Unit-5

Microwave Measurements

Square law detection, Broadband and tuned detectors. Wave-guide probes, Probe and detector mounts, Slotted line arrangement and VSWR meter, Measurement of wave-guide impedance at load port by slotted line, Microwave bench components and source modulation. Measurement of scattering matrix parameters, High, Medium and low-level power measurement techniques, Characteristics of bolometers, bolometer mounts, Power measurement bridges, Microwave frequency measurement techniques, calibrated resonators (transmission and absorption type). Network Analyzer and its use in measurements.

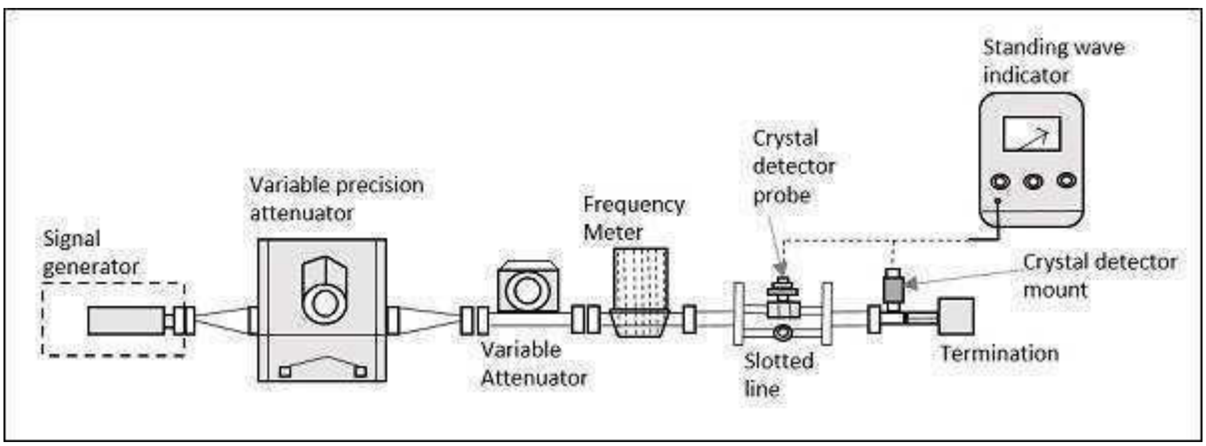
Measurement Devices

Among the Microwave measurement devices, a setup of Microwave bench, which consists of Microwave devices has a prominent place. This whole setup, with few alternations, is able to measure many values like guide wavelength, free space wavelength, cut-off wavelength, impedance, frequency, VSWR, Klystron characteristics, Gunn diode characteristics, power measurements, etc.

The output produced by microwaves, in determining power is generally of a little value. They vary with the position in a transmission line. There should be an equipment to measure the Microwave power, which in general will be a Microwave bench setup.

Microwave Bench General Measurement Setup

This setup is a combination of different parts which can be observed in detail. The following figure clearly explains the setup.



Microwave Bench General Measurement Setup

Signal Generator

As the name implies, it generates a microwave signal, in the order of a few milliwatts. This uses velocity modulation technique to transfer continuous wave beam into milliwatt power.

A Gunn diode oscillator or a Reflex Klystron tube could be an example for this microwave signal generator.

Precision Attenuator

This is the attenuator which selects the desired frequency and confines the output around 0 to 50db. This is variable and can be adjusted according to the requirement.

Variable Attenuator

This attenuator sets the amount of attenuation. It can be understood as a fine adjustment of values, where the readings are checked against the values of Precision Attenuator.

Isolator

This removes the signal that is not required to reach the detector mount. Isolator allows the signal to pass through the waveguide only in one direction.

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.

Standing Wave Indicator

The standing wave voltmeter provides the reading of standing wave ratio in dB. The waveguide is slotted by some gap to adjust the clock cycles of the signal. Signals transmitted by waveguide are forwarded through BNC cable to VSWR or CRO to measure its characteristics.

A microwave bench set up in real-time application would look as follows −

Microwave Bench

Now, let us take a look at the important part of this microwave bench, the slotted line.

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 is necessary to have a knowledge on impedance mismatch for effective transmission. This slotted line helps in measuring the standing wave ratio of a microwave device.

Construction

The slotted line consists of a slotted section of a transmission line, where the measurement has to be done. It has a travelling probe carriage, to let the probe get connected wherever necessary, and the facility for attaching and detecting the instrument.

In a waveguide, a slot is made at the center of the broad side, axially. A movable probe connected to a crystal detector is inserted into the slot of the waveguide.

Operation

The output of the crystal detector is proportional to the square of the input voltage applied. The movable probe permits convenient and accurate measurement at its position. But, as the probe is moved along, its output is proportional to the standing wave pattern, which is formed inside the waveguide. A variable attenuator is employed here to obtain accurate results.

The output VSWR can be obtained by

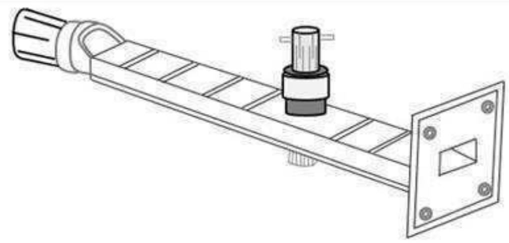
$$\text{VSWR}=\sqrt{\frac{V_{max}}{V_{min}}}$$

Where, V is the output voltage.

In order to obtain a low frequency modulated signal on an oscilloscope, a slotted line with a tunable detector is employed. A slotted line carriage with a tunable detector can be used to measure the following.

- VSWR (Voltage Standing Wave Ratio)
- Standing wave pattern
- Impedance
- Reflection coefficient
- Return loss
- Frequency of the generator used
- Tunable Detector

The tunable detector is a detector mount which is used to detect the low frequency square wave modulated microwave signals. The following figure gives an idea of a tunable detector mount.



Tunable waveguide detector

To provide a match between the Microwave transmission system and the detector mount, a tunable stub is often used. There are three different types of tunable stubs.

- Tunable waveguide detector
- Tunable co-axial detector
- Tunable probe detector

Also, there are fixed stubs like −

- Fixed broad band tuned probe
- Fixed waveguide matched detector mount

The detector mount is the final stage on a Microwave bench which is terminated at the end.

Measurements

In the field of Microwave engineering, there occurs many applications, as already stated in first chapter. Hence, while using different applications, we often come across the need of measuring different values such as Power, Attenuation, Phase shift, VSWR, Impedance, etc. for the effective usage.

Measurement of Power

The Microwave Power measured is the average power at any position in waveguide. Power measurement can be of three types.

Measurement of Low power (0.01mW to 10mW)

Example − Bolometric technique

Measurement of Medium power (10mW to 1W)

Example − Calorimeter technique

Measurement of High power (>10W)

Example − Calorimeter Watt meter

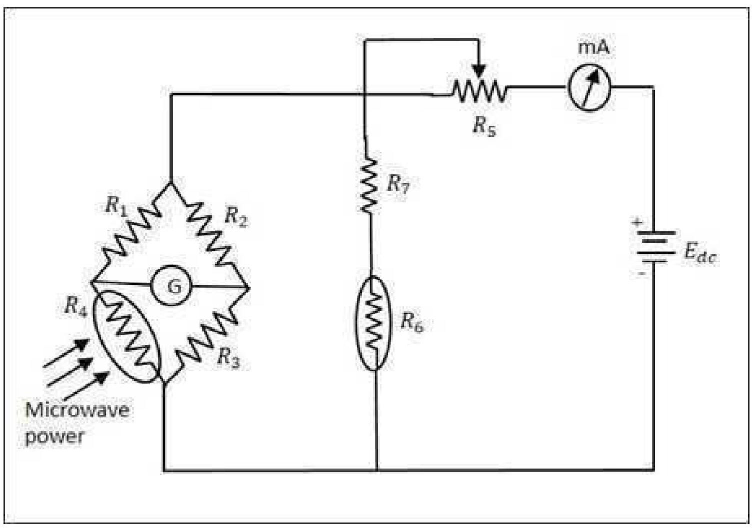
Let us go through them in detail.

<u>Measurement of Low Power</u>

The measurement of Microwave power around 0.01mW to 10mW, can be understood as the measurement of low power.

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.



Bolometer

The milliammeter 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.

$$\text{Attenuation in dBs} = 10 \log P_{in}/P_{out}$$

Where P_{in} = Input power and P_{out} = Output power

Power Ratio Method

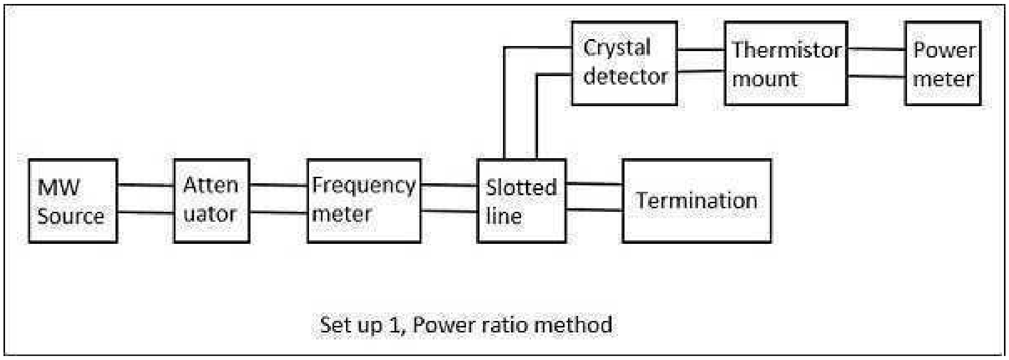
In this method, the measurement of attenuation takes place in two steps.

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

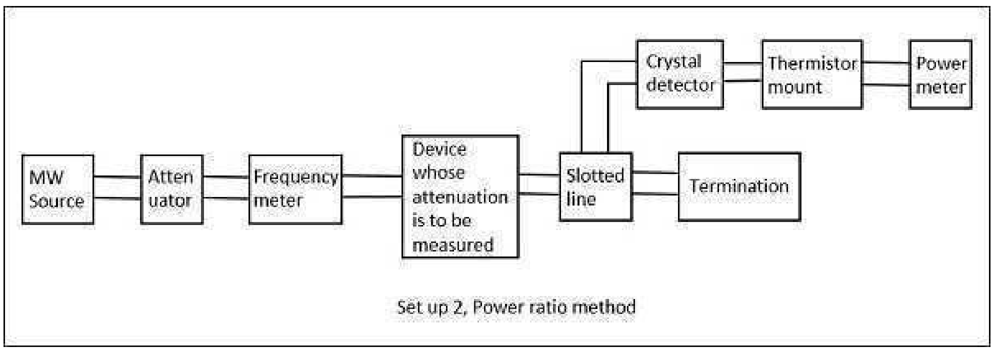
Step 2 − The input and output power of the whole Microwave bench is done with the device whose attenuation has to be calculated.

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

The following figures are the two setups which explain this.



Power Ratio Method Setup 1



Power Ratio Method Setup 2

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

RF Substitution Method

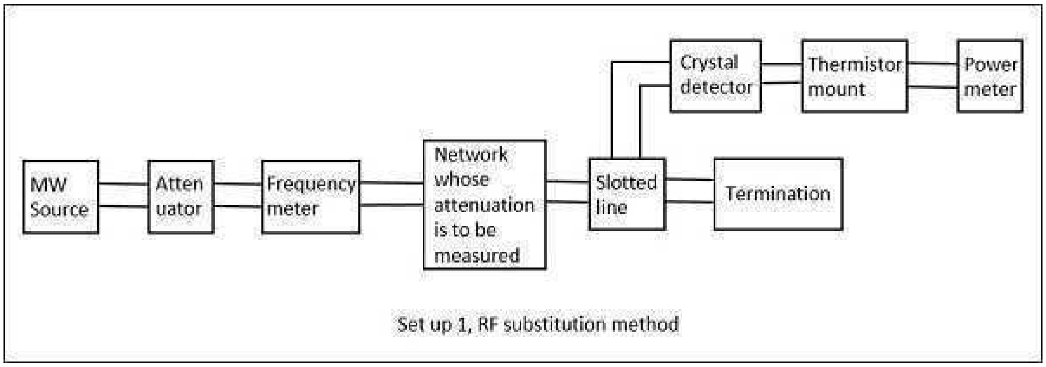
In this method, the measurement of attenuation takes place in three steps.

Step 1 − The output power of the whole Microwave bench is measured with the network whose attenuation has to be calculated.

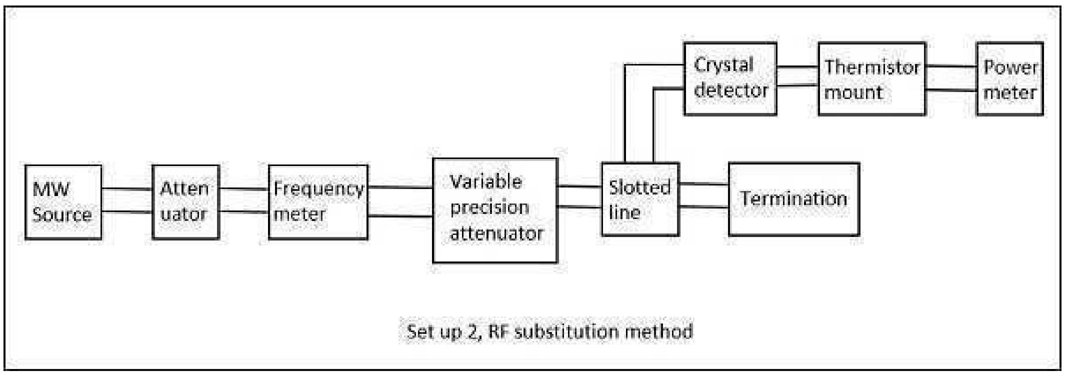
Step 2 − The output power of the whole Microwave bench is measured by replacing the network with a precision calibrated attenuator.

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.



RF Substitution Method Setup 1



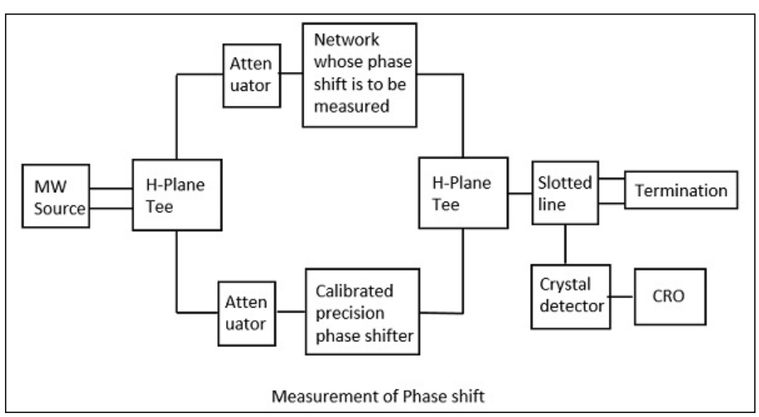
RF Substitution Method Setup 2

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.

Measurement of Phase Shift

In practical working conditions, there might occur a phase change in the signal from the actual signal. To measure such phase shift, we use a comparison technique, by which we can calibrate the phase shift.

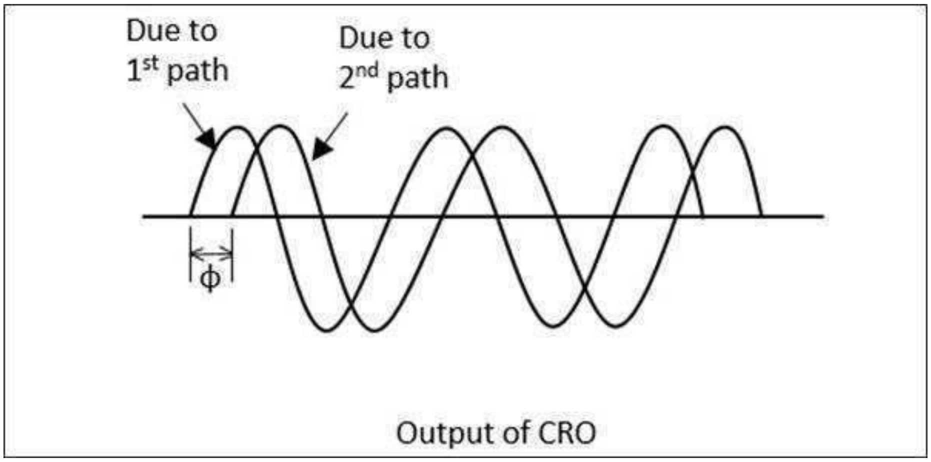
The setup to calculate the phase shift is shown in the following figure.



Measurement of Phase Shift

Here, after the microwave source generates the signal, it is passed through an H-plane Tee junction from which one port is connected to the network whose phase shift is to be measured and the other port is connected to an adjustable precision phase shifter.

The demodulated output is a 1 KHz sine wave, which is observed in the CRO connected. This phase shifter is adjusted such that its output of 1 KHz sine wave also matches the above. After the matching is done by observing in the dual mode CRO, this precision phase shifter gives us the reading of phase shift. This is clearly understood by the following figure.



Output of CRO

This procedure is the mostly used one in the measurement of phase shift. Now, let us see how to calculate the VSWR.

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 (VSWR). The ratio of maximum to minimum voltage gives the VSWR, which is denoted by S.

$$S=V_{max}/V_{min}=(1+\rho)/(1-\rho)$$

Where, ρ=reflection coefficient $=P_{reflected}/P_{incident}$

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

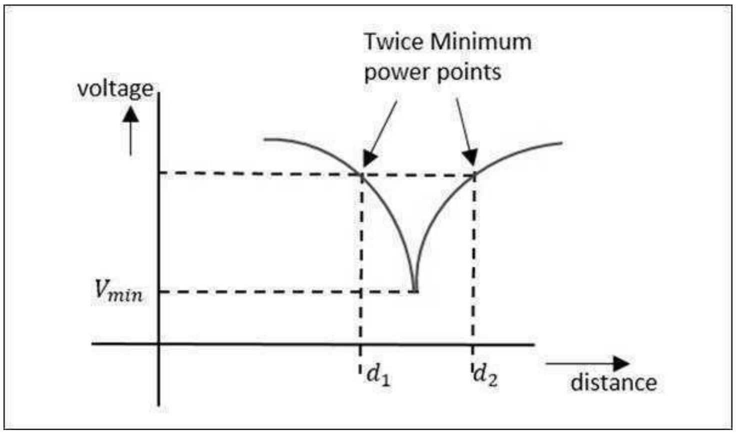
Measurement of Low VSWR (S <10)

The measurement of low VSWR can be done by adjusting the attenuator to get a reading on a DC millivoltmeter which is VSWR meter. The readings can be taken by adjusting the slotted line and the attenuator in such a way that the DC millivoltmeter 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.

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.



Measurement of High VSWR

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

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

As the two minimum points are being considered here, this is called as double minimum method. Now, let us learn about the measurement of impedance.

Measurement of Impedance

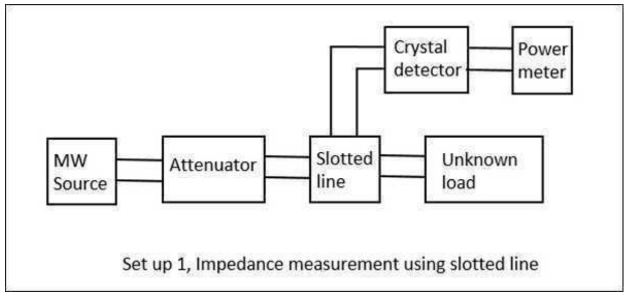
Apart from Magic Tee, we have two different methods, one is using the slotted line and the other is using the reflectometer.

Impedance Using the Slotted Line

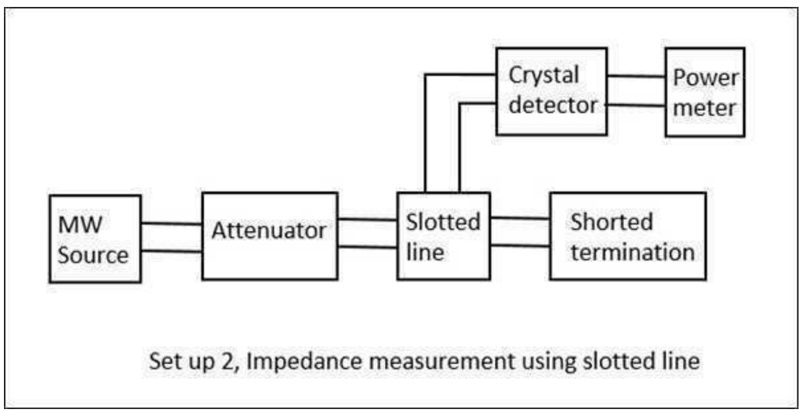
In this method, impedance is measured using slotted line and load ZL and by using this, Vmax and Vmin can be determined. In this method, the measurement of impedance takes place in two steps.

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

This is shown in the following figures.

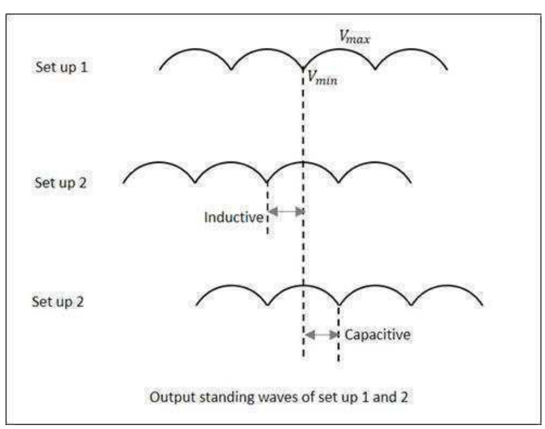


Impedance Measurement Setup1



Impedance Measurement Setup2

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.



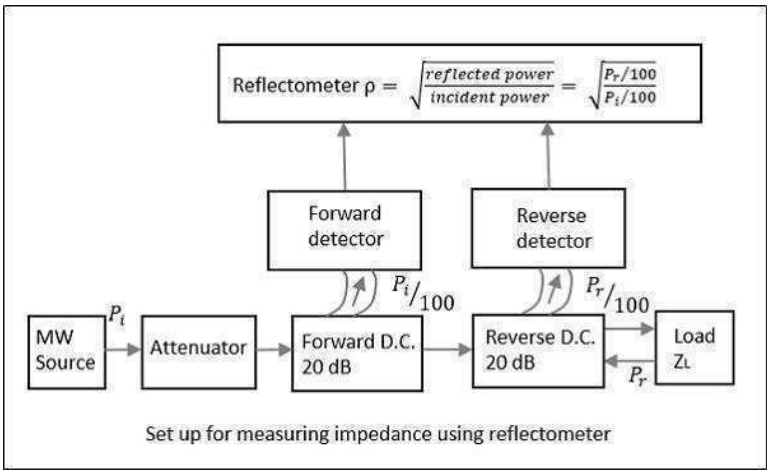
Output Standing Waves

By recording the data, an 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.



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

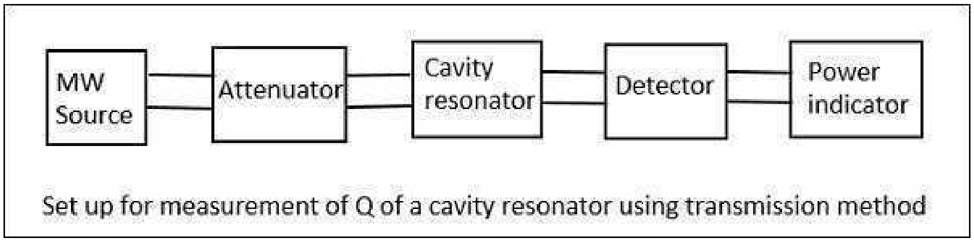
$$S=\frac{1+\rho}{1-\rho} \text{ and } \frac{z-z_g}{z+z_g}= \rho$$

Where, z_g 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.

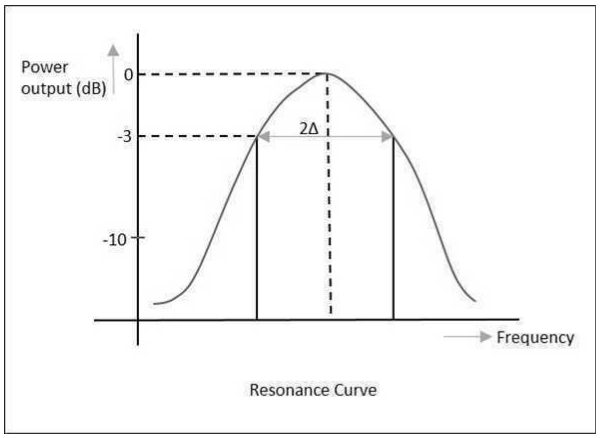
Measurement of Q of Cavity Resonator

Though there are three methods such as Transmission method, Impedance method, and Transient decay or Decrement method for measuring Q of a cavity resonator, the easiest and most followed method is the Transmission Method. Hence, let us take a look at its measurement setup.



Cavity Resonator Transmission Method

In this method, the cavity resonator acts as the device that transmits. The output signal is plotted as a function of frequency which results in a resonant curve as shown in the following figure.



Resonance Curve

From the setup above, the signal frequency of the microwave source is varied, keeping the signal level constant and then the output power is measured. The cavity resonator is tuned to this frequency, and the signal level and the output power is again noted down to notice the difference.

When the output is plotted, the resonance curve is obtained, from which we can notice the Half Power Bandwidth (HPBW) (2Δ) values.

$$2\Delta=\pm1/Q_L$$

Where, Q_L is the loaded value

$$\text{Or } Q_L=\pm1/2\Delta=\pm w/2(w-w0)$$

If the coupling between the microwave source and the cavity, as well the coupling between the detector and the cavity are neglected, then

$$Q_L=Q_0(\text{unloaded Q})$$

Drawback

The main drawback of this system is that, the accuracy is a bit poor in very high Q systems due to narrow band of operation.

We have covered many types of measurement techniques of different parameters. Now, let us try to solve a few example problems on these.