AMRITA VISHWA VIDYAPEETHAM

DEEMED TO BE UNIVERSITY UNDER SECTION 3 OF THE UGC ACT, 1956

B. Tech - Computer and Communication Engineering

19CCE383 Electromagnetic Simulation Lab
6th Semester B. Tech. CCE

Lab Manual

Department of Electronics and Communication Engineering Amrita School of Engineering, Coimbatore - 641112

Feb 2023

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prepared by

Department of Electronics and Communication Engineering Amrita School of Engineering, Coimbatore - 641112

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Verified by   Approved by

19CCE383	ELECTRO MAGNETIC SIMULATION LAB	L-T-P-C: 0-0-3-1

Pre Requisite(s): Computational Electromagnetics

Course Objectives

- To get hands on experience in building the RF circuits and analyze its performance
- To practice the tools used for simulations and its parameters and syntax in the circuit design
- To become the expertise in RF design and performance analysis

Course Outcomes

CO1: Ability to understand the concepts of RF signal transmission through waveguides
CO2: Ability to analyze the scattering parameters of RF devices
CO3: Ability to apply the RF design concepts and characterize using simulation tools
CO4: Ability to design and analyze RF circuits using simulation tools

CO/PO Mapping

PO/PSO CO	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12	PSO1	PSO2
CO1	3	3	3	3	3	-	-	-	-	-	-	3	3	3
CO2	3	3	3	3	3	-	-	-	-	-	-	3	3	3
CO3	3	3	3	3	3	-	-	-	-	-	-	3	3	3
CO4	-	2	-	-	-	-	-	-	3	3	-	3	-	-

Syllabus

1. Characterization of waveguide based microwave setup.
2. Measurement of radiation pattern of horn antennas.
3. Measurement of return loss and insertion loss of any selected microwave component.
4. Characterization of materials using two-antenna method.
5. Electromagnetic simulation and scattering parameters study on microstrip lines.
6. Electromagnetic simulation and characterization of rectangular microstrip antenna.
7. Electromagnetic simulation and characterization of circular microstrip antenna.
8. Electromagnetic simulation and characterization of microstrip power dividers.
9. Electromagnetic simulation and characterization of rectangular microstrip resonator.
10. Electromagnetic simulation and characterization of hybrid ring couplers.

Text book(s)
David M. Pozar, "Microwave Engineering", Wiley India Limited, Fourth Edition, 2012.

Reference(s)
Samuel. Y. Liao, "Microwave Devices and Circuits", Pearson Education, Third Edition, 2004.

Evaluation Pattern

Assessment	Internal	External
*Continuous Assessment (CA)	80	
End Semester		20

*CA – Can be Quizzes, Assignment, Projects, and Reports

Evaluations:

Continuous Assessment	Preparation	20	Details of activity in the record, prior to its implementation
	Methodology	20	Procedure and conduct of activity
	Results & analyses	30	Calculations; graphs; details about trends and patterns in data; conclusions
	Quiz	10	Q1 & Q2 – in hardware & simulation topics; over AUMS (across their 4 tasks; 10 marks applied to each corresponding activity)
End Semester	Lab activity	20	Hardware or simulation task in the labs
	Total	100	Submit of the Lab Record

Lab Record:

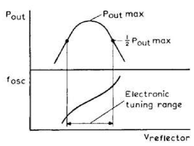
Bridge Circuit/schematic & block diagram(s)

Formula(s)

Tabulation

Calculations/analyses

Graph(s)



Marks Table

Exp.# & Date Title CO

Aim:

Components List:

Calibration data:

Operating frequency: ____ GHz
Beam Current: ____ mA
Repeller voltage:____V

Observations:

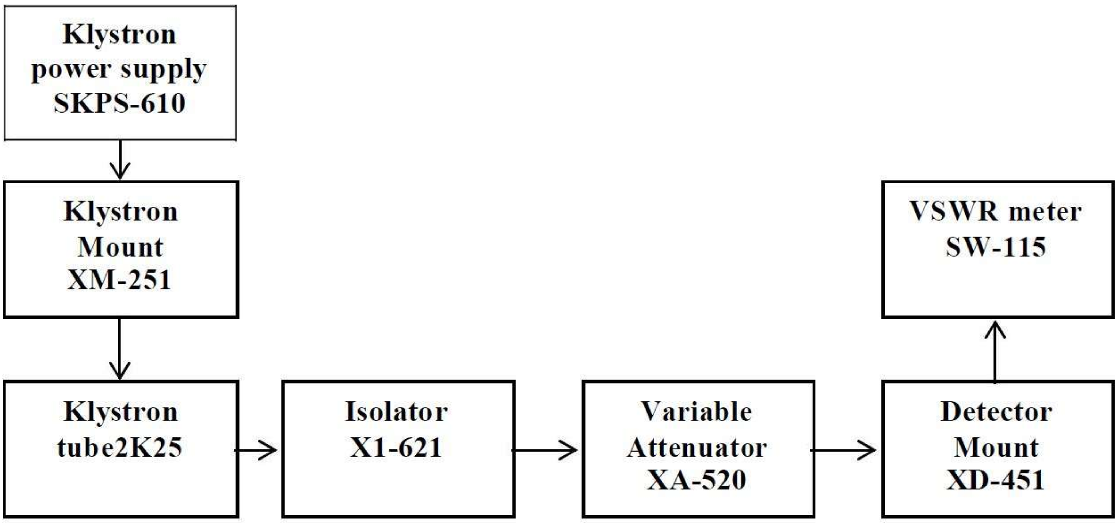
Result(s)

Marks Table:

Component	Maximum Marks	Marks Obtained
Preparation	20	
Methodology	20	
Result & Analyses	30	
Quiz	10	
Total	80	

Exp.#	H0	**Characterization of waveguide based microwave setup**	CO: 01
Date			

Block Diagram:



Microwave bridge / bench:

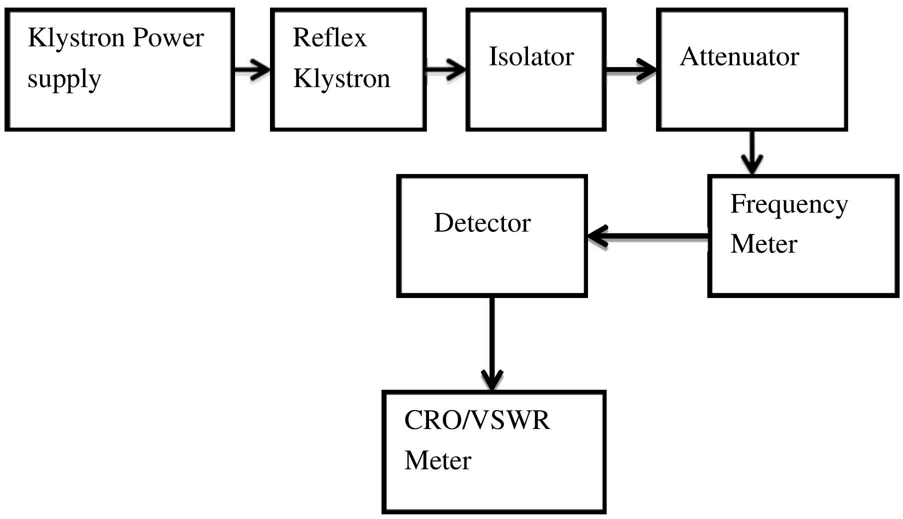
Aim of the Experiment: To study the working of reflex klystron oscillator and determine the repeller voltage –power and repeller voltage- frequency relationships.

Demonstrate the characteristics of the Microwave source.

Apparatus Required:

1. Klystron Oscillator
2. Klystron Power Supply
3. Isolator
4. Attenuator
5. Frequency Meter
6. Detector
7. CRO, VSWR meter, and Probes and screws.

Block Diagram of the Waveguide Bench: (To be drawn on the left side of the Notebook)



Procedure:

1. Switch ON the Klystron Power supply.
2. Check whether the "BEAM" knob is in MINIMUM position and the "REPELLER" knob in MAXIMUM position. Select the "EXTERNAL" position in the "MODE SELECT" knob.
3. Set the signal generator to 1KHz square wave with amplitude around 10V (p-p).
4. Switch ON the “HT” toggle switch in the Kly□ □tron power supply□ □nd try□ □ observing a square wave 1KHz in the CRO.
5. Check the Beam current to be below 15mA. Note the beam voltage reading.
6. Change the repeller voltage from around -270 to -100 V and observe the changes in the square wave.
7. Identify the klystron modes, and identify the repeller voltages for these modes.
8. Employ the dip technique to measure the Frequency.
9. Connect the probe to the VSWR meter and observe the power level.
10. Tabulate the readings: Repeller voltage – Frequency and Power level. Observe at least 5 readings for each mode.

Observations: (Left-hand side of the Record)

Repeller Voltage (V)	Power (dB)	Frequency (GHz)

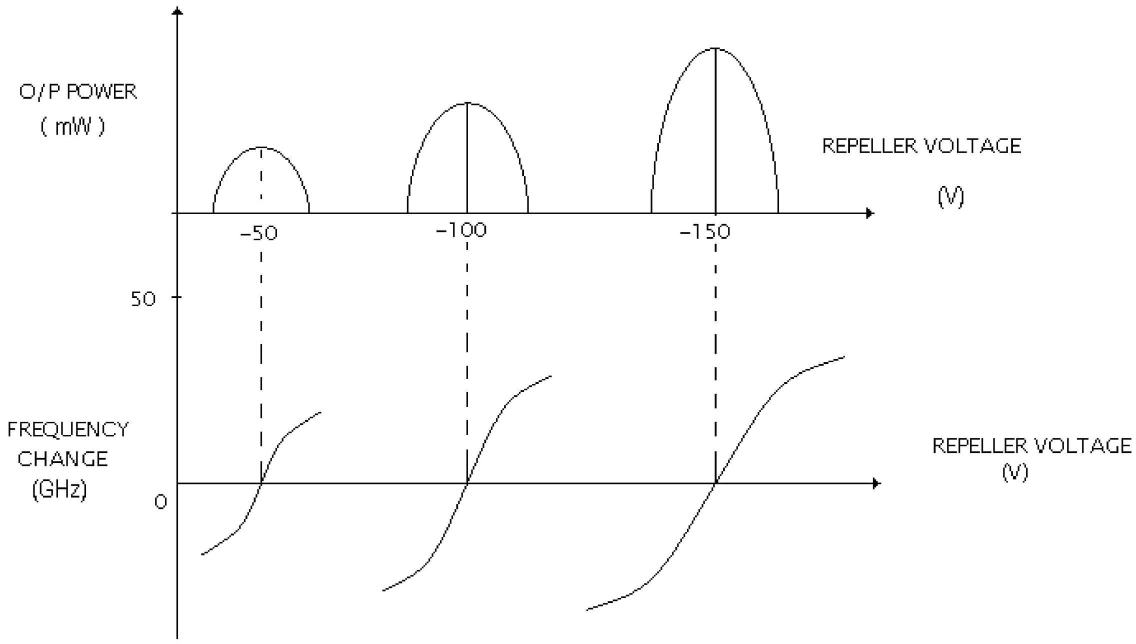
Graphs to be drawn

1. Frequency vs Repeller Voltage
2. Power vs Repeller Voltage

Results and Conclusion:

(Provide your comments on observing the readings)

MODEL GRAPH:



Calculations / Analyses:

i. By taking the values of repeller voltage we can calculate the mode number

N_1 = n+3/4 with V_2 =
N_2 = (n+1)+3/4 with V_1 =

N_1 , N_2 are the respective mode numbers

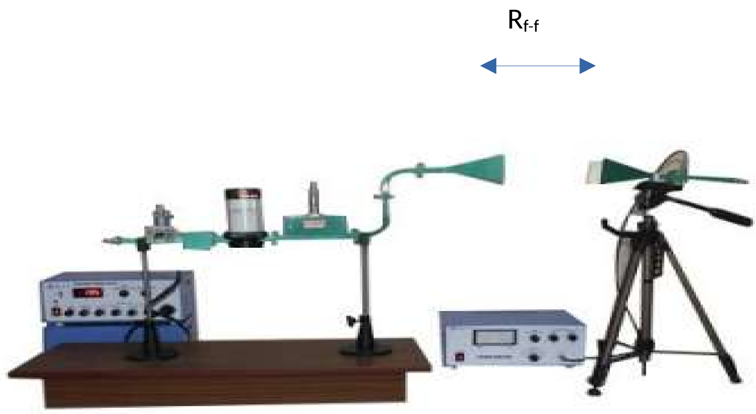
ii. ETS (Electronic Tuning Sensitivity) = f_2 - f_1 / V_2 – V_1 MHz / V

1. Knowing the maximum voltage of two adjacent modes, mode number can be computed using the relation

   N2/N1 = V1/V2 = (n+1+3/4)/(n+3/4)
   Where N1, N2 -------- mode numbers
   V1, V2-------- repeller voltages
2. Knowing mode number, transit time of each mode may be calculated from
   T = (n+3/4)/f0 :::> t1 = N1/f01, t2 = N2/f02
3. Calculate electronic tuning range, i.e., the frequency band from one end of the mode to another.
4. ETS may be calculated using the relation
   ETS = (f2 – f1) / (V2 – V1)
   Where f1, f2 being half power frequencies in GHz, and V2 and V1 are Corresponding repeller voltages for a particular mode.

Exp.#	H1	**Measurement of radiation pattern of horn antennas**	CO: 01, 02
Date			

Experimental arrangement:



$$R_{\text{far-field}}\ (\text{m}) \geq 2\ D^2 / \lambda$$

Aim of the Experiment: To conduct an experiment to determine the parameters of waveguide-based Horn antenna.

To analyze and measure the radiation pattern and gain of the antenna.

Apparatus Required:

1. Klystron Oscillator
2. Klystron Power Supply
3. Isolator
4. Attenuator
5. Frequency Meter
6. Detector
7. CRO, VSWR meter, and Probes and screws.
8. Two Horn Antennas

Block Diagram of the Waveguide Bench: (To be drawn on the left side of the Notebook)

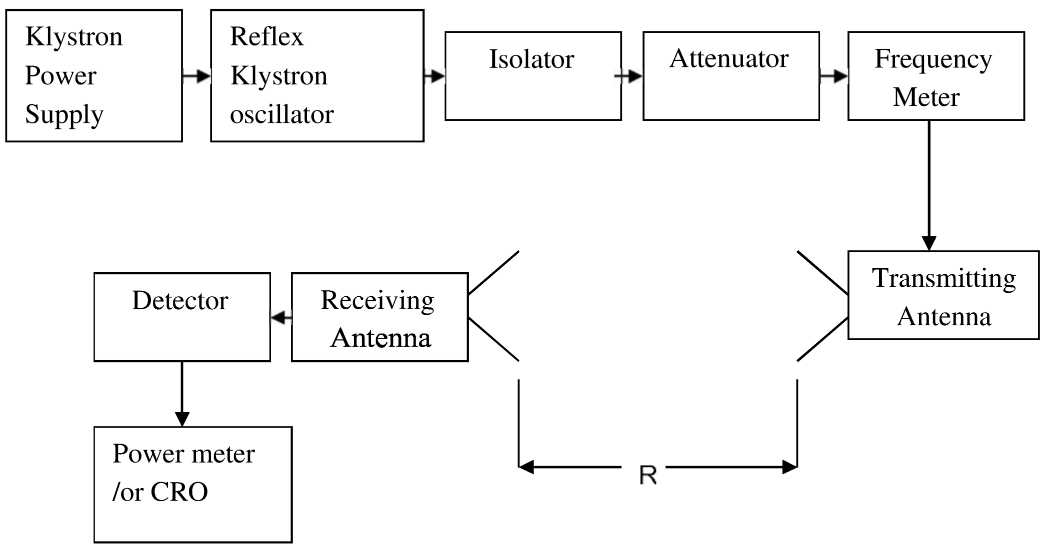


Figure 1: Experimental Set up for Determining Antenna Radiation Pattern

Procedure:

Phase 1: Calibration

1. Initially check whether the waveguide bench is physically intact with the detector connected to the frequency meter.
2. Set up the Klystron-based waveguide bench for a good power level as high as -3 dB. The power level should not be below -10dB for this experiment.
3. Determine the frequency of operation, and free space wavelength (λ).
4. Get the calibration details verified by the lab staff. The calibration details include Beam voltage, beam current, repeller voltage, Power level, and Frequency should be written in the observation and verified by the laboratory staff.
5. Measure the physical cross-section area of Horn (**Ap**), and note the observed

power level as input power **Pin**

Phase 2: Determination of Antenna Radiation Pattern

a. Remove the detector and connect one horn antenna to the transmitter.
b. Mount the receiver horn on the centre of the Ellipsometry table.
c. Measure the distance between the transmit and receive antennas as '**d**'.
d. Turn the receiving Horn over the angle range 0-180 degrees in the ellipsometry table and tabulate the power readings. The angle interval could be 5°. Repeat the same for the other side.
e. Plot the radiation pattern on a polar chart, and observe the 3dB beamwidth (θ3dB)

Observations: (Left-hand side of the Record)

Angular Position (Degrees)	Power (dB)

Table 1. Observations for Rectangular Horn

Calculations: (Left Hand Side of the Record)

Calculations:

a) **Operating Wavelength (λ)**:

$$\lambda = \frac{C}{F} \; ..... (1)$$

C = velocity of EM wave in free space (m/s), F= Operating Frequency (Hz)

b) Antenna Directivity (D):

Since the employed antenna was rectangular horn, the 3dB beamwidth in both elevation and azimuthal planes are identical or $\theta_E = \theta_H$.

$$D = \frac{32400}{\theta_{3d}^2} \; ..... (2)$$

θ_{3dB} = 3dB beamwidth (in degrees)

c) Computation of The gain of the Antenna (G):

$$G = \eta D \; ..... (3)$$

D= Directivity obtained from equation (2)
η = Efficiency of the Antenna (100 % for waveguide-based antennas)

d) Effective Aperture of the Horn Antenna (A_E):

$$A_E = \frac{D\lambda^2}{4\pi} \; ..... (4)$$

D = Directivity as obtained from equation (2)
λ = Operating Wavelength, obtained from equation (1)

Phase 3: Friis Formula Verification and Gain Computation

a) Friis Formula Verification

$$P_R = \frac{P_T G_T G_R \lambda^2}{(4\pi R)^2}\ W ---------(5)$$

P_t = Transmitted power is given by $\boldsymbol{\eta P_{in}}$
$G_T = G_R = G$ (from equation (2)) [Identical antennas are employed as transmitter and receiver]
R= Distance between transmitter and Receiver (in meter)
λ = Operating Wavelength, obtained from equation (1)
The calculated received power (P_r) is to be compared with the received power obtained at Line of Sight ($\theta = 0^\circ$) from table 1. Provide your opinion on the difference observed in the calculated and observed power levels.

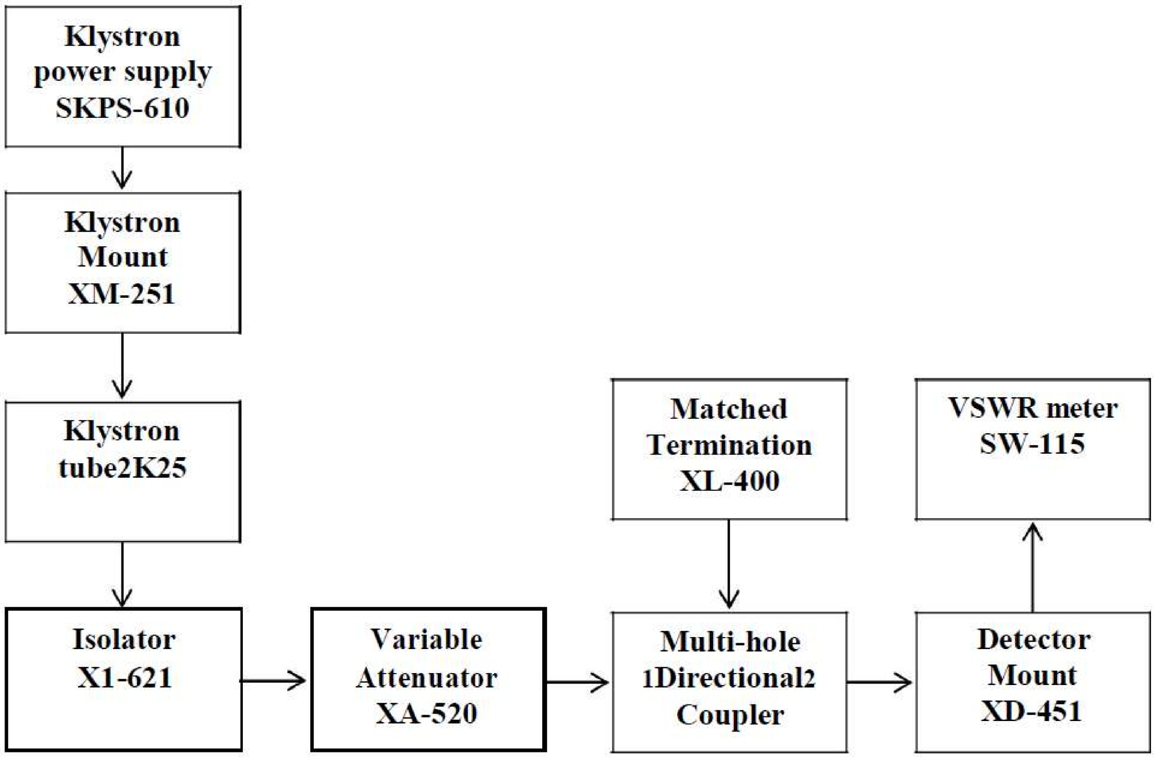
b) Determination of Unknown Antenna Gain

1. Gain of antennas could be experimentally observed using the above experiment.
2. Mount the antenna whose gain is to be determined on the table.
3. Determine the received power level (P_r) at boresight.
4. The gain of the antenna GR can be determined from equation 6.

Result and Conclusions:

Exp.#	H2	**Measurement of return loss and insertion loss of any selected microwave component (Directional Coupler)**	CO: 01, 02
Date			

Block Diagram:



Directional Coupler:

Data Table:

Input Port	Output Port	Matched Termination	S-parameters
1	2	3	S12
1	3	2	S13
2	1	3	S21
2	3	1	S23
3	1	2	S31
3	2	1	S32

THEORY:

A directional coupler is a device with which it is possible to measure the incident and reflected wave separately. It consist of two transmission lines the main arm and auxiliary arm, electromagnetically coupled to each other Refer to the Fig.1. The power entering, in the main-arm gets divided between port 2 and 3, and almost no power comes out in port (4) Power entering at port 2 is divided between port 1 and 4.

The coupling factor is defined as

Coupling (db) = 10 $\log_{10}$ [P1/P3] where port 2 is terminated, Isolation (dB) = 10 $\log_{10}$ [P2/P3] where P1 is matched.

With built-in termination and power entering at Port 1, the directivity of the coupler is a measure of separation between incident wave and the reflected wave. Directivity is measured indirectly as follows:

Hence Directivity D (db) = I-C = 10 $\log_{10}$ [P2/P1]

Main line VSWR is SWR measured, looking into the main-line input terminal when the matched loads are placed at all other ports.

Auxiliary live VSWR is SWR measured in the auxiliary line looking into the output terminal when the matched loads are placed on other terminals.

Main line insertion loss is the attenuation introduced in the transmission line by insertion of coupler, it is defined as:

Insertion Loss (dB) = 10 $\log_{10}$ [P1/P2]

EXPERIMENTAL PROCEDURE:

1. Set up the equipments as shown in the Figure.
2. Energize the microwave source for particular operation of frequency .
3. Remove the multi hole directional coupler and connect the detector mount to the slotted section.
4. Set maximum amplitude in CRO with the help of variable attenuator, Let it be X.
5. Insert the directional coupler between the slotted line and detector mount. Keeping port 1 to slotted line, detector mount to the auxiliary port 3 and matched termination to port 2 without changing the position of variable attenuator.
6. Note down the amplitude using CRO, Let it be Y.
7. Calculate the Coupling factor X-Y in dB.
8. Now carefully disconnect the detector mount from the auxiliary port 3 and matched termination from port 2 , without disturbing the setup.
9. Connect the matched termination to the auxiliary port 3 and detector mount to port 2 and measure the amplitude on CRO, Let it be Z.
10. Compute Insertion Loss= X – Z in dB.
11. Repeat the steps from 1 to 4.
12. Connect the directional coupler in the reverse direction i.e., port 2 to slotted section, matched termination to port 1 and detector mount to port 3, without disturbing the position of the variable attenuator.
13. Measure and note down the amplitude using CRO, Let it be Y_0.
14. Compute the Directivity as $Y-Y_0$ in dB.

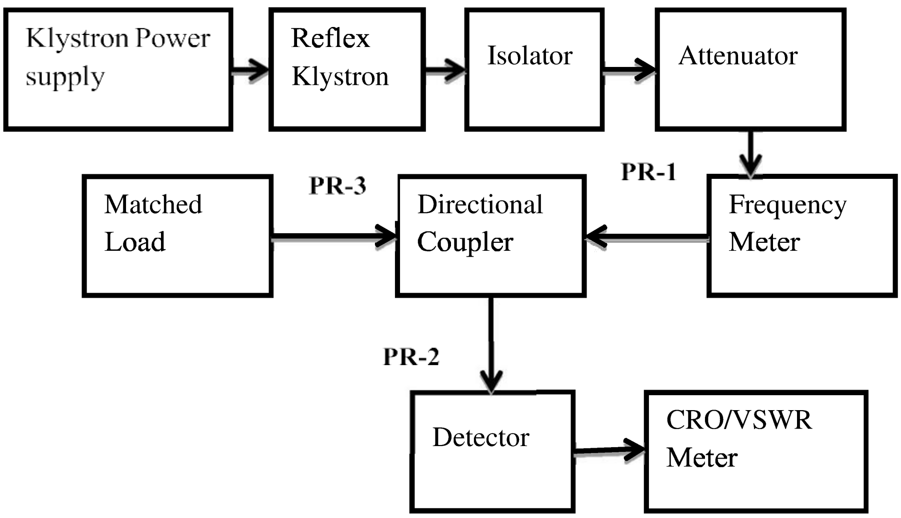
Aim of the Experiment: To conduct an experiment to determine the S-matrix of a Directional coupler.

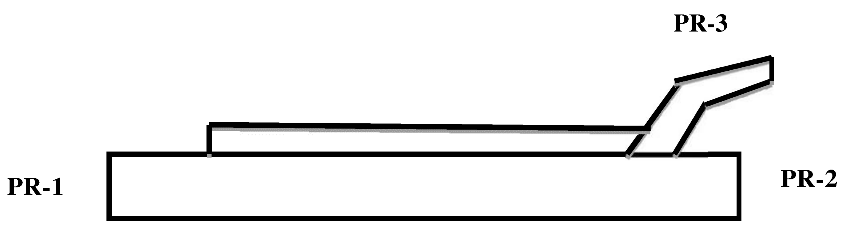
To test the characteristics of microwave components

Apparatus Required:

1. Klystron Oscillator
2. Klystron Power Supply
3. Isolator
4. Attenuator
5. Frequency Meter
6. Detector
7. CRO, VSWR meter, and Probes and screws.
8. Directional Couplet – Device under test
9. Matched load

Block Diagram of the Waveguide Bench: (To be drawn on the left side of the Notebook)





Basic Three Port Directional Coupler

Procedure:

1. Initially check whether the waveguide bench is physically intact with the detector connected to the frequency meter.

2. Set up the Klystron-based waveguide bench for a good power level around -14 dB. The power level should not be below -20dB for this experiment.
3. Determine the frequency of operation.
4. Get the calibration details verified by the lab staff. The calibration details include Beam voltage, beam current, repeller voltage, Power level, and Frequency should be written in the observation and verified by the laboratory staff.
5. Remove the detector and insert the directional coupler between the frequency meter and detector. Attach port PR-1 to the frequency meter and port PR-2 to the detector
6. Attach a matched load to Port P3.
7. Now port P1 is acting as an input port, measure the power level at port 2 as P2 and record it. The calibrated power level is the input power P1.
8. Interchange the detector and matched load positions and measure the power level at port 3 as P3.
9. Repeat the experiment with other ports acting as input ports and measure the power level at all ports. The unused ports should be connected with matched load to avoid spurious reflections.
10. Each time the input port is changed, check whether the power output at the frequency meter is the same as calibrated power, if not note down the new reading.
11. Complete the tabular column. Determine the S matrix from the observed power readings
12. The S matrix calculations are as

    To determine one entry of the S

    matrix

$$S_{mn} = \text{Antilog}\left((P_m - P_n)/20 \right)$$

13. The main diagonal elements S_{mm} cannot be determined experimentally. A directional coupler is a reciprocal device and hence these main diagonal values can be computed employing the reciprocity property of the S matrices.

Observations: (Left-hand side of the Record)

Input power at Port -1 (P1) (dB)	Power at Port 2 (P2) (dB)	Power at Port 3 (P3) (dB)

Input power at Port -2 (P2) (dB)	Power at Port 1 (P1) (dB)	Power at Port 3 (P3) (dB)

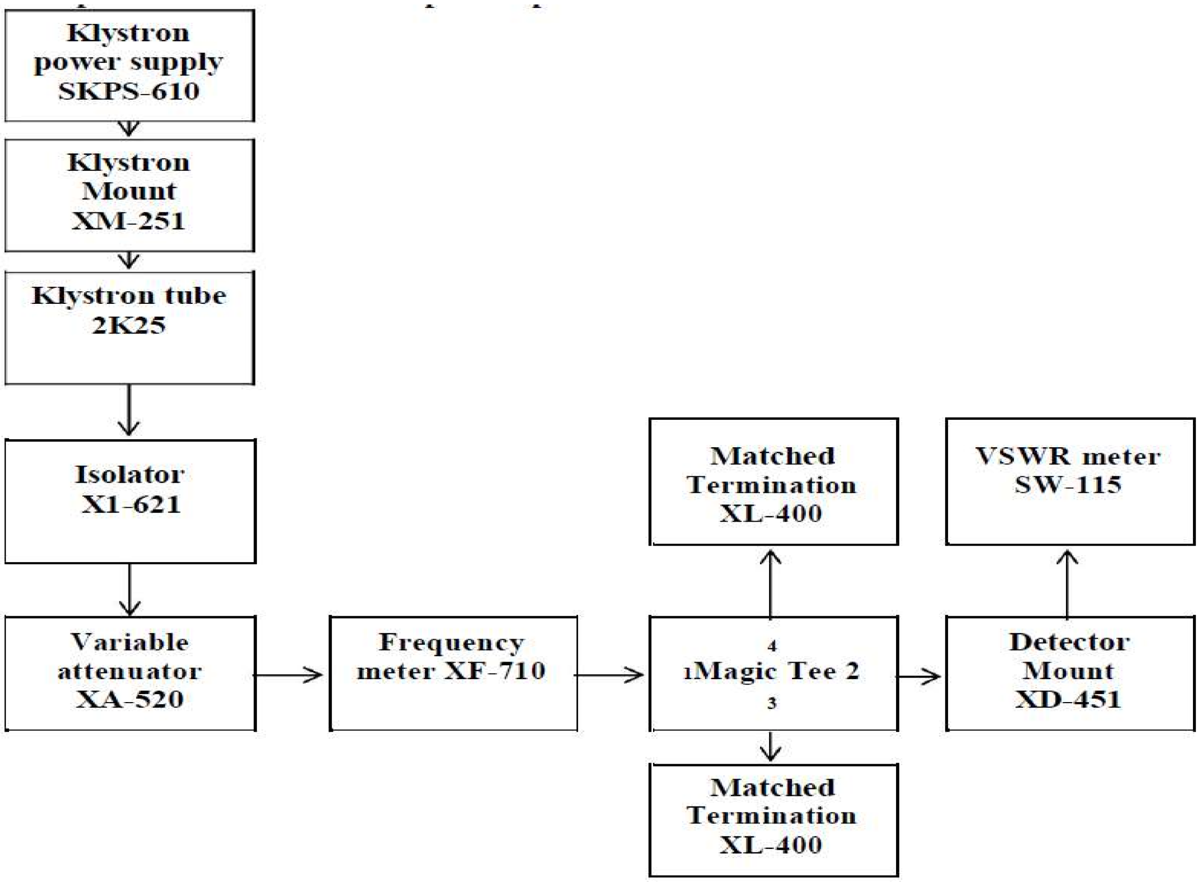
Input power at Port -3 (P1) (dB)	Power at Port 1 (P1) (dB)	Power at Port 2 (P2) (dB)

Results and Conclusion:

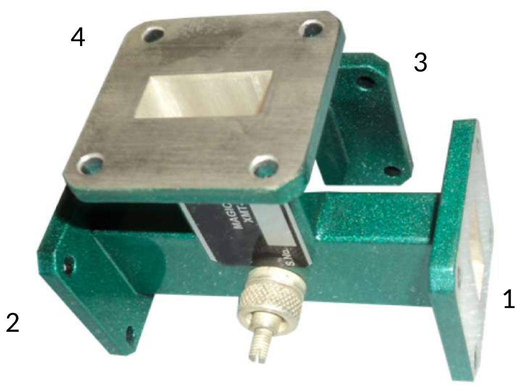
Provide the numerical S matrix and provide your comments on the power coupling relation between port 1 and port 3

Exp.#	H3	**Measurement of return loss and insertion loss of any selected microwave component (Tee junction)**	CO: 01, 02
Date			

Block Diagram:



Magic-Tee junction (4 port device)



Data Table:

Input Port	Output Port	Matched Termination	Matched Termination	Power output
1	2	3	4	P2
1	3	2	4	P3
1	4	2	3	P4
2	1	3	4	P5
2	3	1	4	P6
2	4	1	3	P7
3	1	2	4	P8
3	2	1	4	P9
3	4	1	2	P10
4	1	2	3	P11
4	2	1	3	P12
4	3	1	2	P13

Analysis:

S12 = P2 – P1 S21 = P5 – P1 S31 = P8 – P1

S13 = P3 – P1 S23 = P6 – P1 S32 = P9 – P1

S14 = P4 – P1 S24 = P7 – P1 S34 = P10 – P1

Insertion Loss = P1 – P2

S12 = P2 – P1 **S21 = P4 – P1** **S31 = P6 – P1**

S13 = P3 – P1 **S23 = P5 – P1** **S32 = P7 – P1**

Where**, P1** is the reference value (0 dB) i.e. without E-plane Tee.

THEORY:

The device Magic Tee is a combination of E and H plane Tee. Arm 3 is the H-arm and arm 4 is the E-arm. If the power is fed, into arm 3 (H-arm) the electric field divides equally between arm1 and 2 with the same phase and no electric field exists in the arm 4. If 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 in arm 1 and 2 simultaneously it is added in arm 3 (H-arm) and it is subtracted in E-arm i.e., arm 4.

A. Isolation:

The Isolation between E and H arm 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 (port 3) when side arm 1 and 2 terminated in matched load.

Isolation (dB) = $10 \log_{10} [P4/P3]$

Similarly, Isolation between other ports may be defined.

B. Coupling Factor:

It is defined as $Cij = 10 - \propto/20$

Where '$\propto$' is attenuation / isolation in dB when 'i' is input arm and 'j' is output arm.

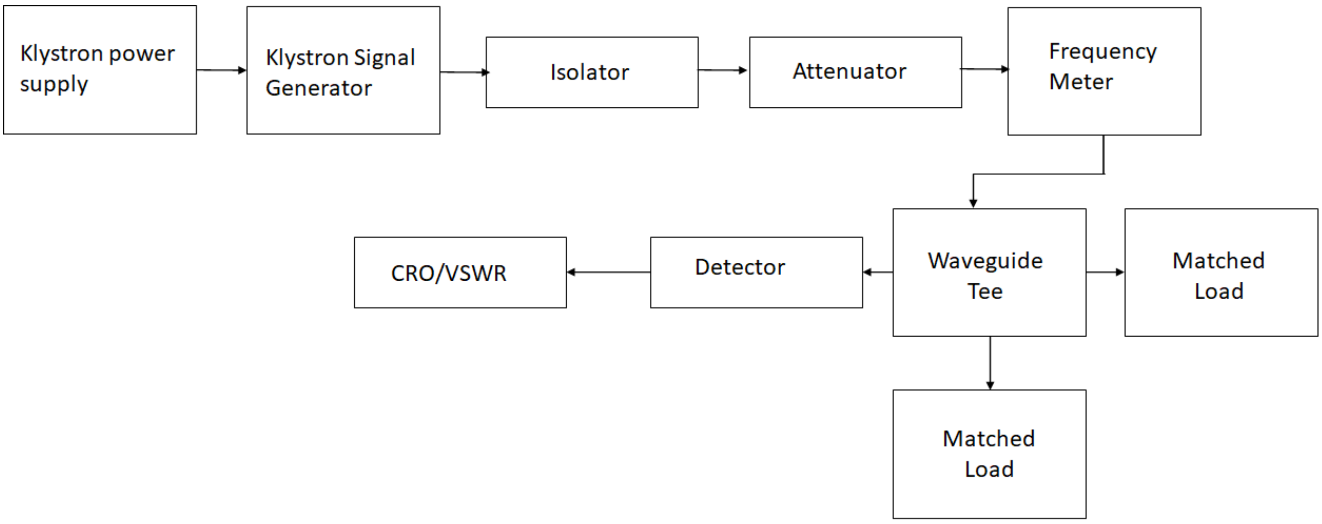
Thus, $\propto = 10 \log_{10} [P4/P3]$

Where P3 is the power delivered to arm 'i' and P4 is power detected at 'j' arm.

AIM:
To study the properties of waveguide tee junctions and to determine isolation and coupling coefficients.

EQUIPMENT:
Klystron power supply, Klystron signal generator, Isolator, Attenuator, Frequency meter, Waveguide tee, VSWR meter, Matched load, Detector.

EXPERIMENTAL SETUP:



PROCEDURE:

1. Set up the apparatus as shown in the figure and calibrate.
2. Measure the input power.
3. Connect the waveguide tee and measure the power from all the ports. While other ports are with the matched load.

FORMULA:

Isolation = $I_{12} = P_2 - P_1 = P_3 - P_1$

$$P_1 - -Power\ incident\ in\ port\ 1$$
$$P_2 - -Power\ detected\ in\ port\ 2$$

Coupling = $C_{ij} = 10^{-\alpha/20}$ where, α (dB) = $P_i - P_j$

TABLE:

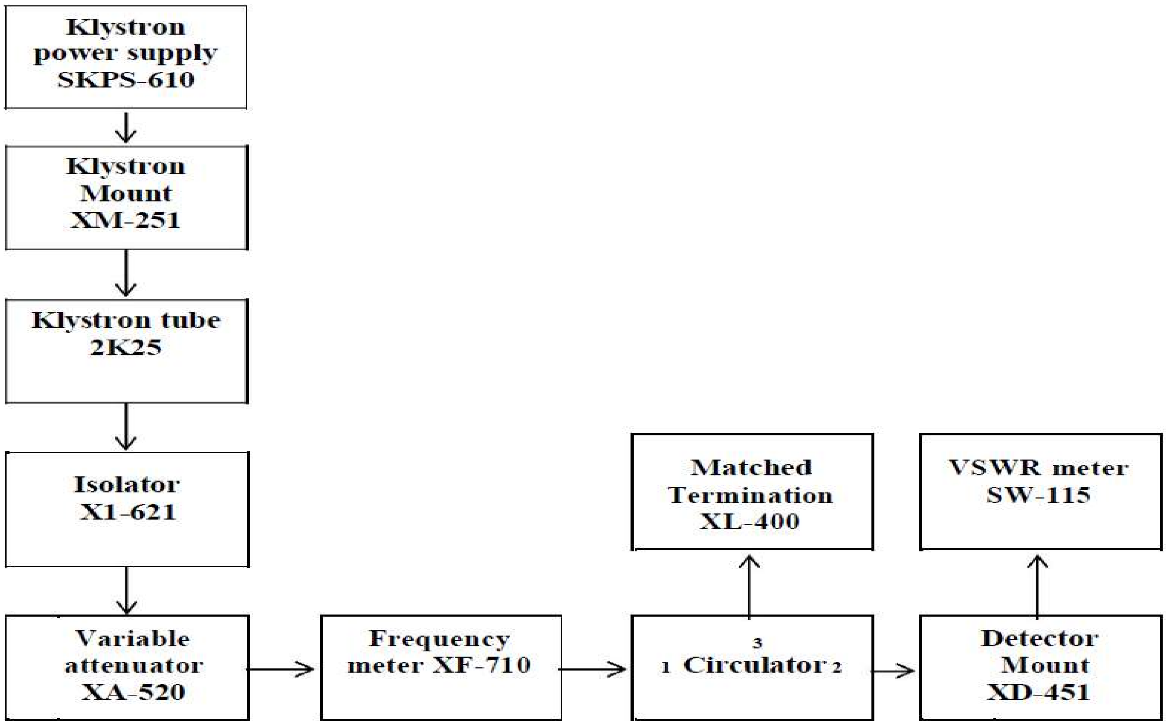
SI. NO	Nature of Tee	Power		Isolation	Coupling
		Input	Output		
		1st arm	2nd arm	I12	C12
			3rd arm	I13	C13
		3rd arm	2nd arm	I32	C32
			1st arm	I31	C31
		1st arm	2nd arm	I12	C12
			3rd arm	I13	C13
		3rd arm	2nd arm	I32	C32
			1st arm	I31	C31

RESULTS:

Provide measured data and relevant results.

Exp.#	H4	**Characterization of materials using circulator**	CO: 01, 02
Date			

BLOCK DIAGRAM:



Data Table:

Input Port	Output Port	Matched Termination	S-parameters
1	2	3	S12
1	3	2	S13
2	1	3	S21
2	3	1	S23
3	1	2	S31
3	2	1	S32
1	1	2,3	S11
2	2	1,3	S22
3	3	1,2	S33

THEORY:

Circulator can have any number of ports. Circulator is a multi-port junction. A wave incident in port 1 is coupled to port 2 only, a wave incident at port 2 is coupled to port 3 only and so on. Following is the basic parameters of isolator and circulator.

Insertion Loss:

Insertion loss is the ratio of power detected at output port to power supplied by source to the input port, measured with other ports terminated in matched load. It is expressed in dB.

Isolation:

Isolation is ratio of power applied to output to that measured at that input. This ratio is expressed in dB. The relation of a circulator is measured with 3rd port terminated in a matched load.

CALCULATIONS:

Insertion Loss = **P1 – P2**

Isolation = **P1 – P3**

P1 → without circulator -- > reference level (0 dB)

P2 → Port 1 (input)
Port 2 (output)
Port 3 (matched termination)

P3 → Port 3 (input)
Port 1 (output)
Port 2 (matched)

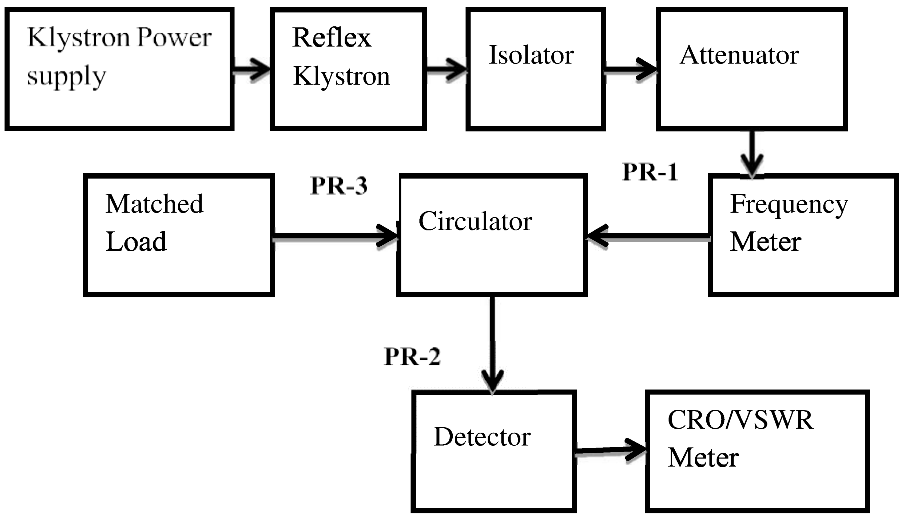
Aim of the Experiment: To conduct an experiment to determine the S-matrix of a Circulator

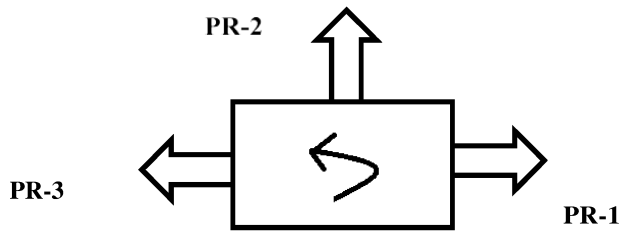
To test the characteristics of microwave components

Apparatus Required:

1. Klystron Oscillator
2. Klystron Power Supply
3. Isolator
4. Attenuator
5. Frequency Meter
6. Detector
7. CRO, VSWR meter and Probes and screws.
8. Circulator – Device under test
9. Matched load

Block Diagram of the Waveguide Bench: (To be drawn on the left side of the Notebook)





Basic Three Port Circulator

Procedure:

Phase 1: Calibration

1. Initially check whether the waveguide bench is physically intact with the detector connected to the frequency meter.
2. Set up the Klystron-based waveguide bench for a good power level around -14 dB. The power level should not be below -20dB for this experiment.
3. Determine the frequency of operation.
4. Get the calibration details verified by the lab staff. The calibration details include Beam voltage, beam current, repeller voltage, Power level, and Frequency should be written in the observation and verified by the laboratory staff.

Phase 2: S-Matrix Characterization of Circulator

a. Remove the detector and insert the directional coupler between the frequency meter and detector. Attach port PR-1 to the frequency meter and port PR-2 to the detector
b. Attach a matched load to Port (P)-3.
c. Now port P1 is acting as an input port, measure the power level at port 2 as P2 and record it. The calibrated power level is the input power P1.
d. Interchange the detector and matched load positions and measure the power level at port 3 as P3.
e. Repeat the experiment with other ports acting as input ports and measure the power level at all ports. The unused ports should be connected with matched load to avoid spurious reflections.
f. Each time the input port is changed, check whether the power output at the frequency meter is the same as calibrated power, if not note down the new reading.
g. Complete the tabular column. Determine the S matrix from the observed power readings
h. The S matrix calculations are as follows: To determine one entry of S matrix S_{mn} = Antilog ($(P_m - P_n)/20$)

Observations: (Left-hand side of the Record)

Input power at Port -1 (P1) (dB)	Power at Port 2 (P2) (dB)	Power at Port 3 (P3) (dB)

Input power at Port -2 (P2) (dB)	Power at Port 1 (P1) (dB)	Power at Port 3 (P3) (dB)

Input power at Port -3 (P1) (dB)	Power at Port 1 (P1) (dB)	Power at Port 2 (P2) (dB)

Phase 3: Material Analysis

1. Determine the input power and connect the input to port 1.
2. Fix the detector at Port 3
3. Keep different material sheets at Port 2, and determine the power levels at port 3
4. Provide your conclusions regarding the parameters that can be determined using the setup described in phase -3

Results and Conclusion:

Provide the numerical S matrix and provide your comments on the power coupling relation between port 1 and port 3. Provide your comments on the reading obtained with different materials.