# LAKSHMI NARAIN COLLEGE OF TECHNOLOGY EXCELLECNE

LAB MANUAL

[redacted]

## SEMESTER

**MICROWAVE LAB**

**VII,EC-704**

## VISION of the department:

*To become reputed in providing technical education in the field of electronics and communication engineering and produce technocrats working as leaders..*

## MISSION of the department:

*1. To provide congenial academic environment and adopting innovative learning process.*

*2. To keep valuing human values and transparency while nurturing the young engineers.*

*3. To strengthen the department by collaborating with industry and research organization of repute.*

*4. To facilitate the students to work in interdisciplinary environment and enhance their skills for employability and entrepreneurship.*

# SCHEME

## Rajiv Gandhi Proudyogiki Vishwavidyalaya, Bhopal

**New Scheme of Examination as per AICTE Flexible Curricula**

**VII Semester** **Bachelor of Technology (B.Tech.) [Electronics & Communication Engg.]** *(w.e.f. July, 2020)*

| S.No. | Subject Code | Category | Subject Name | Maximum Marks Allotted | | | | | Total Marks | Contact Hours per week | | | Total Credits |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Theory | | | Practical | | | | | | |
| | | | | End Sem. | Mid Sem. Exam. | Quiz/ Assignment | End Sem | Term work Lab Work & Sessional | | L | T | P | |
| 1. | EC701 | DC | VLSI Design | 70 | 20 | 10 | 30 | 20 | 150 | 2 | 1 | 2 | 4 |
| 2. | EC702 | DE | Departmental Elective | 70 | 20 | 10 | - | - | 100 | 3 | 1 | - | 4 |
| 3. | EC703 | OE | Open Elective | 70 | 20 | 10 | - | - | 100 | 3 | 0 | 0 | 3 |
| 4. | EC704 | D Lab | Microwave Lab | - | -- | - | 30 | 20 | 50 | - | - | 6 | 3 |
| 5. | EC705 | O/E lab | I.O.T. Lab | - | - | - | 30 | 20 | 50 | - | - | 6 | 3 |
| 6. | EC706 | P | Major Project-I | - | - | - | 100 | 50 | 150 | - | - | 8 | 4 |
| 7. | EC607 | | Evaluation of Internship -III | - | - | - | - | 100 | 100 | - | - | 6 | 3 |
| 8. | Additional Credits* | *Additional credits can be earned through successful completion of credit based MOOC's Courses available on SWAYAM platform (MHRD) at respective UG level. | | | | | | | | | | | |
| | | | Total | 210 | 60 | 30 | 190 | 210 | 700 | 8 | 2 | 28 | 24 |

| Departmental Electives | Open Electives |
|---|---|
| 702(A) Microwave Engg. | 703(A) Cellular Mobile Communication |
| 702 (B) Information Theory & Coding | 703(B) Internet of Things |
| 702 (C) Nano Electronics | 703(C) Probability Theory & Stochastic Processor |

| 1 Hr Lecture | 1 Hr Tutorial | 2 Hr Practical |
|---|---|---|
| 1 Credit | 1 Credit | 1 Credit |

# LIST OF EXPERIMENTS

| Exp. No. | AIM |
|---|---|
| 1 | To become familiar with microwave components and instruments available in the laboratory |
| 2 | Reflex Klystron Characteristics. |
| 3 | To study the V-I characteristics of Gunn diode. |
| 4 | To study the function of multi-hole directional coupler |
| 5 | To determine the standing-wave ratio and reflection coefficient. |
| 6 | To measure an unknown impedance using the smith chart. |
| 7 | To Study the operation of Magic Tee and calculate Coupling Co-efficient and Isolation. |
| 8 | To study the Isolator and circulators and measure the Insertion Loss and Isolation of Circulator. |
| 9 | To study insertion loss and attenuation measurement of attenuator. |
| 10 | To determine the frequency and wavelength in a rectangular wave guide working in $TE_{10}$ mode. |

## 1-Introction to Microwave Components

**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:**

1. Klystron Power Supply
2. Klystron tube
3. Isolator
4. Circulator
5. Attenuator
6. Direct reading frequency meter
7. Slotted line section with probe carriage
8. Crystal Detector
9. VSWR Meter
10. Different types of Antennas available
11. Magic tee
12. E and H Plane Tee
13. Matched Termination
14. 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.

### 1. Klystron Power Supply

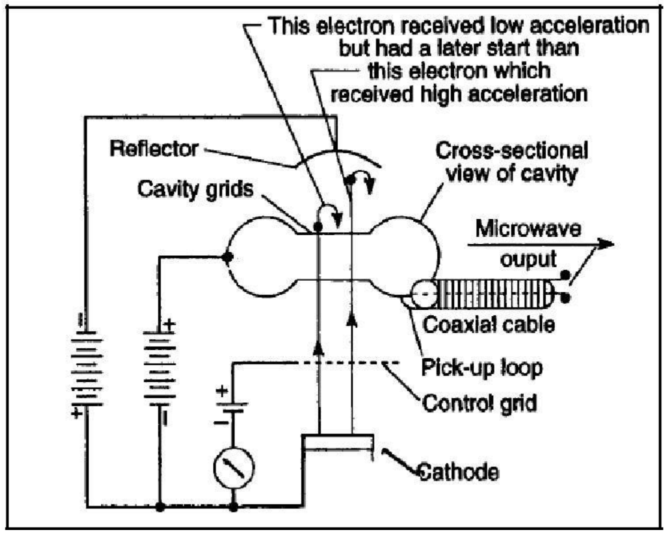
Klystron Power supply is a regulated power supply for operating low power klystron. Klystron power supply generates voltage required for driving the reflex klystron tubes like 2k25, 2k56, 2k22. It is absolutely stable, regulated and short circuit protected power supply. It has the facility to vary the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

2. **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 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 reflector with sufficient energy to pass through the cavity grids, thence to be collected by the control 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.

## 3. Isolator:

The microwave test bench includes an attenuator, and an isolator. Both of these help 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. An


ideal isolator transmits all the power entering port 1 to port 2, while absorbing all the power entering port 2.

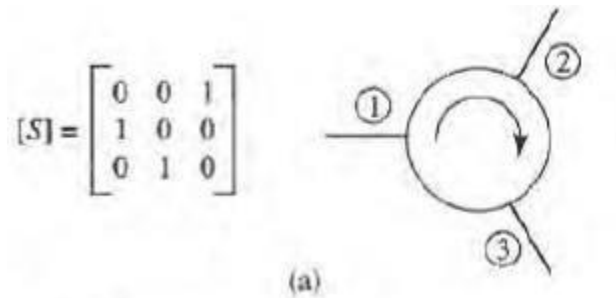
An isolator in a non-reciprocal device, with a non-symmetric matrix.

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

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 in opposite directions. Depending on the exact operating conditions, the signal travelling in one direction may either be phase-shifted, displaced from the ferrite or absorbed.

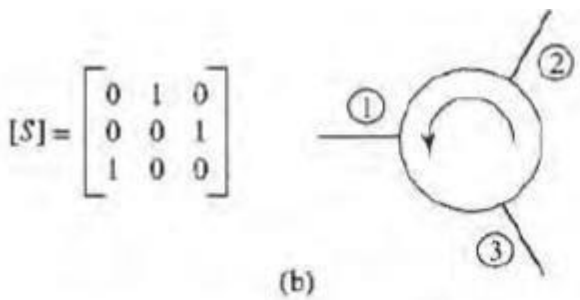
## 4. Circulator

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**

**Counterclockwise Circulator**




## 5. Attenuator:

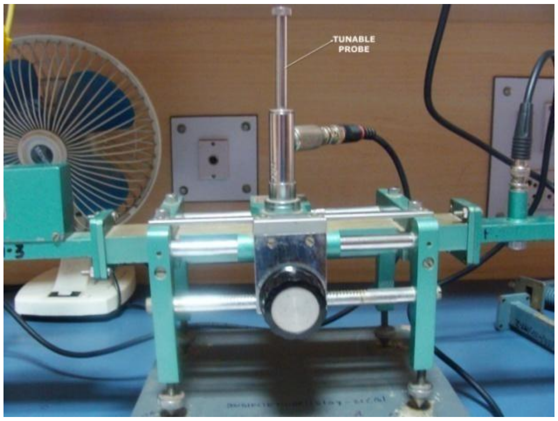
Attenuators are required to adjust the power flowing in a waveguide. Attenuators are of fixed, variable and rotary vane type, i.e.

**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.

## 6. 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. The shorting plunger is used to change the resonance frequency of the cavity by changing 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.

## 7. 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.

## 8. 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 approximate to square law characteristics and may be used with a high gain selective amplifier having a square law meter calibration.

## 9. VSWR Meter


The SWR 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 ( $\Gamma$ ). 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:

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

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

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

## 10. Different types of Antennas available

### Conical Horn :

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.

### Parabolic Dish:

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 uncurved 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.

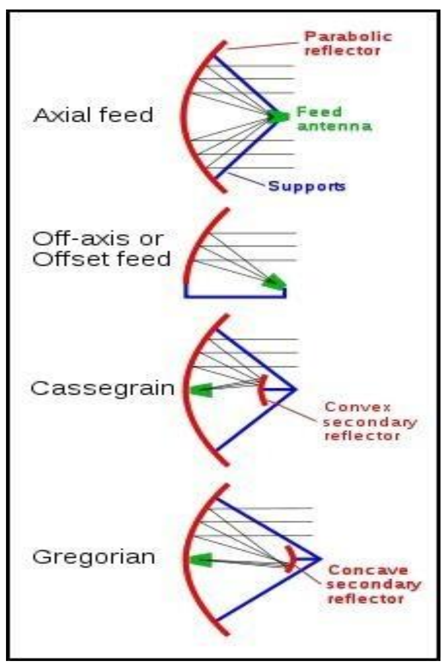



**Figure (right) shows the main types of parabolic antenna feeds.**

- **Cassegrain** - In a Cassegrain antenna the feed is located on or behind the dish, and radiates forward, illuminating a convex hyperboloidalsecondary 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.

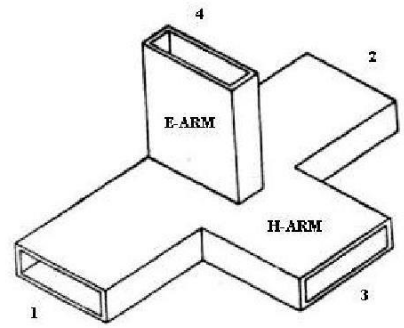
**$e_A$** is a dimensionless parameter called the aperture efficiency. The aperture efficiency of typical parabolic antennas is 0.55 to 0.60.

## 11. Magic Tee:

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 4 forms an E-plane tee with arms 1 and 2. Arms 1 and 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).

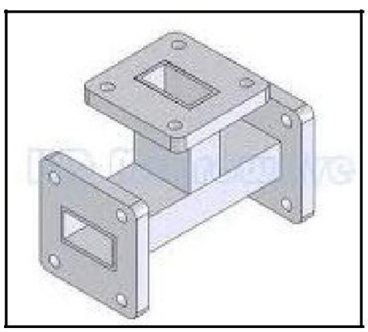
The name "magic tee" is derived from the way in which power is divided among the various ports. A signal injected into the H-plane port will be divided equally between ports 1 and 2, and will be in phase. A signal injected into the E-plane port will also be divided equally between ports 1 and 2, but 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

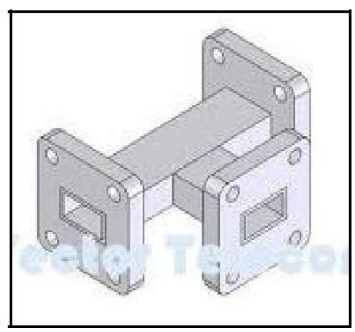
$$S = \frac{1}{\sqrt{2}} \begin{pmatrix} 0 & 0 & 1 & -1 \\ 0 & 0 & 1 & 1 \\ 1 & 1 & 0 & 0 \\ -1 & 1 & 0 & 0 \end{pmatrix}$$




## 12. 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**

## 13. 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 loads with tee junctions, directional couplers etc.

**14. W/g Coaxial Adaptor:**

**These adapters consist of a short section of waveguide with aprobe 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.**

# 2.REFLEX KLYSTRON CHARACTERISTICS

**AIM:** To study the mode characteristics of the reflex klystron tube and to determine its Electronic tuning range.

**EQUIPMENT REQUIRED:**

1. Klystron power supply
2. Klystron tube with klystron mount
3. Isolator
4. Frequency meter
5. Detector mount
6. Variable Attenuator
7. Wave guide stand
8. VSWR meter
9. Oscilloscope
10. BNC Cable

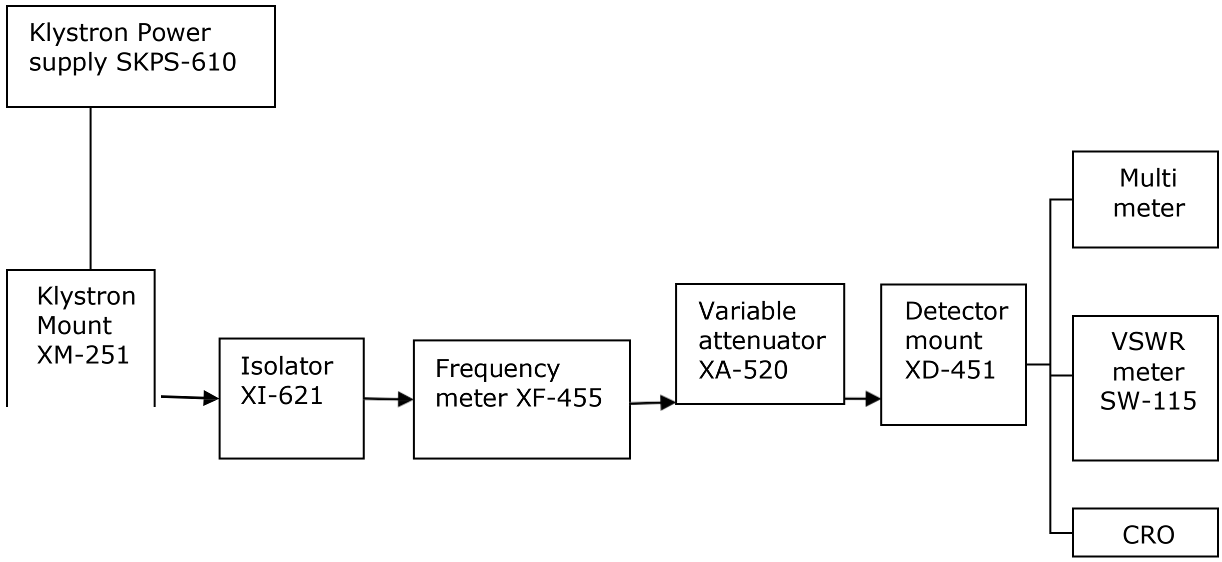
**THEORY:** The reflex klystron is a single cavity variable frequency microwave generator of low power and low efficiency. This is most widely used in applications where variable frequency is desired as

1. In radar receivers
2. Local oscillator in μw receivers
3. Signal source in micro wave generator of variable frequency
4. Portable micro wave links.
5. Pump oscillator in parametric amplifier

**Voltage Characteristics:** Oscillations can be obtained only for specific combinations of anode and repeller voltages that gives farable transit time.

**Power Output Characteristics**: The mode curves and frequency characteristics. The frequency of resonance of the cavity decides the frequency of oscillation. A variation in repeller voltages slightly changes the frequency.

## BLOCK DIAGRAM:




## EXPERIMENTAL PROCEDURE:

## CARRIER WAVE OPERATION:

1. Connect the equipments and components as shown in the figure.
2. Set the variable attenuator at maximum Position.
3. Set the MOD switch of Klystron Power Supply at CW position, beam voltage control knob to fully anti clock wise and repeller voltage control knob to fully clock wise and meter switch to 'OFF' position.
4. Rotate the Knob of frequency meter at one side fully.
5. Connect the DC microampere meter at detector.
6. Switch "ON" the Klystron power supply, CRO and cooling fan for the Klystron tube..
7. Put the meter switch to beam voltage position and rotate the beam voltage knob clockwise slowly up to 300 Volts and observe the beam current on the meter by changing meter switch to beam current position. The beam current should not increase more than 30 mA.
8. Change the repeller voltage slowly and watch the current meter, set the maximum voltage on CRO.
9. Tune the plunger of klystron mount for the maximum output.
10. Rotate the knob of frequency meter slowly and stop at that position, where there is less output current on multimeter. Read directly the frequency meter between two horizontal line and vertical marker. If micrometer type frequency meter is used read the micrometer reading and find the frequency from its frequency calibration chart.
11. Change the repeller voltage and read the current and frequency for each repeller voltage.

**B. SQUARE WAVE OPERATION:**

1. Connect the equipments and components as shown in figure
2. Set Micrometer of variable attenuator around some Position.
3. Set the range switch of VSWR meter at 40 db position, input selector switch to crystal impedance position, meter switch to narrow position.
4. Set Mod-selector switch to AM-MOD position .beam voltage control knob to fullyanti clockwise position.
5. Switch "ON" the klystron power Supply, VSWR meter, CRO and cooling fan.
6. Switch "ON" the beam voltage. Switch and rotate the beam voltage knob clockwise upto 300V in meter.
7. Keep the AM – MOD amplitude knob and AM – FREQ knob at the mid position.
8. Rotate the reflector voltage knob to get deflection in VSWR meter or square wave on CRO.
9. Rotate the AM – MOD amplitude knob to get the maximum output in VSWR meter or CRO.
10. Maximize the deflection with frequency knob to get the maximum output in VSWR meter or CRO.
11. If necessary, change the range switch of VSWR meter 30dB to 50dB if the deflection in VSWR meter is out of scale or less than normal scale respectively. Further the output can be also reduced by variable attenuator for setting the output for any particular position.

C. **MODE STUDY ON OSCILLOSCOPE**:

1. Set up the components and equipments as shown in Fig.
2. Keep position of variable attenuator at min attenuation position.
3. Set mode selector switch to FM-MOD position FM amplitude and FM frequency knob at mid position keep beam voltage knob to fully anti clock wise and reflector voltage knob to fully clockwise position and beam switch to 'OFF' position.
4. Keep the time/division scale of oscilloscope around 100 HZ frequency measurement and volt/div. to lower scale.
5. Switch 'ON' the klystron power supply and oscilloscope.
6. Change the meter switch of klystron power supply to Beam voltage position and set beam voltage to 300V by beam voltage control knob.
7. Keep amplitude knob of FM modulator to max. Position and rotate the reflector voltage anti clock wise to get the modes as shown in figure on the oscilloscope. The horizontal axis represents reflector voltage axis and vertical represents o/p power.
8. By changing the reflector voltage and amplitude of FM modulation in any mode of klystron tube can be seen on oscilloscope.

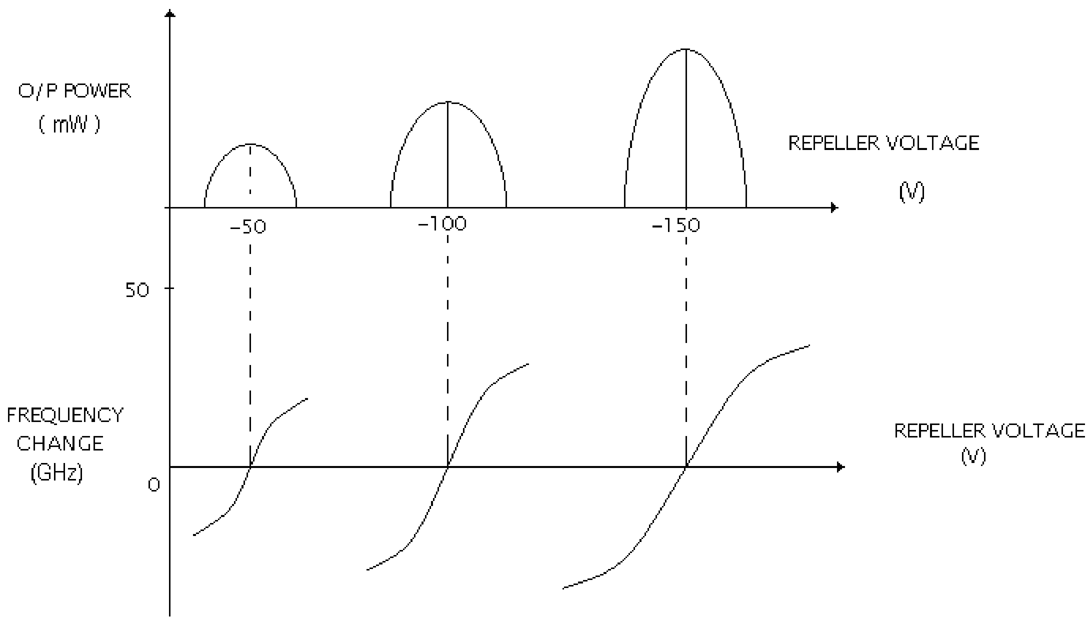
**OBSERVATION TABLE:**

Beam Voltage ................ V (Constant)

Beam Current.................. mA

| Repeller Voltage (V) | Current (mA) | Power (mW) | Dip Frequency (GHz) |
|---|---|---|---|
| | | | |

**EXPECTED GRAPH:**




**RESULT:**

# 3.GUNN DIODE CHARACTERISTICS

**AIM:** To study the V-I characteristics of Gunn diode.

**EQUIPMENT REQUIRED**:

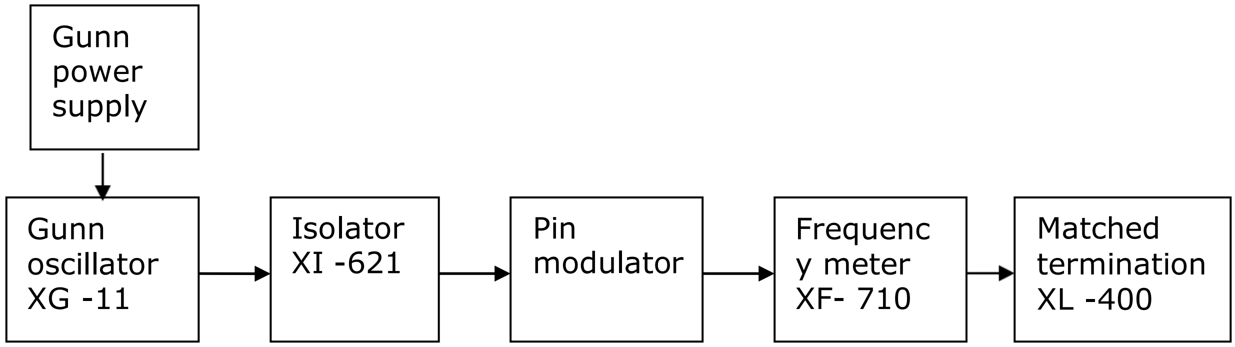
1. Gunn power supply
2. Gunn oscillator
3. PIN Modulator
4. Isolator
5. Frequency Meter
6. Variable attenuator
7. Slotted line
8. Detector mount and CRO.

**THEORY:**

Gunn diode oscillator normally consist of a resonant cavity, an arrangement for coupling diode to the cavity a circuit for biasing the diode and a mechanism to couple the RF power from cavity to external circuit load. A co-axial cavity or a rectangular wave guide cavity is commonly used.

The circuit using co-axial cavity has the Gunn diode at one end at one end of cavity along with the central conductor of the co-axial line. The O/P is taken using a inductively or capacitively coupled probe. The length of the cavity determines the frequency of oscillation. The location of the coupling loop or probe within the resonator determines the load impedance presented to the Gunn diode. Heat sink conducts away the heat due to power dissipation of the device.

## BLOCK DIAGRAM




## EXPERIMENTAL PROCEDURE:

**Voltage-Current Characteristics:**

1. Set the components and equipments as shown in Figure.
2. Initially set the variable attenuator for minimum attenuation.
3. Keep the control knobs of Gunn power supply as below

   Meter switch – "OFF"

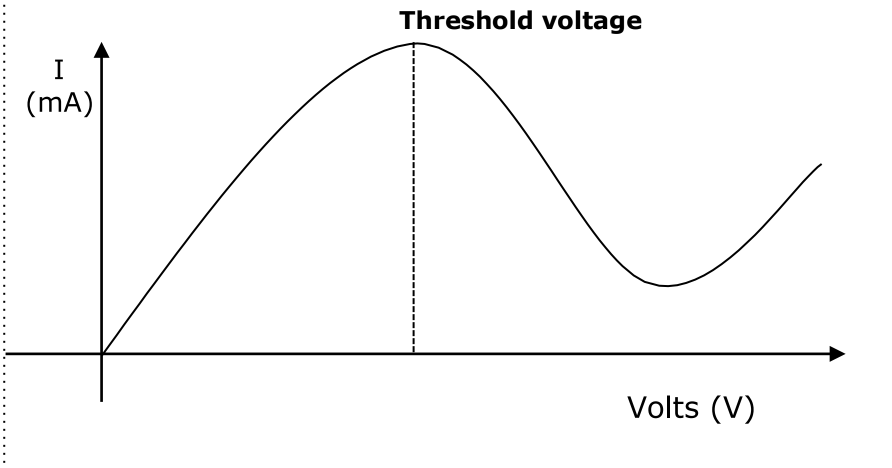
   Gunn bias knob – Fully anti clock wise

   PIN bias knob – Fully anti clock wise

   PIN mode frequency – any position
4. Set the micrometer of Gunn oscillator for required frequency of operation.
5. Switch "ON" the Gunn power supply.
6. Measure the Gunn diode current to corresponding to the various Gunn bias voltage through the digital panel meter and meter switch. Do not exceed the bias voltage above 10 volts.
7. Plot the voltage and current readings on the graph.
8. Measure the threshold voltage which corresponding to max current.

**Note:** Do not keep Gunn bias knob position at threshold position for more than 10-15 sec. readings should be obtained as fast as possible. Otherwise due to excessive heating Gunn diode may burn

**EXPECTED GRAPH:**




**I-V CHARACTERISTICS OF GUNN OSCILLATOR**

**OBSERVATION TABLE:**

| Gunn bias voltage (v) | Gunn diode current (mA) |
|---|---|
| | |

***RESULT:***

# 4. DIRECTIONAL COUPLER CHARACTERISTICS

**AIM:** To study the function of multi-hole directional coupler by measuring the following parameters.

1. The Coupling factor, Insertion Loss and Directivity of the Directional coupler

**EQUIPMENT REQUIRED:**

1. Microwave Source (Klystron or Gunn-Diode)
2. Isolator, Frequency Meter
3. Variable Attenuator
4. Slotted Line
5. Tunable Probe
6. Detector Mount Matched Termination
7. MHD Coupler
8. Waveguide Stand
9. Cables and Accessories
10. CRO.

**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.

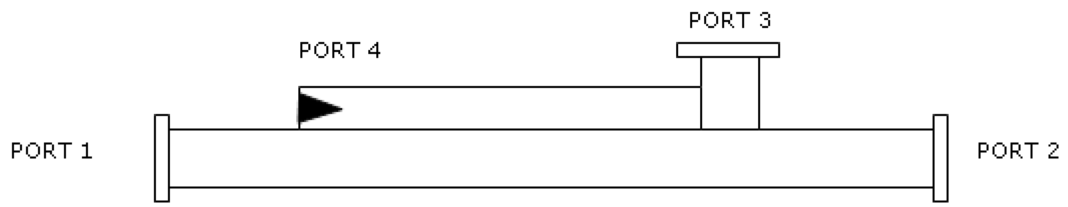



FIG. DIRECTIONAL COUPLER



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]

**BLOCKDIAGRAM:**

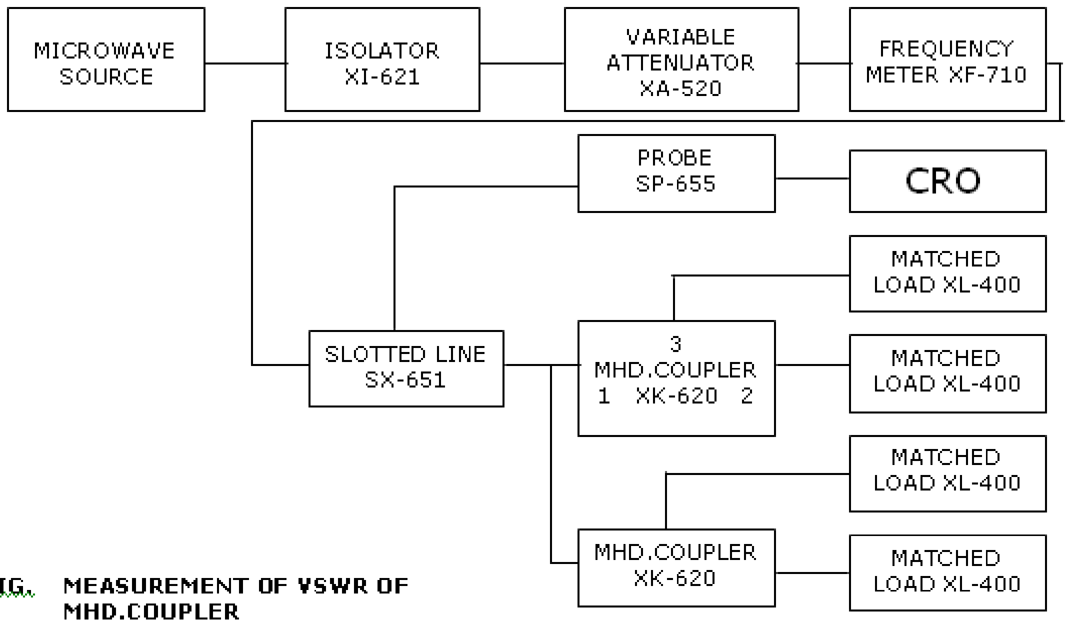



FIG. MEASUREMENT OF VSWR OF MHD.COUPLER

**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.

**PRECAUTIONS:**

1. Avoid loose connections.
2. Avoid Parallax errors.

**RESULT:**

## 5. VSWR MEASUREMENT

**AIM:** To determine the standing-wave ratio and reflection coefficient.

**EQUIPMENT REQUIRED:**

1. Klystron tube
2. Klystron power supply
3. VSWR meter
4. Klystron mount
5. Isolator
6. Frequency meter
7. Variable attenuator
8. Slotted line
9. Wave guide stand
10. Movable short/termination
11. BNC CableS-S Tuner

**THEORY:**

Any mismatched load leads to reflected waves resulting in standing waves along the length of the line. The ratio of maximum to minimum voltage gives the VSWR. Hence minimum value of S is unity. If $S<10$ then VSWR is called low VSWR. If $S>10$ then VSWR is called high VSWR. The VSWR values more than 10 are very easily measured with this setup. It can be read off directly on the VSWR meter calibrated. The measurement involves simply adjusting the attenuator to give an adequate reading on the meter which is a D.C. mill volt meter. The probe on the slotted wave guide is moved t get maximum reading on the meter. The attenuation is now adjusted to get full scale reading. Next the probe on the slotted line is adjusted to get minimum, reading on the meter. The ratio of first reading to the second gives the VSWR. The meter itself can be calibrated in terms of VSWR. Double minimum method is used to measure VSWR greater than 10. In this method, the probe is inserted to a depth where the minimum can be read without difficulty. The probe is then moved to a point where the power is twice the minimum.

## BLOCK DIAGRAM

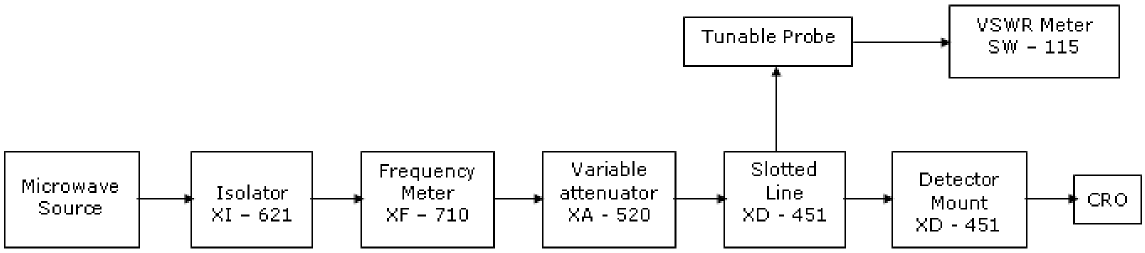



FIG: SET UP FOR LOW VSWR MEASUREMENT

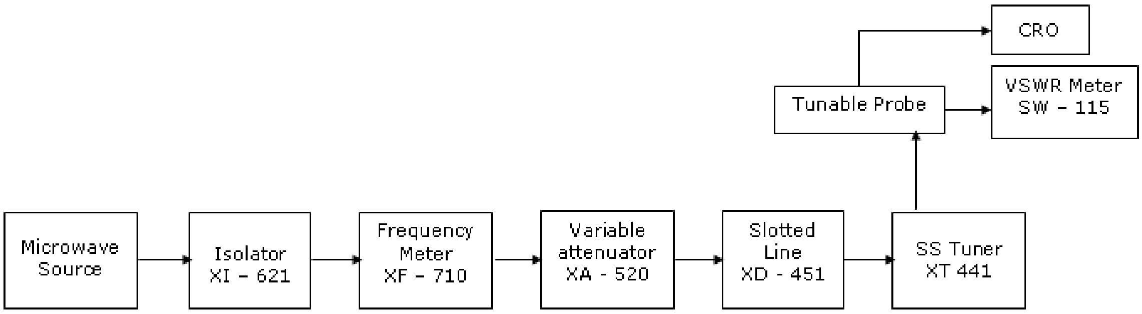



FIG: SET UP FOR HIGH VSWR MEASUREMENT

**PROCEDURE:**

1. Set up equipment as shown in figure.
2. Keep variable attenuator in minimum attenuation position.
3. Keep control knobs of VSWR meter as below

    Range dB = 40db / 50db

    Input switch = low impedance

    Meter switch = Normal

    Gain (coarse fine) = Mid position approximately

4. Keep control knobs of klystron power supply asbelow.

    Beam Voltage = OFF

    Mod-Switch = AM

    Beam Voltage Knob = fully anti clock wise

    Reflection voltage knob = fully clock wise

    AM-Amplitude knob = around fully clock wise

    AM frequency and amplitude knob = mid position

5. Switch 'ON' the klystron power supply, VSWR meter and cooling fan.
6. Switch 'ON" the beam voltage switch position and set (down) beam voltage at 300V.



7. Rotate the reflector voltage knob to get deflection in VSWR meter.
8. Tune the O/P by turning the reflector voltage, amplitude and frequency of AM modulation.
9. Tune plunges of klystron mount and probe for maximum deflection in VSWR meter.

10. If required, change the range db-switch variable attenuator position and (given) gain control knob to get deflection in the scale of VSWR meter.
11. As your move probe along the slotted line, the deflection will change.

**A. Measurement of low and medium VSWR:**

1. Move the probe along the slotted line to get maximum deflection in VSWR meter.
2. Adjust the VSWR meter gain control knob or variable attenuator until the meter indicates 1.0 on normal VSWR scale.
3. Keep all the control knob as it is move the probe to next minimum position. Read the VSWR on scale.
4. Repeat the above step for change of S-S tuner probe depth and record the corresponding SWR.
5. If the VSWR is between 3.2 and 10, change the range 0dB switch to next higher position and read the VSWR on second VSWR scale of 3 to 10.

**B. Measurement of High VSWR: (double minimum method)**

1. Set the depth of S-S tuner slightly more for maximum VSWR.
2. Move the probe along with slotted line until a minimum is indicated.
3. Adjust the VSWR meter gain control knob and variable attenuator to obtain n a reading of 3db in the normal dB scale (0 to 10db) of VSWR meter.
4. Move the probe to the left on slotted line until full scale deflection is obtained on 0-10 db scale. Note and record the probe position on slotted line. Let it be d1.
5. Repeat the step 3 and then move the probe right along the slotted line until full scale deflection is obtained on 0-10db normal db scale. Let it be d2.
6. Replace S-S tuner and termination by movable short.
7. Measure distance between 2 successive minima positions of probe. Twice this distance is guide wave length $\lambda g$.
8. Compute SWR from following equation

$$SWR = \frac{\lambda g}{\pi (d1 - d2)}$$

**OBSERVATION TABLE:**

LOW VSWR

VSWR = ________

**HIGH VSWR**

| Beam Voltage (v) | $x_1$ (cm) | $x_2$ (cm) | $x_1$ (cm) | $x_2$ (cm) | Avg $(x_1-x_2) = x$ (cm) | $\lambda g=2x$ (cm) |
|---|---|---|---|---|---|---|
| | | | | | | |

$\lambda g = 6cm$

| d1 (cm) | d2 (cm) | d1-d2 (cm) | VSWR = $\lambda g / \pi(d1-d2)$ |
|---|---|---|---|
| | | | |

**RESULT:** .

# 6.IMPEDANCE MEASUREMENT USING REFLEX KLYSTRON

**AIM:** To measure an unknown impedance using the smith chart.

**EQUIPMENT REQUIRED:**

1. Klystron tube
2. Klystron power supply Skps
3. Klystron mount
4. Isolator
5. Frequency meter
6. Variable attenuator
7. Slotted line
8. Tunable probe
9. VSWR meter
10. Wave guide stand
11. S-S tuner
12. Movable short/termination

**THEORY:**

The impedance at any point on a transmission line can be written in the form R+jx.

For comparison SWR can be calculated as

$$S = \frac{1+|R|}{1-|R|}$$ where reflection coefficient 'R'

Given as

$$R = \frac{Z - Z_0}{Z + Z_0}$$

$Z_o$ = characteristics impedance of wave guide at operating frequency.

Z is the load impedance

The measurement is performed in the following way.

The unknown device is connected to the slotted line and the position of one minima is determined. The unknown device is replaced by movable short to the slotted line. Two successive minima portions are noted. The twice of the difference between minima position will

be guide wave length. One of the minima is used as reference for impedance measurement. Find the difference of reference minima and minima position obtained from unknown load. Let it be

'd'. Take a smith chart, taking '1' as centre, draw a circle of radius equal to S. Mark a point on circumference of smith chart towards load side at a distance equal to d/λg.

Join the center with this point. Find the point where it cut the drawn circle. The co-ordinates of this point will show the normalized impedance of load.

## BLOCK DIAGRAM

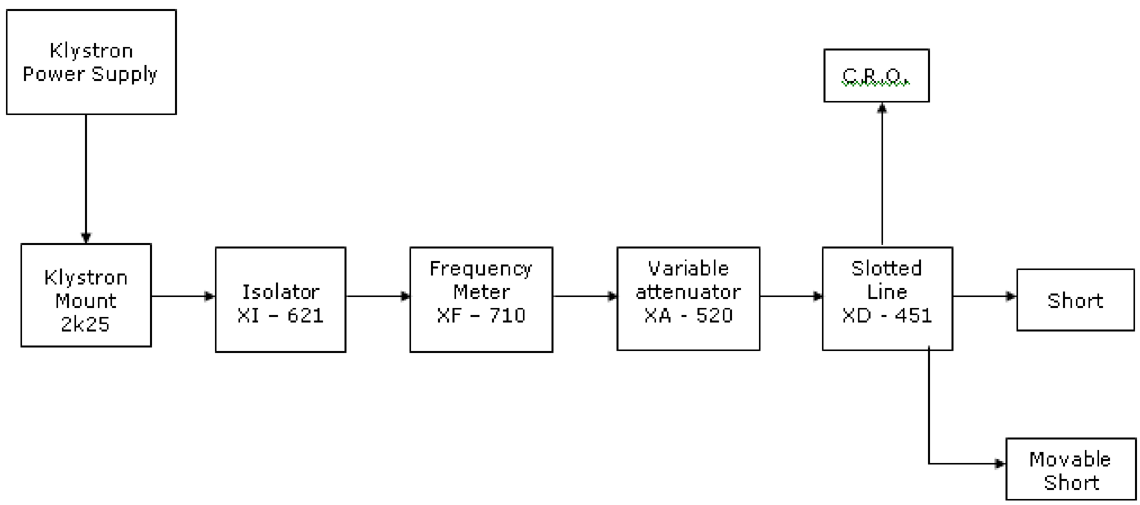



FIG: SET UP FOR IMPEDANCE MEASUREMENT



**PROCEDURE:**

1. Calculate a set of Vmin values for short or movable short as load.

2. ~~Calculate a set of Vmin values for S-S Tuner + Matched termination as a load.~~

**Note:** Move more steps on S-S Tuner

3. From the above 2 steps calculate $d = d_1 \sim d_2$
4. With the same setup as in step 2 but with few numbers of turns (2 or 3). Calculate low VSWR.

**Note:** High VSWR can also be calculated but it results in a complex procedure.

5. Draw a VSWR circle on a smith chart.
6. Draw a line from center of circle to impedance value ($d/\lambda g$) from which calculate admittance and Reactance ($Z = R \pm jx$)

**OBSERVATION TABLE:**

| Load (short or movable short) | | | | | |
|---|---|---|---|---|---|
| $x_1$ (cm) | $x_2$ (cm) | $x_1$ (cm) | $x_2$ (cm) | $x_1$ (cm) | $x_2$ (cm) |
| | | | | | |

x = ________

λg = _______

| Load (S.S. Tuner + Matched Termination) |
|---|
| |

| S.S Tuner + Matched Termination | Short or Movable Short |
|---|---|
| | |

d1= , d2 =

d = d1 ~ d2 =

Z = d/λg =

**RESULT:**.

# 7. SCATTERING PARAMETERS OF MAGIC TEE

**AIM:** To Study the operation of Magic Tee and calculate Coupling Co-efficient and Isolation.

**EQUIPMENT REQUIRED:**

1. Microwave source : Klystron tube
2. Isolator
3. Frequency meter
4. Variable Attenuator
5. Slotted line
6. Tunable probe
7. Detector Mount
8. Matched Termination
9. Magic Tee
10. Klystron Power Supply + Klystron Mount
11. Wave guide stands and accessories

**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.

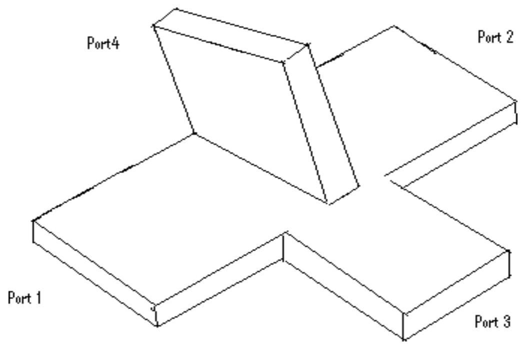



Fig: Magic Tee

**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:**

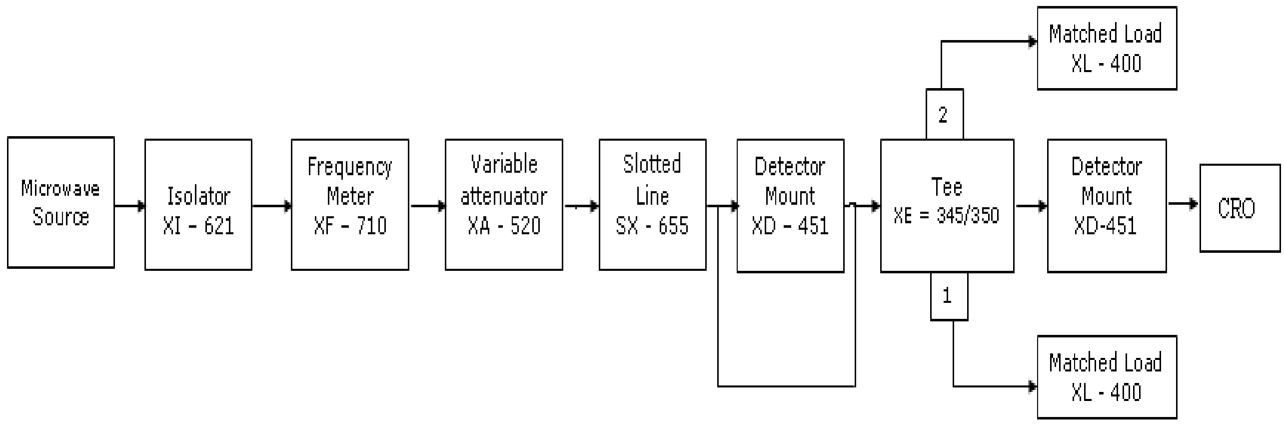
It is defined as Cij = $10 - \propto/20$

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.

**BLOCK DIAGRAM:**



## EXPERIMENTAL PROCEDURE:

1. Setup the components and equipments as shown in figure.
2. Energize the microwave source for particular frequency of operation and tune the detector mount for maximum output.
3. With the help of variable frequency of operation and tune the detector mount for maximum output attenuator, set any reference in the CRO let it be $V_3$.
4. Without disturbing the position of the variable attenuator, carefully place the Magic Tee after the slotted line, keeping H-arm to slotted line, detector mount to E-arm and matched termination to Port-1 and Port-2.
5. Note down the amplitude using CRO, Let it be $V_4$.
6. Determine the Isolation between Port-3 and Port-4 as $V_3$-$V_4$.
7. Determine the coupling co-efficient from the equation given in theory part.
8. The same experiment may be repeated for other Ports also.

## OBSERVATIONS:

| Ports | Power (W) |
|---|---|
| | |

## Calculations:

Coupling Co-efficient:

$$\alpha = 10 \log \frac{Vi}{Vj}$$

Therefore $C = 10^{-\alpha/20}$

## RESULT:

# 8. SCATTERING PARAMETERS OF CIRCULATOR

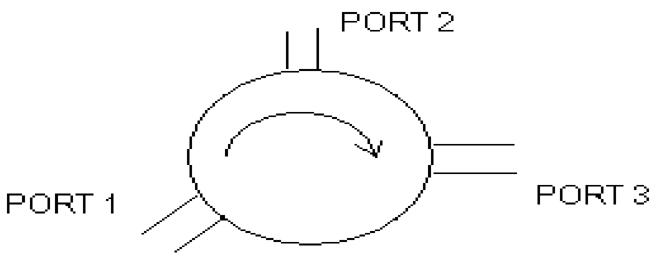
**AIM:** To study the Isolator and circulators and measure the Insertion Loss and Isolation of Circulator.

**EQUIPMENT REQUIRED:**

1. Microwave Source (Klystron or Gunn-Diode)
2. Isolator, Frequency Meter
3. Variable Attenuator
4. Slotted Line
5. Tunable Probe
6. Detector Mount Matched Termination
7. Circulator
8. Waveguide Stand
9. Cables and Accessories
10. VSWR Meter.

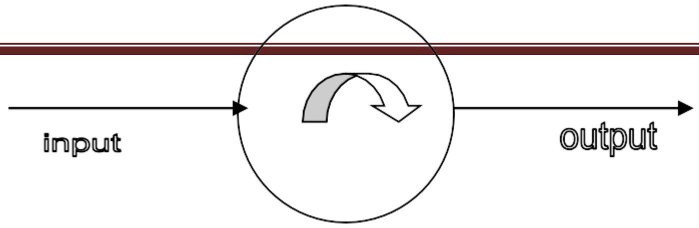
**CIRCULATOR:**

Circulator is defined as device with ports arranged such that energy entering a port is coupled to an adjacent port but not coupled to the other ports. This is depicted in figure circulator can have any number of ports.




**ISOLATOR:**

An Isolator is a two-port device that transfers energy from input to output with little attenuation and from output to input with very high attenuation.




The isolator, shown in Fig. can be derived from a three-port circulator by simply placing a matched load (reflection less termination) on one port.

The important circulator and isolator parameters are:

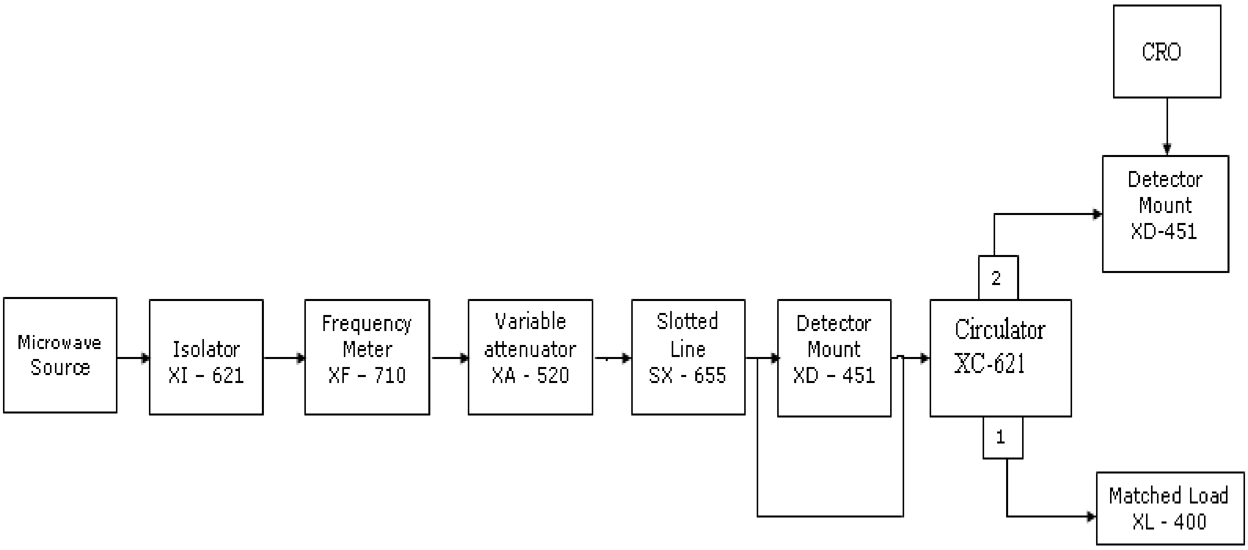
**A. Insertion Loss**

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

**B. Isolation**

Isolation is the ratio of power applied to the output to that measured at the input. This ratio is expressed in db. The isolation of a circulator is measured with the third port terminated in a matched load.

**BLOCK DIAGRAM:**



## EXPERIMENTAL PROCEDURE:

**Measurement of insertion**

1. Remove the isolator or circulator from slotted line and connect the detector mount to the slotted section. The output of the detector mount should be connected with CRO.
2. Energize the microwave source for maximum output for a particular frequency of operation. Tune the detector mount for maximum output in the CRO.
3. Set any reference level of output in CRO with the help of variable attenuator, Let it be $V_1$.
4. Carefully remove the detector mount from slotted line without disturbing the position of the set up. Insert the isolator/circulator between slotted line and detector mount. Keep input port to slotted line and detector its output port. A matched termination should be placed at third port in case of Circulator.
5. Record the output in CRO, Let it be $V_2$.
6. Compute Insertion loss given as $V_1$-$V_2$ in db.

**Measurement of Isolation:**

7. For measurement of isolation, the isolator or circulator has to be connected in reverse i.e. output port to slotted line and detector to input port with other port terminated by matched termination (for circulator).
8. Record the output of CRO and let it be $V_3$.
9. Compute Isolation as $V_1$-$V_3$ in db.
10. The same experiment can be done for other ports of circulator.
11. Repeat the above experiment for other frequency if needed.

**PRECAUTIONS:**

1. Avoid loose connections.
2. Avoid Parallax errors.

**RESULT:**

# 9. ATTENUATION MEASUREMENT

**AIM:** To study insertion loss and attenuation measurement of attenuator.

**EQUIPMENT REQUIRED:**

1. Microwave source Klystron tube
2. Isolator
3. Frequency meter
4. Variable attenuator
5. Slotted line
6. Tunable probe
7. Detector mount
8. Matched termination
9. Test attenuator
   a) Fixed
   b) Variable
10. Klystron power supply & Klystron mount
11. Cooling fan
12. BNC-BNC cable
13. VSWR or CRO

**THEORY:**

The attenuator is a two port bidirectional device which attenuates some power when inserted into a transmission line.

Attenuation A (dB) = 10 log (P1/P2)

Where P1 = Power detected by the load without the attenuator in the line

P2 = Power detected by the load with the attenuator in the line.

## BLOCK DIAGRAM

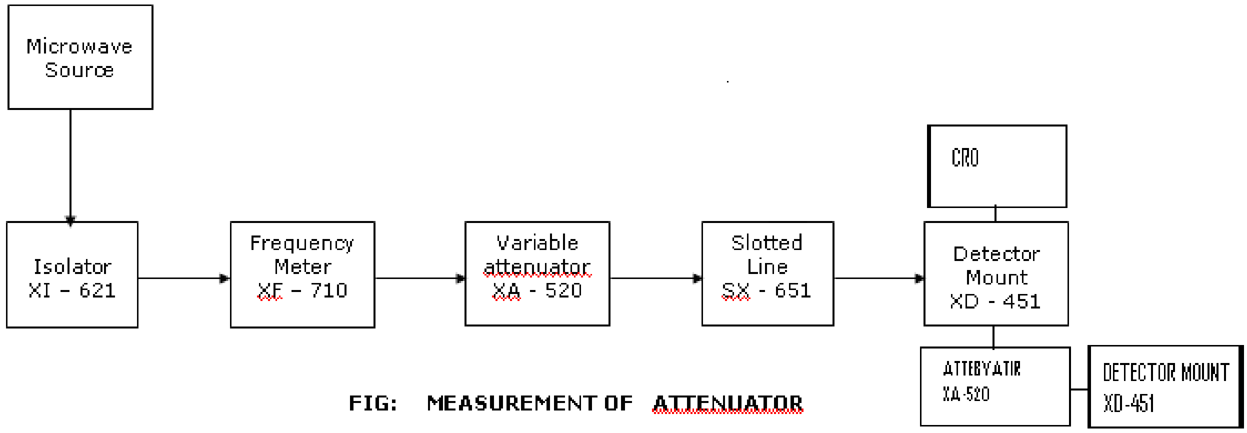


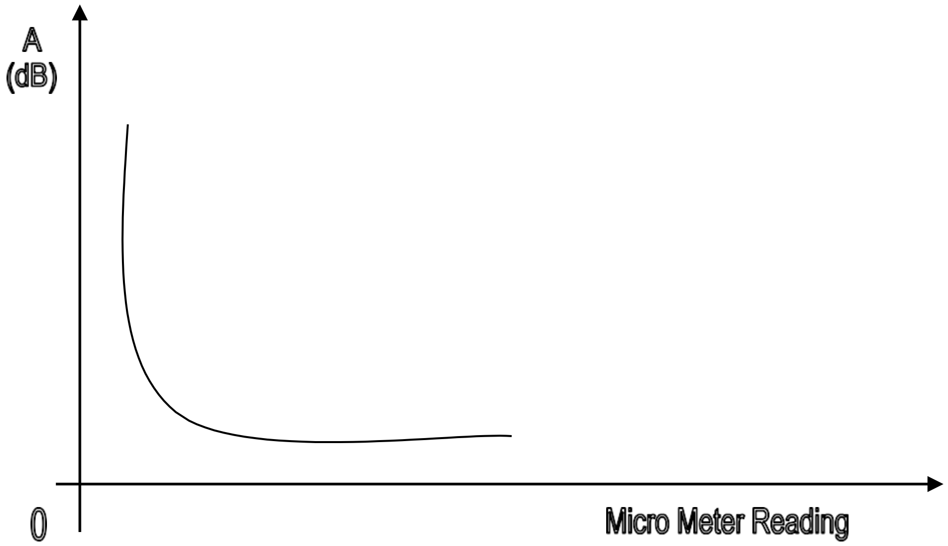

FIG: MEASUREMENT OF ATTENUATOR

**PROCEDURE:**

1. Connect the equipments as shown in the above figure.
2. Energize the microwave source for maximum power at any frequency of operation
3. Connect the detector mount to the slotted line and tune the detector mount also for max deflection on VSWR or on CRO
4. Set any reference level on the VSWR meter or on CRO with the help of variable attenuator. Let it be P1.
5. Carefully disconnect the detector mount from the slotted line without disturbing any position on the setup place the test variable attenuator to the slotted line and detector mount to O/P port of test variable attenuator. Keep the micrometer reading of text variable attenuator to zero and record the readings of VSWR meter or on CRO. Let it to be P2. Then the insertion loss of test attenuator will be P1-P2 db.
6. For measurement of attenuation of fixed and variable attenuator. Place the test attenuator to the slotted line and detector mount at the other port of test attenuator. Record the reading of VSWR meter or on CRO. Let it be P3 then the attenuation value of variable attenuator for particular position of micrometer reading of will be P1-P3 db.
7. In case the variable attenuator change the micro meter reading and record the VSWR meter or CRO reading. Find out attenuation value for different position of micrometer reading and plot a graph.
8. Now change the operating frequency and all steps should be repeated for finding frequency sensitivity of fixed and variable attenuator.

**Note:1.** For measuring frequency sensitivity of variable attenuator the position of micrometer reading of the variable attenuator should be same for all frequencies of operation.

**EXPECTED GRAPH:**




**OBSERVATION TABLE:**

| Micrometer reading | P1 (dB) | P2 (dB) | Attenuation = P1-P2 (dB) |
|---|---|---|---|
| | | | |

**RESULT:**

## 10.MEASUREMENT OF FREQUENCY AND WAVELENGTH

**AIM:** To determine the frequency and wavelength in a rectangular wave guide working in $TE_{10}$ mode.

**EQUIPMENT REQUIRED:**

1. Klystron tube
2. Klystron power supply
3. Klystron mount
4. Isolator
5. Frequency meter
6. Variable attenuator
7. Slotted section
8. Tunable probe
9. VSWR meter
10. Wave guide stand
11. Movable Short
12. Matched termination

**THEORY:**

The cut-off frequency relationship shows that the physical size of the wave guide will determine the propagation of the particular modes of specific orders determined by values of m and n. The minimum cut-off frequency is obtained for a rectangular wave guide having dimension a>b, for values of m=1, n=0, i.e. $TE_{10}$ mode is the dominant mode since for $TM_{mn}$ modes, n#0 or n#0 the lowest-order mode possible is $TE_{10}$, called the dominant mode in a rectangular wave guide for a>b.

For dominant $TE_{10}$ mode rectangular wave guide λo, λg and λc are related as below.

$1/\lambda o^2 = 1/\lambda g^2 + 1/\lambda c^2$

Where λo is free space wave length

λg is guide wave length

λc is cut off wave length

For $TE_{10}$ mode λc – 2a where 'a' is broad dimension of wave guide.

## BLOCK DIAGRAM

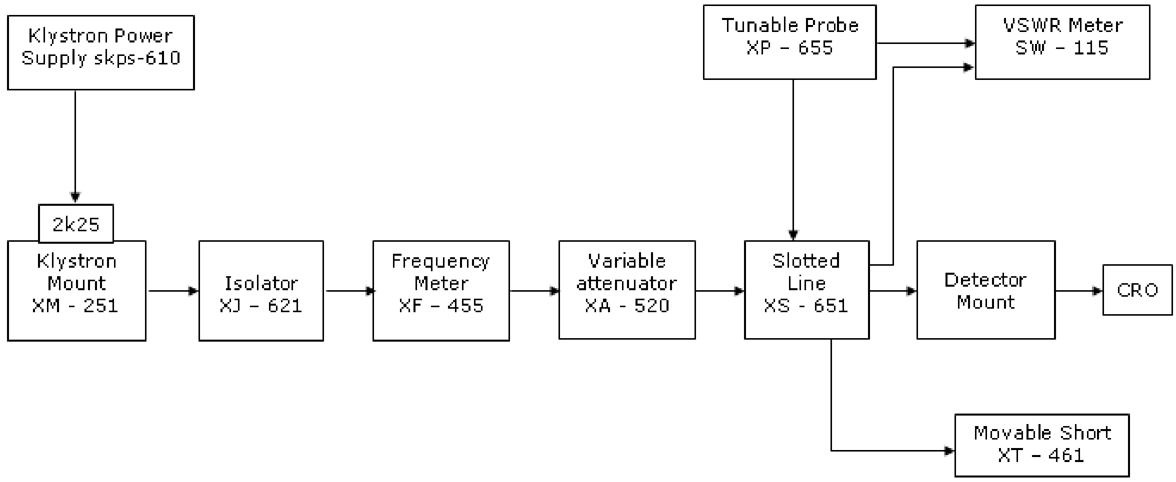



**FIG: SET UP FOR FREQUENCY AND WAVELENGTH MEASUREMENT**

**PROCEDURE:**

1. Set up the components and equipments as shown in figure.
2. Set up variable attenuator at minimum attenuation position.
3. Keep the control knobs of klystron power supply as below:

   Beam voltage – OFF

   Mod-switch – AM

   Beam voltage knob – Fully anti clock wise

   Repeller voltage – Fully clock wise

   AM – Amplitude knob – Around fully clock wise

   AM – Frequency knob – Around mid position
4. Switch ‘ON’ the klystron power supply, CRO and cooling fan switch.
5. Switch ’ON’ the beam voltage switch and set beam voltage at 300V with help of beam voltage knob.
6. Adjust the repeller voltage to get the maximum amplitude in CRO
7. Maximize the amplitude with AM amplitude and frequency control knob of power supply.
8. Tune the plunger of klystron mount for maximum Amplitude.
9. Tune the repeller voltage knob for maximum Amplitude.
10. Tune the frequency meter knob to get a ‘dip’ on the CRO and note down the frequency from frequency meter.
11. Replace the termination with movable short, and detune the frequency meter.

12. Move the probe along with slotted line. The amplitude in CRO will vary .Note and record the probe position , Let it be d1.
13. Move the probe to next minimum position and record the probe position again, Let it be d2.
14. Calculate the guide wave length as twice the distance between two successive minimum position obtained as above.
15. Measure the wave guide inner board dimension 'a' which will be around 22.86mm for x-band.
16. Calculate the frequency by following equation.

$$f = \frac{c}{\lambda} = \sqrt{\left(\frac{1}{\lambda_g^2} + \frac{1}{\lambda_c^2}\right)}$$

Where C = $3 \times 10^8$ meter/sec. i.e. velocity of light.

17. Verify with frequency obtained by frequency modes
18. Above experiment can be verified at different frequencies.

$f_o = C/\lambda o$ => C => $3 \times 10^8$ m/s (i.e., velocity of light)

$1/\lambda o^2 = 1/\lambda g^2 + 1/\lambda c^2$

$$\lambda_0 = \frac{\lambda_g \lambda_c}{\lambda_g^2 + \lambda_c^2}$$

$\lambda g = 2x\ \Delta d$

For $TE_{10}$ mode => $\lambda c = 2a$

a ➐ wave guide inner broad dimension

a = 2.286cm" (given in manual)

$\lambda c$ = 4.6cm

**OBSERVATION TABLE:**

| Beam voltage(v) | Beam current (mA) | Repeller voltage(v) | fo (using freq meter) (GHZ) | d1 (cm) | d2 (cm) | d3 (cm) | d4 (cm) | Δd1= d2-d1 (cm) | Δd2= d3-d2 (cm) | Δd3= d4 - d 3 | Δd=(Δd1+Δd2+ Δd3)/3 | λg=2 x Δd | λo (cm) | fo (HZ) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | | |

**RESULT:**