Chapter 17 : Antenna Measurement

- Introduction
- Antenna Ranges
- Radiation Patterns
- Gain Measurements
- Directivity Measurements
- Impedance Measurements
- Polarization Measurements
- Scale Model Measurements

Introduction

- Practical antennas : complex structural configuration & excitation method
- Need experimental results to validate theoretical data.
- Ideal condition : test antenna in receiving mode and illumination of test antenna by plane wave, i.e., *uniform amplitude and phase*.
- Actual system : “large enough” separation -> far-field region.

Phase Error

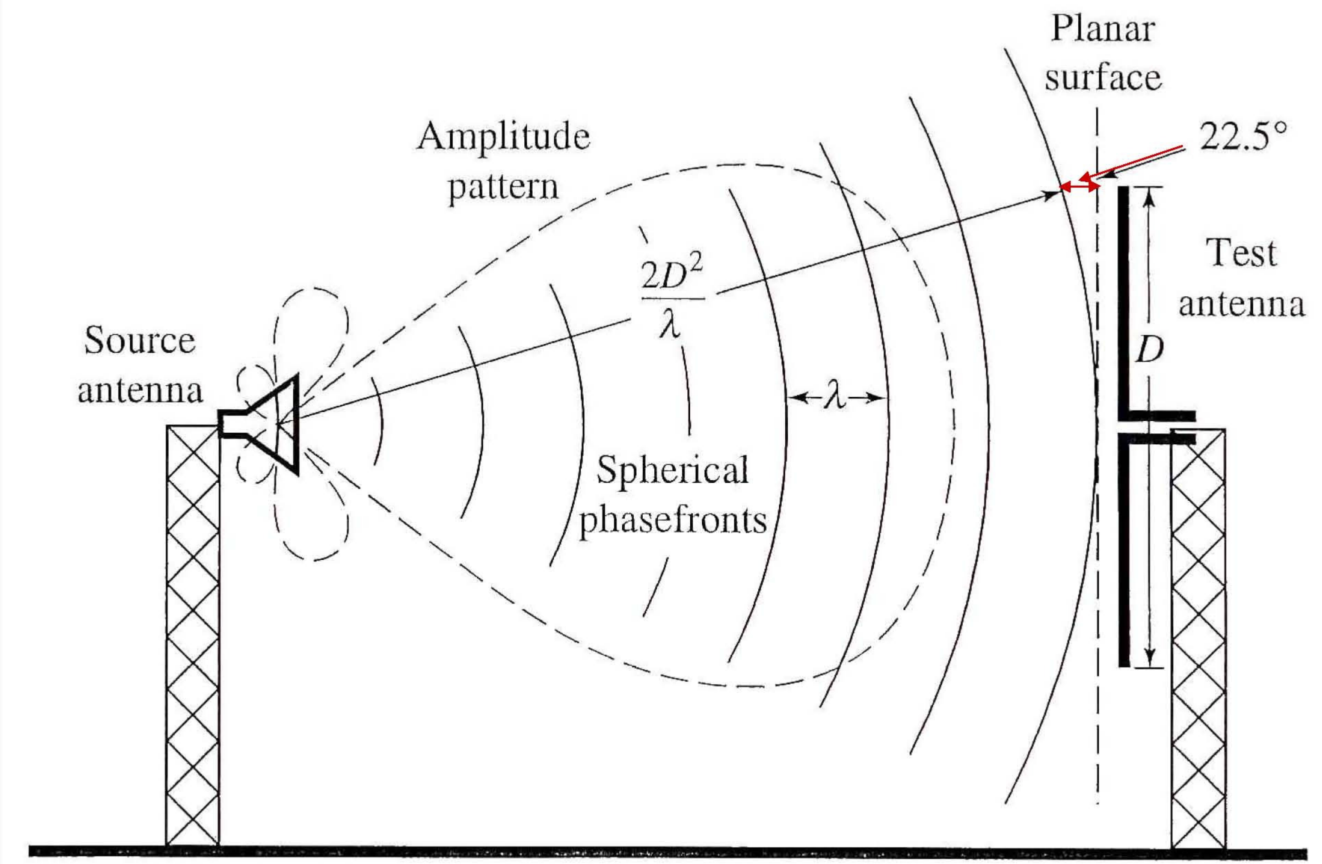


Fig. 17.1

Chapter 17
Antenna Measurements

Measurement Drawbacks

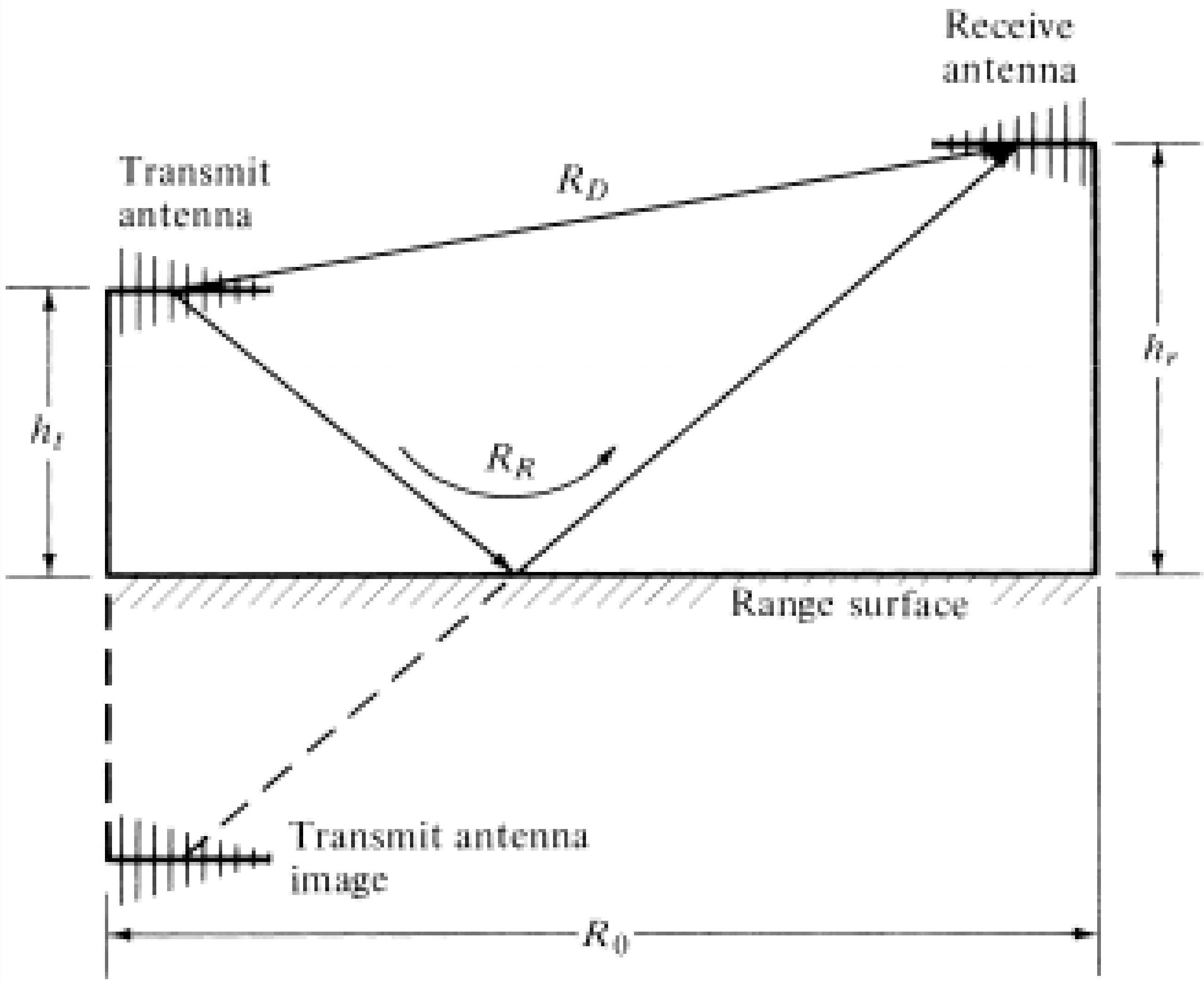
- Pattern Measurements : far-field distance too long -> difficult to suppress “unwanted” reflections from ground and surrounding objects.
- Impractical to move antenna to measuring site.
- Take time to measure characteristics, e.g., antenna array.
- For outside measuring systems, uncontrolled environment and no all-weather capability
- For enclosed systems, cannot accommodate large antenna systems, e.g., ship, aircraft, antenna arrays, etc.
- Measurement techniques are expensive.

Antenna Ranges

- By antenna facilities : Outdoor & Indoor ranges.
- Receiving mode & far-field required -> Ideal incident field : uniform plane wave -> large space required.
- Antenna Ranges:
  - Reflection : suppress reflection effects
  - Free-space : suppress contributions from surrounding environments; *Elevated ranges, Slant ranges, anechoic chambers, compact ranges, near-field ranges.*
  - Near-field ranges use Near-field/Far-field method to convert measured near-field data to far-field.

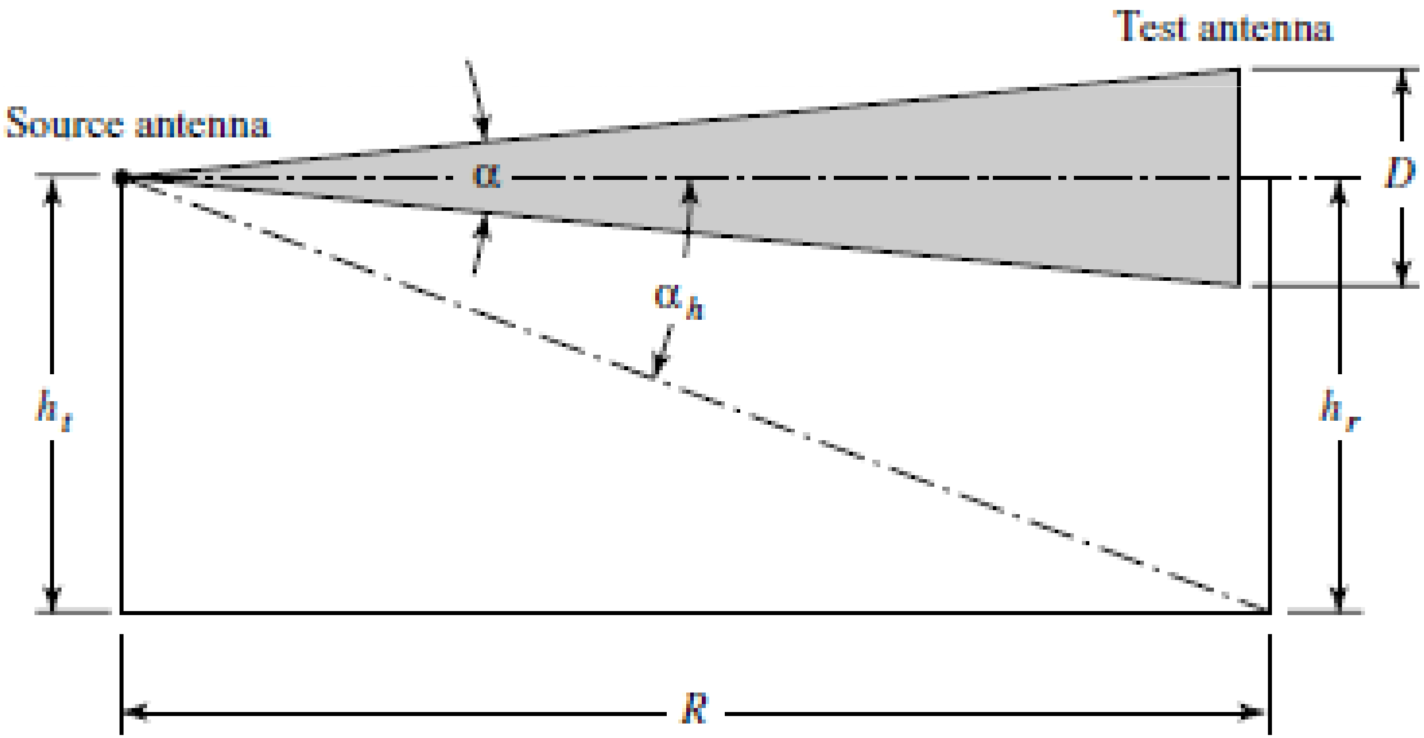
Reflection Range

- "constructive interference" is desirable -> "quiet zone".



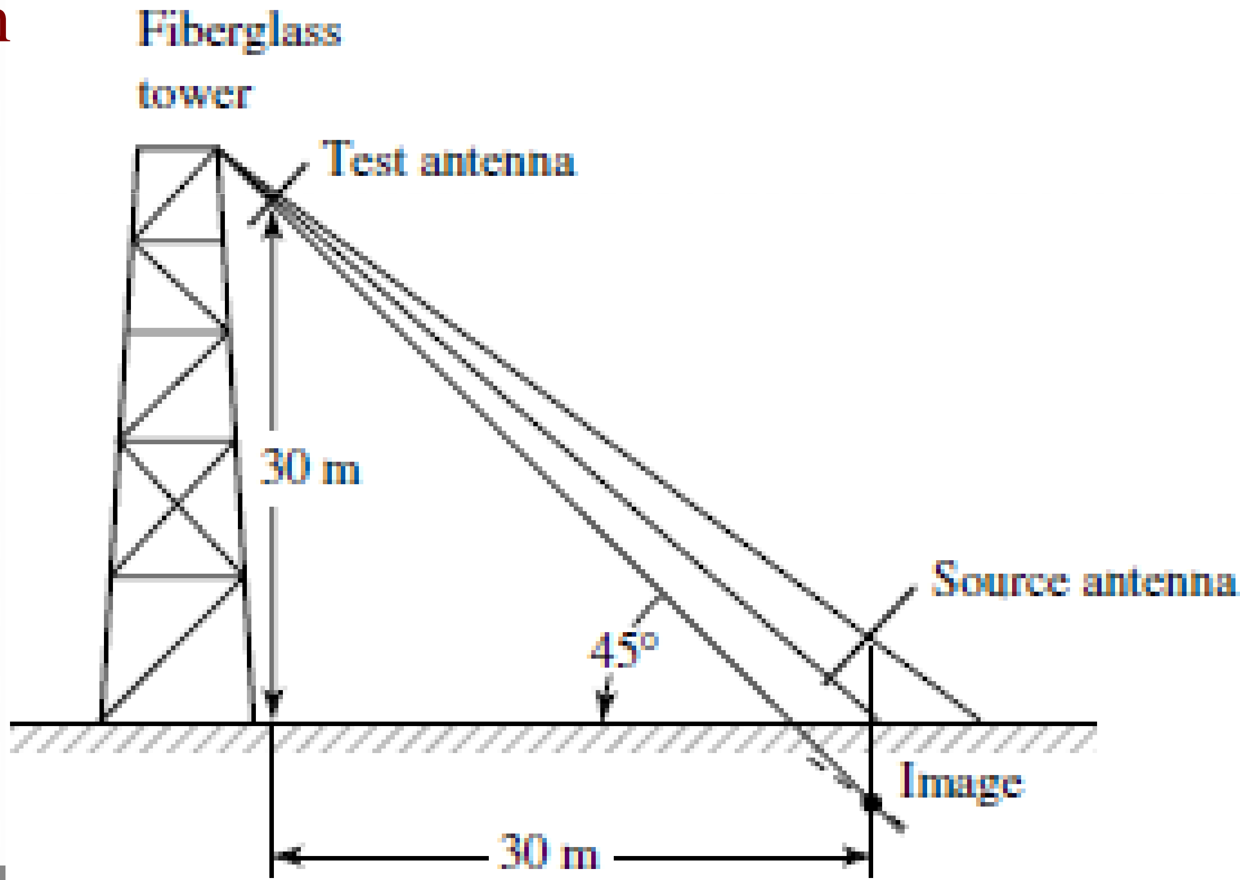
Elevated Ranges

- Reduce contributions from surrounding environments by 1. select proper directivity & side lobe of source antenna. 2. clear between line-of-sight. 3. redirect or absorb reflected energy that cannot removed. 4. utilize some special signal-processing techniques.



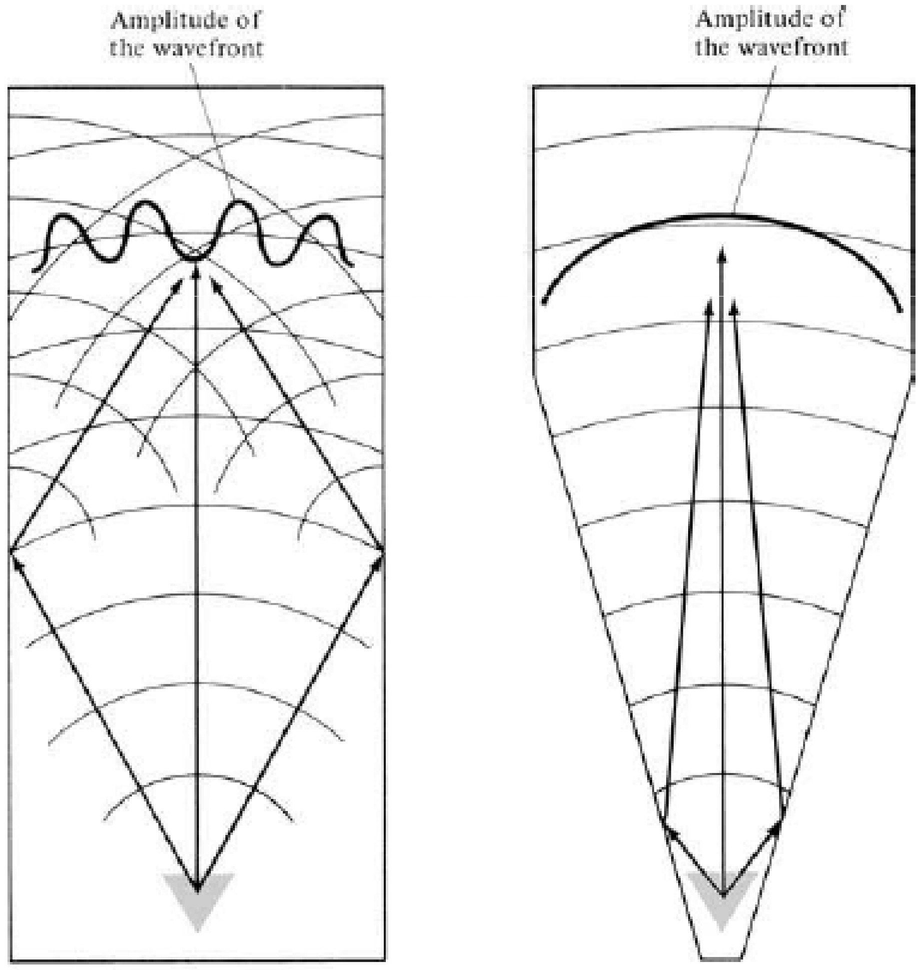
Slant Ranges

- Pattern maximum of free-space radiation toward center of the test antenna
- First null toward the ground to suppress reflection.
- More compact than elevated ranges.



Anechoic chambers

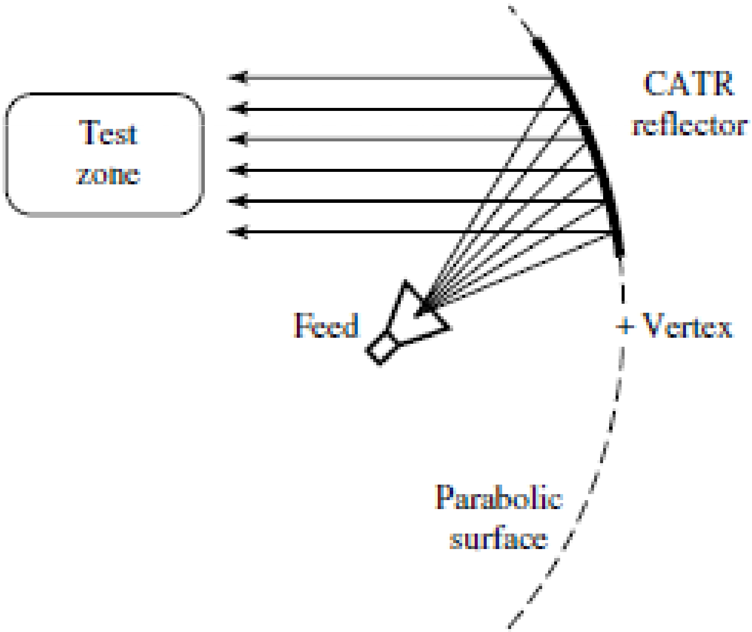
- Controlled environment, all-weather capability, security & minimize EM interference -> Indoor anechoic chambers.
- After high-quality absorbing materials are available.
- Two basic types to minimize specular reflections.
- Rectangular : maximize quiet zone and simulate free-space. Require absorbers.
- Tapered : phase difference between direct and reflected waves is small.

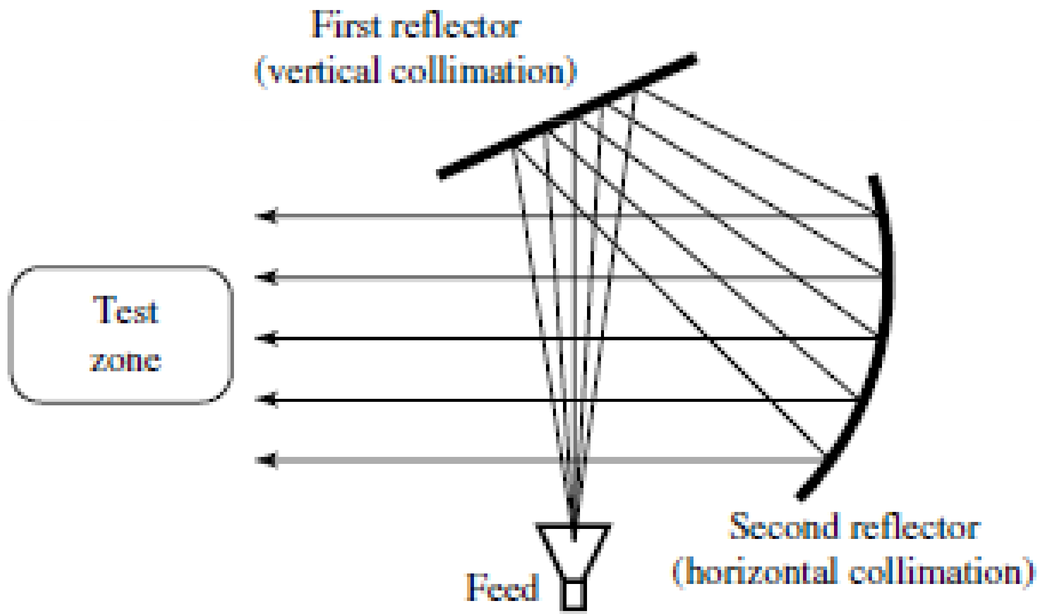


(a) Rectangular chamber (b) Tapered chamber

Compact Ranges

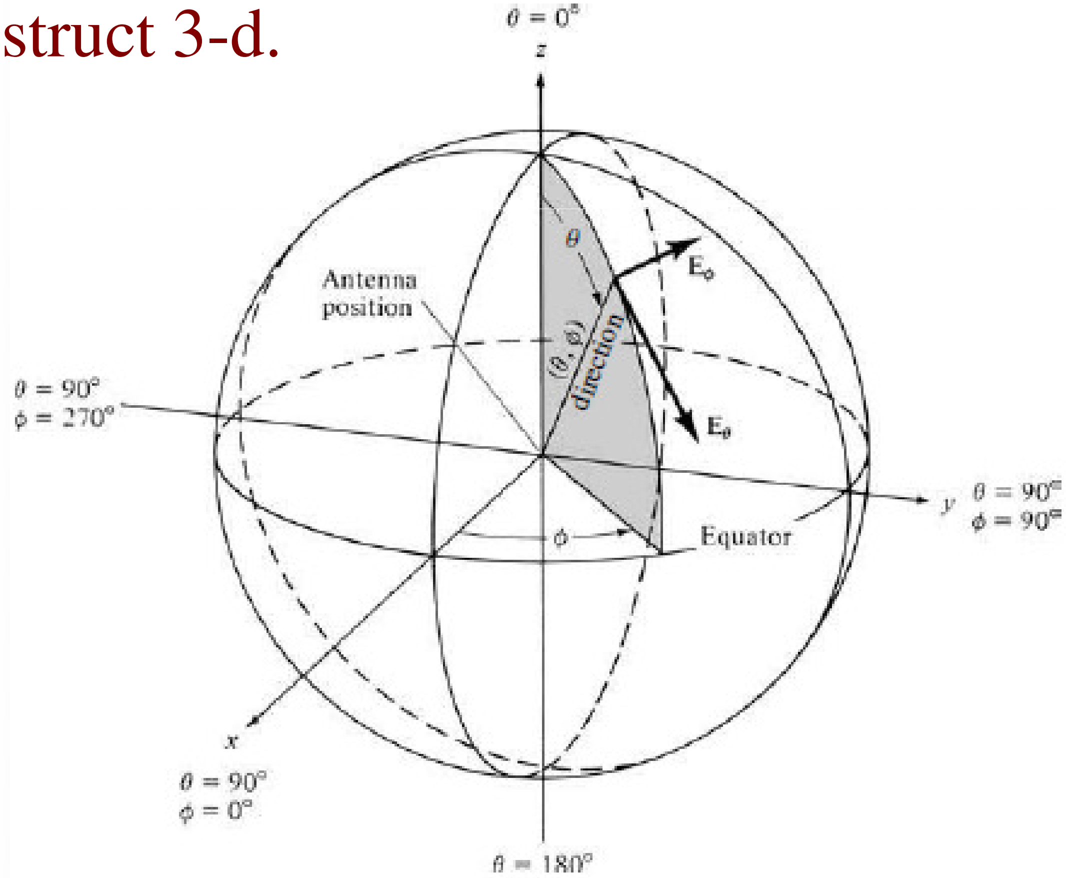
- To obtain “ideal” plane wave illumination.
- Compact Antenna Test Range (CATR) can generate nearly planar wavefronts in a very short distance.





Radiation Patterns

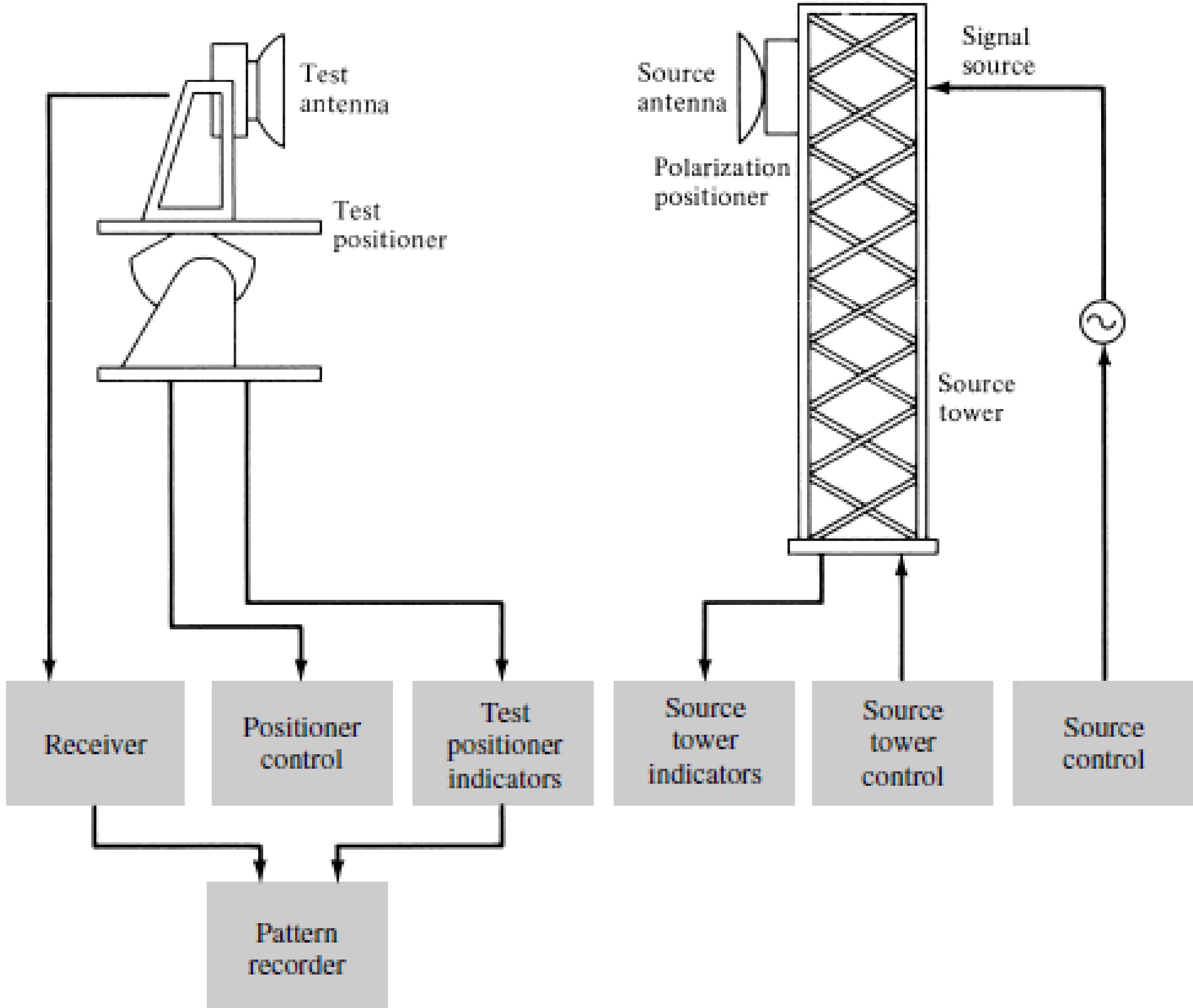
- Spherical coordinate system -> 3-dimensional pattern.
- Impractical to obtain 3-d pattern.
- Alternatively, a number of 2-d patterns (pattern cuts) are measured and used to construct 3-d.
- To obtain pattern cuts:
  - Fix ϕ and vary θ. -> Elevation patterns
  - Fix θ and vary ϕ. –> Azimuthal patterns.



Instrumentation

Classification of instrumentations:

1. Source antenna & Transmitting system
2. Receiving system
3. Positioning system
4. Recording system
5. Data-processing system

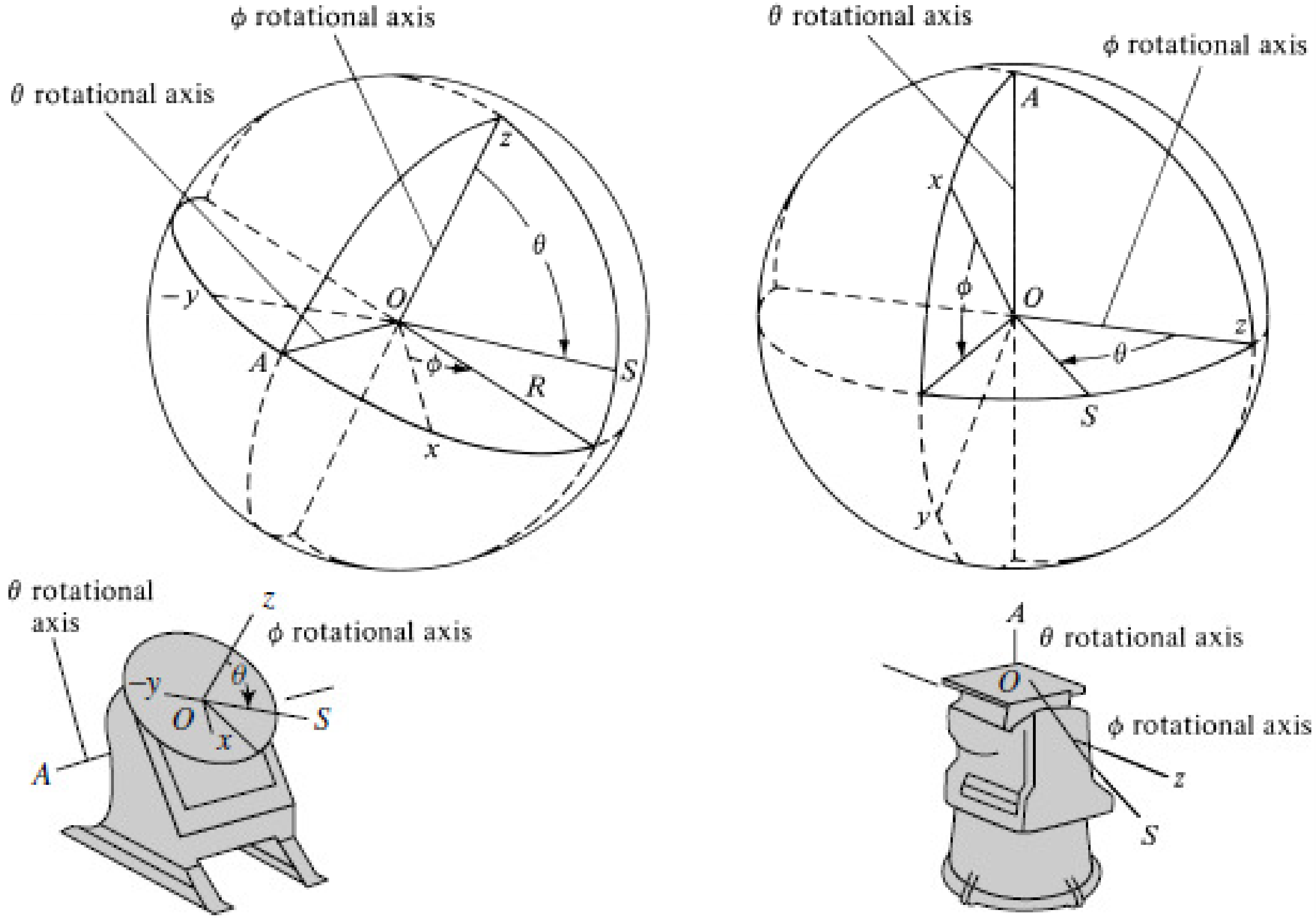


Instrumentation (2)

- Source antenna : typically log-periodic antenna, parabolas with broadband feeds, horn antenna; polarization must be controllable.
- Source : frequency control, frequency stability, spectral purity, power level, and modulation.
- Receiving system : bolometer detector, amplifier, recorder; or a heterodyne system.
- Recording system : linear plot or polar plot; record relative field or power patterns -> relative pattern.

Instrumentation (3)

- Positioning system : must be capable to rotate in various planes to generate pattern cuts.

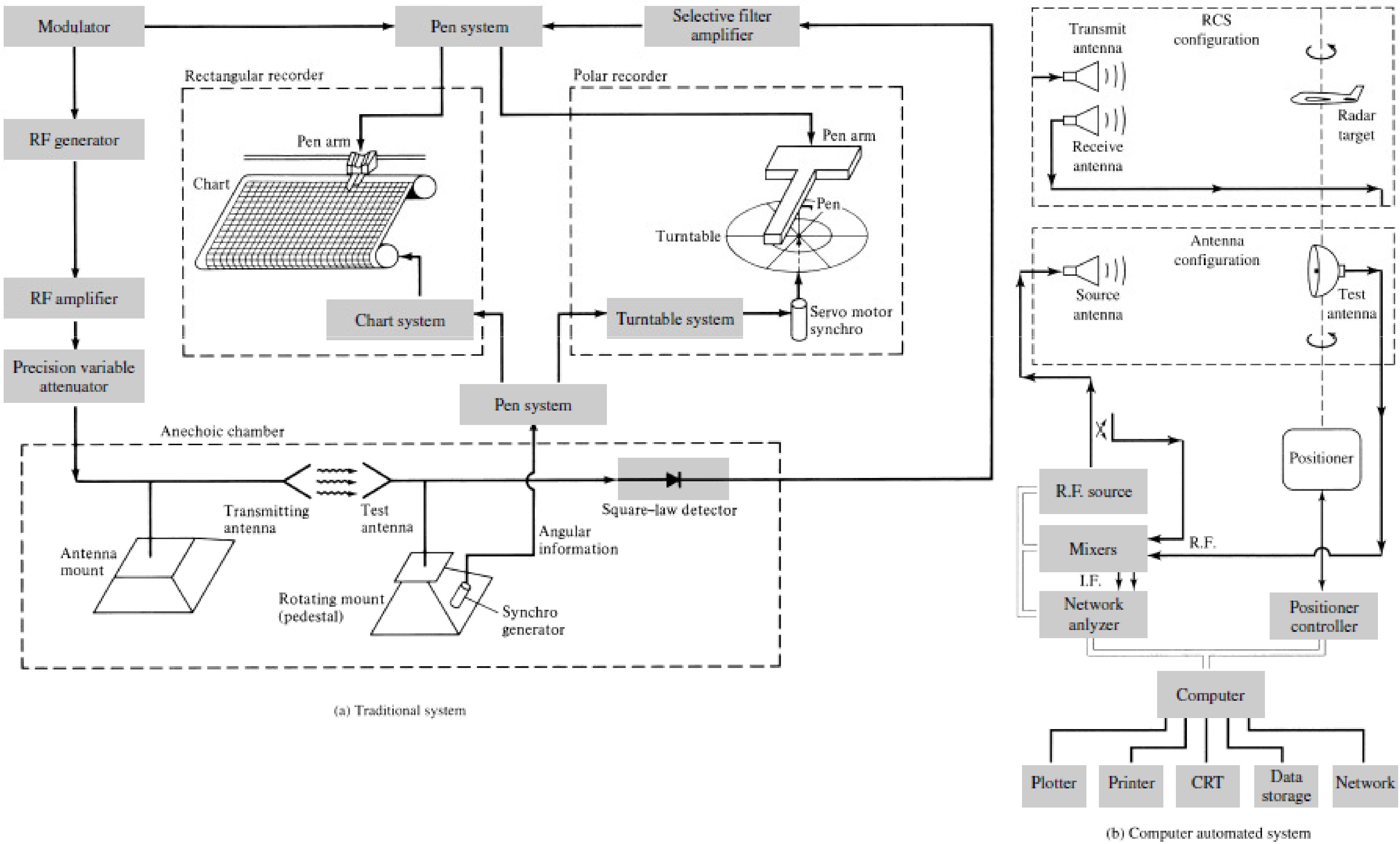


(a) Azimuth-over-elevation positioner

(b) Elevation-over-azimuth positioner

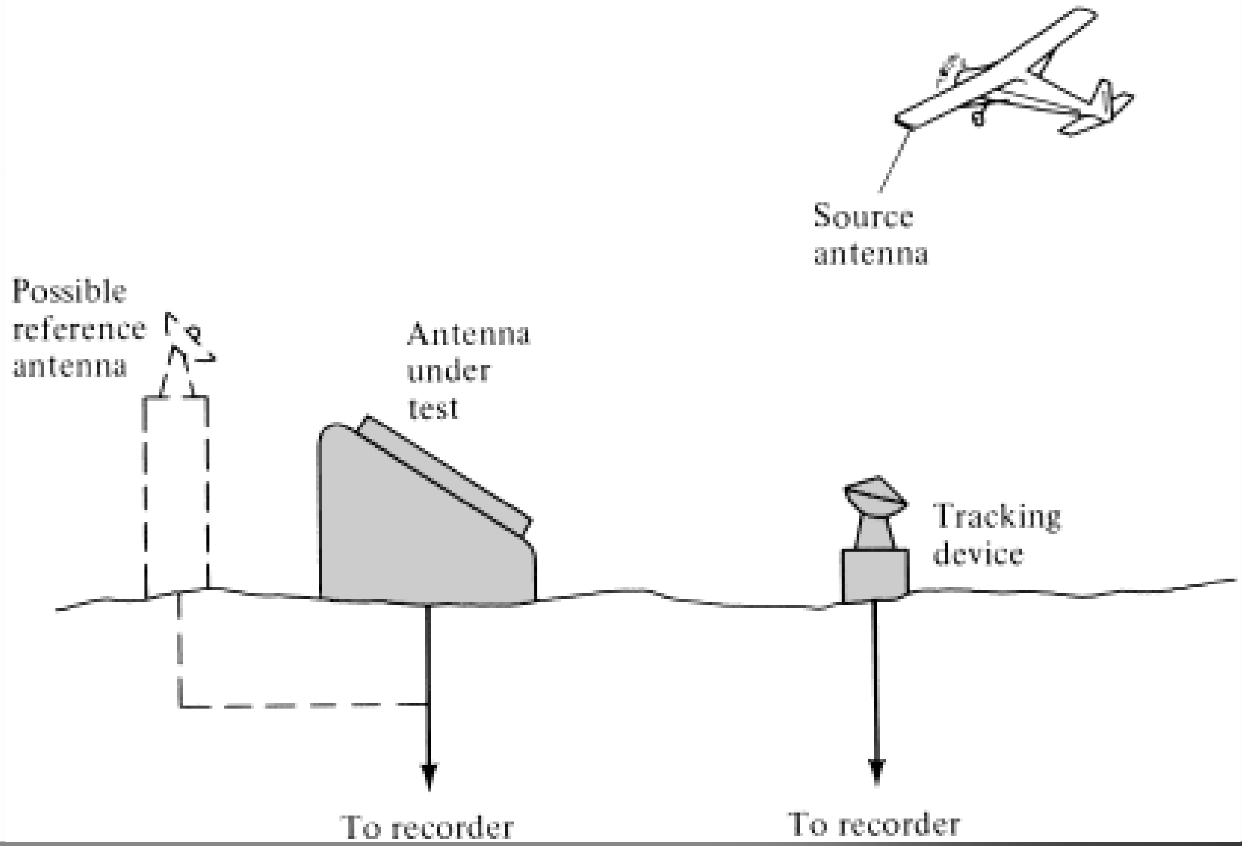
Instrumentation (4)

- Typical systems for measuring antenna & RCS pattern.



Amplitude Pattern

- Amplitude pattern = vector sum of two orthogonally polarized field components. Can be measured using same system as radiation pattern measurement.
- *In situ* measurement : preserve environmental performance characteristics.

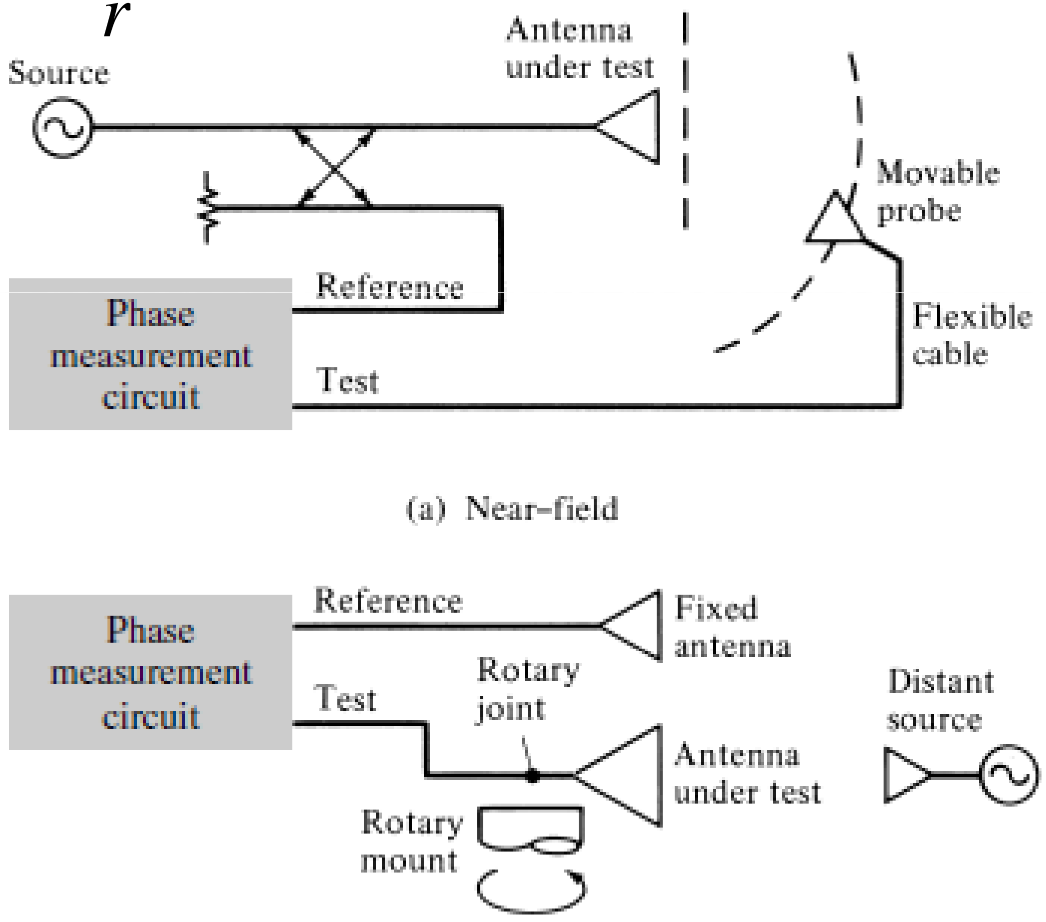


Phase Measurements

- In general, far-field component given by

$$\mathbf{E}_u = \hat{\mathbf{u}} E(\theta,\phi) e^{j\psi(\theta,\phi)} \frac{e^{-jkr}}{r}$$

- E, ψ : amplitude, phase
- Phase is “periodic”.
- Need reference.



(a) Near-field

(b) Far-field

Gain Measurements

- Two basic methods: *absolute-gain* and *gain-transfer*.
- Absolute-gain used to calibrate antennas that can be used as standards for gain measurements and requires no *a priori* knowledge of the gains.
- Gain-transfer (or gain-comparison) used in conjunction with standard gain antennas to determine absolute gain of the antenna under test.
- Typical antennas used for gain standards:
  - Resonant $\lambda/2$ dipole (gain around 2.1 dB) : broad pattern, affected by surrounding environments.
  - Pyramidal horn antenna (gain 12-25 dB) : very directive, less affected by environments.

Absolute Gain : 2-antenna

- Gain equation: $$(G_{0t})_{dB}+(G_{0r})_{dB}=20\log_{10}\left(\frac{4\pi R}{\lambda}\right)+10\log_{10}\left(\frac{P_r}{P_t}\right)$$

G_{0t}, G_{0r} : transmitting, receiving gains.

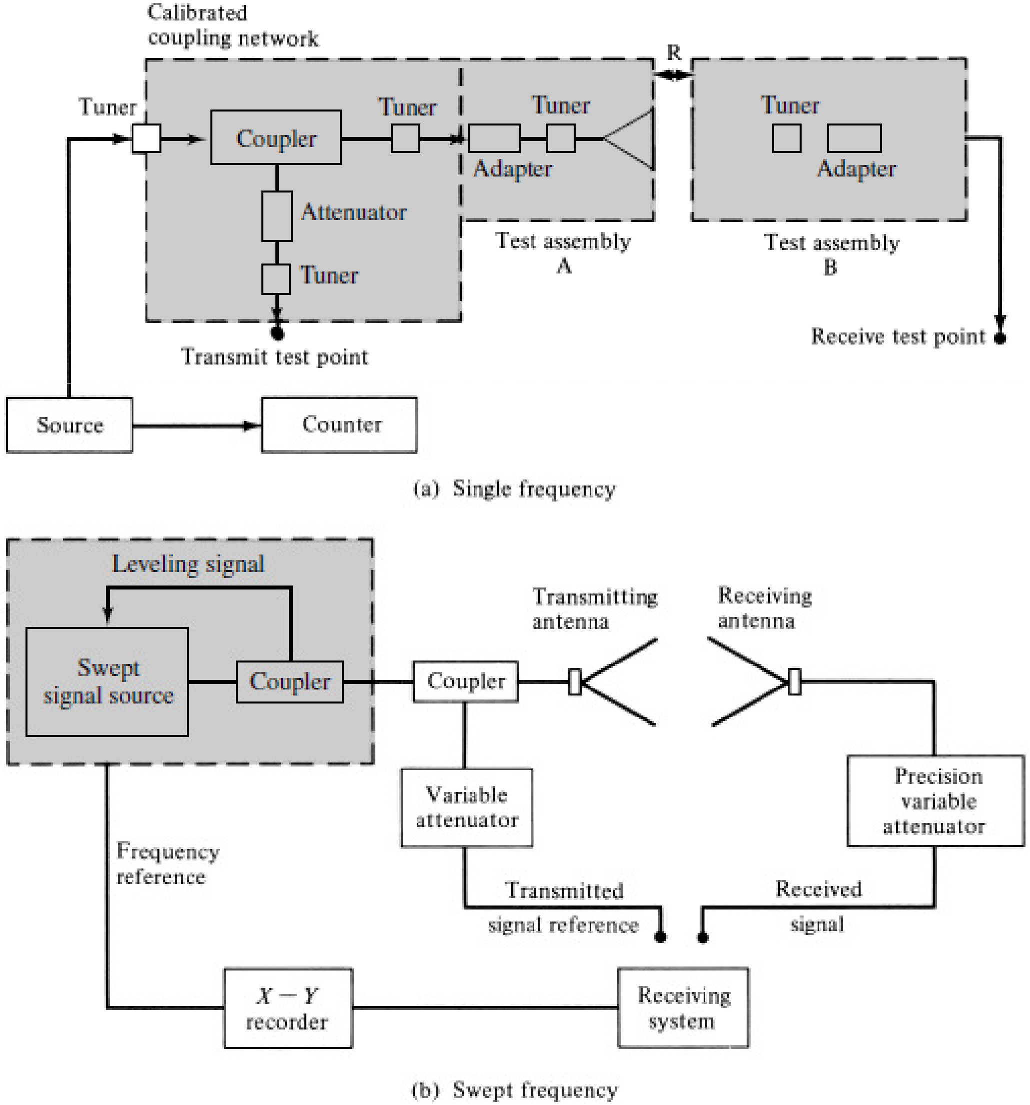
P_t, P_r : transmitting, receiving powers.

R : antenna separation

λ : wavelength

- For identical antennas:

$$(G_{0t})_{dB}=(G_{0r})_{dB}=\frac{1}{2}\left[20\log_{10}\left(\frac{4\pi R}{\lambda}\right)+10\log_{10}\left(\frac{P_r}{P_t}\right)\right]$$



Absolute Gain : 3-antenna

- 2-antenna method is not applicable for "nonidentical" antennas.
- Need 3 antennas with 3 following gain equations:

$$(G_a)_{dB} + (G_b)_{dB} = 20\log_{10}\left(\frac{4\pi R}{\lambda}\right) + 10\log_{10}\left(\frac{P_{rb}}{P_{ta}}\right)$$

$$(G_a)_{dB} + (G_c)_{dB} = 20\log_{10}\left(\frac{4\pi R}{\lambda}\right) + 10\log_{10}\left(\frac{P_{rc}}{P_{ta}}\right)$$

$$(G_b)_{dB} + (G_c)_{dB} = 20\log_{10}\left(\frac{4\pi R}{\lambda}\right) + 10\log_{10}\left(\frac{P_{rc}}{P_{tb}}\right)$$

Then solve for G_a, G_b, G_c.

•Homework #4 [pdf] Solution [pdf]

Gain Transfer

- Most commonly-used.
- Use *gain standards* to determine absolute gain.
- Use two set, first AUT as receiving antenna, second AUT replaced by standard gain antenna.

Test: $$(G_T)_{dB} + (G_0)_{dB} = 20\log_{10}\left(\frac{4\pi R}{\lambda}\right) + 10\log_{10}\left(\frac{P_T}{P_0}\right)$$

Standard: $$(G_S)_{dB} + (G_0)_{dB} = 20\log_{10}\left(\frac{4\pi R}{\lambda}\right) + 10\log_{10}\left(\frac{P_S}{P_0}\right)$$

Thus, $$(G_T)_{dB} = (G_S)_{dB} + 10\log_{10}\left(\frac{P_T}{P_S}\right)$$

Directivity Measurement

- **Simplest method:**
  1. Measure two principal *E*- and *H*-plane patterns.
  2. Determine half-power beamwidths of each pattern.
  3. Compute directivity using

$$D_0 = \frac{4\pi(180/\pi)^2}{\Theta_{1d}\Theta_{2d}} \quad \text{(2-27) OR} \quad D_0 = \frac{22.181(180/\pi)^2}{\Theta_{1d}^2 + \Theta_{2d}^2} \quad \text{(2-30b)}$$

- **Alternative method:**

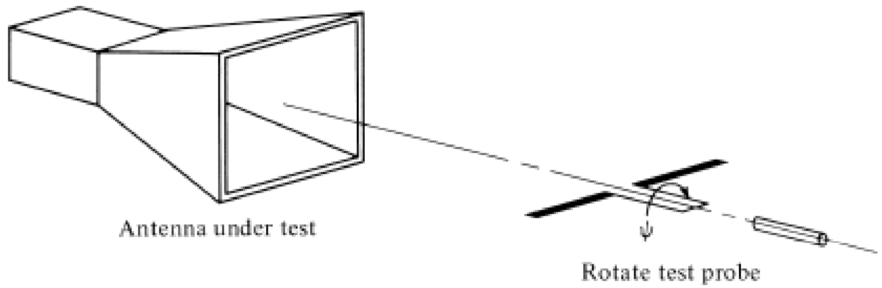
$$D_0 = \frac{4\pi U_{\max}}{P_{rad}}; P_{rad} = B_0\left(\frac{\pi}{N}\right)\left(\frac{2\pi}{M}\right)\sum_{j=1}^{M}\left[\sum_{i=1}^{N} F(\theta_i, \phi_j)\sin\theta_i\right]$$

- **If there are both θ and ϕ components:**

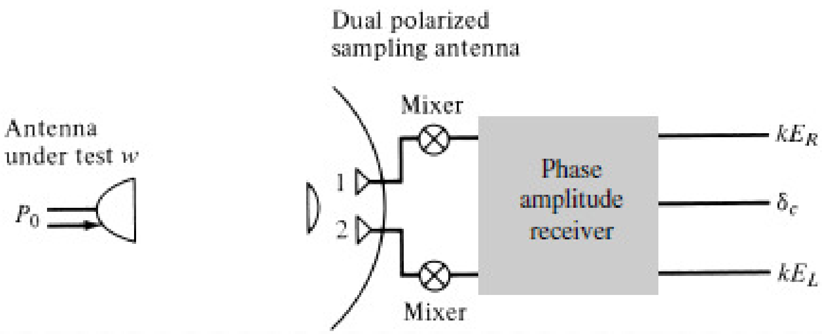
$$D_0 = D_\theta + D_\phi; D_{\{\theta,\phi\}} = \frac{4\pi U_{\{\theta,\phi\}}}{(P_{rad})_\theta + (P_{rad})_\phi}$$

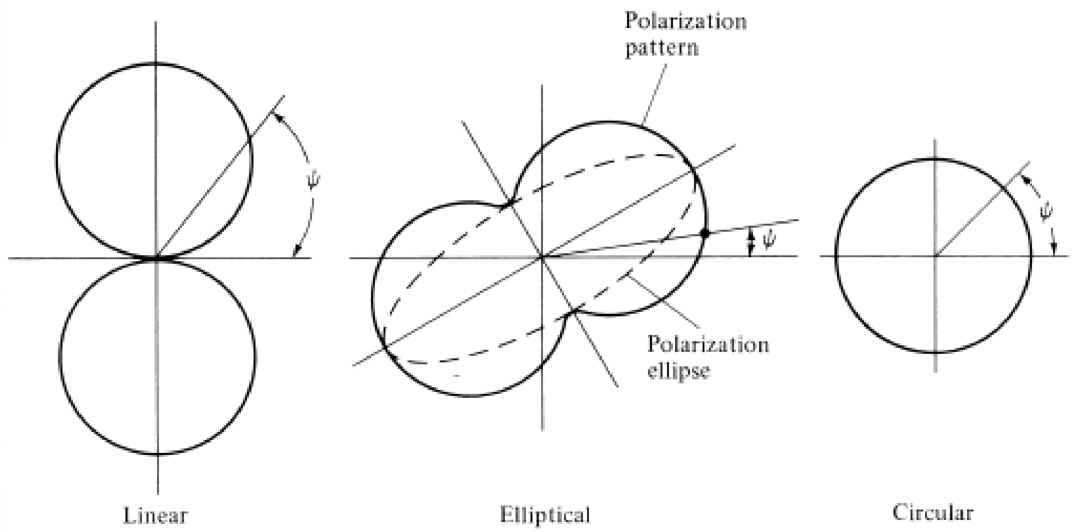
Polarization Measurement

- *Polarization-pattern method.*
- Need additional measurement to determine sense of rotation:
  - Use two antennas:
  CW & CCW.
  - Use dual-polarized probe.



(a) Measuring system





(b) Typical patterns

Impedance Measurement

- Two types of impedances : Self and Mutual
- If antenna radiating into unbounded medium, i.e. *no coupling*, Self-impedance = driving-point impedance.
- If there's coupling between AUT and other sources or obstacles, driving-point impedance is a function of both self and mutual impedances.
- In practice, driving-point impedance = input impedance
- Typically, use vector network analyzer (VNA), slotted lines.

Scale Model Measurement

- In many applications (e.g., aircraft, ship, etc.), antennas and structures are too "large" in weight/size to move.
- Furthermore, moving changes environments.
- Use *Geometrical scale modeling* to
  - physically accommodate, within small ranges, measurements that can be related to large structures.
  - experimental control,
  - minimize costs.
- Need "exact" replicas, physically & electrically.

TABLE 17.1 Geometrical Scale Model

Scaled Parameters		Unchanged Parameters	
Length:	$l' = l/n$	Permittivity:	$\epsilon' = \epsilon$
Time:	$t' = t/n$	Permeability:	$\mu' = \mu$
Wavelength:	$\lambda' = \lambda/n$	Velocity:	$\upsilon' = \upsilon$
Capacitance	$C' = C/n$	Impedance:	$Z' = Z$
Inductance:	$L' = L/n$	Antenna gain:	$G_0{}' = G_0$
Echo area:	$A_e{}' = A_e/n^2$		
Frequency:	$f' = nf$		
Conductivity:	$\sigma' = n\sigma$		