# ANTENNA MEASUREMENTS

- Testing of real antennas is fundamental to antenna theory.
- regarded as a crucial aspect of antenna designing.
- performed at different levels that lead to help in checking whether the desired specifications have met or not.
- It involves a method where the source antenna (either transmitting or receiving) is placed at various positions in correspondence to the **Antenna Under Test** (**AUT**).

- regarded as the experimental validation of the parameter values given in an antenna datasheet.
- The test setup uses source antennas or transmitting antennas with known characteristics so that field incidents on the antenna under test are approximately plane waves.
- to reduce the error in measured parameters to acceptable levels.
- The antenna measurements ensure that the antenna under test meets all specifications.
- There are various antenna measurement methods available to characterize antennas.

# Parameters commonly measured using antenna

- Radiation pattern
- Polarization
- Input impedance
- Voltage standing wave ratio (VSWR)
- Directivity
- Gain
- Efficiency
- Effective Isotropically Radiated Power (EIRP)
- Antenna noise temperature
  - For any of these antenna parameter measurements, a proper test setup is required. The influence of the test setup is very important, as it can create error measurements.

# Antenna Measurement Setup

- utilizes plane waves for testing the antenna under test.
- The test setup uses source antennas or transmitting antennas with known characteristics so that field incidents on the antenna under test are approximately plane waves.
- The antenna measurement setup includes the following systems:

- **Antenna Under Test** - The antenna whose characteristics are to be measured.
- **Source Antenna and Transmitter** -
  - A source antenna with a known radiation pattern and transmitter system is used to send plane waves to the antenna.
  - The source antenna radiates fields that can be approximated to plane waves at the desired frequency.
  - The polarization and beam-width of the source antenna need to be in a range that is suitable for the antenna under test.
  - Horn antennas are an example of a source antenna in the antenna measurement setup.

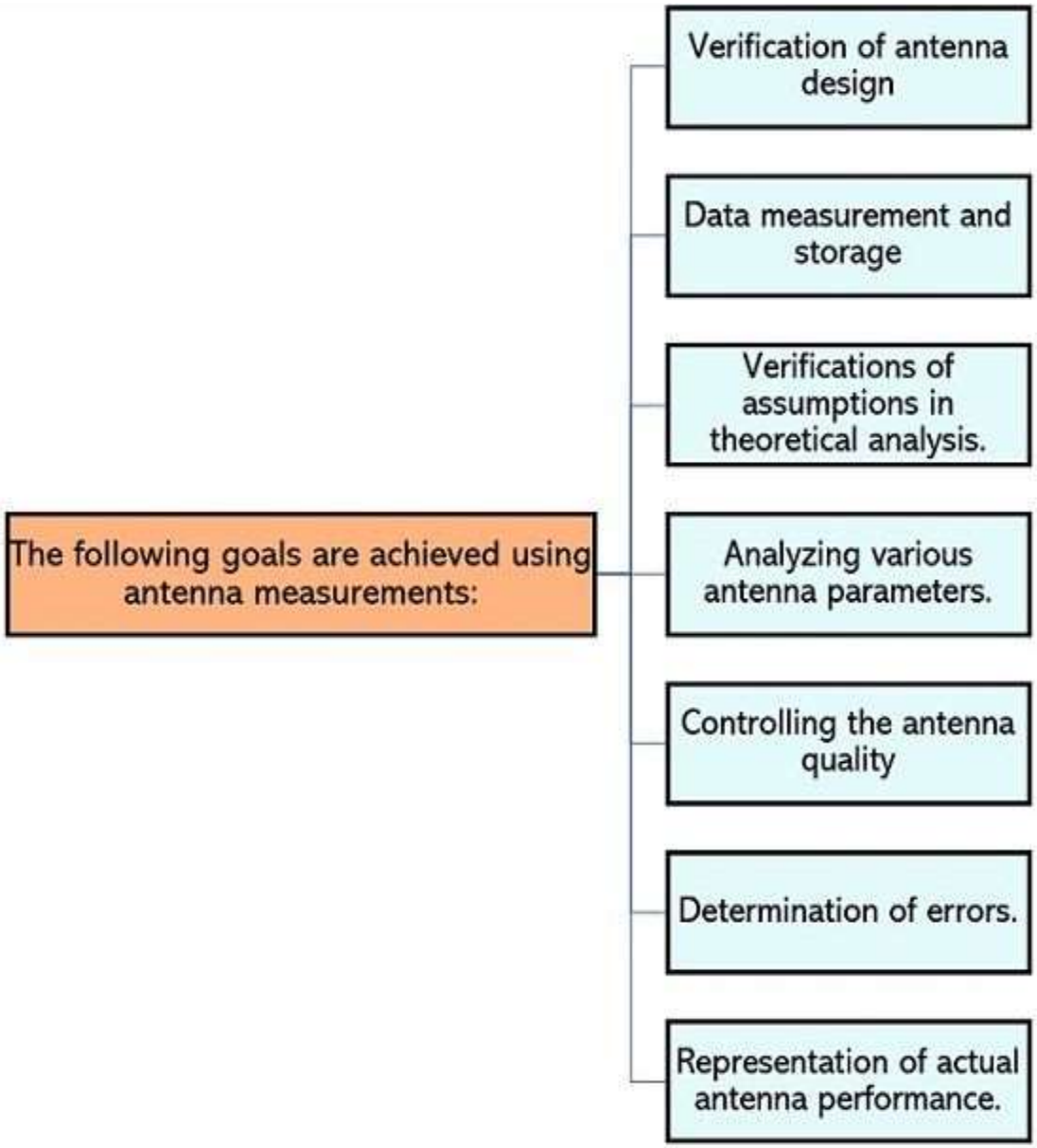
- **Receiver System** -
  - The receiver system is used to measure the power received by the antenna under test.
  - The receiving system must determine how much power is received from the test.
- **Positioning System** -
  - The positioning system controls the orientation of the antenna under test.
  - The positioning system rotates the antenna under test and helps in measuring the radiation pattern of the test antenna.
  - For determining the radiation pattern as a function of angle, the test antenna is rotated with respect to the source antenna.

# Antenna Measurement Methods

- **With a Spectrum Analyzer**
- **With a Vector Network Analyzer**
- **With the Field or Walker Method**
- **In Normal Space**
- **In Anechoic Chambers**
  - Antenna measurements performed in the **anechoic chamber** provide fairly good and accurate measurements when compared to other antenna measurement methods exposed to the reflective environment.

# Need for Antenna Measurement

- The analysis that incorporates validation of the actual measurement of the antenna parameters is more beneficial for complex antenna structures.
- some specific antenna designs for which there are fewer chances of desired results through study and analytical investigations, some experimental validations are important.
- Due to this reason, antenna measurement is necessary where a test antenna is taken into consideration and the experiment is carried out.


The following goals are achieved using antenna measurements:
Verification of antenna design
Data measurement and storage
Verifications of assumptions in theoretical analysis.
Analyzing various antenna parameters.
Controlling the antenna quality
Determination of errors.
Representation of actual antenna performance.

# How antenna measurement is done?

- As w k t, the various parameters are recorded from a different location using the source antenna and the antenna under test.
- just by rotating the AUT at its original position various samples can be collected.
- The received pattern will be sharp only in case when there will be a direct path between source antenna and AUT.
- And this can be achieved when the testing environment is free from reflections.
- Thus, to achieve this use of **anechoic chamber** in free space is used.
- Antenna arrangement follows **Reciprocity Theorem**.

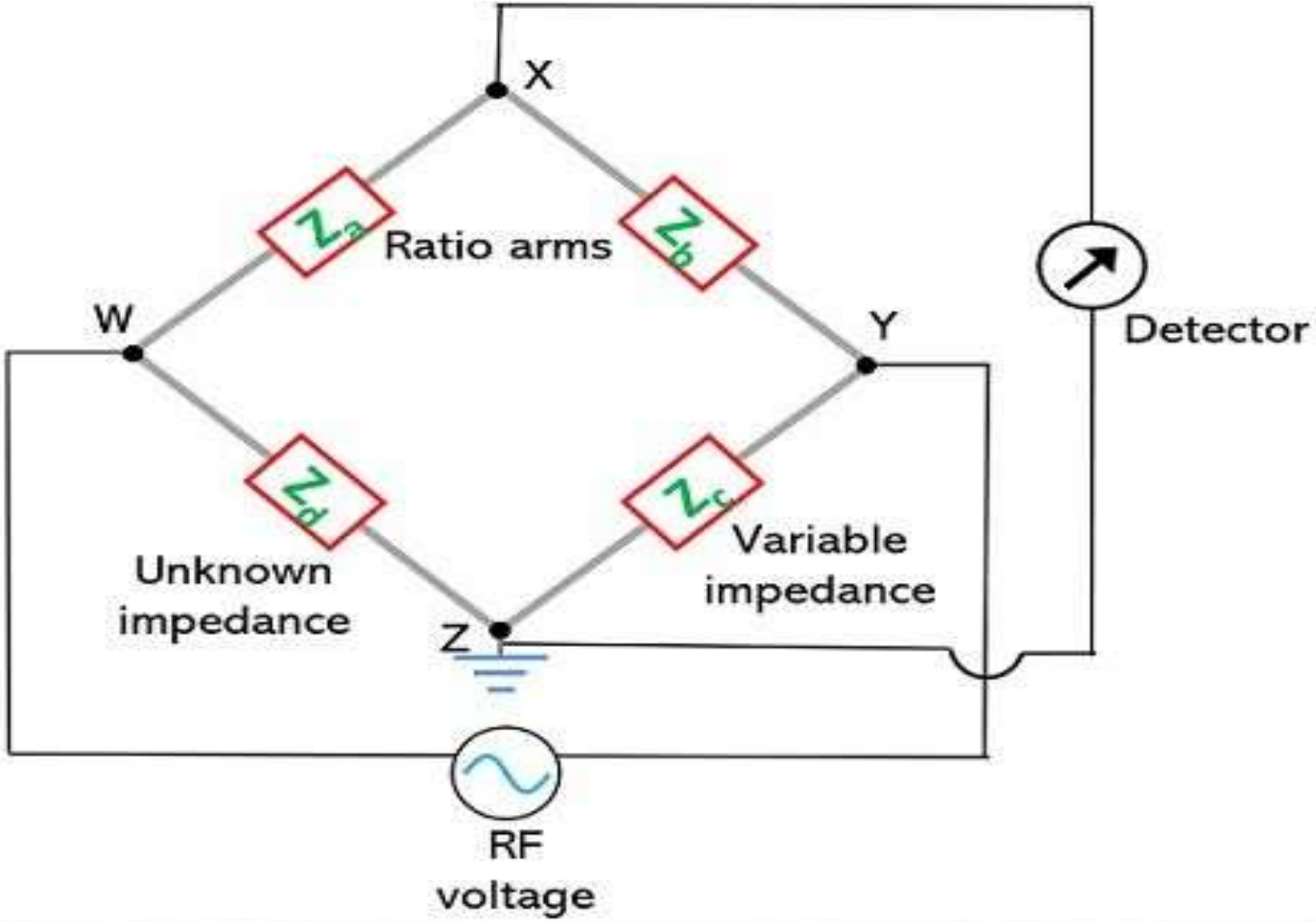
- Experimentally the antenna measurements are classified as:
  - Impedance Measurements
  - Pattern Measurements
- In impedance measurement, the intrinsic, input, self and mutual impedance are measured.
- While in pattern measurements, gain, beam-width, polarization and radiation characteristics are measured.

# Antenna Impedance Measurement

- depends on the frequency of operation.
- basis of the frequency range, there are two methods of impedance measurement.
- for low-frequency applications i.e., below 30 MHz, the bridge method is used for measurement.
- for high-frequency range i.e., above 1000 MHz, slotted line measurement is used.
- Also, in the frequency range between **30 to 1000 MHz**, ant of the methods can be used but that depends on convenience and equipment availability.

# Impedance Measurement by Wheatstone Bridge Method

- used to determine the unknown value of impedance by comparing it with known impedance.
- using this method impedance at frequencies up to 30 MHZ can be determined.
- consists of 4 impedances in the 4 arms.
- Here the $Z_a$ and $Z_b$ are ratio arms while $Z_c$ corresponds to variable arm impedance and $Z_d$ is the unknown impedance which is to be measured.




**Wheat stone bridge for measurement of impedance**

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- Under the balanced condition of the bridge, no potential difference would exist between points X and Z thereby providing a null in the detector.

$$\frac{Z_a}{Z_b} = \frac{Z_d}{Z_c} \qquad \frac{Z_a \angle\theta_a}{Z_b \angle\theta_b} = \frac{Z_d \angle\theta_d}{Z_c \angle\theta_c}$$

- in terms of both magnitude and phase.
- both magnitude and phase balance conditions must be fulfilled.

$$Z_a Z_c \angle\theta_a + \angle\theta_c = Z_b Z_d \angle\theta_b + \angle\theta_d$$

$$Z_a Z_c = Z_b Z_d$$

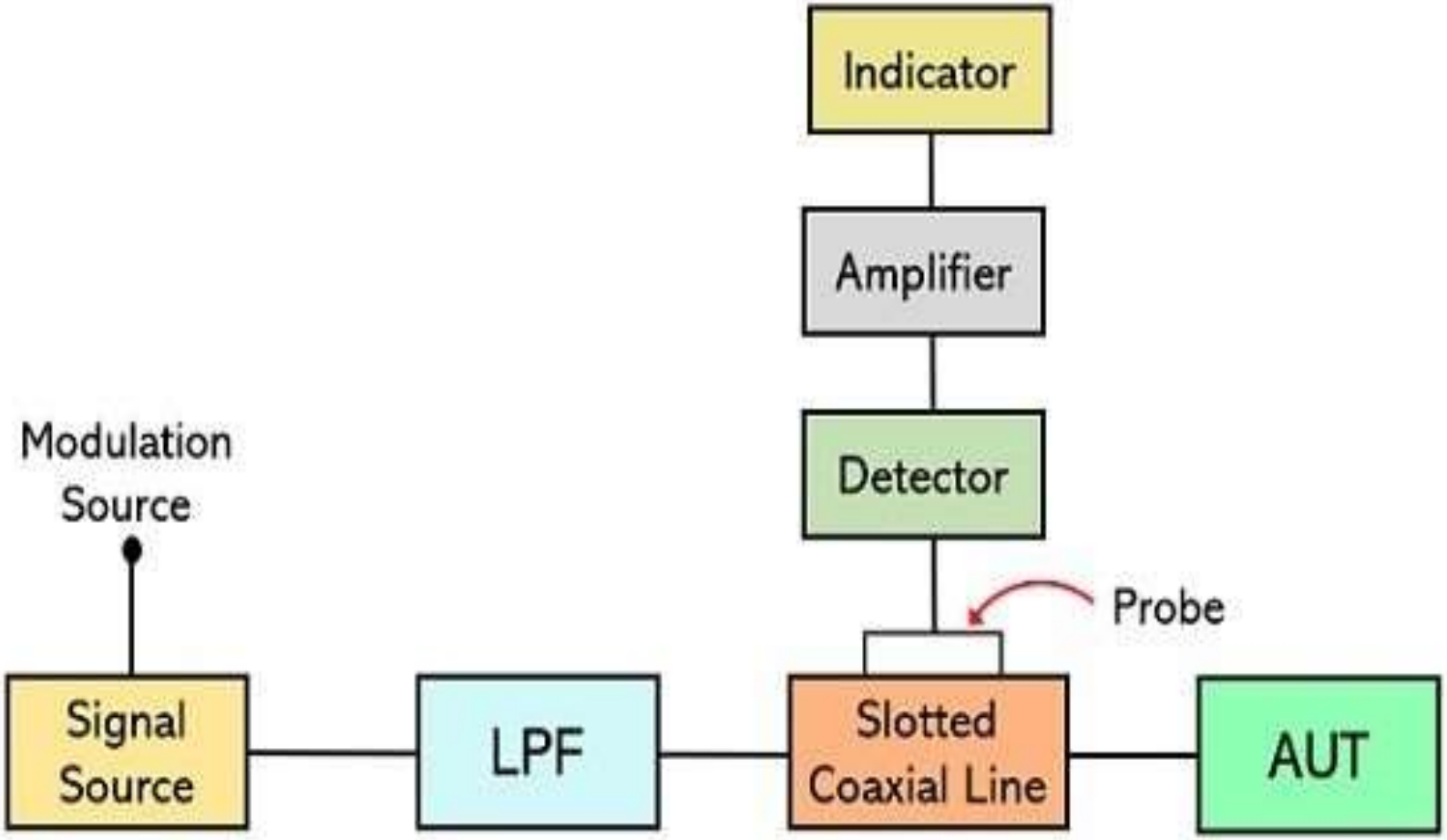
$$\angle\theta_a + \angle\theta_c = \angle\theta_b + \angle\theta_d$$

$$Z_d = Z_c \left[\frac{Z_a}{Z_b}\right]$$

- need to determine the antenna input impedance then the antenna input terminal must be connected between the points W and X.
- It suits grounded vertical antennas of low frequency.
- In order to have desired results, points W and Z must be grounded initially with respect to ground.
- Due to this reason, in the beginning, the bridge is balanced with the short-circuited or open-circuited condition.

# Impedance Measurement by Slotted Line Method

- known as a standing wave ratio method or standing wave method of impedance measurement.
- popular characteristics of travelling waves.
- the method tells the idea of uniquely determining the impedance through voltage or current standing wave ratio and the separation distance between voltage or current minimum and the reference point of impedance.
- It is widely used at UHF and microwave frequencies.




Slotted line setup for measurement of impedance

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- all the devices must be connected in the same manner.
- one side a single source is present while at the other side the unknown impedance to be measured is present.
- improper termination of the antenna with the feeding transmission line gives rise to standing wave along the transmission line.
- So, a portion of the transmission line which is connected to the antenna is replaced by an axial slotted line over which a probe moves.
- for measuring the voltage in order to get the impedance a crystal detector and a micro-ammeter is used.
- at the various locations along the slotted line between the generator and the load, the probe is moved.

- The movement of the detector probe leads to providing the reading in the micro-ammeter which is noted down.
- movement in the two consecutive points of $V_{max}$ and $V_{min}$ of the probe in the slotted coaxial cable are noted.
- Resultantly the ratio of the two will provide VSWR i.e., the input impedance

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

# Antenna Gain Measurement

- a crucial aspect of antenna measurement.
- gain of the antenna plays a very important role in predicting the performance of an antenna.
- Gain is a fundamental parameter of the antenna.
- ability of the antenna to either direct the radiated power of the antenna in a specific direction or efficiently receive the incoming power from a specific direction.

$$Gain = \frac{Max\ radiation\ intensity\ (test\ antenna)}{Max\ radiation\ intensity\ (reference\ antenna)}$$

- It is defined as the ratio of maximum radiation intensity of the test antenna to that of the reference antenna where the input power is the same.

- Directivity of the antenna then it is defined as the maximum radiation intensity to the average radiation intensity of an ideal isotropic antenna.

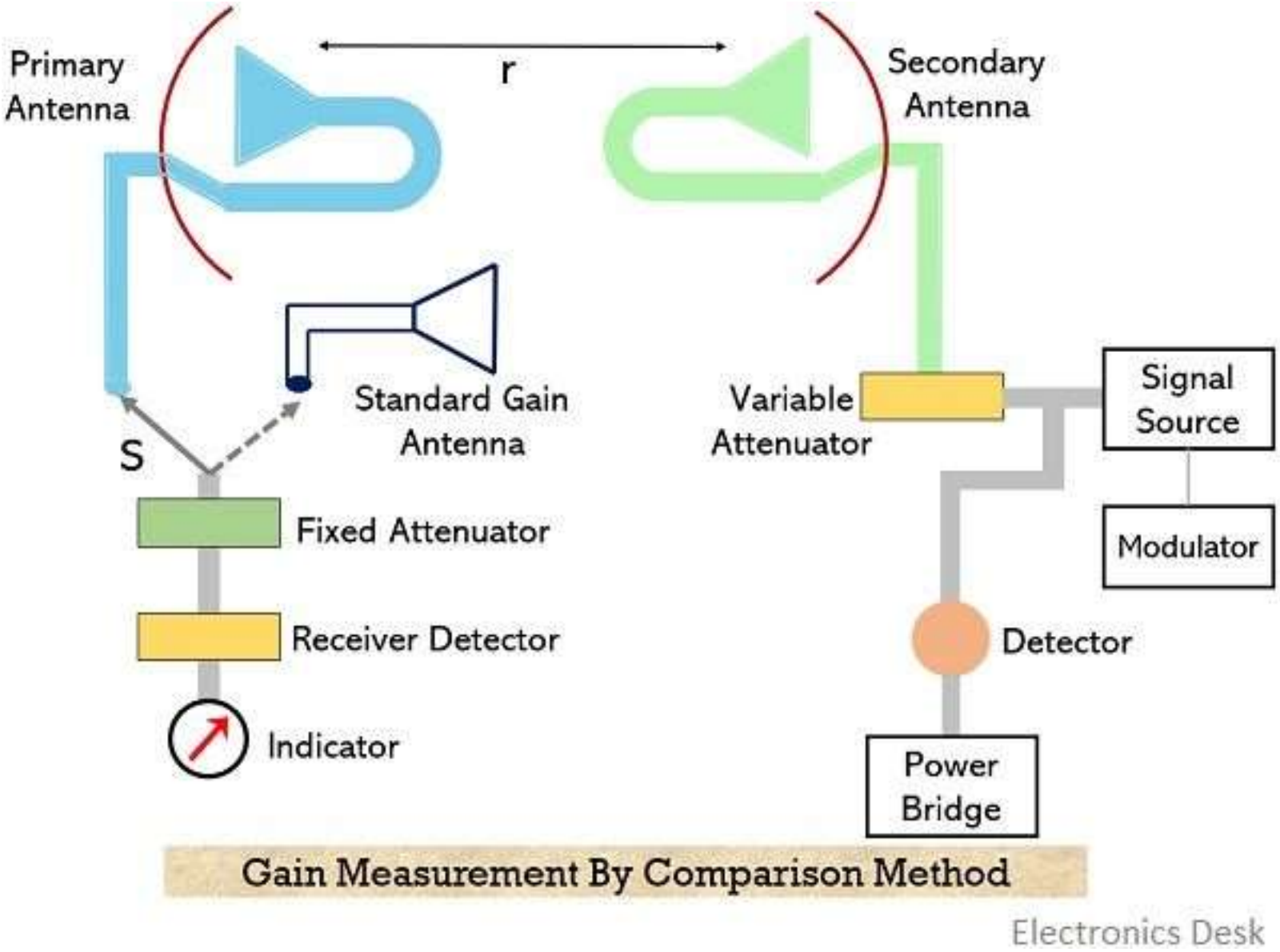
$$Directivity = \frac{Max\ radiation\ intensity}{Avg\ radiation\ intensity} \qquad G_0 = \alpha D$$

# Methods of Antenna Gain Measurement

- there are two standard methods used for antenna gain measurement.
  - Gain transfer or Direct Comparison Method
  - Absolute Gain Method

# Direct Comparison Method

- In this method of gain measurement, comparison between signal strengths of the unknown gain antenna and the standard gain antenna is made.
- Basically, the standard gain antenna is the one with known gain.
- The standard antenna and test antenna together form an arrangement of the primary antenna.
- While the secondary antenna in this arrangement is an arbitrary transmitting antenna with unknown gain.


Primary Antenna
r
Secondary Antenna
Standard Gain Antenna
S
Variable Attenuator
Signal Source
Modulator
Fixed Attenuator
Receiver Detector
Detector
Indicator
Power Bridge
Gain Measurement By Comparison Method
Electronics Desk

- considerable distance between standard and test antenna is maintained so as to avoid the chances of coupling or any type of interaction.
- Generally, an electromagnetic horn antenna is used as a standard gain antenna.
- the pattern measurement that the distance requirement of the arrangement is such that $r \geq 2d^2/\lambda$.
- the distance between the primary and secondary antenna must be properly maintained.
- As standard and test antennas are acting as a unit thus to have appropriate matching with the load, an attenuator pad is placed at the receiver input.

- during the whole measurement there must not be fluctuation in the frequency of the power radiated towards the primary antenna.
- So, to ensure this, power level indicating device or power bridge is used at the transmitter.

# The steps are as follows

- Initially, the standard antenna with a known gain is connected to the receiver using the switch S and it is directed towards the direction of maximal signal intensity of the transmitting antenna (i.e., secondary antenna).
- With the properly applied input to the secondary antenna, reading of the receiver is noted. Along with this, the reading of the attenuator dial ($W_1$) and power bridge ($P_1$) is also noted down.
- the switch is removed from the standard antenna and with the help of same switch connection of the test antenna is made with the receiver.
- Further, the reading of the attenuator dial is adjusted to get the same reading on the receiver as it was in the case with the standard antenna. Let the dial setting be $W_2$ and power bridge reading is $P_2$.

$$G_P = \frac{W_2}{W_1}$$

$$G_{P\,(db)} = W_{2\,(db)} - W_{1\,(db)}$$

$$P = \frac{P_1}{P_2}$$

$$10 \log P_1/P_2 = P\ (db)$$

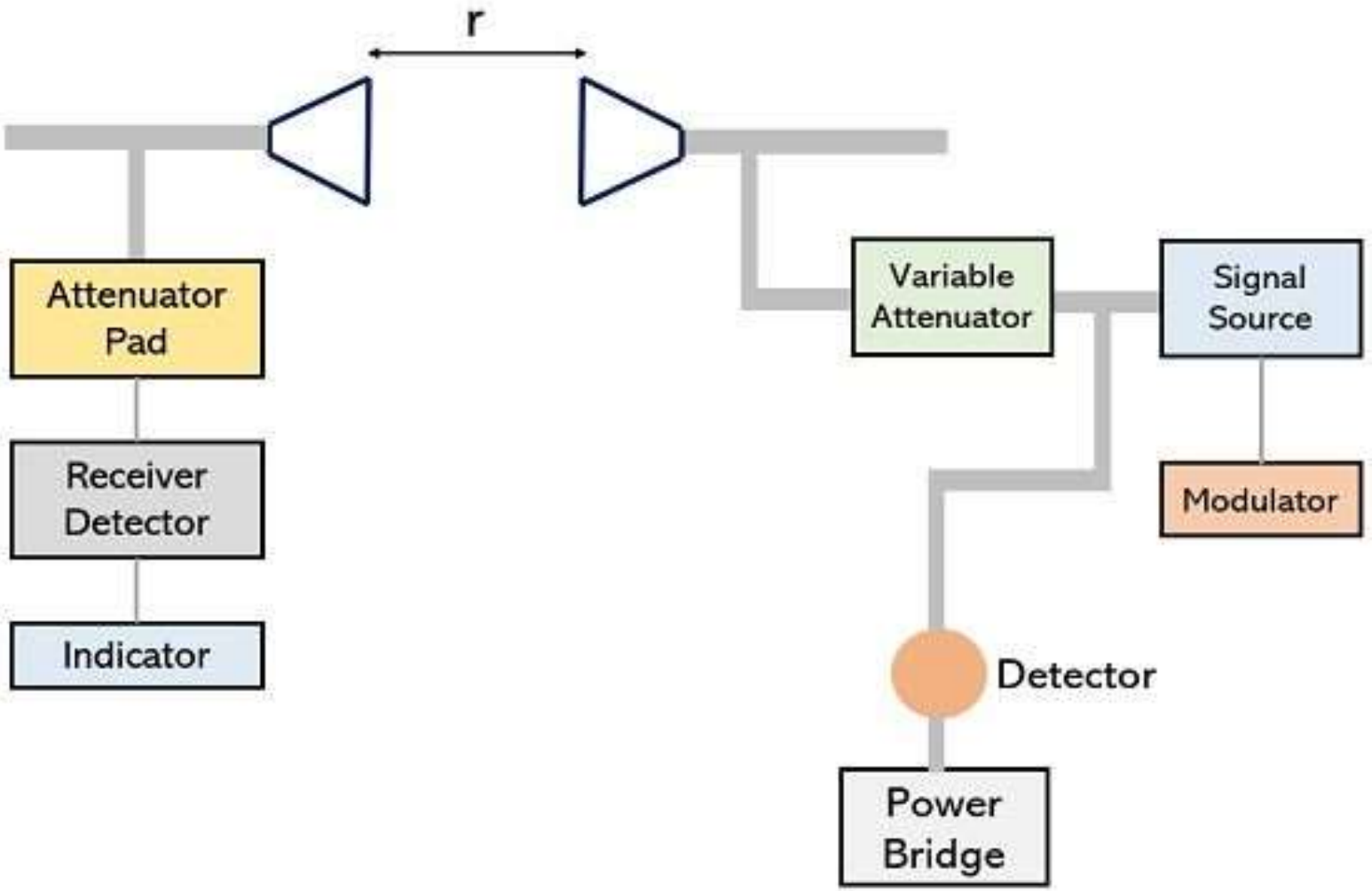
$$G = G_p * \frac{P_1}{P_2}$$

$$G = \frac{W_2}{W_1} * \frac{P_1}{P_2}$$

$$G = G_P * P$$

# Absolute Gain Method

- calibrate the gain using two or three arbitrary antennas.
- two antennas (transmitting and receiving) are separated at a distance r.
- Here, $P_t$ and $P_r$ represent the transmitted and received power respectively.
- While $A_{et}$ and $A_{er}$ is the effective apertures of the transmitting and receiving antennas.
- As the two antennas are identical.


r
Attenuator Pad
Receiver Detector
Indicator
Variable Attenuator
Signal Source
Modulator
Detector
Power Bridge
Transmitting and Receiving Antennas
Electronics Desk

$$A_{et} = A_{er} = \frac{G_0 \lambda^2}{4\pi}$$

$$\frac{P_r}{P_t} = \left(\frac{G_0 \lambda}{4\pi r}\right)^2$$

- By Friis's transmission equation,

$$\sqrt{\frac{P_r}{P_t}} = \frac{G_0 \lambda}{4\pi r}$$

$$\frac{P_r}{P_t} = \left(\frac{A_{et} A_{er}}{\lambda^2 r^2}\right) = \left(\frac{G_0 \lambda^2}{4\pi}\right)\left(\frac{G_0 \lambda^2}{4\pi}\right)\frac{1}{\lambda^2 r^2}$$

$$G_0 = \frac{4\pi r}{\lambda}\sqrt{\frac{P_r}{P_t}}$$

- While if we consider the effect of direct and indirect rays in case of ground reflection then,

$$G_0 = \frac{4\pi r}{\lambda F}\sqrt{\frac{P_r}{P_t}}$$

F is the propagation constant due to interference.

# Antenna Measurements – Radiation Pattern

- way of determining the radiation pattern of the antenna under test i.e., AUT.
- Antenna pattern or radiation pattern graphically represents the radiation properties of the antenna with respect to the space coordinates.
- it refers to the measurement of relative magnitude and phase of the electromagnetic signal transmitted by the test antenna.
- AUT is considered in conjunction with a source antenna that helps in determining system performance.

# Procedure for Pattern Measurement

- setup must necessarily have two antennas.
- One is the antenna under test referred as a primary antenna while the other is the secondary antenna.
- the system follows reciprocity theorem.
- the radiation pattern will be the same for both the antenna thus out of the two any one of them can be the transmitting antenna while the other will be the receiving antenna.

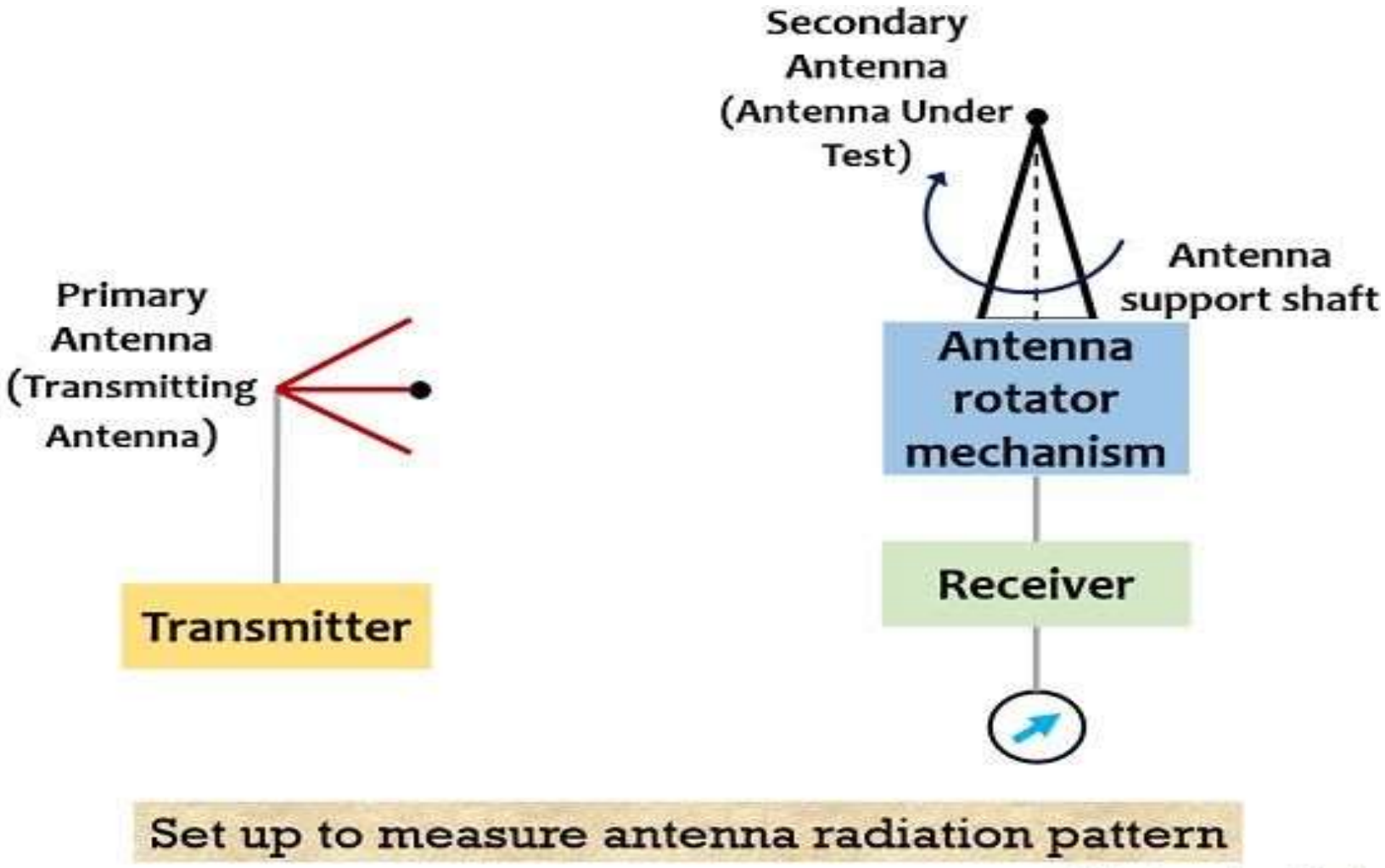
# Procedure I

- the primary antenna is placed at a specific location and is of immobile nature.
- Whereas, the secondary antenna is placed at a certain distance from it.
- However, the secondary antenna is not stationary as it moves around the primary antenna maintaining that specific distance.
- Generally, the primary antenna is the transmitting one while the secondary is the receiving antenna, but this condition is not necessary for the measurement to take place.

# Procedure II

- measurement of antenna both primary as well as secondary antennas are placed at fixed positions separated by a sufficient distance.
- under a general condition, the primary antenna is considered as the transmitting one while the secondary antenna is the antenna under test.
- Here the positions of the two antennas are fixed but the secondary antenna is rotated about the vertical axis.

- during the rotation of the test antenna about the vertical axis, the primary antenna is fixed and is not rotated.
- So, when the transmitting antenna provides the illumination to the test antenna at different angles then field strength at various directions is noted down by stopping the rotation each time at some specific angle.


Secondary Antenna (Antenna Under Test)
Antenna support shaft
Primary Antenna (Transmitting Antenna)
Antenna rotator mechanism
Receiver
Transmitter
Set up to measure antenna radiation pattern
Electronics Desk

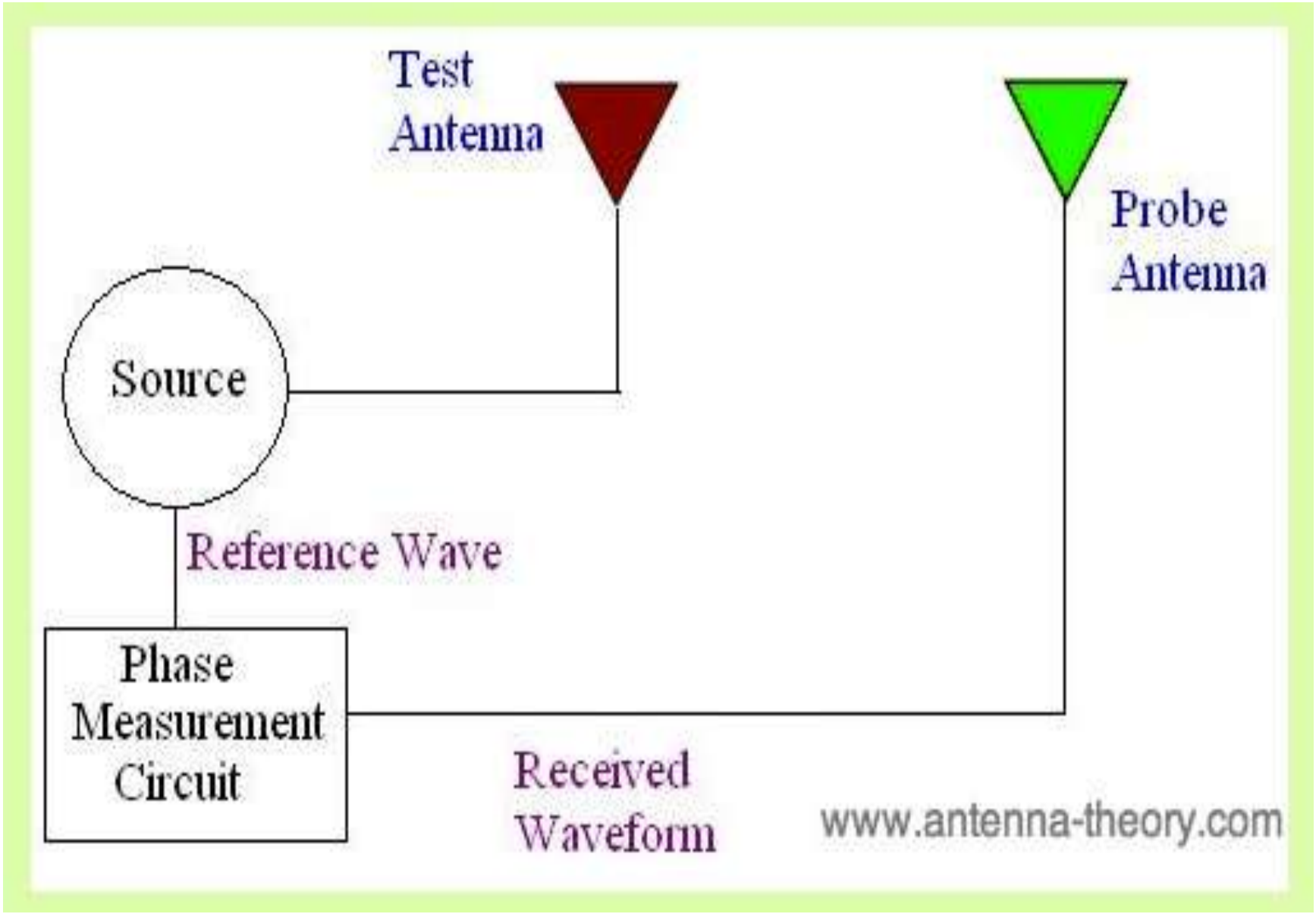
- *The two major requirements of pattern measurement are as follows:*
  - Distance and
  - Uniform Illumination

$$r \geq \frac{2d^2}{\lambda}$$

- Uniform Illumination:
  - transmitting antenna must possess a uniform amplitude and phase over the complete distance of separation.
  - Here the reflections from the ground, buildings, trees, etc. must be greatly avoided.

# Phase Measurements

- The phase is a relative quantity - that is, it must be measured relative to some fixed reference.
- In this method the test antenna is used as the source antenna, and another antenna is used to receive the fields.
- the observation point is not too far from the test antenna, so that the source waveform feeding the test antenna can also be run into a phase measurement box.
- This box compares the locations of the peaks and valleys of the received signals and determines the relative phase from this information.
- The receive antenna is moved and then the process is repeated.

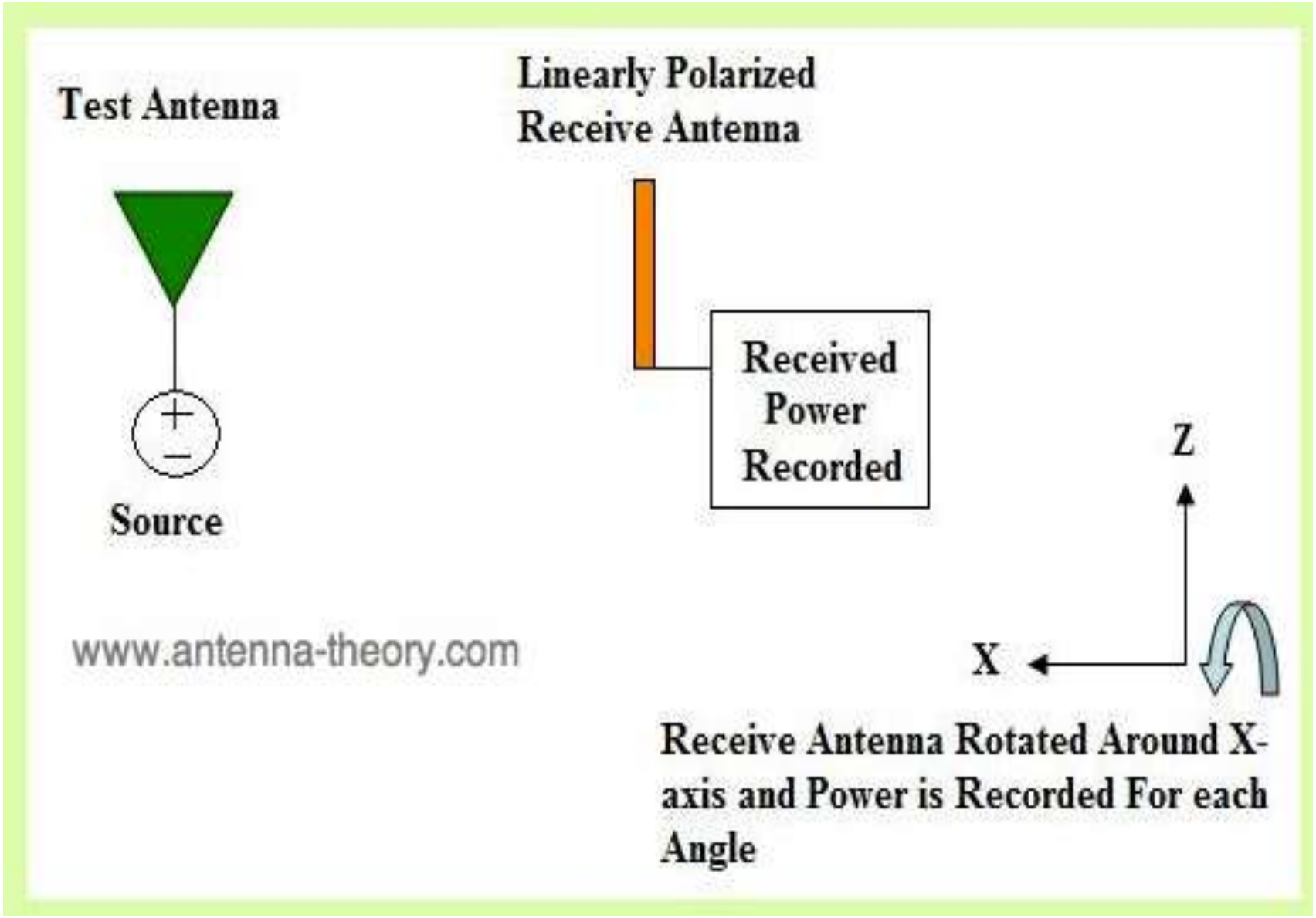

Test
Antenna
Probe
Antenna
Source
Reference Wave
Phase
Measurement
Circuit
Received
Waveform
www.antenna-theory.com

- If the test antennas are very far from each other and the reference (source) waveform can not be fed directly into the phase measurement circuit (this happens at low frequencies and large outdoor ranges where many wavelengths becomes a large distance), then a standard antenna with known phase characteristics is used to transmit a wave, which is used to compare with the received signal from the test antenna.

# Polarization Measurements

- use a linearly polarized antenna (typically a half-wave dipole antenna) as the receive antenna.
- The linearly polarized receive antenna will be rotated, and the received power recorded as a function of the angle of the receive antenna.
- the test antenna must be rotated so that the polarization can be determined for each direction of interest.

- The power is recorded for the fixed position (orientation) of the receive antenna, then it is rotated about the x-axis & the power is recorded again.
- This is done for a complete rotation of the linearly polarized receive antenna.


Test Antenna
Linearly Polarized
Receive Antenna
Received
Power
Recorded
Source
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Z
X
Receive Antenna Rotated Around X-axis and Power is Recorded For each Angle