# Antenna Measurements

Since an antenna is a device that couples power to and from the surrounding space, before measuring any antenna parameter, we first need to ensure that the environment does not influence the measurements.

In otherwords, both i/p and radiation measurements must be carried out with the antenna kept in free space or a simulated free-space condition.

Some of the important antenna parameters of interest are radiation patterns (field amplitude, phase, power, and polarization patterns), gain, directivity, radiation efficiency, antenna effective length, polarization, pattern beamwidth, i/p reflection coefficient, i/p freq bandwidth, noise temperature, etc.

The two important measurements are the radiation pattern and the i/p reflection coefficient.

## Antenna Measurement Range

From the reciprocity theorem we know that the transmit and receive pattern are the same for any antenna. For convenience of measurement, it is common practice to measure the receive pattern than the transmit pattern. The receive pattern of an antenna is the plot of the received power as a function of the direction of arrival of the incident plane wave with a constant power density. It is obvious that we require two antennas for pattern measurement, one transmitting and other receiving. We assume that the receive antenna is the Antenna Under test (AUT) and transmit antenna is used for generating a plane wave at the location of the test antenna.

At a distance $\boxed{R > \frac{2D^2}{\lambda}}$, from a transmit antenna, the far-field approximation is valid. D is the largest transverse dimension of the transmit antenna. Since two antennas are involved in the measurement setup, we have to select the larger of the two transverse dimensions as D to ensure that both antennas are in the far-field of each other.

Generally, the transmit antenna is a horn antenna of small size, and hence, the receive antenna transverse dimension of the or test antenna is taken as D and the distance R is always selected greater than $\frac{2D^2}{\lambda}$.

An antenna range can be constructed in open space. Such a range is known as an outdoor range. In an outdoor range, apart from ground reflections there may be reflections from other objects such as buildings, trees, moving vehicles, etc. The measurement in a outdoor range are usually prone to electromagnetic interference from

Other systems, such as local radio/TV broad cast, radar, mobile phones, etc. It is also possible to construct an antenna range in an enclosed building, which is known as an indoor range. To reduce the reflections from the walls, floor, and ceiling of the building, a special material called absorber is used to cover these surfaces. Such a chamber is called Anechoic chamber.

## Anechoic Chamber:-

It is not desirable to have reflecting surfaces in an antenna range. A closed chamber can be made reflection-free ~~or~~ or echo-free by lining all the surfaces of the chamber with absorbing material. Such a chamber is known as an anechoic chamber. The indoor range is basically an anechoic chamber. The main advantage of an indoor range compared to an outdoor range are protection of expensive equipment from environment severities, security, all-weather operation, and absence of electromagnetic interference.

The main component of an anechoic chamber is the absorber. Absorbers are made in the form of pyramids or wedges. [Fig 17.6 (a) & (b)]

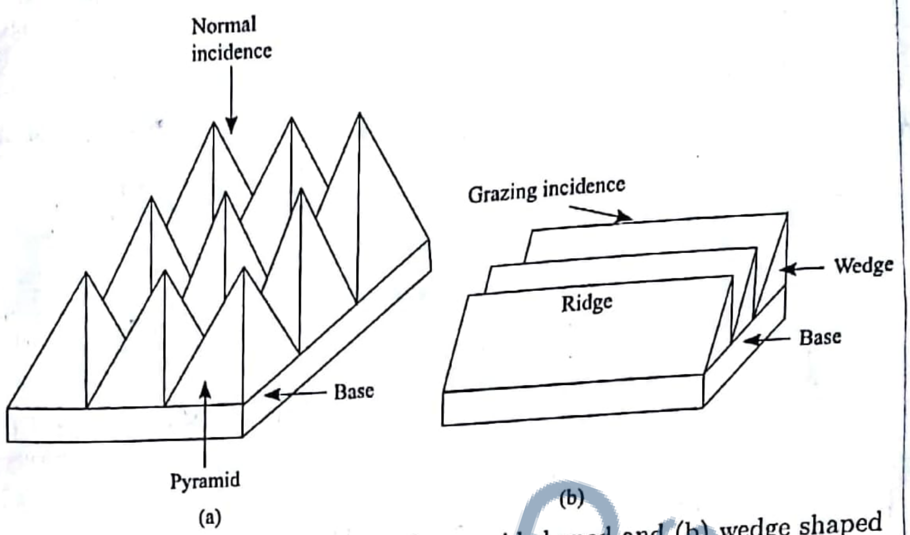


**Fig. 7.6** Two types of absorbers—(a) pyramid shaped and (b) wedge shaped

- The Pyramidal shaped absorbers have very low reflection coefficient over a wide frequency band for normal incidence. e.g, It is possible to achieve a reflection coefficient of -30dB from a one wavelength high pyramidal absorber. The wedge shaped absorbers are best suited for the waves travelling nearly // to the ridges.

A typical construction of an anechoic Chamber is shown in fig 7.7. It is important to realize that depending on the requirements several variants of this arrangement are being used. A grounded metal shield is introduced between the absorber and the brickwork to achieve electromagnetic shielding. The choice of absorber depends on the direction of the RF energy falling on it. For example, Pyramidal absorbers are used on the back wall close to the

AUT, because the energy from the transmit antenna is incident on this surface along the normal direction.

In the region between the two antennas, wedge-type absorbers are best suited as the waves in this area have near grazing incidence on the absorber.

Absorbers are not perfect and they do reflect a small amount of energy. Superposition of waves radiated by the transmitter and the waves reflected by the walls of the chamber results in a standing wave pattern.

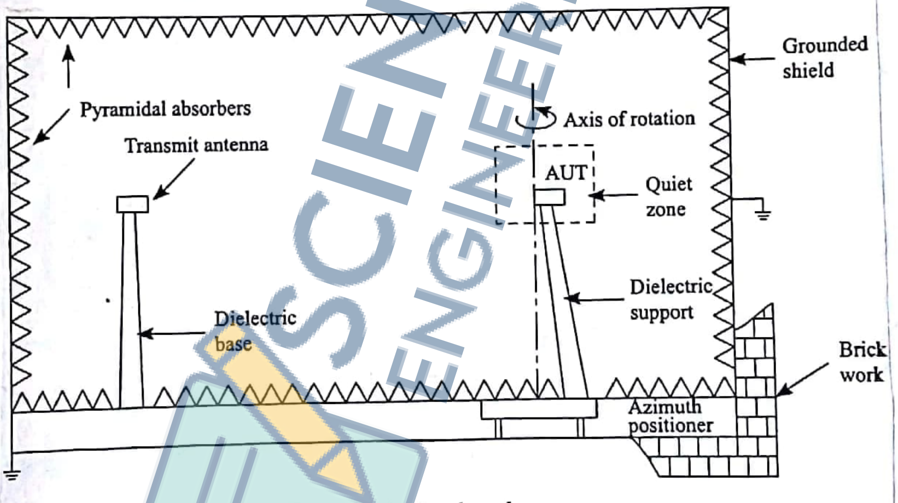


Fig. 7.7 Construction of an anechoic chamber

7.2

→ Close to the absorber surface, an unacceptable level of ripple on the wavefront is observed. However, farther away from the surface, the ripple levels become very small and the electromagnetic waves can be assumed to be plane. In an anechoic chamber, the plane-wave zone condition is created

Over a small volume near the test antenna and this region is known as the quiet zone. The ripple on the wavefront can be minimized by choosing good quality absorbers having low reflection coefficients and by making the size of the chamber large.

## Anechoic Chamber type -

Anechoic chambers are usually rectangular or tapered. Figure 19-10 (a) shows a rectangular Chamber. The end walls and the center parts of the sidewalls, floor and ceiling are covered with pyramids. Other parts are covered with wedges, The antennas are placed on the middle line of the chamber; the source antenna close to one end wall, the AUT a little further away from the other end wall. The test zone where the reflections are minimized is called the quiet zone. The dimensions of the chamber should be such that the angle of incidence on sidewalls is less than 60°. At larger angles the reflections would be large. Typically, the length to width ratio is 2:1. The source antenna should be chosen so that its main beam does not illuminate the sidewalls, ceiling and floor.

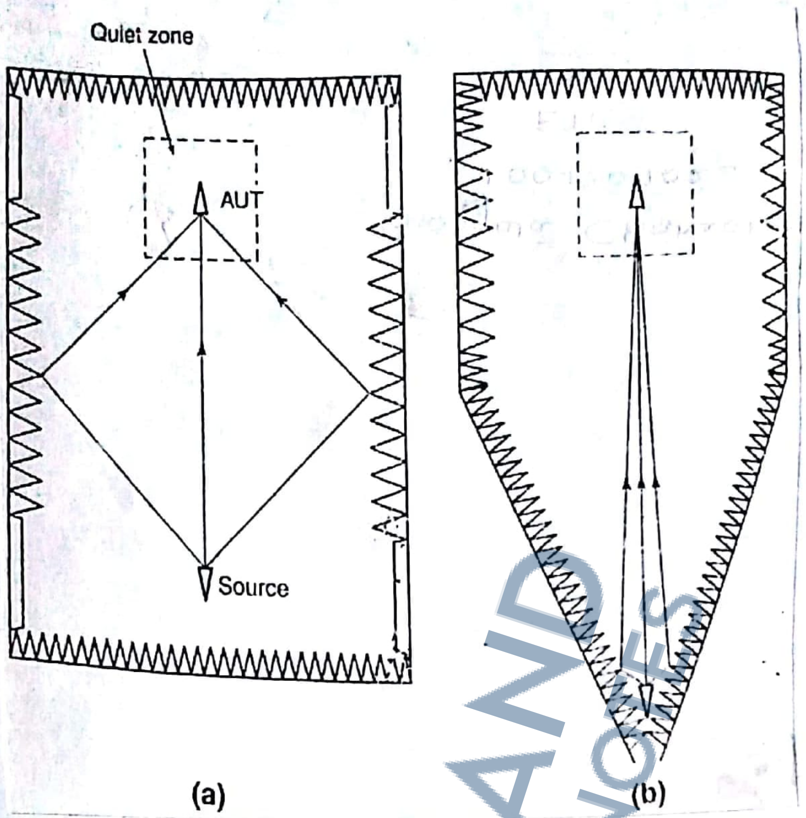


Fig 19-10 Anechoic Chambers: (a) Rectangular, (b) Tapered

At frequencies below about 1 GHz, the rectangular Chambers having absorbers of resonable size has a high level of reflections. Then a tapered Chamber works better. In a tapered Chamber (Fig 19-10, b), the source antenna is close to the apex of the tapered section and the specular reflections occur close to the source. The Phase difference of the direct wave & the specular reflections changes slowly in the quite Zone which results in a more planar wavefront than in case of a rectangular Chamber. At higher frequencies, the source is moved from the apex closer to the rectangular section and the Chamber is used as a normal rectangular Chamber.

# Radiation Pattern Measurement -

The AUT (Antenna Under Test) is always used in the receive mode for pattern measurements. The receive pattern of of an antenna is the power delivered to a matched load as a function of direction of arrival of the incident plane wave of constant power density.

Therefore, to measure the pattern of an antenna we need a second antenne kept at a distance $\left(R > \frac{2D^2}{\lambda}\right)$ transmitting e.m energy, so that it produces a plane wave at the location of the receive antenna.

Now to plot the received power as a function of the angle of incidence of the plane wave, we need to move the transmit antenna over the surface of a sphere of radius R with the test antenne placed at the center of sphere. The transmit antenne orientation must be such that the center of the sphere is always along the same direction w.r.to transmit antenna. This ensures that the power density of the plane wave incident from different directions is the same.

In practice, instead of moving the transmit antenna around a sphere, the receive antenna is rotated about the center of sphere, keeping the position of the transmit antenna unaltered. In this arrangement the direction of arrival of plane wave is kept the same but the receive antenna is rotated so that the plane wave orientation w.r.t receive antenna is changed. This exactly simulates the same condition as moving the transmit antenna around, provided the receive antenna environment doesn't change when rotated.

If an antenna measurement range, either outdoor or indoor, is designed properly to have zero or negligible reflections in all directions, simulating the free space conditions, then the environment of the receive antenna is independent of the rotation about its axis.

Thus, the antenna measurement range must have one fixed position for the transmit antenna and a rotatable mount for the receive antenna (which is the test antenna). In some of the antenna pattern measurements, especially the polarization-dependent parameters, sometimes it becomes necessary to rotate the transmit antenna also. However, in most cases two discrete rotational positions, such as 0° & 90° are sufficient. Hence the transmit antenna mount is generally provided with multiple discrete mounting positions but rarely with continuous rotation capability.

The rotation capability is provided only on the receive antenna mount, which is known as antenna positioner. With this arrangement and appropriate transmit and receive equipment, the pattern of an antenna can be measured. The field pattern, phase pattern, polarization pattern, etc. are measured using the same arrangement but with different sensors to measure the corresponding parameters instead of the received power.

Antenna Positioner:-

An antenna pattern is most often represented by the principal plane cuts of 3D pattern. Consider the coordinate system shown in fig 7.10 and let the test antenna be mounted at the origin. We take the direction of the transmit antenna as

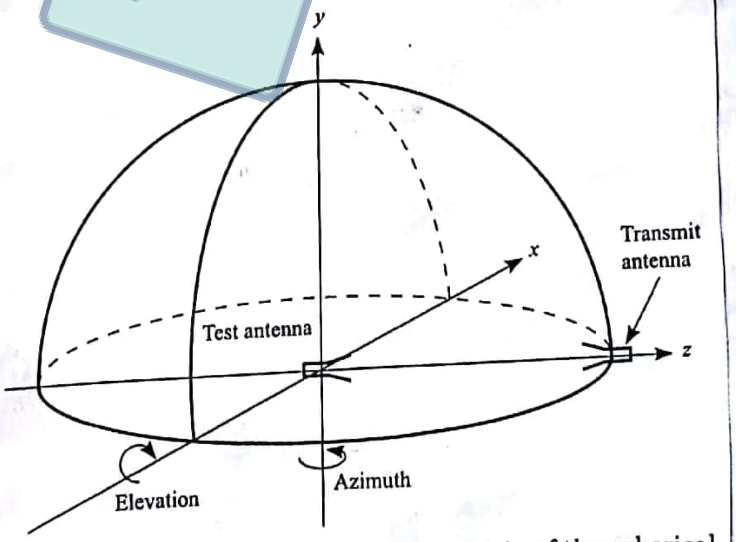


Fig. 7.10 Test antenna located at the origin of the spherical coordinate system

Z-axis for convenience and y-axis as the vertical axis. Assume that the receive antenna, the pattern of which we are interested in measuring, is mounted with its main beam pointing along the Z-axis. Further, assume that the transmit antenna is linearly polarized and is mounted with the E-field along the y-axis ( or vertically polarized) ↑↑↑↑↑.

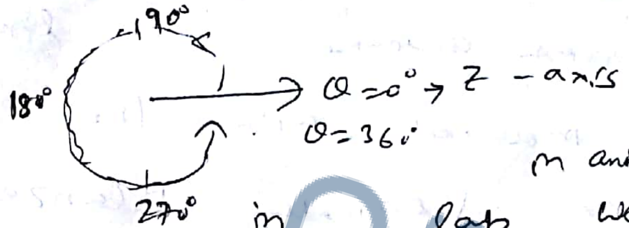
Now, if we have the flexibility to continuously rotate the receive antenna about x, y and Z axes, we can measure the 3D pattern of the antenna or a pattern cut in any desired plane by simply rotating the antenna and recording received power as the $f^n$ of angular position.

The rotation about the y-axis (or vertical axis) is generally known as azimuthal rotation and rotation about Z-axis (or horizontal axis) is known as the elevation rotation.

In fig 7.12, the antenna is mounted in XY plane with main beam pointing towards the transmit antenna or the Z-axis. If we record the received power as the antenna rotated in azimuth, the received power vs the rotation angle produce $\phi=0°$ cut of pattern.

[Note – Try to recall dipole antenna; XZ-plane gives E-plane pattern at φ=0°)

Here also, at φ=0° i.e XZ-plane, φ=0° const, at θ is changing, θ starts with 0° from Z-axis



, we do the same thing, in our lab in antenna experiment, we rotate the antenna in XZ plane, starting from θ=0°]

Generally, rotation about two axes, the azimuthal and elevation rotation, are sufficient for obtaining the principal pattern cuts. Antenna positioners come in single axis, two-axis and in most sophisticated ranges, 3-axis mounts. Two of the most commonly used two-axis mounts are shown in fig 19.19. These are the azimuth-over-elevation and elevation-over-azimuth mounts.

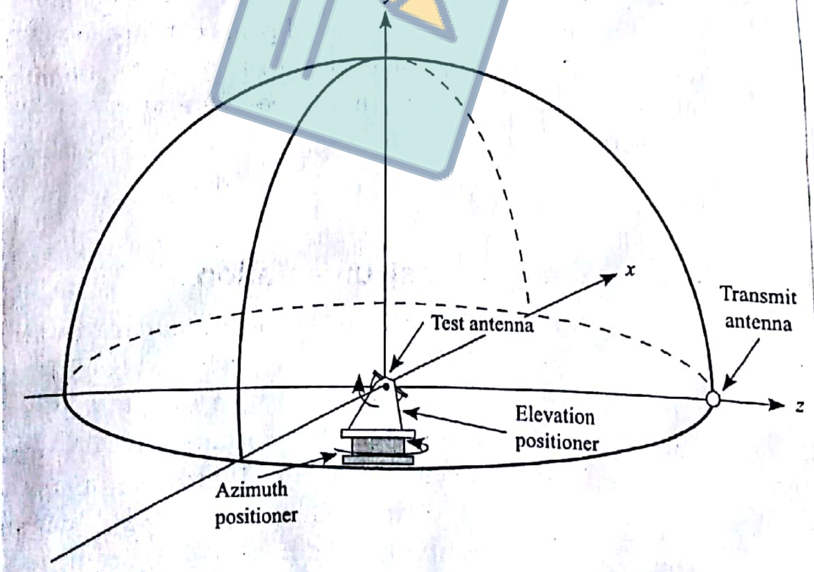


**Fig. 7.12** Pattern measurement system using elevation-over-azimuth positioner

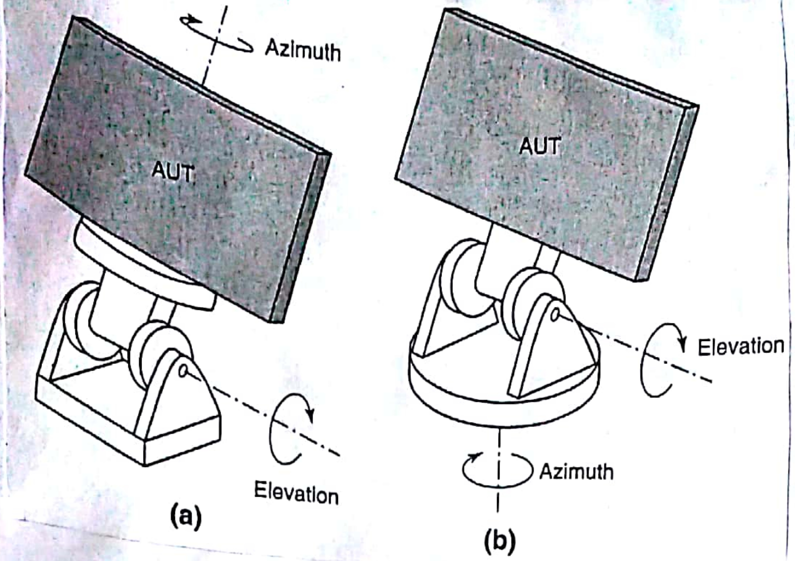


Fig: 19.19 - Positioners for rotating the AUT (a) azimuth - over elevation (b) Elevation over azimuth

One of the arrangements shown in fig 7-12 uses elevation - over - azimuth positioner. The transmit antenne is mounted vertically above and along z - axis. This arrangement can be used to plot different φ. cuts ~~plan~~ of the pattern. [e.g φ = 0°, φ = 90°, etc ]

## Receiver Instrumentation :-

A schematic block diagram of a modern antenne positioner control system and measurement system is shown in fig 7-14. The entire pattern measurement system is controlled by a computer. Present day automatic pattern measurement systems are software driven and generates the pattern plot once the antenne is mounted properly.

For the measurement of any pattern cut, the digital computer rotates the antenne in steps. At each angle the receiver o/p is digitized and stored in the computer.

Pattern plots are generated from the stored data. Further processing of the recorded pattern data can also be carried out to extract other pattern properties, such as directivity, beamwidth, side lobe level, etc. [Note:- As we do in lab, find the gain, HPBW of the antenna from pattern data]

The receiver block is the main measurement unit. A measuring receiver or network analyzer type instrument can measure the received power, field amplitude, and phase. One can also use simpler and less expensive instruments for the pattern measurements. A power meter can be used to measure power with a reasonable dynamic range.

[Note:- In antenna lab experiment, we use power meter to measure the received power.]

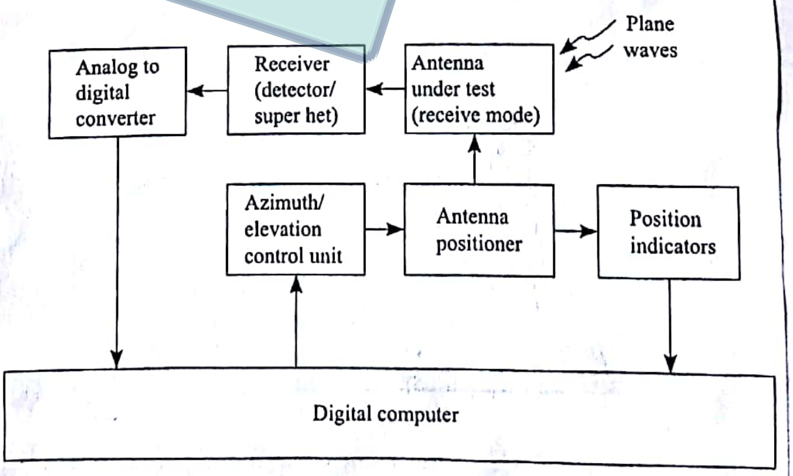


**Fig. 7.14** A computer-based control of the positioner

# Gain & Directivity Measurement

Directivity of an antenna differs from the gain as it does not include the dissipative losses in the antenna. The gain & directivity, along the same direction, are related to each other by radiation efficiency of the antenna.

The gain & directivity are usualy measured in the direction of the pattern maximum. Their values in other direction can be calculated from the radiation pattern. There are 2 techniques used for measuring the gain of an antenna — absolute gain measurement and gain transfer measurement. For the absolute gain measurement it is not necessary to have a prior knowledge of gains of the antennas used in the measurement. The more commonly used gain transfer method, requires the use of a gain standard with which the gain of the antenna under test is compared.

## A, Absolute gain measurement

Friis transmission formula forms the basis for absolute gain measurement.

$$P_r = P_t G_t G_r \left(\frac{\lambda}{4\pi R}\right)^2 \text{ Watt} \qquad \text{①}$$

In dB

(295)

$$10 \log (P_r) = 10 \log \left( P_t G_t G_r \left(\frac{\lambda}{4\pi R}\right)^2 \right)$$

$$\Rightarrow (P_r)_{dB} = (P_t)_{dB} + (G_t)_{dB} + (G_r)_{dB} + 20 \log \left(\frac{\lambda}{4\pi R}\right) \quad (2)$$

Since the received power is very small, we express all the power in dBm.

$$P_{r\,dBm} = P_{t\,dBm} + G_{t\,dB} + G_{r\,dB} + 20 \log \left(\frac{\lambda}{4\pi R}\right) \quad (3)$$

where

$P_{r\,dBm}$ = Power received in dBm by the received antenna into a matched load.

$P_{t\,dBm}$ = Power transmitted in dBm by the transmitting antenna into air

$G_{t\,dB}$ = Gain of transmitting antenna in dB.

$G_{r\,dB}$ = Gain of receive antenna in dB

R = Distance betn the transmit and receive antennas in meter.

$\lambda$ = wavelength in meter.

Consider two identical antennas placed in an elevated range or inside a rectangular anechoic chamber which are properly oriented or aligned such that (1) they are matched in polarization (ii) main beams of the two antennas are aligned with each other.

With this arrangement, the gain in the direction of maximum can be measured. The gain in any other direction can be computed from the radiation pattern.

Let $R$ be the separation between the two antennas chosen such that the antennas operate in the far field region ( $R > \frac{2D^2}{\lambda}$ ). Let $\lambda$ be the wavelength corresponding to the operating frequency. A calibrated coupling network and a matched receiver unit, as shown in fig 7-16, are used to measure the transmit and receive power $P_{tdBm}$ and $P_{rdBm}$ respectively. All the components are impedance matched using tuners.

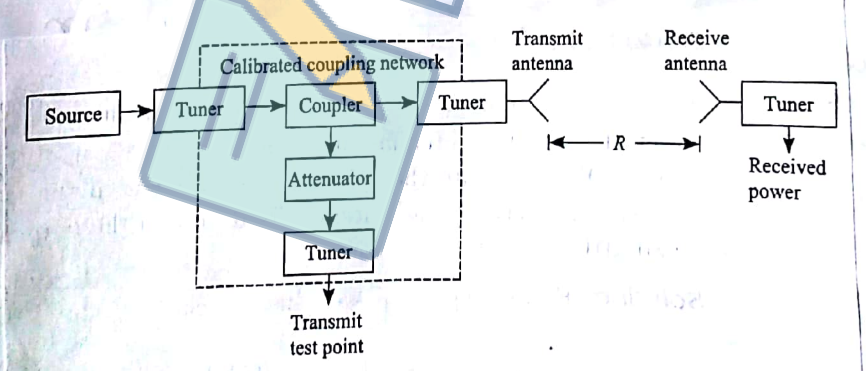


Fig. 7.16 Measurement of transmit and receive powers

If the two antennas are identical, their gains are identical and eqn ③ can be written as

$$G_{tdB} = G_{rdB} = \frac{1}{2}\left[P_{rdBm} - P_{tdBm} - 20\log\left(\frac{\lambda}{4\pi r}\right)\right] \quad ④$$

and hence the gain of antennas can be calculated. Since this method uses two antennas, it is known as two-antenna method for gain measurement.

In the absence of 2 identical antennas, a third antenna is required to measure the gain. This is known as three-antenna method of gain measurement. Let $G_{AdB}$, $G_{BdB}$, and $G_{CdB}$ be the gains of 3 antennas. Transmitted and received powers are recorded by taking two antennas at a time. Let $P^{AB}_{rdBm}$, $P^{BC}_{rdBm}$, and $P^{CA}_{rdBm}$ be the received powers. The ~~subscript~~ superscripts represent the antenna combinations used in the measurement. Similarly let $P^{AB}_{tdBm}$, $P^{BC}_{tdBm}$, and $P^{CA}_{tdBm}$ be the transmitted powers in each measurement. Now, we have 3 linear equations corresponding to these 3 measurements.

$$G_{AdB} + G_{BdB} = P^{AB}_{rdBm} - P^{AB}_{tdBm} - 20\log\left(\frac{\lambda}{4\pi R}\right) \quad ⑤$$

$$G_{BdB} + G_{CdB} = P^{BC}_{rdBm} - P^{BC}_{tdBm} - 20\log\left(\frac{\lambda}{4\pi R}\right) \quad ⑥$$

$$G_{C\,dB} + G_{A\,dB} = P^{CA}_{r\,dBm} - P^{CA}_{t\,dBm} - 20\log\left(\frac{\lambda}{4\pi R}\right) \quad — ⑦$$

Which can be solved simultaneously to calculate the gains of each of the antennas.

Ex:- 1) In a 3-antenna method of gain measurement, the measured receive powers taking two antennas at a time are 0.0297 mW, 0.0471 mW and 0.0374 mW. Calculate the gains of the antennas, if the transmit power is 1 W, spacing between the antennas is 10 m and frequency of operation 980 MHz.

Ans:- Expressing powers in dBm,

$$P^{AB}_{r\,dBm} = 10\log_{w}\left(\frac{0.0297\times10^{-3}}{10^{-3}}\right) = -15.27 \text{ dBm}$$

$$P^{BC}_{r\,dBm} = 10\log\left(\frac{0.0471 \text{ mW}}{1 \text{ mW}}\right) = -13.27 \text{ dBm}$$

$$P^{CA}_{r\,dBm} = 10\log(0.0374) = -14.27 \text{ dBm}.$$

$$P^{AB}_{t\,dBm} = P^{BC}_{t\,dBm} = P^{CA}_{t\,dBm} = 10\log\left(\frac{1}{10^{-3}}\right) = 30 \text{ dBm}.$$

$$\lambda = \frac{c}{f} = \frac{3\times10^{8}}{980\times10^{6}} = \frac{30}{98} = 0.306 \text{ m}$$

Substituting the values in eqn ⑤, ⑥, ⑦, we get

$$G_A + G_B = 7 \text{ dB}, \quad — Ⓐ$$

$$\left(\because G_A + G_B = -15.27 - 30 - 20\log\left(\frac{0.306}{4\pi\times10}\right) = 7 \text{ dB}\right)$$

Similarly

$$G_B + G_C = 9\,dB \quad \text{— (B)}$$

$$G_C + G_A = 8\,dB \quad \text{— (C)}$$

Solving these 3 eqns

$$G_A = 3\,dB, \quad G_B = 4\,dB, \quad G_C = 5\,dB.$$

(Ans)

## B. Gain Transfer Method :-

The gain off the test antenna is measured by comparing it with a standard gain antenna, of which the gain is known accurately. The test antenna is illuminated by a plane wave with its polarization matched to the ~~[illegible]~~ transmit antenna. The received power into a matched load, $P^T_{rdBm}$, is then measured. (T → Test antenna)

Let $G^T_{dB}$ be the gain of test antenna,

From Friis transmission formula

$$G_{tdB} + G^T_{dB} = P^T_{rdBm} - P_{tdBm} - 20\log\left(\frac{\lambda}{4\pi R}\right) \quad ①$$

[ Similarly to eqn ⑤, ⑥, ⑦, as discussed earlier ]

Now the test antenna is replaced by a standard gain antenna having gain $G^S_{dB}$ and the received power $P^S_{rdBm}$ is measured.

Again from Friis transmission formula,

$$G_{tdB} + G^{S}_{dB} = P^{S}_{rdBm} - P_{tdBm} - 20\log\left(\frac{\lambda}{4\pi R}\right) \quad ②$$

Subtracting ② from ①

$$G^{T}_{dB} - G^{S}_{dB} = P^{T}_{rdBm} - P^{S}_{rdBm}$$

$$\Rightarrow \boxed{G^{T}_{dB} = G^{S}_{dB} + P^{T}_{rdBm} - P^{S}_{rdBm}} \quad ③$$

And hence the gain of the test antenna can be calculated. It is important to note that the polarization of the test antenna and the standard gain antenna need to be identical to each other and this should be matched with the polarization of the transmitter. Both antennas should be impedance matched to the receiver. This method is used to measure the gain of a linearly polarized antenna.

Directivity :-

The total ~~Power~~ radiated power can be obtained by integrating the radiation pattern of an antenna over a closed sphere.

$$P_{rad} = \oint_{\Omega} U(\theta,\phi)\, d\Omega \quad ①$$

or//

$$P_{rad} = \int_{\phi=0}^{2\pi} \int_{\theta=0}^{\pi} U(\theta,\phi) \sin\theta \, d\theta \, d\phi \quad ②$$

& $$D(\theta,\phi) = 4\pi \frac{U(\theta,\phi)}{P_{rad}} \quad \text{— ③}$$

Using eqⁿ ③, the directivity of the antenna can be computed. If the antenna has one main lobe and side lobes are ~~Compar~~ reasonably low, the maximum directivity can be computed from the HPBW in the two principal planes.

i.e.

$$D = \frac{4\pi}{\theta_{HP} \cdot \phi_{HP}} \quad \text{— ④}$$

[As derived in module - 1
$\theta_{HP}$ & $\phi_{HP}$ are HPBW in E-plane pattern & H-plane pattern respectively.]

If the losses of an antenna can be determined by other method, its directivity can be estimated from the measured gain. Similarly, the gain can be calculated from the computed value of directivity.

Because

$$\boxed{\text{Gain} = \text{Radiation efficiency} \times \text{Directivity}}$$