STUDY OF MICROWAVE COMPONENTS AND INSTRUMENTS

Aim: To become familiar with microwave components and instruments available in

the laboratory.

Apparatus Used:

Klystron power supply, Gunn power supply, VSWR meter, power meter, Slotted section, Frequency/wave meter, RF Generator, Vector Network Analyzer.

Theory

Components/Devices:

Attenuator, circulator, Isolator, Waveguide twist, Magic Tee, E plane, H plane Tee, Directional coupler, Matched termination, PIN modulator, Crystal detector, Reflex klystron tube, Gunn diode, different types of antennas available.

LIST OF EQUIPMENTS AND DEVICES TO BE STUDIED:

Klystron Power Supply

1. Klystron tube

2. Isolator

3. Circulator

4. Attenuator

5. Direct reading frequency meter

6. Slotted line section with probe carriage

7. Crystal Detector

8. VSWR Meter

9. Different types of Antennas available

10. Magic tee

11. E and H Plane Tee

12. Matched Termination

13. Waveguide to coaxial adapter

INTRODUCTION:

A microwave test bench is an assembly of various microwave components, held together by Nuts & Bolts. It consists of a microwave source (Oscillator) at one end. The waves generated are led down by a wave guide through various components, so that the student can observe the propagation of waves, and their interaction and/or processing by various components.

● **Klystron PowerSupply**

Klystron Power supply is a regulated power supply for operating low power klystron. Klystron power supply generates voltage required for driving the reflex klystron tubes like 2k25, 2k56, 2k22. It is absolutely stable, regulated and short circuit protected power supply. It has the facility to vary the Beam Voltage continuously and built in facility of square wave and saw tooth generators, for amplitude and frequency modulation.


● **Reflex Klystron (Klystron mount with tube)**

A waveguide of suitable length having octal base on the broad wall of the waveguide for mounting the klystron tube. It consists of movable short at one end of the waveguide to direct the microwave energy generated by the klystron tube. A small hole located exactly at the center of the broad wall of the waveguide is used to put the coupling pin of the tube as the electric field vector of EM energy is maximum at the center only. The maximum power transfer can be achieved by tuning of the movable plunger.

The Reflex Klystron

The reflex klystron, shown in Fig., employs a somewhat different stratagem to extract energy from an electron beam in the form of microwave oscillation. The anode of the klystron is a resonant cavity that contains perforated grids to permit accelerated electrons to

pass through and continue their journey. Such electrons are not, however, subsequently collected by a positive electrode. Rather, they are deflected by a negatively polarized 'reflector' and are thereby caused to fall back into the cavity grids. The operational objective of the tube is to have such electrons return to the cavity grids at just the fight time to reinforce the electric oscillatory field appearing across these grids. When this situation exists, oscillations are excited and sustained in the cavity. Microwave power is coupled out of the cavity by means of a loop if coaxial cable is used, or simply through an appropriate aperture if a waveguide is used for delivering the power to the load. After the kinetic energy of the electrons has been given up to the oscillatory field of the cavity, the spent electrons fall back to the positive biased control grid where they are reflector with sufficient energy to pass through the cavity grids, thence to be collected by the control collected, thereby adding to control grid current. If the tube is not oscillating, a relatively high number of electrons are deflected by the retarding field of the grid. However, when oscillations are sustained in the cavity,the falling electrons yield most of their
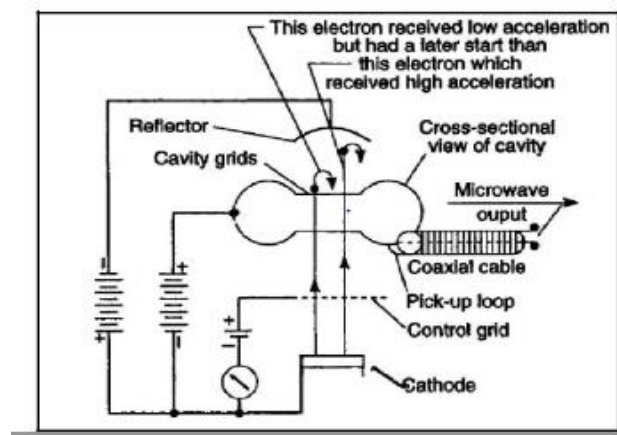
energy to the oscillating electric field appearing across the cavity grids. Such electrons are subsequently collected by the cavity grids, which in this function behave as the plate of an ordinary diode. Inasmuch as the spent electrons do not fall into the positive field of the control grid, a profound dip in control-grid current accompanies the onset of oscillation within the cavity.

● **Isolator:**

The microwave test bench includes an attenuator, and an isolator. Both of these helps to stop the reflected power from reaching the oscillator and pulling the frequency of the cavity and Gunn diode off tune when the load impedance is varied. An isolator is a two-port device that transmits microwave or radio frequency power in one direction only**.** It is used to shield equipment on its input side, from the effects of conditions on its output side; for example, to prevent a microwave source being detuned by a mismatched load. Anideal isolator transmits all the power entering port 1 to port 2, while absorbing all the power entering port 2.

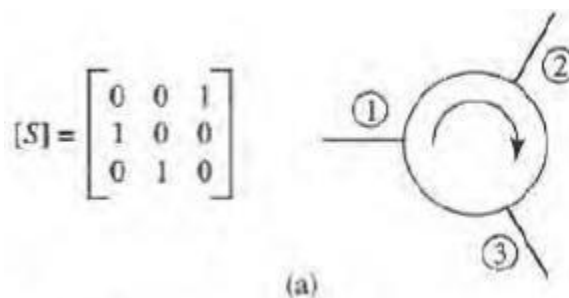An isolator in a non-reciprocal device, with a non-symmetric matrix.

$$S = \begin{pmatrix} 0 & 0 \\ 1 & 0 \end{pmatrix}$$

To achieve non-reciprocity, an isolator must necessarily incorporate a non-reciprocal material. At microwave frequencies this material is invariably a ferrite which is biased by a static magnetic field. The ferrite is positioned within the isolator such that the microwave signal presents it with a rotating magnetic field, with the rotation axis aligned with the direction of the static bias field. The behavior of the ferrite depends on the sense of rotation with respect to the bias field, and hence is different for microwave signals travelling inopposite directions. Depending on the exact operating conditions, the signal travelling in one direction may either be phase-shifted, displaced from the ferrite or absorbed.

● **Circulator**

A circulator is a passive non-reciprocal three port device in which microwave or radio frequency power entering any port is transmitted to the next port in rotation only. There are two types of circulators and their [S] matrices i.e. Clockwise circulator and Counterclockwise circulator.

Clockwise Circulator

$$[S] = \begin{bmatrix} 0 & 0 & 1 \\ 1 & 0 & 0 \\ 0 & 1 & 0 \end{bmatrix}$$

(a)

Counterclockwise Circulator

$$[S] = \begin{bmatrix} 0 & 1 & 0 \\ 0 & 0 & 1 \\ 1 & 0 & 0 \end{bmatrix}$$

(b)
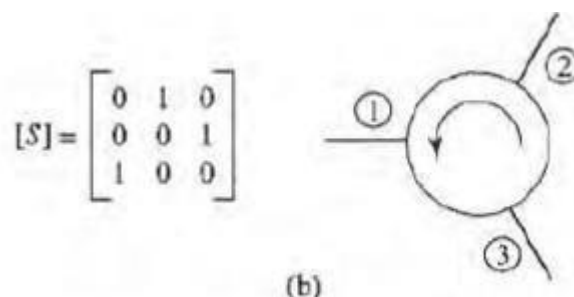
- **Attenuator:**

Attenuators are required to adjust the power flowing in a waveguide. Attenuators are of fixed, variable and rotary vane type, i.e.

Fixed: Any amount of fixed attenuation can be supplied between 3 to 40 dB. These attenuators are calibrated frequency band.

Variable: Variable attenuators provide a convenient means of adjusting power level very accurately.

● **Direct reading frequency meter**

This Frequency Meter has convenient readout with high resolution is provided by long spiral dials. These dials have all frequency calibrations visible so you can tell at a glance the specific portion of each band you are measuring. Overall accuracy of these frequency meters is 0.17% and includes such variables as dial calibration. It is constructed from a cylindrical cavity resonator with a variable short circuit termination. Theshorting plunger is used to change the resonance frequency of the cavity bychanging the cavity length. DRF measures the frequency directly. It is particularly useful when measuring frequency differences of small changes. The cylindrical cavity forms a resonator that produces a suck-out in the frequency response of the unit. This you would turn the knob until a dip in the response is observed.

● **Slotted line section with probe carriage:**

The slotted line represented the basic instrument of microwave measurements. With its help it is possible to determine the VSWR, attenuation, phase and impedances. The position of

carriage (probe) can be read from a scale with its vernier. The total travel of probe carriage is more than three time of half of guide wavelength. This system consists of a transmission line (waveguide), a traveling probe carriage and facility for attaching/detecting instruments. The slot made in the center of the broad face do not radiate for any power of dominant mode. The precision-built probe carriage having centimeters scale with a vernier reading of 0.1 mm least count is used to note the position of the probe. Additionally slotted section can be used to measure reflection coefficient and the return loss.

● **Crystal Detector:**

The crystal detector (Detector mount) can be used for the detection of microwave signal. RF choke is built into the crystal mounting to reduce leakage from BNC connector. Square law characteristics may be used with a high gain selective amplifier having a square law meter calibration. At low level of microwave power, the response of each detector approximates to square law characteristics and may be used with a high gain selective amplifier having a square law meter calibration.

● **VSWR Meter**

The VSWR meter or VSWR (voltage standing wave ratio) meter measures the standing wave ratio in a transmission line. The meter can be used to indicate the degree of mismatch between a transmission line and its load (usually a radio antenna), or evaluate the effectiveness of impedance matching efforts.

Ways to express VSWR

The reflection coefficient is what you'd read from a Smith chart. A reflection coefficient with magnitude of zero is a perfect match and a value of one is perfect reflection. The symbol for reflection coefficient is uppercase Greek letter gamma (Γ). Note that the reflection coefficient is a vector, so it includes an angle. Unlike VSWR, the reflection

coefficient can distinguish between short and open circuits. A short circuit has a value of -1 (1 at an angle of 180 degrees), while an open circuit is one at an angle of 0 degrees. The **return loss** of a load is merely the magnitude of the reflection coefficient expressed in decibels. The correct equation for return loss is:

$$R.L. = -20 \log |\Gamma|$$

Here are the equations that convert between VSWR, reflection coefficient and return loss:

$$\Gamma = \frac{VSWR - 1}{VSWR + 1} \qquad RL = -20 \log \left[\frac{VSWR - 1}{VSWR + 1} \right]$$

$$VSWR = \frac{1 + \Gamma}{1 - \Gamma} \qquad RL = -20 \log (\Gamma)$$

$$\Gamma = 10^{\frac{-RL}{20}} \qquad VSWR = \frac{1 + 10^{\frac{-RL}{20}}}{1 - 10^{\frac{-RL}{20}}}$$

Different types of Antennas available <u>Conical Horn:</u>

It is also called as waveguide fed Conical Horn. The conical horn antenna is a practical microwave antenna, often used as a feed for communication / satellite dishes and radio telescopes. Although the axial symmetry makes it capable of handling any polarization of the exciting fundamental (TE11) mode, the pin-fed horn design provided here is for linearly polarization.

There are a number of permutations on the basic horn design which can serve to minimize the effects of diffractions, improve pattern symmetry and reduce the side lobe levels. These include corrugating the internal walls, curving the walls at the aperture, incorporating corrugations with the wall curvature at the aperture, and introducing higher order modes in the horn to reduce the field at the aperture edges. A lens is often placed across the aperture to compensate for phase error and thus narrow the beam width.

<u>Parabolic Dish:</u>

A parabolic antenna is an antenna that uses a parabolic reflector, a surface with the cross-sectional shape of a parabola, to direct the radio waves. The most common form is shaped like a dish and is popularly called a dish antenna or parabolic dish. The main advantage of a parabolic antenna is that it is highly directive; it functions analogously to a searchlight or flashlight reflector to direct the radio waves in a narrow beam, or receive radio waves from one particular direction only. Parabolic antennas have some of the highest gains that is they can produce the narrowest beam width angles, of any antenna type. They are used as high-gain antennas for point-to-point radio, television and data communications, and also for radiolocation (radar), on the UHF and microwave (SHF) parts of the electromagnetic

spectrum. The relatively short wavelength of electromagnetic radiation at these frequencies allows reasonably sized reflectors to exhibit the desired highly directional response.

With the advent of TVRO and DBS satellite television dishes, parabolic antennas have become a ubiquitous feature of the modern landscape, not only in rural locales where CATV and terrestrial signals were limited or non-existent, but also in urban and suburban regions, where the aforementioned services compete with CATV and broadcast media. Extensive terrestrial microwave links, such as those between cell phone base stations, and wireless WAN/LAN applications have also proliferated this antenna type. Earlier applications included ground-based and airborne radar and radio astronomy.

Although the term dish antenna is often used for a parabolic antenna, it can connote a spherical antenna as well, which has a portion of spherical surface as the reflector shape.

TYPES OF PARABOLIC DISH:

Parabolic antennas are distinguished by their shapes:

Cylindrical - The reflector is curved in only one direction and flat in the other. The radio waves come to a focus not at a point but along a line. The feed is often a dipole antenna located along the focal line. It radiates a fan-shaped beam, narrow in the curved dimension, and wide in the un-curved dimension. The curved ends of the reflector are sometimes capped by flat plates, to prevent radiation out the ends, and this is called a pillbox antenna.

• Orange peel - Another type is very long and narrow, shaped like the letter "C". This is called an orange peel design, and radiates an even wider fan beam. It is often used for radar antennas.

Paraboloidal or dish - The reflector is shaped like a paraboloid. This is the most common type. It radiates a narrow pencil-shaped beam along the axis of the dish.

Shrouded dish - Sometimes a cylindrical metal shield is attached to the rim of the dish. The shroud shields the antenna from radiation from angles outside the main beam axis, reducing the side lobes. It is sometimes used to prevent interference in terrestrial microwave links, where several antennas using the same frequency are located close together. The shroud is coated inside with microwave absorbent material. Shrouds can reduce back lobe radiation by 10 dB.

They are also classified by the type of feed; how the radio waves are supplied to the antenna:

Axial or front feed - This is the most common type of feed, with the feed antenna located in front of the dish at the focus, on the beam axis. A disadvantage of this type is that the feed and its supports block some of the beam, which limits the aperture efficiency to only 55 - 60%.

Offset or off-axis feed - The reflector is an asymmetrical segment of a paraboloid, so the focus, and the feed antenna, is located to one side of the dish. The purpose of this
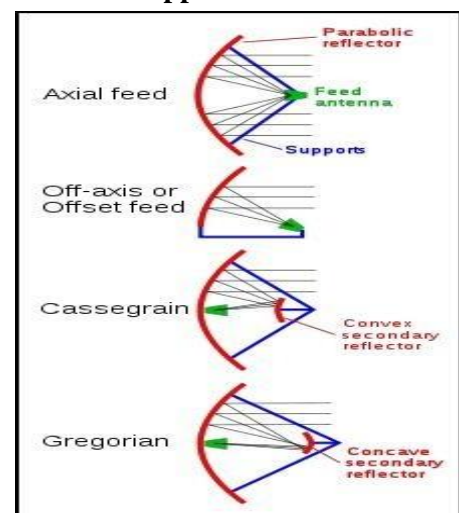
design is to move the feed structure out of
the beam path, so it doesn't block the beam.
It is widely used in home satellite television
dishes, which are small enough that the feed
structure would otherwise block a significant
percentage of the signal.

Cassegrain - In a Cassegrain antenna the feed is located on or behind the dish, and radiates forward, illuminating a convex hyperboloidal secondary reflector at the focus of the dish. The radio waves from the feed reflect back off the secondary reflector to the dish, which forms the main beam. An advantage of this configuration is that the feed, with its waveguides and "front end" electronics does not have to be suspended in front of the dish, so it is used for antennas with complicated or bulky feeds, such as large satellite communication antennas and radio telescopes. Aperture efficiency is on the order of 65 - 70%.

Gregorian - Similar to the Cassegrain design except that the secondary reflector is concave, (ellipsoidal) in shape. Aperture efficiency over 70% can be achieved.
Gain:

The directive qualities of an antenna are measured by a dimensionless parameter called its gain, which is the ratio of the power received by the antenna from a source along its beam axis to the power received by a hypothetical isotropic antenna. The gain of a parabolic antenna is:

$$G = \frac{4\pi A}{\lambda^2} e_A = \frac{\pi^2 d^2}{\lambda^2} e_A$$

Where,

A is the area of the antenna aperture, that is, the mouth of the parabolic reflector

d is the diameter of the parabolic reflector

λ is the wavelength of the radio waves.

eA is a dimensionless parameter called the aperture efficiency. The aperture efficiency of typical parabolic antennas is 0.55 to 0.60.

● **MagicTee:**

The magic tee is a combination of E and H plane tees. Arm 3 forms an H-plane tee with arms 1 and 2. Arm 4forms an E-plane tee with arms 1 and 2. Arms 1and 2 are sometimes called the side or collinear arms. Port 3 is called the H-plane port, and is also called the Sum port or the P-port (for parallel). Port 4 is the E-plane port, and is also called the(delta) port, difference port, or S-port (for Series).The name "magic tee" is derived from the way in which power is divided among the various ports. A signal injected into the H-plane port

will be divided equally between ports 1 and 2, and will be inphase. A signal injected into the E-plane port will also be divided equally between ports 1 and 2, but will be 180 degrees out of phase. If signals are fed in through ports 1 and 2, they are added at the H-plane port and subtracted at the E-plane port. Thus, with the ports numbered as shown, and to within a phase factor, the full scattering matrix for an ideal magic tee is

$$S = \frac{1}{\sqrt{2}} \begin{pmatrix} 0 & 0 & 1 & -1 \\ 0 & 0 & 1 & 1 \\ 1 & 1 & 0 & 0 \\ -1 & 1 & 0 & 0 \end{pmatrix}$$
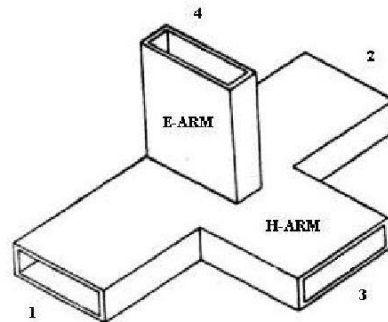
● E and H Plane Tee

In E Plane Tee the junction of the auxiliary arm is made on the broad wall of the main waveguide. And in H Plane Tee the junction of auxiliary arm is made on the narrow wall of the main waveguide.
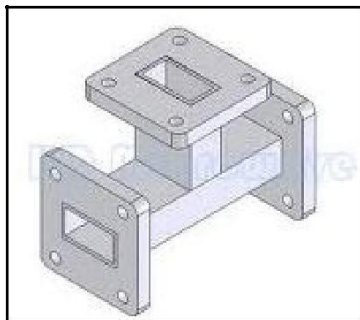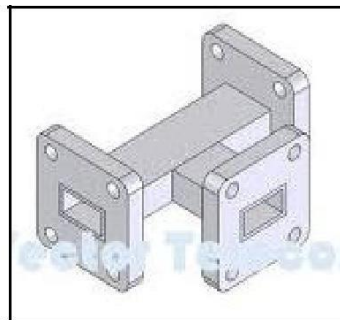
E Plane Tee   H Plane Tee

● Matched Termination

These are used for terminating the waveguide systems operating at low average power and are designed to absorb all the applied power assuring low SWR. Where a matched load is required as in the measurement of reflection, discontinuities of obstacle in waveguide systems, these components are used. These are also employed as a precise reference load with tee junctions, directional couplers etc.

● **W/g Coaxial Adaptor:**

These adapters consist of a short section of waveguide with a probe transition coax **mounted on broad wall. It transforms waveguides impedance into** coaxial impedance. Power can be transmitted in either direction. Each adaptor covers 50% of the waveguide band.

Pin configuration of Reflex Klystron:
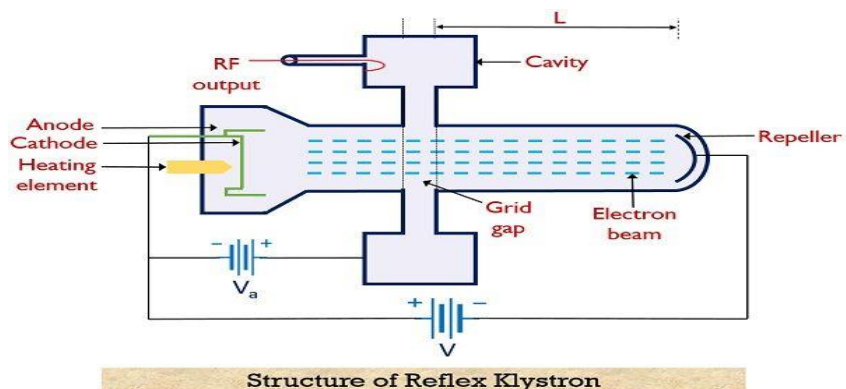
Structure of Reflex Klystron

Objectives:

1. Note relevant Technical specifications of the instruments.

2. Study position and functions of the front panel controls of the equipment.

3. Know basic principle of operation and functional block diagram of the instrument.

4. Facilities provided and limitations of the equipment if any.

5. Know initial settings of controls of the equipments before switching on the supply.

6. Precautions to be taken while carrying out the measurements.

Exp. No:1   **Date:**

REFLEX KLYSTRON CHARACTERISTICS

Aim: To determine the Voltage & Mode characteristics of Reflex Klystron.

Apparatus Required:

S.no	Apparatus	Range/Specification	Quantity
1	Klystron Power Supply	-	1
2	Klystron Mount	-	1
3	Isolator	-	1
4	Variable Attenuator	-	1
5	Frequency Meter	-	1
6	Detector Mount	-	1
7	Meter/CRO	30 MHz	1
8	Waveguide Stands	-	4
9	BNC Cables	-	1
10	Cooling Fan	-	1

Theory:

The Reflex Klystron is a single cavity variable frequency microwave generator of low power and low efficiency. This is most widely used in applications where variable frequency is desired, as in Radar receivers, local oscillators in microwave receivers, signal source in microwave generator of variable frequency, portable microwave links and pump oscillator in the parametric amplifier.

Reflex klystron consists of an Electron gun, a filament surrounded by cathode and a focusing electrode at cathode potential. The electron gun is accelerated towards a repeller electrode which is at a high negative potential V_R. The electrodes never reach the repeller because of the negative potential V_R. The electrons never reach the repeller and are returned back towards the gap, under suitable conditions, the electrons give more energy to the gap than they look. From the gap on their forward journey and oscillations are sustained.

Applications:

1. Pump Oscillator for Parametric amplifiers.
2. Local Oscillator in microwave receivers.

Bench Set Up for Reflex Klystron
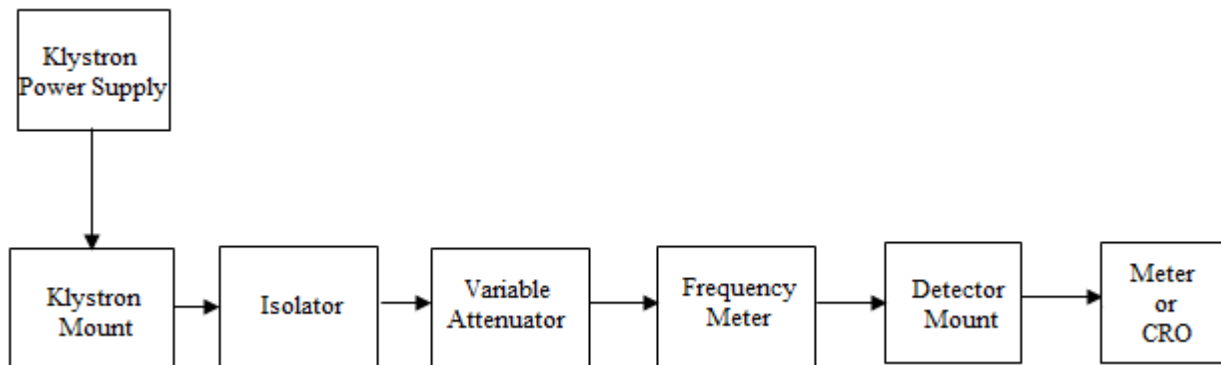
Bench Setup:

1. Set modulator selector switch to AM modulation position

2. Keep AM knob and frequency knob to mid position

3. Set HT/LT switch to LT position

4. Set voltage/current switch to current position

5. Set the display to read beam voltage

6. Now switch HT/LT to HT

7. Wait for some 10secs until tube gets warm up and a square wave is displayed on CRO.

Procedure for Mode Characteristics:

1. Arrange the bench setup as shown in figure.

2. Keep the beam voltage around the value of 300 volts.

3. Vary the repeller voltage in steps of 5 volts and measure the corresponding beam current by switching into current mode using in built ammeter.

4. For various values of repeller voltage find the repeller current.

5. To measure the frequency adjust the frequency meter (rolling in either up or down direction) until minimum dip is obtained in the detector.

6. At this value of dip measure the frequency of incoming signal.

Tabular Column:

S.No.	Repeller Voltage (Volts)	Output Voltage (Volts)	Output Frequency (GHz)

Model Waveforms:
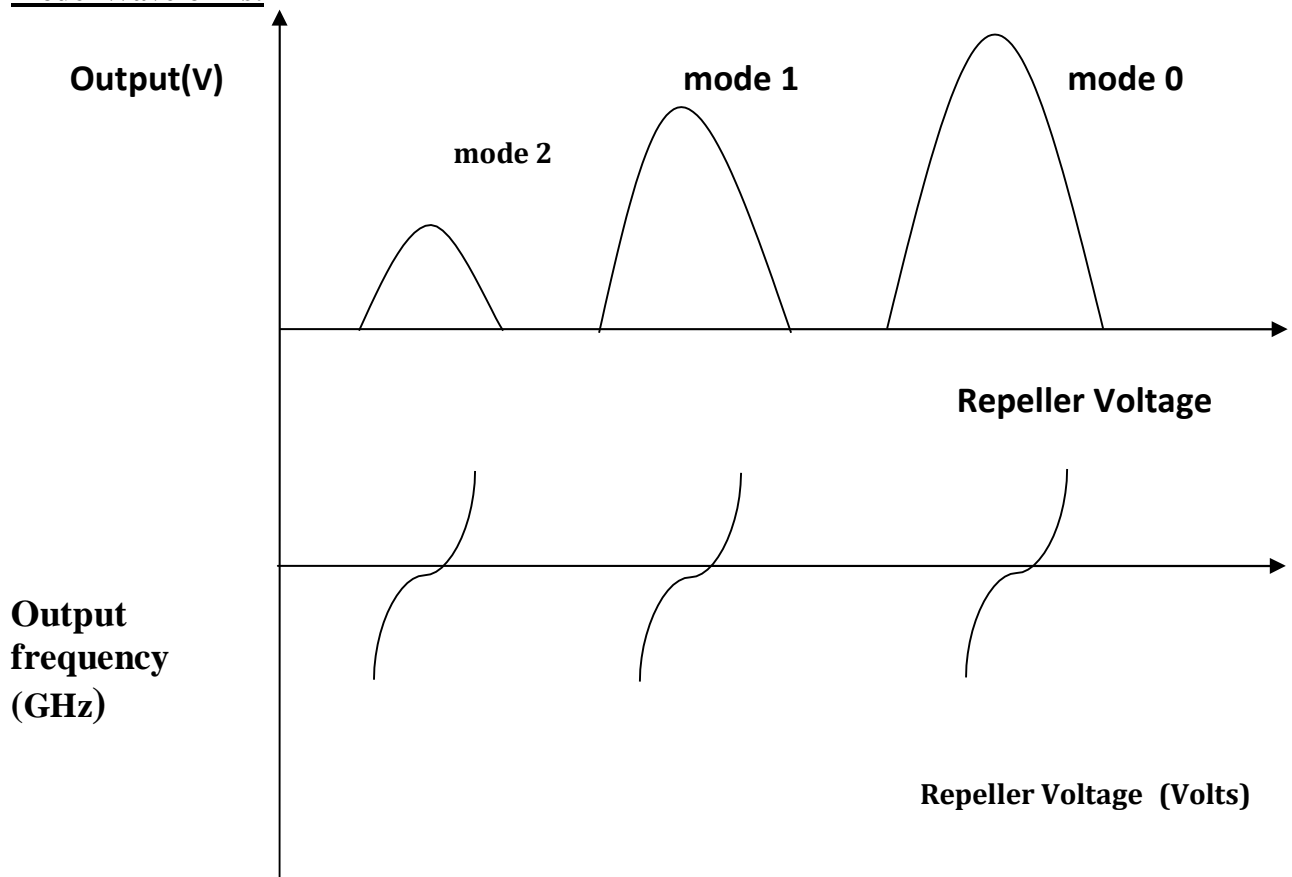
Precautions:

1. For stable operation the Klystron is allowed to warm up to 10 minutes before the experiment is conducted.

2. The attenuator position should not be disturbed after adjusting for maximum power output.

3. Loose connections between the components should be avoided.

Result:

Conclusion:

Viva questions:

1. List two basic configurations of Klystron tubes.

2. What is velocity modulation?

3. List out the characteristic of two cavity klystron amplifier.

4. Draw the reflex klystron modes.

5. When the output power of reflex klystron maximum?

Exp. No:2   **Date:**

GUNN DIODE CHARACTERISICS

Aim: To determine the characteristics of Gunn diode

Apparatus Required:

S.no	Apparatus	Range/Specification	Quantity
1	Gunn Power Supply	-	1
2	Gunn Oscillator	-	1
3	PIN Modulator	-	1
4	Variable Attenuator	-	1
5	Isolator	-	1
6	Detector Mount	-	1
7	Matched terminator	-	1
8	Waveguide Stands	-	4
9	BNC Cables	-	1
10	Cooling Fan	-	1

Theory:

Transferred electron devices operate with hot electrons whose energy is very much greater than the thermal energy. Transistors operate with warm electrons whose energy is not much than their thermal energy (0.026 ev) at room temperature, Gunn diode is an example of this kind. Gunn-Effect diodes are named after J.B.Gunn who in 1963 discovered periodic fluctuations of current passing through the n-type GaAs specimen when the applied voltage exceeded a certain critical value.

From Gunn's observations, the carrier drift velocity is linearly increased from zero to a maximum when the electric field is varied from zero to a threshold value. The Gunn's observations are in complete agreement with the Ridley-Watkin-Hilsum (RWH) theory.

There are two modes of negative resistance devices: 1. Voltage controlled mode 2. Current controlled mode. In the voltage-controlled mode, the current density can be multi valued, whereas in the current controlled mode, the voltage can be multi valued. The negative resistance of the sample at a particular region is $\frac{dI}{dV} = \frac{dJ}{dE}$ = Negative resistance.

Applications:

1. Broadband linear amplifier
2. Fast combinational and sequential logic circuits
3. As pump source in parametric amplifier.

Bench Set Up for Gunn Diode Characteristics
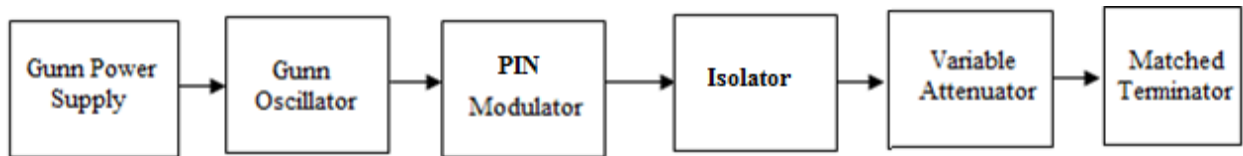
Procedure:

1. Connect the components as shown in the Bench setup.
2. Maintain some PIN bias voltage constantly.
3. Vary the Gunn biasing voltage from 0 to 9V in steps and note the Corresponding current on the panel meter of the power supply.
4. Observe the ammeter output and note the threshold voltage corresponding to where the output current starts decreasing.
5. Observe the ammeter reading and note down the valley voltage at which the current starts increasing again.
6. Plot the V-I Characteristics for the obtained values and determine threshold voltage (V_{th}).

Tabular Column: **Model Graph:**

$V_{th} =$

VOLTAGE(V)	CURRENT (mA)
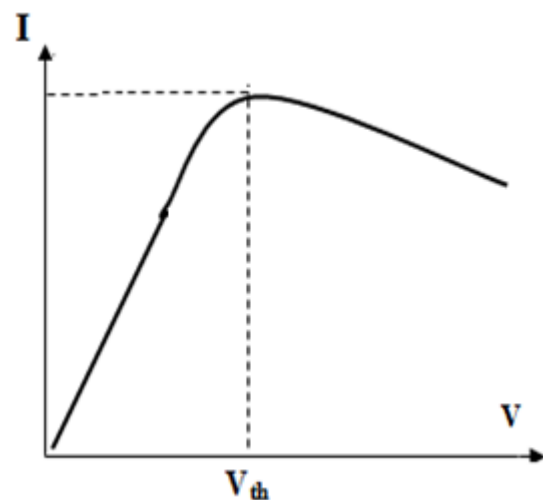
V-I Characteristics of Gunn Diode

Precautions:

1. The bias is kept course and the fine control knobs of the power meter are kept in the minimum position before the meter is switched on.

2. The attenuator position should not be disturbed after adjusting for maximum power output.

3. Loose connection between the components should be avoided.

Result:

Conclusion:

Viva questions:

1. What are the different modes of Gunn diode?

2. What is Gunn Effect?

3. What are the applications of Gunn Diode?

4. Explain LSA Mode.

5. Explain the purpose of PIN modulator.

Exp. No:3   **Date:**

ATTENUATION MEASUREMENT

Aim: To determine the attenuation of the given attenuators using power ratio method.

Apparatus Required:

S.no	Apparatus	Range/Specification	Quantity
1	Klystron Power Supply	-	1
2	Klystron Mount	-	1
3	Isolator	-	1
4	Variable Attenuator	-	1
5	Frequency Meter	-	1
6	Detector Mount	-	1
7	Meter/CRO	30 MHz	1
8	Waveguide Stands	-	4
9	BNC Cables	-	1
10	Cooling Fan	-	1
11	Unknown Attenuator (DUT)	-	1

Theory:

Attenuation is the ratio of input power to the output power and is normally expressed in decibels. Microwave components and devices almost always provide some degree of attenuation.

$$\text{Attenuation (in dB)} = 10 \log \frac{P_{in}}{P_{out}}$$

Where P_{in} = Input power   & P_{out} = Output power.

The amount of attenuation can be measured by two methods: Power ratio method and RF Substitution method. Power ratio method involves measuring the input power with and without the device whose attenuation is to be measured. The powers are measured in each step as $P1$ & P_2. The ratio of power $\frac{P1}{P2}$ expressed in decibels gives the attenuation.

Bench Set Up for Attenuation Measurement

Bench Set-Up:1(Without DUT)
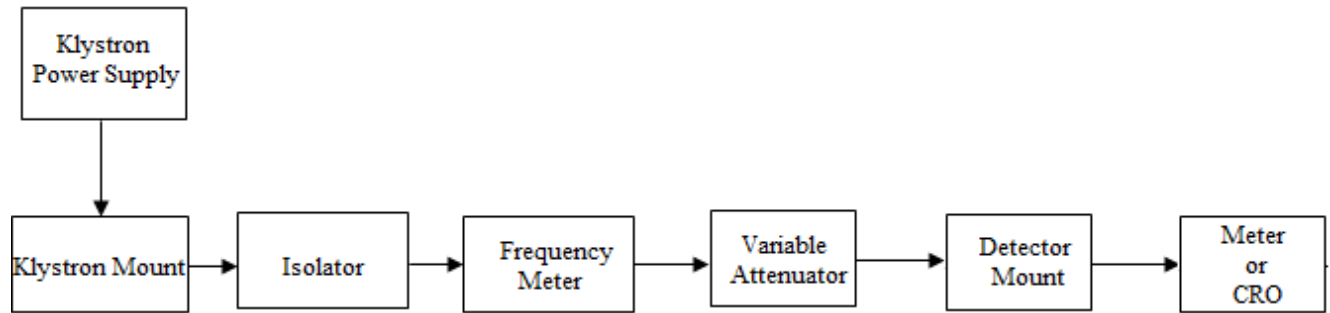
Bench Set-Up:2 (With DUT)
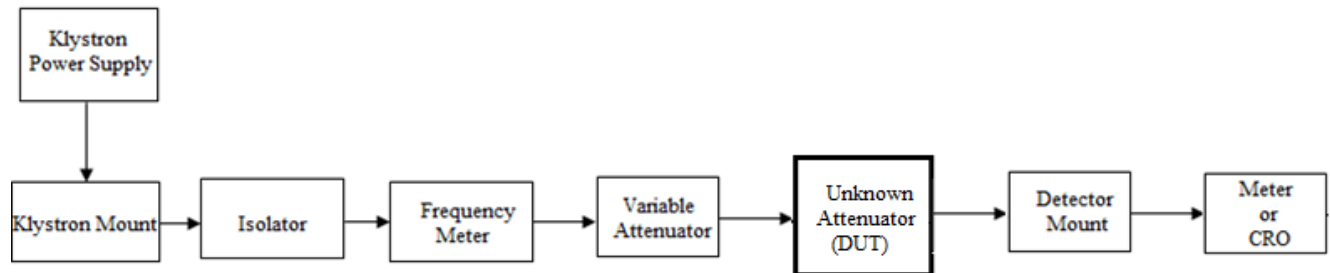
Procedure:

1. Switch on the supply with proper precaution & necessary cooling system

2. Assemble the components as shown in the bench set-up 1.

3. Operate the klystron in any of the mode to get higher output than the expected attenuation of the component under test.

4. Note the power output of the mode which is P_1

5. Connect the component (whose attenuation is to be measured) as shown in the bench setup 2 without disturbing then klystron source.

6. Now measure the output of bench setup 2 which is P_2.

7. The attenuation of the given component is calculated as

$$A = 10 \log [P_1/ P_2] \text{ dB}$$
$$= 20 \log [V_1/V_2] \text{dB}$$

For Attenuator

$V_1 =$

$V_2 =$

$A = 20 \log [V_1/V_2] \quad =$

Precautions:

1. For stable operation the Klystron is allowed to warm up to 10 minutes before the experiment is conducted.

2. The attenuator position should not be disturbed after adjusting for maximum power output.

3. Loose connections between the components should be avoided.

Result:

Attenuation obtained for _____ db.

Conclusion:

By that the attenuator s attenuation is found by using power ratio method and it is as follows A = _____db.

Viva:

1. What are the various methods used for attenuation?

2. What is the drawback of power ratio method?

3. Which is the method eliminates the drawback power ratio method?

4. Give the examples for square law device

5. Define Attenuation.

Exp. No:4   **Date:**

DIRECTIONAL COUPLER CHARACTERISTICS

Aim: To measure the Directivity and Coupling factor for the given Directional couplers.

Apparatus Required:

S.no	Apparatus	Range/Specification	Quantity
1	Klystron Power Supply	-	1
2	Klystron Mount	-	1
3	Isolator	-	1
4	Variable Attenuator	-	1
5	Frequency Meter	-	1
6	Detector Mount	-	1
7	Meter/CRO	30 MHz	1
8	Waveguide Stands	-	4
9	BNC Cables	-	1
10	Cooling Fan	-	1
11	Directional coupler	-	1
12	Matched Terminator	-	1

Theory:

Directional coupler flanged, built in waveguide assembles which can sample a small amount of microwave power for measurement purposes. They can be designed to measure incident and/or reflected powers, SWR values, provide a signal path to a receiver or perform other desirable operations. They can be unidirectional or bidirectional powers.

In its most common form, the directional coupler is a four port waveguide junction consisting of a primary main waveguide and a secondary auxiliary waveguide. A small portion of input power at port 1 is coupled to port 4 so that measurement of this small power is possible. Ideally no power should come out of port 3.

The performance of a directional coupler is usually defined in terms of two parameters:

1. Coupling factor 2. Directivity.

Coupling factor (C): The coupling factor of a directional coupler is defined as the ratio of the incident power (P_i) to the forward power (P_f) measured in dB.

$C = 10 \log_{10} P_i/P_f$ dB.

Directivity (D): The directivity of a directional coupler is defined as the ratio of forward power (P_f) to the back power (P_b)

$D = 10 \log_{10} P_f/P_b$ dB.

Directional Coupler Diagram:
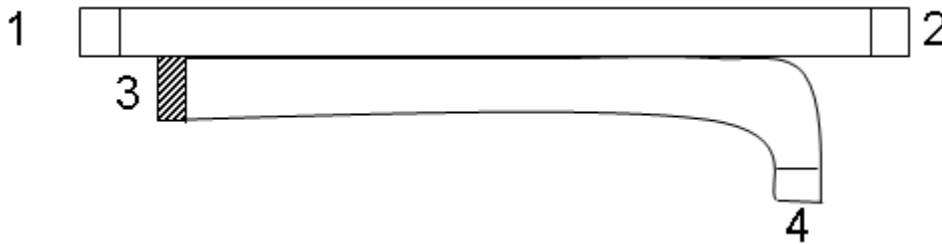
Bench Set-Up 1: Coupling Factor Measurement:
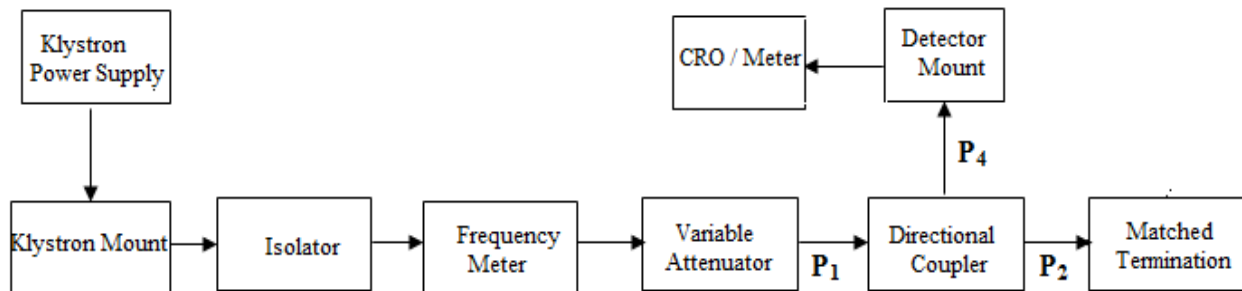
Procedure for Coupling Factor Measurement:

1. Switch ON the klystron supply with necessary precautions.

2. Operate the Klystron in best mode and note the corresponding output power as P_1.

     (P_1 = Incident power)

3. Connect the Directional Coupler as shown in the experimental setup. Measure the

4. sampled power at the auxiliary arm(Port 4) as P_4. (Where P4 = Forward power)

     The coupling factor of the given Directional Coupler can be calculated as

$$\text{Coupling factor (C)} = 10 \log [P_1/P_4]$$
$$= 20 \log [V_1/V_4] \text{ dB}$$

Procedure for Directivity Measurement:

1. Without disturbing the mode of klystron connect the directional coupler as shown in the bench setup.

2. Measure the backward power in the auxiliary arm (port4) as P_3.

3. The directivity of the given Directional Coupler can be calculated as.

     Directivity (D) = 10 log [Forward power/Backward power]

          = **20 log** [Forward voltage/Backward voltage]

     =20 log (V_4/V_3) **dB**

Calculations:

1. For ____ dB directional coupler

    Incident voltage (V_1) =

    Forward voltage (V_4) =

    Backward voltage (V_3) =

    Coupling factor (C) = **20 log** (   ) =

    Directivity (D) = **20 log** (   ) =

Precautions:

1. Beam Voltage should be minimum and Repeller voltage should be normal   before switch ON/OFF the Klystron Power Supply.
2. Loose connections between the components should be avoided.
3. The Directional Coupler must be handled carefully while inserting into the circuit.

Result:

For   dB Coupler:

Coupling factor (C) =

Directivity   (D) =

Conclusion:

<u>**Viva:**</u>

1.   What is a directional coupler?

2.   List the types of directional coupler.

3.   Draw a basic directional coupler?

4.   List the performance of a directional coupler.

5.   Define the directivity `D' of a directional coupler.

Exp. No: 5   **Date:**

VSWR MEASUREMENT

Aim: To measure the VSWR by using direct method and double minima method.

Apparatus Required:

S.no	Apparatus	Range/Specification	Quantity
1	Klystron Power Supply	-	1
2	Klystron Mount	-	1
3	Isolator	-	1
4	Variable Attenuator	-	1
5	Frequency Meter	-	1
6	Meter/CRO	30 MHz	1
7	Waveguide Stands	-	4
8	BNC Cables	-	1
9	Cooling Fan	-	1
10	Slotted Line Section	-	1
11	Tunable Probe Detector	-	1

Theory:

The magnitude of the standing waves can be measured in terms of standing wave ratios. The ratio of V_{max} and V_{min} is the voltage standing wave ratio (or) VSWR, denoted by S.

$S = \dfrac{|V_{max}|}{|V_{min}|}$ which allows to take values in the range $1 \leq S \leq \infty$.

The value of S can be measured experimentally by using a slotted line. Its value depends on the degree of mismatch at the load i.e. on the reflection coefficient. Value of VSWR not exceeding 10 are very easily measured with the set up and can be read off directly on the VSWR meter calibrated.

The measurement basically consists of simply adjusting the Attenuator to give an adequate reading on the meter, which is a DC Milli Volt Meter. The probe on the slotted wave is moved to get maximum reading on the meter. The attenuation is now adjusted to get full scale reading and this full scale reading is noted down. Next the probe on the slotted line is adjusted to get minimum reading on the meter (corresponding to V_{min}). The ratio of the first reading on the meter to the second gives the VSWR (Voltage Standing Wave Ratio).

Bench Set Up For VSWR Measurement

Bench Set-Up 1: Low VSWR Measurement
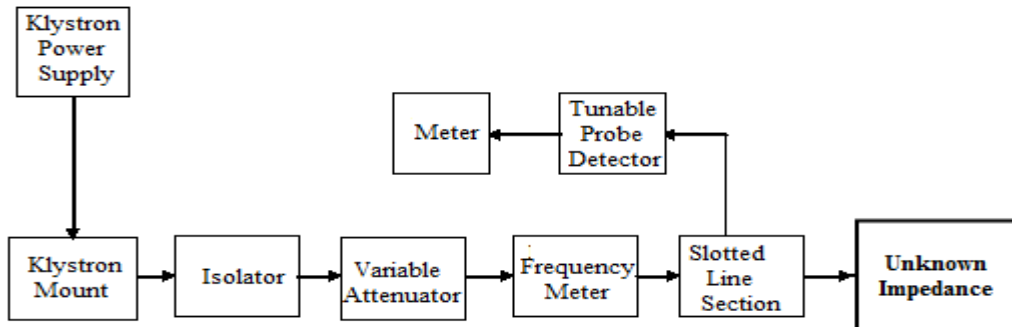
Procedure:

For Low VSWR Measurement:

1. The components are arranged as shown in the bench set-up1.
2. The probe is moved along the slotted line section to get a maximum deflection in the VSWR meter and adjust the meter to read 1.0 on the scale.
3. The probe is moved along the slotted line section and stop at where a minimum deflection is shown. The VSWR meter reading directly gives the values of low VSWR.

Bench Set-Up 2: High VSWR Measurement
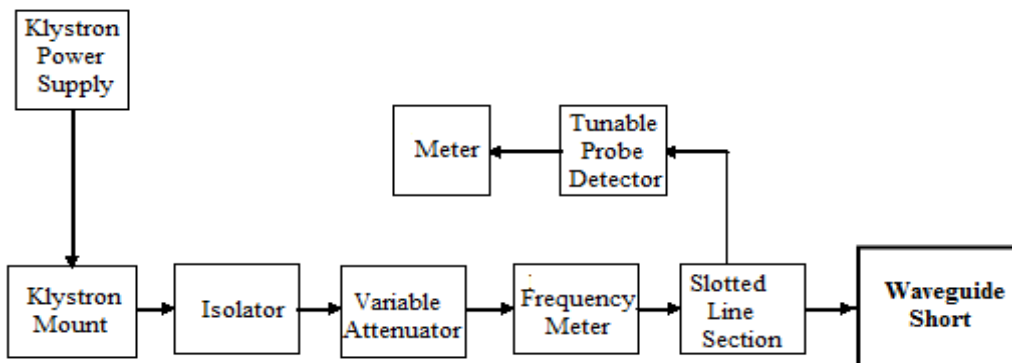
Procedure for High VSWR Measurement:

1. The components are arranged as shown in the bench set-up2.
2. The probe is inserted to depth where the minima can be read without difficulty and then moved to a point where the power is twice the minima power. This point is denoted by **D$_{m1}$**. The probe is then moved to the twice the power point on other side of the minima and corresponding point is noted as **d$_{m2}$**.
3. λg is calculated by replacing unknown impedance with wave guide short.

$$\text{Then High VSWR} = \frac{\lambda g}{\pi(d_{m1} \sim d_{m2})}$$

λg=2x Distance between successive minima
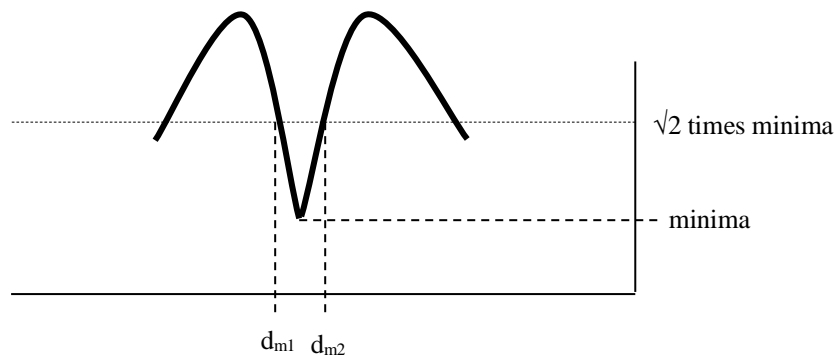
Calculations:

Low VSWR:

$V_{max}=$

$V_{min}=$

$VSWR=V_{max}/V_{min}$

VSWR=

High VSWR:

Readings :

First minima   (d1) = _____ cm.

Second minima   (d2) = _____ cm.

Guide wave length ($λg_1$) = 2 X (**Distance between successive minima**)

$$= 2 \text{ X } (d1 \sim d2)$$

$$= 2 \text{ X } (\qquad)$$

$$= \text{_____ cm.}$$

3dB (left) d_{m1} = _____ cm.

3dB (left) d_{m2} = _____ cm.

$$VSWR = \frac{λg}{\pi(d_{m1} \sim d_{m2})} =$$

Precautions:

1. Beam voltage should be minimum and repeller voltage should be normal before switch ON/OFF the Klystron Power Supply.

Result:

Low VSWR=

High VSWR=

Conclusion:

Viva:

1. What is a directional coupler?

2. List the types of directional coupler.

3. Draw a basic directional coupler?

4. List the performance of a directional coupler.

5. Define the directivity `D' of a directional coupler.

ANTENNAS

SOFTWARE SETUP INSTRUCTIONS

1) a) Run the setup.exe available from the AMS installer folder *(CD provided*

with kit), then following window will appear.
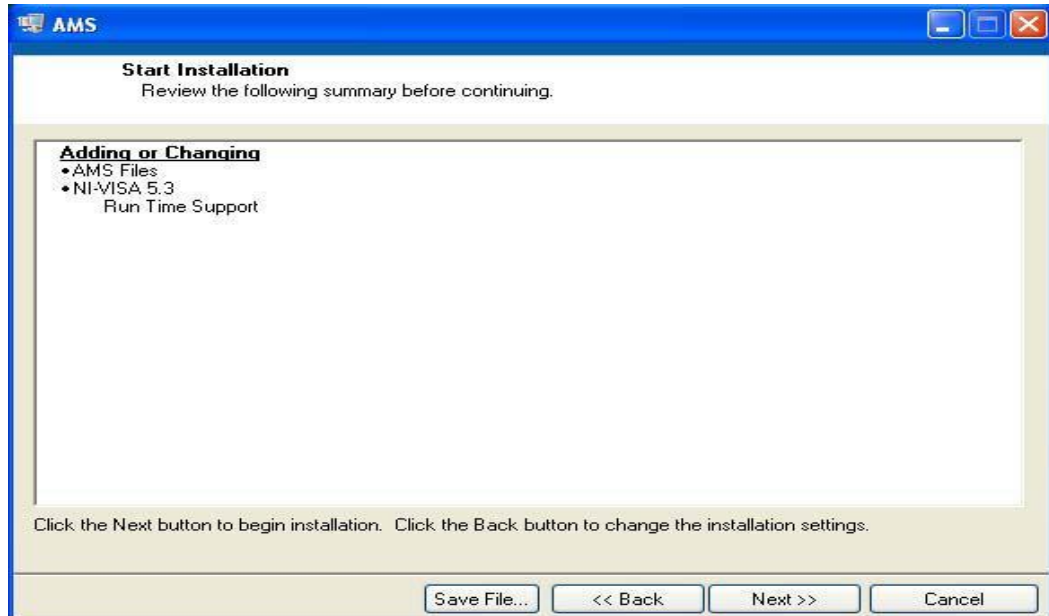
Click on Next then.
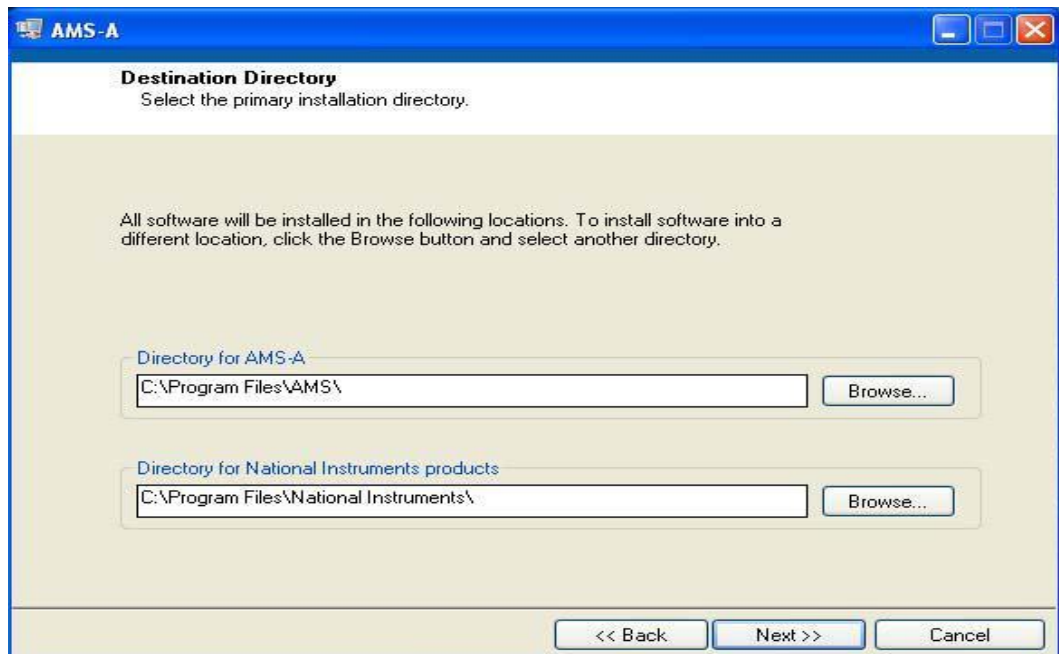
b)   Then select the directory where you want to install the setup, and

then click on Next.

c)   Then click on finish.

2)   Restart the PC.

3) Connect the **AMS (TRAINNER KIT) to the PC** using USB to USB cable (*provided with the kit*), and assign FTDI drivers.

4) After the installation, go to directory where software installation is taken place and open the AMS.exe

I.e. by default C:/program files/AMS/AMS.exe.
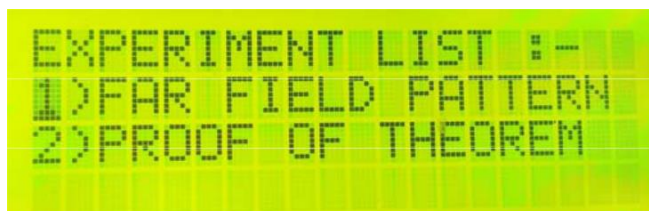
CONTROL THROUGH HARDWARE (PANEL)

1. When we turn on the kit following message will be displayed.

2. Select Main Experiment as **Far Field Pattern.**
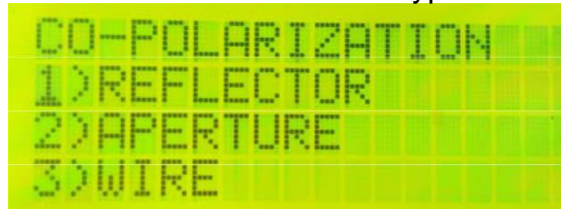
3. Select **Co-Polarization** as Experiment from the panel.

4. Use **SHIFT** button to Scroll. Select Type of Antenna as **WIRE**.

5. Select Antenna as **CIRCULAR LOOP.**

6. Now select the experiment.


```
CIRCULAR LOOP
▮>EXPERIMENT
2>VIEW READINGS
```

7. Make the dipole length as displayed on the screen


```
MOUNT TX&RX ANTENNA
MAKE SURE THAT
DIPOLE LENGTH=16.5cm
      CONFORM????
```

8. Set Receiver Antenna to 0^0 and Press ENTER key to start the experiment.


```
▮ET RX ANTENNA TO 0
DEGREE AND PRESS
ENTER KEY TO START
EXPERIMENT
```

9. Now the selected antenna will be displayed.


```
▮X = DIPOLE
▮X = CIRCULAR LOOP
DIPOLE LENGTH=16.5cm
TX FREQ = 1000MHz
```

10. Antenna will start rotating and reading will be taken.


```
RECEIVED POWER
▮NGLE      POWER(dBm)
 10         -38.2182
```

11. After completion of all the 68 readings, it will ask to upload the Readings on Computer. Confirm the selection using ENTER button. Make sure the software is Running and press ENTER again.


```
SAVE AND UPLOAD DATA
TO COMPUTER??????

▮
```


```
MAKE SURE THAT SOFT-
WARE MUST BE RUNNING

▮
```

12. It will then plot the graph on Software screen PULLING UP the Experiment details and Antenna selected, as shown in fig.
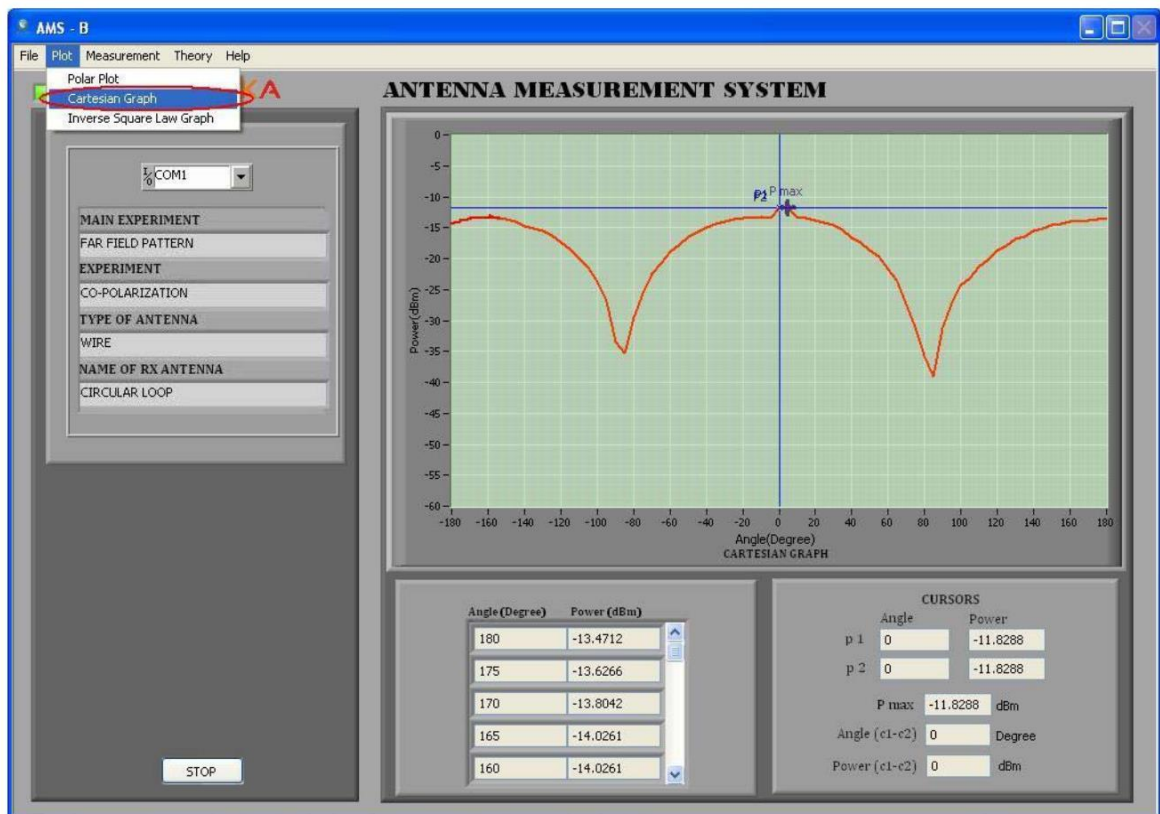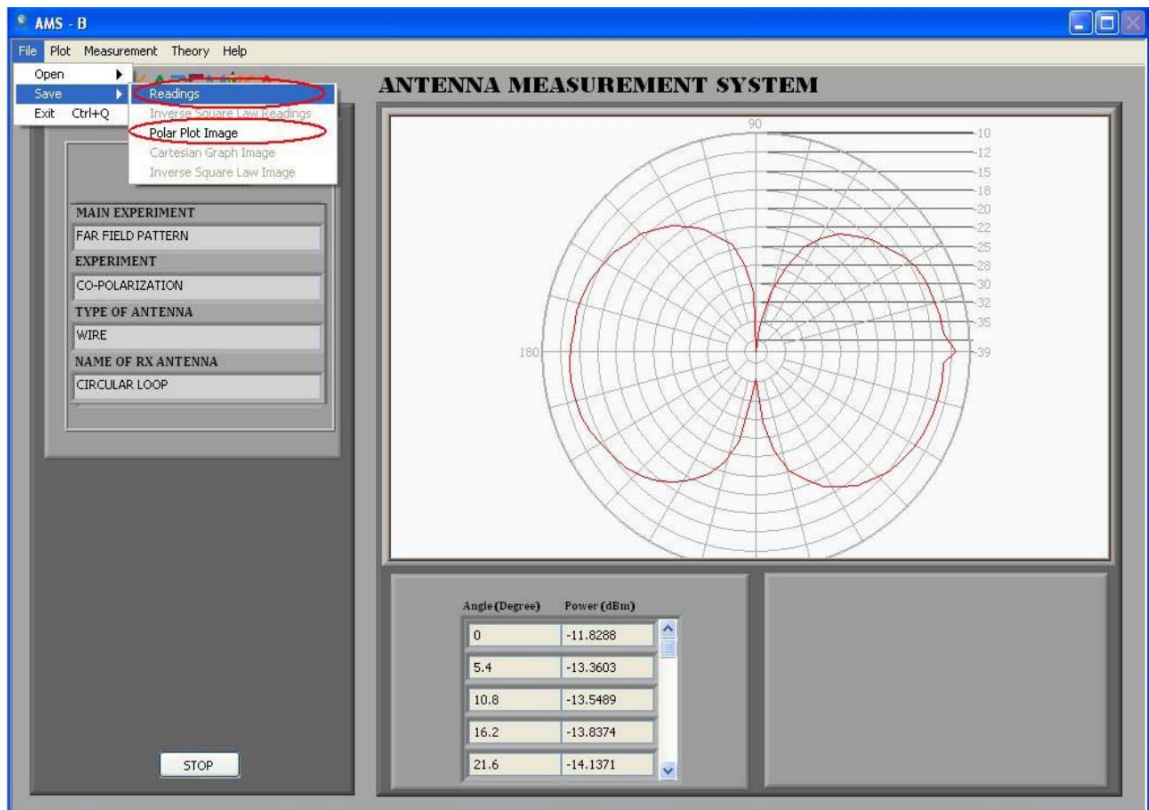
Exp.No: 6   **Date:**

DIPOLE ANTENNA

Aim: To analyze the characteristics of a simple dipole $\lambda/2$ and $\lambda/4$ Antenna

EQUIPMENT REQUIRED:

TX antenna	RX antenna	Transmitter input	Receiver output	Cable
Dipole RMSA	Dipole RMSA	Source (RF out)	Detector (RF input)	SMA To SMA cable
QTY =1	QTY =1	QTY =1	QTY =1	QTY =2

SETUP ARRANGEMENT:
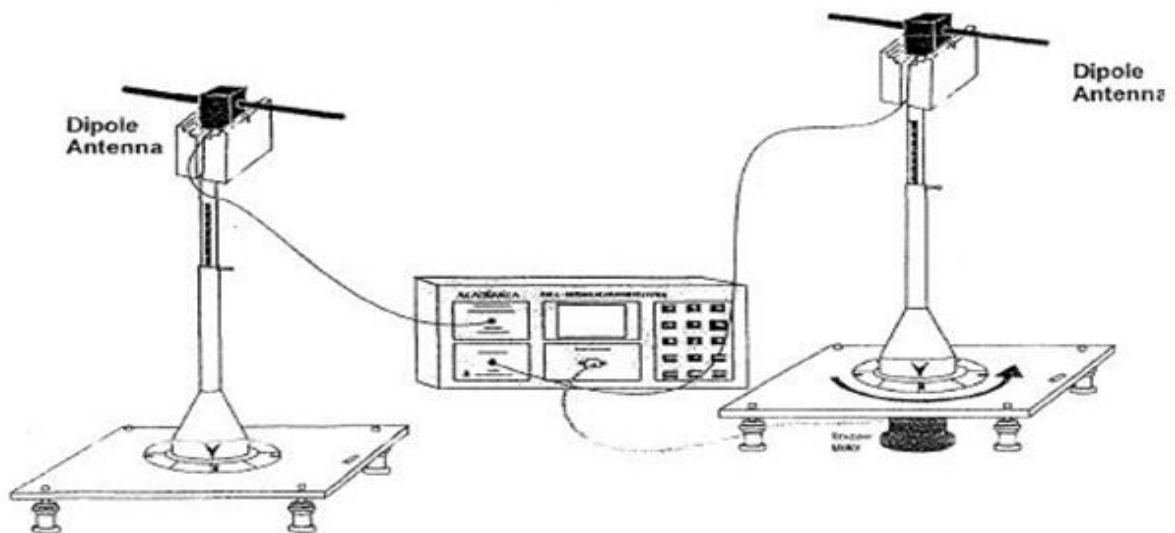
Theory

1.) A dipole antenna is fed in the center.By using a piece of coaxial cable transmission line, one may feed the center conductor of a transmission line to a ¼ wavelength piece of wire. The outer shield or ground of the cable may be connected to the remaining ¼ wavelength piece of wire. Thus, you have a dipole antenna, fed in the center, with an overall length of ½ wavelength. The total ½ wavelength of wire is to be stretched out evenly, being perpendicular to the transmission line. How exactly does the signal come out of the cable and emanate from the wires into space? The ¼ wavelength wire which is fed by the center conductor of the transmission line is known as the hot portion. One quarter of the wave leaks from the attached wire, and the remaining quarter of the wave "hops" over to the grounded second ¼ wavelength wire. Since these two pieces of ¼ wavelength wire work together to emit the wave, we often refer to a dipole as a perfect resonant antenna. Why is this important? If an antenna is resonant, it will be matched to the transmission line and/or transmitter and the bulk of the signal will actually be transmitted, not reflected back and wasted as heat (i.e. Standing Wave Ratio SWR). It should be noted that a dipole has an impedance of 75 ohms, not 50 ohms. Ordinarily a mismatch could cause a problem, but the mismatch of 50 ohm cable feeding a 75 ohm antenna is minimal with a resultant SWR of 1.5:1. This corresponds to roughly a 5% waste of power.

2.) The dipole antenna has a unique radiation pattern.

PROCEDURE:

1. Set up the experiment as per shown in figure above.
2. Set the distance between the antennas to be around 1meter, consult theory for details of far field region.
3. Turn ON the module, select control mode.
4. Open the AMS-A.exe file Select the corresponding COM PORT and Click o Run, Now the software will be in running mode.
5. Select the PROOF OF THEOREM and then select the experiment of RECIPROCITY THEOREM.
6. Then select the RX antenna and click on START button.
7. After completing it will plot the readings.
8. Now interchange the antenna and again take the next reading.
9. Compare both the plots they must be same, hence reciprocity theorem is proved.
10. Similarly do the experiments for different types of antenna.

Tabulation:

S.No	Angle in Degrees	Detector reading(mA)	Gain in dB

CALCULATIONS:

1. Antenna test wave length=
2. Near field boundary=
3. Gain=
4. HPBW=
5. Directivity=
6. FNBW=
7. Antenna Resolution=
8. Antenna Factor=
9. Front to back ratio=

Result:

Conclusion:

VIVA:

VIVA:

Exp. No: 7   **Date:**

RADIATION STRENGTH

Aim: To analyze the variation in the radiation strength at given distance from Antenna

EQUIPMENT REQUIRED:

TX antenna	RX antenna	Transmitter input	Receiver output	CABLE
Wire or Microstrip	Any antenna	Source	Detector	SMA To
DIPOLE		(RF output)	(RF input)	SMA cable
QTY =1	QTY =1	QTY =1	QTY =1	QTY =2
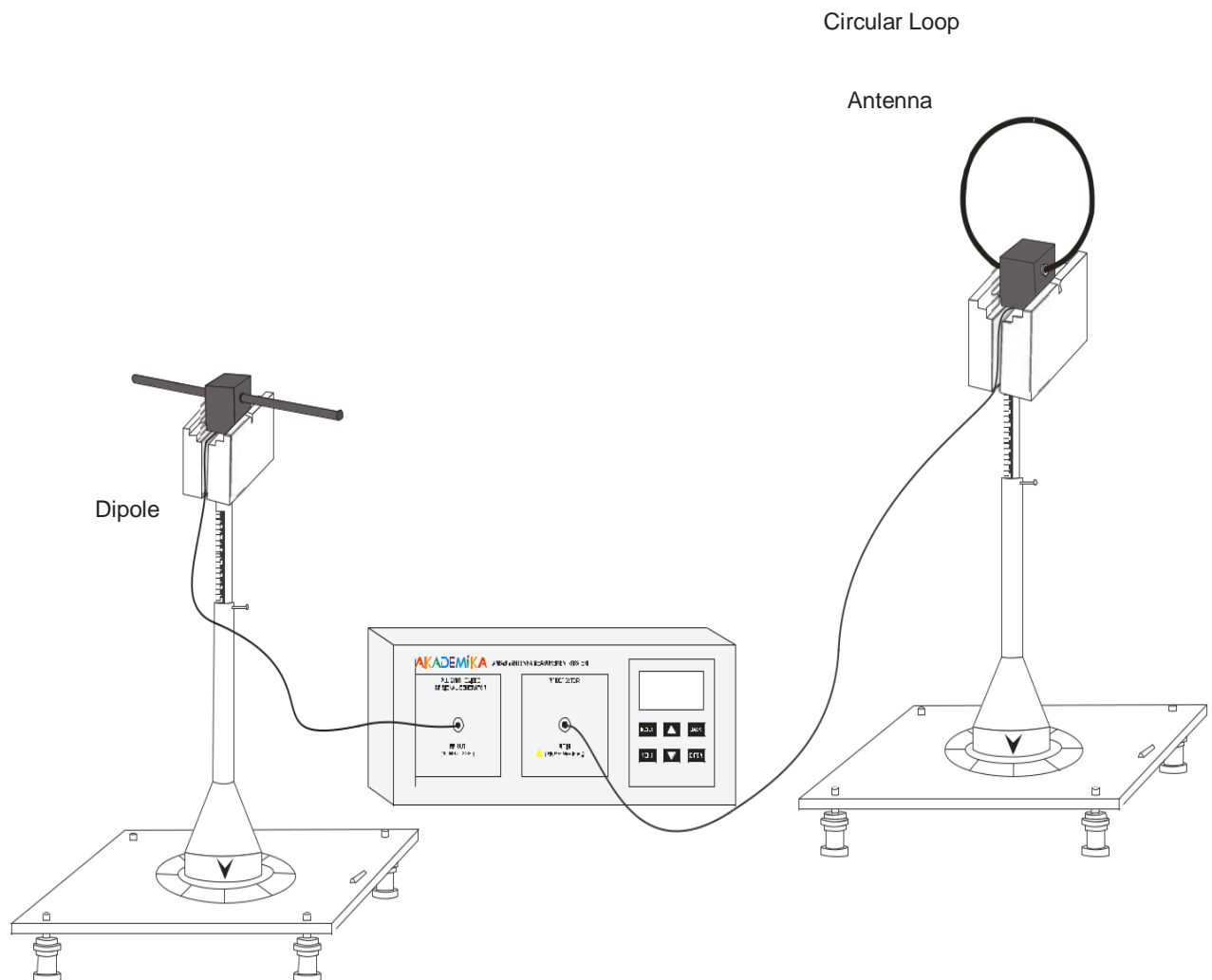
SETUP ARRANGEMENT:

CALCULATIONS:

1.   Antenna test wave length=
2.   Near field boundary=
3.   Gain=
4.   HPBW=
5.   Directivity=
6.   FNBW=
7.   Antenna Resolution=
8.   Antenna Factor=
9.   Front to back ratio=

Procedure:

1. Set up the experiment as per shown in figure above.
2. Turn ON the module.
3. Open the AMS-B.exe file Select the corresponding COM PORT and Click on Run, now the software will be in running mode.
4. Select the PROOF OF THEOREM and then select the experiment of INVERSE SQUARE LAW.
5. Then select the RX antenna and click on START button.
6. A Pop-Up window will appear asking user to Keep the Distance between TX and RX as 10cm then click on NEXT button.
7. After completion of one reading again a popup window will appear asking to Increase the TX and RX distance by 10cm.
8. Repeat the procedure up to a distance of 100cm at an interval of 10cm; click on NEXT to plot the graph.
9. After that it will plot the radiation pattern in inverse square law graph (i.e. Distance in cm V/S power in dBm).
10. While taking the readings, ensure that no scattering objects are in the vicinity of the antenna, this could reradiate and distort the field pattern and consequently the readings. Avoid any movement of persons while taking the readings.
11. Plot these readings manually on graph paper with distance between antennas on X axis and signal level in dB at Y-axis.
12. Use the graph template provided below for plotting your graph.
13. Now take the readings and observe the plots for different types of antenna.

Tabulation:

S.No	Angle in Degrees	Detector reading(mA)	Gain in dB

Result:

Conclusion:

Viva:

Exp. No: 8   **Date:**

RECIPROCITY THEOREM

Aim: To Analyze the Reciprocity theorem of antenna.

EQUIPMENT REQUIRED:

TX antenna	RX antenna	Transmitter input	Receiver output	Cable
Dipole RMSA	Dipole RMSA	Source (RF out)	Detector (RF input)	SMA To SMA cable
QTY =1	QTY =1	QTY =1	QTY =1	QTY =2

SETUP ARRANGEMENT:

CALCULATIONS:

1. Antenna test wave length=

2. Near field boundary=

3. Gain=

4. HPBW=

5. Directivity=

6. FNBW=

7. Antenna Resolution=

8. Antenna Factor=

9. Front to back ratio=

PROCEDURE:

1. Set up the experiment as per shown in figure above.
2. Set the distance between the antennas to be around 1meter, consult theory for details of far field region.
3. Turn ON the module, select control mode.
4. Open the AMS-A.exe file Select the corresponding COM PORT and Click on Run, Now the software will be in running mode.
5. Select the PROOF OF THEOREM and then select the experiment of RECIPROCITY THEOREM.
6. Then select the RX antenna and click on START button.
7. After completing it will plot the readings.
8. Now interchange the antenna and again take the next reading.
9. Compare both the plots they must be same, hence reciprocity theorem is proved.
10. Similarly do the experiments for different types of antenna.

NOTE:

1. *Keep in mind that an antenna that is being rotated is plotted in reception and transmission mode both for proving the reciprocity theorem.*
2. *Observe the two plots and they must be approximately same.*

Tabulation:

S.No	Angle in Degrees	Detector reading(mA)	Gain in dB

Result:

Conclusion:

Viva:

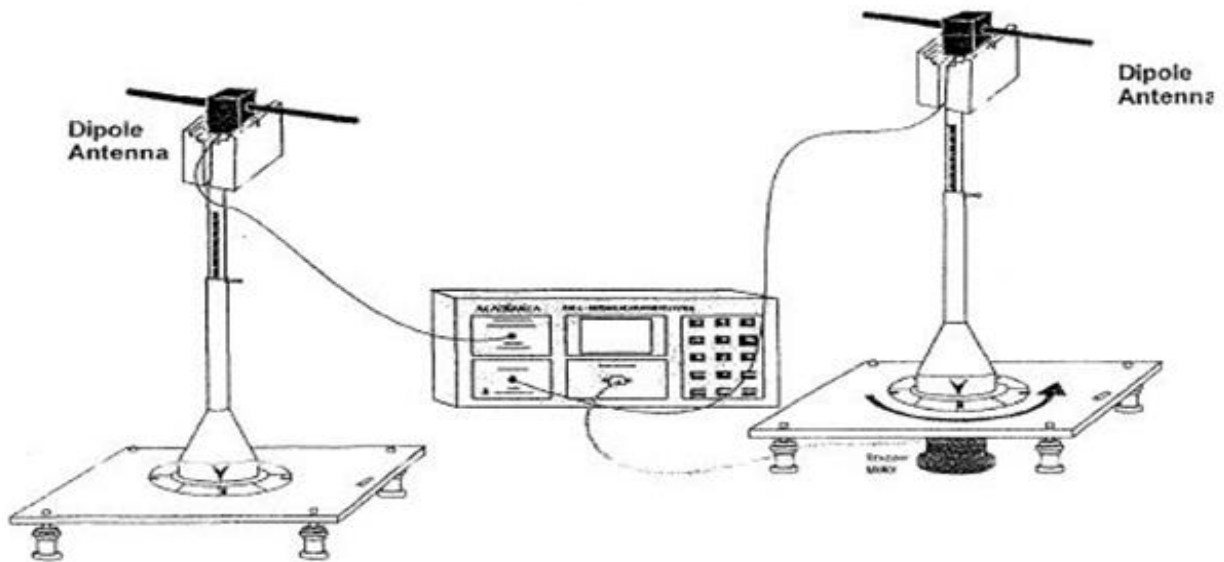**Exp. No: 9**   **Date:**

FOLDED DIPOLE ANTENNA

Aim: To Study Folded dipole λ/2 antenna.

EQUIPMENT REQUIRED:

TX antenna	RX antenna	Transmitter input	Receiver output	Cable
Dipole RMSA	Dipole RMSA	Source (RF out)	Detector (RF input)	SMA To SMA cable
QTY =1	QTY =1	QTY =1	QTY =1	QTY =2

SETUP ARRANGEMENT:
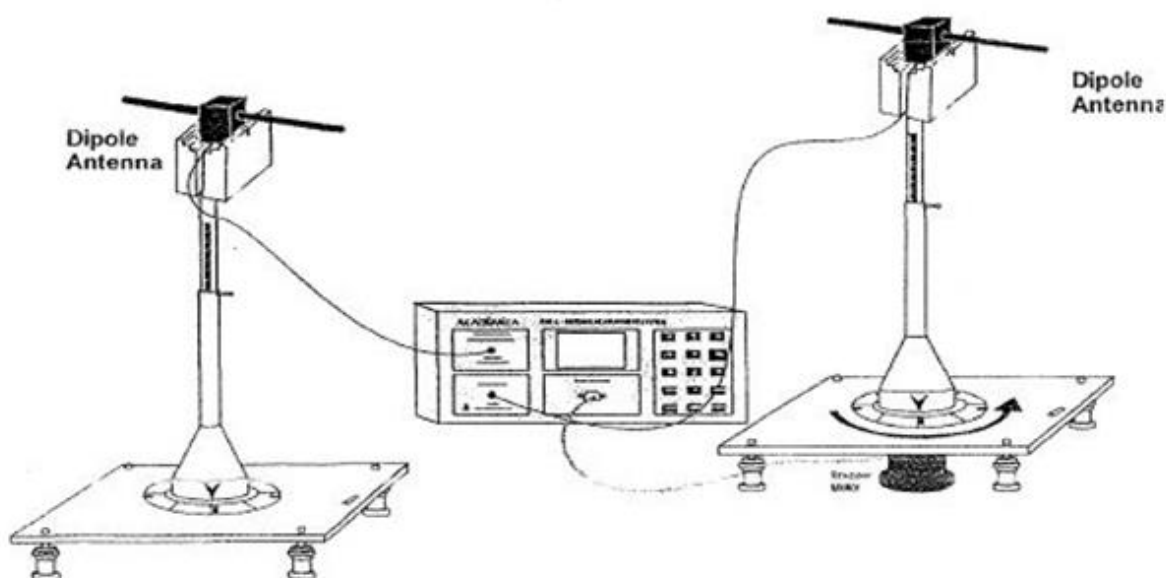
THEORY

A folded dipole is an antenna, with two conductors connected on both sides, and folded to form a cylindrical closed shape, to which feed is given at the center. The length of the dipole is half of the wavelength. Hence, it is called as **half wave folded dipole antenna**.

The range of frequency in which half wave folded dipole operates is around 3KHz to 300GHz. This is mostly used in television receivers.

Construction & Working of Half-wave Folded Dipole

This antenna is commonly used with the array type antennas to increase the feed resistance. The most commonly used one is with Yagi-Uda antenna. The following figure shows a half-wave folded dipole antenna.
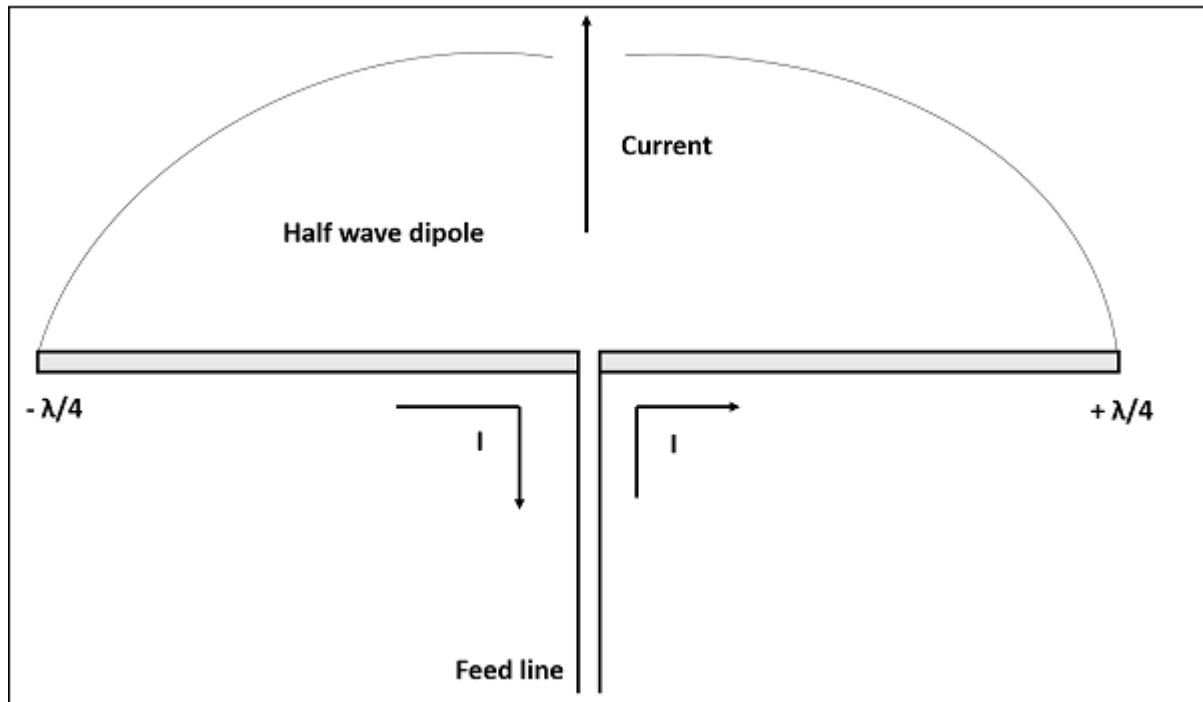
This antenna uses an extra conducting element (a wire or a rod) when compared with previous dipole antenna. This is continued by placing few conducting elements in parallel, with insulation in-between, in array type of antennas.

The following figure explains the working of a half-wave folded dipole antenna, when it is provided with excitation.
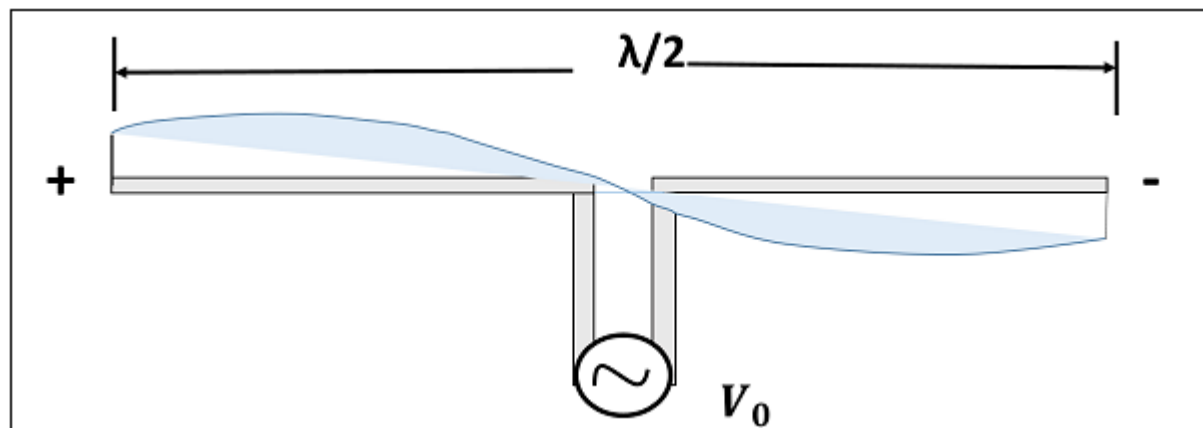
If the diameter of the main conductor and the folded dipole are same, then there will be four folded (two times of squared one) increase in the feed impedance of the antenna. This increase in feed impedance is the main reason for the popular usage of this folded dipole antenna. Due of the twin-lead, the impedance will be around 300Ω.

PROCEDURE:

1. Set up the experiment as per shown in figure above.
2. Set the distance between the antennas to be around 1meter, consult theory for details of far field region.
3. Turn ON the module, select control mode.
4. Open the AMS-A.exe file Select the corresponding COM PORT and Click on Run, Now the software will be in running mode.
5. Select the PROOF OF THEOREM and then select the experiment of RECIPROCITY THEOREM.
6. Then select the RX antenna and click on START button.
7. After completing it will plot the readings.
8. Now interchange the antenna and again take the next reading.
9. Compare both the plots they must be same, hence reciprocity theorem is proved.
10. Similarly do the experiments for different types of antenna.

Radiation Pattern

The radiation pattern of half-wave folded dipoles is the same as that of the half-wave dipole antennas. The following figure shows the radiation pattern of half-wave folded dipole antenna, which is **Omni-directional** pattern.

Tabulation:

S.No	Angle in Degrees	Detector reading(mA)	Gain in dB
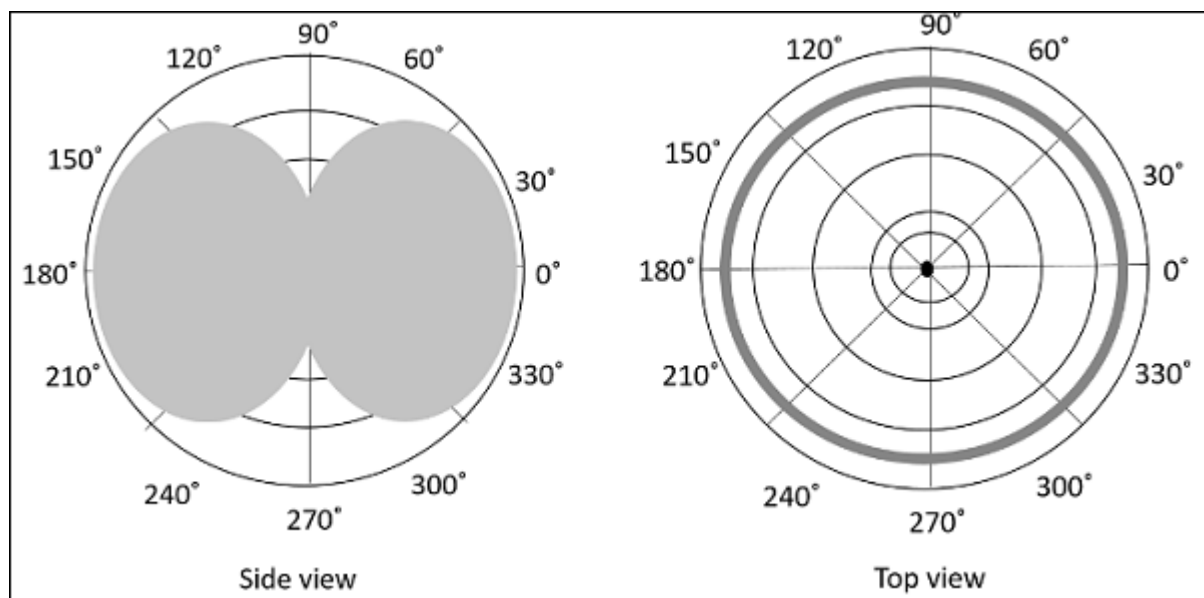
Result:

Conclusion:

Viva:

Exp. No: 10   **Date:**

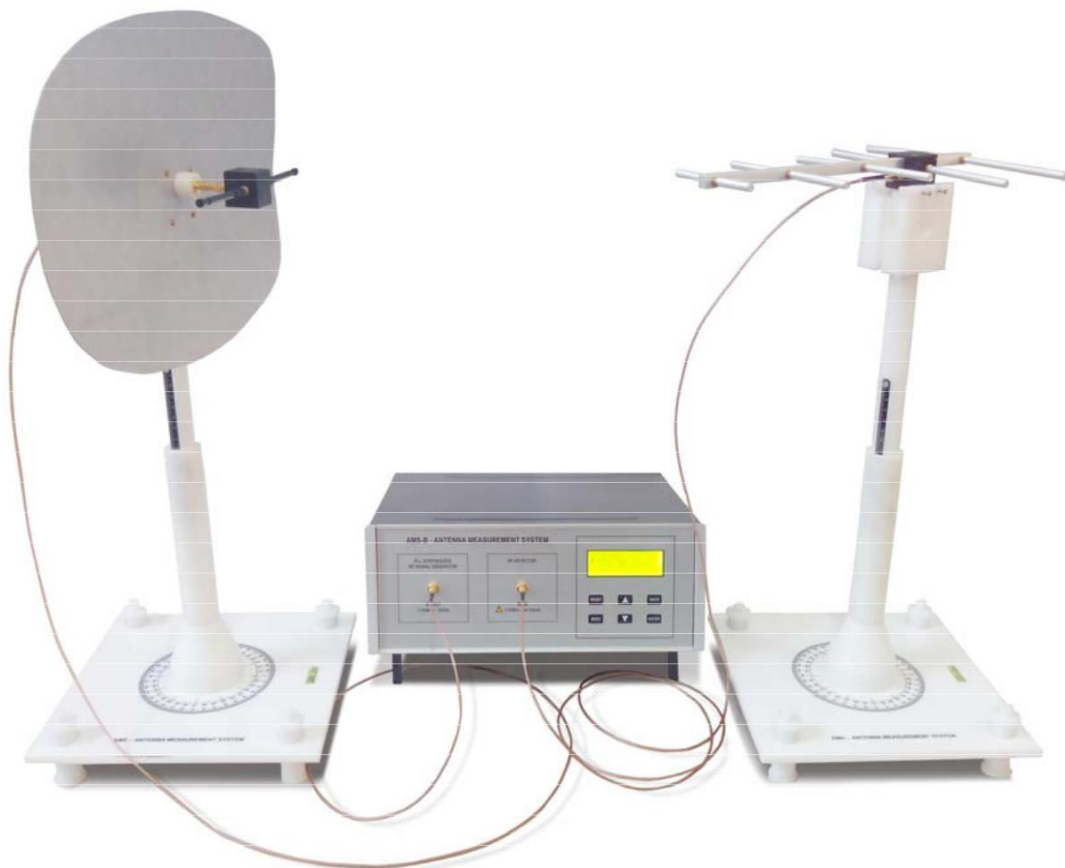## YAGI-UDA & FOLDED DIPOLE ANTENNA

Aim: To Study of Yagi-Uda 3 element Folded dipole, 5 element Folded Dipole antenna.

EQUIPMENT REQUIRED

TX antenna	RX antenna	Transmitter input	Receiver output	CABLE
Dipole	Yagi UDA (5 elements)	Source (RF out)	Detector (RF input)	SMA To SMA cable
QTY =1	QTY =1	QTY =1	QTY =1	QTY =2

SETUP ARRANGEMENT:

THEROY:

This folded dipole is the main element in **Yagi-Uda antenna**. The following figure shows 5 & 3 element **Yagi-Uda antenna**, which we will study later. The main element used here is this folded dipole, to which the antenna feed is given. This antenna has been used extensively for television reception over the last few decades.
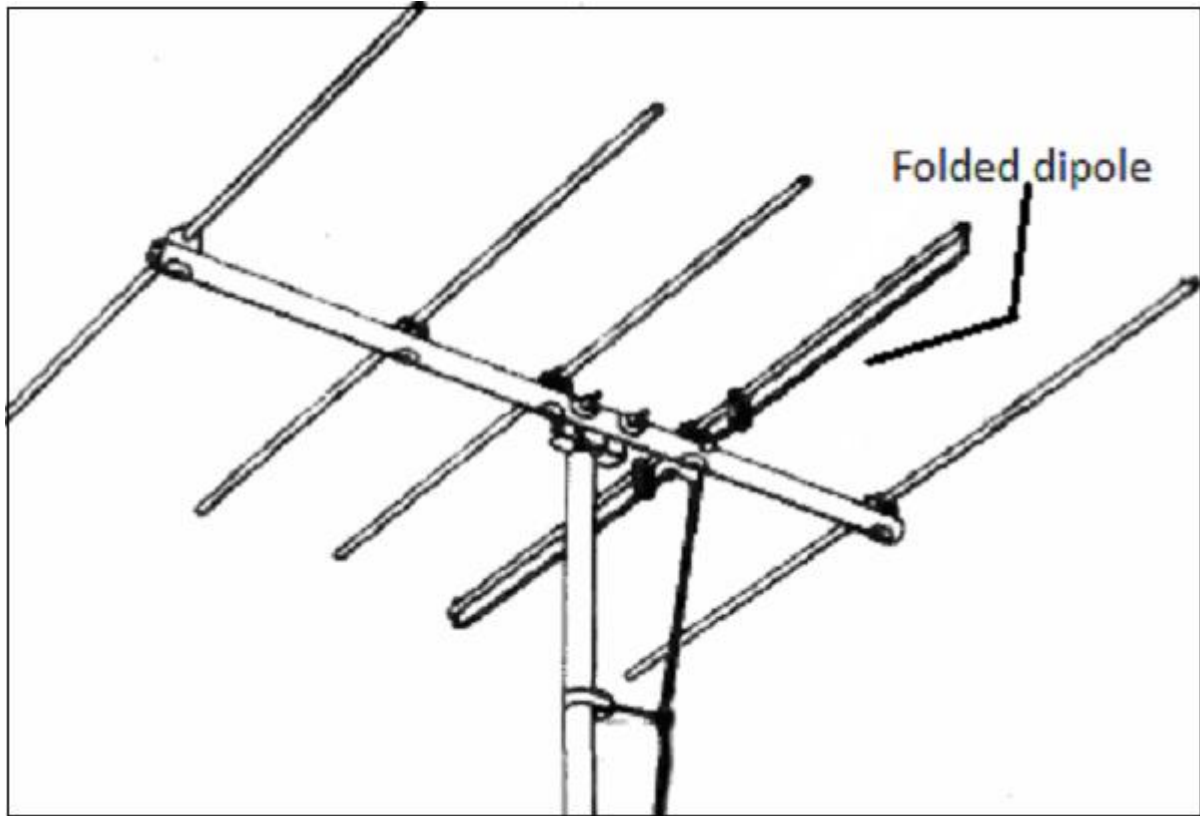
Folded dipole

Consider a Yagi–Uda consisting of a reflector, driven element and a single director as shown here. The driven element is typically a $1/2\lambda$ dipole or folded dipole and is the only member of the structure that is directly excited (electrically connected to the feedline). All the other elements are considered parasitic. That is, they reradiate power which they receive from the driven element. They also interact with each other, but this mutual coupling is neglected in the following simplified explanation, which applies to far-field conditions.

One way of thinking about the operation of such an antenna is to consider a parasitic element to be a normal dipole element of finite diameter fed at its centre, with a short circuit across its feed point. The principal part of the current in a loaded receiving antenna is distributed as in a center-driven antenna. It is proportional to the effective length of the antenna and is in phase with the incident electric field if the passive dipole is excited exactly at its resonance frequency.[12] Now we imagine the current as the source of a power wave at the (short-circuited) port of the antenna. As is well known in transmission line theory, a short circuit reflects the incident voltage 180 degrees out of phase.

PROCEDURE:

1. Set up the experiment as per shown in figure above.
2. Set the distance between the antennas to be around 1meter, consult theory for details of far field region.
3. Turn ON the module, select control mode.
4. Open the AMS-A.exe file Select the corresponding COM PORT and Click on Run, Now the software will be in running mode.
5. Select the PROOF OF THEOREM and then select the experiment of RECIPROCITY THEOREM.
6. Then select the RX antenna and click on START button.
7. After completing it will plot the readings.
8. Now interchange the antenna and again take the next reading.
9. Compare both the plots they must be same, hence reciprocity theorem is proved.
10. Similarly do the experiments for different types of antenna.

Tabulation:

S.No	Angle in Degrees	Detector reading(mA)	Gain in dB

RADIATION PATTERN:

Result:

Conclusion:

Viva:

ADDITIONAL EXPERIMENTS

Exp. No: 11   **Date:**

LASER DIODE CHARACTERISTICS

Aim: To determine the AC characteristics of an intensity modulation for LASER and Fiber optic system.

Apparatus Required:

S.no	Apparatus	Range/Specification	Quantity
1	POT	1kΩ	1
2	RPS	-	1
3	Optical Fiber cable	1 Meter	1
4	DMM	-	1
5	AMMETER		
6	Connecting wires		As per Required

Theory:

The intensity modulation / demodulation system is realized using PHY- 159 transmitter module and the PHY -158 receiver unit linked through an optical fiber. We use PMMA FIBER cable. The laser carrier power P_O is set by adjusting the 'set If' knob in the middle. Laser selection of optimum carrier power is essential to minimize distortion. Limiting the depth of modulation also ensures distortion free transmission. Bandwidth of the system in the present case is limited by the photo detector. We should operate in the APC mode to obtain optical output proportional to the modulating signal V_{in}. We will however operate in the APC mode too. An ideal IM transmission system will have the relationship $V_{out} = G . V_{in}$ where G is a factor depends on the LCD conversion efficiency

Circuit diagram:
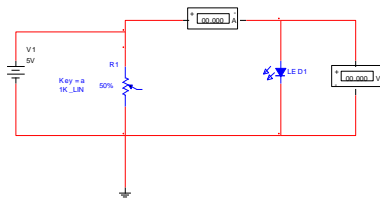
Procedure:

1.   Connect the fiber optic cable, input signal and output as shown in the experimental set-up.

2.   Set the signal frequency and amplitude to 2 KHz (mid band frequency) and 100mV respectively.

3.   Adjust the **IF** Knob to get output of 100mV (i.e., 0dB gain)

4.   Slowly vary the input amplitude   to 1000mV insteps of 100mV And note down the corresponding output amplitude

5.   Tabulate and plot a graph V_{out} Vs V_{in}.

Tabular Column: **Model Graph:**

V_{in} (V)	V_{out} (V)
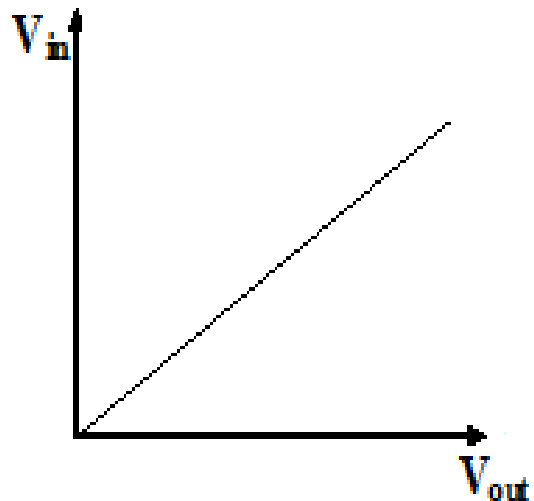
Result:

Conclusion:

Viva Questions:

1. What are the types of optical fibers?

2. What are different types of fibers?

3. What is the principle of optical Fiber?

4. Which light is used in optical Fiber?

5. How is optical Fiber made?

Exp. No: 12   **Date:**

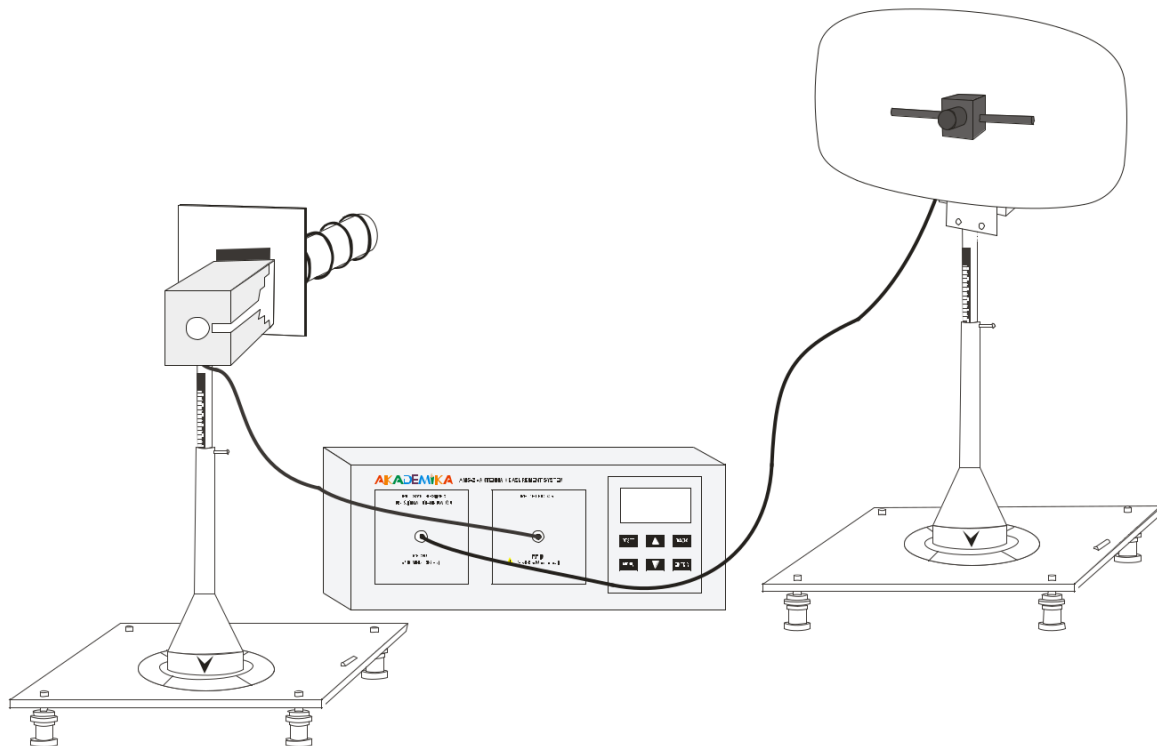# WIRED ANTENNA

Aim: To plot the Radiation pattern of WIRED antenna and observe its parameters.

EQUIPMENT REQUIRED:

TX Antenna	RX antenna	Transmitter input	Receiver output	CABLE
Wire DIPOLE	Any wired antenna	Source (RF out)	Detector (RF input)	SMA To SMA cable
QTY =1	QTY =1	QTY =1	QTY =1	QTY =2

SET UP ARRANGEMENT:

Theory

A wire Antenna is a type of radio antenna that includes a long wire suspended over the ground. The wire in the antenna picks up the signals & radiates them further. In this antenna, the wire antenna length has no relation to its wavelength. The wire is simply connected to the transmitter or the receiver through the tuner of an antenna to transmit or receive the signals

The construction of antennas with long wires is simple because the length of this wire antenna is multiple of $\lambda/2$. Generally, the antennas which have $\lambda/2$ or $\lambda/4$ length is known as half-wave dipole antenna. But an antenna that has greater than $\lambda/2$ length is known as a long wire antenna. So, the length of an antenna with a long wire is considered as multiple of half wavelength. So, the length of the antenna with a long wire is given as $(L = n \lambda/2)$.

These wires are arranged vertically or horizontally, but the direction is sometimes sloppy relating to the ground. The outside excitation to this antenna is provided throughout feed lines where the feed line is simply provided at the end, center, or anywhere in the middle of the length of the wire.

Here the wire antenna's polarization is shown by the antenna's direction with respect to the ground. The feed point's position represents the lobe's direction. In this simple wire antenna construction, a simple conducting wire is connected end to end in between transmitting & receiving stations. So, the direct long wire connection between the two ends will allow the signal from the transmitting station & radiate the signal so that it can be obtained at the remaining end.

PROCEDURE:

1. Set up the experiment as per shown in figure above.

2. Set the distance between the antennas to be around 1meter, consult theory for details.

3. Turn ON the module.

4. Open the AMS-B.exe file; select the corresponding COM PORT and Click on Run, Now the software will be in running mode.

5. Go in FAR FIELD PATTERN, select CO-POLARIZATION, select RX antenna then click on START

6. Then readings from 0 degree to 360 degree will be plotted in the software.

7. Now repeat for CROSS-POLARIZTION of antenna and observe the plot.

Tabulation:

S.No	Angle in Degrees	Detector reading(mA)	Gain in dB

RADIATION PATTERN:

Result:

Conclusion:

Viva: