UNIT-IV

MICROWAVE MEASUREMENTS

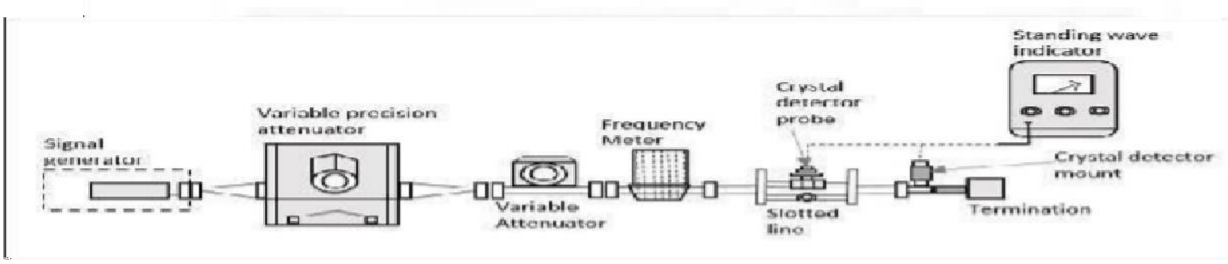
Introduction:

- Measurement of voltage and current is easy at Low frequencies therefore power calculation is easy where as at microwave frequencies it is difficult to measure voltage and current as they are vary with position in a transmission line.
- So at microwave frequencies it is convenient to measure power directly instead of voltage and current.
- At low frequencies, circuits use lumped elements which can be identified and measured. At microwave frequencies, circuit elements are distributed and hence it is not important to know what element make up a line.
- Unlike low frequency measurements, many quantities measured at microwave frequencies are relative and it is not necessary to know their absolute values.
- Further for power measurement, it is usually sufficient to know the ratio of two powers rather than exact input or output powers

The following parameters can be conveniently measured at microwave frequencies

- Frequency
- Power
- Attenuation
- Voltage Standing Wave Ratio (VSWR)
- Phase
- Impedance
- Insertion Loss
- Dielectric Constant
- Noise factor

Microwave Bench Block diagram:



The general set up for measurement of any parameter in microwaves is normally don by a microwave bench.

Power Supply:

- The power supply gives necessary beam voltage and beam current to the circuit. Also repeller voltage delivered by this unit.
- In lab typically we use 300V beam voltage, 24 mA beam current and take output readings by varying repeller voltage from -50V to 270V.

Microwave Source:

- The source of microwave may be Gunn diode oscillator, Reflex Klystron or BWO.
- Microwave source can provide either a continuous wave (CW) or square wave modulated at an audio rate which is normally 1KHz.

Isolator:

- Isolator is used to protect the source from the reflected power due to mismatch of the load.
- Power flows in only one direction from source to load.

Precision Attenuator or Variable Attenuator:

- The precision attenuator can provide 0 to 50 dB attenuation above insertion loss.
- The variable flat attenuator is also used in addition, whose calibration can be checked against readings of the precision attenuator.

Frequency Meter:

This is the device which measures the frequency of the signal. With this frequency meter, the signal can be adjusted to its resonance frequency. It also gives provision to couple the signal to waveguide.

Crystal Detector:

A crystal detector probe and crystal detector mount are indicated in the above figure, where the detector is connected through a probe to the mount. This is used to demodulate the signals.

Slotted Line:

In a microwave transmission line or waveguide, the electromagnetic field is considered as the sum of incident wave from the generator and the reflected wave to the generator. The reflections indicate a mismatch or a discontinuity. The magnitude and phase of the reflected wave depends upon the amplitude and phase of the reflecting impedance.

The standing waves obtained are measured to know the transmission line imperfections which are necessary to have knowledge on impedance mismatch for effective transmission. This slotted line helps in measuring the standing wave ratio of a microwave device.

Standing Wave Integrator:

It is an element that reinforces producing the reading classification of the standing wave proportion. It gives and slots the waveguide with the help of a gap to adjust the clock cycles of the given signal. It forwards the movements through BNC cable to CRO or VSWR to estimate the general characteristics.

Frequency Meter:

It is a component that measures the frequency of the given signal, and it adjusts to its resonance frequency. The frequency meter also delivers regulation from the motion to the waveguide.

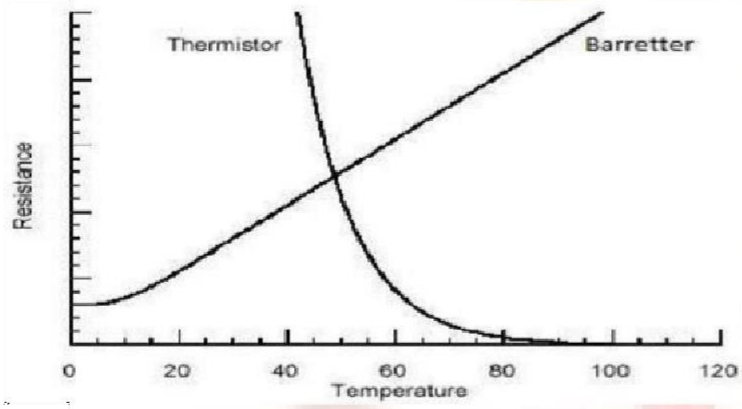
Microwave Power Measurement:

- The Microwave Power measured is the average power at any position in waveguide.
- The measurement of power can be divided into three categories
    - Measurement of Low microwave power (o.o1 mW-10 mW) – Bolometer technique
    - Measurement of medium microwave power (10 mW – 1 W) – Calorimetric Technique
    - Measurement of high power microwave (> 10 W) – Calorimetric Watt meter

Measurement of Low microwave power:

- Devices such as bolometers and thermocouples whose resistance changes with the applied power are capable of measuring low microwave powers.

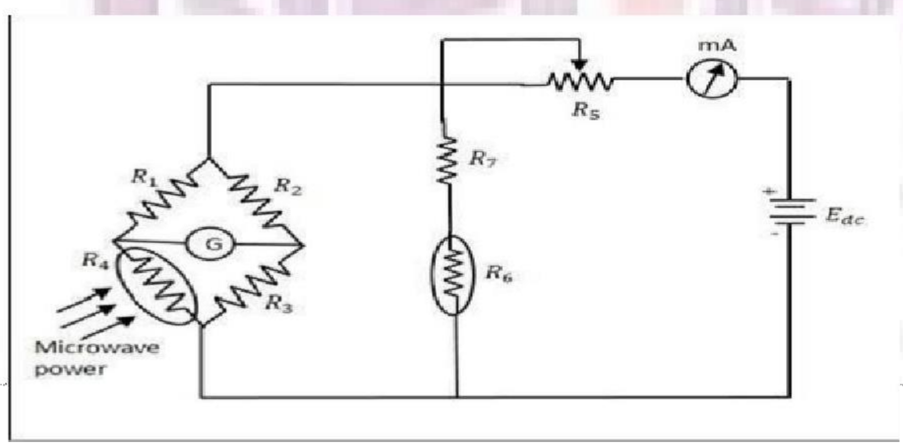
- Bolometer is a simple temperature sensitive device whose resistance varies with temperature.
- Bolometers are two types i.e., Barretters and Thermisters.
- Barretters have positive temperature coefficient and their resistance increases with an increase in temperature



Bolometer is a device which is used for low Microwave power measurements. The element used in bolometer could be of positive or negative temperature coefficient. For example, a barrater has a positive temperature coefficient whose resistance increases with the increase in temperature. Thermistor has negative temperature coefficient whose resistance decreases with the increase in temperature.

Any of them can be used in the bolometer, but the change in resistance is proportional to Microwave power applied for measurement. This bolometer is used in a bridge of the arms as one so that any imbalance caused, affects the output. A

typical example of a bridge circuit using a bolometer is as shown in the following figure.



The millimeter here, gives the value of the current flowing. The battery is variable, which is varied to obtain balance, when an imbalance is caused by the behavior of the bolometer. This adjustment which is made in DC battery voltage is proportional to the Microwave power. The power handling capacity of this circuit is limited.

Measurement of Medium Power

The measurement of Microwave power around 10mW to 1W, can be understood as the measurement of medium power.

A special load is employed, which usually maintains a certain value of specific heat. The power to be measured, is applied at its input which proportionally changes the output temperature of the load that it already maintains. The difference in temperature rise, specifies the input Microwave power to the load.

The bridge balance technique is used here to get the output. The heat transfer method is used for the measurement of power, which is a Calorimetric technique.

Measurement of High Power

The measurement of Microwave power around 10W to 50KW, can be understood as the measurement of high power.

The High Microwave power is normally measured by Calorimetric watt meters, which can be of dry and flow type. The dry type is named so as it uses a coaxial cable which is filled with di-electric of high hysteresis loss, whereas the flow type

is named so as it uses water or oil or some liquid which is a good absorber of microwaves.

The change in temperature of the liquid before and after entering the load, is taken for the calibration of values. The limitations in this method are like flow determination, calibration and thermal inertia, etc.

Measurement of Attenuation

In practice, Microwave components and devices often provide some attenuation.

The amount of attenuation offered can be measured in two ways. They are − Power ratio method and RF substitution method.

Attenuation is the ratio of input power to the output power and is normally expressed in decibels.

1. Power Ratio Method

In this method, the measurement of attenuation takes place in two steps.

- **Step 1** − The input and output power of the whole Microwave bench is done without the device whose attenuation has to be calculated.
- **Step 2** − The input and output power of the whole Microwave bench is done with the device whose attenuation has to be calculated.

The ratio of these powers when compared, gives the value of attenuation.

The following figures are the two setups which explain this.

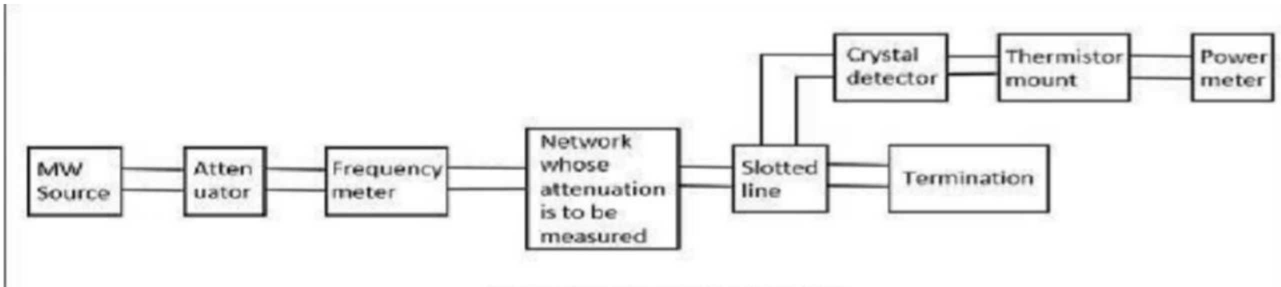
Drawback − the power and the attenuation measurements may not be accurate, when the input power is low and attenuation of the network is large.

2. RF Substitution Method

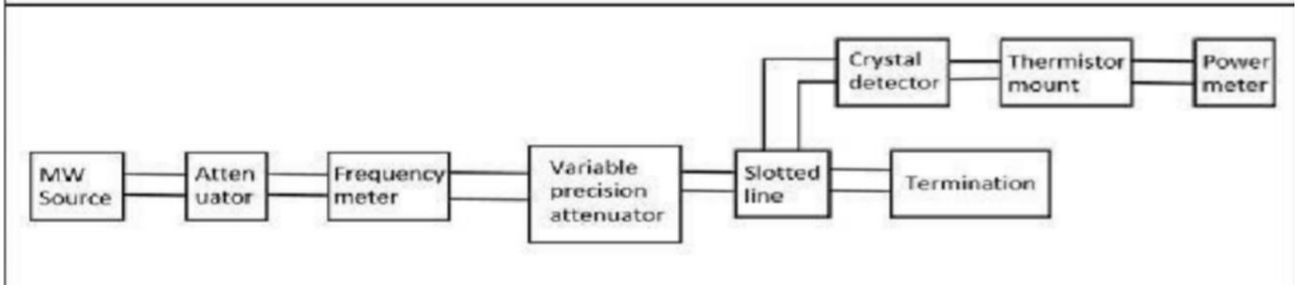
In this method, the measurement of attenuation takes place in three steps.

- **Step 1** − the output power of the whole Microwave bench is measured with the network whose attenuation has to be calculated.
- **Step 2** − The output power of the whole Microwave bench is measured by replacing the network with a precision calibrated attenuator.
- **Step 3** − Now, this attenuator is adjusted to obtain the same power as measured with the network.

The following figures are the two setups which explain this.



Set up 1, RF substitution method



Set up 2, RF substitution method

The adjusted value on the attenuator gives the attenuation of the network directly. The drawback in the above method is avoided here and hence this is a better procedure to measure the attenuation.

Frequency Measurement:

Mechanical techniques

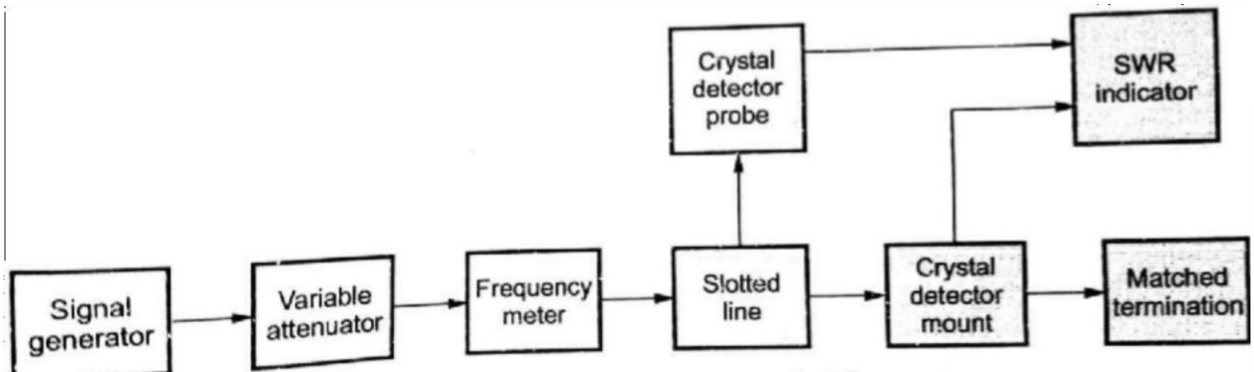
The mechanical techniques can be divided into two types

1. Slotted line technique
2. Cavity wave meter technique

The above techniques operation and accuracy depends upon the physical dimensions of the mechanical devices.

Slotted Line Technique

- A slotted line is a piece of transmission line and it is constructed in such a way that the voltage and current along it can be measured continuously over its length.
- The general set up for the measurement of microwave frequency is shown



Set-up for the measurement of frequency

- When a waveguide is mismatched by a load, a standing wave is created in the waveguide.
- The distance between the two adjacent maxima or minima is one half of the wavelength.
- Standing waves are set up in a slotted line producing minima every half wavelength apart.
- The distance between minima can be measured and guide wavelength hence frequency can be measured.

$$\frac{\lambda_g}{2} = (D_2 - D_1) = \Delta D$$

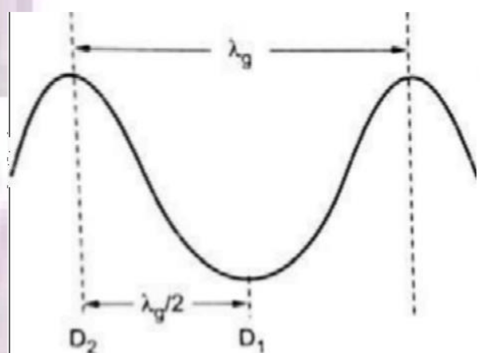
$$\lambda_g = \frac{\lambda_0}{\sqrt{1-\left(\frac{\lambda_0}{\lambda_c}\right)^2}}$$

But for TE_{10} mode

$$\lambda_c = 2a$$

and $$\lambda_0 = \frac{c}{f}$$

$$\therefore \quad f = \frac{c}{\lambda_0}$$

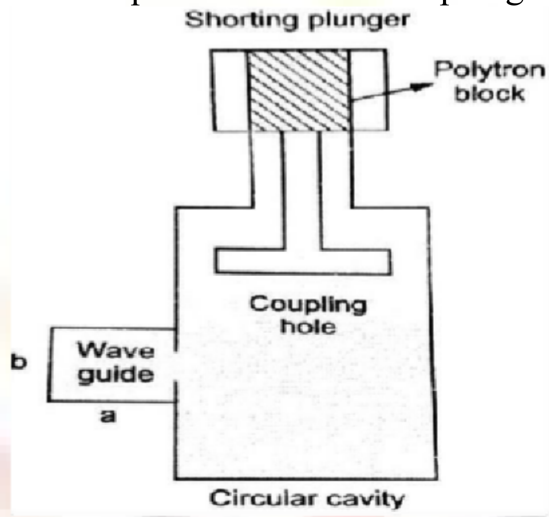


Maxima and minima of a wave

Cavity Wave meter Technique or Resonant Cavity Technique:

- A typical wave meter is a cylindrical cavity with a variable short circuit termination which changes the resonance frequency of the cavity by changing cavity length.
- Wave meter axis placed perpendicular to the broad wall of the waveguide.

- Wave meter axis is coupled by a hole in the narrow wall as shown
- A block of absorbing material placed at the back of the tuning plunger prevents oscillation on the top of it.
- Cavity resonates at different frequencies for different plunger positions.



- The wave meter is called absorption type wave meter because the power is absorbed in wave meter at resonance and they attenuate the signal frequency to which they are tuned.
- The wave meter is called transitive cavity wave meter which passes the signal frequency to which they are tuned.
- The absorption type wave meters are preferred for the laboratory frequency measurement.
- The general set up for the frequency measurement by absorption type cavity wave meter is shown

Measurement of VSWR:

In any Microwave practical applications, any kind of impedance mismatches lead to the formation of standing waves. The strength of these standing waves is measured by Voltage Standing Wave Ratio

the ratio of maximum to minimum voltage gives the VSWR which is denoted by S.

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

$$\text{where, } \rho = \text{reflection coefficient} = \frac{P_{reflected}}{P_{incident}}$$

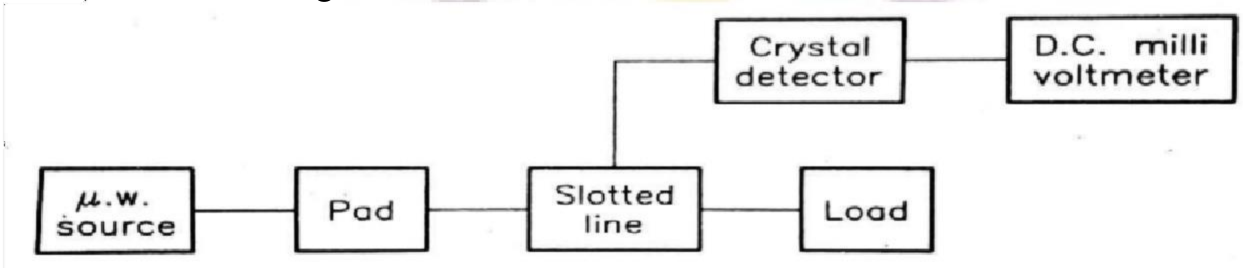
S varies from 1 to ∞

as ρ varies from 0 to 1

The measurement of VSWR can be done in two ways, Low VSWR and High VSWR measurements.

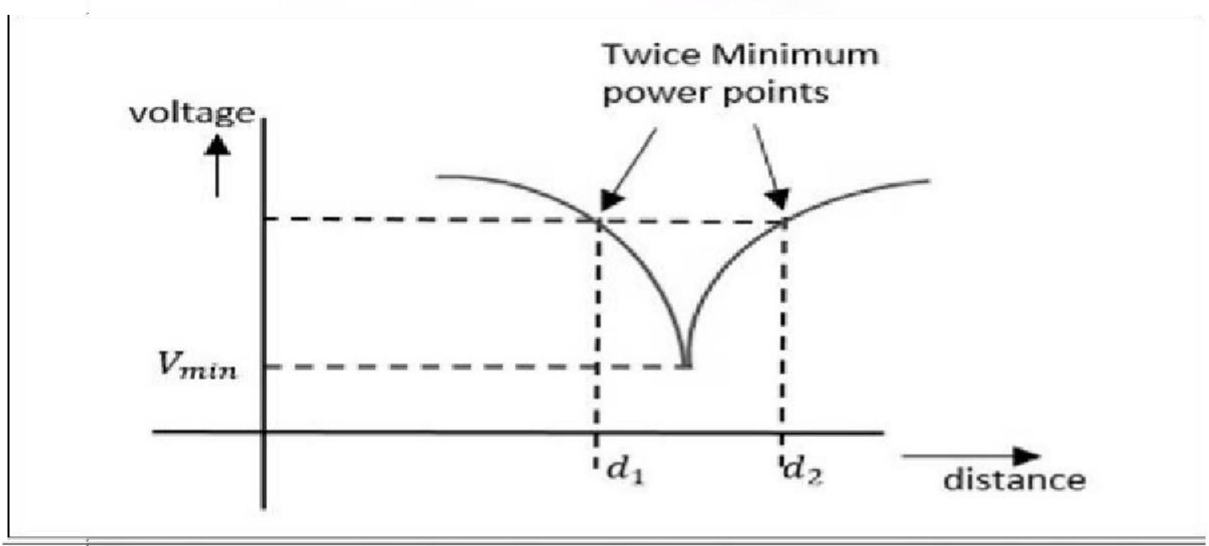
1. Measurement of Low VSWR S<10:

The measurement of low VSWR can be done by adjusting the attenuator to get a reading on a DC mill voltmeter which is VSWR meter. The readings can be taken by adjusting the slotted line and the attenuator in such a way that the DC mill voltmeter shows a full scale reading as well as a minimum reading.
Now these two readings are calculated to find out the VSWR of the network.



2. Measurement of High VSWR S>10:

The measurement of high VSWR whose value is greater than 10 can be measured by a method called the **double minimum method**. In this method, the reading at the minimum value is taken, and the readings at the half point of minimum value in the crest before and the crest after are also taken. This can be understood by the following figure.



Now, the VSWR can be calculated by a relation, given as −

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

Where, λ_g *is the guided wavelength*

$$\lambda_g = \frac{\lambda_0}{\sqrt{1 - (\frac{\lambda_0}{\lambda_c})^2}} \quad where\ \lambda_0 = c/f$$

As the two minimum points are being considered here, this is called as double minimum method.

Measurement of Impedance:

Impedance at microwave frequencies can be measured by using following 3 methods

- Using Magic T
- Using Slotted line
- Using Reflectometer

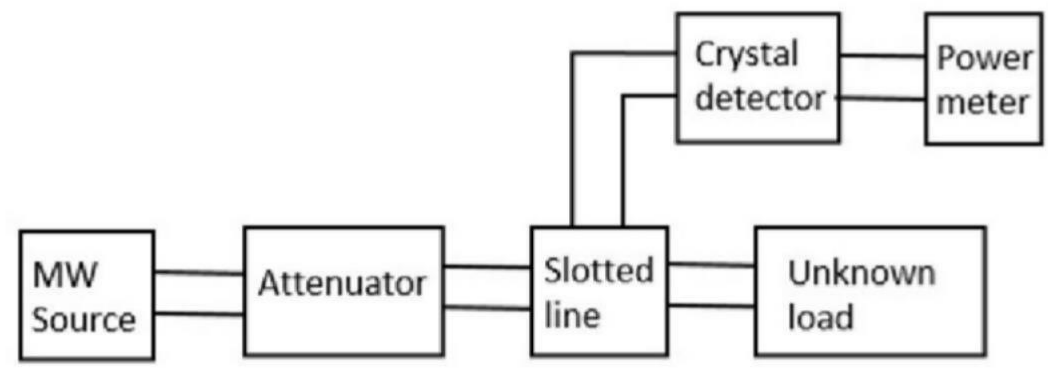
Apart from Magic Tee, we have two different methods, one is using the slotted line and the other is using the reflectometer.

1. Impedance Using the Slotted Line:

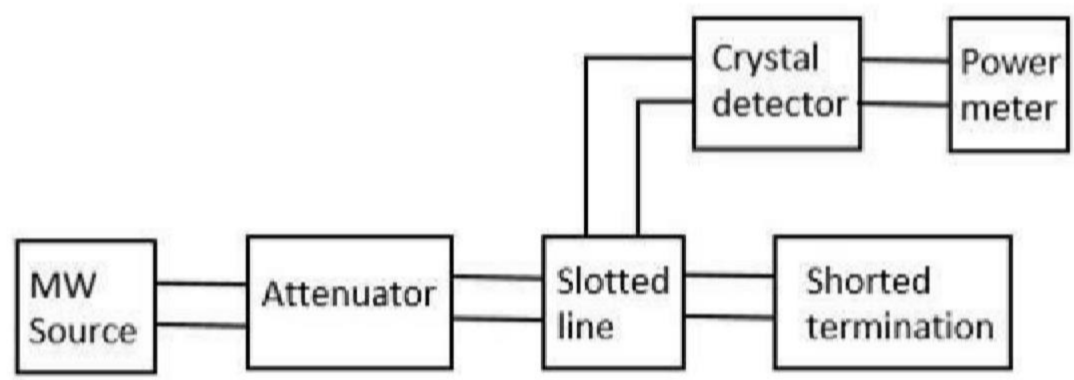
In this method, impedance is measured using slotted line and load ZL and by using this, Vmax and Vmin can be determined. In this method, the measurement of impedance takes place in two steps.

- **Step 1** − Determining Vmin using load ZL.
- **Step 2** − Determining Vmin by short circuiting the load.

This is shown in the following figures.

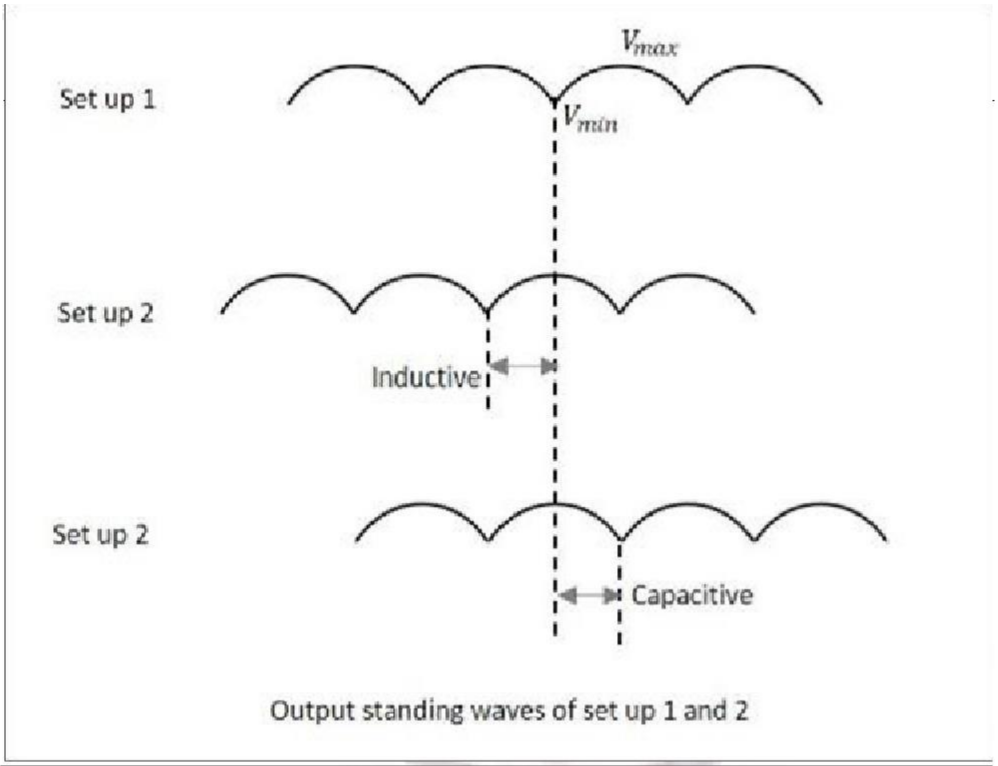


Set up 1, Impedance measurement using slotted line



Set up 2, Impedance measurement using slotted line

When we try to obtain the values of Vmax and Vmin using a load, we get certain values. However, if the same is done by short circuiting the load, the minimum gets shifted, either to the right or to the left. If this shift is to the left, it means that the load is inductive and if it the shift is to the right, it means that the load is capacitive in nature. The following figure explains this.

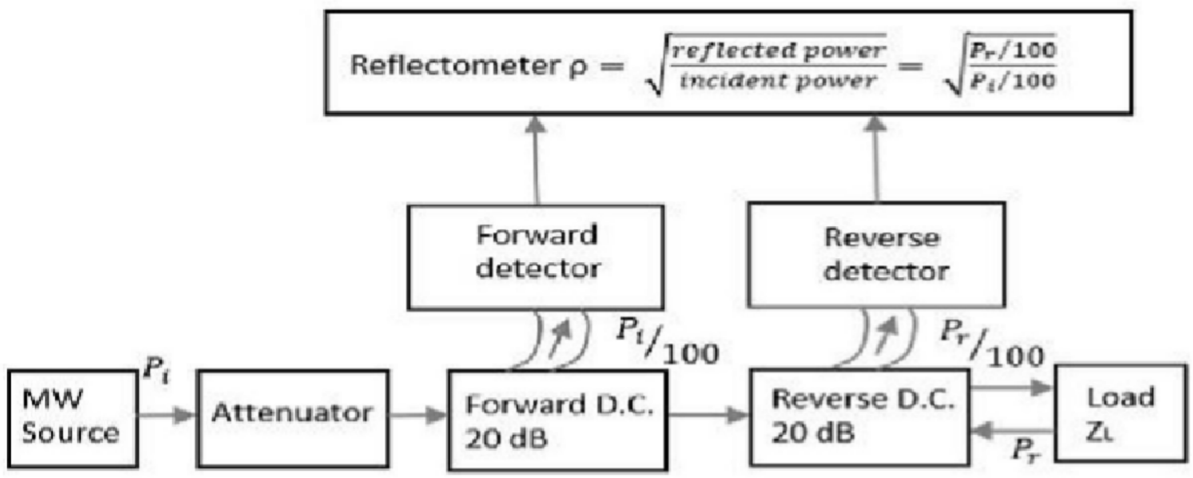


By recording the data, unknown impedance is calculated. The impedance and reflection coefficient ρ can be obtained in both magnitude and phase.

Impedance Using the Reflectometer:

Unlike slotted line, the Reflectometer helps to find only the magnitude of impedance and not the phase angle. In this method, two directional couplers which are identical but differs in direction are taken.

These two couplers are used in sampling the incident power Pi and reflected power Pr from the load. The reflectometer is connected as shown in the following figure. It is used to obtain the magnitude of reflection coefficient ρ, from which the impedance can be obtained.



Set up for measuring impedance using reflectometer

From the reflectometer reading, we have

$$\rho = \sqrt{\frac{P_r}{P_i}}$$

From the value of ρ, the $VSWR$, i.e. S and the impedance can be calculated by

$$S = \frac{1+\rho}{1-\rho} \quad and \quad \frac{z - z_g}{z + z_g} = \rho$$

Where, zg is known wave impedance and z is unknown impedance.

Though the forward and reverse wave parameters are observed here, there will be no interference due to the directional property of the couplers. The attenuator helps in maintaining low input power.