UNIT V
MICROWAVE MEASUREMENTS

DESCRIPTION OF MICROWAVE BENCH

Introduction:
Electrical measurements encountered in the microwave region of the electromagnetic spectrum are discussed through microwave measurement techniques. This measurement technique is vastly different from that of the more conventional techniques. The methods are based on the wave character of high frequency currents rather than on the low frequency technique of direct determination of current or voltage.

For example, the measurement of power flow in a system specifies the product of the electric and magnetic fields .Where as the measurement of impedance determines their ratio .Thus these two measurements indirectly describe the distribution of the electric field and magnetic fields in the system and provides its complete description .This is ,in fact ,the approach to most of the measurements carried out in the micro wave region of the spectrum.

Microwave Bench:
The micro wave test bench incorporates a range of instruments capable of allowing all types of measurements that are usually required for a microwave engineer .The bench is capable of being assembled or disassembled in a number of ways to suit individual experiments .A general block diagram of the test bench comprising its different units and ancillaries are shown bellow.

1. Klystron Power Supply:

Klystron Power Supply generates voltages required for driving the reflex Klystron tube like 2k25 .It is stable, regulated and short circuit protected power supply. It has built on facility of square wave and saw tooth generators for amplitude and frequency modulation. The beam voltage ranges from 200V to 450V with maximum beam current.50mA. The provision is given to vary repeller voltage continuously from-270V DC to -10V.

Gunn Power Supply:

Gunn Power Supply comprises of an electronically regulated power supply and a square wave generator designed to operate the Gunn oscillator and PIN Modulator. The Supply Voltage ranges from 0 to 12V with a maximum current, 1A.

Gunn oscillator:

Gunn oscillator uti1izes Gunn diode which works on the principle that when a DC voltage is applied across a sample of n-type Gallium Arsenide; the current oscillates at .microwave frequencies. This does not need high voltage as it is necessary for Klystrons and therefore solid state oscillators are now finding wide applications. Normally, they are capable of delivering 0.5 watt at 10GHz, but as the frequency of operation is increased the microwave output power gets considerably reduced.

4. Isolator:

This unattenuated device permits un attenuated transmission in one direction (forward direction) but provides very high attenuation in the reverse direction {backward direction). This is generally used between the source and rest of the set up to avoid overloading of the source due to reflected power.

5. Variable Attenuator:

The device that attenuates the signal is termed as attenuator. Attenuators are categorized into two categories namely, the fixed attenuators and variable attenuators. The attenuator used in the microwave set is of variable type. The variable attenuator consists of a strip of absorbing material which is arranged in such a way that its profusion into the guide is adjustable. Hence, the signal power to be fed to the microwave set up can be set at the desired level.

6. Frequency Meter:

It is basically a cavity resonator. The method of measuring frequency is to use a cavity where the size can be varied and it will resonate at a particular frequency for given size. Cavity is attached to a guide having been excited by a certain microwave source and is tuned to its resonant frequency. It sucks up some signal from the guide to maintain its stored energy.

Thus if a power meter had been monitoring the signal power at the resonating condition of the cavity it will indicate a sharp dip. The tuning of the cavity is achieved by a micrometer screw and a curve of frequency versus screw setting is provided. The screw setting at which the power indication dip is noted and the frequency is read from the curve.

7. Slotted Section:

To sample the field with in a wave guide, a narrow longitudinal slot with ends taperedto provide smoother impedance transformation and thereby providing minimum mismatch, is milled on the top of broader dimension of wave guide. Such section is known as slotted wave guide section. The slot is generally so many wave lengths long to allow many minima of standing wave pattern to be covered. The slot location is such that its presence does not influence the field configurations to any great degree. On this Section a probe inserted with in a holder, is mounted on a movable carriage. The output is connected to detector and indicating meter. For detector tuning a tuning plunger is provided instead of a stub.

8. Matched Load:

The microwave components which absorb all power falling on them are matched loads. These consist of wave guide sections of definite length having tapered resistive power absorbing materials. The matched loads are essentially used to test components and circuits for maximum power transfer.

9. Short Circuit Termination:

Wave guide short circuit terminations provide standard reflection at any desired, precisely measurable positions. The basic idea behind it is to provide short circuit by changing reactance of the terminations.

10. VSWR meter:

Direct-reading VSWR meter is a low-noise tuned amplifier voltmeter calibrated in db and VSWR for use with square law detectors. A typical SWR meter has a standard tuned frequency of 100-Hz, which is of course adjustable over a range of about 5 to 10 per cent, for exact matching in the source modulation frequency. Clearly the source of power to be used while using SWR meter must be giving us a 1000-Hz square wave modulated output. The band width facilitates single frequency measurements by reducing noise while the widest setting accommodates a sweep rate fast enough for oscilloscope presentation.

11. Crystal Detector:

The simplest and the most sensitive detecting element is a microwave crystal. It is a nonlinear, non reciprocal device which rectifies the received signal and produces a current proportional to the power input. Since the current flowing through the crystal is proportional to the square of voltage, the crystal is rejoined to as a square law detector. The square law detection property of a crystal is valid at a low power levels (<10 mw). However, at high and medium power level (>10 mw), the crystal gradually becomes a linear detector.

FREQUENCY MEASUREMENT.

Counters and pre-scalers for direct frequency measurement in terms of a quartz crystal reference oscillator are often used at lower frequencies, but they give up currently at frequencies above about 10GHz. An alternative is to measure the wavelength of microwaves and calculate the frequency from the relationship (frequency) times (wavelength) = wave velocity. Of course, the direct frequency counter will give a far more accurate indication of frequency. For many purposes the 1% accuracy of a wavelength measurement suffices. A resonant cavity made from waveguide with a sliding short can be used to measure frequency to a precision and potential accuracy of 1/Q of the cavity, where Q is the quality factor often in the range 1000-10,000 for practical cavities.

"Precision" and "accuracy".

Precision is governed by the fineness of graduations on a scale, or the "tolerance" with which a reading can be made. For example, on an ordinary plastic ruler the graduations may be 1/2mm at their finest, and this represents the limiting precision. Accuracy is governed by whether the graduations on the scale have been correctly drawn with respect to the original standard. For example, our plastic ruler may have been put into boiling water and stretched by 1 part in 20. The measurements on this ruler may be precise to 1/2mm, but in a 10 cm measurement they will be inaccurate by 10/20 cm or 5mm, ten times as much. In a cavity wavemeter, the precision is set by the cavity Q factor which sets the width of the resonance. The accuracy depends on the calibration, or even how the scale has been forced by previous users winding down the micrometer against the end stop...

WAVELENGTH MEASUREMENT.

Wavelength is measured by means of signal strength sampling probes which are moved in the direction of wave propagation by means of a sliding carriage and vernier distance scale. The signal strength varies because of interference between forward and backward propagating waves; this gives rise to a standing wave pattern with minima spaced 1/2 wavelength. At a frequency of 10 GHz the wavelength in free space is 3 cm. Half a wavelength is 15mm and a vernier scale may measure this to a precision of 1/20mm. The expected precision of measurement is therefore 1 part in 300 or about 0.33% The location of a maximum is less precise than the location of a minimum; the indicating signal strength meter can be set to have a gain such that the null is very sharply determined. In practice one would average the position of two points of equal signal strength either side of the null; and one would also average the readings taken with the carriage moving in positive and negative directions to eliminate backlash errors. Multiple readings with error averaging can reduce the random errors by a further factor of 3 for a run of 10 measurements.

Measurements of impedance and reflection coefficient.

A visit to your favourite microwave book shows that a measurement of the standing wave ratio alone is sufficient to determine the magnitude, or modulus, of the complex reflection coefficient. In turn this gives the return loss from a load directly. The standing wave ratio may be measured directly using a travelling signal strength probe in a slotted line. The slot in waveguide is cut so that it does not cut any of the current flow in the inside surface of the guide wall. It therefore does not disturb the field pattern and does not radiate and contribute to the loss. In the X band waveguide slotted lines in our lab, there is a ferrite fringing collar which additionally confines the energy to the guide. To determine the phase of the reflection coefficient we need to find out the position of a standing wave minimum with respect to a "reference plane". The procedure is as follows:- First, measure the guide wavelength, and record it with its associated accuracy estimate. Second, find the position of a standing wave minimum for the load being measured, in terms of the arbitrary scale graduations of the vernier scale. Third, replace the load with a short to establish a reference plane at the load position, and measure the closest minimum (which will be a deep null) in terms of the arbitrary scale graduations of the vernier scale. Express the distance between the measurement for the load and the short as a fraction of a guide wavelength, and note if the short measurement has moved "towards the generator" or "towards the load". The distance will always be less than 1/4 guide wavelength towards the nearest minimum.

Fourth, locate the r > 1 line on the SMITH chart and set your dividers so that they are on the centre of the chart at one end, and on the measured VSWR at the other along the r > 1 line. (That is, if VSWR = 1.7, find the value r = 1.7). Fifth, locate the short circuit point on the SMITH chart at which r = 0, and x = 0, and count round towards the generator or load the fraction of a guide wavelength determined by the position of the minimum. Well done. If you plot the point out from the centre of the SMITH chart a distance "VSWR" and round as indicated you will be able to read off the normalised load impedance in terms of the line or guide characteristic impedance. The fraction of distance out from centre to rim of the SMITH chart represents the modulus of the reflection coefficient [mod(gamma)] and the angle round from the r>1 line in degrees represents the phase angle of the reflection coefficient [arg(gamma)].

IMPEDANCE MEASUREMENT:

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

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

where reflection coefficient ‘R given as

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

Zo = characteristics impedance of wave guide at operating frequency.
Z is the load impedance
The measurement is performed in the following way.

The unknown device is connected to the slotted line and the position of one minima is determined. The unknown device is replaced by movable short to the slotted line. Two successive minima portions are noted. The twice of the difference between minima position will be guide wave length. One of the minima is used as reference for impedance measurement. Find the difference of reference minima and minima position obtained from unknown load. Let it be ‘d’. Take a smith chart, taking ‘1’ as centre, draw a circle of radius equal to S. Mark a point on circumference of smith chart towards load side at a distance equal to d/λg. Join the center with this point. Find the point where it cut the drawn circle. The co-ordinates of this point will show the normalized impedance of load.

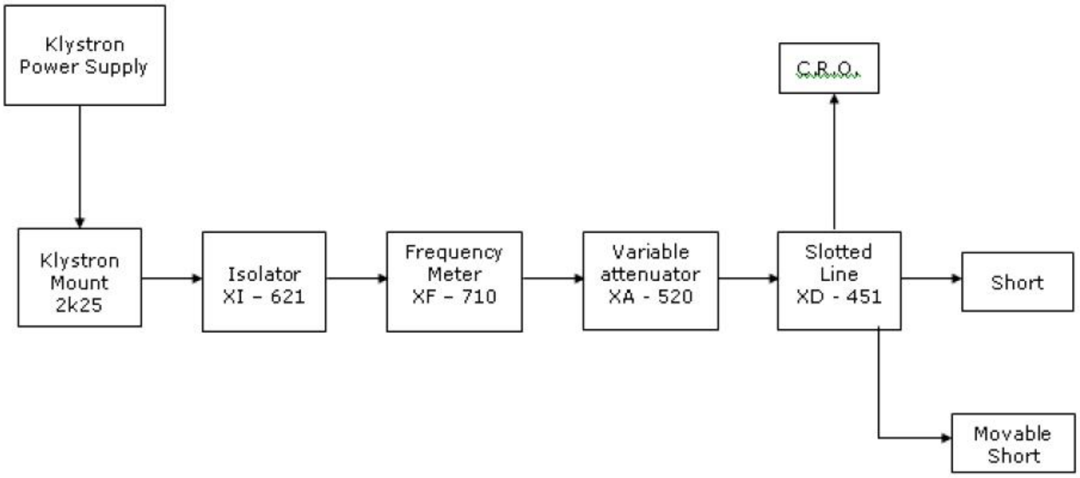


Figure : setup for impedance measurement

Steps:

1. Calculate a set of Vmin values for short or movable short as load.
2. Calculate a set of Vmin values for S-S Tuner + Matched termination as a load.

Note: Move more steps on S-S Tuner

3. From the above 2 steps calculate d = d1~d2
4. With the same setup as in step 2 but with few numbers of turns (2 or 3). Calculate low VSWR.

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

5. Draw a VSWR circle on a smith chart.

6. Draw a line from center of circle to impedance value (d/λg) from which calculate admittance and

Reactance (Z = R+jx)nce

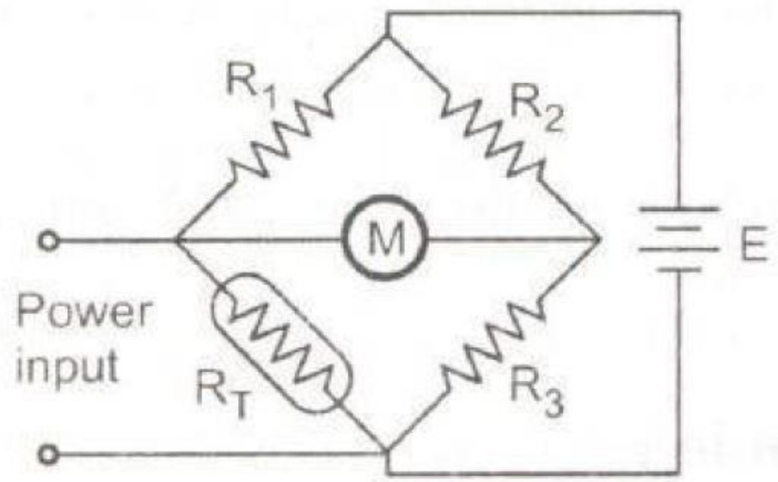
MEASUREMENT OF POWER:

To measure power at high frequencies from 500 MHz to 40 GHz two special type of absorption meters are popularly used. These meters are,

1. Calorimeter power meter
2. Bolometer power meter

Both these meters use the sensing of heating effects caused by the power signal to be measured.

Introduction to Bolometer power meter:



Bolometer Power meter.

The Bolometer power meter basically consists of a bridge called Bolometer Bridge. One of the arms of this bridge consists of a temperature sensitive resistor. The basic bridge used in Bolometer power meter is shown in the Fig 8.14. The high frequency power input is applied to the temperature sensitive resistor RT. The power is absorbed by the resistor and gets heated due to the high frequency power input signal. This heat generated causes change in the resistance RT. This change in resistance is measured with the help of bridge circuit which is proportional to the power to be measured.

The most common type of temperature sensitive resistors are the thermistor and barretter. The thermistor is a resistor that has large but negative temperature coefficient. It is made up of a semiconductor material. Thus its resistance decreases as the temperature increases. The barretter consists of short length of fine wire or thin film having positive temperature coefficient. Thus its resistance increases as the temperature increases. The barretters are very deli<::ate while thermistors are rugged. The bolometer power meters are llsed to measure radio frequency power in the range 0.1 to 10 mW.

In modern bolometer power meter set up uses the differential amplifier und bridge [orl11 an oscillator which oscillates at a particular amplitude when bridge is unbalanced. Initially when temperature sensitive resistor is cold, bridge is almost balance. With d.c. bias, exact balance is achieved. When power input at high frequency is applied to RT, it absorbs power and gets heated.

Due to this its resistance changes causing bridge unbalance. This unbalance is in the direction opposite to that of initial cold resistance. Due to this, output from the oscillator decreases to achieve bridge balance.

MEASUREMENT OF VSWR

High VSWR by Double Minimum Method:

The voltage standing wave ratio of

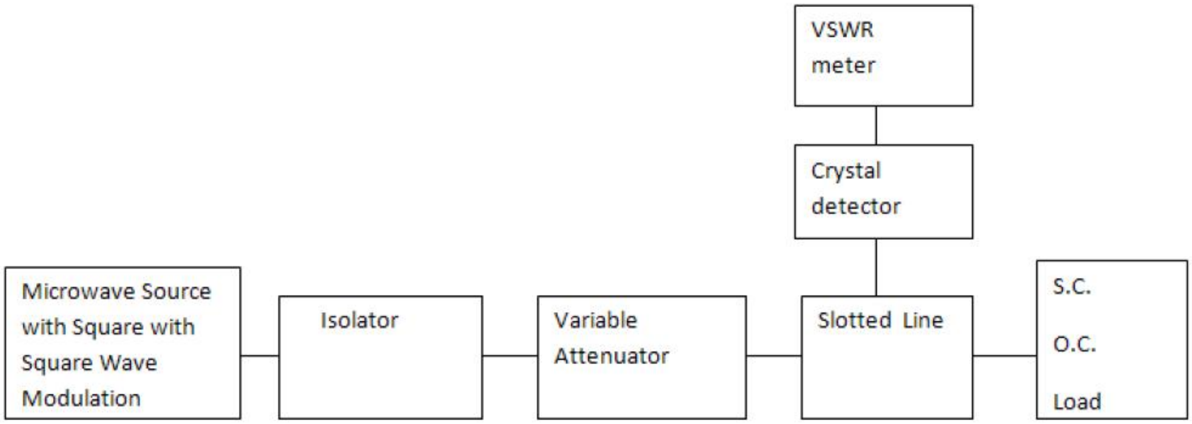
$$VSWR = \frac{V_{max}}{V_{min}}$$

where Vmax and Vmin are the voltage at the maxima and minima of voltage standing wave distribution. When the VSWR is high (, the standing wave pattern will have a high maxima and low minima. Since the square law characteristic of a crystal detector is limited to low power, an error is introduced if ≥ 5)Vmax is measured directly. This difficulty can be avoided by using the 'double minimum method' in which measurements are take on the standing wave pattern near the voltage minimum. The procedure consists of first finding the value of voltage minima. Next two positions about the position of Vmax are found at which the output voltage is twice the minimum value.

If the detector response is square

$$VSWR = [1 + \frac{1}{sin^2(\frac{\pi d}{\lambda_g})}]^{\frac{1}{2}}$$

where λ g is the guide wavelength and d is the distance between the two points where the voltage is 2 Vmin.



Measurement of high VSWR:

Select "Unmatched Load" to terminate the slotted line by pressing the button.

1. Use slider to fix the value of "Resistance" and "Reactance" of the load.
2. Locate the position of Vmin and take it as a reference.(If VSWR meter is used in actual experiment, set the output so that meter reads 3dB).
3. Move the slider (probe of slotted line) along the slotted line on either side of Vmin so that the reading is 3 db below the reference i.e. 0 db. Record the probe positions and obtain the distance between the two. Determine the VSWR using equation (2).
4. The simulated value for VSWR can be seen by clicking the buttons "Technique used to calculate VSWR 1 & 2".
5. Then match the calculated value with the value displayed in the simulated VSWR