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MICROWAVE EXPERIMENT MANUAL

SCIENTIFIC MICROWAVE
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MICROWAVE TEST BENCH

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GUNN POWER SUPPLY

1. **Gunn Power Supply :**

   Gunn power supply comprises of an electronically regulated DC power supply and a square wave generator designed to operate Gunn oscillator and pin modulator simultaneously.

   The DC voltage is variable from 0 to 10 volts. The frequency of square wave can be continuously varied from 800 to 1200 Hz. The front panel meter can read the Gunn voltage and the current drawn by the Gunn diode.

   The power supply is designed to protect Gunn diode from reverse voltage application from over voltage transients and from low frequency oscillations.

2. **Gunn Oscillator :**

   Gunn oscillator has been designed as a stable and spectrally pure microwave source. The oscillator has a Gunn diode mounted in a waveguide cavity which is tunable over the range 8.5 to 11.5 GHz by a micrometer controlled tuning plunger. Minimum output power available is 10 mW – 15 mW.

3. **PIN Modulator :**

   The CW output of the Gunn oscillator can be a square wave pulse modulated by superimposing the modulating voltage on the Gunn diode bias voltage. It is however rather difficult to achieve good modulation due to varying impedance of Gunn diode with temperature. Moreover the generating circuit of modulating voltage should have a low output impedance and should be able to deliver as much as 300 to 500 mA. These disadvantages can be overcome by using an external pin diode modulator operating on the CW output of the Gunn oscillator.

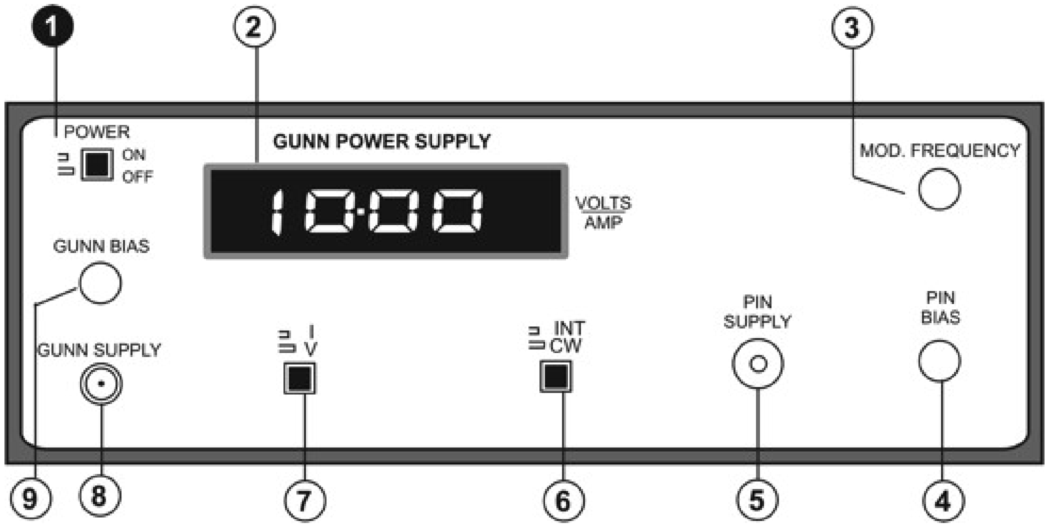
   The Pin Modulator is a transmission line i.e. wave guide shunted with a Pin Diode. The impedance of diode varies with the bias applied to it. At negative or zero bias the diode presents very low impedance, thus reflecting the signal. At positive bias, the diode presents very high impedance and therefore does not affect the signal propagating along the transmission line.

   Since the propagating power is reflected during the period when positive voltage is on the Pin Diode, it is advisable to place an isolator between the Gunn Oscillator and Pin Modulator, to protect the former.

TECHNICAL SPECIFICATIONS

Voltage Range	:	0 to 10V
Current	:	750 mA max
Stability	:	0.1 % for + 10% mains variation
Ripple	:	1.0 mV typical
Modulating Frequency	:	800 to 1200 Hz
Modulating Voltage	:	0 – 10 Vpp variable
Output Connector	:	BNC for Gunn Bias
Frequency Range of Gunn Oscillator	:	8.5 to 11.5 Ghz (mechanical tunable)
Frequency Accuracy	:	± 1%
Load VSWR	:	1.5 max
Output Power of Gunn Oscillator	:	Min 10mW – 15mW over the entire frequency range
Frequency Stability	:	500 KHz /°C temp
Pushing Sensitivity	:	10 MHz
Power Supply	:	220 VAC ± 10%, 50Hz.
Waveguide Type	:	WR – 90
Dimension (mm)	:	273 x 197 x 80

FRONT PANEL CONTROL



(1) **Power :** Push button switch for supplying power to instrument.

(2) **Digital Display :** 3 ½ digit readout for Gunn supply voltage and current

(3) **Modulation Frequency :** Frequency control for the PIN supply (square wave).

(4) **PIN Bias :** Amplitude control for the PIN supply (square wave) from 0 to 10Vpp.

(5) **PIN Supply :** Square wave output for PIN modulator.

(6) **INT/CW :** Selection switch for CW (continuous wave) operation that is no modulation, only Gunn bias voltage is applied on Gunn oscillator. During INT mode modulation takes place and square wave is simultaneously available at PIN supply whose amplitude and frequency can be varied.

(7) **V/I (Push button) :** For switching the display from voltage to current reading or vice versa. When the pushbutton is pressed, the current supplied is displayed with a resolution of 10mA. In released position the voltage is displayed with a resolution of 0.01 V.

(8) **Gunn Supply 0 - 10 V :** Gunn supply output is available here.

(9) **Gunn Bias :** (adjusting knob): For the setting of the Gunn Bias voltage.

OPERATING INSTRUCTIONS

The following operating instructions should be followed for operating the Gunn source.

Gunn Power Supply :

1. Before switching ON the power supply, keep Gunn Bias and Pin Bias knobs fully anticlockwise.

2. Connect the Power Supply to the Gunn Bias Terminal at the Gunn Oscillator with BNC to BNC cable

3. Rotate the Gunn bias knob gradually to the operating voltage.

4. For amplitude modulation of CW output of Gunn Oscillator connect Pin Bias supply to Pin Modulator by cable, keep the modulation selector switch at INT position. Rotate the pin bias knob in clock-wise direction. Maximum depth of modulation is obtained when the pin bias knob is fully clock-wise.

5. When detector is used along with VSWR meter, turn the Mod. Freq. Knob till max indication is obtained on the VSWR Meter.

6. Before switching off the Power Supply rotate the Gunn Bias and Pin Bias knobs fully anticlockwise and disconnect Gunn Oscillator and Pin Modulator.

Gunn Oscillator :

1. Connect the Power Supply to Bias terminal of Gunn Oscillator with BNC coaxial cable supplied.

2. Increase the Gunn Supply Voltage to the operating voltage specified on the calibration chart provided with each Oscillator.

3. The Gunn Oscillator Cavity is tunable by a movable short which is connected to a micrometer.

4. If during operation of Gunn Oscillator the Power Supply Meter indicates +12V then disconnect the oscillator immediately from the Power Supply.

5. If the Gunn oscillator fails to give output check the Gunn-diode current by keeping the meter selector switch in CURRENT position. If the meter fails to indicate current the Gunn Diode may have burnt. Never test the Gunn Diode by a multi-meter.

6. Negative or more than positive +12V should never be applied to the Gunn Oscillator, which will cause a permanent damage to. Gunn Diode.

PIN Modulator :

1. If the CW output of the Gunn Oscillator is required to be amplitude modulated, the Pin Modulator should be connected to the output of X-band Gunn source such that power flow through the modulator is in direction of arrow marked an it and press INT for getting modulation.

2. If amplitude modulation with 1 KHz frequency and 50% duty cycle is required for VSWR measurements, bias the Pin modulator using the Power Supply as described earlier.

3. If amplitude modulation of any other duty cycle is needed then use suitable pulse generator to. BNC (F) connector of Pin modulator with a series resistance to limits max. average current to about 20 mA.

4. A 3dB fixed attenuating vane is fitted in Pin modulator's waveguide section to Isolate Gunn Diode and Pin Diode. Thus a DC biasing to. Pin Modulator by 10 to 20mA DC current, the output will be 3dB down.

5. In case CW output is required, the Pin Modulator should be removed from the test setup.

SAFETY PRECAUTIONS

1. Before connecting the Gunn Power Supply to the Gunn Oscillator and Pin modulator, switch ON the Gunn Power Supply and check Gunn bias varying the control knob from o to 10V. If this voltage exceeds 12V for any position Gunn Bias Control, do not connect the Power Supply to the Gunn Oscillator.

2. If the voltage variation is proper, rotate the Gunn Bias Knob fully anti clock-wise and follow the operating instructions.

3. If during operation of the Gunn Oscillator, the meter reads more than 12V and Gunn Bias Control loses control of supply, disconnect the Gunn Oscillator from Power Supply immediately.

4. If on rotating the Gunn Bias Control Knob in the clock-wise direction the Gunn Supply Voltage saturates at about 3 to 5 Volts again disconnect the Power Supply immediately. The Power Supply needs servicing in case of situation 4.

KLYSTRON POWER SUPPLY

Klystron Power Supply, is a state-of the-art solid-state, regulated power supply for operating low power Klystrons such as 2K25, 723 AB, RK 5976, 726 etc.

It incorporates a number of proprietary features:

1. Regulated Beam Supply and Repeller Supply voltages
2. LED Digital metering for Beam voltage, current and Repeller voltage
3. Compact and Reliable
4. Modular construction for easy maintenance

In addition to AM and FM modulation of Beam current, a provision for externally modulating the Klystron supply with desired signal waveform has been provided.

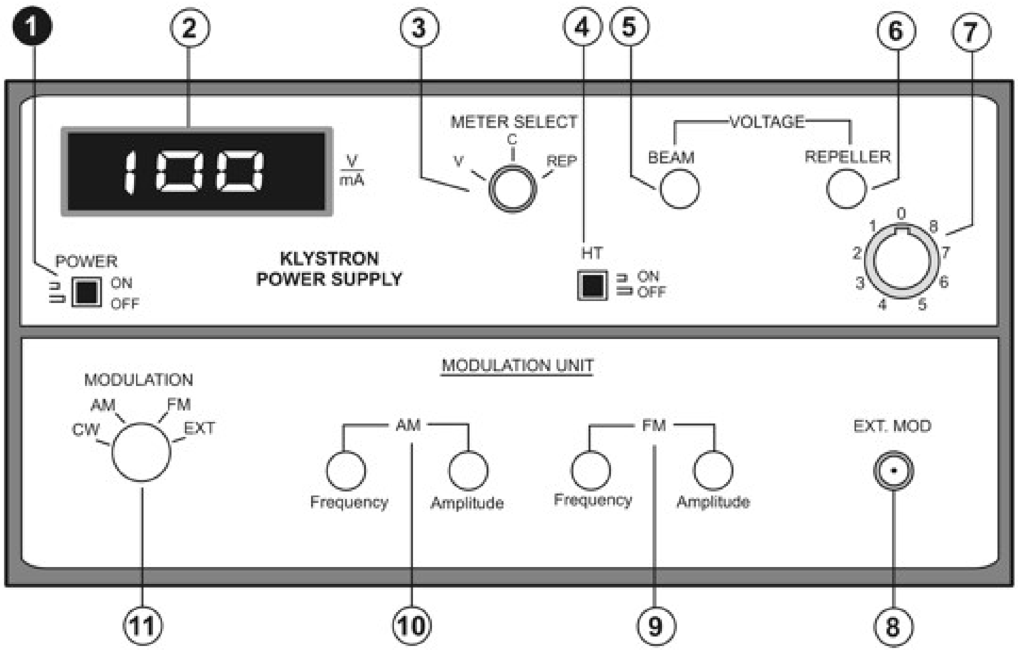
Klystron Power supply utilizes quality components and rugged construction. A careful handling of the instrument will provide years of trouble free service. The equipment is divided in two parts one is high voltage unit and other is modulation unit. It makes it users friendly.

TECHNICAL SPECIFICATIONS

Beam Supply	:	**Voltage :** 240 - 420 VDC, Variable	
		Current : 50 mA	
		Regulation : 0.5 % for 10% I/P variation	
		Ripple : < 5m Vrms	
Repeller Supply	:	-18V to -270V DC Variable	
		Regulation : 0.25%, for 10% I/P variation	
Filament Supply	:	6.3 VDC (adjustable on rear panel)	
Over-Load Trip Current	:	65mA	
Modulation	:	AM (Square)	FM (Saw-tooth)
Frequency Range		500-2000 HZ	50-150 Hz
Amplitude		0-110 Vpp	0-60 Vpp
External		Through External Modulating Signal	
Display	:	Digital display for	
		1. Beam voltage	
		2. Beam Current	
		3. Repeller voltage	
Modulation Selector	:	CW/AM/FM/EXT	
3 ½ Digital Panel meter	:	2V	
Meter Selector	:	Beam Voltage (V)/ Current (I)/ Rep. (Rep)	

Connectors	:	**a.** 8-Pin Octal Socket
		b. BNC for External Modulation
Power Supply	:	220 V AC ± 10%, 50Hz
Dimensions (mm)	:	345 x 283 x 153

FRONT PANEL CONTROL



(1) **Power :** Push button switch for supplying the power to instrument.

(2) **3 ½ Digit LED Display :** for monitoring beam voltage (in volts), Repeller voltage and beam current (mA).

Beam voltage : 240 V to 420 V DC

Repeller voltage : -10V to -270 V DC

Beam current : 0 to 50 mA

(3) **Meter Select Switch :** For selecting display mode in V – shows Beam voltage (volts), I – shows Beam current (mA) and REP – shows Repeller voltage in volts.

(4) **HT :** Output ON/OFF switch.

(5) **Beam voltage :** Adjust potentiometer, it is vary from 240 to 420 V DC.

(6) **Repeller voltage :** Adjust potentiometer, it is vary from -10V to -270V DC.

(7) **8 Pin octal socket :** Pin 8 – 1 = Beam voltage

Pin 8 – 5 = Rep. voltage

Pin 2 – 7 = Heater voltage

(8) **Ext. mode :** To provide external modulating signal.

(9) **FM modulation :** Frequency potentiometer controls the frequency or the sweep modulating signal (50 – 150 Hz). Amplitude potentiometer controls the amplitude or sweep modulating signal (0 – 60Vpp)

(10) **AM modulation :** Frequency potentiometer controls the frequency or the square wave modulating signal (500 – 2000 Hz). Amplitude potentiometer controls the amplitude or square wave modulating signal (0 – 110Vpp).

(11) **Modulation Selection switch :** For selecting modulation types CW mode – No modulation signal applied to the beam voltage. AM mode – A square wave modulating signal is applied to the beam voltage. FM mode – A sweep modulation is applied to the beam voltage, EXT mode – External modulating signal is accepted for modulation or beam current through BNC connector.

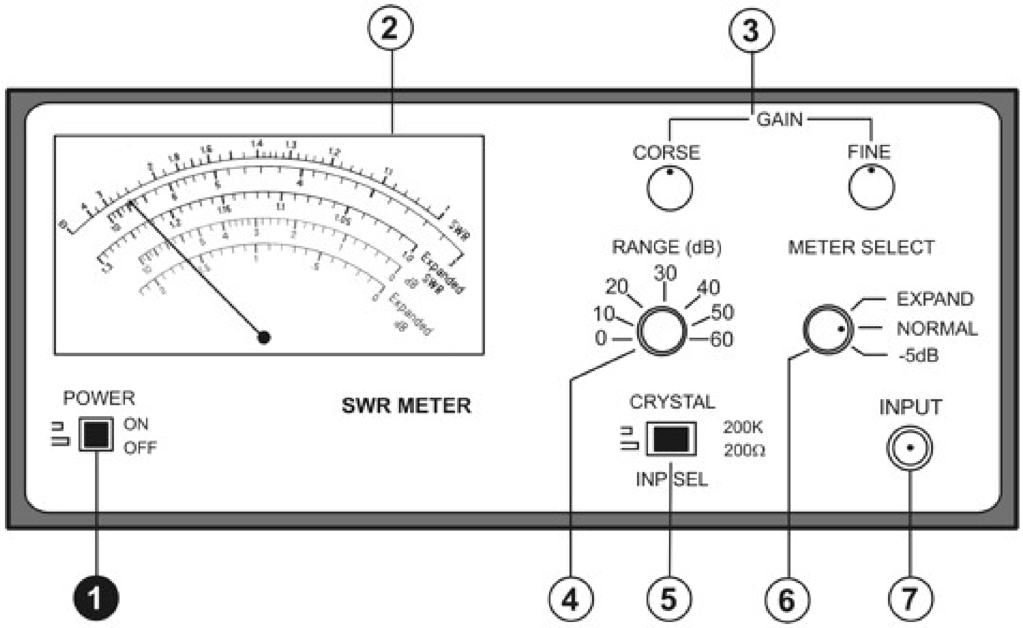
VSWR METER

The model **MW 103 SWR meter** is a high gain low noise, tuned voltmeter operating at fixed frequency. It is designed for making standing wave measurement in conjunction with a suitable detector and slotted line or wave guide section. It may be used as null detector in bridge circuit and as fixed frequency indicator. It is calibrated to indicate directly SWR or db when used with square law devices such as crystal diode. It has expanded scales for accurate reading of small increments. It is adjusted for operation at 980Hz to 1020 Hz to avoid harmonics of the line frequency.

TECHNICAL SPECIFICATIONS

Sensitivity	:	0.1μV for 200Ω input impedance for full scale deflection.
Noise Level	:	Less than 0.02μV
Range	:	0 – 60dB in 10dB steps.
Input	:	Un-biased low and high impedance crystal biased crystal (200Ω and 200K)
Meter Scale	:	SWR 1-4, SWR 3-10, dB 0-10, expand SWR 1-1.3, dB 0-2.
Gain Control	:	Adjusts the reference level, variable range 0 - 10dB (approx.)
Input Connector	:	BNC (F)
Input Frequency	:	1000Hz ± 10%
Power	:	220 Volts A.C. ± 10%, 50Hz
Dimension (mm)	:	300 x 222 x 122

FRONT PANEL CONTROL



(1) **Power :** Push button switch for supplying power to instrument.

(2) **Meter Calibrated in SWR & dB :** Meter, for measuring SWR and gain.

(3) **Gain Coarse :** Control for adjustments of meter on full scale / any other coMWenient reading.

Gain Fine : Control for fine adjustments of meter on full scale / any other coMWenient reading (0.8dB)

(4) **Range Switch :** A seven position attenuator minimum in 10 dB steps.

(5) **Crystal :** It is an input selector switch for low and high inputs i.e. High 200K – crystal, Low 200Ω.

(6) **Meter Selector switch :** Three position switch Normal – selection or normal scale, Expand – selection or expanded scale and – 5dB scale.

(7) **Input :** BNC (Female) connector for connecting signal to be measured.

OPERATING THEORY AND INSTRUCTIONS

Auxiliary equipment required :

For SWR measurement, following equipments are required :

1. **Signal Source :**

   The signal source should cover the desired frequency range and be amplitude modulated at operating frequency of the SWR meter. Generally square wave modulation is used which reduces to a minimum the effects of harmonic and frequency modulation. In any application, it is necessary to minimize interaction between the oscillator and the load. In these cases, an isolation device should be used.

2. **Cables or waveguides :**

   Te cable or the wave guide used for connecting the source to a slotted match the source impendence over the desired frequency range

3. **Slotted Section :**

   The slotted section should cover the desired frequency and be equipped with an accurate scale or indicator

4. **Detector :**

   The detector should be square law (out put proportional to RF power input) device such as a Barretter or a crystal diode operated at low signal level. A Barretter is reasonable square law when used at low signal level but in general this cannot be said in all cases with crystal diode. However the sensitivity of crystal is considerably better than with barretters so that crystals are widely used as detectors for SWR measurements.

5. **Known loads :**

   Various termination are required (i.e. a fixed and a movable short circuit) to establish reference points and to aid in calibrating the test setup.

Techniques in Measurements :

Basically, the measurement of a standing wave ratio consists of the probe carriage at a voltage maximum position and setting the gain to obtain a reading of 1.0. The probe carriage is then move along with the slotted line to a voltage minimum and the SWR is indicated directly on the scale.

But there are other cases, specially in design and development, where complete knowledge of the terminating equipment is desired. This can be obtained by measuring SWR and phase in the standing wave pattern.

Generally, the impedance characteristic of the load is obtained by measuring the position of the voltage minimum. This position is compared to a shifted position of the voltage minimum which occurs when a known load replaces the load under test at reference point on the slotted line. The distance between these two minima is entered on a smith chart and the reactive component is determined. For coMWenience the known load usually a short circuit or shorting plate and the reference point is the load connection.

Detector probe penetration :

A general rule in slotted line work is that the penetration of a sampling probe into the line should be held to a minimum. The power extracted by the sampling probe caused distortion in the standing-wave pattern. This effect usually becomes greater as probe penetration is increased and can be explained by considering the probe as and admittance shunting the line.

Impedance in the standing-wave pattern varies along the line from maximum at a voltage maximum to a minimum at a voltage minimum. The shunt admittance introduced by the probe lowers these impedance this causing the measured SWR to be lower than the true SWR and shifting both the maxima & minima from their neutral position. The shift will be greater at a voltage maximum that at a voltage minimum.

Besides absorbing power and affecting the standing-wave pattern the probe will also cause reflections in the line. These reflections will travel towards the signal source. If the signal source is not matched, these reflection are re-fleeted towards the load and will cause additional errors in low SWR measurements.

An exception to the minimum penetration rule occurs when it is desired to examine in details a voltage minimum in a high SWR measurement. For this work, greater probe penetration can be tolerated because the voltage minimum corresponds to low impedance point in the line. However only at a voltage minimum you can tolerate substantial probe penetration.

Precaution when crystal detectors used :

Whenever a crystal detector with a matched load resistor is used, the input selector switch must be set at the XTAL - 200 K ohms position to obtain accurate square-law response. With unloaded crystal, select the input impedance which gives maximum sensitivity. Usually, the XTAL 200 position will give the best [sensitivity. However, some crystal diodes may given higher output in the XTAL - 200 K ohms position. maximum sensitivity is desirable so probe penetration in the slotted line can be kept to a minimum.

Operation procedures :

1. Low SWR Measurements (10 and below):

- **a.** Turn ON the instrument. For a maximum stability allow approximately 5 minutes warm up.
- **b.** Set Input Selector Switch for the type of detector that is to be used.
- **c.** Connect the detector cable to the input of the VSWR meter
- **d.** Set GAIN (COARSE & FINE) controls to approximately of maximum.
- **e.** Set range switch on 30-db or 40-db position. Adjust probe penetration to obtain up-scale reading.
- **f.** Peak the meter by adjusting the modulation frequency of the signal source, if adjustable. Reduce probe penetration to keep on scale.

g. Peak the meter by tuning the probe detector, if tunable. Reduce the gain control knob or attenuator to keep meter on scale, i.e. to obtain full scale reading.

h. Peak the meter by moving the probe carriage along the line. To reduce gain control knob or attenuator to keep meter on scale.

i. Adjust GAIN controls and /or output power from the signal source to obtain exactly full scale reading.

j. Move the probe carriage along the line to obtain minimum reading. Do not retune probe or detector

k. Read SWR, Which is indicated directly on the scale.

2. If the reading at the minimum is lower than 3 on the top scale, set RANGE Switch to next higher range and read the indication on the second SWR or (3 to 10) scale of SWR.

3. If the range switch is changed by two steps used top SWR scale, however all indication on this scale must be multiplied by 10.

High SWR Measurements (Above 10) **:**

When the SWR is high, probe coupling must be increased if a reading is to be obtained at the voltage minimum. However, at the voltage maximum, this high coupling may result in a deformation of the pattern with consequent error in reading, In addition to this error caused by probe loading there is also danger of error resulting from the change in detector characteristics at higher R.F. levels.

Double Minimum Method :

In the double minimum method, it is necessary to establish the electrical distance between the points where the output is double the minimum.

1. Repeat steps 1 to 7 in the low SWR measurement procedures. .
2. Move the probe carriage along the line to obtain minimum reading and note the probe carriage position.
3. For reference, adjust gain controls to obtain reading of 3.0 on the db scale. If a linear detector is being used, adjust gain controls for an indication of 1.5 on db scale.
4. Move the probe carriage along the line to obtain a reading of full scale ('o') on the db scale on each side of the minimum.
5. Record as d1 and d2 the probe carriage position at the two equal readings obtained in step 4.
6. Short the line and measure the distance between successive minima. Twice this distance is, the guide wavelength.

The SWR can be obtained by substituting this distance into the expression.

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

Where λg is the guide wave length d1 and d2 are the location of the twice-minimum points.

The method overcomes the effect of probe loading since the probe is always set around a voltage minimum where larger probe loading can be tolerated however it does not overcome the effect of detector characteristics

Calibrated attenuator method :

Another method for measuring high SWR's is to use a calibrated variable attenuator between the signal source and the slotted line. Adjust the attenuator to keep the rectified output of the crystal diode equal at the voltage minimum and voltage maximum points. The SWR in db is the difference in the attenuator settings.

1. Repeat steps 1 to 7 in low SWR measurements procedure.

2. Move the probe carriage along the line for a voltage minimum, adjust the attenuator to give a coMWenient indication on the meter, note the attenuator setting.

3. Move the probe carriage along the line to a voltage maximum, adjust the attenuator to obtain the same indication on the meter as established in step 2, and note the attenuator setting,

4. The SWR may be read directly (in dB) as the difference between the first and second readings. While this method overcomes the effect of detector variations from a square Law characteristic, the effect of probe loading still remains. Be careful; always use minimum probe penetration.

Location of voltage maximum or voltage minimum :

From the discussion on probe loading it has shown that it is more desirable to locate the voltage minimum that the voltage maximum since the effect of probe loading is less at the minimum. However, the location of voltage minimum by a single measurement, particularly on low SWR, is usually inaccurate because of its broadness, thus making the true minimum position hard to determine. An accurate method of location the voltage minimum is to obtain the position of the probe carriage at two equal output readings on either side of the minimum and then averaging these two readings.

EXPERIMENT 1

Object :

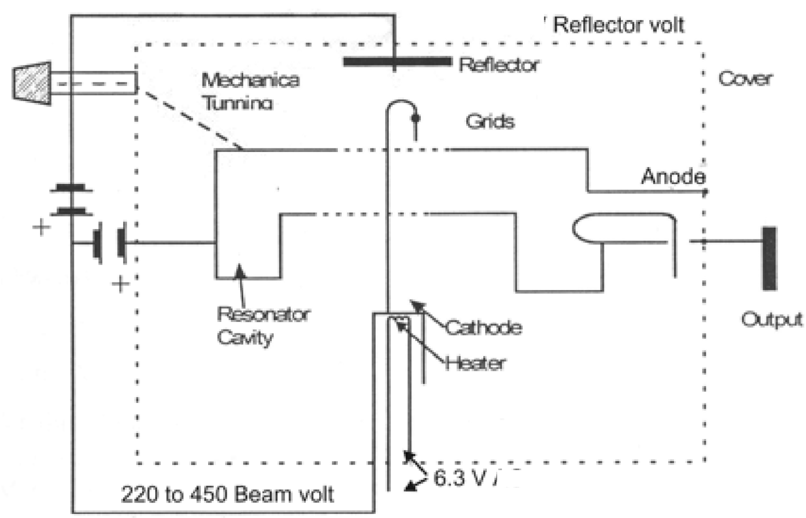
To study the characteristics of the Reflex Klystron Tube and to determine its electronic tuning range. (For MT 9000)

Equipment Required :

Klystron power supply, Klystron tube with Klystron mount, Isolator, Frequency meter, Variable attenuator, Detector mount, Wave guide stand, VSWR meter and oscilloscope BNC cable

Theory :

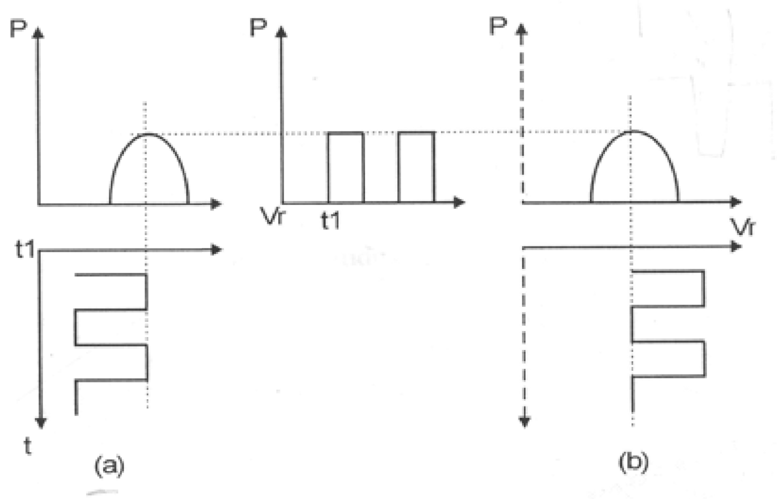
The Reflex Klystron makes the use of velocity modulation to transform a continuous electron beam into microwave power. Electrons emitted from the cathode are accelerated & passed through the positive resonator towards negative reflector, which retards and finally, reflects the electrons and the electrons turn back through the resonator. Suppose an rf-field exists between the resonators the electrons traveling forward will be accelerated or retarded, as the voltage at the resonator changes in amplitude.



Schematics Diagram of Klystron 2K25

Fig. 1

The accelerated electrons leave the resonator at an increased velocity and the retarded electrons leave at the reduced velocity. The electrons leaving the resonator will need different time to return, due to change in velocities. As a result, returning electrons group together in bunches, as the electron bunches pass through resonator, they interact with voltage at resonator grids. If the bunches pass the grid at such a time that the electrons are slowed down by the voltage then energy will be delivered to the resonator; and Klystron will oscillate. Fig. 2 shows the relationship between output power, frequency and reflector voltages.



Square Wave modulation of the Klystron

Fig. 2

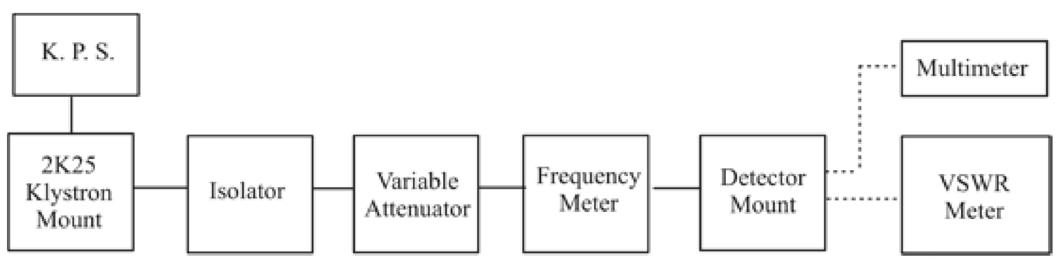
The frequency is primarily determined by the dimensions of resonant cavity. Hence, by changing the volume of resonator, mechanical tuning of klystron is possible. Also, a small frequency change can be obtained by adjusting the reflector voltage. This is called Electronic Tuning

The same result can be obtained, if the modulation voltage is applied on the reflector voltage as shown in the fig.

Procedure :

Carrier Wave Operation :

1. Connect the components and equipments as shown in fig.



Setup for study of klystron tube

Fig. 3

2. Set the Variable Attenuator at the maximum position (A highest of micrometer reading).

3. Set the mode switch of klystron power supply to CW position, beam voltage control knob to full anti-clock wise and reflector voltage control knob to fully clock wise and the meter switch to 'OFF position.

4. Rotate the knob of Frequency meter at one side fully.

5. Put VSWR meter in 50dB att. and coarse and fine on mid direction and put in low crystal impedance position.

6. Put the multi-meter in DC microampere range of 250 microampere

7. Switch 'ON' the klystron power supply, cooling fan for klystron tube. .

8. Put the meter switch to beam voltage position and rotate beam voltage knob clockwise slowly upto 300V reading. Observe beam current on the meter by changing the meter switch to beam current position. 'The beam current should not increase more than 25mA.

9. Change the reflector voltage slowly and watch on the VSWR meter. Set the voltage for maximum deflection in the meter. If no deflection is obtained, hence the plunger position of klystron mount and detector mount if get full deflection than change the dB position. Then replace VSWR to multi-meter.

10. Tune the plunger of klystron mount for the maximum output.

11. Rotate the knob of frequency meter slowly and stop at that position, when there is less output current on multi-meter. Read directly the frequency meter between two horizontal line and vertical marker. If micro meter type frequency meter is used, read micrometer frequency and find the frequency from its calibration chart.

12. Change the reflector voltages and read the current and frequency for each reflector voltage and plot the graph. For example.

Voltage (V)	Current (mA)	Frequency (GHz)
220	0.25	9.65
219	0.75	9.64
218	2.00	9.63

Square Wave Operation :

1. Connect the equipments and components as shown in the fig.

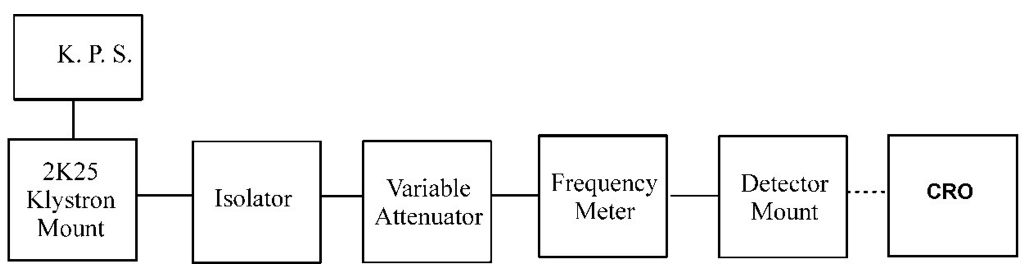


Fig. 4

2. Set Micrometer of variable attenuator around highest position.

3. Set the range switch of VSWR meter at 40dB position, input selector switch to crystal impedance position, meter switch to normal position.

4. Set Mod-selector switch to AM- MOD position. Beam voltage control knob to fully anticlockwise position. Reflector voltage control knob to the maximum clockwise position and meter switch to 'OFF' position.
5. Switch "ON" the Klystron Power Supply, VSWR meter and cooling fan.
6. Change the meter switch of Klystron Power Supply to beam voltage knob clockwise up to 300V.
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.
9. Rotate the AM-MOD amplitude knob to get the maximum output in VSWR meter.
10. Maximize the deflection with & frequency control knob of AM-MOD.
11. If necessary, change the range switch of VSWR meter 50 db to 30 db 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.
12. Find the oscillation by frequency by Frequency Meter as described in the earlier setup.
13. Connect oscilloscope in place at VSWR and see square wave across detector mount.

Mode Study on Oscilloscope :

1. Set up the components and equipments as shown in fig.
2. Keep position of variable attenuator at maximum attenuation position.
3. Set Mode selector switch to FM-MOD position with FM amplitude and FM frequency knob at mid position. Keep beam voltage control knob fully anticlockwise and reflector voltage knob to fully clockwise with meter switch to 'OFF' position.

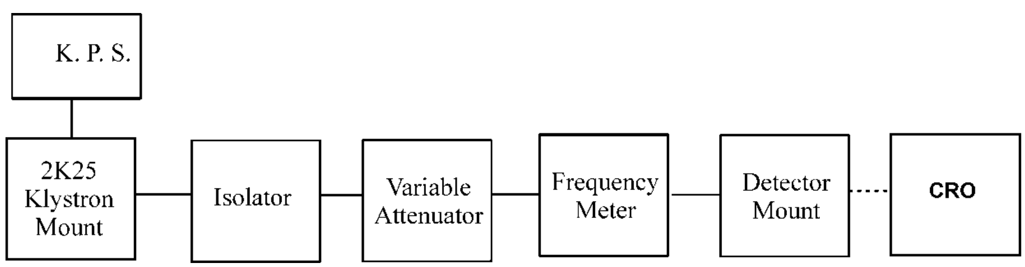
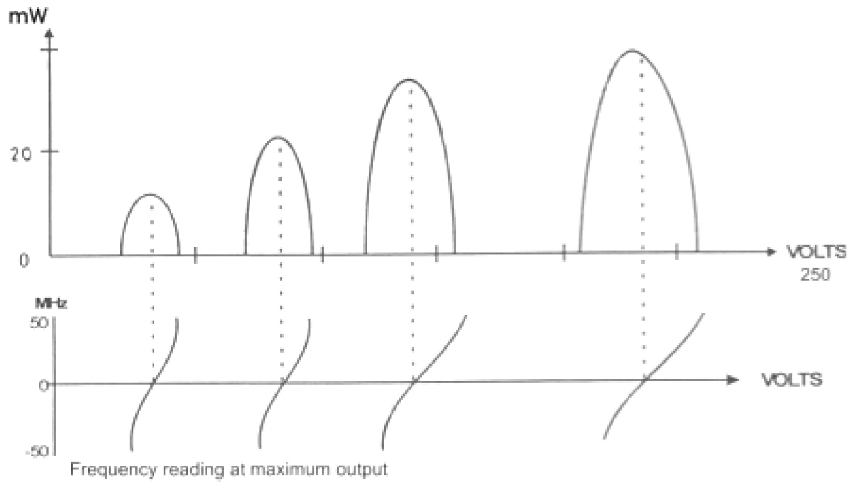


Fig. 5



Modes of 2k25

Fig. 6

4. Keep the time/division scale of oscilloscope around 100Hz 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 maximum position and rotate the reflector voltage anti-clockwise to get modes as shown in fig. As well as on the oscilloscope. The horizontal axis represents reflector voltage axis, and vertical axis represents output power.

8. By changing the reflector voltage and amplitude of FM modulation, any mode of Klystron tube can be seen on an oscilloscope.

EXPERIMENT 2

Object :

To determine the frequency & wavelength in a rectangular waveguide working on TE_{10} mode

Equipment Required :

Klystron power supply, Klystron tube, Isolator, Frequency meter, Variable attenuator, Slotted section, Tunable probe, Wave guide stand, VSWR meter, Movable short, and Matched termination.

Theory :

Mode represents in wave guides as either

$$TE\ m, n / TM\ m, n$$

Where
TE – Transverse electric,
TM – Transverse magnetic
m – Number of half wave length variation in broader direction.
n – Number of half wave length variation in shorter direction.

$$\frac{\lambda g}{2} = (d_1 - d_2)$$

Where d_1 and d_2 are the distance between two successive minima/maxima.

It is having highest cut off frequency hence dominant mode.

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

Where
λo is free space wave length
λg is guide wave length
λc is cutoff wave length

For TE_{10} mode, $\lambda c = \frac{2a}{m}$

Where m = 1 in TE_{10} mode and 'a' is broad dimension of waveguide. The following relationship can be proved

$$C = f\lambda$$

Where
$c = 3 \times 10^8$ m/s is velocity of light and f is frequency.

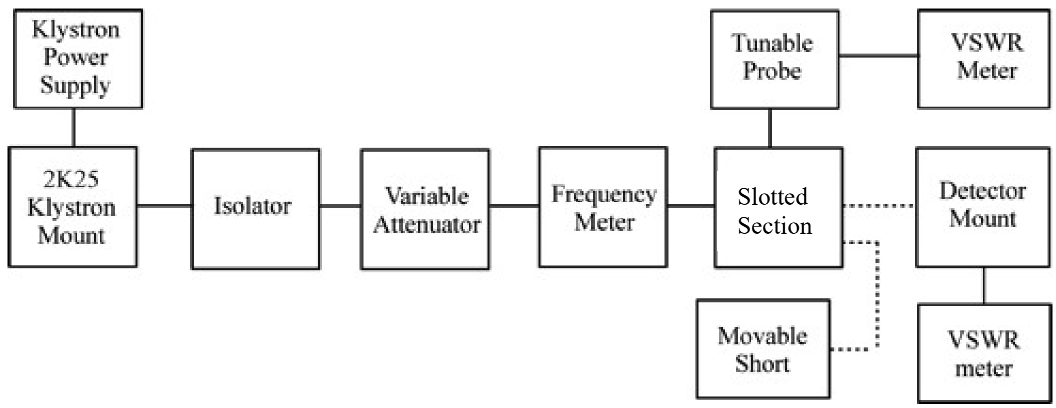
Procedure :

1. Set up the components and equipments as shown in fig.
2. Set the variable attenuator at maximum position.
3. Keep the control knobs of VSWR Meter as below :

Range db	:	50 db position
Input Switch	:	Crystal low Impedance
Meter Switch	:	Normal Position
Gain (Coarse & Fine)	:	Mid Position

4. Keep the Control knobs of Klystron power supply as below.

Meter Switch	:	OFF
Mod- Switch	:	AM
Beam Voltage Knob	:	Fully anticlockwise
Reflector Voltage	:	Fully clockwise
AM-Amplitude Knob	:	Around fully clockwise
AM-Frequency	:	Around Mid Position



Setup for study of frequency & wave length measurement

Fig. 7

5. Switch on the klystron power supply, VSWR meter and cooling fan.

6. Turn the meter switch of power supply to beam voltage position and set beam voltage at 300V with help of beam voltage knob, current around 15 to 20mA.

7. Adjust the reflector voltage to get some deflection in VSWR Meter.

8. Maximize the deflection with AM amplitude and frequency control knob of power supply.

9. Tune the plunger of klystron mount for maximum deflection.

10. Tune the reflector voltage knob for maximum deflection on VSWR meter.

11. Tune the probe for maximum deflection in VSWR meter.

12. Tune the frequency meter to get a 'dip' on VSWR scale and note down the frequency directly from frequency meter.

13. Replace the termination with movable short, and detune the frequency meter.

14. Move the tunable probe along with the slotted line to get the deflection in VSWR meter. Move the tunable probe to a minimum deflection position. To get accurate reading, it is necessary to increase the VSWR meter range dB switch to higher position, record the probe position i.e. d_1

15. Move the probe to next minimum position and record the probe position again i.e. d_2.
16. Calculate the guide wavelength as twice the distance between two successive minimum positions obtained as above.
17. Measure the wave-guide inner broad dimension 'a' which will be around 22.86 mm for X band.
18. Calculate the frequency by following equation:

$$f = \frac{c}{\lambda_0} = c\sqrt{\frac{1}{\lambda_g^2} + \frac{1}{\lambda_c^2}}$$

    Where
    c =3 x 10^8 meter/sec. i.e. velocity of light.

19. Verify with frequency obtained by frequency meter.
20. Above experiment can be verified at different frequencies.

EXPERIMENT 3

Object :

To determine the Standing Wave-Ratio and Reflection Coefficient

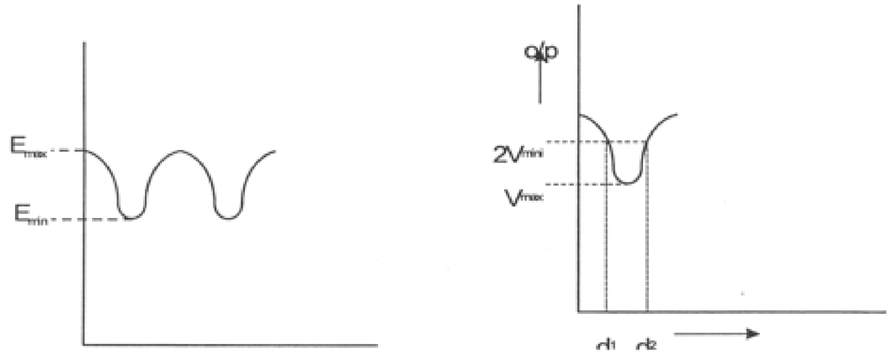
Equipment Required :

Klystron power supply, Klystron tube, VSWR meter, Isolator, Frequency meter, Variable attenuator, Slotted line, Tunable probe, Wave guide stand, Movable short/ Termination or any unknown load and BNC cable, S-S tuner.

Theory :

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

The electromagnetic field at any point of transmission line may be considered as the sum of two traveling waves: the 'Incident Wave' propagates from generator and the reflected wave propagates towards the generator. The reflected wave is set up by reflection of incident wave from a discontinuity on the line or from the load impedance. The magnitude and phase of reflected wave depends upon amplitude and phase of .the reflecting impedance. The superposition of two traveling waves, gives rise to standing wave along with the line. The maximum field strength is found where two waves are in phase and minimum where the line adds in opposite phase. The distance between two successive minimum (or maximum) is half the guide wavelength on the line. The ratio of electrical field strength of reflected and incident wave is called reflection between maximum and minimum field strength along the line.



Double Minima Method

Fig. 8

Hence VSWR denoted by S is

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

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

Where
E_I = Incident Voltage
E_r = Reflected Voltage

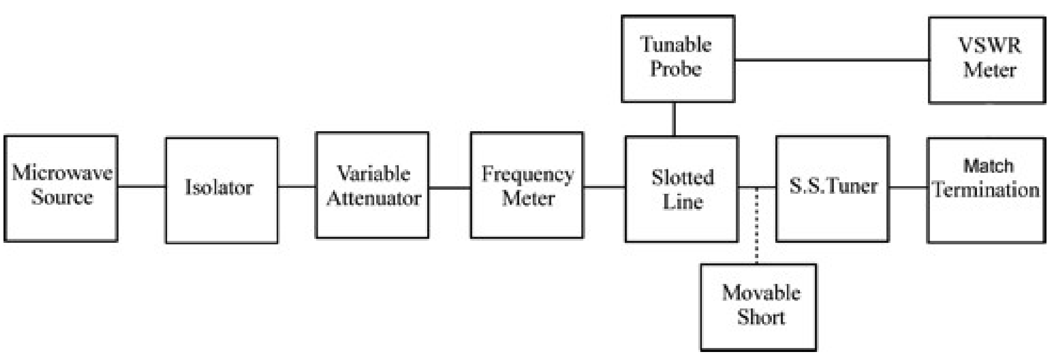
Reflection Coefficient, ρ is

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

Where
Z is the impedance at a point on line,
Zo is characteristic Impedance.

The above equation gives following equation

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



Setup for VSWR measurement

Fig. 9

Procedure :

1. Set up the equipment as shown in the fig.

2. Keep variable attenuator at maximum-position.

3. Keep the Control knobs of VSWR Meter as below .

Range	:	40 dB/50 dB
Input Switch	:	Impedance low
Meter Switch	:	Normal
Gain (Coarse-fine)	:	Mid Position approx.

4. Keep the control knobs of klystron power supply as below:

Meter Switch	:	OFF
Mod-Switch	:	AM
Beam Voltage Knob	:	Fully Anticlockwise
Reflector Voltage Knob	:	Fully clockwise
AM Frequency & amplitude Knob	:	Mid Position

5. Switch ON the klystron power supply, VSWR meter and cooling fan

6. Turn the meter switch of klystron power supply to beam. Voltage position and set the beam voltage at 300V.

7. Rotate the reflector voltage knob to get deflection in VSWR Meter.

8. Tune the output by tuning the reflector voltage, amplitude and frequency of AM modulation.

9. Tune for Maximum deflection by tuning the plunger of Klystron Mount. Then tune for maximum deflection by tuning the probe.

10. If necessary change the range db-switch, variable attenuator position and gain control knob to get deflection in the scale of VSWR meter.

11. Move the probe along with slotted line, the deflection will change.

a. Measurement of low and medium VSWR

i. Move the probe along with slotted line to maximum deflection in VSWR Meter.

ii. Adjust the VSWR Meter gain control knob or variable attenuator until the meter indicates 1.0 on normal SWR scale (o-∞).

iii. Keep all the Control knobs as it is, move the probe to next minimum position. Read the VSWR on scale and record it.

iv. Repeat the above step for change of S.S. Tuner probe path & record the corresponding SWR.

v. If the VSWR is between 3.2 and 10, change the range dB switch to next higher position and read the VSWR scale is 3 to 10.

b. Measurement of High VSWR (Double Minimum Method)

i. Set the depth of SS Tuner slightly more for maximum VSWR.

ii. Move the probe along with Slotted line until a minimum is indicated.

iii. Adjust the VSWR meter gain control knob and variable attenuator to obtain a reading of 3 dB of normal dB scale (0 to 10 dB) of VSWR Meter.

iv. Move the probe to the left on slotted line until full-scale deflection is obtained i.e. '0' db on 0-10 dB scale. Note and record the probe position on slotted line. Let it be d_1.

v. Repeat the step 3 and 4 and then move the probe right along with slotted line until full scale deflection is obtained on 0-10 dB normal dB scale. Let it be d_2.

vi. Replace the SS Tuner and terminator by movable short.

vii. Measure the distance between two successive minima position or probe. Twice this distance is wave guide length λg

viii. Calculate SWR by following equation.

$$\text{SWR} = \frac{\lambda_g}{\pi(d_1 - d_2)}$$

For different SWR, calculate the refection coefficient.

EXPERIMENT 4

Object :

To measure an unknown Impedance with Smith chart

Equipment Required :

Klystron Tube 2K25, Klystron power supply, Klystron Mount, Isolator, Frequency meter, Variable attenuator, Slotted Line, probe, VSWR meter, Wave guide stand, S.S. Tuner, Movable Short, Termination.

Theory :

The impedance at any point of a transmission line can be written in the form R + jX. For comparison SWR can be calculated as

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

Reflection Coefficient

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

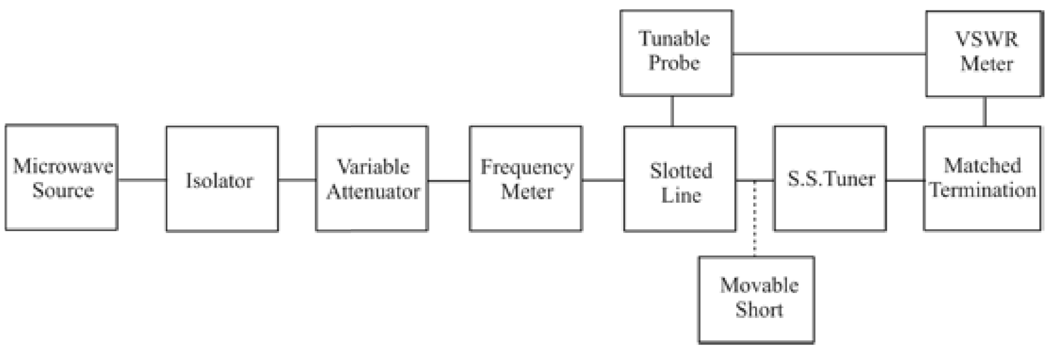
Where

Z_o = Characteristics impedance of w/g at operating frequency

Z = Load impedance at any point.

The measurement is performed in following way:

The unknown device is connected to the slotted line and the SWR = S_o and the position of one minima is determined. Then unknown device is replaced by movable short to the slotted line. Two successive minima positions 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 center; draw a circle of radius equal to So. Mark a point on circumference of 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 coordination of this point this will show the normalized impedance of load.



Setup for Impedance measurement **Fig. 10**

Procedure :

1. Set up the equipments as shown in the fig.

2. Set the variable attenuator at maximum position

3. Keep the control knobs of VSWR meter as below.

Range dB	:	50 dB position
Input Switch	:	Crystal low impedance
Meter Switch	:	Normal Position
Gain (Coarse & fine)	:	Mid Position.

4. Keep the Control knobs of Klystron power supply as below

Meter Switch	:	OFF
Mod Switch	:	AM

Beam Voltage Knob	:	Fully anticlockwise
Reflector Voltage	:	Fully clockwise
AM-Amplitude	:	Around Fully Clockwise
AM-Frequency Knob	:	Around Mid Position

5. Switch "ON' the Klystron power supply, VSWR meter and cooling Fan.

6. Turn the meter switch of power supply to beam voltage position and set beam voltage at 300V with help of beam voltage knob.

7. Adjust the reflector voltage to get some deflection in VSWR Meter.

8. To get the maximize deflection change AM amplitude and frequency control knob of power supply.

9. After getting maximum deflection on VSWR meter replace detector mount to S.S. tuner and V match terminal.

10. Tune the reflector voltage knob for maximum deflection.

11. Tune the tunable probe for maximum deflection in VSWR meter.

12. Tune the frequency meter knob to get dip on the VSWR scale, and note down the frequency directly from frequency meter.

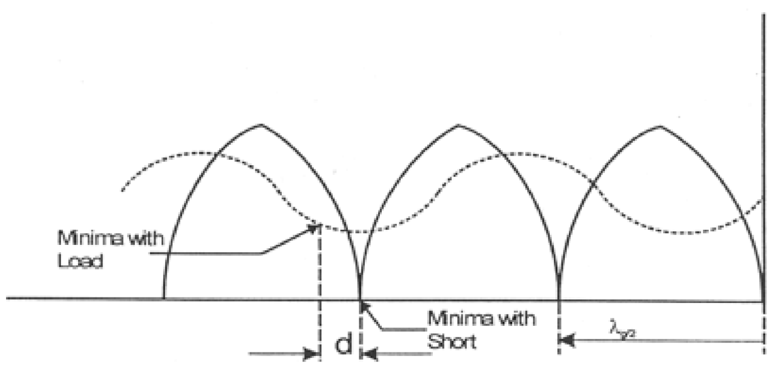
13. Keep the depth of pin of S.S. Tuner to around 3-4mm and lock it.

14. Move the probe along with slotted line to get maximum deflection

15. Adjust VSWR meter gain control knob and variable attenuator unit such that the meter indicates 1.0 on the normal upper SWR scale.

16. Move the probe to next minima point note down the SWR = S_o on the scale. Also note down the probe position, let it be d

17. Remove the S.S. Tuner and Matched Termination and place movable short at slotted line. The plunger of short should be at zero.



Standing waves in impedance measurement

Fig. 11

18. Note the position of two successive minimum position. Let it be as d_1 and d_2. Hence

$$\lambda g = 2\,(d_1 - d_2)$$

19. Calculate $\frac{d}{\lambda_g}$

20. Find out the normalization impedance as described in the theory section.

21. Repeat the same experiment for other frequency if required.

EXPERIMENT 5

Object :

To study V-I characteristics of Gunn Diode (For MT 9001)

Equipment Required :

Gunn oscillator, Gun power supply, PIN modulator, Isolator, Frequency meter; Variable attenuator, Detector mount, Wave guide stands, SWR Meter, Cables and accessories.

Theory :

The Gunn Oscillator is based on negative differential conductivity effect in bulk semiconductors, which has two conduction bands minima separated by an energy gap (greater than thermal agitation energies). A disturbance at the cathode gives rise to high field region, which travels towards the anode. When this high field domain reaches the anode, it disappears and another domain is formed at the cathode and starts moving towards anode and so on. The time required for domain to travel from cathode to anode (transit time) gives oscillation frequency.

In a Gunn Oscillator, the Gunn diode is placed in a resonant cavity. In this case the Oscillation frequency is determined by cavity dimension than by diode itself.

Although Gunn oscillator can be amplitude modulated with the bias voltage. We have used separate PIN modulator through PIN diode for square wave modulation.

A measure of the square wave modulation capability is the modulation depth i.e. the output ratio between, 'ON and 'OFF state.

Procedure :

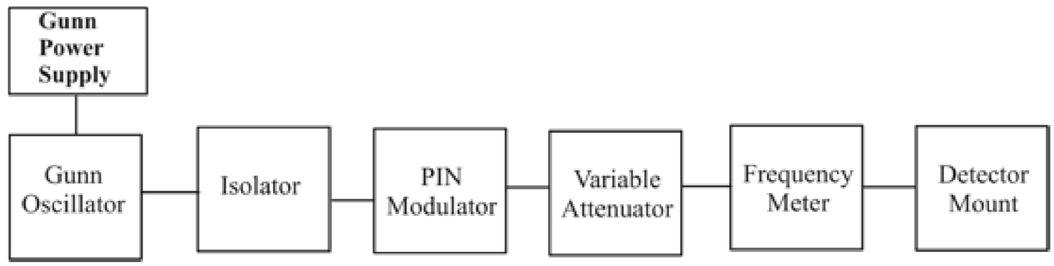
1. Set the components and equipment as shown in the fig.

2. Initially set the variable attenuator for maximum attenuation.

3. Keep the control knob of Gunn Power Supply as below:

Meter Switch : 'OFF'

Gunn Bias Knob : Fully anticlockwise



Setup for Study of V-I characteristics of Gunn Diode

Fig. 12

4. Keep the control knob of VSWR meter as below:

Meter Switch	:	Normal
Input Switch	:	Low impedance
Range dB Switch	:	40dB
Gain Control Knob	:	Fully clockwise

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

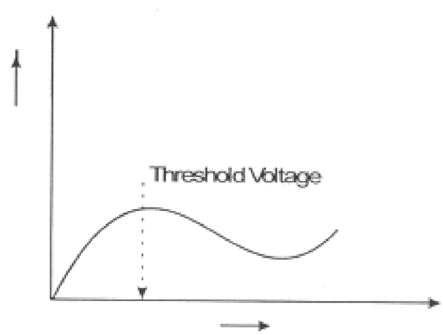
6. Switch ON the Gunn power supply VSWR Meter and cooling fan

7. Turn the meter switch of Gunn power supply to voltage position.

8. Measure the Gunn diode current corresponding to the various voltage controlled by Gunn bias knob through the panel meter and meter switch, do not exceed the bias voltage above 10 volts.

9. Plot the voltage and current reading on the graph as shown in fig.

10. Measure the threshold voltage which, corresponds to maximum current.



I-V Characteristics of GUNN Oscillator

Fig. 13

Note : Do not keep Gunn bias knob position at threshold position for more than 10-15 seconds. Reading should be obtained as fast as possible. Otherwise due to excessive heating, Gunn Diode may bum.

Sr. No.	V (v)	I (mA)

1		
2		
3		
4		
5		
6		

EXPERIMENT 6

Object :

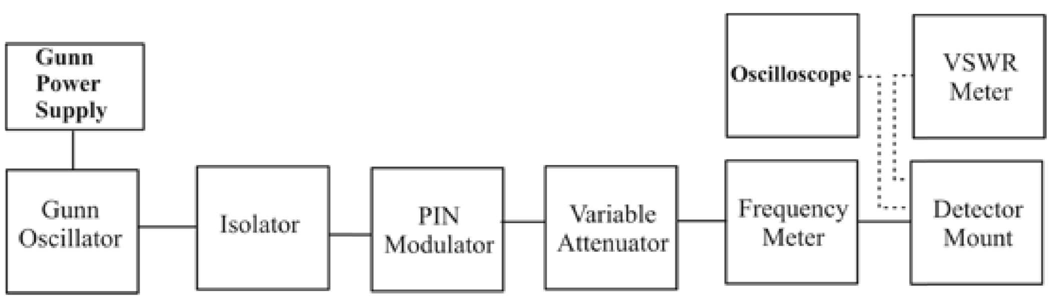
To study the following characteristic of Gunn Diode (For MT 9001)

1. Output power and frequency as a function of Bias Voltage.

2. Square wave modulation through PIN diode.

Equipment Required :

Gunn oscillator, Gun power supply, PIN modulator; Isolator, Frequency meter, Variable attenuator, Detector Mount, Wave guide stands, SWR meter, Cables and accessories.



Setup for the study of the Gunn Oscillator

Fig. 14

Procedure :

1. Set the components and equipment as shown in the fig.
2. Initially set the variable attenuator for maximum attenuation.
3. Keep the control knob of Gunn Power Supply as below:

   Meter Switch : 'OFF'

   Gunn Bias Knob : Fully anticlockwise

   Pin bias Knob : Fully anti-clockwise

   Pin Mod frequency : Mid position
4. Keep the control knob of VSWR meter as below

   Meter Switch : Normal

   Input Switch : Low impedance

   Range db Switch : 40dB/ 50dB

   Gain Control knob : Fully clockwise
5. Set the micrometer of Gunn oscillator for required frequency of operation
6. Switch ON the Gunn Power Supply VSWR Meter.

   a. *Out Put Power and Frequency as a Function of Bias Voltage.*

   i. Turn the meter switch of Gunn power supply to voltage position.

   ii. Increase the Gunn bias control knob upto 10V.

   iii. Rotate PIN bias knob to around maximum position.

   iv. Tune the output in the VSWR meter through frequency control knob of modulation

   v. If necessary change the range dB switch of VSWR meter to higher or lower dB position to get deflection on VSWR meter. Any level can be set through variable attenuator and gain control knob of VSWR meter.

   vi. Measure the frequency using frequency meter and detune it.

   vii. Reduce the Gunn bias voltage from 10V in the interval of 0.5V or 1.0V and note down corresponding reading of output at VSWR meter in dB and corresponding frequency by frequency meter

   viii. Use the reading to drawing the power vs. Voltage curve and Frequency vs. Voltage and plot the graph.

   ix. Measure the pushing factor (MHz /Volt) which is frequency sensitivity against variation in bias voltage for an oscillator. The pushing factor should be measured around 8 volt bias. For example

Volt (V)	Power (dB)	Frequency (GHz)
10	30 dB	8.75
9.5	32 dB	8.74

b. *Square Wave Modulation*

- **i.** Keep the meter switch of Gunn power supply to volt position and rotate Gunn bias voltage slowly so that panel meter of Gunn power supply reads 10V.
- **ii.** Tune the PIN modulator bias voltage and frequency knob for maximum output on the oscilloscope.
- **iii.** Coincide the bottom of square wave in oscilloscope to some reference level and note down the micrometer reading of variable attenuator.
- **iv.** Now with help of variable, attenuator coincide the top of square wave to same reference level and note down the micrometer reading.
- **v.** Connect VSWR to detector mount and note down the dB reading in VSWR Meter for both the micrometer reading of the variable attenuator.
- **vi.** The difference of both dB reading of VSWR meter gives the modulation depth of PIN modulator.

Note : After tuning the GUNN Source, the procedure for SWR & Impedance measurement is same as for the Klystron source experiment.

EXPERIMENT 7

Object :

To measure the polar pattern and the gain of a waveguide horn Antenna. (For MT 9002)

Equipment Required :

Gunn power supply, Gunn oscillator, PIN modulator or Klystron mount with klystron tube, Klystron power supply, Frequency meter, Isolator, Variable attenuator, Detector mount, Two horn antenna, Turn table, VSWR meter, and VSWR meter & accessories.

Theory :

If a transmission line propagating energy is left open at one end, there will be radiation from this end. In case of a rectangular wave-guide this antenna presents a mismatch of about 2:1 and it radiates in many directions. The match will improve if the open wave-guide is a horn shape.

The Radiation pattern of an antenna is a diagram of field strength or more often the power intensity as a function of the aspect angle at a constant distance from the radiating antenna. An antenna pattern is of course three dimensional but for practical reasons it is normally presented as a two dimensional pattern in one or several planes. An antenna pattern consists of several lobes, the main lobe, side lobes and the back lobe. The major power is concentrated in the main lobe and it is required to keep the power in the side lobes arid back lobe as low as possible. The power intensity at the maximum of the main lobe compared to the power intensity achieved from an imaginary omni-directional antenna (radiating equally in all directions) with the same power fed to the antenna is defined as gain of the antenna.

3dB Beam Width :

This is the angle between the two points on a main lobe where the power intensity is half the maximum power intensity.

When measuring an antenna pattern, it is normally most interesting to plot the pattern far from the antenna.

Far field pattern is achieved at a minimum distance of

$$\frac{2D^2}{\lambda_0} \text{ - (for rectangular Horn antenna)}$$

Where
D is the size of the broad wall of horn aperture
λ_0 is free space wave length.

It is also very important to avoid disturbing reflection. Antenna measurement are normally made at outdoor ranges or in so called anechoic chambers made of absorbing materials.

Antenna measurements are mostly made with unknown antenna as receiver. There are several methods to measure the gain of antenna. One method is to compare the unknown antenna with a standard gain antenna with known gain. Another method is to use two identical antennas, as transmitter and other as receiver. From following formula the gain can be calculated.

$$P_r = \frac{P_t \lambda_0 G_1 G_2}{(4\pi)^2}$$

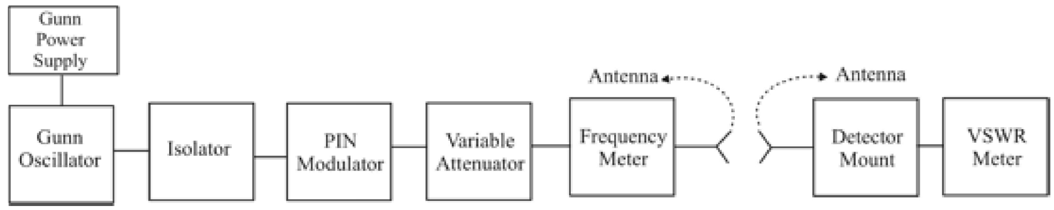
Where
PI is transmitted power
P_r is received Power,
G_1, G_2 is gain of transmitting and receiving antenna
S is the radial distance between two antennas
λo is free space wave length.

If both, transmitting and receiving antenna are identical having gain G then above equation becomes.

$$P_r = \frac{P_t \lambda_0 G^2}{(4\pi S)^2}.$$

$$G = \frac{4\pi S}{\sqrt{\lambda_0}} \sqrt{\frac{P_r}{P_t}}$$

In the above equation P_t, P_r and S and λo can be measured and gain can be computed. As is evident from the above equation, it is not necessary to know the absolute value of P_t and P_r only ratio is required which can be measured by VSWR meter.



Setup for the Antenna Radiation Pattern Plotting

Fig. 15

Procedure :

Antenna Radiation Pattern Plotting :

1. Set up the equipments as shown in the figure, keeping the axis of both antennas in same axis line.

2. Energize the Microwave source for maximum output at desired frequency with square wave modulation by tuning square wave amplitude and frequency of modulating signal of Gunn Power Supply and by tuning the detector.

3. Also tune the S.S. Tuner in the line for maximum output (if S.S. Tuner is in the setup).

4. Obtain full scale deflection (0 dB) on normal dB scale (0 - 10dB) at any coMWenient range switch position of the VSWR Meter by gain control knob of VSWR meter or by variable attenuator.

5. Turn the receiving horn to the left in 2° or 5° steps up to 40° - 50° and note the corresponding VSWR dB reading in normal dB range. When necessary change the range switches to next higher range and add 10dB to the observed value.

6. Repeat the above step but this time turns the receiving horn to the right and note down the readings.

7. Draw a relative power pattern i.e. output V /S angle.

8. From diagram determine 3db width (beam width) of the horn antenna can be measured

Gain Measurement :

1. Set up the equipments as shown in fig. Both horns should be in line.

2. Keep the range dB switch of VSWR meter at 50dB position with gain control full

3. Energize the Gunn Oscillator for maximum output at desired frequency with modulating amplitude and frequency of Gunn power supply and by tuning of detector.

4. Obtain full scale deflection in VSWR meter with variable attenuator.

5. Replace the transmitting horn by detector mount and change the appropriate range db position to get the deflection "On Scale (do not touch the gain control knob) Note and record the range db position and deflection of VSWR Meter.

6. Calculate the difference in dB between the power measured in step 4 and 5.

Example :

Suppose that a deflection of 5dB on 20 dB range dB position was obtained in step 5, the difference between 4 and 5 is

$$50 - (20-5) = 25\text{dB}$$

CoMWert the dB in to power ratio. As for above example it will come 316 which will be P_t P_r calculate gain by following equation in our above example

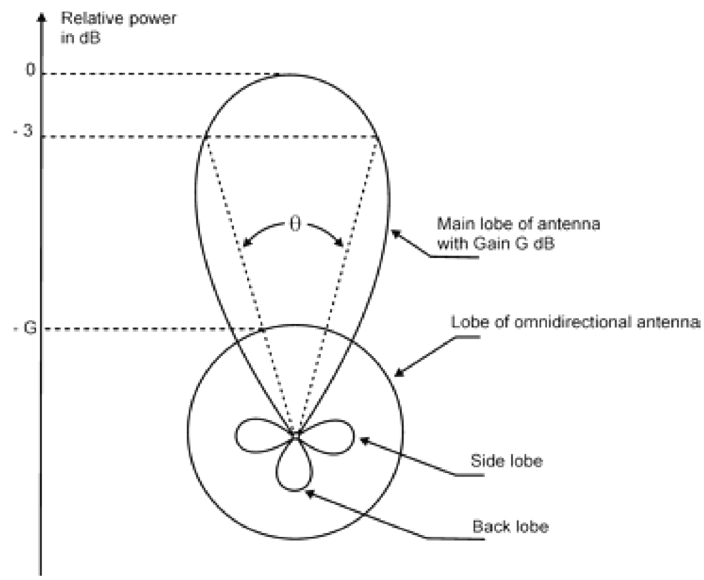
$$G = \frac{4\pi S}{\sqrt{\lambda_0}} \sqrt{\frac{P_r}{P_t}}$$

Suppose operating frequency is 9 GHz, λo = 3.33 cm where C is velocity of light and is 3×10^{10} cm/ sec and distance between antennas is 150 cm. (suppose).

CoMWert G into dB in above example G db = 10 log 318 = 15.02 dB

The same set-up can be used for other frequency of operation.

Note : Same experiment can also be performed using klystron source.



Antenna Pattern Diagram

Fig. 16

EXPERIMENT 8

Object :

Study the function of multi-hole directional coupler by measuring the following parameters:

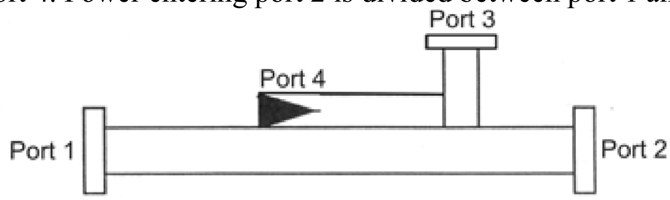
1. **To Measure main-line and auxiliary-line VSWR.**
2. **To Measure the coupling factor and directivity**

Equipment Required :

Microwave source; (Klystron or Gunn Diode type), Isolator, frequency meter, Variable attenuator, Slotted line, Tunable Probe, Detector mount, Matched Terminator, MHD coupler, Wave guide stand, Cables & accessories, VSWR meter

Theory :

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



Directional Coupler

Fig. 17

$$\text{Coupling (db)} = 10\log_{10}\left[\frac{P_1}{P_3}\right] \text{where port 2 is terminated}$$

$$\text{Isolation} = 10\log_{10}\left[\frac{P_2}{P_3}\right] \text{ where } P_1 \text{ is matched.}$$

With built-in termination and power is entering at port 1. The directivity of the coupler is a measure of separation between incident and the reflected wave. It is measured as the ratio of two power outputs from the auxiliary line when a given amount of power is successively applied to each terminal of the main lines with the port terminated by material loads.

Hence

$$\text{Directivity 0 (dB)} = \text{Isolation - Coupling} = 10\log_{10}\left[\frac{P_2}{P_1}\right]$$

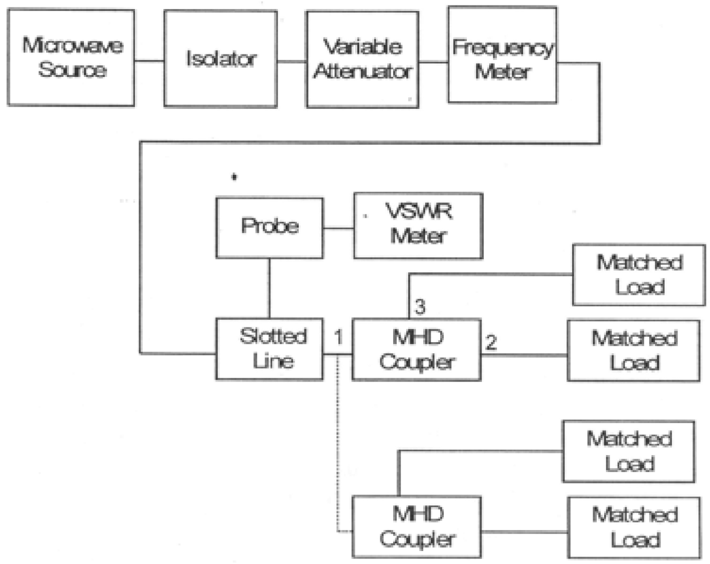
Main line VSWR is SWR measured looking into the main line input terminal when the matched loads are placed. At all other ports.

Auxiliary line 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 transmission line by insertion of coupler. It is defined as insertion:

$$\text{Loss} = 10\log_{10}\left[\frac{P_1}{P_2}\right] \text{ when power is entering at port 1.}$$

Procedure :



Setup for measurement of VSWR of MHD Coupler

Fig. 18

1. Main Line SWR Measurement

- **a.** Set up the equipments as shown in the fig.
- **b.** Energize the microwave source for particular frequency operation as described. (procedures given in the operation of klystron and Gunn oscillator)
- **c.** Follow the procedure as described for VSWR measurement experiment (Low and medium SWR measurement).
- **d.** Repeat the same for other frequency.

2. Auxiliary Line SWR Measurement

- **a.** Set up the components and equipments as shown in the fig.
- **b.** Energize the microwave source for particular frequency operation as described operation of Klystron and Gunn Oscillator
- **c.** Measure SWR as described in the experiment of SWR measurement (low and medium SWR measurement).
- **d.** Repeat the same for other frequencies.

3. Measurement of Coupling Factor, Insertion Loss

- **a.** Set up the equipments as shown in the fig.
- **b.** Energize the microwave source for particular frequency operation as described operation of Klystron and Gunn Oscillator.
- **c.** Remove the multi-hole directional coupler and connect the detector mount to the frequency meter. Tune the detector for the maximum output.

d. Set any reference level of power on VSWR meter with the help of variable attenuator, gain control knob of VSWR meter, and note down the reading. (Reference level let it be X)

e. Insert the directional coupler as shown in second fig. with detector to the auxiliary port 3 and matched termination to port 2, without changing the position of variable attenuator and gain control knob of VSWR meter.

f. Note down the reading on VSWR meter on the scale with the help of range-db switch if required. (Let it be Y)

g. Calculate coupling factor, which will be X-Y in dB.

h. Now carefully disconnect the detector from the auxiliary port 3 and match termination from port 2 without disturbing the set-up.

i. Connect the matched termination to the auxiliary port 3 and detector to port 2 and measure the reading on VSWR meter. Suppose it is Z.

j. Compute insertion loss X-Z in dB.

k. Repeat the steps from 1 to 4.

l. Connect the directional coupler in the reverse direction, i.e. port 2 to frequency meter side, matched termination to port 1 and detector mount to port 3, without disturbing the position of the variable attenuator and gain control knob of VSWR meter.

m. Measure and note down the reading on VSWR meter; let it be Y_d.

n. Compute the directivity as $Y\text{-}Y_d$

o. Repeat the same for other frequencies.

EXPERIMENT 9

Object :

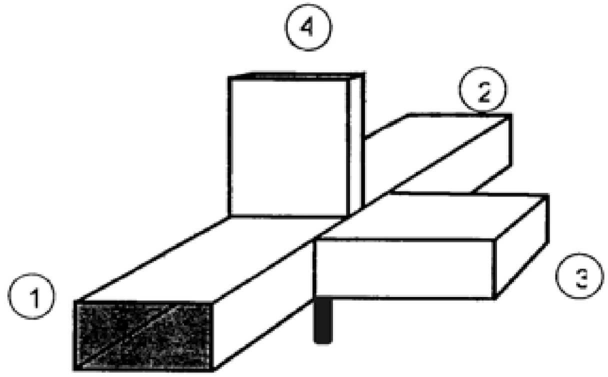
Study of Magic Tee.

Equipment Required :

Microwave source, Isolator, Variable attenuator, frequency meter, slotted line, tunable probe, Magic Tee, matched termination, wave guide stand, detector mount, VSWR meter and accessories.

Theory :

The device magic Tee is a-combination of the E and H plane Tee. Arm 3, the H-arm forms an H plane Tee and arm 4, the E-arm forms an E plane Tee in combination with arm 1 and 2 a side or collinear arms. If power is fed into arm 3 (H-arm) the electric field divides equally between arm 1 and 2 in the same phase, and no electrical field exists in arm 4. Reciprocity demands no coupling in port 3 (H-arm). 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 from arm 1 and 2, it is added in arm 3 (H-arm), and it is subtracted in E-arm, i.e. arm 4.



Magic Tee

Fig. 19

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

1. Input VSWR

Value of SWR corresponding to each port, as a load to the line while other ports are terminated in matched load

2. Isolation

The isolation between E and H arms is defined as the ratio of the power supplied by the generator connected to the E-arm (port 4) to the power detected at H -arm (port 3) when side arms I and 2 are terminated in matched load.

Hence,

$$\text{Isolation (dB)} = 10 \log_{10} \left[\frac{P_4}{P_3}\right]$$

Similarly, isolation between other parts may also be defined

3. Coupling coefficient.

It is defined as $C_{ij} = 10^{-\alpha / 20}$

Where
α = attenuation / isolation in dB
'i' is input arm
'j' is output arm.

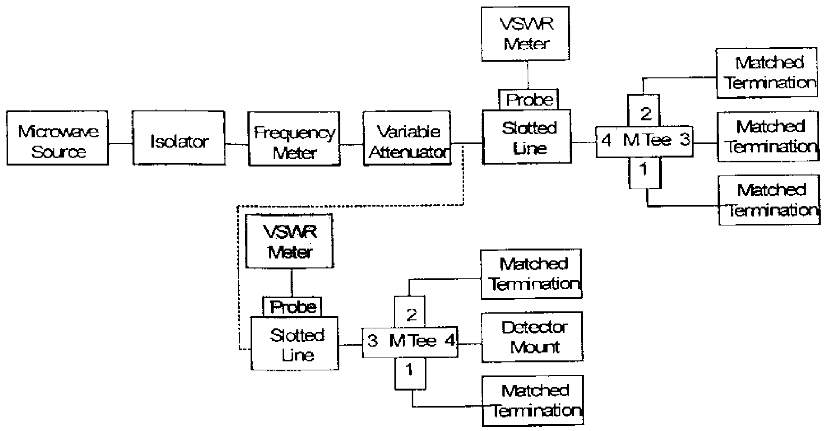
Thus

$$\alpha = 10 \log_{10} \left[\frac{P_i}{P_j}\right]$$

Where

P_i is the power delivered to arm i
P_j is power detected at j arm.

Procedure :



Setup for the study of Magic Tee **Fig. 20**

1. VSWR Measurement of the Ports

a. Set up the components and equipments as shown in fig. keeping E arm towards slotted line and matched termination to other ports.

b. Energize the microwave source for particular frequency of operation and tune the detector mount for maximum output.

c. Measure the VSWR of E-arm as described in measurement of SWR for low and medium value.

d. Connect another arm to slotted line and terminate the other port with matched termination. Measure the VSWR as above. Similarly, SWR of any port can be measured.

2. Measurement of Isolation and Coupling Coefficient

a. Remove the tunable probe and Magic Tee from the slotted line and connect the detector mount to slotted line.

b. Energize the microwave source for particular frequency of operation and tune the detector mount for maximum output.

c. With the help of variable attenuator and gain control knob of VSWR meter, set any power level in the VSWR meter and note down. Let it be P_3.

d. Without disturbing the position of variable attenuator and gain control knob, carefully place the Magic Tee after slotted line keeping H-arm connected to slotted line, detector to E arm and matched termination to arm 1 and 2. Note down the reading of VSWR meter. Let it be P_4.

e. Determine the isolation between port 3 and 4 as P_3-P_4 in dB.

f. Determine the coupling coefficient from equation given in the theory part.

g. The same experiment can be repeated for other ports also.

h. Repeat the above experiment for other frequencies.

EXPERIMENT 10

Object :

To Study the Isolator and Circulators.

Equipment Required :

Microwave source, Isolators, Circulators, frequency meter, Variable attenuator, slotted line, tunable probe, detector mount, VSWR meter, test isolation and circulation and accessories

Theory :

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.

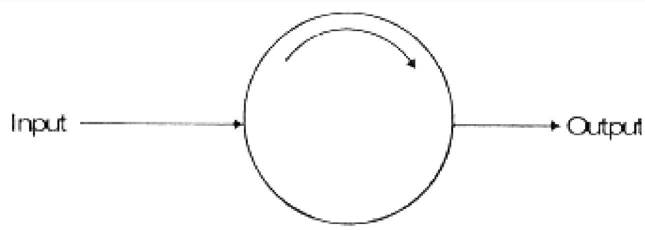


Fig. 21

Circulator : The circulator is defined as a device with ports arranged such that energy entering a port is coupled to an adjacent port but not coupled to other ports. Refer to the fig. A wave incident on port 1 is coupled to port 2 only, a wave incident at port 2 is coupled to port 3 only and so on.

Fig. 22

Following are the basic parameters of isolator and circulator for study.

1. Insertion loss

The ratio of power supplied by a source to the input port to the power detected by a detector in the coupling arm, i.e. output arm with other port terminated in the matched load, is defined as insertion loss or forward loss. .

2. Isolation

It is the ratio of power fed to input arm to the power detected at not coupled port with other port terminated in the matched load

3. Input VSWR

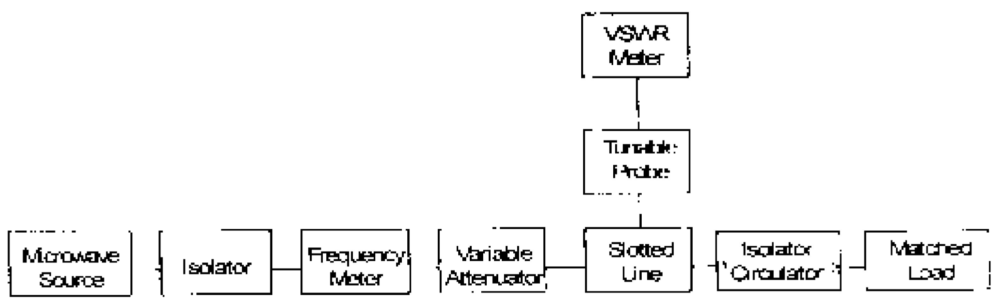
The input VSWR of an isolator or circulator is the ratio of voltage maximum to voltage minimum of the standing wave existing on the line when one port of it terminates the line and other have matched termination.

Note : When port which is not coupled to input port is terminated by matched termination it marks as Isolator. (Two port device).

Procedure :

1. Input VSWR Measurement

a. Set up the components and equipments as shown in the fig with input port of isolator or circulator towards slotted line and matched load on other ports of it



Measurement of VSWR of Isolator or Circulator

Fig. 23

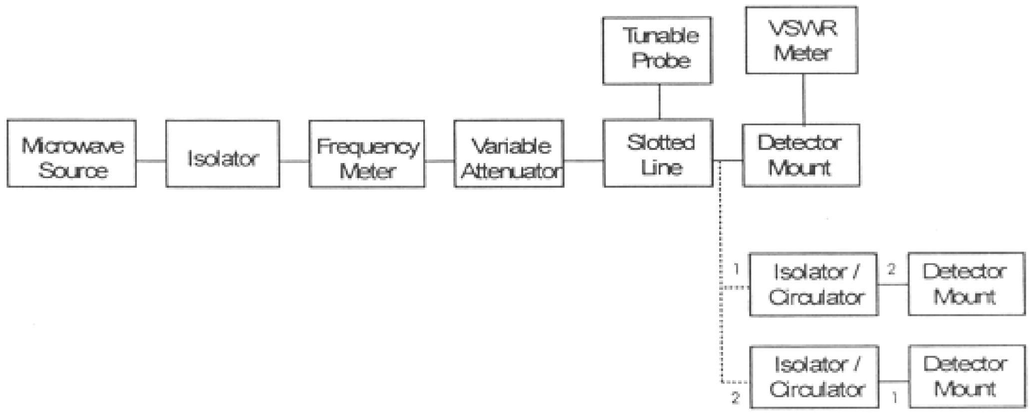
b. Energize the microwave .source for particular operation of frequency.

c. With the help of slotted line, probe and VSWR meter. Find SWR, of the isolator or circulator as described for low and medium SWR measurements.

d. The above procedure can be repeated for other ports or for other frequencies.

2. Measurement of Insertion Loss and Isolation

a. Remove the probe and isolator or circulator from slotted line and connect the detector mount to the slotted section. The output of the detector mount should be connected VSWR meter.



Setup for Measurement Loss & Isolation of Isolator & Circulator

Fig. 24

b. Energize the microwave source for maximum output particular frequency of operation. Tune the detector mount for maximum output in the VSWR Meter.

c. Set any reference level of power in VSWR meter with the help of variable attenuator and gain control knob of VSWR meter. Let it be P_1.

d. Carefully remove the detector mount from slotted line without disturbing the position of set up. Insert the isolator/circulator between slotted line and detector mount. Keeping input port to slotted line and detector at its output port. A matched termination should be placed a third port in case of circulator.

e. Record the reading in the VSWR meter. If necessary change range -dB switch to high or lower position and 10dB change for one step change of switch position. Let it be P_2.

f. Compute insertion loss on $P_1 - P_2$ in dB.

g. 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 another port terminated by matched termination (in case circulator) after setting a reference level without isolator or circulator in the set up as described in insertion loss measurement. Let same P_1 level is set.

h. Record the reading of VSWR meter inserting the isolator or circulator as given in step 7. Let it be P_3.

i. Compute isolation as P_1 - P_3 in dB.

j. The same experiment can be done for other ports of circulator.

k. Repeat the above experiment for other frequencies if required

EXPERIMENT 11

Object :

To Study the Attenuators (Fixed and Variable type)

Equipment Required :

Microwave source, Isolator, Frequency meter, Variable attenuator, Slotted line, Tunable probe, Detector mount, Matches termination, VSWR meter, Test fixed and variable attenuator and accessories.

Theory :

The attenuators are two port bi-directional devices which attenuate power when inserted into the transmission line.

$$\text{Attenuation A (dB)} = 10 \log_{10} \left[\frac{P_1}{P_2} \right]$$

Where
P_1 = Power absorbed or detected by the load without the attenuator in the line.
P_2 = Power absorbed/detected by the load with attenuator in line.

The attenuators consist of a rectangular wave guide with a resistive vane inside it to absorb microwave power according to their position with respect to side wall of the wave-guide. As electric field is maximum, at center in TE_{10} mode, the attenuation will be maximum if the vane is placed at center of the wave-guide. Moving from center toward the side wall, attenuation decreases in the fixed attenuator, the vane position is fixed where as in a variable attenuator, its position can be changed by help of micrometer or by other methods.

Following characteristics of attenuators can be studied

1. Input VSWR.

2. Insertion loss (in case of variable attenuator).

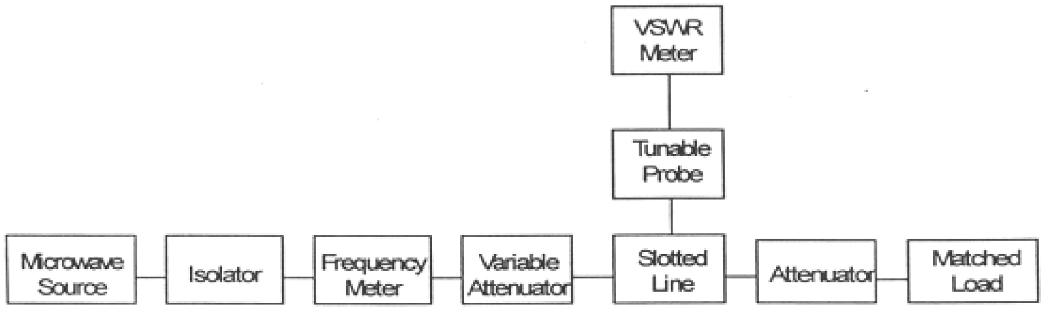
3. Amount of attenuation offered into the lines.

4. Frequency sensitivity i.e. variation of attenuation at any fixed position of vane and frequency is changed.

Procedure :

1. Input VSWR Measurement

- **a.** Connect the equipments as shown in the fig.
- **b.** Energize the microwave source for maximum power at any frequency of operation.
- **c.** Measure the VSWR with the help of tunable probe, Slotted line and VSWR meter as described in the experiment of measurement of low and medium VSWR.
- **d.** Repeat the above step for other frequencies if required.



Setup for VSWR measurement of Attenuator

Fig. 25

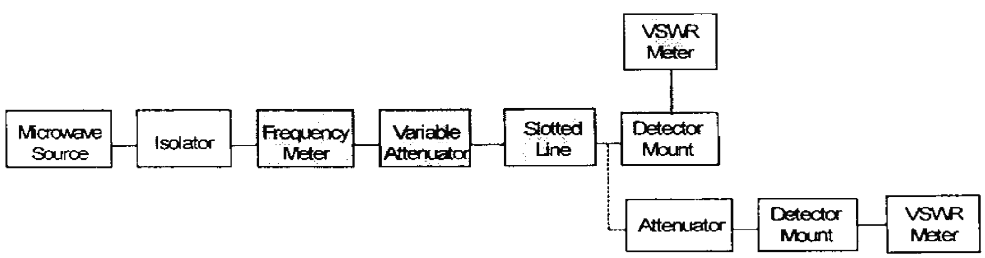
2. Insertion Loss /Attenuation Measurement

a. Remove the tunable probe, attenuator and matched termination from the slotted section in the above set up.

b. Connect the detector mount to the slotted line, and tune the detector mount also for maximum deflection on VSWR meter (Detector mount's output should be connected to VSWR meter).

c. Set any reference level on the VSWR meter with the help of variable attenuator (not test attenuator) and gain control knob of VSWR meter. Let it be P_1.

d. Carefully disconnect the detector mount from the slotted line, without disturbing any position on the set up. Place the test variable attenuator to the slotted line and detector mount to other port; of test variable attenuator. Keep the micrometer reading of test variable attenuator to zero and record the reading of VSWR meter. Let it be P_2. Then the insertion loss or test attenuator will be P_1 - P_2 dB.



Setup for Insertion Loss & Attenuation measurement of Attenuator

Fig. 26

e. For measurement of attenuation of fixed and variable attenuator, after step 4 of above measurement, carefully disconnect the detector mount from the slotted line without disturbing any position obtained up to step 3. Place the test attenuator to the slotted line and detector mount to the other port of test attenuator. Record the reading of VSWR meter. Let it be P_3. Then the attenuation value of fixed attenuator or attenuation value of variable attenuator for particular position of micrometer reading will be P_1 - P_3 dB.

f. In case of variable attenuator, change the micrometer reading and record the VSWR meter reading. Find out Attenuation value for different position of micrometer reading and plot a graph.

g. Now change the operating frequency and whole step should be repeated for finding frequency sensitivity of fixed and variable attenuator.

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

Micro meter reading of variable attenuator	**VSWR reading**

EXPERIMENT 12

Object :

To Study the Phase Shifter

Equipment Required :

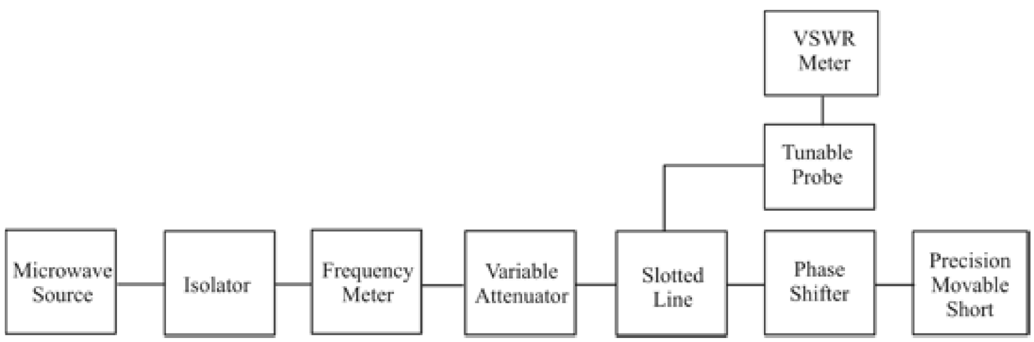
Microwave source, Isolator, Variable attenuator, Frequency meter, Slotted section, Tunable probe, Phase shifter, Movable short, VSWR meter, Cables and accessories

Theory :

A phase shifter consists of a piece of Wave-guide and a dielectric material inside the wave-guide placed parallel to Electric vector of TE_{10} mode. The phase changes as piece of dielectric material is moved from edge of wave-guide towards the center of the wave- guide.

Procedure :

1. Set up the equipment as shown in the fig.



Setup for Study of Phase Shifter **Fig. 27**

2. First movable short is placed at the end of slotted line.

3. Energize the microwave source for maximum output at particular frequency of operation.

4. Find out the λg (guide wavelength) with help of tunable probe Slotted line and VSWR meter. It is the twice the distance between two minima on the slotted line.

5. Note and record the reference minima position on the slotted line. Let it be X

6. Remove carefully the movable short from the slotted line without disturbing its current position. Place the phase shifter to the slotted line with its micrometer reading zero and then place the movable short to the other port.

7. The reference minima will short from its precision position, rotate the micrometer of movable precision short to get the minima at reference minima position and note the micrometer reading.

8. Open the phase shifter in suitable steps. i.e. 1mm, 2mm, 3mm etc.

9. Fill in the given table as per step 7 and 8

Micro meter reading of	Micro meter reading of

Phase shifter	Precision movable short
2 mm	
4 mm	
6 mm	
8 mm	
10 mm	

10. Precision movable short is rotated to get the minima, at reference minima position at different values or phase shift of micrometer.

Calculation :

We can calculate phase shift in terms of degree by

$$\lambda g = 360° \text{ (One cycle)}$$

For example : If $\lambda g = 4.32$ cm

Phase shifter position or micrometer is moved to 2mm. Now the reference minima gets changed vary the precision movable short to get the reference minima position i.e 0.5 cm now the shift in phase is

Since, 4.32 cm = 360°

Let it be Y

0.5 cm = Y

$$Y = \frac{360 \text{ x } 0.5}{4.32} = 56°$$

Plot the graph :

EXPERIMENT 13

Object :

Measurement of Dielectric Constant

Equipment Required :

Microwave source, Isolator, Variable attenuator, Frequency meter, Slotted line, Tunable probe, Phase shifter, lovable, Short, VSWR meter, Cables and accessories.

Theory :

The most general description for electromagnetic purposes of a given homogeneous material is given by complex permittivity (Dielectric Constant) together with complex magnetic permeability.

By Maxwell's equation for a homogeneous isotropic material are:

$$\nabla x E = \frac{dB}{dt}; \quad \nabla x H = \frac{dD}{dt} + \sigma E \qquad \ldots\ldots\ldots\ldots..(1)$$

$$B = \mu H \qquad D = \varepsilon E \qquad \ldots\ldots\ldots\ldots\ldots(2)$$

$$\nabla \text{ x } E = -jw\mu; \ \nabla \text{ x } H = jw\varepsilon \ H + \sigma \ E \qquad \ldots\ldots\ldots\ldots(3)$$

Where
μ^* = Complex permeability;
ε = (Real) Dielectric constant;
σ = Conductivity

The ∇ x H of equation (3) can be written as

$$\nabla x H = jw\left(\varepsilon - j\frac{\sigma}{w}\right)E \qquad \ldots\ldots\ldots\ldots..(4)$$

where
$\varepsilon^* = \varepsilon - j(\sigma/w)$ is complex dielectric constant

The above equation can also be written as

$$\varepsilon^* = \varepsilon_0(\varepsilon' - j\varepsilon'')$$

where
$\varepsilon = (\sigma/w\varepsilon_o)$ and
$\varepsilon = (\varepsilon/\varepsilon_o)$

It is usually practical to employ normalized complex dielectric constant

$$\varepsilon_r = \frac{\varepsilon^*}{\varepsilon_0} = \varepsilon' - j\varepsilon''$$

In the above terms ε"is called loss factor and ε' is associated with ability of material to store electric energy. It is also useful to write the relative dielectric constant as

$$\varepsilon_r = \varepsilon'(1 - j \tan \ \delta)$$

where $\tan \delta = (\varepsilon''/\varepsilon')$, The $\tan \delta$ is referred as loss tangent

The dielectric constant is not independent of frequency and stays constant only over small frequency spectrum, In many cases ε_r is affected by temperature. So it should be held reasonable during measurements.

Fabrication of sample for testing in Wave-Guide :

The accuracy of measurement largely depends upon smoothness of the sample, the fit of waveguide and care which has been taken to insure that its surfaces are properly squared wit to each other. It is advisable to machine samples very carefully for smoothness, size and squared surface.

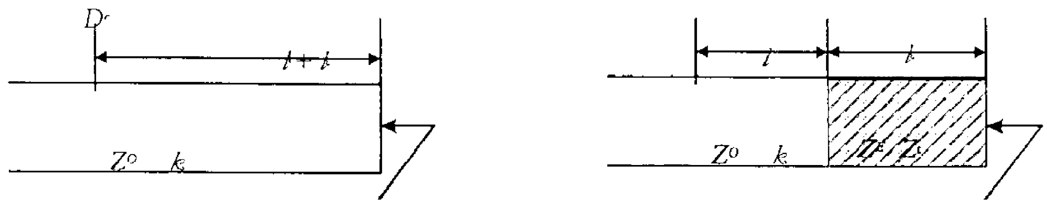


Fig. 28

Dielectric Measurement :

The fig (a) shows an empty short circuited waveguide with a probe located at voltage minimum. Fig (b) shows the same waveguide containing sample of length IE with a probe located at new minimum D. The sample is adjacent to short circuit. From well known equation

$$\frac{\tan k(Dr-D-I\varepsilon)}{kI\varepsilon} = \frac{\tan k_{\varepsilon} I_{\varepsilon}}{k_{\varepsilon} I_{\varepsilon}}$$

We find that all the quantities associated with left hand are measurable. While right hand is of (tan z/z), so that once the measurement has been performed, the complex number $z = k_\varepsilon\ I_\varepsilon$ can be solution of transcendental equation and from it, k_ε. Of course ε_r follows readily from I_ε. In view of nature of tangent function, there exists infinite no. of solutions for ε_r. Hence it is necessary to know E_r approximately in order to pick soln or to perform a second identical experiment with other sample of different length Iε. The proper solution in the latter case is the one, common to the two sets of solutions.

Procedure :

1. Connect the equipment as shown in Fig.
2. With no sample in short circuited line, find position at voltage minima D_R w.r.t. an arbitrarily chosen reference, with the help of slotted section and probe.
3. Measure the guide wave length λg by measuring the distance between two adjacent minima in slotted line.
4. Remove the short circuit, insert sample dielectric and replace the short circuit in such a manner that it touches the end of the sample.
5. Measure D, the position of minima in the slotted line with respect to the reference plane (D = 0).
6. Measure VSWR in the slotted line.
7. Repeat steps (1) to (6) with sample having different length.

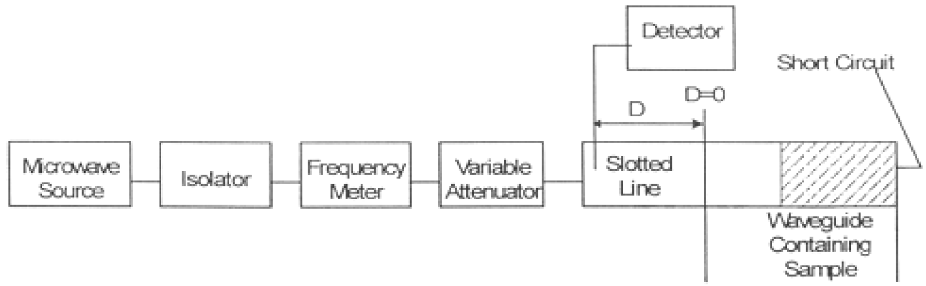


Fig. 29

Analysis of the data :

Case 1 : Loss less Dielectric Sample (VSWR - ∝)

a. Compute propagation constant $k = \frac{2\pi}{\lambda g}$

b. Compute k = $\frac{\tan k(Dr - D - I\varepsilon)}{kI\varepsilon}$

where

Lε is length of sample

c. Solve transcendental equation for X : K = (tan X / X)

If tables of solutions are not available, plot values of tan X/X vs. X and determine graphically approximate value tan(X) /X (and the. corresponding value of X) equal to K, thereafter, X can be determined more accurately by trial and error.

If approximate value of dielectric constant is not known, it is necessary to solve for two sets of X values corresponding to the sample of length $L_{1\varepsilon}$ and $L_{2\varepsilon}$. Of the solutions X available, one from the set associated with one of the measured samples will result in the same computed dielectric constant as one from the set associated with the second sample. The proper solution is picked up by computing (X / $L_{1\varepsilon}$) for each X in one set equals (X $L_{2\varepsilon}$) from the other set is the proper solution (X/$L_{2\varepsilon}$).

If dominant mode is propagating through the rectangular waveguide the dielectric, Constant 'ε' is as follows:

$$\varepsilon = \frac{\left[\frac{a}{\pi}\right]^2 \left[\frac{X}{L_{\varepsilon 2}}\right]^{-2} + 1}{\left[\frac{2a}{\lambda_g}\right]^2 + 1}$$

Where

'a' = Width of wave guide

λg = Guide wave length in empty waveguide.

$$\frac{X'}{L_\varepsilon} = \frac{\text{X(Determin ed in step3)}}{\text{Length of sample}}$$

(If measurements are made on one dielectric sample)

$$\frac{X'}{L\varepsilon} = \frac{X}{X_{1\varepsilon}} = \frac{X}{L_{2\varepsilon}}$$

(If measurements are made on two different dielectric samples)

Case 2 : Complex Dielectric Sample (Lossy)

If dielectric constant is complex, Le. VSWR $\neq \infty$ we compute as follows:

a. Determine $k = \frac{2\pi}{\lambda g}$

b. Compute $\phi = 2k(D - D_R - L\varepsilon)$

c. Determine the complex number C $\angle\psi$

$$C\angle\Psi = \frac{1}{jkL_\varepsilon} = \left[\frac{1-|\Gamma|\,e^{j\phi}}{1+|\Gamma|\,e^{j\phi}}\right]$$

d. Solve the equation for T and j:

$$C \angle - \psi = \left[\frac{\tanh(T\angle J)}{(T\angle J)}\right]$$

e. The admittance is Yε given by

$$Y\varepsilon = \left(\frac{T}{kL\varepsilon}\right)^2 \angle 2\ (J - 90°)$$

f. Compute ε_r as follows

$$Y\varepsilon = G\varepsilon + jB\varepsilon$$

$$\varepsilon_r = \frac{\left[Y_\varepsilon + \left(\frac{\lambda_g}{\lambda_c}\right)^2\right]}{1+\left(\frac{\lambda_g}{\lambda_c}\right)^2}$$

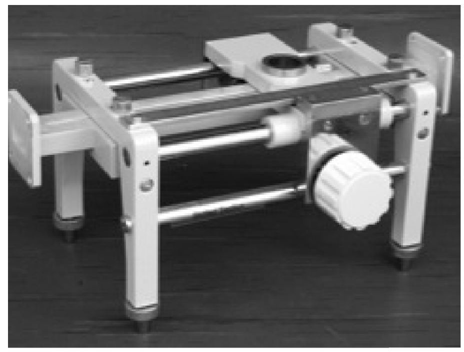
$$\varepsilon' = \frac{\left[G_\varepsilon + \left(\frac{\lambda_g}{2a}\right)^2\right]}{1+\left(\frac{\lambda_g}{2a}\right)^2} \qquad \varepsilon'' = \frac{-B_\varepsilon}{1+\left(\frac{\lambda_g}{2a}\right)^2}$$

IDENTIFICATION OF MICROWAVE COMPONENTS

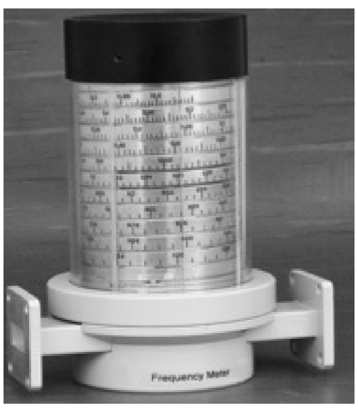
Gunn Oscillator (25mW)- MW201

Isolator – MW204

PIN Modulator – MW202



Slotted Section – MW207

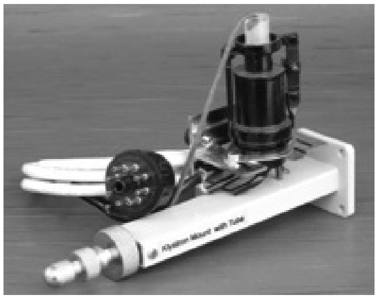


Frequency Meter – MW205

Variable Attenuator – MW206

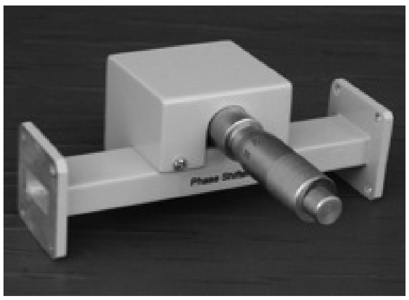
Detector Mount – MW209

Tunable Probe – MW208



Klystron Mount – XKM139

Coaxial Adapter – XCA100



Phase Shifter – XPS145

C. D. Coupler 20dB – XCC199

E Plane Bend – XEB102

E Plane Tee – XHB102

Fixed Attenuator – XA103

Matched Termination – XMT157

Magic Tee – XMT140

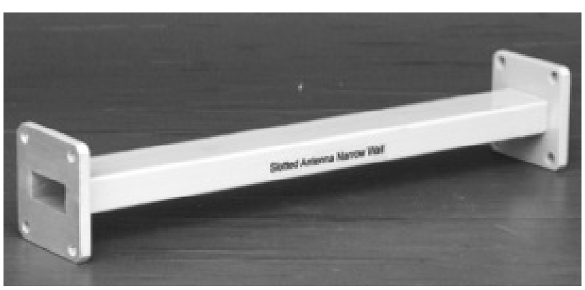
T-Circulator – XTC115

Multi hole Directional Coupler (10dB) – XMC210

SS Tuner – XSS161

Precision movable short – XPS147

Slotted Antenna Broad Wall – XAB108



Slotted Antenna Narrow Wall – XAN107

Parabolic Antenna – XPD1447

Waveguide Cavity – XWG165

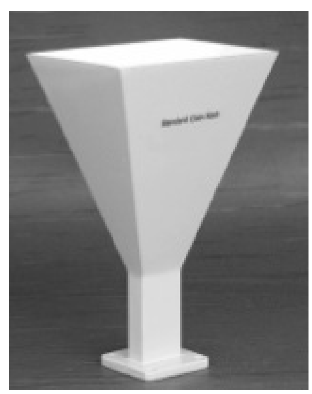
Waveguide Twist – XT163

Dielectric Antenna – XDA111

H Plane Sectorial Horn – XHH136

Pickup Horn – XHP132

Pyramidal Horn – XHP133



Standard Gain Horn - XHS133

WARRANTY

1) We guarantee the instrument against all manufacturing defects during 24 months from the date of sale by us or through our dealers.

2) The guarantee covers manufacturing defects in respect of indigenous components and material limited to the warranty extended to us by the original manufacturer and defect will be rectified as far as lies within our control.

3) The guarantee will become **INWALID.**

- **a)** If the instrument is not operated as per instruction given in the instruction manual.
- **b)** If the agreed payment terms and other conditions of sale are not followed.
- **c)** If the customer resells the instrument to another party.
- **d)** Provided no attempt have been made to service and modify the instrument.

4) The non-working of the instrument is to be communicated to us immediately giving full details of the complaints and defects noticed specifically mentioning the type and sr. no. of the instrument, date of purchase etc.

5) The repair work will be carried out, provided the instrument is dispatched securely packed and insured with the railways. To and fro charges will be to the account of the customer.

DISPATCH PROCEDURE FOR SERVICE

Should it become necessary to send back the instrument to factory please observe the following procedure.

1) Before dispatching the instrument please write to us giving full details of the fault noticed.

2) After receipt of your letter our repairs dept. will advise you whether it is necessary to send the instrument back to us for repairs or the adjustment is possible in your premises.

Dispatch the instrument (only on the receipt of our advice) securely packed in original packing duly insured and freight paid along with accessories and a copy of the details noticed to us at our factory address.