# UNIT V   MICROWAVE ANTENNAS AND MEASUREMENTS

Horn antenna and its types, micro strip and patch antennas. Network Analyzer, Measurement of VSWR, Frequency and Power, Noise, cavity Q, Impedance, Attenuation, Dielectric Constant and antenna gain.

DEFINITION:

A conductor or group of conductors used either for radiating electromagnetic energy into space or for collecting it from space.or Is a structure which may be described as a metallic object, often a wire or a collection of wires through specific design capable of converting high frequency current into em wave and transmit it into free space at light velocity with high power (kW) besides receiving em wave from free space and convert it into high frequency current at much lower power (mW). Also known as transducer because it acts as coupling devices between microwave circuits and free space and vice versa. Electrical energy from the transmitter is converted into electromagnetic energy by the antenna and radiated into space. On the receiving end, electromagnetic energy is converted into electrical energy by the antenna and fed into the receiver.
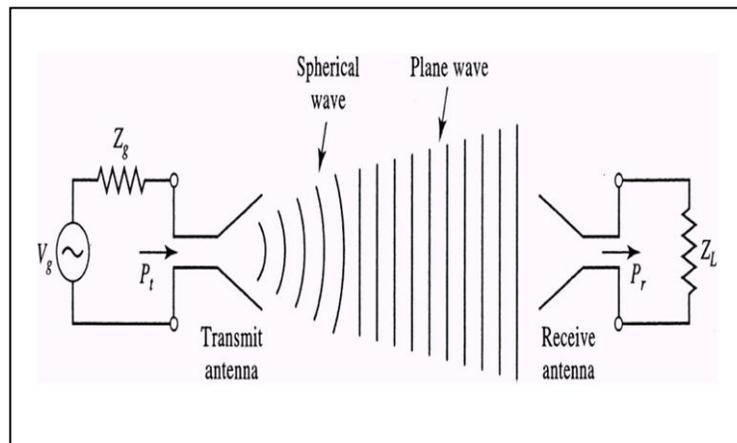
Basic operation of transmit and receive antennas.

- Transmission - radiates electromagnetic energy into space
- Reception - collects electromagnetic energy from space

In two-way communication, the same antenna can be used for transmission and reception. Short wavelength produced by high frequency microwave, allows the usage of highly directive antenna. For long distant signal transmission, the usage of antenna at microwave frequency is more economical. Usage of waveguide is suitable for short distant signal transmission.

TYPES OF MICROWAVE ANTENNAS

- Horn / aperture antenna
- Paraboloid / dish antenna
- Dipole antenna
- Slotted (leaky-wave) antenna
- Dielectric lens antenna
- Printed (patch or microstrip) antenna
- Phase Array antenna

HORN / APERTURE ANTENNA

Like parabolic reflectors, you can use HORN RADIATORS to obtain directive radiation at microwave frequencies. Because they do not use resonant elements, horns have the advantage of being useful over a wide frequency band. The operation of a horn as an rf radiating device is similar to that of an automobile horn radiating sound waves. However, the throat of an automobile horn usually is sized much smaller than the sound wavelengths for which it is used. The throat of the rf radiating horn is sized to be comparable to the wavelength being used. Horn radiators are used with waveguides because they serve both as an impedance-matching device and as a directional radiator. Horn radiators may be fed by coaxial and other types of lines. Horn radiators are constructed in a variety of shapes, as illustrated in figure 3-9. The shape of the horn determines the shape of the field pattern. The ratio of the horn length to the size of its mouth determines the beam angle and directivity. In general, the larger the mouth of the horn, the more directive is the field pattern.

- Horn antenna is used to provide a gradual flare at the end of the waveguide, thus producing maximum radiation into space with minimum reflection back to the source

- Because of impedance mismatch, the horn is tapered in one dimension to a rectangular shape as shown in Figure 4 (a) and (b), thus produce an impedance matching between the waveguide and that of the impedance of free space. Horn tapered / flared in the E or H planes are called sectoral horn. If flared in E and H plane (2 dimensions) it is called a pyramidal horn. A circular waveguide can be matched to free space with conical taper as shown in Figure 4 (d) and is called conical horn antenna.

- Higher gain and directivity – for longer horn dimension.

- Enhance performance when use together with parabolic reflector.

- Its narrow beam angle caused increase in antenna gain.
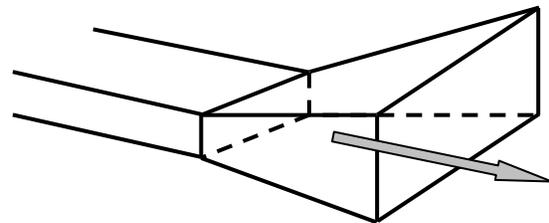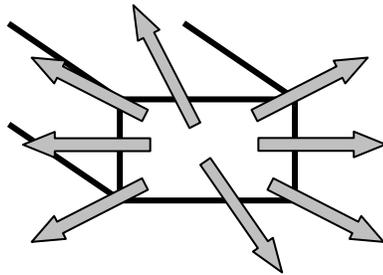
☞ **WAVEGUIDE AS A TRANSMITTER**

➢ RF energy reaching the open end of a waveguide will be partly radiated into space and partly reflected back into the waveguide because the end is not well matched to free space so VSWR will result.

➢ Produce a weak and tidak berarah radiation pattern due to refraction around the open ends.

☞ **BASIC HORN ANTENNA**

➢ Used to overcome the problem facing by an open ended waveguide. (i.e to avoid mismatch).

➢ Directivity improved and diffraction reduced.

☞ Difference types of Horn Antenna Structures :

E – PLANE HORN SECTORAL ANTENNA	**H – PLANE HORN SECTORAL ANTENNA**
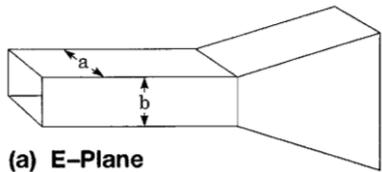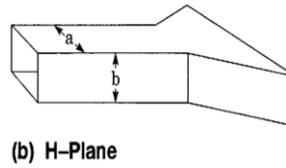
(a) E–Plane

(b) H–Plane

PYRAMIDAL HORN ANTENNA (E & H PLANE)	**CONICAL HORN ANTENNA**

(c) Pyramidal

Circular Waveguide
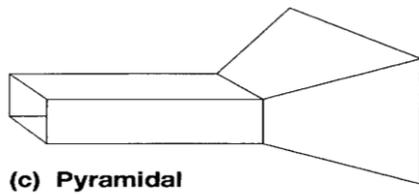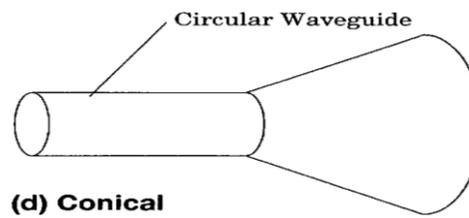
(d) Conical

TYPES OF HORN ANTENNA :-

i) Horn antenna tapered / flared in one dimension only i.e in E-plane or H-plane (known as sectoral horn).

ii) Horn antenna tapered / flared in two dimensions in E-plane and H-plane (known as pyramidal horn).

iii) Conical taper / flares uniformly in all direction i.e in circular form.

E–plane, H–plane Horn sectoral antenna and the pyramidal antenna is used to provide matching between rectangular waveguide and free space. Whereas matching between circular waveguide and free space can be achieved by using conical horn.

THE DIFFERENCES BETWEEN THE E-, H- PLANE & PYRAMIDAL HORN SECTORAL ANTENNA

E- PLANE HORN SECTORAL ANTENNA

Radiation pattern exhibits side lobe
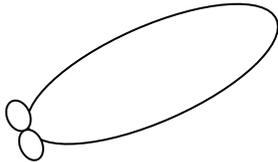
H- PLANE HORN SECTORAL ANTENNA

Radiation pattern exhibits no side lobe, thus more popular.
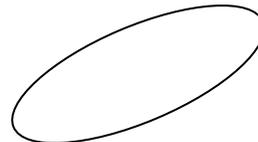
PYRAMIDAL HORN ANTENNA

Radiation pattern flares in 2 direction i.e in E-plane and H-plane. Therefore improves directivity.

Parameters :

Area

$$A = H \times W \quad, m^2$$

A - area (m^2); H – height (m); W – width (m)

➤ Horn length : between 2 – 15 from the wavelength of operational the frequency. Beam angle range for antenna directivity : between 10° - 60° and gain range between :10 - 20 dB.

$$\text{BEAM WIDTH} ; \quad \alpha = \frac{80}{W / \lambda}$$

α = beam width (°) ;

W = horn width (m)

λ = wavelength of the operational

    frequency (m)

$$\text{GAIN} ; \quad G = \frac{4 \pi k A}{\lambda^2}$$

G = gain;

A = area (m^2)

k = uniform phase distribution & e.m field

amplitude across the aperture (0.5 -0.6)

Small Beam width produce wavefront, shallow horn, and flared radiation pattern. Thus such type is not suitable for long distance transmission.

RADIATION PATTERN OF SECTORAL HORN

The used of horn pyramid helps to improve directivity due to dual flaring. Pyramid and conical horn produce pencil beam radiation pattern, hence better directivity as compared to sectoral horn. Horn antenna is a non resonant (wide band) device which operate at a very high frequency range (usually at 10 % of the operational frequency).

    Example; At operating frequency of 10 GHz, the bandwidth is 1 GHz.

Introduction:

In low frequency circuits parameters such as voltage, current, etc can be measured and from these impedance, power factor and phase angle can be calculated. At microwave frequencies it is more convenient to measure power instead of V and I. Properties of devices and circuits at microwave frequencies i.e characterized by S-parameters, power, frequency and VSWR and noise figure.Direct microwave measuring devices are vector network analyzers, spectrum analyzers and power meters. Due to their complications and high cost, microwave measurements in lab are often carried out using 1 kHz square wave modulating signal which modulates the microwave test signal. Measurements of microwave power, frequency, VSWR and losses in the network have certain procedures. The procedures must be followed in order to obtain accurate results.

Important measurement devices

- The tunable detectors are used to demodulate the signal and couple the required output to high frequency scope analyzer. The low frequency demodulated output is detected using non reciprocal detector diode mounted in the microwave transmission line.

- Slotted section with line carriage is a microwave sectioned coaxial line connecting a coaxial E-field probe which penetrates inside a rectangular waveguide slotted section. The longitudinal slot is cut along the center of the waveguide broad walls. The probe is made to move along the slotted wall which samples the electric field proportional to probe voltage.

- Main purpose of slotted section with line carriage is

1. For determination of location of voltage standing wave maxima and minima along the line.
2. Measure the VSWR and standing wave pattern.
3. Wavelength.
4. Impedance.
5. Reflection co-efficient.
6. Return loss measurement.

- VSWR meter is a highly sensitive, high gain, low noise voltage amplifier tuned normally at fixed frequency of 1KHZ of which microwave signals modulated. This meter indicates calibrated VSWR reading for any loads.

Power Measurement

- Power is defined as the quantity of energy dissipated or stored per unit time.

- Microwave power is divided into three categories – low power (less than 10mW), medium power (from 10mW to 10W) and high power (greater than 10w).

- The general measurement technique for average power is to attach a properly calibrated sensor to the transmission line port at which the unknown power is to be measured.

- The output from the sensor is connected to an appropriate power meter. The RF power to the sensor is turned off and the power meter zeroed. This operation is often referred to as "zero setting" or "zeroing." Power is then turned on.

- The sensor, reacting to the new input level, sends a signal to the power meter and the new meter reading is observed.

- There are three popular devices for sensing and measuring average power at RF and microwave frequencies. Each of the methods uses a different kind of device to convert the RF power to a measurable DC or low frequency signal. The devices are the diode detector, the bolometer and the thermocouple.

- Diode Detector

    The low-barrier Schottky (LBS) diode technology which made it possible to construct diodes with metal-semiconductor junctions for microwave frequencies that was very rugged and consistent from diode to diode. These diodes, introduced as power sensors in 1974, were able to detect and measure power as low as −70 dBm (100 pW) at frequencies up to 18 GHz.

- Bolometer Sensor:

    Bolometers are power sensors that operate by changing resistance due to a change in temperature. The change in temperature results from converting RF or microwave energy into heat within the bolometric element.

There are two principle types of bolometers, barretters and thermistors. A barretter is a thin wire that has a positive temperature coefficient of resistance. Thermistors are semiconductors with a negative temperature coefficient. Thermistor elements are mounted in either coaxial or waveguide structures so they are compatible with common transmission line systems used at microwave and RF frequencies.Power meters are constructed from balanced bridge circuits. The principal parts of the power meter are two self-balancing bridges, the meter-logic section, and the auto-zero circuit. The RF Bridge, which contains the detecting thermistor, is kept in balance by automatically varying the DC voltage Vrf, which drives that bridge. The compensating bridge, which contains the compensating thermistor, is kept in balance by automatically varying the DC voltage Vc, which drives that bridge. The power meter is initially zero-set (by pushing the zero-set button) with no applied RF power by making Vc equal to Vrfo (Vrfo means Vrf with zero RF power). After zero-setting, if ambient temperature variations change thermistor resistance, both bridge circuits respond by applying the same new voltage to maintain balance.

POWER METER

The meter logic circuitry is designed to meter the voltage product shown in above equation. Ambient temperature changes cause V_c and V_{rf} to change so there is zero change to $V_c^2 - V_{rf}^2$ and therefore no change to the indicated P_{rf}.

If RF power is applied to the detecting thermistor, V_{rf} decreases so that

$$P_{rf} = \frac{V^2}{4R} \quad \frac{V^2}{4R}$$

Where P_{rf} is the RF power applied and R is the value of the thermistor resistance at balance. But from zero-setting, $V_{rfo} = V_c$ so that

$$P_{rf} = \frac{V_c^2 - V_{rf}^2}{4R}$$

Which can be written

$$P_{rf} = \frac{(V_c - V_{rf})(V_c + V_{rf})}{4R}$$

- Thermocouple Sensors

Thermocouple sensors have been the detection technology of choice for sensing RF and microwave power since their introduction in 1974. The two main reasons for this evolution are: 1) they exhibit higher sensitivity than previous thermistor technology, and 2) they feature inherent square-law detection characteristic (input RF power is proportional to DC voltage out). Since thermocouples are heat-based sensors, they are true "averaging detectors."Thermocouples are based on the fact that dissimilar metals generate a voltage due to temperature differences at a hot and a cold junction of the two metals. The power sensor contains two identical thermocouples on one chip, electrically connected as in Figure.
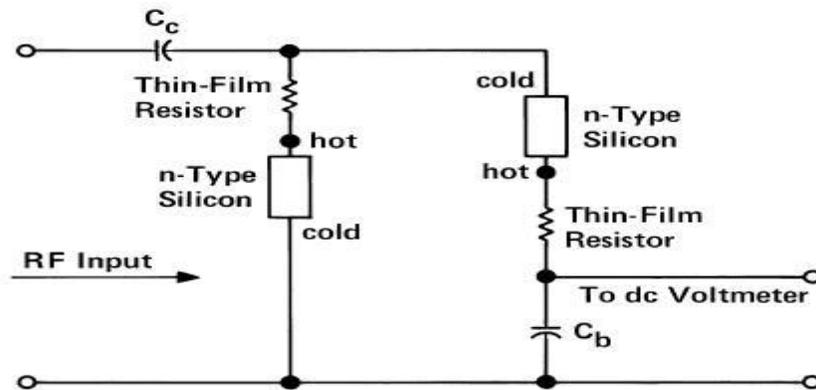
Thermocouple power sensor
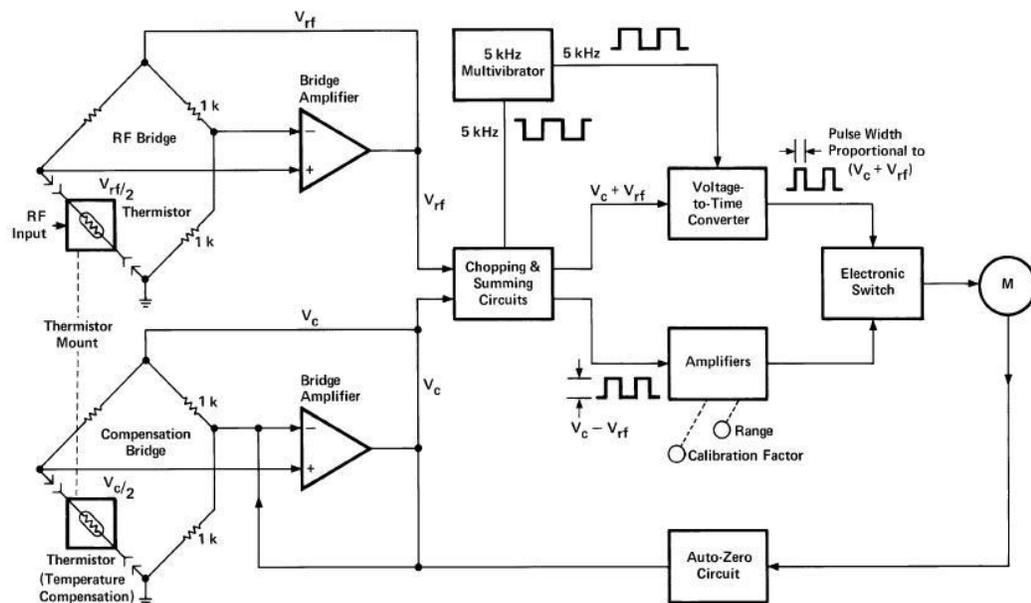
The thermocouples are connected in series as far as the DC voltmeter is concerned. For the RF input frequencies, the two thermocouples are in parallel, being driven through coupling capacitor Cc. Half the RF current flows through each thermocouple. Each thin-film resistor and the silicon in series with it have a total resistance of 100 Ω. The two thermocouples in parallel form a 50 Ω termination to the RF transmission line. The lower node of the left thermocouple is directly connected to ground and the lower node of the right thermocouple is at RF ground through bypass capacitor Cb. The DC voltages generated by the separate thermocouples add in series to form a higher DC output voltage. The principal advantage, however, of the two thermocouple scheme is that both leads to the voltmeter are at RF ground; there is no need for an RF choke in the upper lead. If a choke were needed it would limit the frequency range of the sensor. For a square wave modulated signal the peak power can be calculated from the average power measured as $P_{peak} = \dfrac{P_{av}Y}{\tau}$ where T is the time period and τ is the pulse width.

Frequency Measurement

- Microwave frequency can be measured by a number of different mechanical and electronic techniques. The Mechanical techniques are,

  Slotted Line Method (Indirect Method)
  The standing waves setup in a transmission line or a waveguide that produce minima for every half wavelength apart.
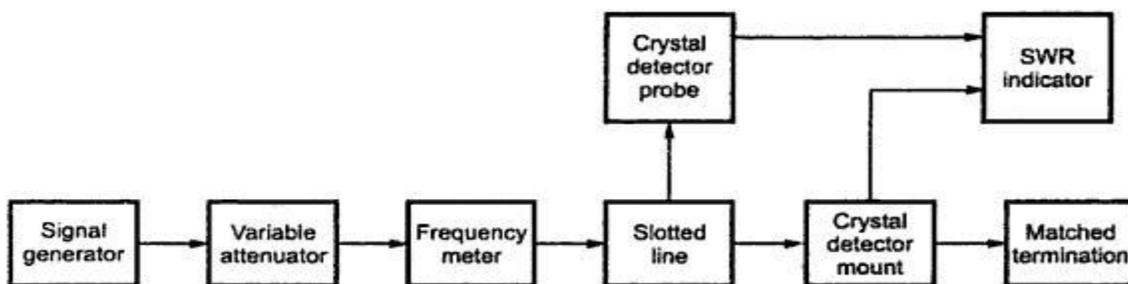
Set-up for the measurement of frequency

These minima are detected and the distance between them is measured. From which

the wavelength and frequency can be calculated by

$$\lambda_g = 2d_{min}$$

$$f = \frac{C}{\lambda_0}$$

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

where λ_0 – free space wavelength

λ_c - cut off wavelength

λ_g – guide wavelength

d_{min} can be measured by the slotted line probe carriage.

Resonant Cavity Method (Direct Method)

The most commonly used type of microwave frequency meter is wave meters. It consists of a cylindrical or coaxial resonant cavity. The size of the cavity can be altered by adjustable plunger. The cavity is designed in such a way that for a given position of the plunger, the cavity is resonant only at one frequency in the specified range.
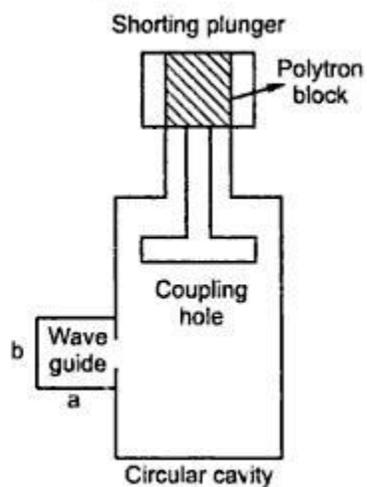
WAVEMETER

The cavity is coupled to the waveguide through an iris in the narrow wall of the waveguide. If the frequency of the wave passing through the waveguide is different from the resonance frequency of the cavity, the transmission is not affected. If these two frequencies coincide then the wave passing through the waveguide is attenuated due to power loss. It will be indicated as a dip in the meter.

- Electronic Technique
  Counter Method

  An accurate measurement of microwave frequency can be measured here. The input signal is divided into two equal signals by a resistive power divider. These two parts of the signal are fed to 2 mixers. The mixer 1 is used in the input PLL (Phase Locked Loop) and the mixer 2 is used to determine the harmonic number. The frequency f1 of the input PLL is also fed to the direct counter circuits.

  The input PLL consists of a voltage controlled oscillator (VCO), mixer, an IF amplifier, a phase detector and a gain control block. The VCO searches over its range until an IF signal equal to 20MHz is found. Phase lock occurs when the phase detector output sets the VCO frequency f1 such that

  $$f_x \ \square \ nf_1 \ \square \ IF_1$$

  where IF1 = 20 MHz at the phase lock and f_x is the unknown frequency to be measured.

IF$_1$

Mixer 1 → IF Amplifier → Phase detector ← IF$_{ref}$

fx

f$_1$

PLL

20 MHz

input → Power divider

Vco

f$_1$

f$_1$

Gain control system

FTU

to direct count ckt

f$_2$

fx

Mixer 2 → IF Amplifier → Mixer → nf$_0$

IF$_2$
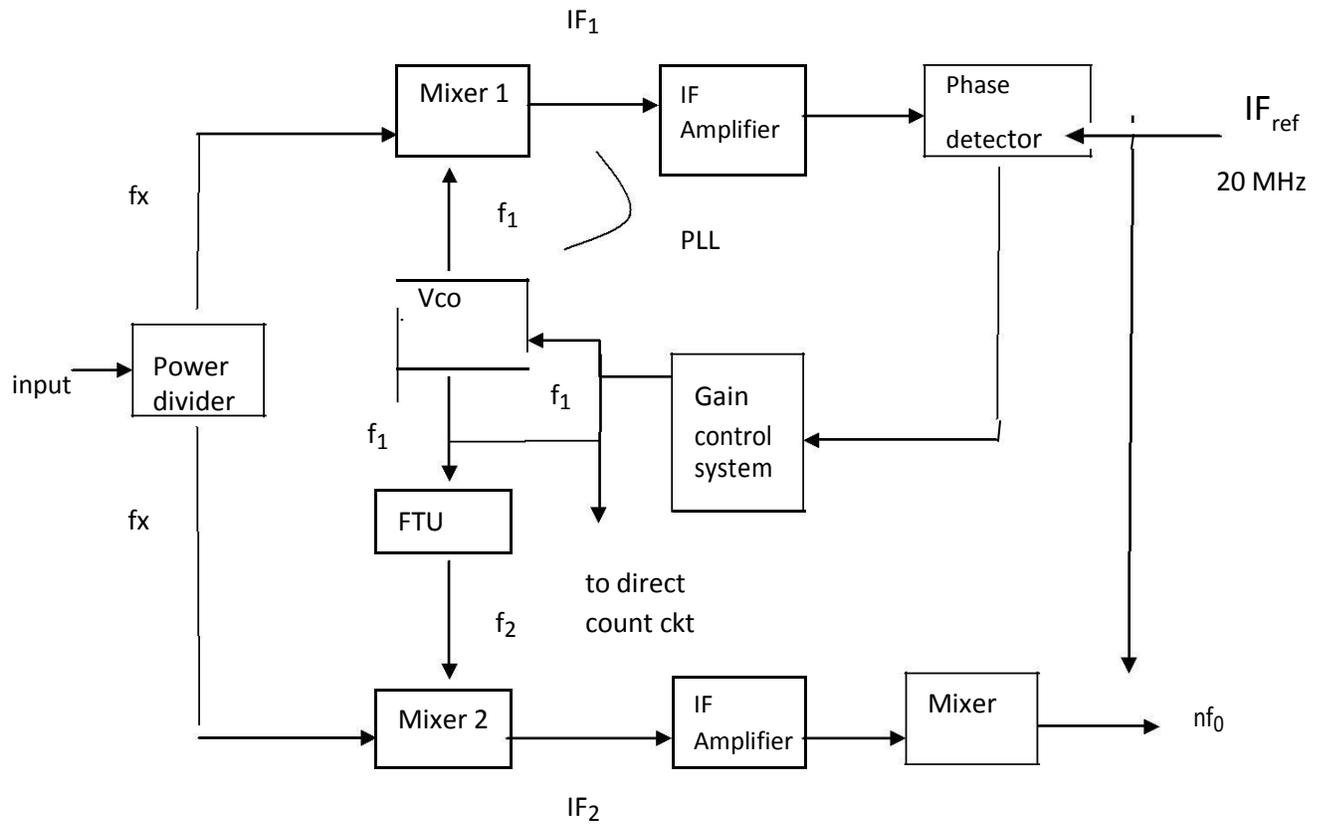
The f_1 is translated to a frequency f_2 so that

$$f_2 = f_1 \pm f_0$$

where f_0 = 20 MHz offset frequency. This is done by a frequency translation unit (FTU). The frequency f_2 drives the second sampler and produces a second output. IF_2 is given as

$$
\begin{aligned}
IF_2 &= nf_2 - f_x \\
&= n(f_1 \pm f_0) - (nf_1 - 20MHz) \\
&= \pm nf_0 + 20
\end{aligned}
$$

By mixing IF_2 with IF_1 and rejecting 20 MHz and higher frequencies, nf_0 is obtained. Counting the number of zero crossing for the period of f_0, determines the harmonic number n of the phase lock loop. The input frequency is then calculated by presetting into IF_{ref} counter, measuring f_1 and extending gate time according to number n.

VSWR Measurements:

In a microwave network, if load impedance and line impedance are not matched, signal fed from the source is reflected again towards source causing standing wave pattern in the network. Voltage Standing Wave Ratio is a measure used for finding the magnitude of ration of reflected signals maximum and minimum amplitudes.

$$S = \frac{V_{max}}{V_{min}} \qquad\qquad \text{_____ (1)}$$

For analyzing standing wave pattern and to find S slotted line carriage is used in laboratory.

Low VSWR Measurements: (S<20)
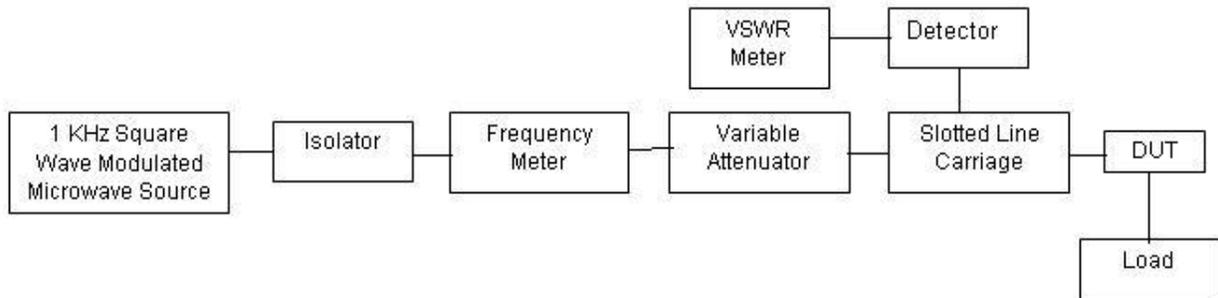
Procedure:

1. Microwave Source is energized with 1 KHz square wave signal as carrier.

2. Tunable passive components are so adjusted to get reading across the VSWR meter in 30 dB scale.

3. Detector (Tunable probe detector) is adjusted to get maximum power across the VSWR meter.

4. Slotted line carriage is moved from the load towards source to find the standing wave minimum position.

5. By adjusting the gain control knob of VSWR meter and attenuator the reading across the VSWR meter is made as 1 or 0 dB known as normalization.

6. Again the slotted carriage is moved towards source to find the next minimum position. The reading shown at this point in the VSWR meter is the ratio of magnitude of reflected signals minimum and maximum voltages ($S = \dfrac{V_{max}}{V_{min}}$).

7. VSWR meter has three different scales with different ranges as specified below.

    a) NORMAL SWR Scale 1   ---- $\rightarrow$ $1-4$

    b) NORMAL SWR Scale 2   ---- $\rightarrow$ $3.2-10$

    c) EXPANDED SWR Scale 3   ---- $\rightarrow$ $1-1.33$

8. If the device under test (DUT) is having the range of VSWR $1 - 4$, reading is

   taken from the first scale from the top (NORMAL SWR Scale $1 - 1 - 4$).

9. If the device under test (DUT) is having the range of VSWR $3.2 - 10$, reading is taken from the second scale from the top (NORMAL SWR Scale 2 ($3.2 - 10$).

10. If the device under test (DUT) is having the range of VSWR $1 - 1.33$, reading is taken from the third scale from the top (EXPANDED SWR Scale 3 ($1 - 1.33$).

11. If the device under test (DUT) is having the range of VSWR $10 - 40$, a 20 dB range is selected in the VSWR meter and reading is taken from the first scale from the top (NORMAL SWR Scale $1 - 1 - 4$) which is then multiplied by 10 for getting the actual reading.

    Possible Errors in Measurements:

    1. Detector may not work square law region for both $V_{max.}$ and $V_{min.}$

    2. Depth of the probe in the slotted line carriage is made as minimum. If not, it may cause reflections in addition to the load reflections.

    3. For the device having low VSWR, connector used for measurement must have proper matching with line impedance.

    4. If the geometrical shape of the slotted line is not proper, $V_{max.}$ (or) $V_{min.}$ Value will not constant across the slotted line.

    5. If the microwave signal is not properly modulated by a 1 KHz square wave, then signal becomes frequency modulated thereby it causes error in the $V_{min.}$ value measured. The value becomes lower than the actual.

    6. Residual VSWR of slotted line carriage may cause error in the measurements.

   High VSWR Measurements - Double Minima Method - (S>20)

    Measurement of high VSWR needs separate procedure because the detector may not be tuned to work in square law region. An alternate method known as double minimum method is used for finding high VSWR with the same experimental set up as shown above.

<u>Procedure:</u>

1. Microwave Source is energized with 1 KHz square wave signal as carrier.

2. Tunable passive components are so adjusted to get reading across the VSWR meter in 30 dB scale.

3. Detector (Tunable probe detector) is adjusted to get maximum power across the VSWR meter.

4. Slotted line carriage is moved from the load towards source to find the standing wave minimum position. Let it be d_1.

5. Slotted line carriage is moved further to find the next immediate minimum position. Let it be d_2. Now $\lambda_g = 2 (d_1 - d_2)$

6. By adjusting the gain control knob of VSWR meter and attenuator the reading across the VSWR meter is made as 3 dB at this minimum position.

7. By taking this point as reference, slotted line carriage is moved on either side. The points at which the VSWR meter shows 0 dB reading on both sides are noted as x_1 and x_2.

8. High VSWR can be calculated by using the formula $S = \dfrac{\lambda_g}{\pi(x_1 - x_2)}$

<u>VSWR Measurements by Return Loss (Reflectometer) Method:</u>

To overcome the difficulties faced in slotted line carriage for measuring VSWR, reflectometer can be used. Reflectometer is a device having two directional couplers combined together with ideal coupling factor and directivity. It is a four-port device.
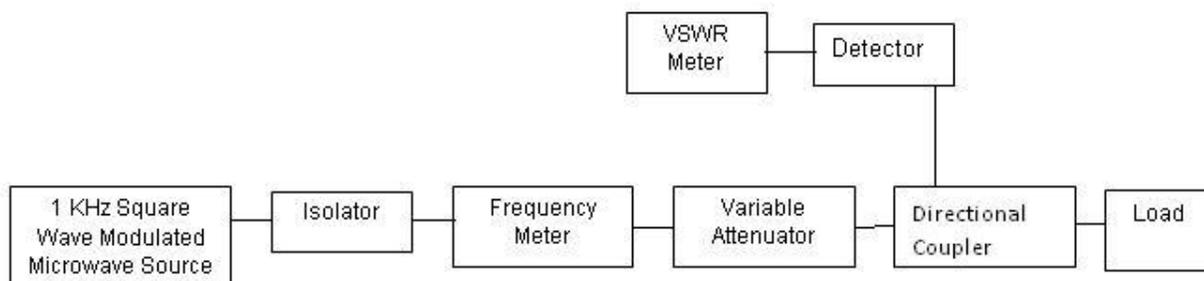
Experimental Procedure:

1. Microwave Source is energized with 1 KHz square wave signal as carrier.

2. Tunable passive components are so adjusted to get reading across the VSWR meter in 30 dB scale.

3. Detector (Tunable probe detector) is adjusted to get maximum power across the VSWR meter.

4. Port 2 is with a movable short and is adjusted for getting the output across the detector to unity in VSWR meter. Port 3 is matched terminated.

5. VSWR meter and matched load at port4 and port 3 are interchanged. The output of the port3 is noted which should be ideally equal to the output from port 4.

6. Without disturbing the VSWR meter adjustment, the unknown load is connected at port 2 by replacing the short and the output at port3 is noted to obtain $\dfrac{1}{\overline{\Gamma_L}}$,

directly from the VSWR meter.

$$\text{Return loss} = -20 \log |\Gamma_L|$$

$$\text{VSWR} = \frac{1 + |\Gamma_L|}{1 - |\Gamma_L|}$$

This method is well suited for loads having low VSWR. The major sources of errors are

1. Unstability of the signal source causes a change of signal power level during measurement of input and reflected signals.

2. Non-ideal directional couplers and detectors are also sources of error.

Attenuation and Insertion loss

When a device or network is inserted in the transmission line, part of the input signal power is reflected from the input terminal and the remaining part which actually enters the network is attenuated due to the non-zero loss of the network.

Insertion loss = Reflection loss + Attenuation loss

- Insertion loss is defined as difference in power arriving at the terminating load

  .with or without the network in circuit.

  Insertion loss (dB) =10 log (P_0/P_i)

- Attenuation is defined as a power ratio between 2 points along a transmission path. It is measured under matched conditions.
  Commonly 2 methods are used to measure the attenuation.
- Power ratio Method

 Measure of power delivered to the load

  1. First without network as P_1.
  2. Then with network whose attenuation is to be measured as P_2.

 The ratio of second to the first power gives attenuation.

$$\text{Attenuation} = \frac{\text{Power(without N/W)}}{\text{Power(with N/W}}$$

- RF substitution Method

   If the input power is low and the device (network) has a high attenuation, then this method is used. This is a simple method in which the output power from the unknown device or network is measured. This network is then replaced by a calibrated attenuator which is adjusted until output power is the same. Under this condition the attenuation of the two is same and can read off from the attenuator.
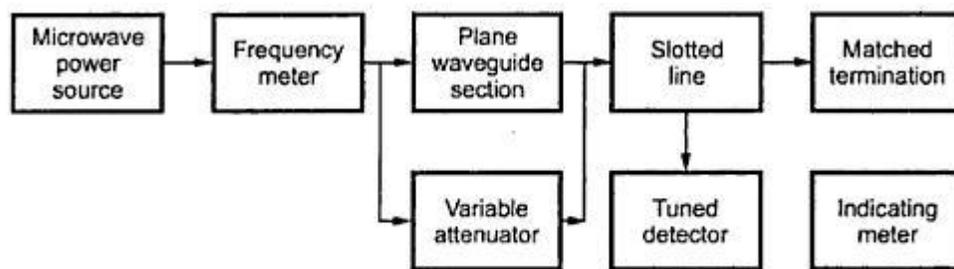
NETWORK ANALYZER

A **network analyzer** is an instrument that measures the network parameters of electrical networks. Today, network analyzers commonly measure s–parameters because reflection and transmission of electrical networks are easy to measure at high frequencies, but there are other network parameter sets such as y-parameters, z-parameters, and h-parameters. Network analyzers are often used to characterize two-port networks such as amplifiers and filters, but they can be used on networks with an arbitrary number of ports.

Network analyzers are used mostly at high frequencies; operating frequencies can range from 5 Hz to 1.05 THz. Special types of network analyzers can also cover lower frequency ranges down to 1 Hz. These network analyzers can be used for example for the stability analysis of open loops or for the measurement of audio and ultrasonic components.

The two basic types of network analyzers are

- **scalar network analyzer** (SNA)—measures amplitude properties only
- **vector network analyzer** (VNA)—measures both amplitude and phase properties

A VNA is a form of RF network analyzer widely used for RF design applications. A VNA may also be called a **gain-phase meter** or an **automatic network analyzer**.

An SNA is functionally identical to a spectrum analyzer in combination with a tracking generator. Another category of network analyzer is the **microwave transition analyzer** (MTA) or **large signal network analyzer** (LSNA), which measure both amplitude and phase of the fundamental and harmonics. The MTA was commercialized before the LSNA, but was lacking some of the user-friendly calibration features now available with the LSNA.

Questions :

1. Explain the various methods of microwave power measurement.
2. Describe how can the power of a microwave generator be measured using (a) Bolometer (b) Calorimeter techniques.
3. Write short notes about Low and High VSWR.
4. Compare the power ratio and RF substitution method of measuring attenuation.
5. Explain about low frequency measurement techniques.