Short Circuit, Cables and accessories, dielectric sample.

THEORY:

Two point method is most used method to measure the dielectric constant of any sample. It is a best method to either lossless dielectric or dielectric with medium loss. In the lossless case, the measured VSWR value are found to be infinite

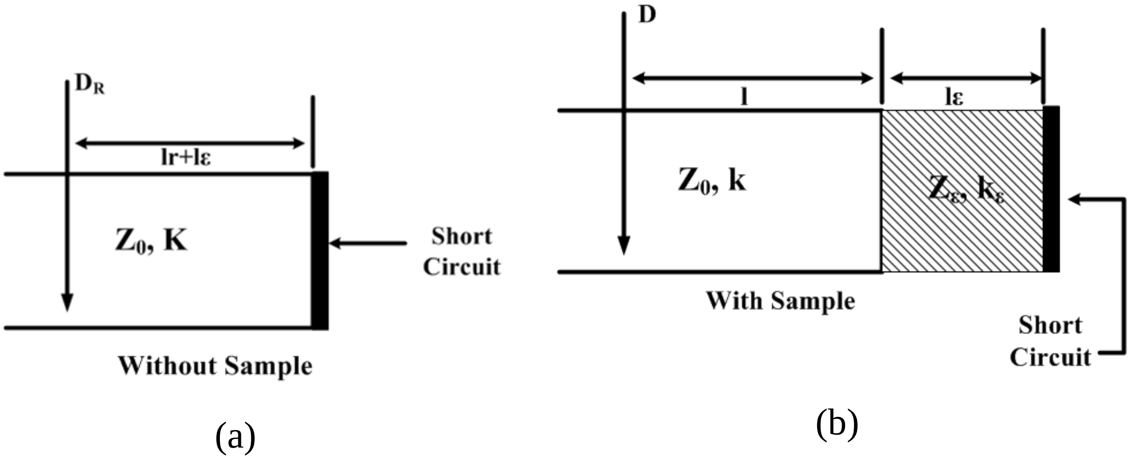


Fig.11.1 Dielectric Constant Measurement with Short-circuited waveguide

Fig. 11.1 (a) shows an empty short circuited waveguide with probe located at voltage minimum D_R.

Fig. 11.1 (b) shows the same waveguide containing a sample of length 'l_ε' with probe located at new voltage minimum ***'D'***. The sample is adjacent to the short circuit.

Looking from TE1 towards the right and left side one can write the impedance equation

$$Z_O \tan kl = -Z_E \tan k_E \, l_E \qquad \text{.......(11.1)}$$

Likewise in figure (a)

$$Z_O \tan k(l_R + l_E) = 0 \qquad \text{........(11.2)}$$

Now consider

$$\tan k(D_R - D + l_E) \quad = \tan k(l_R + l_E - l - l_E + l_E)$$

$$\tan k((l_R + l_E) - l)$$

$$= -\tan kl$$

$$Z_0 \tan k(D_R - D + l_E) = Z_E \tan k_E l_E$$

$$\frac{\tan k(D_R - D + l_E)}{kl_E} = \frac{\tan k_E l_E}{k_E l_E} \qquad \left(\frac{Z_O}{Z_E} = \frac{k_E}{k}\right)$$

It is noted that all the quantities associated with left member are measurable, while the right hand member is of the form of ***(tan X)/X***. so, once measurement has been performed ***'X'*** can be found by solving transcendental equation.

Due to periodic nature of the tangent function, there exists an infinite solution of 'ε_r' now perform a second identical experiment with same sample of different length. The proper solution in the latter case is one common to two set of solution i.e. intersection point.

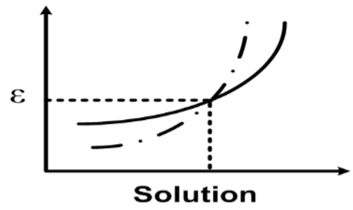


Fig.11.2.Solution for **ε** obtained from measurement of two different length sample of same material

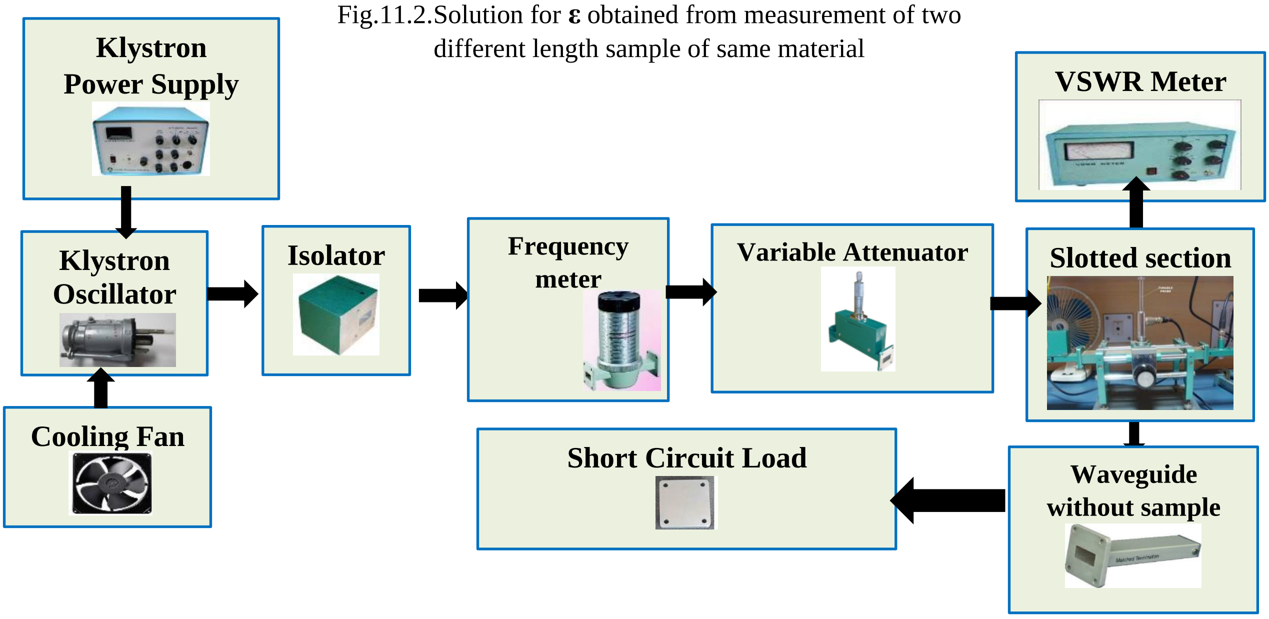


Fig.11.3 Experimental setup to measure D_R and λ_g for different length

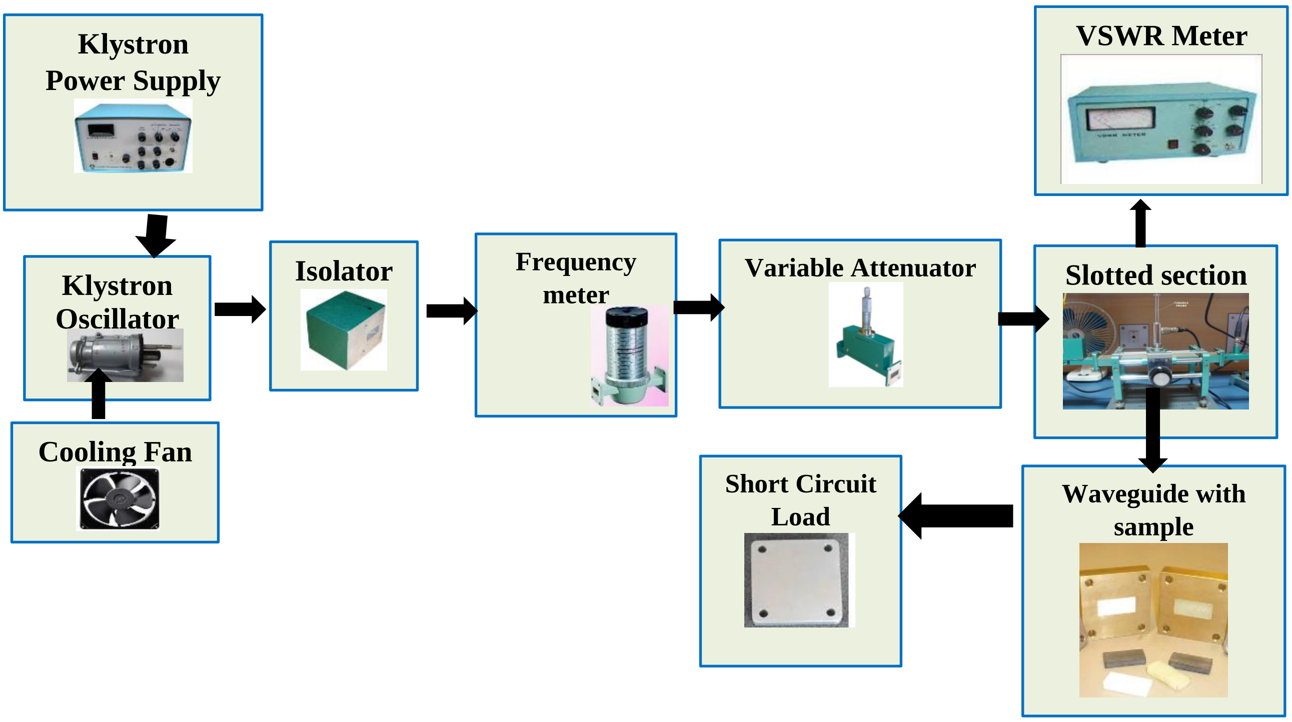


Fig.11.4 Experimental setup to measure D and for different length

PROCEDURE:

1. Connect the equipment as shown in block diagram
2. With no sample dielectric in the short circuited line, find the position of minima's are noted to calculate **'D_R'** and guided wavelength **'λ_g'**.
3. The short circuit is removed. The dielectric sample is inserted to empty waveguide. Now, again short circuit is connected at the end of the waveguide. Short circuit is replaced in such a manner that short circuit touches end of the sample.
4. Now, ***'D'*** is measured i.e. position of minima in the slotted line, with respect to reference plane.
5. Now, another sample is inserted and repeat the process with different length of sample to measure ***'D'.***
6. Repeat the process with different length of sample to measure ***'D'***.
7. The values are calculated and plotted for different lengths and their intersection point is measured to find the dielectric constant.

OBSERVATION:

Type	**Position of Minima**	**Distance between two minima**
Only Short circuit (No sample)	L_1= L_2=	D_R=
One sample inserted to waveguide	L_1= L_2=	D_1=
Two sample inserted to waveguide	L_1= L_2=	D_2=
Three sample inserted to waveguide	L_1= L_2=	D_3=

CALCULATION:

1. Calculate guided wavelength (λ_g) and the value of k
2. Calculate the value of K_1 when one sample is inserted.

$$K_1 = \frac{\tan(k(D_R+l_{E1}-D))}{Kl_{E1}}$$

3. $k_i = \frac{\tan X_i}{X_i}$,   where, i= 1,2, 3.
4. Calculate K_1, K_2 and K_3
5. Now calculate $\varepsilon' = \frac{(a/\pi)^2+(X'/l_E)^2+1}{(2a/\lambda_g)^2+1}$
6. X' will be calculated using computational technique and plotted graphically to ε

RESULTS & DISCUSSION:

ERROR CALCULATION:

PRECAUTIONS:

1. The direction of isolator should be correct.

2. All the connection should be tightly fixed.

3. Repeller voltage must be applied before beam voltage.

4. The knob of slotted line should be moved very slowly

Viva Qustions:

1. Define dielectric constant.

2. Explain two-point method.

3. What are the merits and demerits of two point method.

EXPERIMENT - 12

OBJECTIVE:

Determine experimentally the S-parameters of reciprocal device with the help of slotted line in X-Band of microwave frequencies using microwave test bench.
Outcomes: Students are able to analyze reflection and transmission coefficients of a two port reciprocal device by using the microwave test bench setup.

EQUIPMENTS:

Klystron power supply, Klystron mount, Isolator, Variable attenuator, Frequency meter, Slotted line, S-S tuner, Matched load, Movable short

THEORY:

S-parameter are power wave descriptor that permits to define the input and output relation of network in terms of incident and reflected waves.

For a two port network;

$$b_1 = S_{11}\, a_1 + S_{12}\, a_2 \quad \text{...........(12.1)}$$

$$b_2 = S_{21}\, a_1 + S_{22}\, a_2 \quad \text{............(12.2)}$$

Where,

a_1, a_2 are incident waves at port 1 and port 2, respectively.

b_1, b_2 are reflected waves at port 1 and port 2, respectively.

Input impedance at port 1 is;

$$Z_{in} = Z_0 \frac{Z_L + j\, Z_0 \tan(\beta L)}{Z_0 + j\, Z_L \tan(\beta L)} \quad \text{.... .(12.3)}$$

On normalizing,

$$\overline{Z_{in}} = \frac{\overline{Z_L} + j \tan(\beta L)}{1 + j\, \overline{Z_L} \tan(\beta L)} \quad \text{..... ...(12.4)}$$

$$\overline{Z_L} = \frac{\overline{Z_{in}} - j \tan(\beta L)}{1 - j\, \overline{Z_{in}} \tan(\beta L)} \quad \text{.....(12.5)}$$

We know that;

$$\text{VSWR} = S = \frac{1 + |\Gamma|}{1 - |\Gamma|} \quad \text{.......(12.6)}$$

$$\Gamma = \frac{Z_{in} - Z_0}{Z_{in} + Z_0} = \frac{\overline{Z_{in}} - 1}{\overline{Z_{in}} + 1} \quad \text{......(12.7)}$$

When $Z_{in} < Z_0$

$$S = \frac{1 - \Gamma}{1 + \Gamma}$$

$$\Rightarrow S = \frac{1 - \left(\frac{\overline{Z_{in}} - 1}{\overline{Z_{in}} + 1}\right)}{1 + \left(\frac{\overline{Z_{in}} - 1}{\overline{Z_{in}} + 1}\right)}$$

$$\Rightarrow S = \frac{1}{\overline{Z_{in}}}$$

$$\Rightarrow \overline{Z_{in}} = \frac{1}{S} \quad \text{..........(12.8)}$$

Substitute equation (12.8) in equation (12.5);

$$\overline{Z_L} = \frac{\frac{1}{S} - j \tan(\beta L)}{1 - j\, \frac{1}{S} \tan(\beta L)}$$

$$\Rightarrow \overline{Z_L} = \frac{1 - j\, S \tan(\beta L)}{S - j \tan(\beta L)} \quad \text{........(12.9)}$$

Different cases to calculate S-parameters:

A. Matched at port 2 (Γ_2 = 0)

$$\Rightarrow a_2 = 0$$

$$b_1 = S_{11}\, a_1$$

$$\left.\frac{b_1}{a_1}\right|_1 = S_{11} \qquad \text{..................(12.10)}$$

B. Short circuit at port 2 (Γ_2 = -1)

$$\Gamma_2 = \frac{a_2}{b_2} = -1$$

$$\Rightarrow b_2 = -\, a_2$$

$$b_1 = S_{11}\, a_1 + S_{12}\, a_2$$

$$b_2 = S_{21}\, a_1 + S_{22}\, a_2$$

Substituting $a_2 = -\, b_2$ in above two equations.

$$b_1 = S_{11}\, a_1 + S_{12}\,(-\, b_2)$$

$$b_2 = S_{21}\, a_1 + S_{22}\,(-\, b_2)$$

$$\Rightarrow b_2 = \frac{S_{21} a_1}{1 + S_{22}}$$

$$b_1 = S_{11}\, a_1 + S_{12}\left(-\frac{S_{21} a_1}{1 + S_{22}}\right)$$

$$\Rightarrow \frac{b_1}{a_1} = S_{11} - \frac{S_{12} S_{21}}{1 + S_{22}}$$

$$Y = \left.\frac{b_1}{a_1}\right|_2 = S_{11} - \frac{S_{12} S_{21}}{1 + S_{22}} \qquad \text{.........(12.11)}$$

C. Open circuit at port 2 (Γ_2 = 1)

Short circuit is placed at $^{\lambda_g}/_4$ wavelength from reference plane.

$$\Gamma_2 = \frac{a_2}{b_2} = 1$$

$$\Rightarrow b_2 = a_2$$

$$b_1 = S_{11}\, a_1 + S_{12}\, a_2$$

$$b_2 = S_{21}\, a_1 + S_{22}\, a_2$$

Substituting $a_2 = b_2$ in above two equations.

$$b_1 = S_{11}\, a_1 + S_{12}\, b_2$$

$$b_2 = S_{21}\, a_1 + S_{22}\, b_2$$

$$\Rightarrow b_2 = \frac{S_{21} a_1}{1 - S_{22}}$$

$$b_1 = S_{11}\, a_1 + S_{12} \left(\frac{S_{21} a_1}{1 - S_{22}} \right)$$

$$\Rightarrow \frac{b_1}{a_1} = S_{11} + \frac{S_{12} S_{21}}{1 - S_{22}}$$

$$Z = \left.\frac{b_1}{a_1}\right|_3 = S_{11} + \frac{S_{12} S_{21}}{1 - S_{22}} \qquad \ldots\ldots\ldots\ldots(12.12)$$

From equation (12.11)

$$\text{Let } m = Y - S_{11} = - \frac{S_{12} S_{21}}{1 + S_{22}} \qquad \ldots\ldots\ldots\ldots(12.13)$$

From equation (12.12)

$$\text{Let } n = Z - S_{11} = \frac{S_{12} S_{21}}{1 - S_{22}} \qquad \ldots\ldots\ldots\ldots(12.14)$$

$$\text{Then} \quad \frac{n - m}{n + m} = \frac{\frac{S_{12} S_{21}}{1 - S_{22}} + \frac{S_{12} S_{21}}{1 + S_{22}}}{\frac{S_{12} S_{21}}{1 - S_{22}} + \frac{S_{12} S_{21}}{1 + S_{22}}}$$

$$\Rightarrow \frac{n - m}{n + m} = S_{22} \qquad \ldots\ldots\ldots\ldots..(12.15)$$

From equation (8.11);

$$Y = \left.\frac{b_1}{a_1}\right|_2 = S_{11} - \frac{S_{12} S_{21}}{1 + S_{22}}$$

$$\Rightarrow \left(S_{11} - \left.\frac{b_1}{a_1}\right|_2\right)(1 + S_{22}) = S_{12} \,.\, S_{21}$$

$$\Rightarrow S_{12} \,.\, S_{21} = (1 + S_{22}) \left(S_{11} - \left.\frac{b_1}{a_1}\right|_2\right) \qquad \ldots.(12.16)$$

For reciprocal device $S_{12} = S_{21}$ and can be calculated from equation (12.16).

Slide Screw Tuner:

It utilizes broadband slot line transmission structure and passive probes to create impedance for devices. The probes are designed to be very close to one quarter wavelength in the linear dimension at the mid band of each range. The depth of penetration of probe into transmission line determines the magnitude of reflection while position along the line determine the phase.

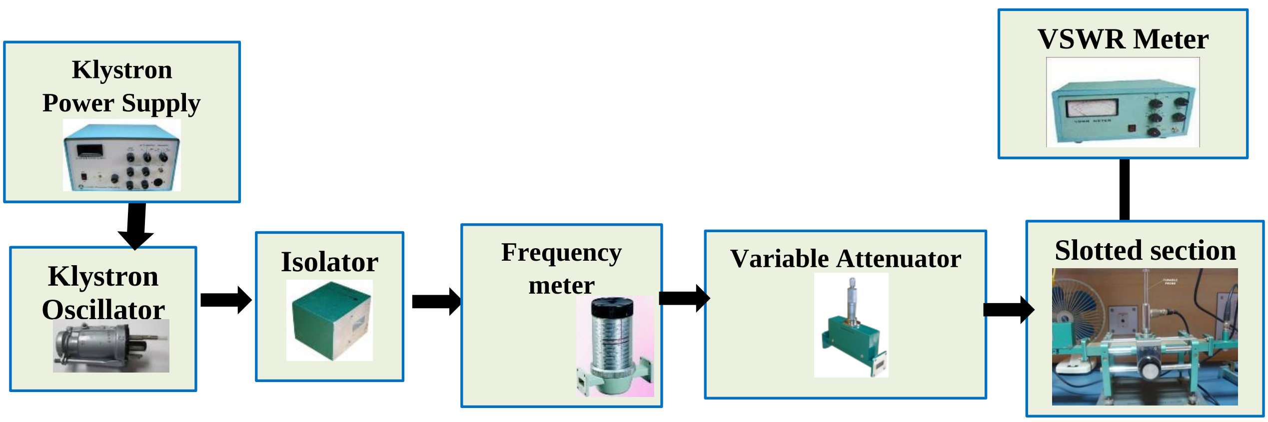


Fig.12.1.Experimental set-up for measuring S-parameter of reciprocal device using slotted line.

PROCEDURE:

1. Arrange the microwave bench setup as shown in figure (first connect short circuit load without S-S tuner).
2. Switch ***'ON'*** klystron power supply, cooling fan and VSWR meter.
3. Set the beam voltage to 290 V.
4. Rotate frequency meter to see the dip in VSWR meter. The frequency at which dip occur is resonant frequency. Note down the resonant frequency.
5. Detune the frequency meter.
6. Note down the first and second minima positions. Calculate the guided wavelength using successive minima method.
7. Terminate the slotted line by S-S tuner and then by matched load.
8. Note down the position of V_{min} and also the value of V_{max} and V_{min}.
9. Repeat the same with short circuit load and open circuit load.
10. Calculate reflection coefficient in each case and using the derived formulas calculate the S-parameter of the device.

OBSERVATIONS:

1. **Short Circuit Load (without S-S Tuner):**

Resonant frequency using frequency meter, $f =$ GHz

First minima position = $d_1 = P_1 =$ cm

Second minima position = $d_2 =$ cm

2. **Matched Load (after S-S Tuner):**

$V_{max} =$ V

$V_{min} =$ V , $P_2 =$ cm

$L = P_1 - P_2 =$ cm

3. **Short Circuit Load (after S-S Tuner):**

$V_{max} =$ V

$V_{min} =$ V , $P_3 =$ cm

$L = P_1 - P_3 =$ cm

4. **Open circuit Load (after S-S Tuner):**

V_{max} = V

V_{min} = V, P_4 = cm

$L = P_1 – P_4$ = cm

<u>CALCULATIONS:</u>

Guided wavelength using successive minima method, $\lambda_g = 2 \times (d_2 – d_1)$ = cm

$$\beta = \frac{2\pi}{\lambda_g} = ?$$

A. Matched Load ((Γ= 0)

$$\text{VSWR} = S = \frac{\text{Vmax}}{\text{Vmin}} = ?$$

$$\overline{Z_L} = \frac{1-j\,S\tan(\beta L)}{S-j\tan(\beta L)} = ?$$

$$\Gamma = \frac{\overline{Z_L}-1}{\overline{Z_L}+1} = \frac{b_1}{a_1} = S_{11} = ?$$

B. Short circuit Load ((Γ= -1)

$$\text{VSWR} = S = \frac{\text{Vmax}}{\text{Vmin}} = ?$$

$$\overline{Z_L} = \frac{1-j\,S\tan(\beta L)}{S-j\tan(\beta L)} = ?$$

$$\Gamma = \frac{\overline{Z_L}-1}{\overline{Z_L}+1} = Y = ?$$

C. Movable short circuit placed at $\lambda_g/4$ distance from the reference plane ((Γ= 1)

$$\text{VSWR} = S = \frac{\text{Vmax}}{\text{Vmin}} = ?$$

$$\overline{Z_L} = \frac{1-j\,S\tan(\beta L)}{S-j\tan(\beta L)} = ?$$

$$\Gamma = \frac{\overline{Z_L}-1}{\overline{Z_L}+1} = Z = ?$$

From equation (12.13);

$$m = Y – S_{11} = -\frac{S_{12}S_{21}}{1+S_{22}} = ?$$

From equation (12.14);

$$n = Z – S_{11} = \frac{S_{12}S_{21}}{1-S_{22}} = ?$$

From equation (12.15);

$$\frac{n-m}{n+m} = S_{22} = ?$$

From equation (12.16);

$$S_{12} . S_{21} = (1+ S_{22}) \ (S_{11} - Y) = ?$$

Since, it is a reciprocal network;

$$S_{12} = S_{21}$$

$$\Rightarrow S_{12}{}^{2} = S_{21}{}^{2} = ?$$

$$\Rightarrow S_{12} = S_{21} = ?$$

RESULTS & DISCUSSION:

PRECAUTIONS:

1. Beam voltage should not exceed 300 V.
2. Make sure that the cooling fan is ‘ON’ before switching on the klystron power supply.
3. Screws should be tightened properly to avoid any leakage.

Viva Questions:

1. What is the condition of reciprocity for a network?
2. What does S-Parameter mean?
3. Why S-Parameters are used in microwave?
4. What is S-Parameter S_{21}?
5. Are all passive networks reciprocal?