Today isn’t so bad…
It’s a sign that I
somehow survived on Monday..

Hello Tuesday

Chapter 2

Antenna Parameters

http://ee.ump.edu.my/hazlina/#portfolio

Home Updates Portfolio Universiti Malaysia PAHANG Research Outreach Contacts

UQD 2011 Robocon | BEE 4433 Antenna & Propagation | BEE 4433 Taught Subjects

Antenna & Propagation (BEE4433) - 1819 II - *updated on Feb 10th 2019*
UMP Syllabus

This course covered: Antenna fundamentals, Antenna parameters, Antenna impedance matching techniques, Practical antenna design, Antenna measurement technique and Introduction to Radio wave Propagation.

Lesson Plan

Teaching Materials	
1. Introduction to Antenna	notes
2. Basic Antenna Parameters	notes1 notes2 notes3 SmithChart tut_1Q tut_1A tut_2Q tut_2A tut_Obj tut_SChart Q tut_SChart A
3. Array Antenna	notes tut_QA
4. Broadband Antenna	notes
5. Microwave Antenna	notes tut_uScript Q tut_uScript A
6. Antenna Measurement	notes
7. Introduction to Radiowave Propagation	notes

* Exam Requirements: List of Formulas SmithChart

Useful Links	
VSWR	Visualization on VSWR youTube Finding VSWR using Smith Chart youTube
Smith Chart	Finding values on Smith Chart youTube Reflection Coefficient using Smith Chart youTube

Desktop

Antenna Parameters (1)

- Frequency
- Radiation Pattern
- Field Regions
- Directivity
- Antenna Efficiency

Antenna Parameters (2)

- Antenna Gain
- Beamwidths and Sidelobes
- Impedance
- Radiation Intensity
- Polarization

Introduction

Antenna Fundamentals

- To design an antenna... “We need to know what is the desired frequency, gain, bandwidth, impedance, and polarization?“

- Before we can design an antenna or discuss antenna types, we must understand the basics of antennas, which are the fundamental parameters that characterize an antenna.

- So let us learn something. We'll start with frequency and step through radiation patterns, directivity and gain, and so on..

Let’s get started..

Overview of what is antenna?

- In wireless communication systems, an RF signal generated by a transmitter is sent into free space and eventually picked up by a receiver.
- The interface between the transmitter and free space and between free space and the receiver is the **antenna**.
- Antenna is the device for radiating or receiving electromagnetic wave in free space.
- The antenna is the interface between transmission lines and free space.
- The simple antenna is the isotropic antenna but it is not practical to built.
- The practical antenna is a half-wave dipole antenna.

Radio Waves

- A radio signal is called an *electromagnetic wave* because it is made up of both electric and magnetic fields.
- Whenever voltage is applied to the antenna, an electric field is set up. At the same time, this voltage causes current to flow in the antenna, producing a magnetic field.
- The electric and magnetic fields are at right angles to each other.
- These electric and magnetic fields are emitted from the antenna and propagate through space over very long distances at the speed of light.

Frequency

- The basics of sinusoids (sine and cosine waves), wavelength, frequency and the speed of light.
- All electromagnetic waves propagate at the same speed in air or in space. This speed (the speed of light) is roughly 671 million miles per hour (1 billion kilometers per hour). This is roughly a million times faster than the speed of sound (which is about 761 miles per hour at sea level).
- The speed of light will be denoted as c in the equations that follow. We like to use "SI" units in science (length measured in meters, time in seconds, mass in kilograms), so we will forever remember that:

$$c = 300{,}000{,}000 \frac{\text{meters}}{\text{second}}$$

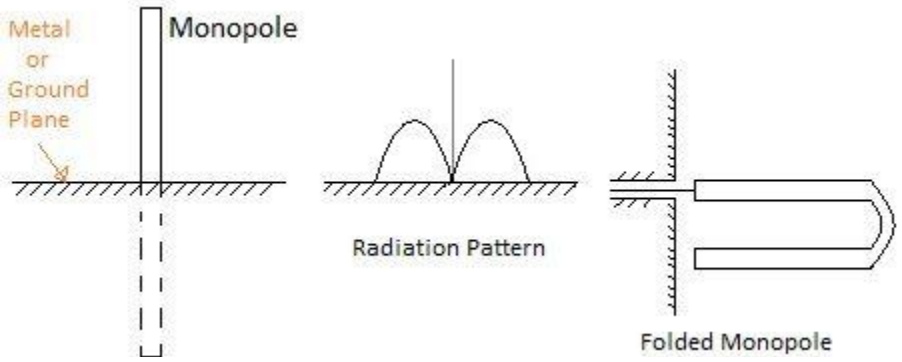
where $c = 3x10^8\ m/s$ (speed of light in vacuum)

Monopole vs Dipole Antennas

The monopole and dipole antennas are used for cellular phones, broadcasting and wireless communications due to their omnidirectional property.

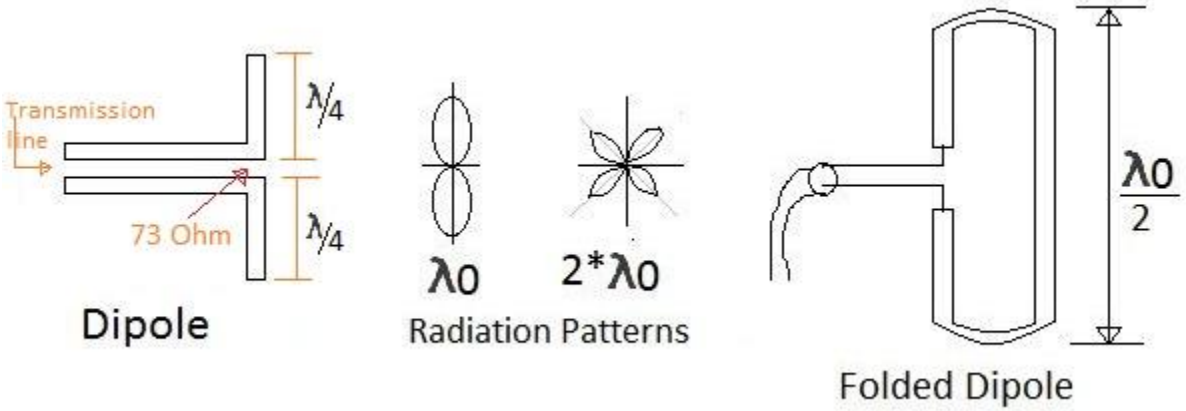
- Monopole

  Figure 1



- Dipole

  Figure 2



Monopole

- Figure 1 depicts **monopole antenna** with its radiation pattern. It also depicts folded monopole antenna. The monopole antenna has image through a metal or ground plane.

- There are variations to monopole antenna which will provide antennas of inverted-L and inverted-F types. These type of monopole antennas are used for hand held portable telephones.

Dipole

- Figure 2 depicts **dipole antenna** with its radiation pattern. It also depicts folded dipole antenna.
- The most common dipole antenna is a half-wave dipole which is a piece of wire or rod which is one half wavelength in length.
- The antenna is cut into two quarter wavelength sections. The transmission line is connected at center point as shown. The dipole antenna has an impedance of about 73 Ohm.
- The radiation pattern of half wave dipole antenna has shape of doughnut. For multiple of λ radiation pattern changes as shown in the figure2.
- The max gain of a typical half-wavelength dipole antenna is 2.15dB.

Half-wave Dipole Antenna

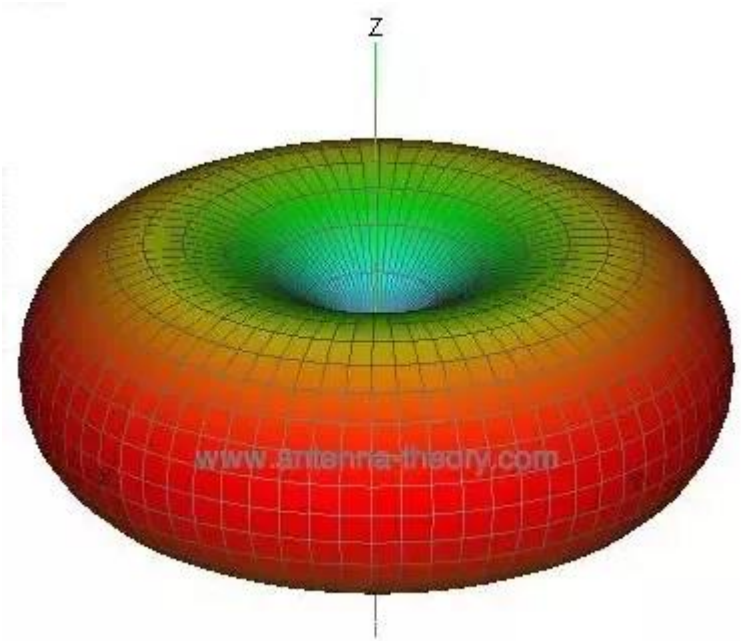
- The half-wave dipole antenna is just a special case of the dipole antenna.
- Half-wave term means that the length of this dipole antenna is equal to a half-wavelength at the frequency of operation.
- The dipole antenna, is the basis for most antenna designs, is a balanced component, with equal but opposite voltages and currents applied at its two terminals through a balanced transmission line.

Radiation Pattern

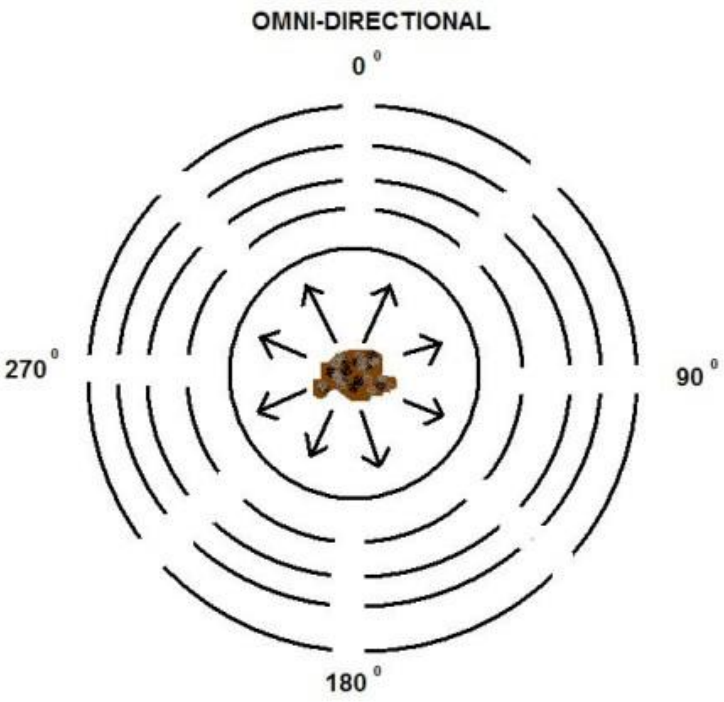
- Radiation pattern provide information that describe how an antenna directs the energy it radiates.
- It determine in the far field region
- A math and/or graphical representation of the radiation properties of an antenna such as the
  - Amplitude
  - Phase
  - Polarization, etc
- As a function of the angular space coordinates θ, Φ

Radiation Pattern

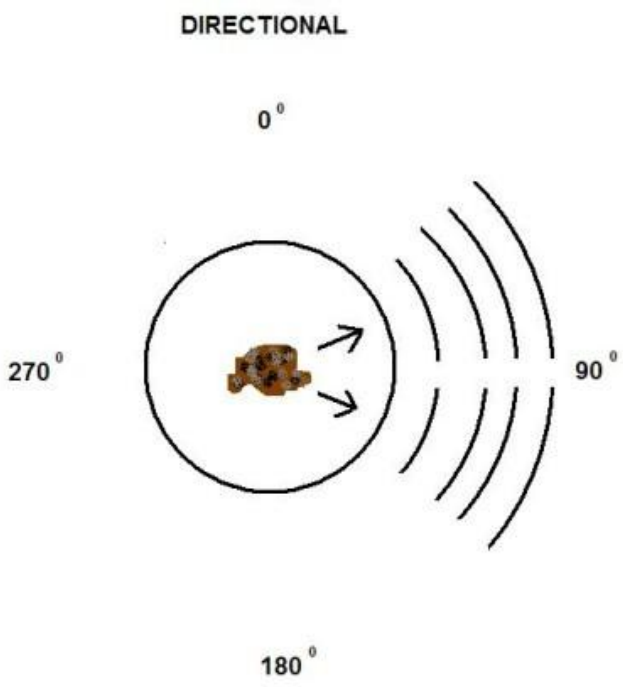
- Dipole radiation pattern



Omindirectional vs directional



EXAMPLE 1

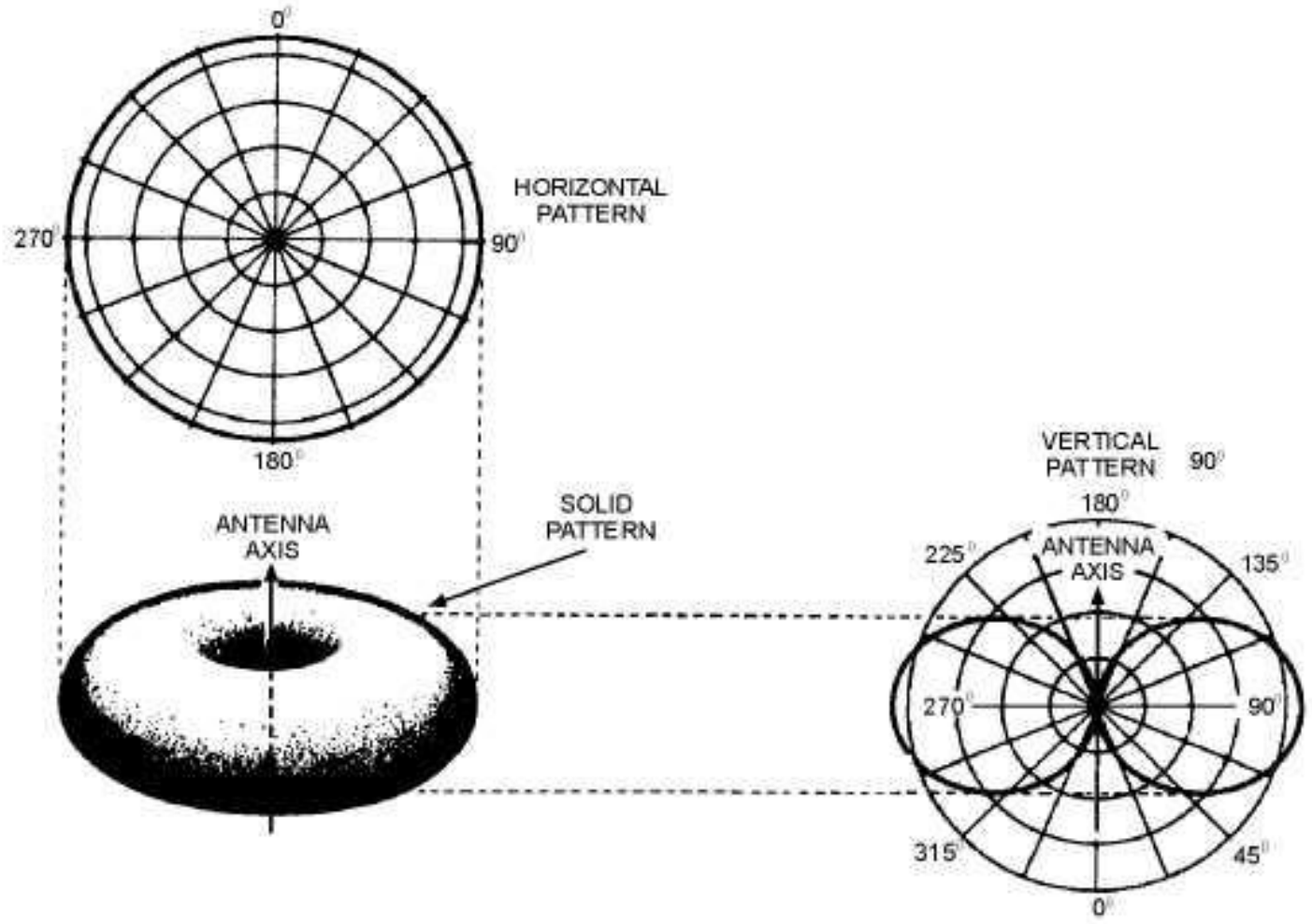


EXAMPLE 2

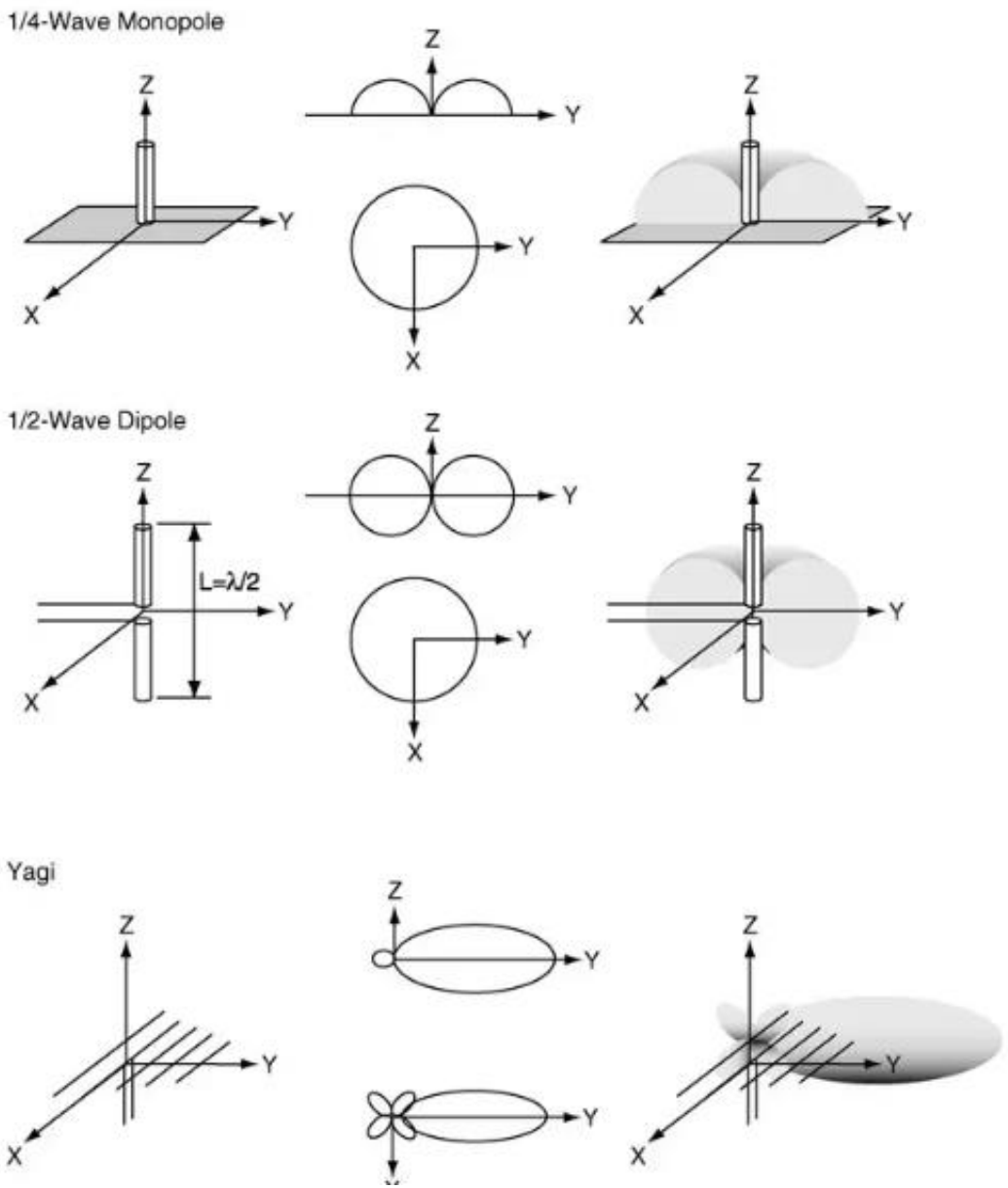
Terminology

- Think of the ripple that is created when a person throws a stone in the middle of a calm body of water (such as a pond). As the rock enters the water it causes the water all around it to rise and creates a ripple in the water.
- Example 1 shows an “Omni-directional” wave where the wave is traveling from the rock to the shore equally in all directions.
- Example 2 shows a “Directional” wave where the wave is traveling from the rock to the shore in a defined direction

Dipole Radiation pattern

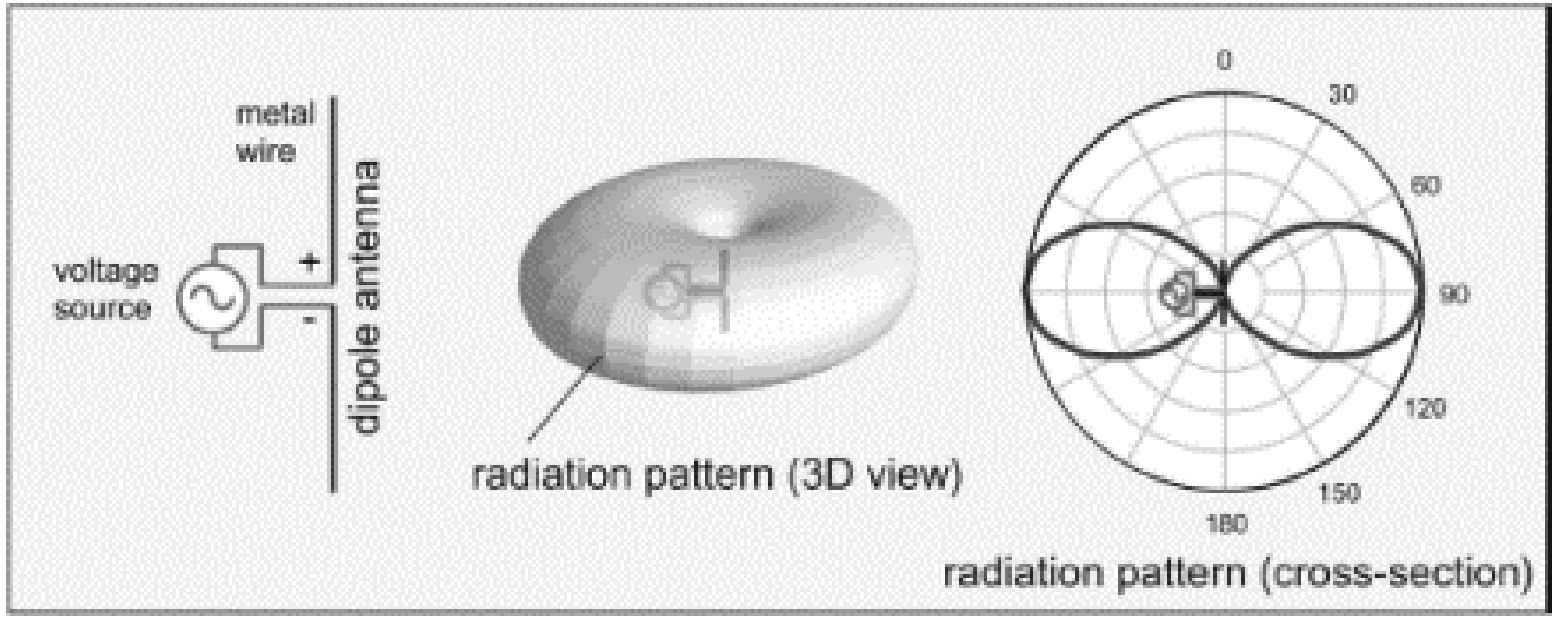


Example of Radiation Pattern

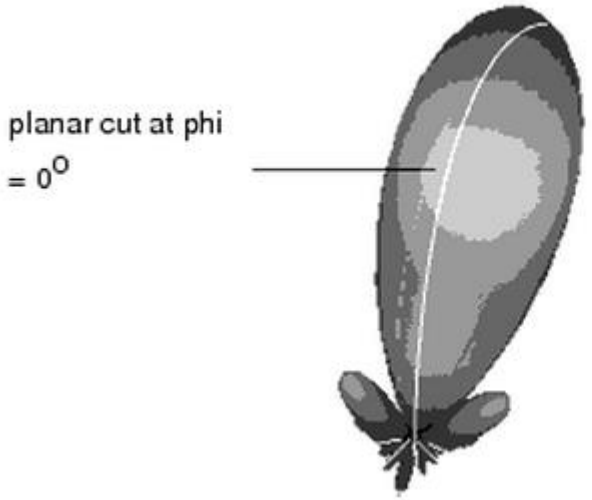


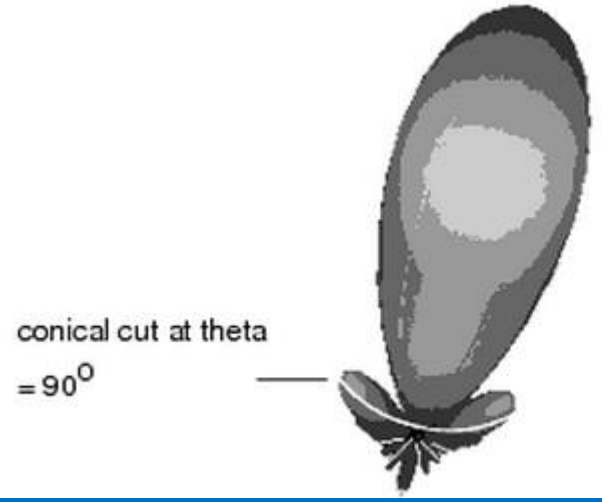
Radiation Pattern

- *Dipole Antenna with Views of the Corresponding Radiation Pattern*



Cutting Plane





Radiation Pattern

- Normalised radiation pattern ($E_\theta/E_\theta max$) can plotted in:
  - polar and rectangular (Cartesian) plots
  - linear (ratio) and logarithmic (dB) scales
  - main lobe (main beam), side lobes (minor lobes), nul
  - HPBW and FNBW

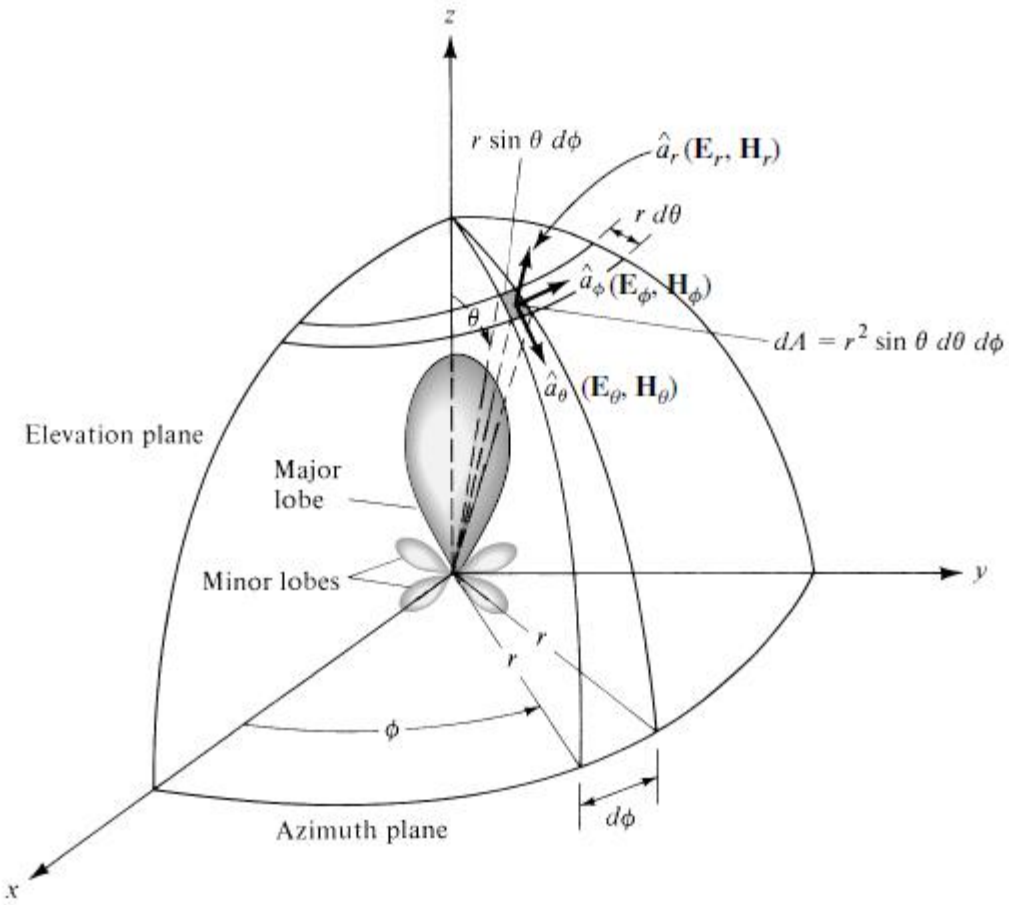
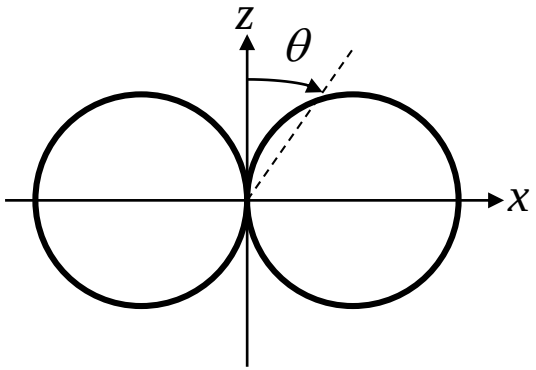


Figure 2.1 Coordinate system for antenna analysis.

E-Plane and H-Plane

E plane (elevation)

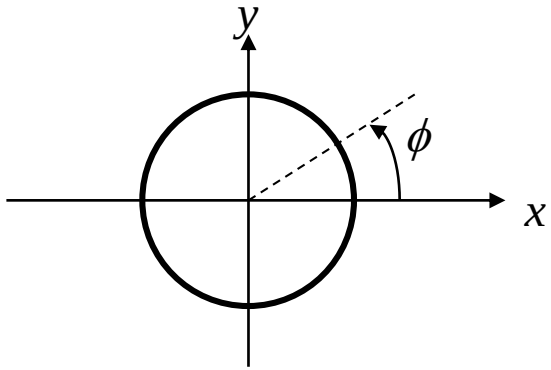
- Electromagnetic field is in vertical plane
- θ= 90°
- 0°<Φ<90°, 270°<Φ<360°



E-plane

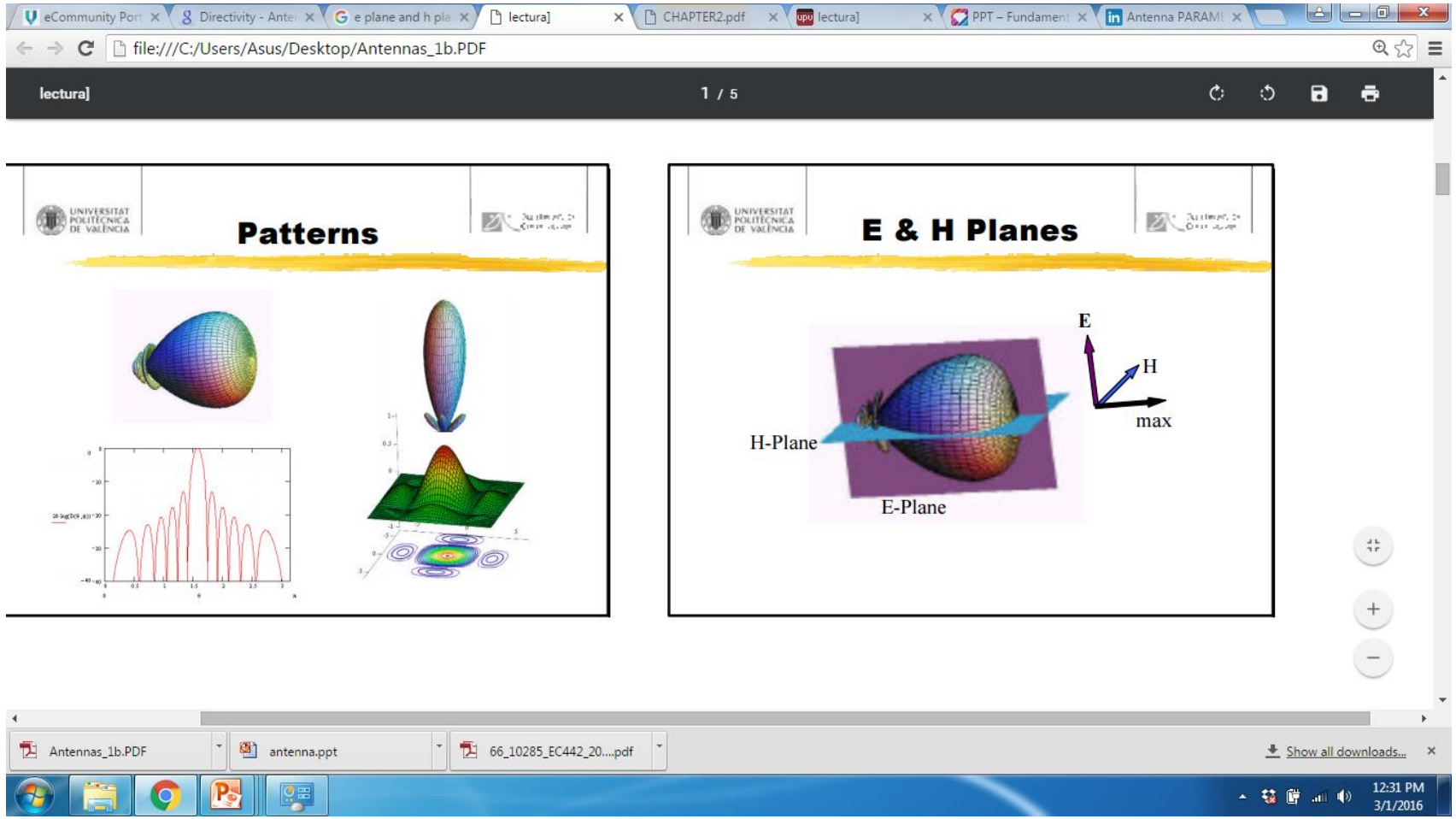
H plane (azimuth)

- Electromagnetic field is in horizontal plane
- 0° < θ < 180°
- Φ = 0°



H-plane

E-Plane and H-Plane



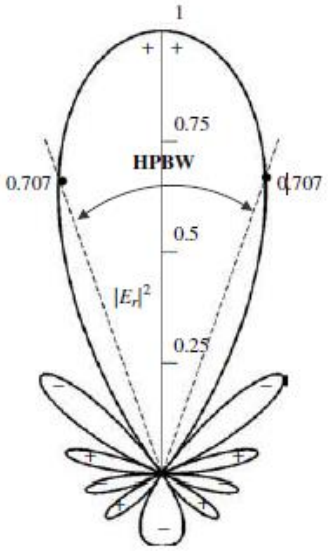
Types of radiation pattern

Field pattern

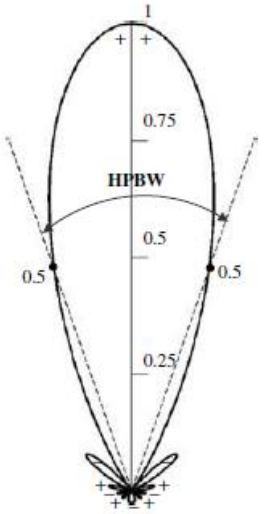
- *in linear scale*
- typically represents a plot of the magnitude of the electric or magnetic field as a function of the angular space.

Power pattern

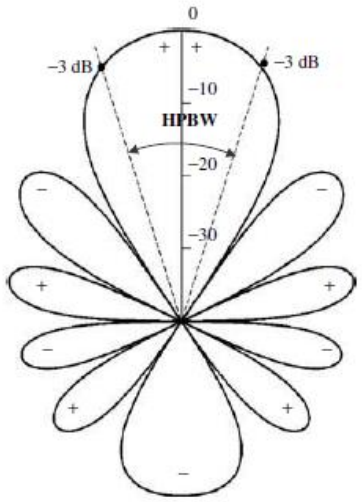
- in linear scale and in dB scale
- typically represents a plot of the square of the magnitude of the electric or magnetic field as a function of the angular space.



(a) Field pattern (in linear scale)



(b) Power pattern (in linear scale)



(c) Power pattern (in dB)

Radiator

- Isotropic Radiator: A hypothetical lossless antenna having equal radiation in all directions.

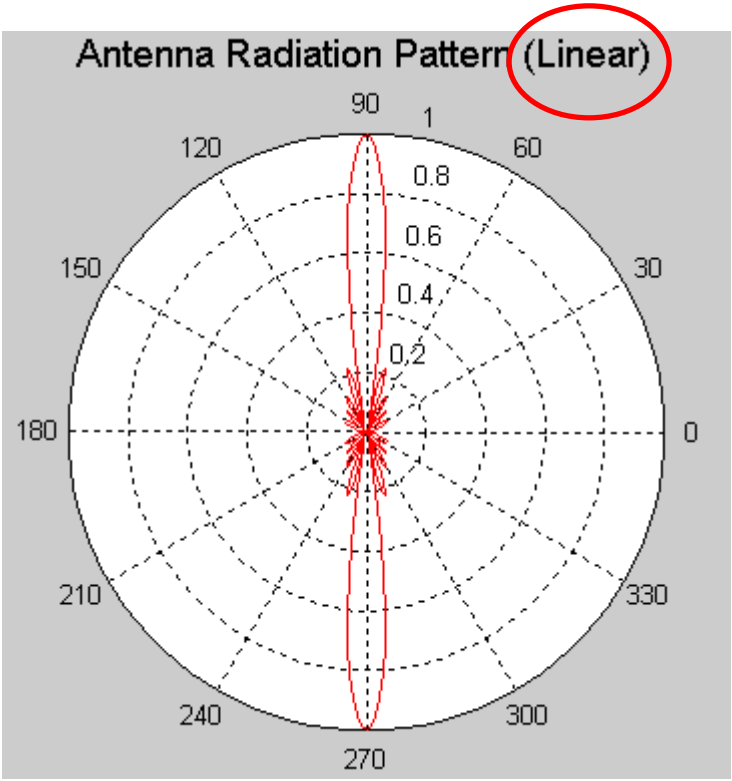
- **Omnidirectional** Radiator: An antenna having an essentially nondirectional pattern in a given plane (e.g., in azimuth) and a directional pattern in any orthogonal plane.

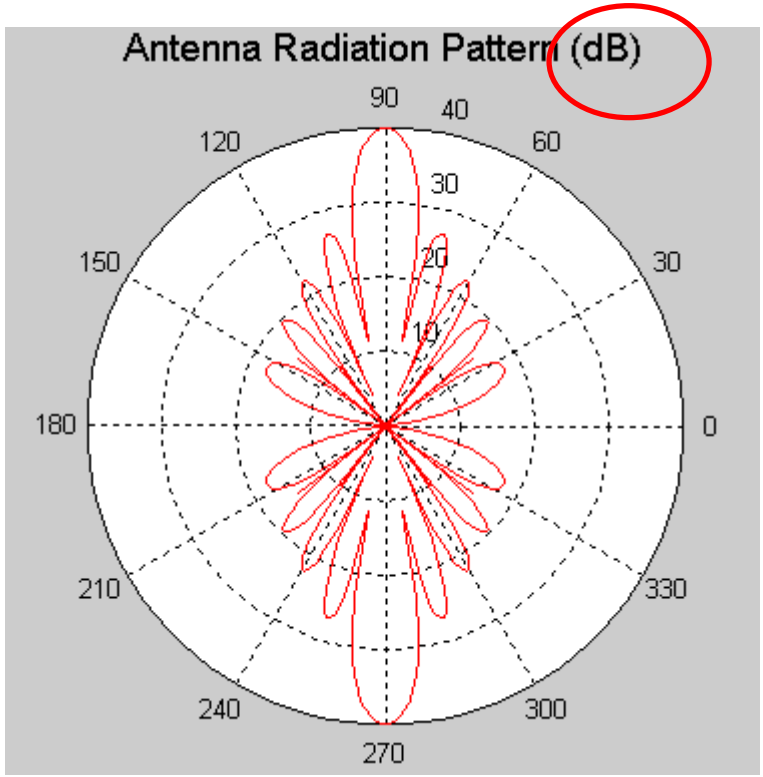
- **Directional** Radiator: An antenna having the property of radiating or receiving more effectively in some directions than in others. Usually the maximum directivity is significantly greater than that of a half-wave dipole.

Patterns

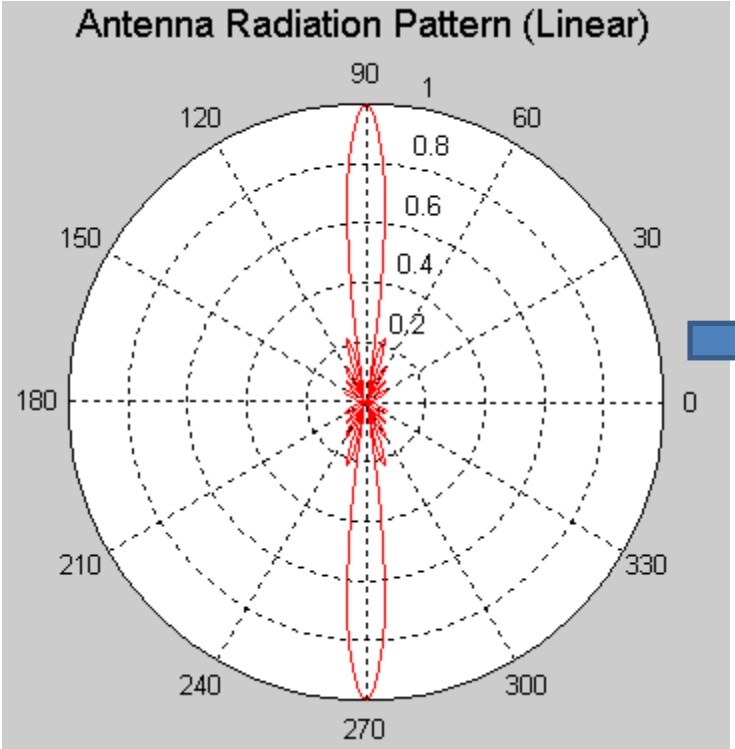
- GRAPHIC REPRESENTATION OF ANTENNA RADIATION PROPERTIES

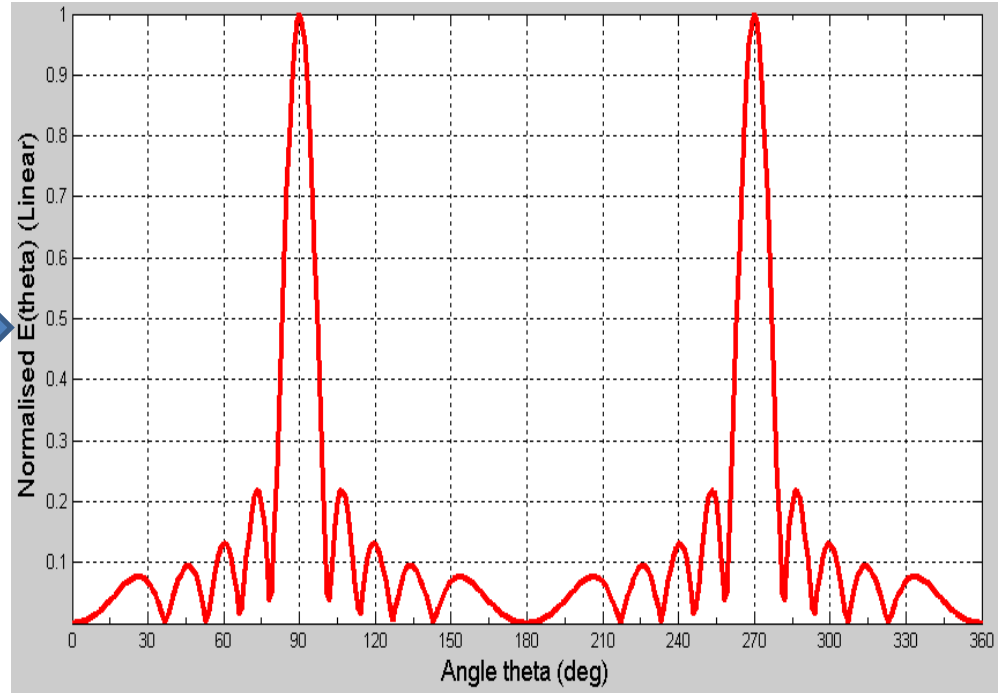
Polar Pattern



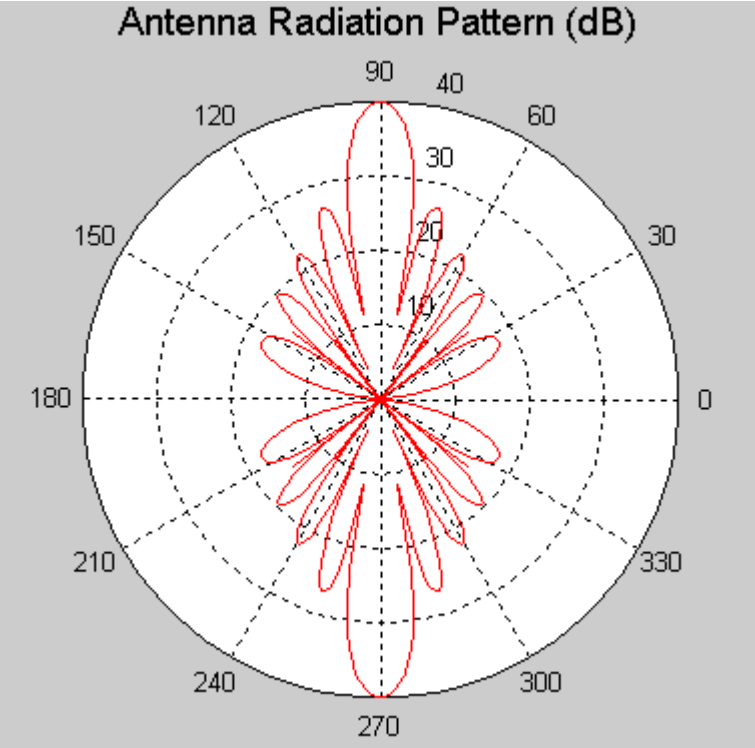


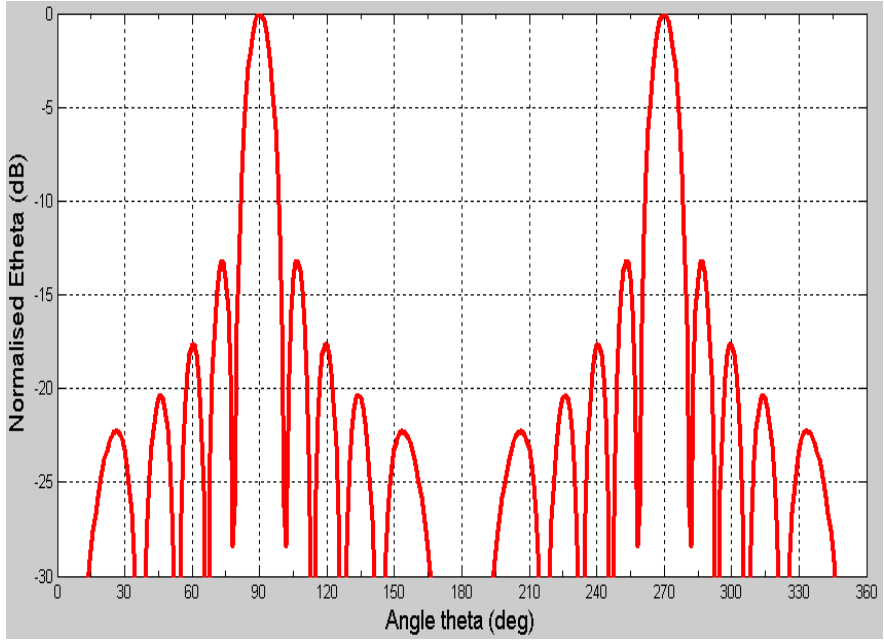
Rectangular/Cartesian Pattern



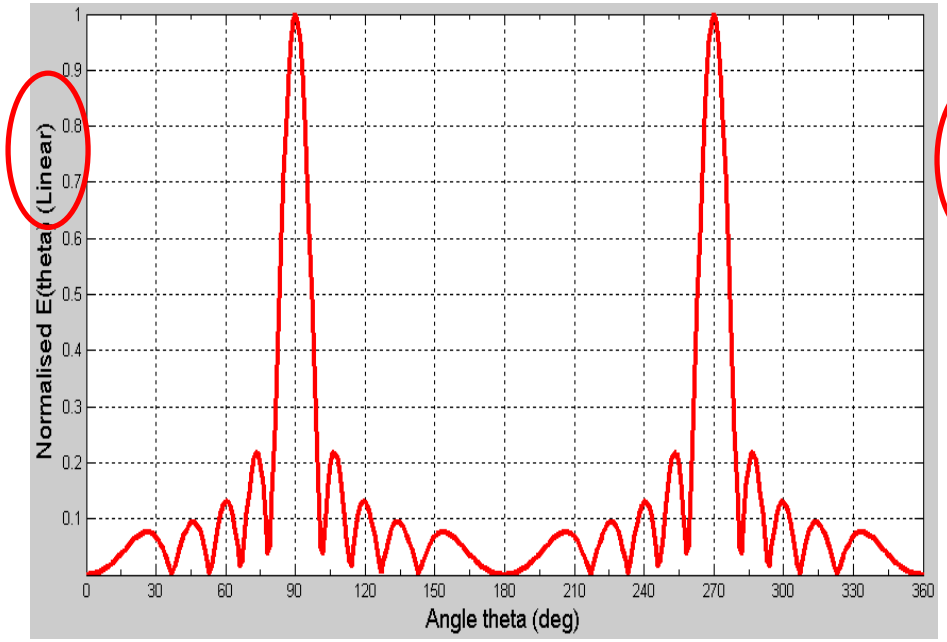


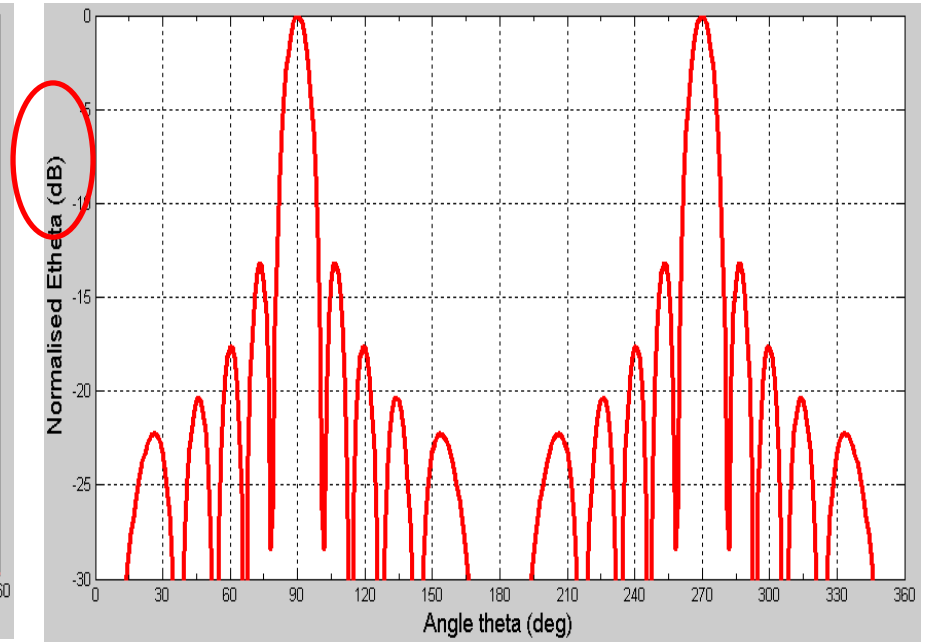
Rectangular/Cartesian Pattern





Rectangular/Cartesian Pattern





Lobes, nulls, and beamwidths (HPBW and FNBW)

Beam Efficiency (BE):
>90% for radiometry, astronomy, radar, etc.

$$BE = \frac{tx\_or\_rx\_power\_within\_FNBW}{total\_power\_tx\_or\_rx}$$

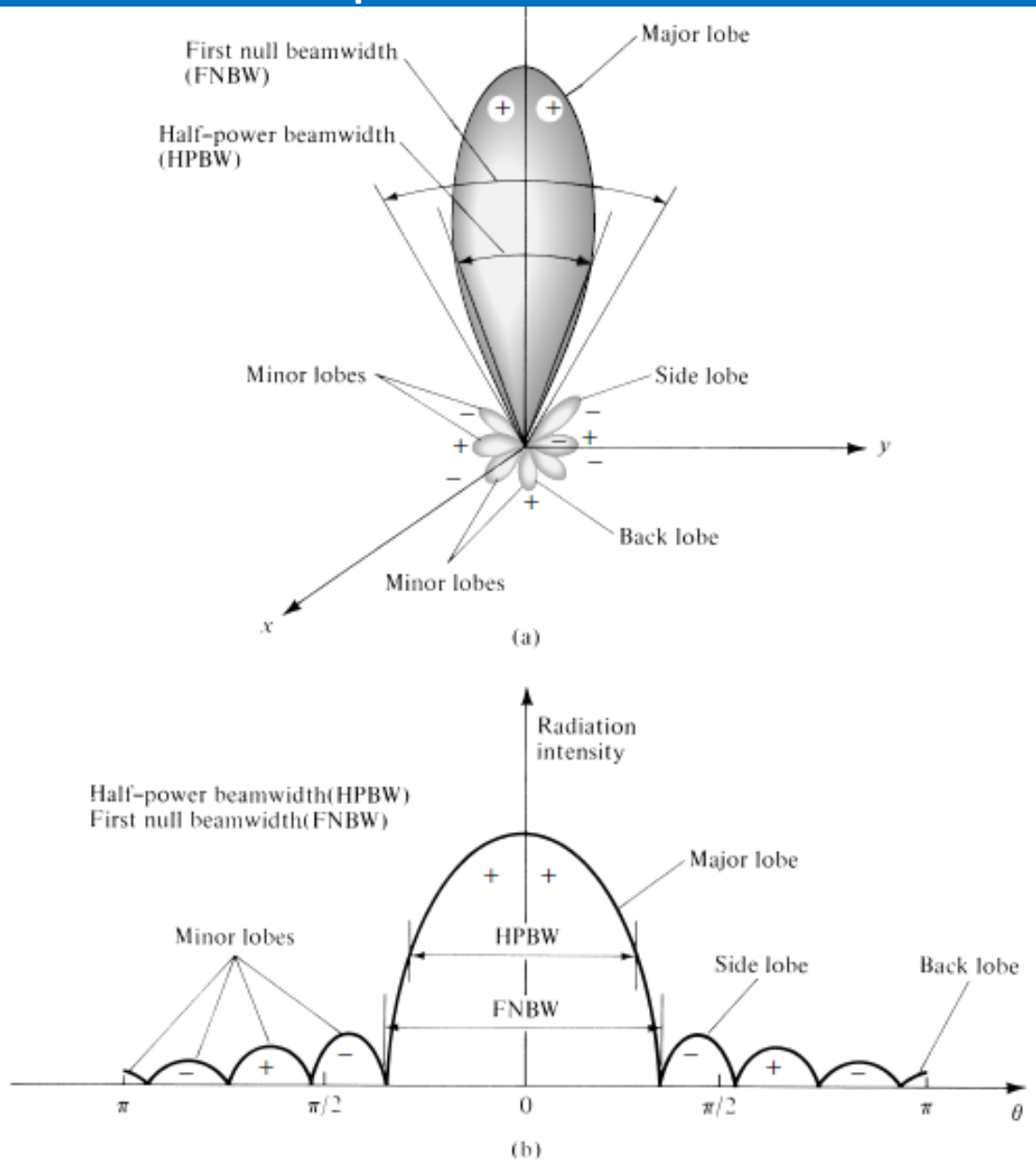
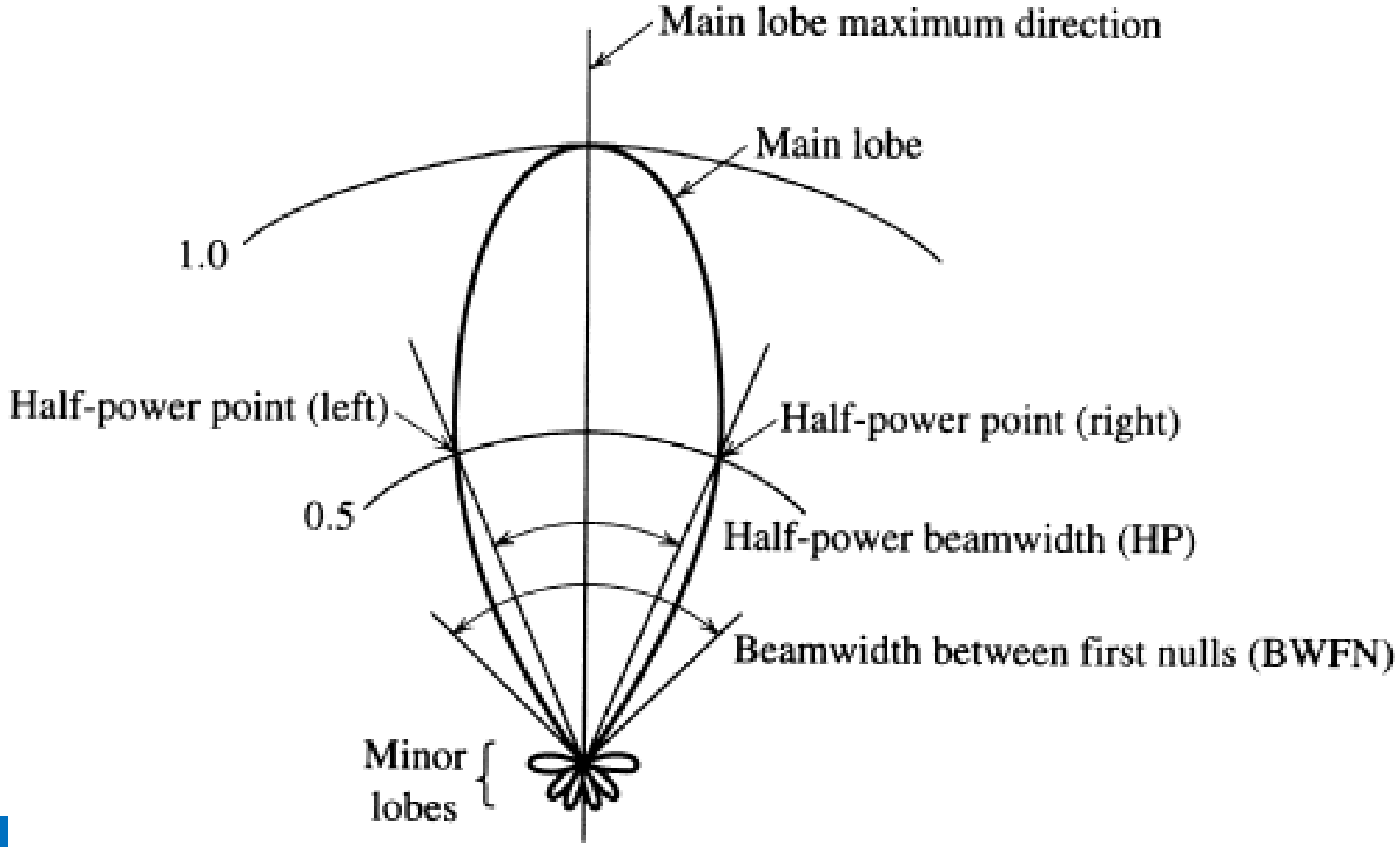
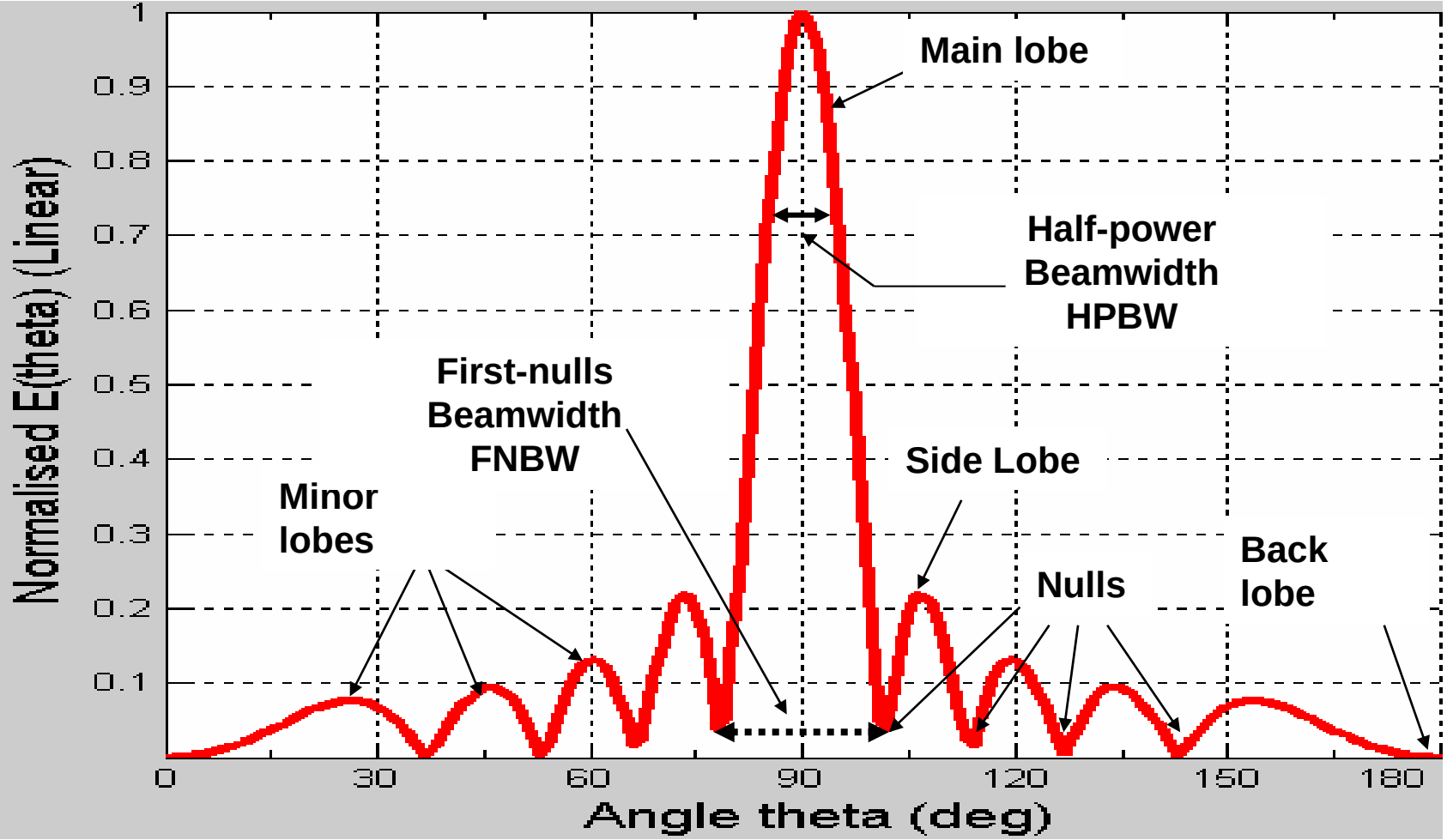


Figure 2.3 (a) Radiation lobes and beamwidths of an antenna pattern. (b) Linear plot of power pattern and its associated lobes and beamwidths.

Beamwidths


Main lobe maximum direction
Main lobe
1.0
Half-power point (left)
Half-power point (right)
0.5
Half-power beamwidth (HP)
Beamwidth between first nulls (BWFN)
Minor lobes

Radiation Properties



Beamwidth and Sidelobes

- A *major lobe* (also called main beam) is defined as "the radiation lobe containing the direction of maximum radiation."
  - the major lobe is pointing in the $\vartheta = 0$ direction. In some antennas, such as split-beam antennas, there may exist more than one major lobe.
- A *minor lobe* is any lobe except a major lobe and all the lobes with the exception of the major can be classified as minor lobes.
  - Minor lobes usually represent radiation in undesired directions, and they should be minimized.
- A *side lobe* is "a radiation lobe in any direction other than the intended lobe."
  - Usually a side lobe is adjacent to the main lobe and occupies the hemisphere in the direction of the main beam.
  - Side lobes are normally the largest of the minor lobes.
- A *back lobe* is "a radiation lobe whose axis makes an angle of approximately 180◦ with respect to the beam of an antenna."
  - Usually it refers to a minor lobe that occupies the hemisphere in a direction opposite to that of the major (main) lobe.

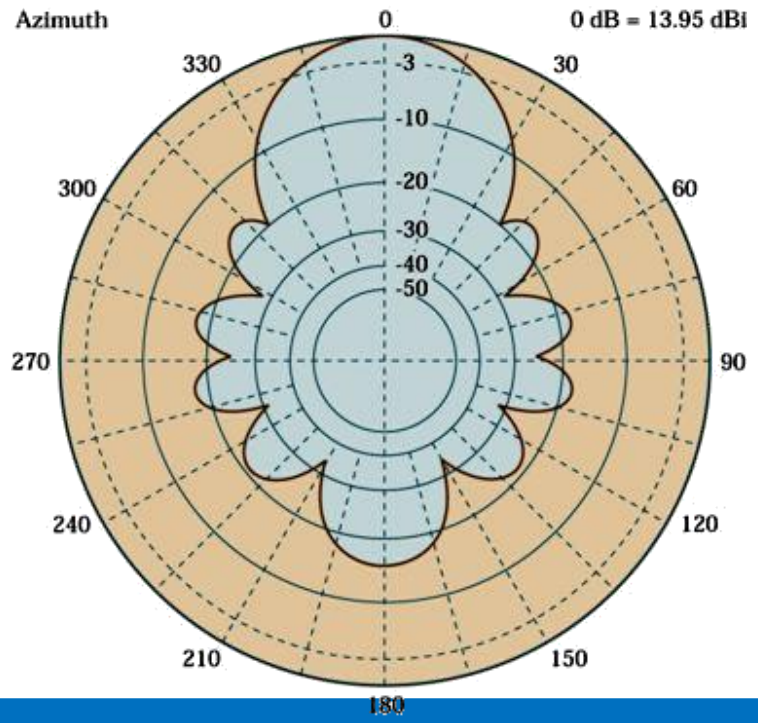
HPBW & FNBW

- The **Half Power Beamwidth (HPBW)** is the angular separation in which the magnitude of the radiation pattern decrease by 50% (or -3 dB) from the peak of the main beam.

- The **First Null Beamwidth (FNBW)** is the angular separation from which the magnitude of the radiation pattern decreases to zero (negative infinity dB) away from the main beam.

Front-to-Back Ratio

- The direction of maximum radiation is in the horizontal plane is considered to be the *front* of the antenna, and the back is the direction 180º from the front
- For a dipole, the front and back have the same radiation, but this is not always the case



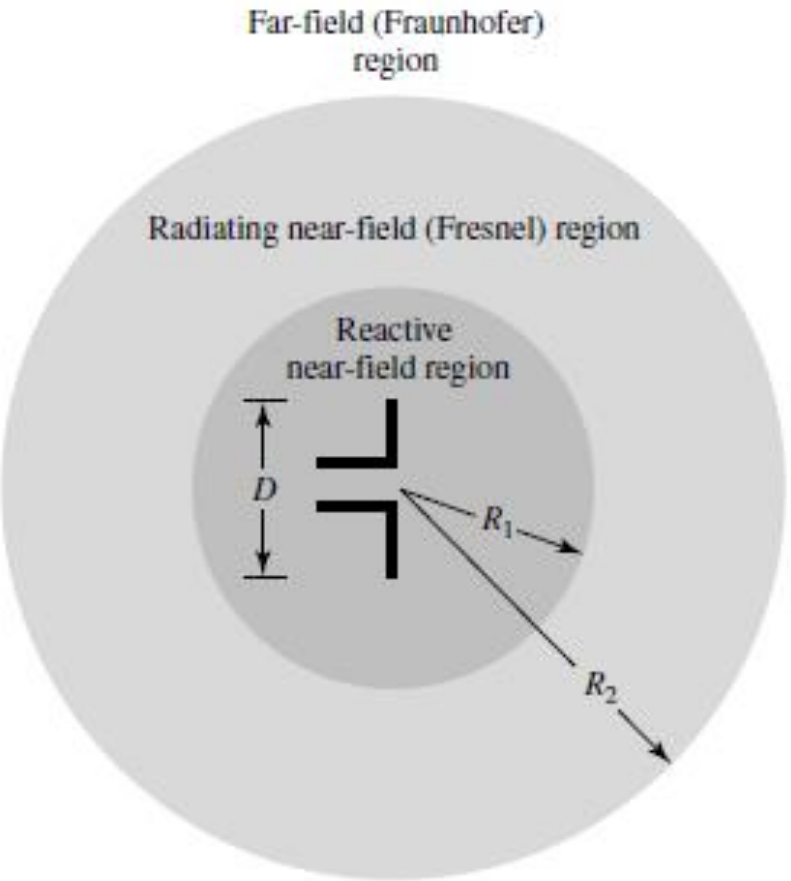
Field Region

The fields surrounding an antenna are divided into 3 principle regions:

- Reactive Near Field
- Radiating Near Field or Fresnel Region
- Far Field or Fraunhofer Region

- The far field region is the most important, as this determines the antenna's radiation pattern. Also, antennas are used to communicate wirelessly from long distances, so this is the region of operation for most antennas.

Field Regions



$R_1 = 0.62\sqrt{D^3/\lambda}$

$R_2 = 2D^2/\lambda$

Definition of Fields

1)Reactive Near Field
- Phase of electric & magnetic fields are often near quadrature; thus
  - High reactive wave impedance
  - High content of non-propagating stored energy near the antenna

2) Radiating Near Field
- Field are predominantly in phase
- Region where near-field measurements are made

3) Far Field
- Fields exhibit spherical wavefront; thus the pattern ideally does not vary with distance
- Electric & magnetic fields are in-phase
- Wave impedance is ideally, real
- Power predominantly real, propagating energy

Antenna Gain

- Is how much power is transmitted in the direction of peak radiation to that of an isotropic source.
- Antenna gain is more commonly quoted than directivity in an antenna's specification sheet because it takes into account the actual losses that occur.
- Ex: A transmitting antenna with a gain of 3 dB means that the power received far from the antenna will be 3 dB higher than what would be received from a lossless isotropic antenna with the same input power.
- Note that a lossless antenna would be an antenna with an antenna efficiency of 0 dB (or 100%). Similarly, a receive antenna with a gain of 3 dB in a particular direction would receive 3 dB more power than a lossless isotropic antenna.

Isotropic Antenna

- An isotropic antenna is an ideal antenna that radiates its power uniformly in all directions.
- There is no actual physical isotropic antenna. However, an isotropic antenna is often used as a reference antenna for the antenna gain.
- The antenna gain is often specified in dBi, or decibels over isotropic.
- A theoretical point source radiating power equally in all directions, 100% efficiency.

- Power Density: $$\boxed{S = \frac{P_T}{4\pi r^2}}$$ (W/m2)

- Directivity and Gain: D = G = 1 = 0 dBi (unity gain)

Units for Antenna Gain

- dB - decibels, as we have been discussing. 10 dB means 10 times the energy relative to an isotropic antenna in the peak direction of radiation.

- dBi - "decibels relative to an isotropic antenna". This is the same as dB as we have been using it. 3 dBi means twice (2x) the power relative to an isotropic antenna in the peak direction.

- dBd - "decibels relative to a dipole antenna". Note that a half-wavelength dipole antenna has a gain of 2.15 dBi. Hence, 7.85 dBd means the peak gain is 7.85 dB higher than a dipole antenna; this is 10 dB higher than an isotropic antenna.

Unit for Antenna Gain

- Therefore, the gain of an antenna referenced to an isotropic radiator is the gain referenced to a half-wavelength dipole plus 2.15 dB:
- G(dBi) = G(dBd) + 2.15 dB

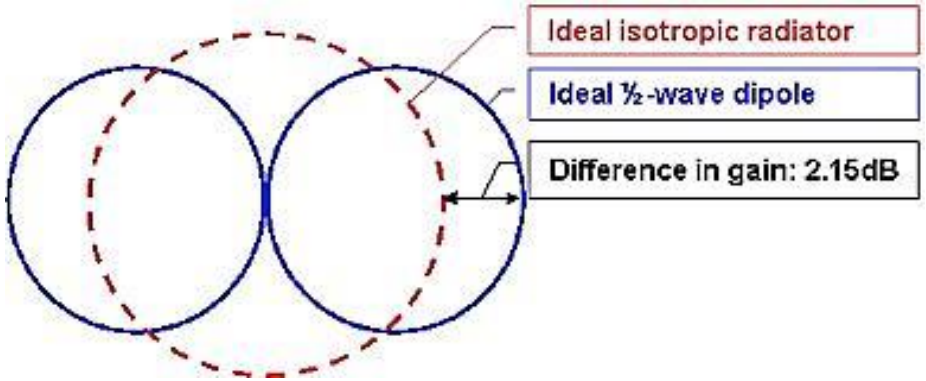
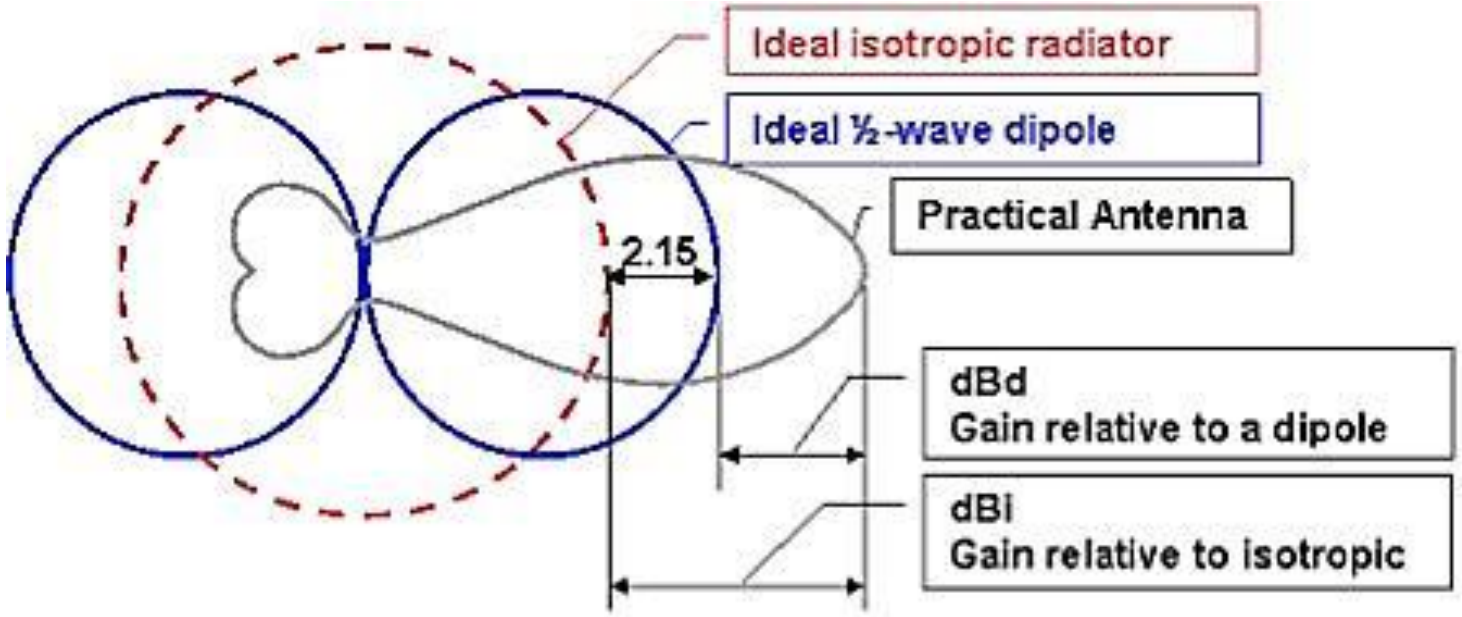


Figure: Half wave dipole vs isotropic antenna

Unit for Antenna Gain



Gain of a practical antenna:

G_{dBi} is gain referenced to an isotrope

G_{dBd} is gain referenced to a dipole

$G_{dBi} = G_{dBd} + 2.15$

Gain in dBd vs dBi

Possible combinations of dB and dBm

Operation	Resulting Unit	Physical meaning	Allowed?
dB + dB	dB	Product of two numbers	Yes
dB – dB	dB	comparing of two numbers	Yes
$dB_m + dB_m$	XX	Multiplying of two powers	No
$dB_m - dB_m$	dB	comparing two powers	Yes
$dB_m + dB$	dB_m	Power amplification	Yes
$dB_m - dB$	dB_m	Power attenuation	yes

Example: Antenna Gain (G)

- A dipole antenna gain is 1.64 (unitless)

$$10\log_{10}(1.64) = 2.15 \text{ dBi}$$

- A half-wave dipole antenna has a power gain of 1.64 (or 2.15 dB) over an isotropic source.
- Antenna gain relative to a dipole antenna can be expressed in decibels as dBd.
- Thus, an antenna with a gain of 3 dBd would have a gain of 5.15 dBi ; (3 dB + 2.15 dB)

Radiation intensity

- Radiation intensity in a given direction is defined as the power radiated from an antenna per unit solid angle.
- The radiation intensity is a far-field parameter.
- Total Radiated Power Using Radiation Intensity is obtained by integrating the radiation intensity over the entire solid angle of 4π. Thus,

$$P_{\text{rad}} = \oiint_{\Omega} U\, d\Omega = \int_0^{\pi} \int_0^{2\pi} U \sin\theta\, d\theta\, d\phi$$

- where dΩ is the element of solid angle = sinθdθdϕ.

Directivity

- D = directivity (dimensionless)
- D_0 = maximum directivity (dimensionless)
- $U = U(\theta, \phi)$ = radiation intensity (W/sr)
- U_{max} = maximum radiation intensity (W/sr)
- U_0 = radiation intensity of isotropic source (W/sr)
- P_{rad} = total radiated power (W)

ion

from the

ections.

um

$$D_{max} = D_0 = \frac{\quad}{U_0} = \frac{\quad}{U_0} = \frac{\quad}{U_0} = \frac{\quad}{P_{rad}}.$$

Directivity and Gain

- Directive Gain: $D(\theta,\phi)$ or $G_D(\theta,\phi)$
- Directivity: D

Antenna	D (ratio)	D (dB)
isotropic	1	0
λ/2 dipole	1.64	2.15

$$\boxed{G = \eta D}$$

G = *gain*

D = *Directivity (dimensionless)*

η = antenna efficiency, $\eta = \dfrac{P_r}{P_t}$ (Radiated power) (Transmitted power)

$$\boxed{D = \frac{4\pi}{\Omega_{HP}} = \frac{4\pi}{\theta_{HP}.\phi_{HP}}} \Rightarrow D = \frac{4\pi.\left(\frac{180}{\pi}\right)^2}{\Omega_{HP\,\deg^2}} = \frac{41253}{\theta^o_{HP}.\phi^o_{HP}}$$

Antenna Efficiency (η)

- The efficiency of an antenna is a ratio of the power delivered to the antenna relative to the power radiated from the antenna.
- **A high efficiency** antenna has most of the power present at the antenna's input radiated away.
- **A low efficiency** antenna has most of the power absorbed as losses within the antenna, or reflected away due to impedance mismatch.
- The antenna efficiency (or radiation efficiency) can be written as the ratio of the radiated power to the input power of the antenna

$$\eta = \frac{P_r}{P_t}$$

(Radiated power)
(Transmitted power)

Antenna Efficiency (η)

- Being a ratio, antenna efficiency is a number between 0 and 1.
- However, antenna efficiency is commonly quoted in terms of a percentage.
- For example, an efficiency of 0.5 is the same as 50%.
- Antenna efficiency is also frequently quoted in decibels (dB); an efficiency of 0.1 is 10% or (-10 dB), and an efficiency of 0.5 or 50% is -3 dB.

Example 1

- A dipole antenna, with a directivity of 2.15 dBi, has an efficiency of 85%. Calculate its gain in decibels.

- Solution:

  The directivity of dipole is 2.15 dBi can be converted to a power ratio:

  $D = log^{-1}\frac{2.15}{10}$ = 1.64

  Now, find the gain: G=ηD

  = 0.85 x1.64 = 1.394

  This gain can easily be converted to dBi

  G(dBi)= 10 log 1.39 = <u>1.44 dBi</u>

Example 2

- A dipole antenna has a radiation resistance of 67 Ω and a loss resistance of 5 Ω, measured at the feed-point. Calculate the efficiency.

Solution:

$$\eta = \frac{I^2 R_r}{I^2 R_t} = \frac{R_r}{R_t}$$

$$= \frac{67}{67+5} = 0.93 \; or \; 93\%$$

EIRP and ERP

- Effective Isotropic Radiated Power, also called the Equivalent Isotropic Radiated Power.
- In antenna measurements, the measured radiated power in a single direction (that is, for a fixed θ and Φ) is known as the EIRP.
- Typically, for an antenna radiation pattern measurement, if a single value of EIRP is given, this will be the maximum value of the EIRP over all measured angles.
- EIRP can also be thought of as the amount of power a perfectly isotropic antenna would need to radiate to achieve the measured value.

EIRP and ERP

- Effective Isotropic Radiated Power (EIRP):

$$\boxed{ERP = \frac{EIRP}{G_{\lambda/2dipole}}} \Rightarrow \boxed{EIRP = P_T.G_T}$$

- Effective Radiated Power (ERP): $ERP = \frac{P_T.G_T}{G_{\lambda/2dipole}} = \frac{P_T.G_T}{1.64}$

$$ERP_{dBm} = EIRP_{dBm} - 2.15_{dB}$$

$$EIRP_{dBm} = ERP_{dBm} + 2.15_{dB}$$

EIRP is referenced to an isotropic antenna.
ERP is referenced to a half-wave dipole.
.

Example

- The ERP of a transmitting station is specified as 17 W in a given direction. Express this as an EIRP in dBm.

- Solution:
- 1) convert ERP to dBm
- 2) Using equation EIRP(dBm)

Effective Area (A_e)

- The effective area of an antenna can be used to calculate the received power

$$P_R = A_e.PowerDensity = A_e.S$$

where

$$A_e = \frac{\lambda^2}{4\pi} G$$

- Example:

A half-wave dipole at 900 MHz (mobile phone) has a Gain = 1.64.

- How long is the antenna? L = m = mm
- Calculate its effective area. Ae = m^2 = mm^2

Actual Antenna Lengths

- A dipole resonates best when it is approx. 95% of the actual "half-wavelength length"
- Dipole hung vertically is closest to an isotropic radiator
- Bottom of dipole antenna should be at least ½ a wavelength off the ground
  - May make total structure height unreasonable

Half-wave dipole antenna’s length

- To make it crystal clear, if the antenna is to radiate at 600 MHz, what size should the half-wavelength dipole be?
- One wavelength at 600 MHz is

$$\lambda = c / f = 0.5 \text{ meters}$$

- Hence, the half-wavelength dipole antenna's length is 0.25 meters.

Antenna Bandwidth: Frequency Range

- The **bandwidth of an antenna** is the band of frequencies, over which it is considered to perform acceptably.
- The wider the range of frequencies a band encompasses, the wider the bandwidth of the antenna.
- Antennas are ordered **pre-tuned by the manufacturer**, for use in a specified band segment.
- The trade-off in designing an antenna for a wider bandwidth is that it would generally not have as good of performance in comparison to a similar antenna that is optimized for a narrower bandwidth.

Antenna Bandwidth: Frequency Range

Percent Bandwidth is Defined as:

- $BW = 100 \times \frac{F_H - F_L}{F_C}$ where:
- F_H is the highest frequency in the band
- F_L is the lowest frequency in the band
- F_C is center frequency in the band $F_C = \frac{F_H + F_L}{2}$

Friis Transmission

- Friis Transmission Formula is the most fundamental equation of antenna theory.
- This equation relates transmit power, antenna gains, distance and wavelength to received power.

Friis Transmission Equation

$$P_R = \frac{P_T G_T G_R \lambda^2}{(4\pi R)^2} \quad (*)$$

To convert this equation from linear units in Watts to decibels, we take the logarithm of both sides and multiply by 10:

$$10 \cdot \log_{10} P_R = 10 \cdot \log_{10}\left(\frac{P_T G_T G_R \lambda^2}{(4\pi R)^2}\right)$$

A nice property of logarithms is that for two numbers *A* and *B* (both positive), the following result is always true:

$$\log_{10}(AB) = \log_{10}(A) + \log_{10}(B)$$

Equation (*) then becomes:

$$10 \cdot \log_{10} P_R = 10 \cdot \log_{10}(P_T) + 10 \cdot \log_{10}(G_T) + 10 \cdot \log_{10}(G_R) + 10 \cdot \log_{10}\left(\frac{\lambda}{4\pi R}\right)^2$$

Using the definition of decibels, the above equation becomes a simple addition equation in dB:

$$[P_R]_{dB} = [P_T]_{dB} + [G_T]_{dB} + [G_R]_{dB} + \left[\left(\frac{\lambda}{4\pi R}\right)^2\right]_{dB}$$

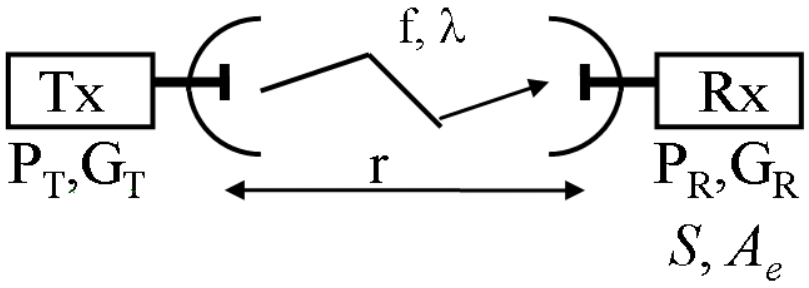
Friis Transmission Equation

S = power density

A_e = effective area

$$S = \frac{P_T G_T}{4\pi r^2}$$

$$P_R = S.A_e = \frac{P_T G_T}{4\pi r^2} \cdot \frac{\lambda^2 G_R}{4\pi} \Rightarrow \boxed{\frac{P_R}{P_T} = \left(\frac{\lambda}{4\pi r}\right)^2 G_T G_R}$$



Exercise

- For a transmitter-receiver distance of 20 m at 10.2 GHz, with PT = 100 W, PR = 3 mW, and GR = 15 dB,
- (a) what is the required GT?
- (b) what is the maximum power density at a point 20 m from the transmitter?

Another Examples

Q1

Find the optimum wavelength and frequency for a half-wave dipole of length 10 m.

Ans1

The length of a half-wave dipole is one-half the wavelength of the signal that can be transmitted most efficiently. Therefore, the optimum wavelength in this case is $\lambda = 20$ m. The optimum free space frequency is $f = c/\lambda = (3\text{x}10^8)/20 = 15$ MHz.

Q2

The audio power of the human voice is concentrated at about 300 Hz. Antennas of the appropriate size for this frequency are impracticably large, so that to send voice by radio the voice signal must be used to modulate a higher (carrier) frequency for which the natural antenna size is smaller.

a) What is the length of an antenna one-half wavelength long for sending radio at 300 Hz?

b) An alternative is to use a modulation scheme, as described in one of the Lectures, for transmitting the voice signal by modulating a carrier frequency, so that the bandwidth of the signal is a narrow band centered on the carrier frequency. Suppose we would like a half-wave antenna to have a length of 1 m. What carrier frequency would we use?

Ans2

What is the length of an antenna one-half wavelength long for sending radio at 300 Hz?

a. Using $\lambda f = c$, we have $\lambda = (3 \times 10^8 \text{ m/sec})/(300 \text{ Hz}) = 1{,}000 \text{ km}$, so that $\lambda/2 = 500 \text{ km}$.

An alternative is to use a modulation scheme,(as in Principle of Communication), for transmitting the voice signal by modulating a carrier frequency, so that the bandwidth of the signal is a narrow band centered on the carrier frequency. Suppose we would like a half-wave antenna to have a length of 1 m. What carrier frequency would we use?

b. The carrier frequency corresponding to $\lambda/2 = 1$ m is given by:

$f = c/\lambda = (3 \times 10^8 \text{ m/sec})/(2 \text{ m}) = 150 \text{ MHz}$.

Q3

Suppose you have one areal that is 2.5 mm **(0.0025** m) long that acts as a radio antenna. That is, it is equal in length to one-half the wavelength. What frequency do you receive?

Ans3

$$\lambda = 2 \times 2.5 \times 10^{-3}\ \text{m} = 5 \times 10^{-3}\ \text{m}$$
$$f = c/\lambda = (3 \times 10^{8}\ \text{m/sec})/(5 \times 10^{-3}\ \text{m}) = 6 \times 10^{10}\ \text{Hz} = 60\ \text{GHz}$$

Q4

The normalized radiation intensity of an antenna is given by:

$U = \sin\theta \sin^2\Phi$.

The intensity exists only in $0 < \theta < 180°$ and $0 < \Phi < 180°$ region.

Find the exact directivity (dimensionless and in dB). Assume Umax =1

Use the $\cos^2\theta = \frac{1+\cos 2\theta}{2}$ $\sin^2\theta = \frac{1-\cos 2\theta}{2}$

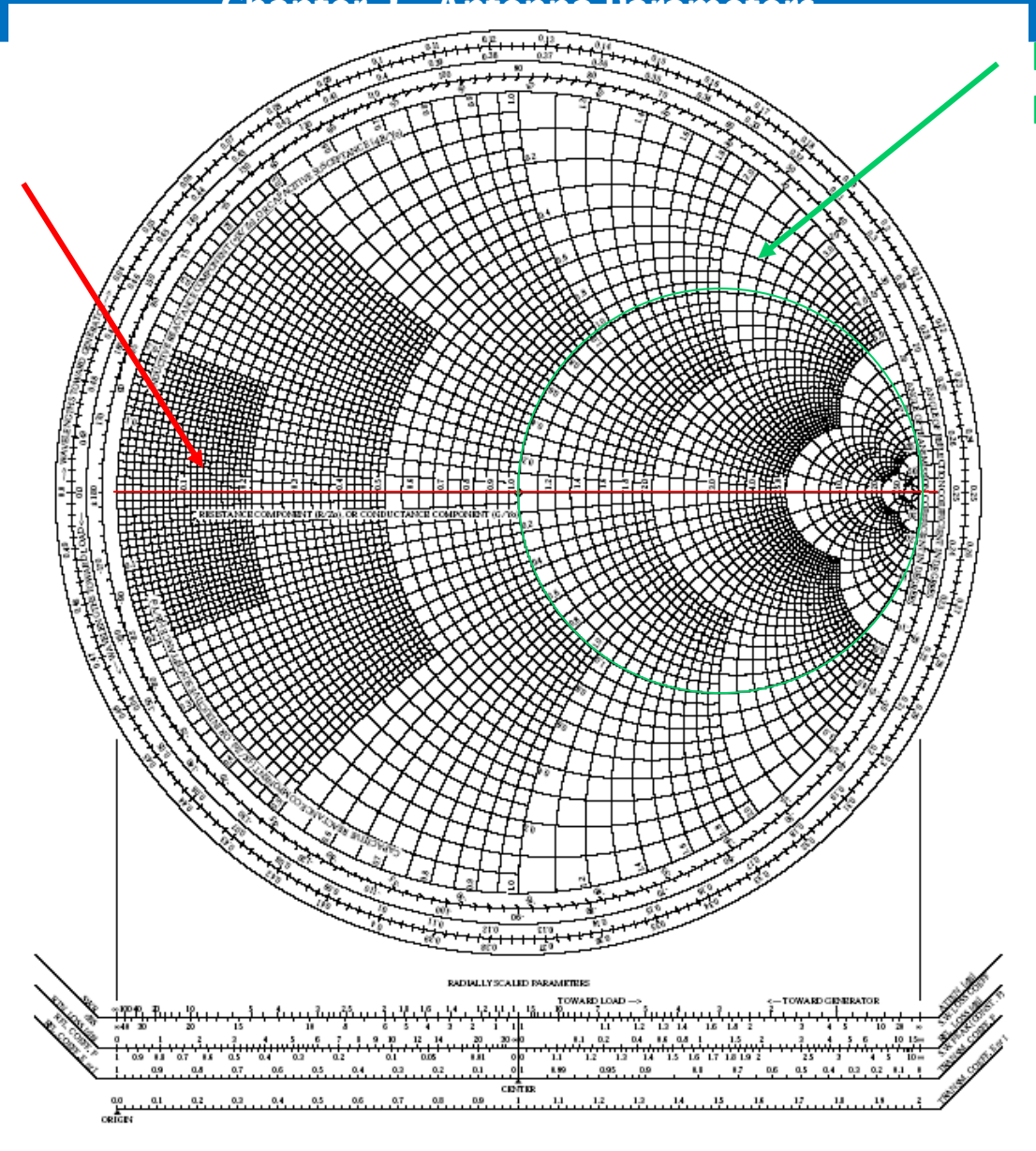
Ans

To be continued in Chapter 2 Part 2…

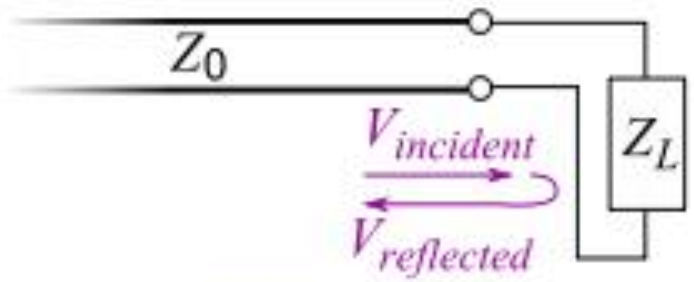
- Polarization
- Input impedance
- Smith Chart
- VSWR
- Reflection coefficient

Real Impedance Axis

Imaginary Impedance Axis



Smith Chart



$$z = \frac{Z_L}{Z_0}$$

$$\Gamma = \frac{V_{reflected}}{V_{incident}}$$