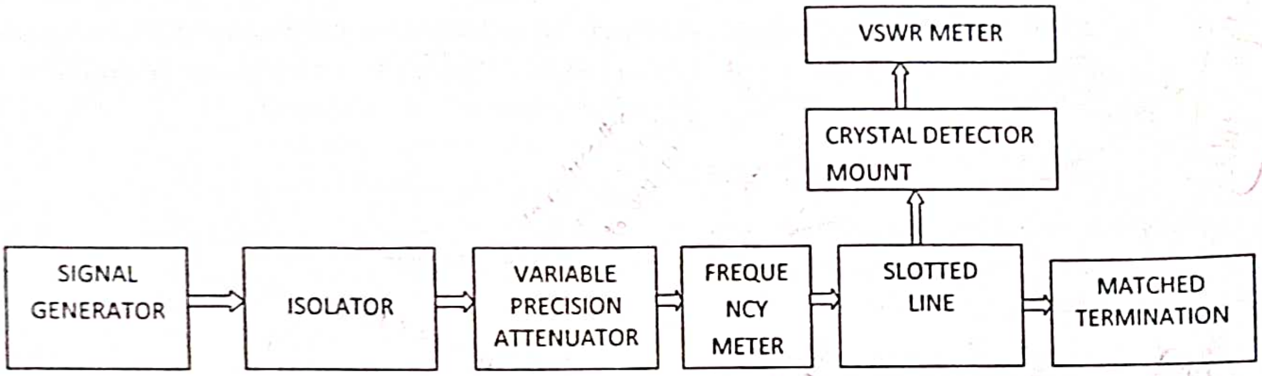
10

Bench
IV ECE - MW - LML

MICROWAVE ENGINEERING
UNIT V

MICROWAVE BENCH SETUP:-



The general bench setup for measurement of any parameter at microwave frequencies is called **MICROWAVE TEST BENCH**. It mainly consists of

SIGNAL GENARATOR:-

A signal generator is a microwave source whose output is in the order of milli-watts. Generally it may be a Reflex Klystron or Gunn Diode Oscillator or Backward wave Oscillator. These are used to generate continuous waves which are square-wave modulated at a frequency of 1 GHz.

ISOLATOR:-

A microwave source is followed by an Isolator which is used to prevent source due to load variations that causes reflections in the circuit.

PRECISION ATTENUATOR:-

Attenuator is used to adjust the power or to reduce the power flowing in waveguide. The power level is reduced to a particular stage to prevent overloading. It produces attenuation in the range of 0 to 40dB.

FREQUENCY METER:-

It is used for direct measurement of frequency and it consists of cylindrical cavity. The cavity is adjusted to resonance and is slot coupled to the waveguide. It provides high resolution.

SLOTTED LINE:-

It is basically used for measuring the Standing Wave Ratio. It consists of slotted line section of waveguide, travelling probe and the facility for attaching the instrument. A slot is made in the center of the broader dimension of waveguide. A small probe is inserted through the slot which senses the relative field strength of standing waves inside the waveguide. As the position of probe is varied along the transmission line, it gives an output proportional to the standing wave pattern in the waveguide. The low frequency modulated signal can be detected by tunable probe with a slotted line. At the position of probe, the detector gives an output proportional to the square of the input voltage.

MATCHED TERMINATION:-

The waveguide transmission line operating at low average power can be terminated using matched load. The loads are carefully designed such that all the applied power is absorbed avoiding the reflected power.

Pavg

VSWR METER:-

G, Q, low NVA

A high gain, high quality factor, low noise voltage amplifier that is tuned to a fixed frequency is called VSWR Meter. The VSWR Meter along with slotted waveguide is used to measure standing wave ratio directly in decibels.

ERRORS & PRECAUTIONS:-

Different errors in microwave measurements are

i) **Errors due to frequency Instability:-**

The frequency instability in a microwave causes the standing wave to shift during the measurement. This is due to the thermal changes, mechanical vibrations and inadequate regulation from the source.

ii) **Coupling errors:-**

These are due to coupling between the components and the measuring device. To remove these errors the coupling should be tight and properly align to avoid reflections.

iii) **Probe Errors:-**

The probes introduce field's distortions which affects the standing wave pattern. These are minimized by reducing the length of probe.

iv) **Slot Errors:-**

Slot in the slotted line section loads in the waveguide and produces variations in the guide wavelength which introduces discontinuity effect. To remove these errors slot should be narrow and cut symmetrically with proper tapering.

v) **Square law detector Errors:-**

The microwave crystals used in oscillators are made of germanium or cadmium. Their characteristics are strongly dependent on contact between wires and semi conductors which are subjected to changes with temperature and radio frequency.

PRECAUTIONS:-

Different precautions while setting up a microwave bench setup are

i. Connections among the components should me made tightly to avoid leakages.
ii. The source should be isolated from load to prevent the damage of source due to reflected power.
iii. Impedance matching has to be provided to avoid mismatching.
iv. While measuring the power the frequency meter should be detained each time because there is a dip in output power when the frequency is tuned.
v. Always keep the attenuator in position in minimum mode and VSWR should be kept in range between 40 to 50 dB.
vi. The power source should be turned off when assembling or dissembling components.

2

ATTENUATION MEASUREMENT:-

The attenuation is defined as the decrease in power at the load by inserting a device between source and load. This device has a factor called **Attenuation** which decreases or adjust the power levels of microwave signal. It is defined as the ratio of input power to output power in dB.

$$\text{Attenuation in (dB)} = 10 \log (P_1/P_2)$$

Gain = $\frac{P_{out}}{P_{in}} = \frac{P_2}{P_1}$

Where P_1= power at load without attenuator in the line.
P_2= power at load with attenuator in the line.

To calculate attenuation, various techniques are applied depending on frequency range, accuracy and type of attenuator. They are

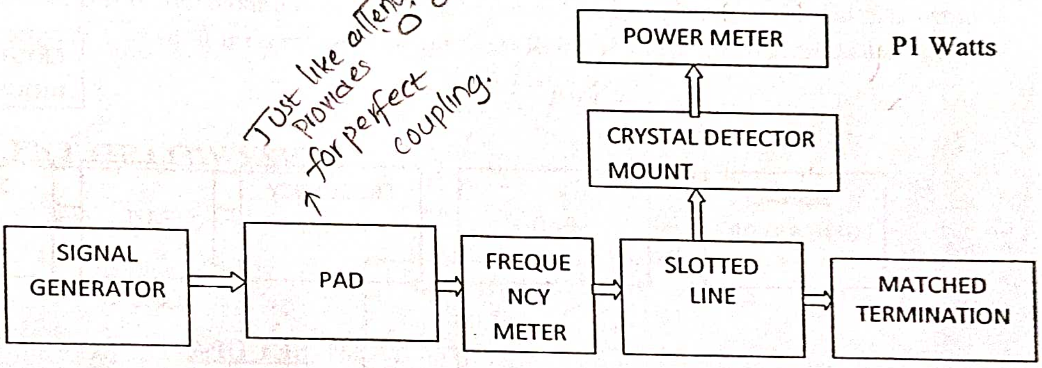
1) Power Ratio Method
2) RF Substitution Method.

FR, A, TA.

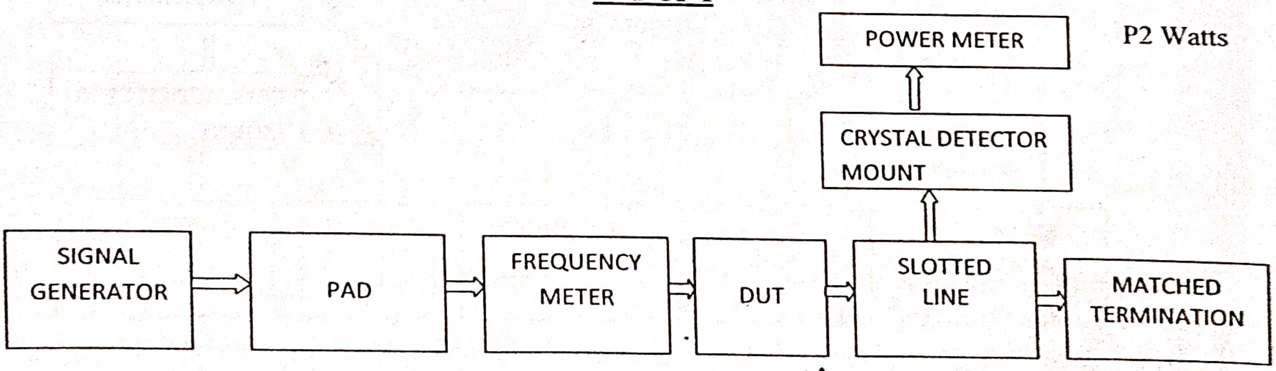
POWER RATIO METHOD:-

Just like attenuator 0 attenuator provides for perfect coupling.

$P_1, P_2 \rightarrow$ Full swing powers.



SET UP-I



SET UP-II

Device under test and calculate the power.

This is simple method for measuring attenuation. This method is useful where the accuracy is not required. This method traces the linearity of power meter used.

The power P_1 is measured without DUT (Device Under Test) from set up-I.

The power P_2 is measured with DUT (Device Under Test) inserted from set up-II.

The attenuation of DUT is calculated by taking the ratio of P_1 & P_2.

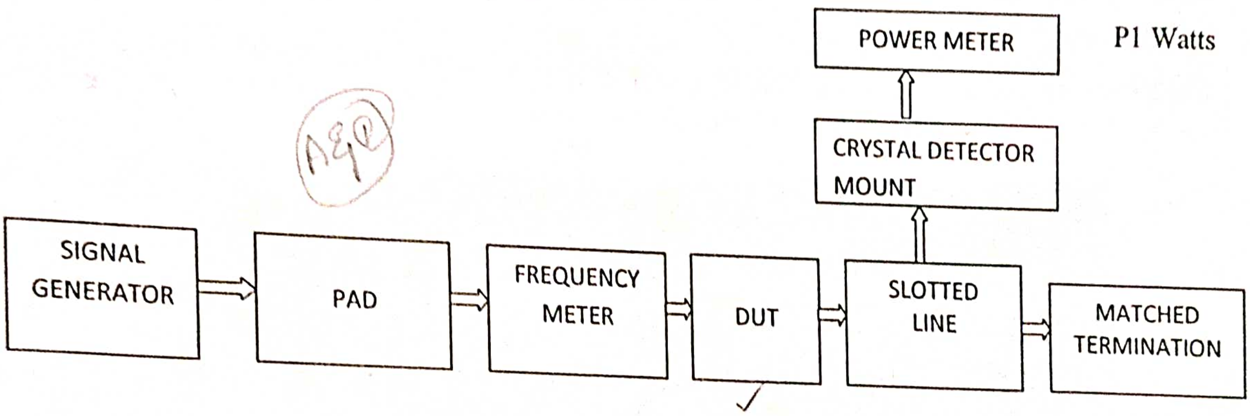
$$Attenuation\ (A) = \frac{P_1}{P_2}$$

→ Not accurate because it is non-linear.

$$A(dB) = 10 \log {}^{P_1}/_{P_2}$$

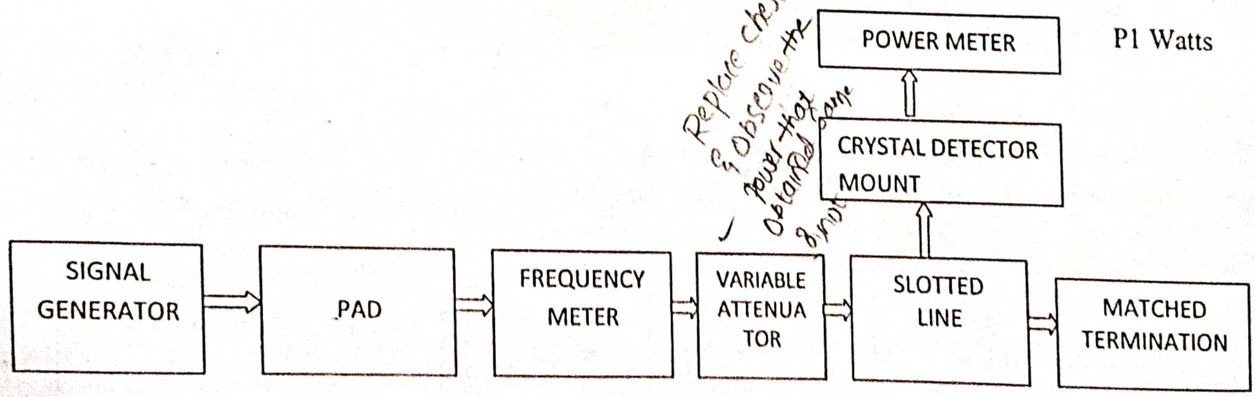
This method is having low accuracy because of different insertion points in the slotted line section and the powers are non linear. To measure perfect attenuation the insertion points are to be matched by using tuners or matching pads.

RF SUBSTITUTION METHOD:-



SET UP-I

Replace crystal & observe the power that obtained same & prove



SET UP-II

This method is having very high accuracy to calculate attenuation. In this method the power P1 is measured by inserting DUT whose attenuation is to be measured from setup-I.

In setup-II, the DUT is replaced with variable attenuator which is varied to get same power P1 on the power meter. At this point the reading on the attenuator gives directly the attenuation of DUT. In this method the accuracy is high since the powers are measured at the same insertion points on the slotted line section.

(2) MEASUREMENT OF VSWR:-

TWT — low noise device, High Gain, Delivers e Avg peak power, mode pe

Generally VSWR occurs if there is any mismatch between the termination and the operating circuit and there are reflections along the length of slotted line.

Generally $S = \frac{1+\rho}{1-\rho} = \frac{V_{max}}{V_{min}}$

where ρ is the reflection Co-efficient.

$\rho = \frac{\text{Reflected power}}{\text{Incident power}}$

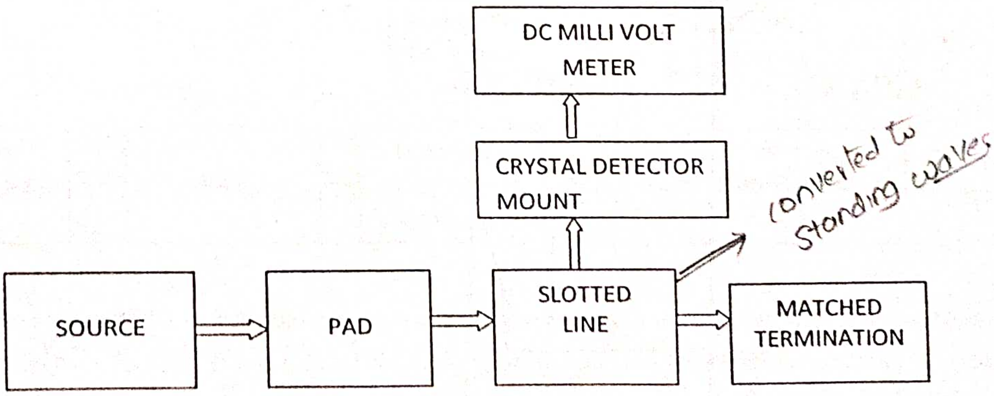
Wide-band device due to the non-resonant wave

$$\rho = \frac{V_{max} - V_{min}}{V_{max} + V_{min}}$$

The minimum value of ρ is 0 and maximum is 1. Similarly the minimum value of S is 1 and maximum is ∞. If S is in the range of 1 to 10, it is represented as low VSWR and if S>10, it is represented as high VSWR.

MEASUREMENT OF LOW VSWR:-

VP ↗ (W)

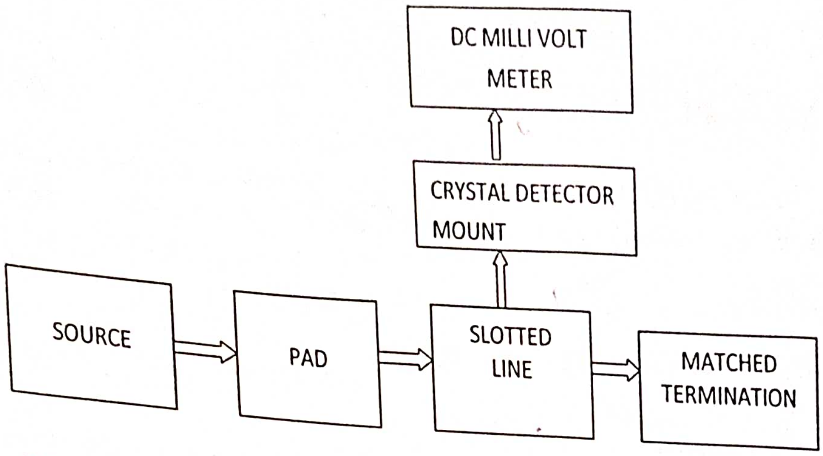


If VSWR < 10, it can be measured directly on VSWR meter. This method basically depends on adjusting of probe on slotted line to give maximum and minimum voltage on the DC voltmeter. The probe on the slotted line is adjusted to get maximum reading on DC voltmeter by varying attenuator to get full scale reading. i.e.. V_{max}

Again the probe is moved on the slotted line to get minimum reading i.e.. V_{min}.

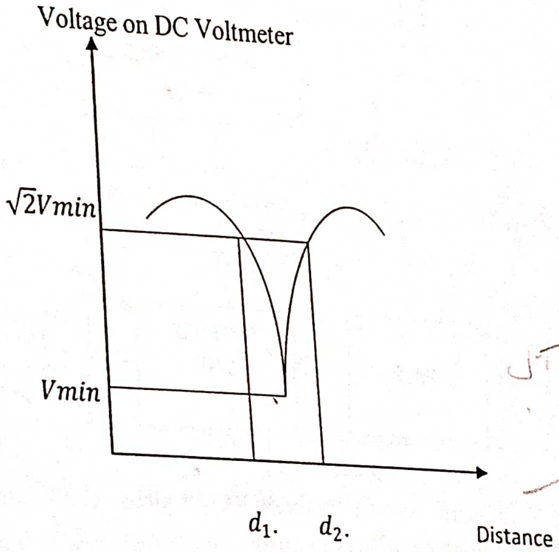
The SWR is given by $S = \frac{V_{max}}{V_{min}}$

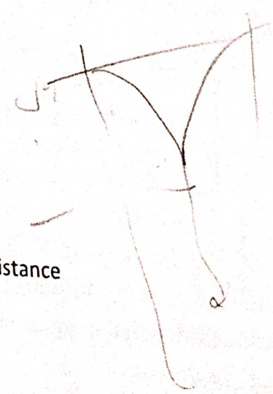
MEASUREMENT OF HIGH VSWR:-



If S > 10, double minimum method is used to measure VSWR. In this method, probe is adjusted to get minimum reading at the DC Voltmeter. Then the probe is adjusted to a point where the power is $\sqrt{2}$ times of minimum and this position is indicated as d_1.

Again the probe is moved to get $\sqrt{2}$ times of minimum value on the other side of minimum value which is indicated as d_2.





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

$S = \frac{\lambda g}{\pi(d_1}$

The empirical relation for High VSWR is $S = \frac{\lambda_g}{\pi(d_2 - d_1)}$

For TE_{10} mode, $\lambda_c = 2a$, $\lambda_g = \frac{\lambda_0}{\sqrt{1 - \frac{\lambda_0^2}{\lambda_c^2}}}$ $\quad \lambda g = \frac{\lambda_0}{\sqrt{1 - \frac{\lambda_0^2}{\lambda_c^2}}}$

The above formula is applicable only for high VSWR and it is approximate value.

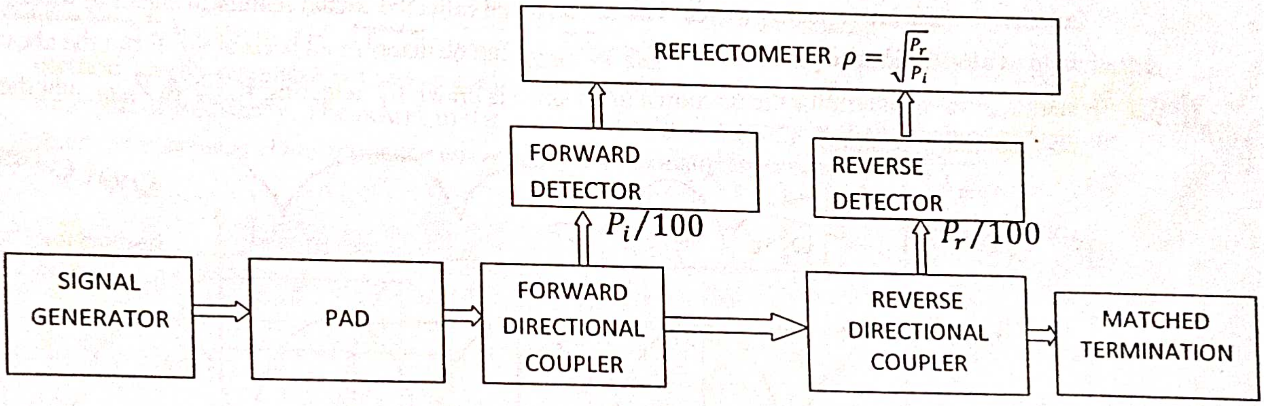
MEASUREMENT OF IMPEDANCE:-

To measure the impedance at microwave frequencies there are 3 different ways.

Applications

1. Using Magic Tee
2. Using Slotted Line
3. Using Reflectometer

MEASUREMENT OF IMPEDANCE USING REFLECTOMETER:-



In the above setup the directional couplers are identical and are used to sample the incident power P_i and reflected power P_r. The magnitude of reflection coefficient is obtained directly from reflectometer which is given by $\rho = \sqrt{\frac{P_r}{P_i}}$. The relation between impedance and reflection coefficient is

$$\rho = \frac{Z_L - Z_0}{Z_L + Z_0}$$

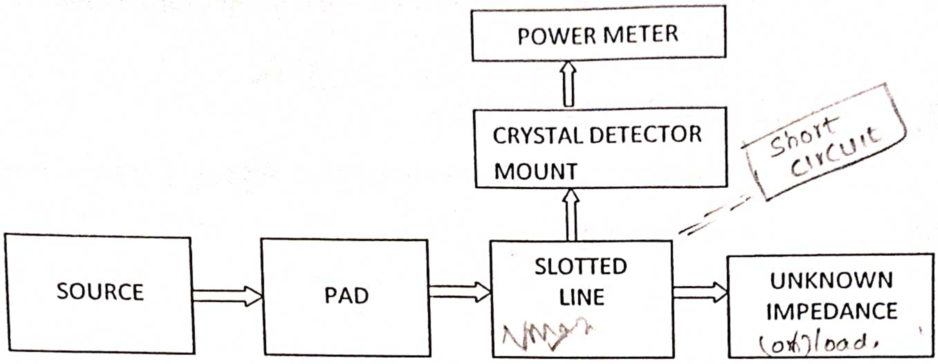
Where $Z_L = Unknown\ Impedance$

2 → M # φ

$Z_0 = Characterstic\ Impedance$

From this method only the magnitude of impedance is measured but not phase angle. This method is suitable for low VSWR i.e.. for low reflection coefficients. The accuracy is very high if the ρ is in the range of 0 to 0.3

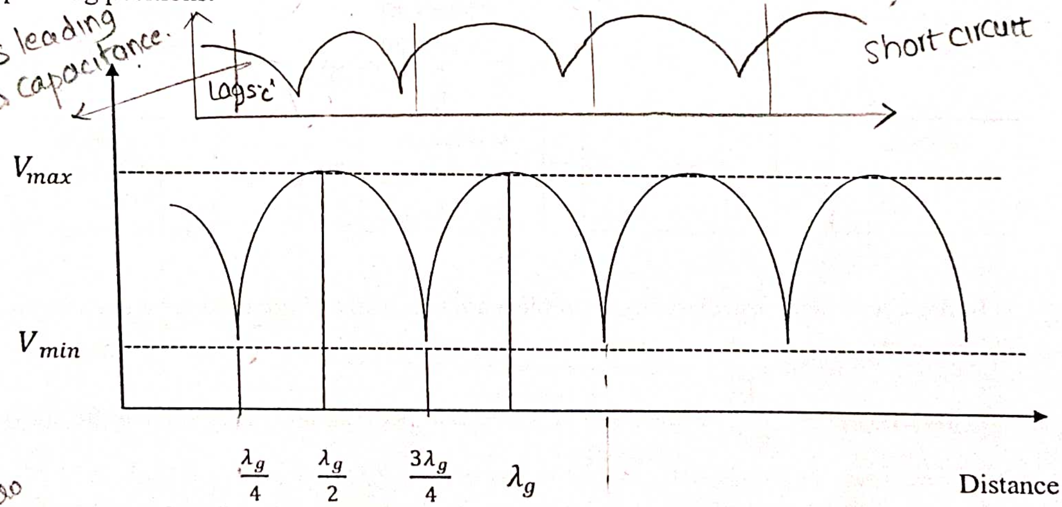
MEASUREMENT OF IMPEDANCE USING SLOTTED LINE:-



m→RN.

In the above setup, the load whose impedance is to be measured is placed as termination and due to mismatch there are reflected waves. The incident and reflected waves results in standing waves. With the help of slotted line the positions of V_{max} & V_{min} can be determined accurately. From the above setup the standing wave pattern for the unknown impedance is drawn by detecting V_{max} & V_{min} and their corresponding positions.

current is leading ∴ It is capacitance.

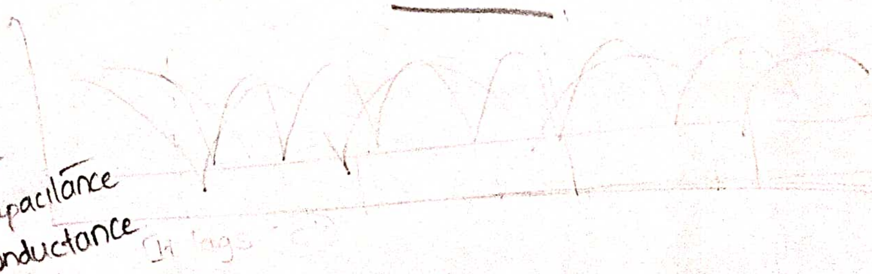


Standing wave pattern of Unknown Impedance.

If Vmin current exists Voltage → zero

open circuit :-
Lead → Inductance
Lag → capacitance

The positions of maximum and minimum voltage may vary according to load impedance.



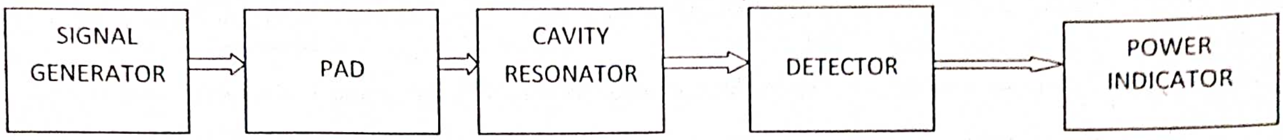
Short circuit
Lag → capacitance
Lead → Inductance

MIA-L → Q1 → L

To find the information about phase angle, the load is replaced with short circuit i.e.. $Z_L = 0$. Due to short circuit the positions of V_{max} & V_{min} are varied. If the minimum is shifted to left, the impedance is inductance and if the minimum is shifted to right the impedance is capacitance. The magnitude of impedance is measured and from smith chart the phase angle is measured by using the difference of positions of minimum for load and short circuit. From this method both impedance and phase angle are measured.

MEASUREMENT OF QUALITY FACTOR:-

Here we will passes the microwaves.



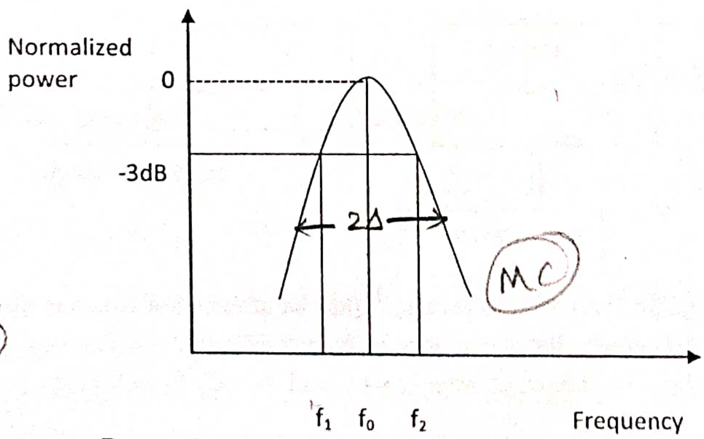
To measure the quality factor of a cavity resonator there are three methods.

O/P → f

1. Transmission Method
2. Impedance Method
3. Transient delay or Decrement Method.

Among these methods , the transmission method is simple and having high accuracy.In this method, cavity resonator is used as a transmission device and the output signal (or) power is measured asa function of frequency. The power in the power indicator is varying with the frequency from the microwave source. The resonance curve of cavity resonator is shown below.

For resonant circuit, the quality factor will present.



Q =

P → f → f

By varying the frequency of microwave source and keeping magnitude as constant, the output power atr the power indicator is drawn which is called as resonance curve. From the resonance curve the 3dB bandwidth is $2\Delta = \pm \frac{1}{Q_l}$ where Q_l is quality factor with load.

$2\Delta = \pm \frac{1}{Ql}$

$$Q_l = \pm \frac{1}{2\Delta}$$

$$Q_l = \pm \frac{\omega}{2(\omega - \omega_0)}$$

$\omega \rightarrow$ operating freq

$\omega_0 \rightarrow$ cuttoff freq

$Q_l = \pm \frac{\omega}{2\omega \ldots}$

If the coupling between cavity resonator and the source is neglected then $Q_l = Q_0$

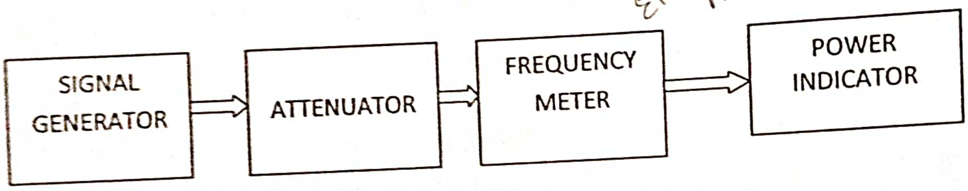
FREQUENCY MEASUREMENT:-

The frequency of a microwave can be measured with highest accuracy by using two different methods where 1% accuracy is obtained by using the wavelengths measurement i.e.. $f = \frac{c}{\lambda}$

To measure frequency Electro-Mechanical Technique & Electronic Technique is used.

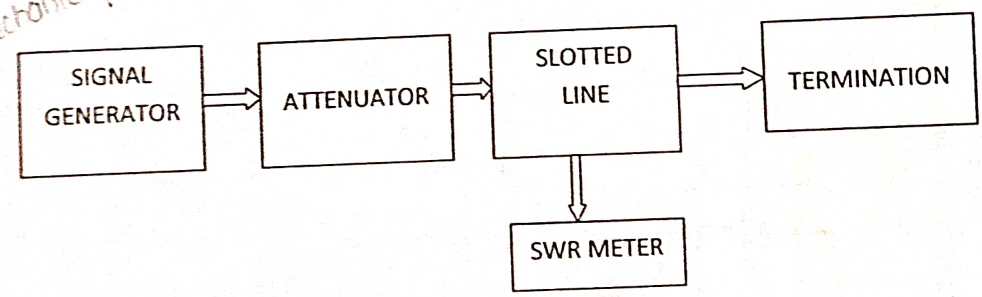
ELECTRO-MECHANICAL TECHNIQUE:-

Electronic method



(OR)

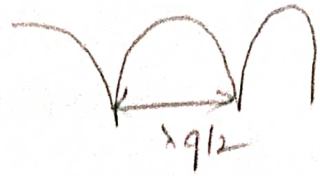
mechanical



In the above setup, attenuator is placed to produce 10dB of attenuation which is used to eliminate the frequency pulling from the frequency meter when the resonance is "OFF". When the resonance is ON, a dip in the indicator occurs and the frequency of wave can be read directly from frequency meter.

The frequency of microwave can be measured alternatively by using slotted line. The slotted line is terminated by short circuit so that a standing wave occurs. From the standing wave locate the positions of two adjacent maximum or minimum. The difference of these two locations is given by

$$\frac{\lambda_g}{2} = (d_1 \sim d_2)$$

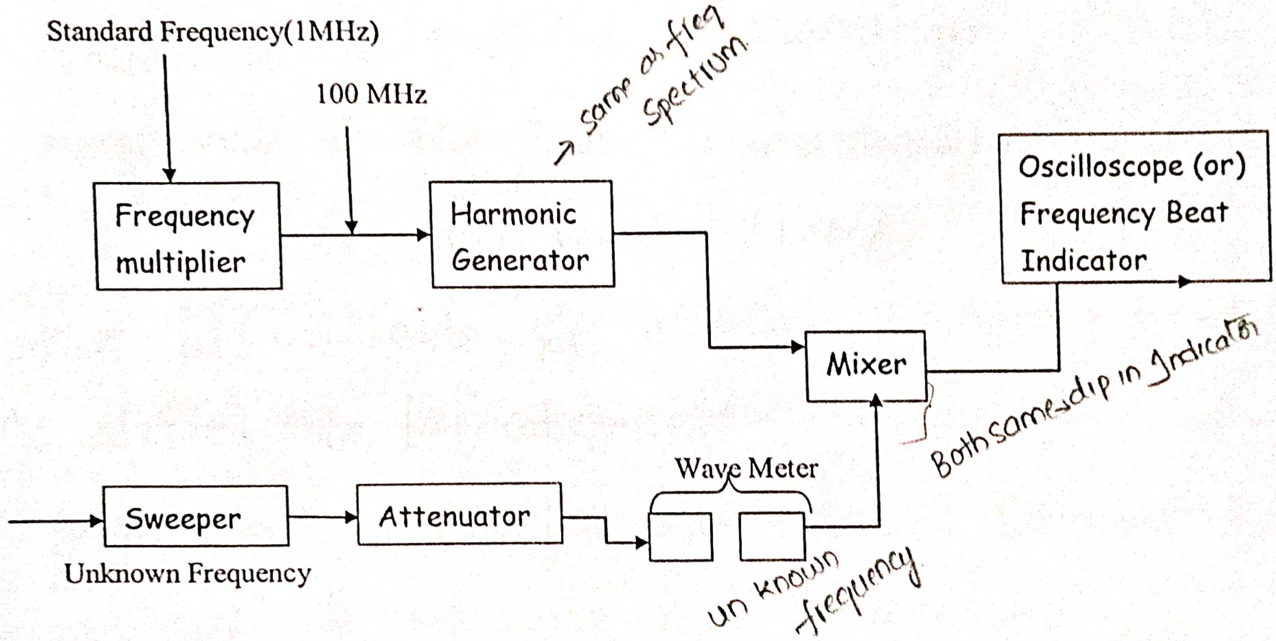


The wavelength of microwave is given by $\lambda = \frac{\lambda_g}{\sqrt{1+\frac{\lambda_g^2}{\lambda_c^2}}}$

$$\lambda_g = 2(d_1 \sim d_2) \;\&\; \lambda_g = 2a$$

The frequency of microwave is $f = \frac{c}{\lambda}$, $f_{GHZ} = \frac{30}{\lambda(cm)}$

ELECTRONIC TECHNIQUE:-



A signal from standard frequency source is amplified and it is given to harmonic generator. It generates harmonics of standard frequency in the desired microwave range. This harmonic generator provides harmonics upto 100^{th} number. The unknown frequency given to sweep generator and the output of sweep circuit are given to mixer through the series of wave meter. If the standard signal frequency is varied the mixer output connected to indicator is detected. If the frequency of stable source is matched with the harmonics of unknown frequency, a null beat is observed in the indicator.

...ment of Power :-

→ measurement of microwave Power Plays an important role in microwave engineering. It determines the o/p Powers of generators & decides the functioning of transmitting & Recieving systems.

→ generally $P=VI$, but at microwave frequencies it is very difficult to specify & measure currents and voltages.

→ Depending on Powerlevel, there are two different methods of measuring microwave Power.

(i) measurement of Low Power ($<10mW$)

(ii) measurement of ~~high~~ medium Power ($10mW$ to $10W$)

(iii) " " high Power ($>10W$)

→ Devices are available for microwave Power measurement are basically divided into two categories:

(i) Devices such as detectors, bolometers and thermocouples, these devices are used for measuring Power in microwatts.

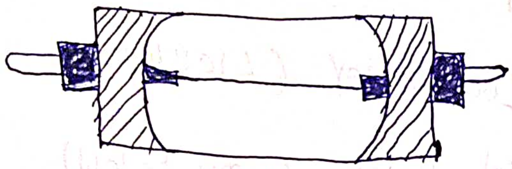
(ii) Calorimeters are capable of measuring Power as high as hundreds of kilowatts.

(i) measurement of Low Power ($<10mW$) :-

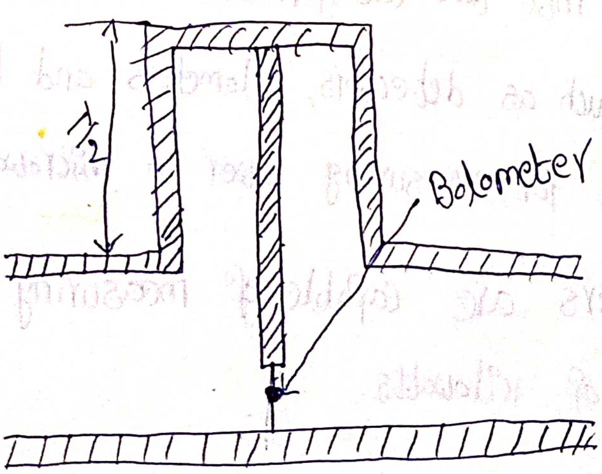
for measuring Low Power typically b/n 1 to 10mW is Performed using bolometers.

Bolometer:- Bolometer is the most commonly used se power is element in microwave freq range. Bolometer is a Temp. sensitive element, when microwave Power falls on it, it's tem raises which results in change in resistance.

The elements having PTC is used generally. These elements are also called as "barretters". (or) "Bolometers". it consists of a thin wire enclosed in a sealed glass tube. The below figure shows simple sketch of a Bolometer.



→ Bolometer mountings are used to place the bolometers in coaxial lines (or) in waveguides. Typically a bolometer mount used for waveguide is shown in below figure.



→ The bolometer in this ckt act as a load resistance. suppose the initial Resistance of bolometer is $R_1 \Omega$. when the microwave Power applied to bolometer load, then some resitance is absorbed at the bolometer load. in the form of heat and there is a change in the resistance of bolometer load.

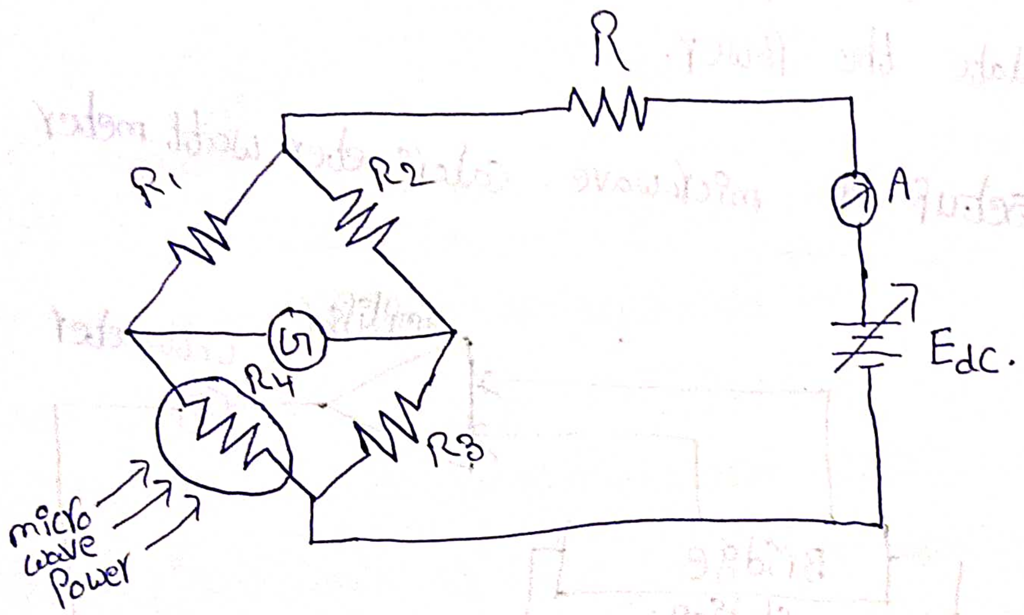
...se R_2 is a resistance of bolometer when the micro power is applied. (3)

change in resistance is given by the difference of two resistances R_1 and R_2:

change in resistance $= R_1 - R_2$.

→ The change in resistance is propotional to the micro-wave power which can be measured by using micro wave bridge circuit.

Microwave Power measurement using bolometer :-



→ initially the bridge is balanced by adjusting R_1. let the voltage of battery is E_1 at balanced condition.

→ The microwave Power is now applied and these Power gets dissipiated in bolometers.

→ The bolometer heats up and it changes its resistance. Therefore the bridge becomes unbalanced.

→ The applied dc Power is changed to E_2. The change in battery $(E_1 \sim E_2)$ will be proposnal to the microwave Power.

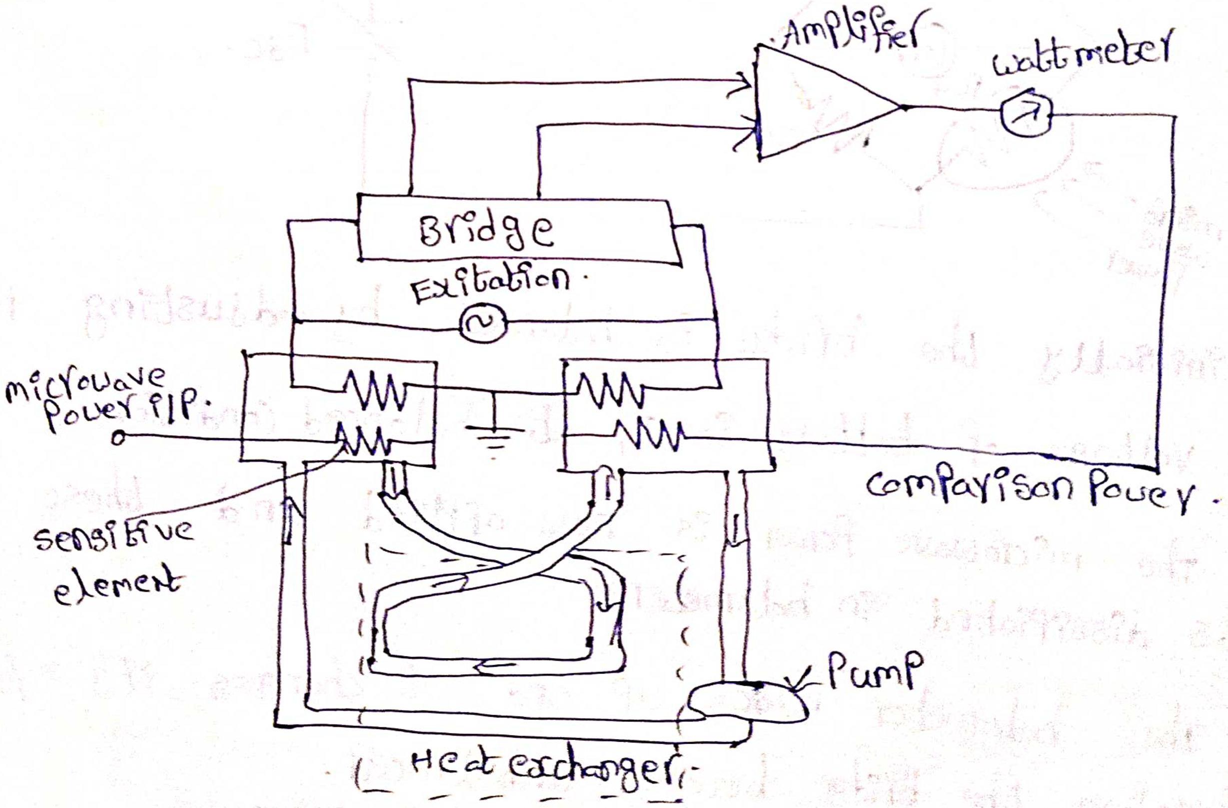
→ Alternatively the detector 'ω' can directly m
microwave power.

(ii) measurement of ~~high~~ medium Power:-

The Power in the range of 10mw to 10W is consid
as medium Power.

This High Power microwave measurements can be ~~confine~~ conveniently done by the calorimetric method which involves conversion of microwave energy into heat. This heat absorbed by the fluid (usually water) and then temparature of fluid measured to calculate the Power.

The setup of microwave calorimeter watt meter is shown below.



set up consists of

(1) Two identical temparature gauges
(2) An indicating meter
(3) Two load resistors.

→ The Two identical temparature gauges along with the two load resistors are placed in the two arms.

→ The o/p arm is referred as comparison head, The resistor load as comparison load and the gauge as comparison Temp gauge. similarly input arm is referred as i/p head, The resistor load as i/p load and the gauge as i/p gauge.

<u>operation:-</u> when an unknown i/p power is applied by a microwave source, heat is generated in the i/p load resistor which raises the Temp of gauge. This unbalances the bridge. The resulting signal is amplified and applied to comparison load resistor which heats up the comparison Temp gauge and the bridge is rebalanced. The meter on the comparison side measures this power which is directly equal to unknown i/p power

<u>Disadvantages of calorimeter wattmeter method:-</u>

→ unsuitable for small microwave power

→ Low accuracy $\approx 5\%$.