ANTENNA AND WAVE PROPAGATION

 by Dr. K. Rasadurai, Professor, ECE, KEC

UNIT I FUNDAMENTALS OF RADIATION

- Definition of antenna parameters :
  - Gain,
  - Directivity,

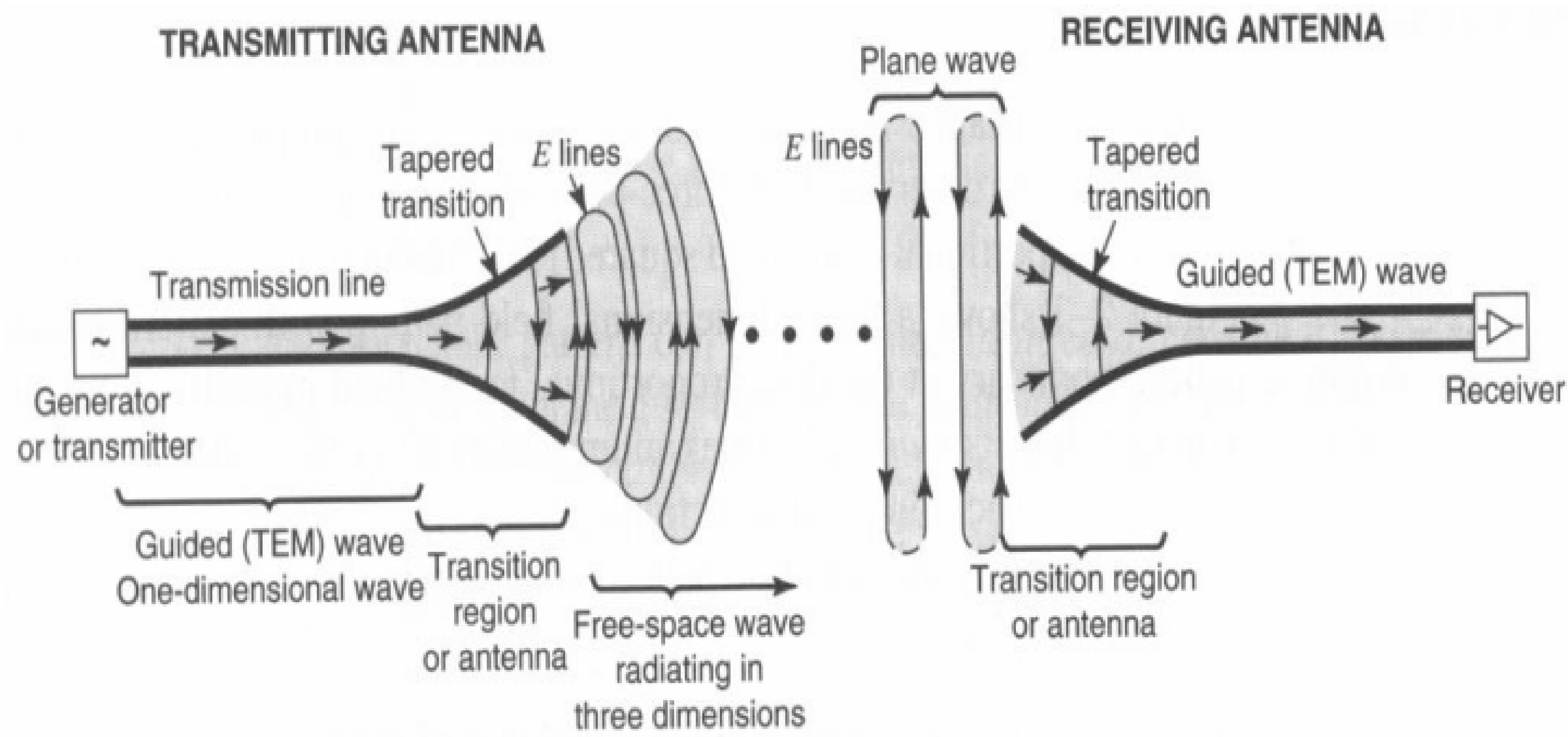
- Effective aperture,
- Radiation Resistance,
- Band width,
- Beam width,
- Input Impedance.
  - Matching – Baluns,
  - Polarization mismatch,
  - Antenna noise temperature,
- Radiation from oscillating dipole, Half wave dipole. Folded dipole, Yagi array.

Antenna Background

• Maxwell (1831-79) Fundamental equations. (Scottish) • Hertz (1857-94) First aerial propagation (German) • Marconi (1874-1937) Transatlantic transmission (Italian) • DeForest (Triode tube 1920) Signal generators (American) • World War II (1939-45) Intense war-driven development

 An antenna is a way of converting the guided waves present in a waveguide, feeder cable or transmission line into radiating waves travelling in free space, or vice versa.

An antenna is a passive structure that serves as transition between a transmission line and air used to transmit and/or receive electromagnetic waves. Converts Electrons to Photons of EM energy It is a transducer which interfaces a circuit and freespace



Only accelerated (or decelerated) charges radiate EM waves.

A current with a time-harmonic variation (AC current) satisfies this requirement.

The role of antennas

Antennas serve four primary functions: • Spatial filter

directionally-dependent sensitivity

• Polarization filter

polarization-dependent sensitivity

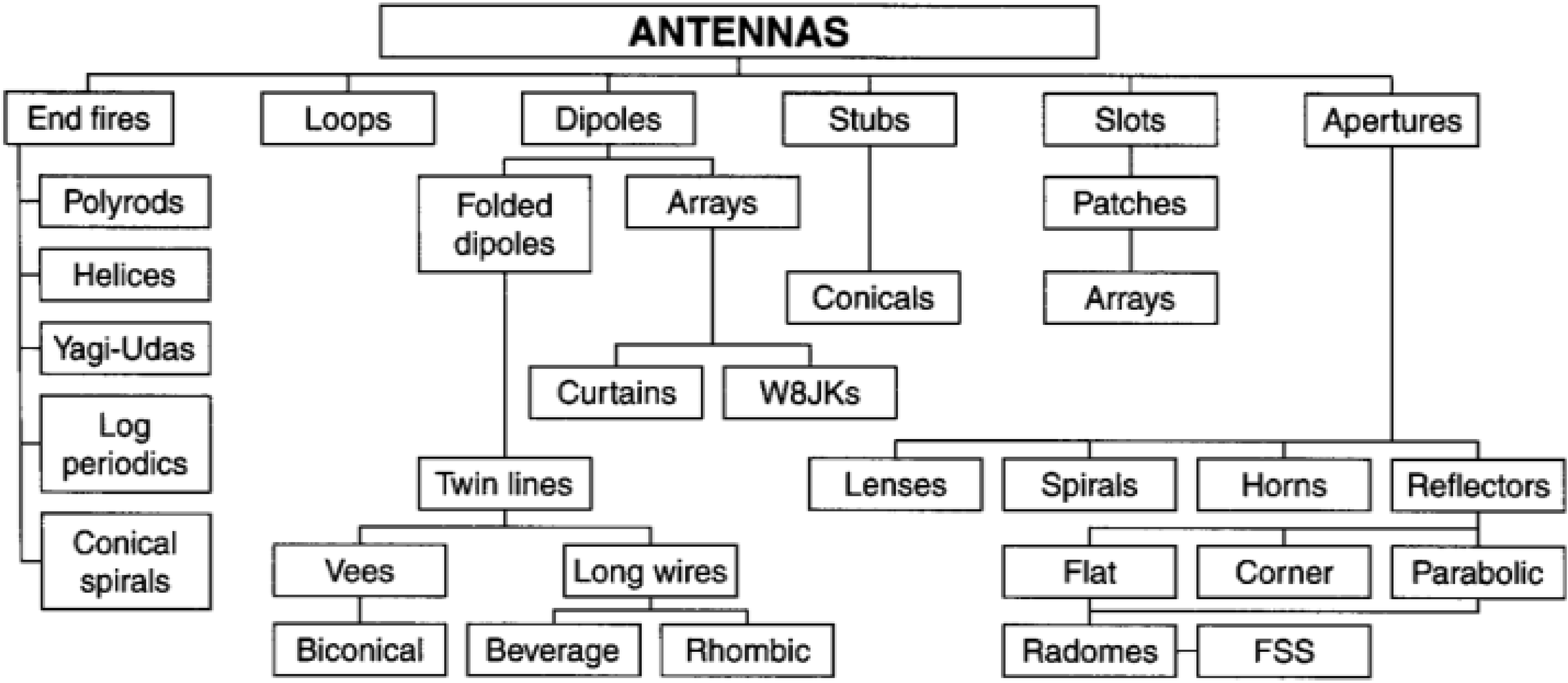
• Impedance transformer (50 Ω to 377Ω)

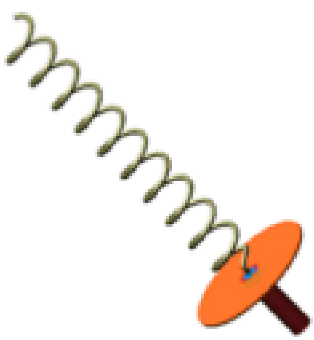
transition between free space and transmission line • Propagation mode adapter

from free-space fields to guided waves

(e.g., transmission line, waveguide)

Antenna types





Helical antenna Horn antenna Parabolic reflector antenna

Antenna parameters

- Solid angle, Ω_A and Radiation intensity, U
- Radiation pattern, P_n, sidelobes, *HPBW* •

Far field zone, r_{ff}

- Directivity, D or Gain, G
- Antenna radiation impedance, R_{rad}
- Effective Area, A_e

All of these parameters are expressed in terms of a **transmission** antenna, but are identically applicable to a **receiving** antenna. We'll also study:

Isotropic antenna

- It's an hypothetic antenna, i.e., it does not exist in real life, yet it's used as a measuring bar for real antenna characteristics.

- It's a point source that occupies a negligible space. Has no directional preference.

- Its pattern is simply a sphere so it has ,

  beam area (Ω_A) = $\Omega_{isotropic}$= 4π [steradians].

$$\Omega_{isotropic} = \Omega \iint_{4\pi} \qquad (1)$$

$$d \qquad 2 \; \pi$$

$$\pi$$

$$\int \int \qquad \theta \; \varphi \; \pi$$

$$(1)\sin 4 \; \theta$$

$$\theta \qquad = = \qquad d\, d \quad =$$

$$0 \qquad \varphi \qquad 0$$

<u>Isotropic Radiator</u>:

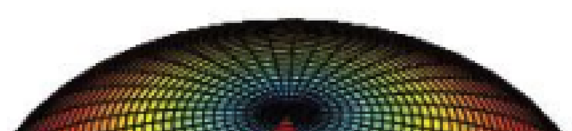
A hypothetical lossless antenna having equal radiation in all directions.

<u>Omnidirectional Radiator:</u>

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

<u>Directional Radiator:</u>

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.

Spherical coordinates z

(zenith)

θ

φ=90

y

φ

θ=0

θ=90

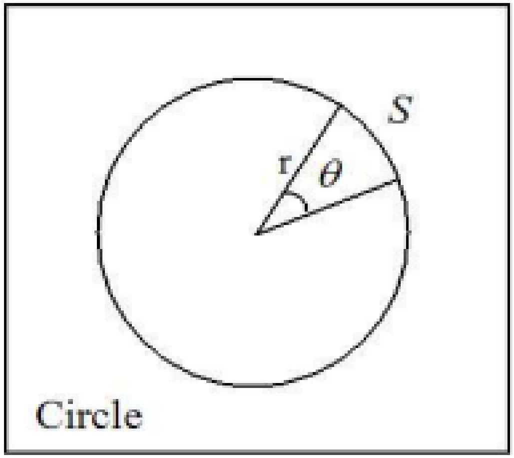
x

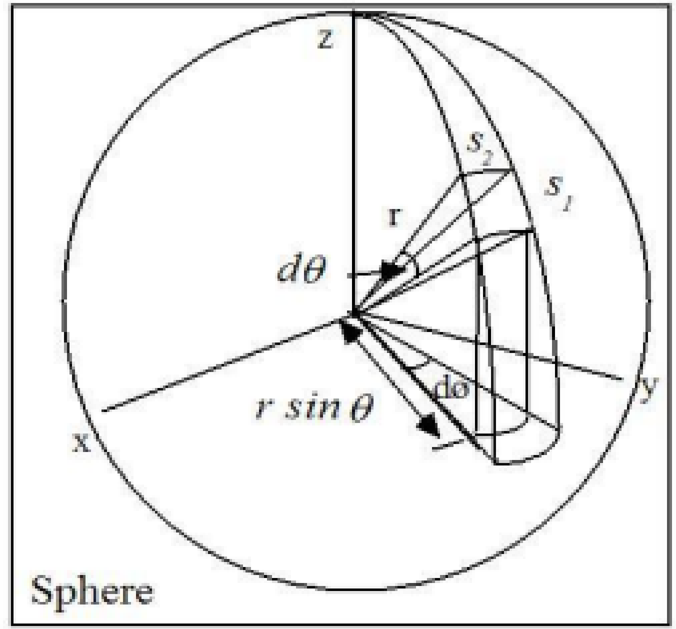
φ= azimuth

θ= elevation θ=90

φ=0

Solid Angle



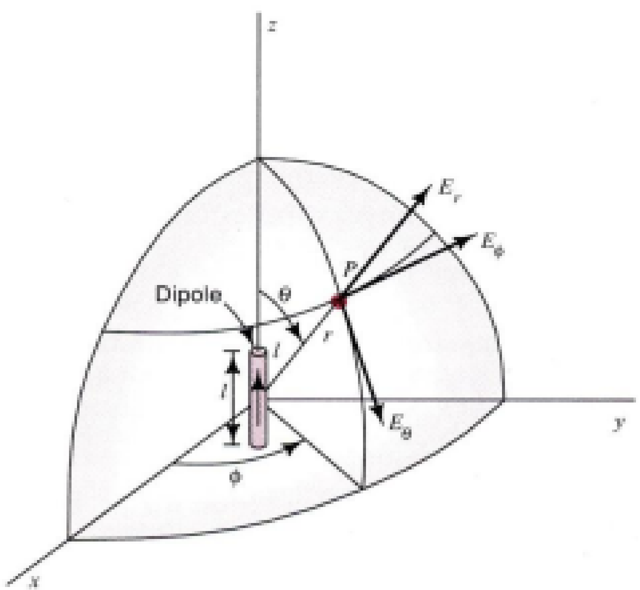


$s_1 = r\,d\theta \quad s_2 = r \sin\theta\, d\varnothing$

$s = \theta r$ = arco $dA = s_1 s_2$

$dA = r^2 \sin\theta\, d\varnothing\, d\theta$

$= r^2\, d\Omega$



Radiation Intensity

- Is the **power density per solid angle**:

$$U = r^2 \mathcal{P}_r \; [\text{W/sr}]$$

where $\mathcal{P}_r = \frac{1}{2}\,\text{Re}\{E \times H^*\}\hat{r} \; [\text{W/m}^2]$

is the power density also known as Poynting vector.

Radiation Pattern

- A **radiation pattern** is a three-dimensional, graphical representation of the **far-field** radiation properties of an antenna as a function of space coordinates. The far-field region is a region far enough for the radiation pattern to be independent of the distance from the antenna. The radiation pattern of a particular antenna can be measured by experiment or can be calculated, if the current distribution is known.
- Typically measured in two planes:
  - E Plane
  - H Plane

$$E_n = \frac{E(\theta, \varphi)}{E(\theta, \varphi)}$$

Field pattern: $(,)$ $_{max}$ θ φ

θ φ U U

P φ

$(,)$ θ

$(,)$

Power pattern: θ φ

$F_n = =$

$(,)$

P

$_{max}$ $_{max}$ θ φ $(,)$

θ φ $(,)$

Radiation pattern – variation of the field intensity of an antenna as an angular function with respect to the axis

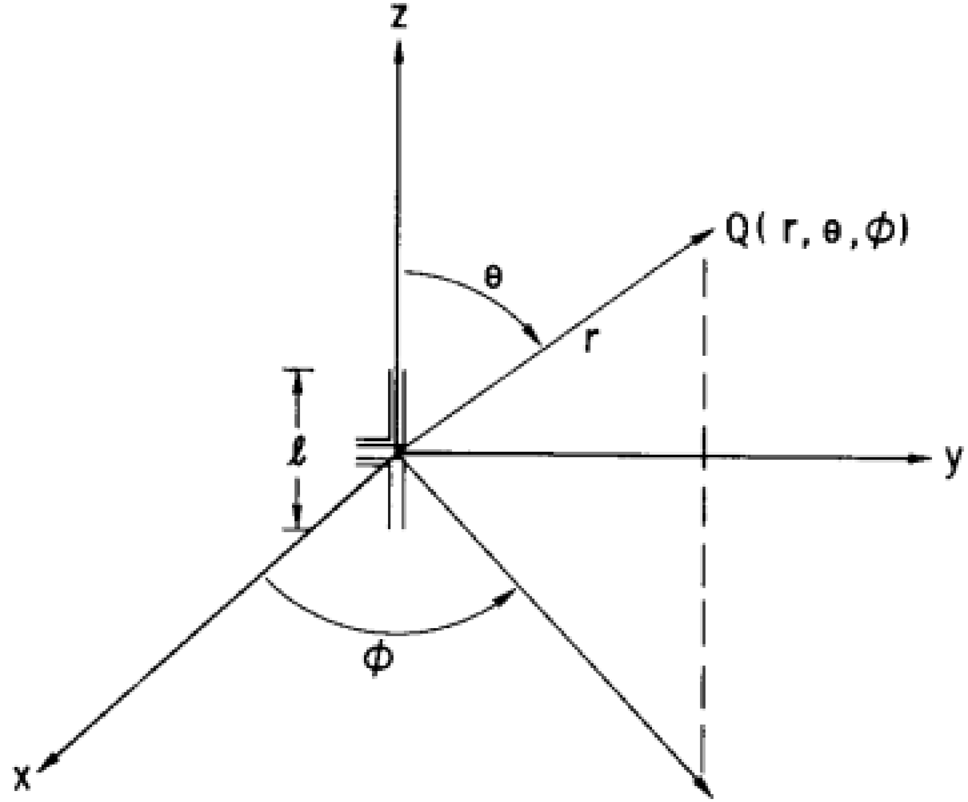
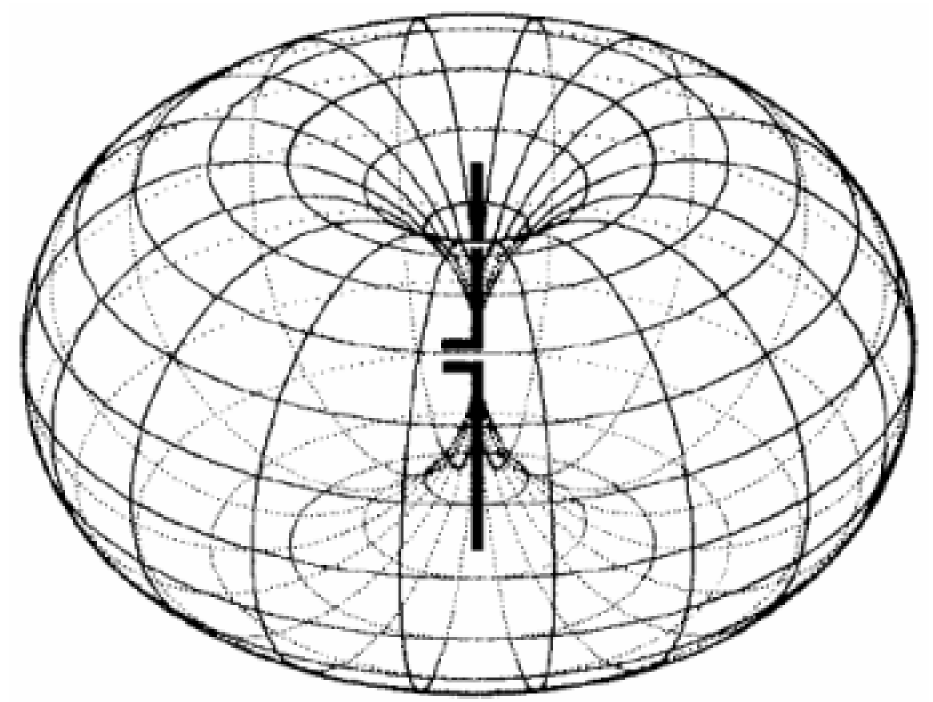
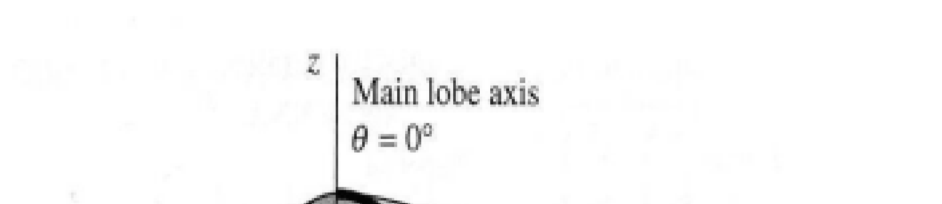


Fig. 3.7 Short dipole placed at the origin of a spherical coordinate system.


Three-dimensional representation of the radiation pattern of a dipole antenna

Radiation Pattern Characteristics

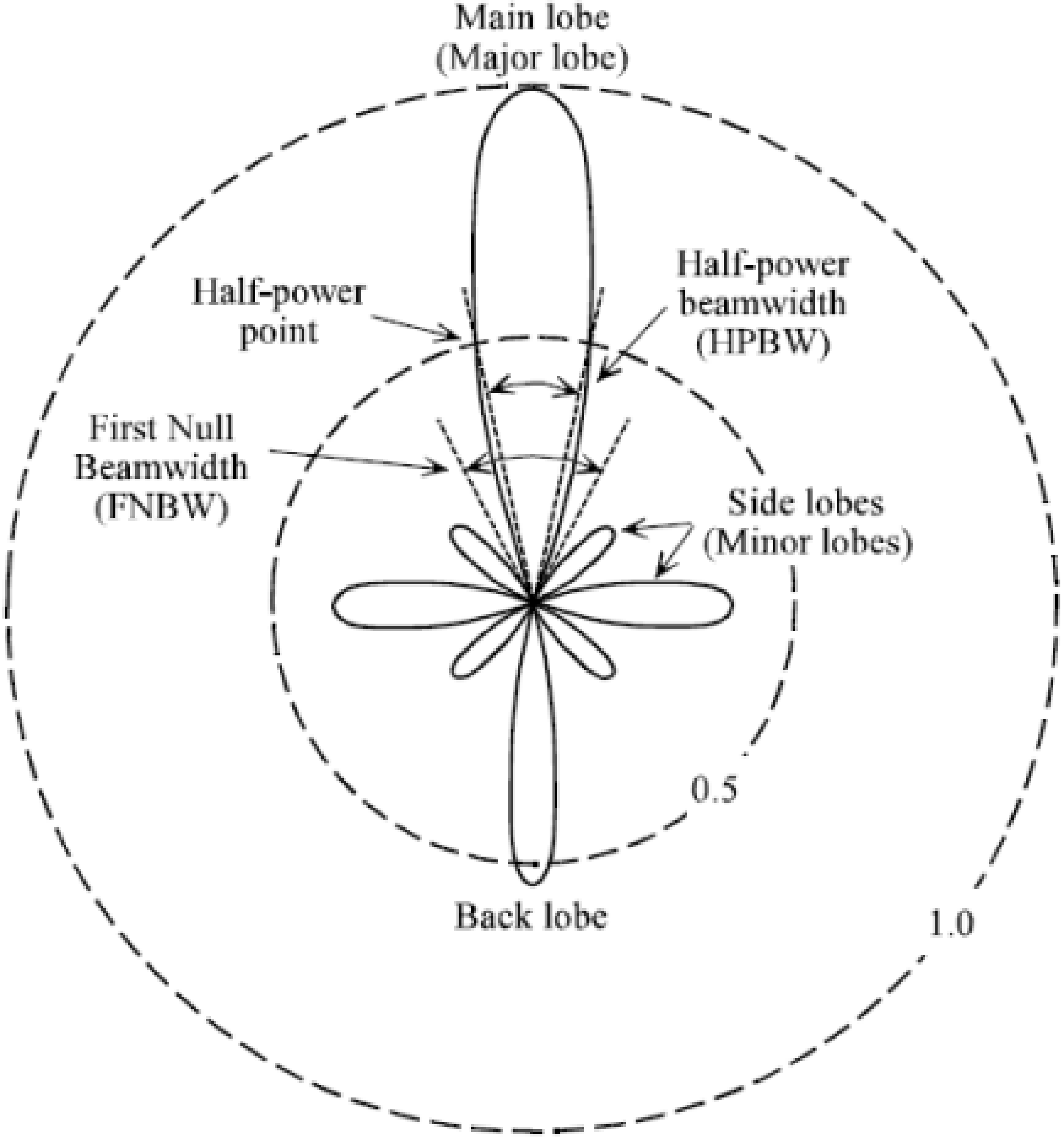
- 3 dB beamwidth

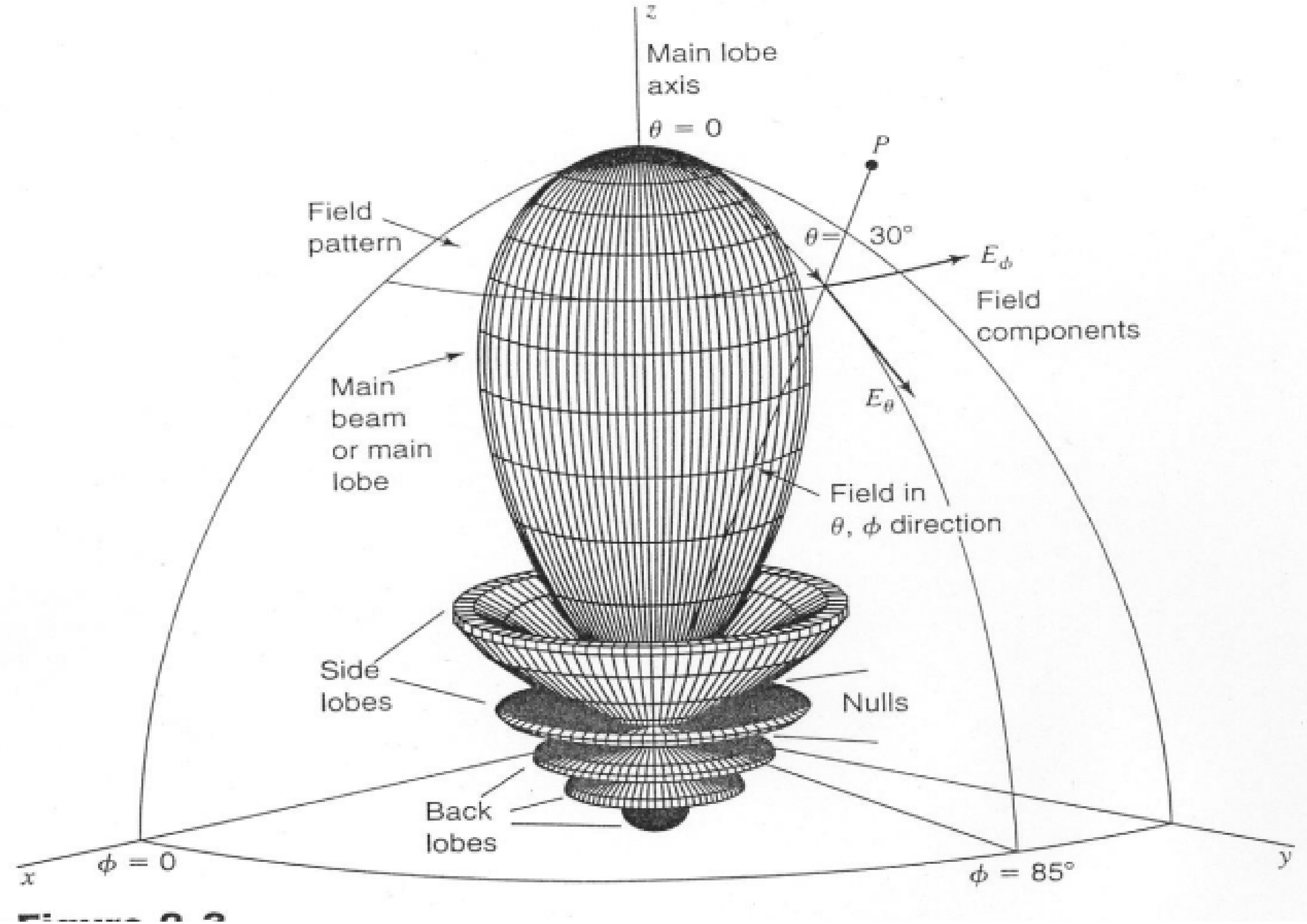


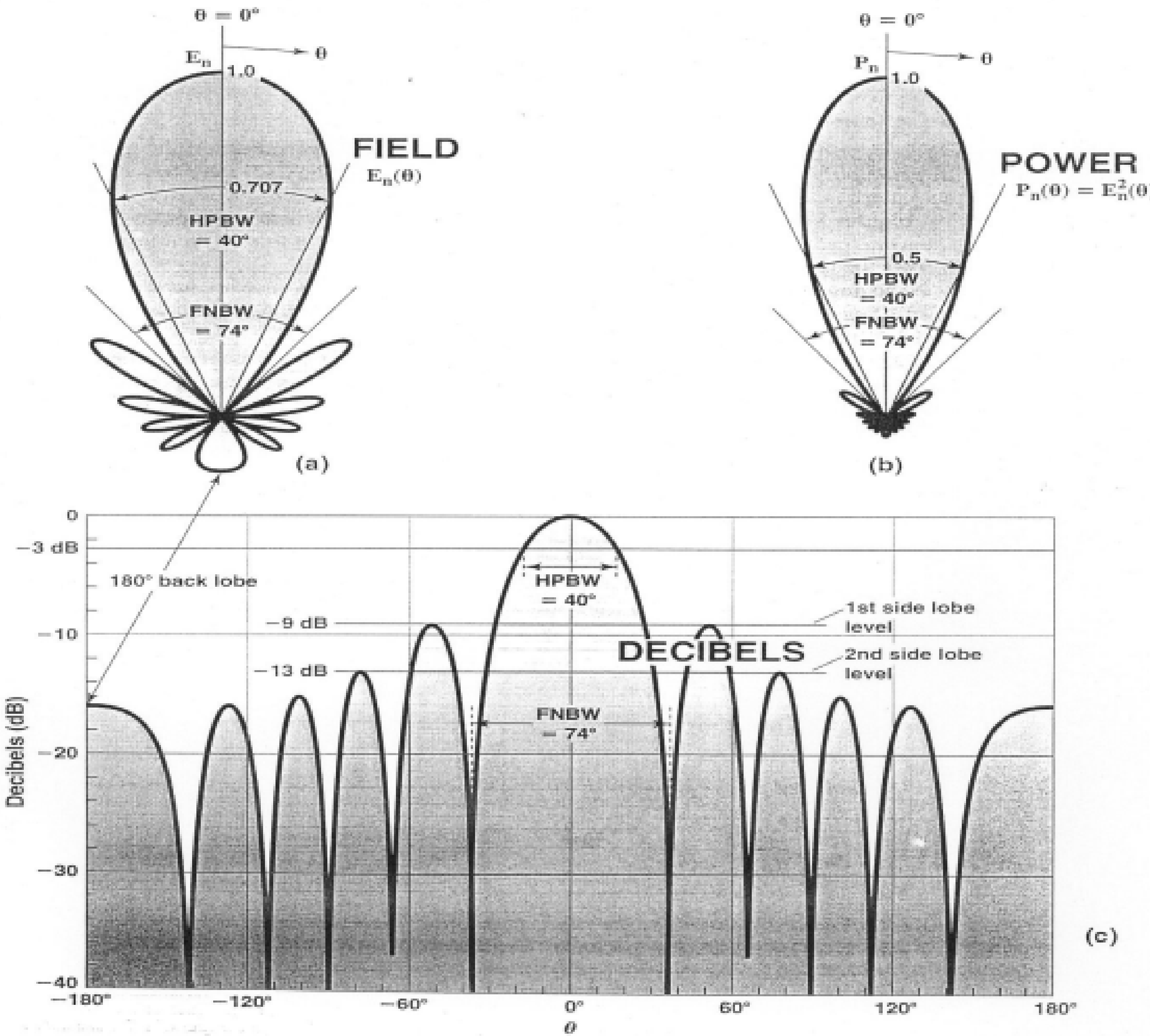
(HPBW)

- Sidelobes
- Nulls
- Front-to-back ratio
- Gain (approximate)
- Maximum signal position

Antenna Pattern Parameters


Main lobe
(Major lobe)
Half-power
point
Half-power
beamwidth
(HPBW)
First Null
Beamwidth
(FNBW)
Side lobes
(Minor lobes)
0.5
Back lobe
1.0


z
Main lobe
axis
θ = 0
P
Field
pattern
θ = 30°
E_ϕ
Field
components
Main
beam
or main
lobe
E_θ
Field in
θ, φ direction
Side
lobes
Nulls
Back
lobes
x
φ = 0
φ = 85°
y


θ = 0°
θ
E_n
1.0
FIELD
$E_n(\theta)$
0.707
HPBW
= 40°
FNBW
= 74°
(a)
θ = 0°
θ
P_n
1.0
POWER
$P_n(\theta) = E_n^2(\theta)$
0.5
HPBW
= 40°
FNBW
= 74°
(b)
0
−3 dB
180° back lobe
HPBW
= 40°
−9 dB
1st side lobe
level
−10
DECIBELS
−13 dB
2nd side lobe
level
FNBW
= 74°
Decibels (dB)
−20
−30
(c)
−40
−180°
−120°
−60°
0°
60°
120°
180°
θ

Directivity and GAIN

"The ratio of the radiation intensity in a given direction from the antenna to the radiation intensity averaged over all directions."

Max Radiation intensity from subject or test antenna

Max Radiation Intensity from reference (Isotropic)antenna with same power input.

$G=\eta D$

Directivity and GAIN of an Antenna

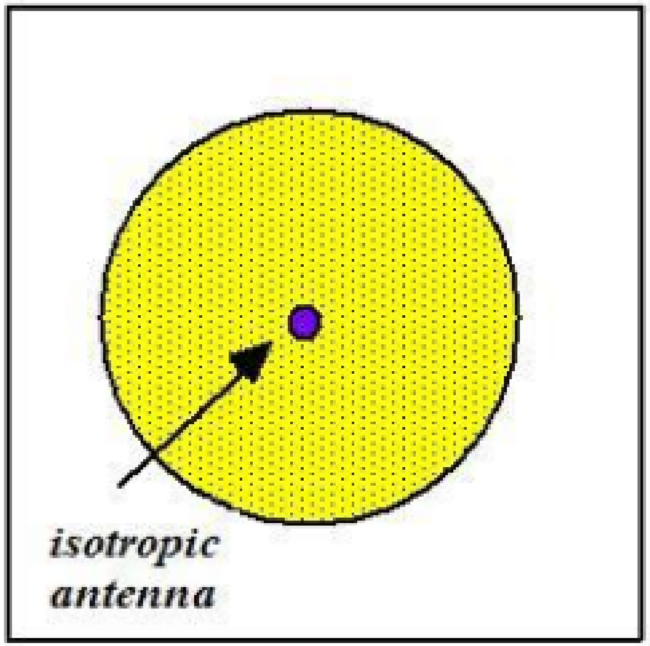
The ***Directivity*** or ***Gain*** of an antenna is defined as the ratio of the maximum value of the power radiated per unit solid angle to the average power radiated per unit solid angle

Directivity is a fundamental antenna parameter. It is a measure of how '***directional***' an antenna's radiation pattern is. An antenna that radiates equally in all directions would have effectively zero directionality, and the directivity of this type of antenna would be 1 (or 0 dB).

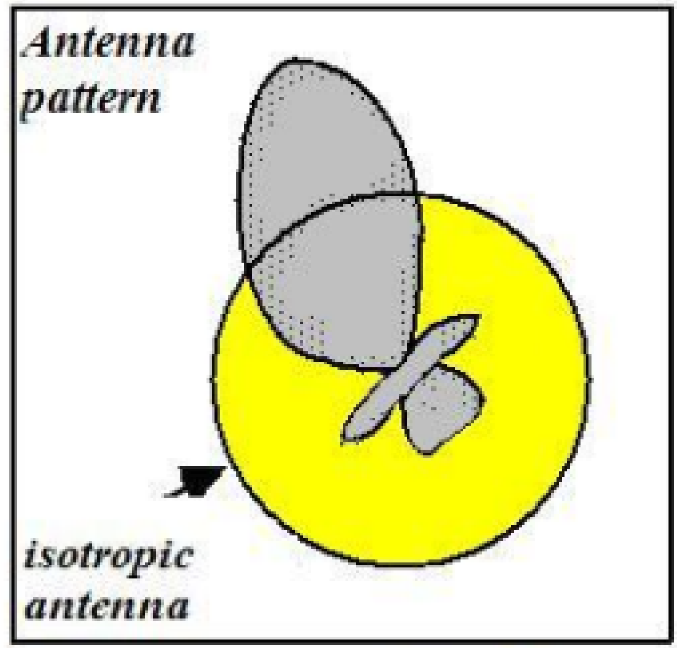
It measures the power density of the antenna radiates in the direction of its strongest emission, versus the power density radiated by an ideal Isotropic Radiator (which emits uniformly in all directions) radiating the same total power.

 Directivity is a component of its Gain, If lossless antenna, $G=D$ 22

Gain or Directivity



Isotropic Pattern



Comparison of regular antenna pattern with isotripic

An isotropic antenna and a practical antenna fed with the same power. Their patterns would compare as in the figure on the right.

Directivity and Gain

- All practical antennas radiate more than the isotropic antenna in some directions and less in others.
- Gain is inherently directional; the gain of an antenna is **usually measured in the direction which it radiates best**.

"The directivity of an antenna is equal to the ratio of the maximum power density P_{max} to its average value over a sphere as observed in the far field of an antenna"

$$ave\ ave\ D = D_{max}(\theta,\varphi) = P_{max}/P = U_{max}/U$$

Gain or Directivity

- Gain is measured by comparing an antenna to a model antenna, typically the isotropic antenna which radiates equally in all directions.

2

P (,)

D4 (,) θ φP θ φ π θ φ

r

(,) /

= P P = =

1

$_{AVE} P \iint$

dA A

π P

D

$_{rad}$

4 U

$=^{\max} = \pi\ \Omega = \Omega\ \Omega$

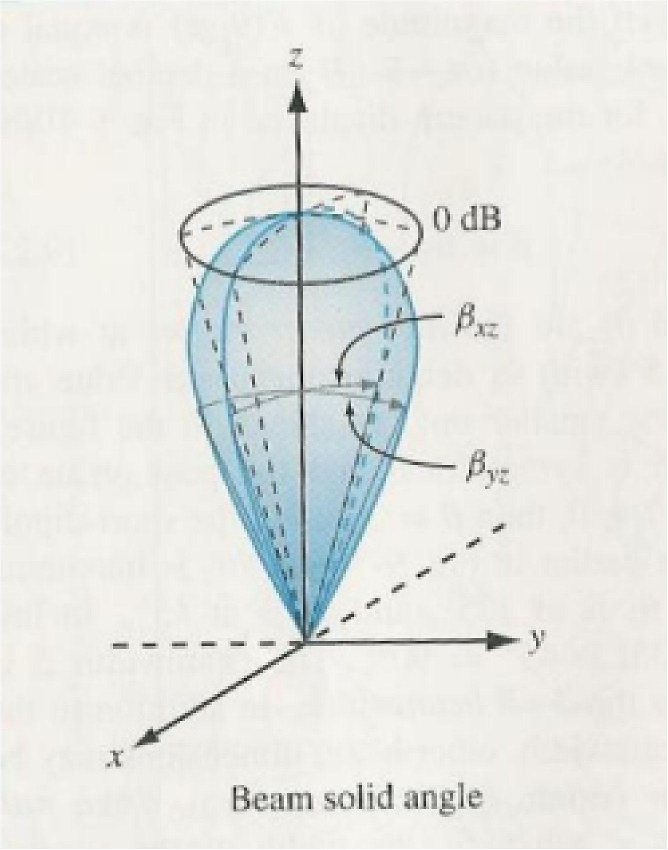
$_o P_{rad}$

$4 / /_{A\ isotropic\ A}$

Relation b/w Directivity, HPBW,Ω_A

- For an antenna with a single main lobe pointing in the z direction , Beam area(Ω_A) can be approximated to the product of the HPBW

β β



A xz yz

then

The Directivity:

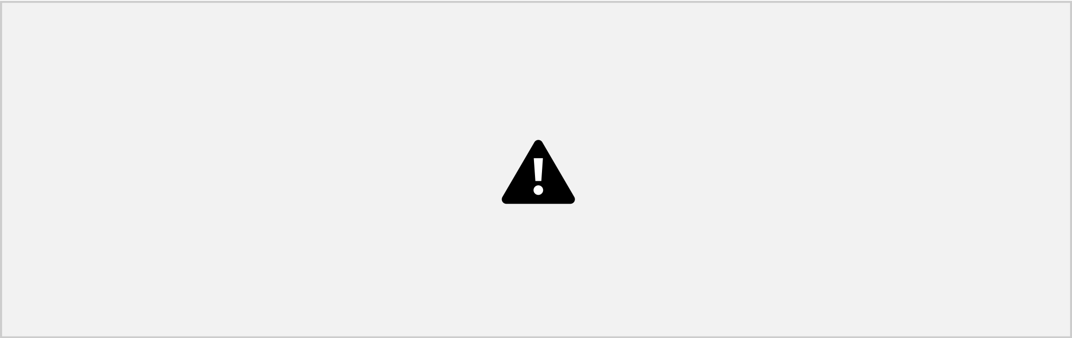
4

π

$$D = 4\pi / \Omega_A \cong 4\pi / \beta_{xz}\beta_{yz}$$

Effective Aperture

"A useful parameter in calculating the received power of an antenna is the ***effective area*** or ***effective aperture***"



Effective area or Effective aperture (square meters)

The effective area corresponds to the effective absorbance area presented by an antenna to an incident plane wave. For an aperture antenna, it is equal to or smaller than the physical aperture. The relationship between the gain and the wavelength is

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

Effective Aperture

It is also defined as the ratio of power received at the antenna load terminal to the poynting vector(or power density)in Watts/meter^2 of the incident wave. Thus

Effective Area= Power Received

Poynting Vector of incident wave

$$A_e = W/P$$

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Antenna Impedance

Antenna *Input impedance* is very important because it is generally desired

- to supply maximum available power from the transmitter to the antenna or
- to extract maximum amount of received energy from the antenna.

Antenna Impedance

- An antenna is “seen" by the generator as a load with impedance Z_A, connected to the line.

$$Z = R + R + jX$$

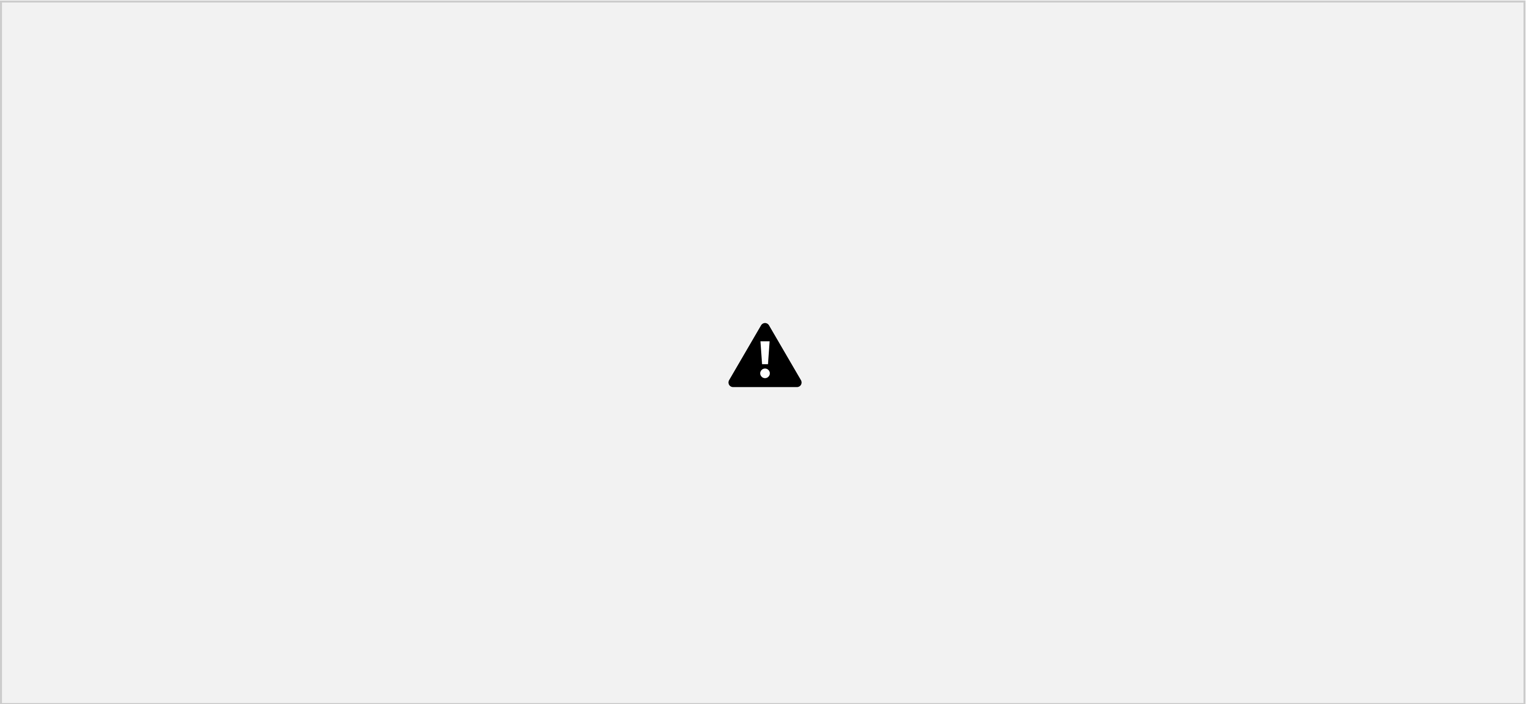
$$(\ )_{A \; rad \; L \; A}$$

$$Z_A$$

- **The real part is the radiation resistance plus the ohmic resistance**. – Minimizing impedance differences at each interface will reduce SWR and maximize power transfer through each part of the antenna system. – Complex impedance, Z_A, of an antenna is related to the electrical length of the antenna at the wavelength in use.
  - The impedance of an antenna can be matched to the feed line and radio by adjusting the impedance of the feed line, using the feed line as an impedance transformer.
  - More commonly, the impedance is adjusted at the load with an antenna tuner, a balun, a matching transformer, matching networks composed of inductors and capacitors, or matching sections such as the gamma match.

Antenna Impedance

The radiation resistance does not correspond to a real resistor present in the antenna but to the resistance of space coupled via the beam to the antenna terminals.



Radiation Resistance

- The antenna is a radiating device in *which power is radiated into space in the form of electromagnetic waves* .Hence there must be power dissipation which may be expressed in usual manner as

$$W=I^2R$$

- If it is assumed that all this power appears as electromagnetic radio waves then this power can be divided by square of current i.e

$$R_r=W/I^2$$

at a point where it is fed to antenna and obtain a fictitious resistance called as ***Radiation resistance***.

Radiation Resistance

- Thus "Radiation Resistance can be defined as that fictitious resistance which when substituted in series with the antenna will consume the same power as is actually radiated".

- Total Power loss in an antenna is sum of the two losses

  Total Power Loss = Ohmic Loss + Radiation Loss

$$W = W' + W''$$

$$= I^2 R_r + I^2 R_l$$

$$= I^2 (R_r + R_l)$$

$$= I^2 R$$

Radiation Resistance

The value of Radiation Resistance depends on:

✔ Configuration of Antenna

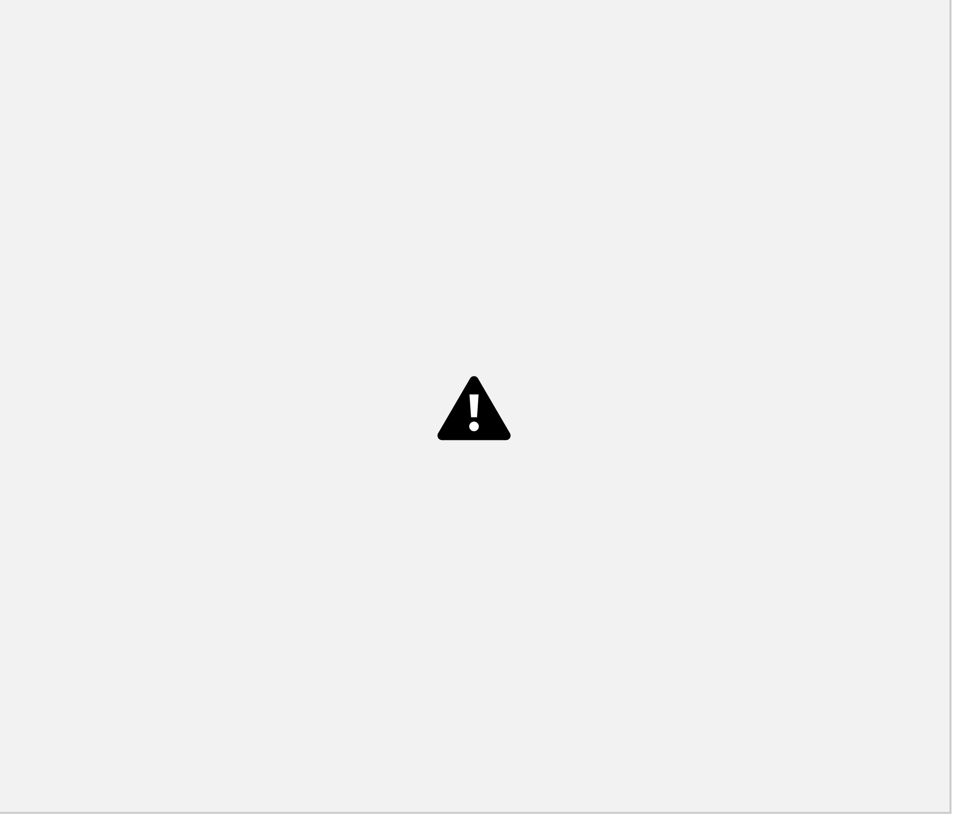
✔ The Point where radiation resistance is considered ✔
Location of antenna with respect to ground and other objects

✔ Ratio of length of diameter of conductor used

✔ Corona Discharge-a luminous discharge round the surface of antenna due to ionization of air etc.

So , Antenna Input Impedance is

- Input Impedance (resistance + reactance)
- Radiation Resistance (corresponds to energy that is transmitted)
- Loss Resistance



Antenna Bandwidth

- Antenna Bandwidth is the range of frequency over which the antenna maintains certain required characteristics like gain, front to back ratio or SWR pattern (shape or direction), polarization and impedance

- It is the bandwidth within which the antenna maintains a certain set of given specifications.

$\Delta = - = =$

$w\ w\ w\ w\ Q\ Bandwidth$

/

2 1

r

$\Delta = - =$

$f\ f\ f\ f\ Q$

$$\Delta \propto f \quad {}_{2}\,{}_{1}\,1\;{}^{r} \; / \quad Q$$

f_r=Centre or Resonant Frequency

Q= 2π Total Energy Stored by antenna

Energy Radiated or Dissipated per cycle

Lower the "Q" of antenna higher is the bandwidth and vice versa

Antenna Bandwidth

Most antenna technologies can support operation over a frequency range that is 5 to 10% of the central frequency (e.g., 100 MHz bandwidth at 2 GHz)

To achieve wideband operation requires specialized antenna technologies

(e.g., Vivaldi, bowtie, spiral)

Antenna Bandwidth

- The **bandwidth** of an antenna is the range of frequencies over which it is effective, usually centered around the operating or resonant frequency.

  – The bandwidth of an antenna may be increased by several techniques, including using thicker wires, replacing wires with *cages* to simulate a thicker wire, tapering antenna components (like in a feed horn), and combining multiple antennas into a single assembly(Arrays) and allowing the natural impedance to select the correct antenna.

Bandwidth

- For broadband antennas, the bandwidth is usually expressed as the ratio of the upper-to-lower frequencies of acceptable operation. For example, a 10:1 bandwidth indicates that the upper frequency is 10 times greater than the lower.

- For narrowband antennas, the bandwidth is expressed as a percentage of the frequency difference (upper minus lower) over the center frequency of the bandwidth. For example, a 5% bandwidth indicates that the frequency difference of acceptable operation is 5% of the center frequency of the bandwidth.

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Baluns

A balun is a device that joins a balanced line (one that has two conductors, with equal currents in opposite directions, such as a twisted pair cable) to an unbalanced line (one that has just one conductor and a ground, such as a coaxial cable). So it's used to convert an unbalanced signal to a balanced one or vice versa.

Baluns isolate a transmission line and provide a balanced output.

A typical use for a **balun** is in television antenna.

Baluns

- A **balun** is a type of transformer Used at RF
  - Impedance-transformer baluns having a 1:4 ratio are used between systems with impedances of 50 or 75 ohms (unbalanced) and 200 or 300 ohms (balanced). Most television and FM broadcast receivers are designed for 300-ohm balanced systems, while coaxial cables have characteristic impedances of 50 or 75 ohms. Impedance-transformer baluns with larger ratios are used to match high-impedance balanced antennas to low

    impedance unbalanced wireless receivers, transmitters, or transceivers.
- Usually band-limited
- Improve matching and prevent unwanted currents on coaxial cable shields

- As in differential signaling, the **rejection of common mode current** is the most important metric for an antenna feed balun, although performance also requires proper impedance ratios and matching to the antenna.

Baluns

Balun for connecting a center-fed dipole to a coaxial cable

Baluns As Impedance Transformers

Transition from a 50Ώ coaxial cable to a 300 Ώ half-wave folded dipole through a four-to one impedance transformation balun

Forcing I_C to be zero somehow - this is often called choking the current or a current choke is needed.

d

to

The green sleeve in Figures 1 and 2 acts as a transmission line

Balanced Unbalanced

Television receiver Coaxial_cable network Television receiver Coaxial antenna system FM broadcast receiver Coaxial antenna system Dipole antenna Coaxial transmission line Parallel-wire transmission line Coaxial transmitter output Parallel-wire transmission line Coaxial receiver input Parallel-wire transmission line Coaxial transmission line

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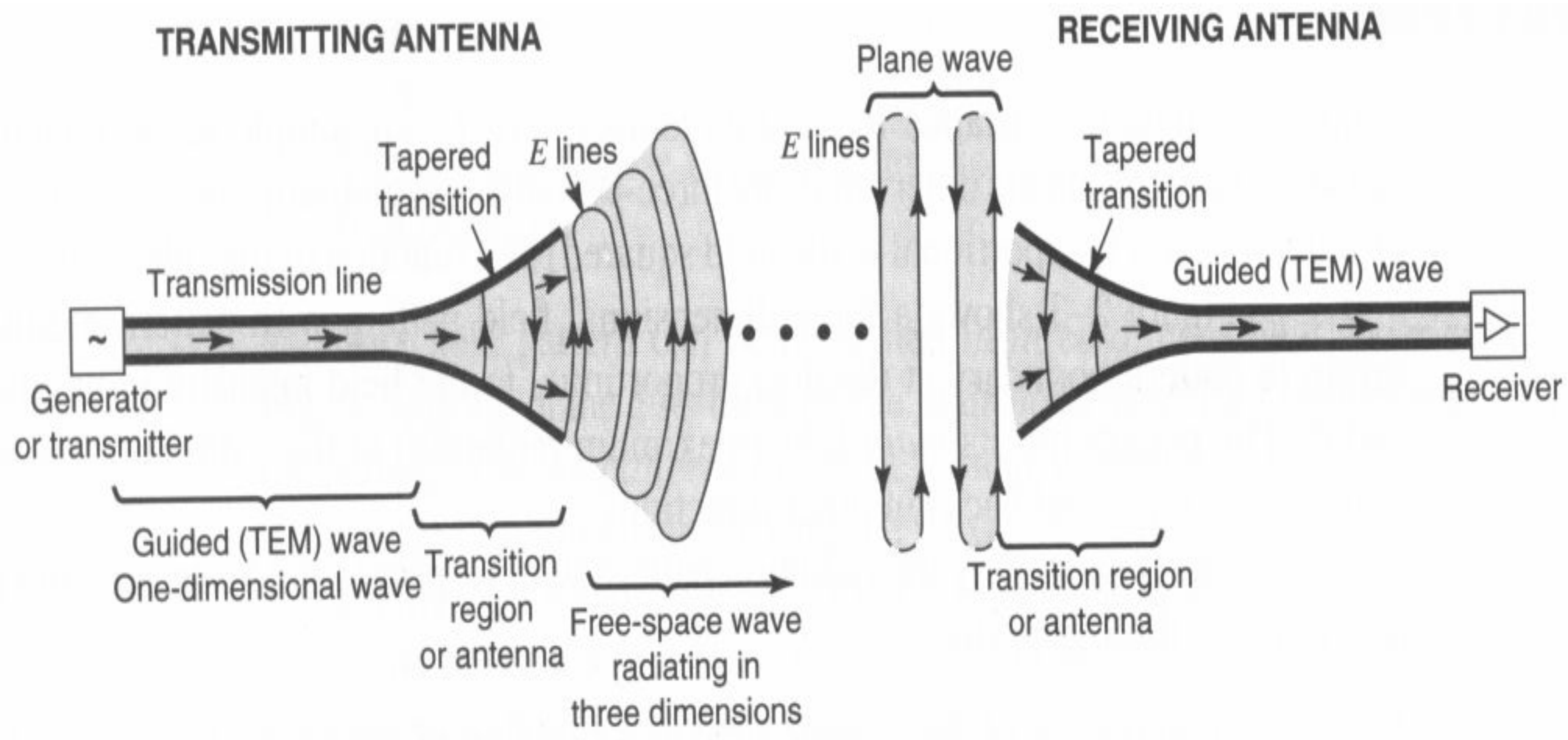
- An antenna is a <u>passive structure</u> that serves as transition between a <u>transmission line</u> and <u>air</u> used to transmit and/or receive electromagnetic waves.
- Converts Electrons to Photons of EM energy
- It is a transducer which interfaces a circuit and freespace



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- Spatial filter
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- Polarization filter
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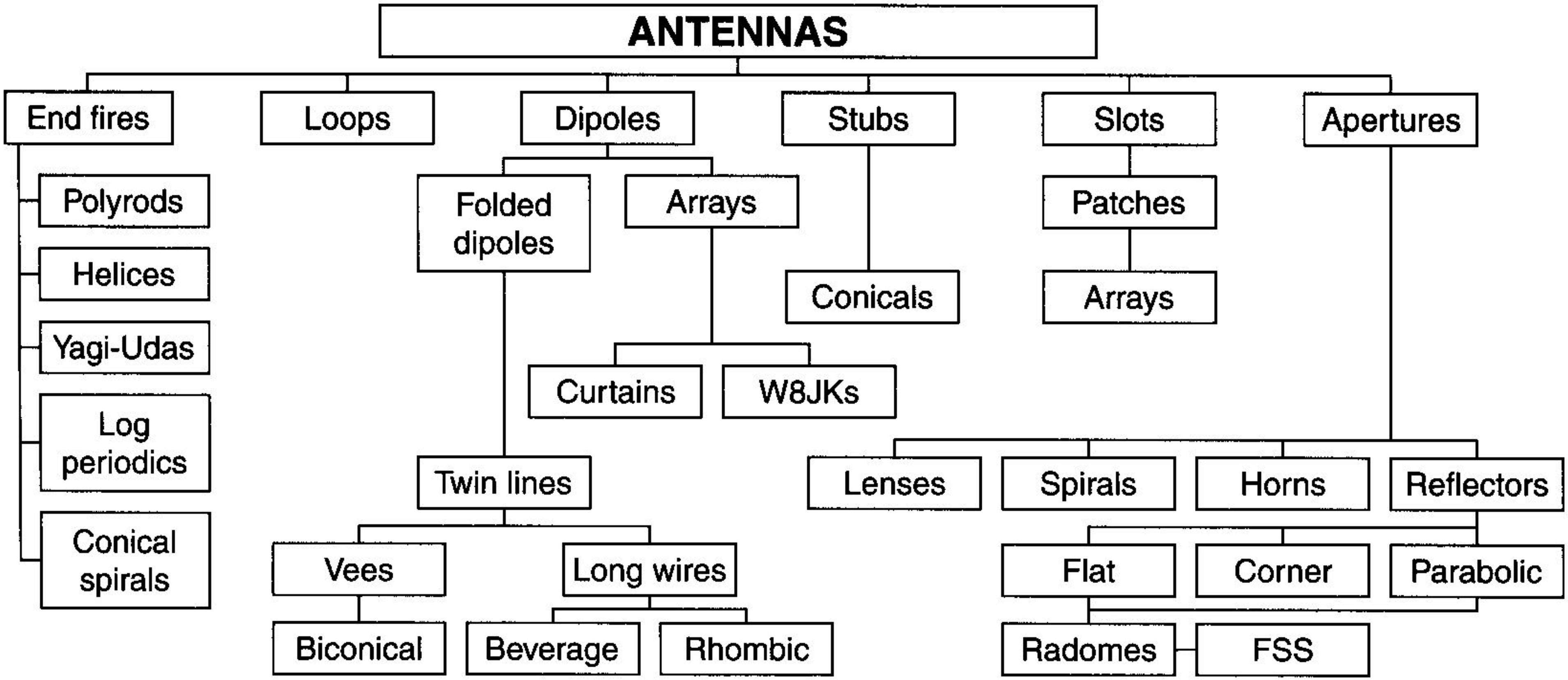
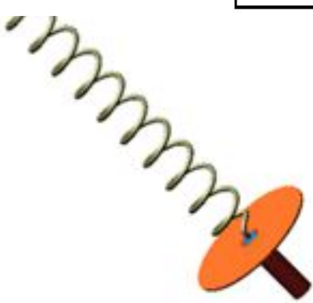
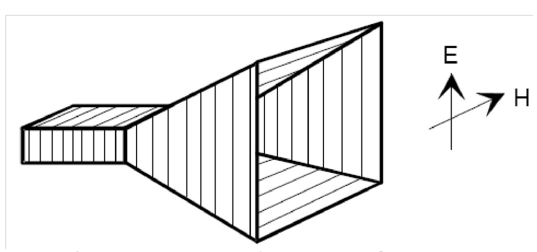
- Impedance transformer (50 Ω to 377Ω)
  transition between free space and transmission line
- Propagation mode adapter
  from free-space fields to guided waves
  (e.g., transmission line, waveguide)

Antenna types

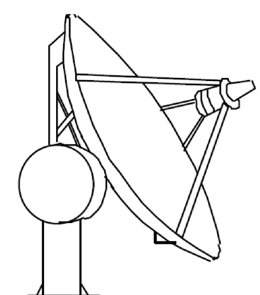




Helical antenna



Horn antenna



Parabolic reflector antenna

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- Far field zone, r_{ff}
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$$\Omega_{\text{isotropic}} = \iint_{4\pi} (1)\, d\Omega$$

$$\int_{\theta=0}^{\pi} \int_{\phi=0}^{2\pi} (1) \sin\theta \, d\theta \, d\phi = 4\pi$$

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

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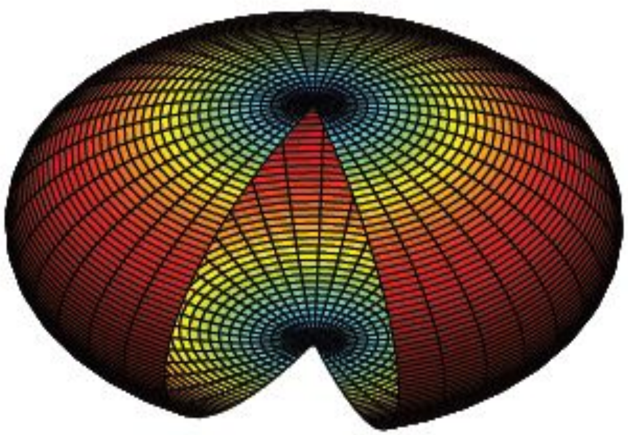
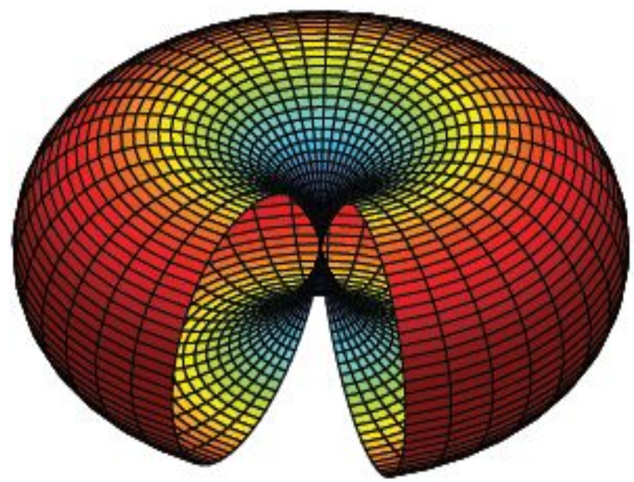
An antenna having the property of radiating or receiving more effectively in some directions than in others. Usually the maximum directivity is significantly greater than that of a half-wave dipole.

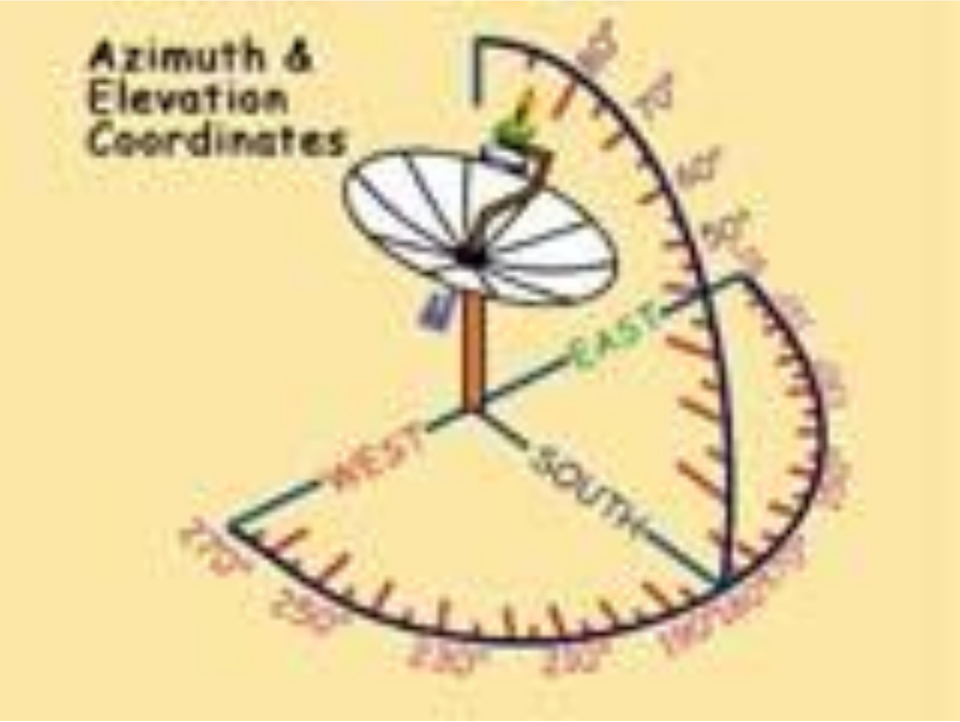


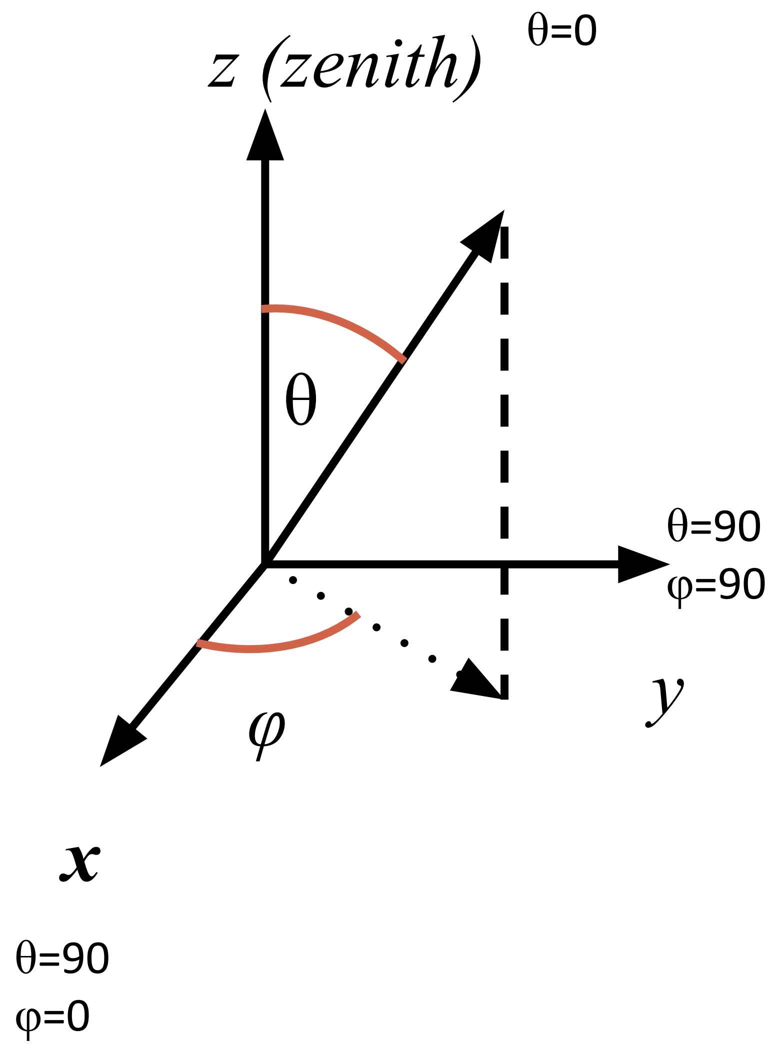
Isotropic



Omni-directional

Spherical coordinates

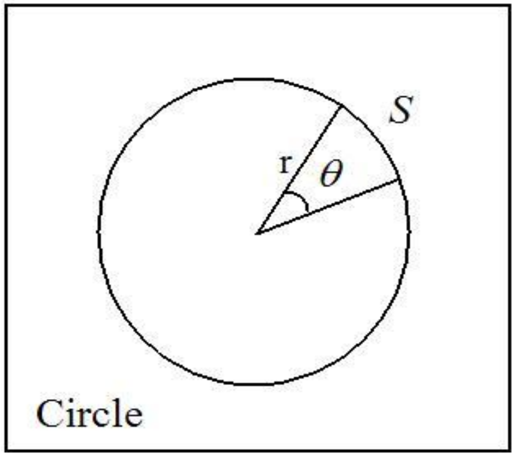


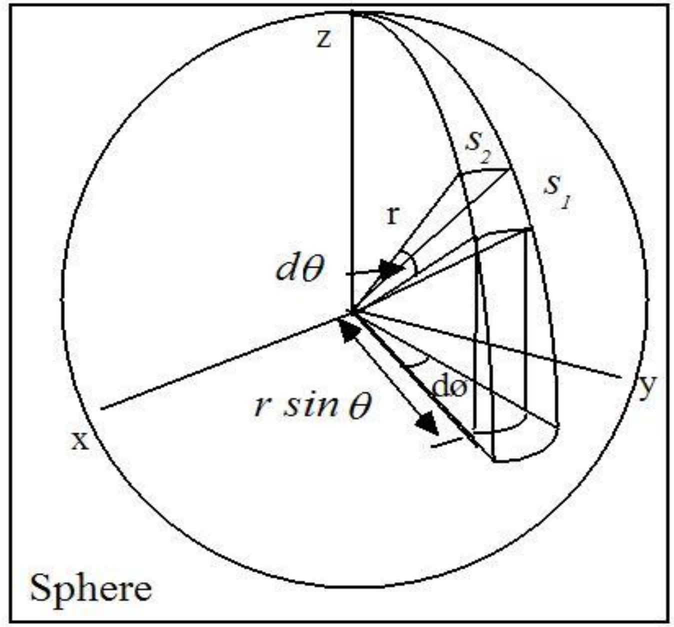


φ= azimuth

θ= elevation

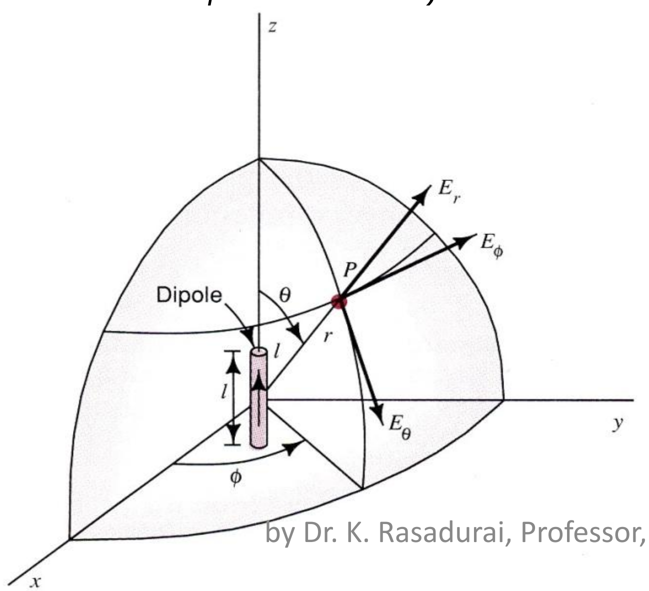
Solid Angle





$s_1 = r\, d\theta \quad s_2 = r \sin \theta\, d\phi$

$s = \theta r$ = arco



Radiation Intensity

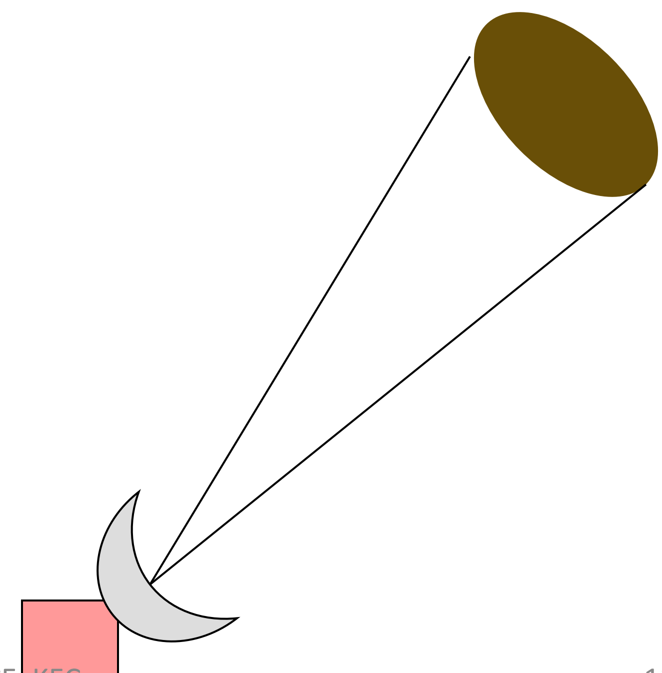
- Is the **power density per solid angle**:

$$U = r^2 P_r \qquad [\mathrm{W/sr}]$$

where

$$P_r = ½ \ \mathrm{Re}\{E \times H^*\}\hat{r} \ [\mathrm{W/m^2}]$$

is the power density also known as Poynting vector.



Radiation Pattern

- A **radiation pattern** is a three-dimensional, graphical representation of the **far-field** radiation properties of an antenna as a function of space coordinates. The far-field region is a region far enough for the radiation pattern to be independent of the distance from the antenna. The radiation pattern of a particular antenna can be measured by experiment or can be calculated, if the current distribution is known.
- Typically measured in two planes:
  - E Plane
  - H Plane

Field pattern:

$$E_n(\theta,\phi) = \frac{E(\theta,\phi)}{E_{\max}(\theta,\phi)}$$

Power pattern:

$$F_n(\theta,\phi) = \frac{\mathrm{P}(\theta,\phi)}{\mathrm{P}_{\max}(\theta,\phi)} = \frac{U(\theta,\phi)}{U_{\max}(\theta,\phi)}$$

Radiation pattern – variation of the field intensity of an antenna as an angular function with respect to the axis

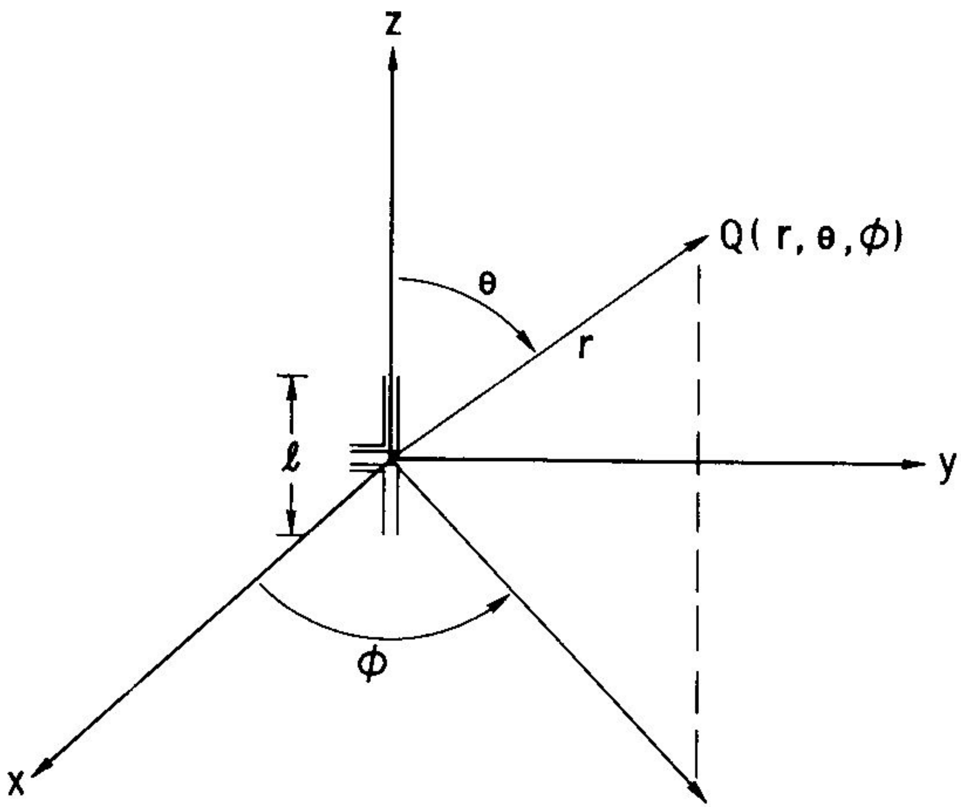
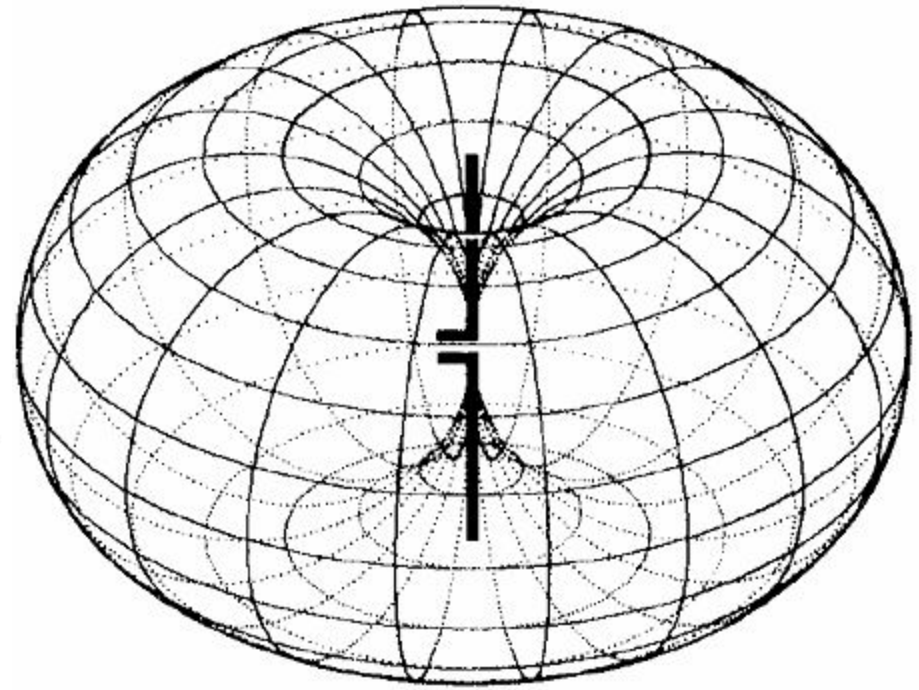


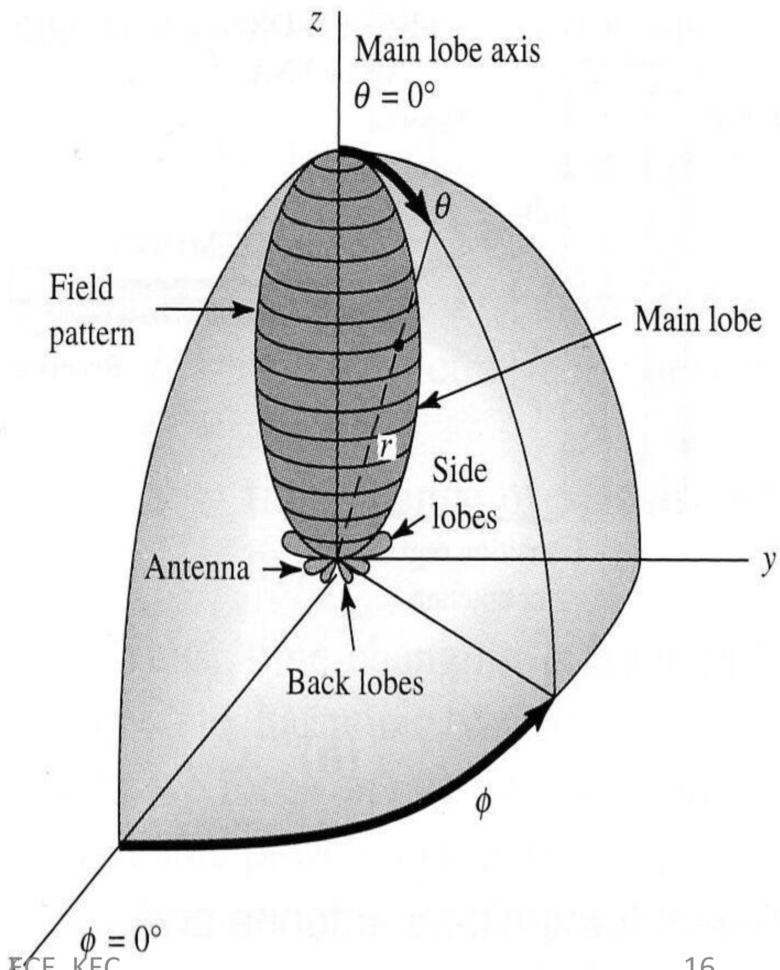
Fig. 3.7 Short dipole placed at the origin of a spherical coordinate system.



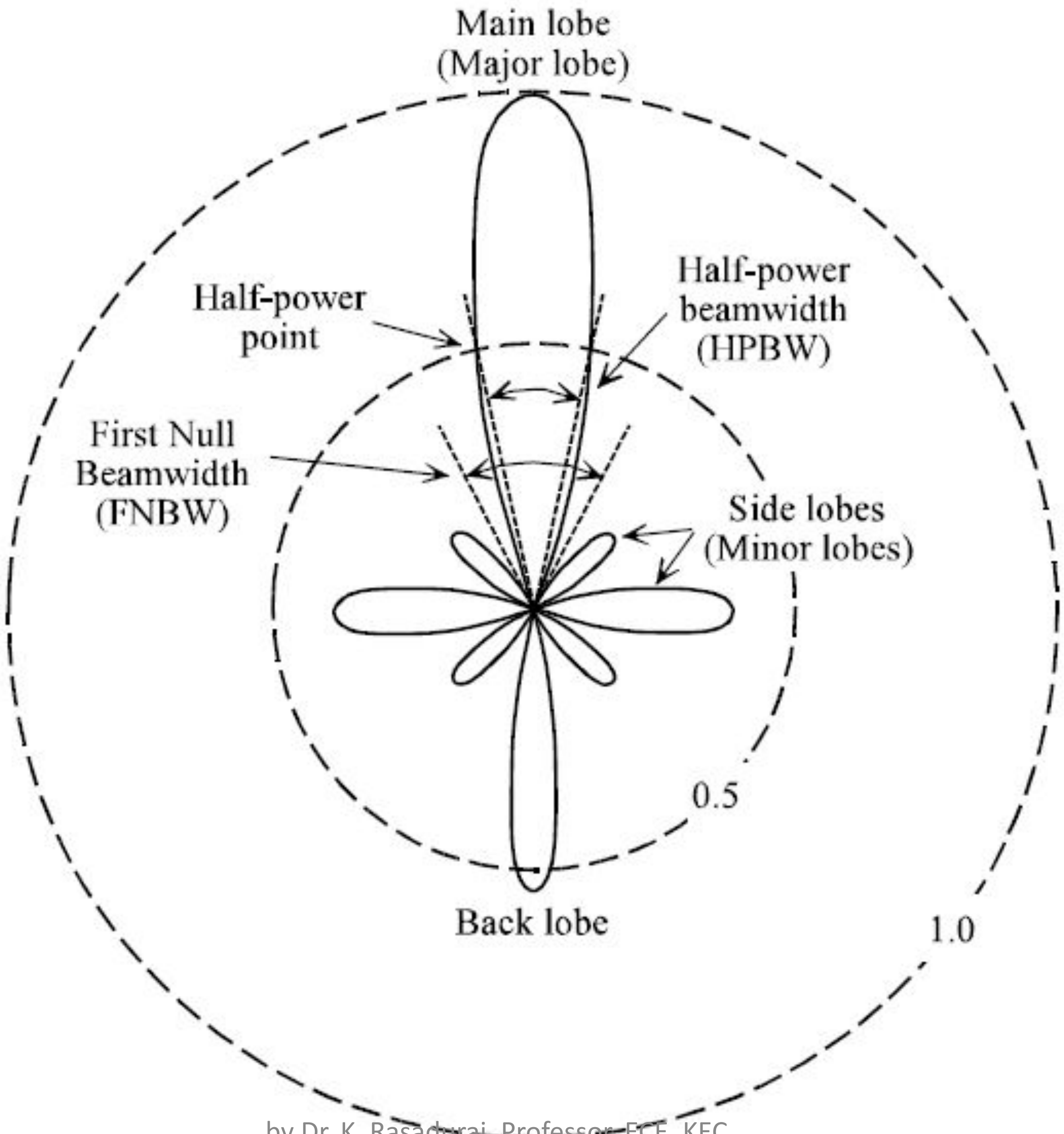
Three-dimensional representation of the radiation pattern of a dipole antenna

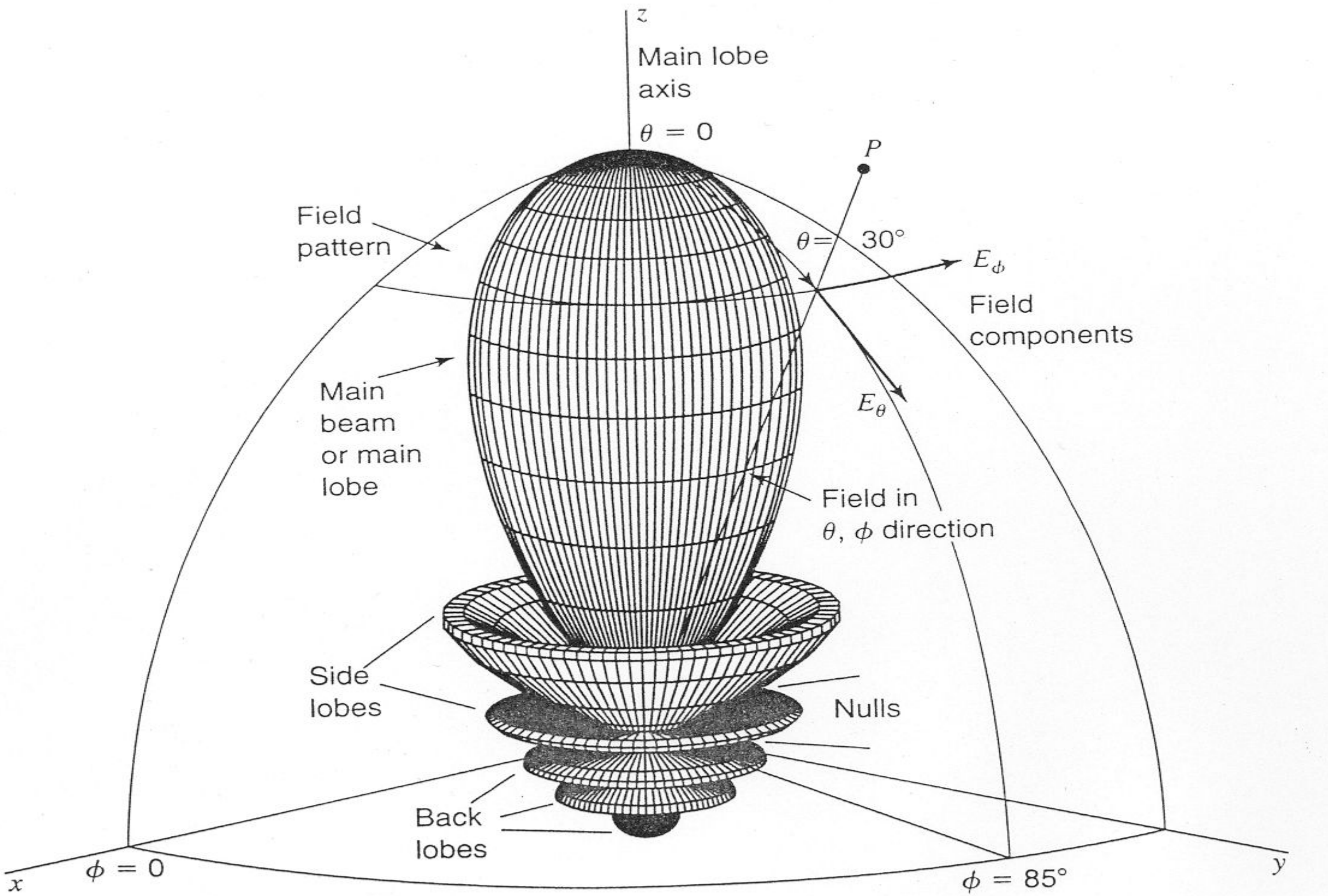
Radiation Pattern Characteristics

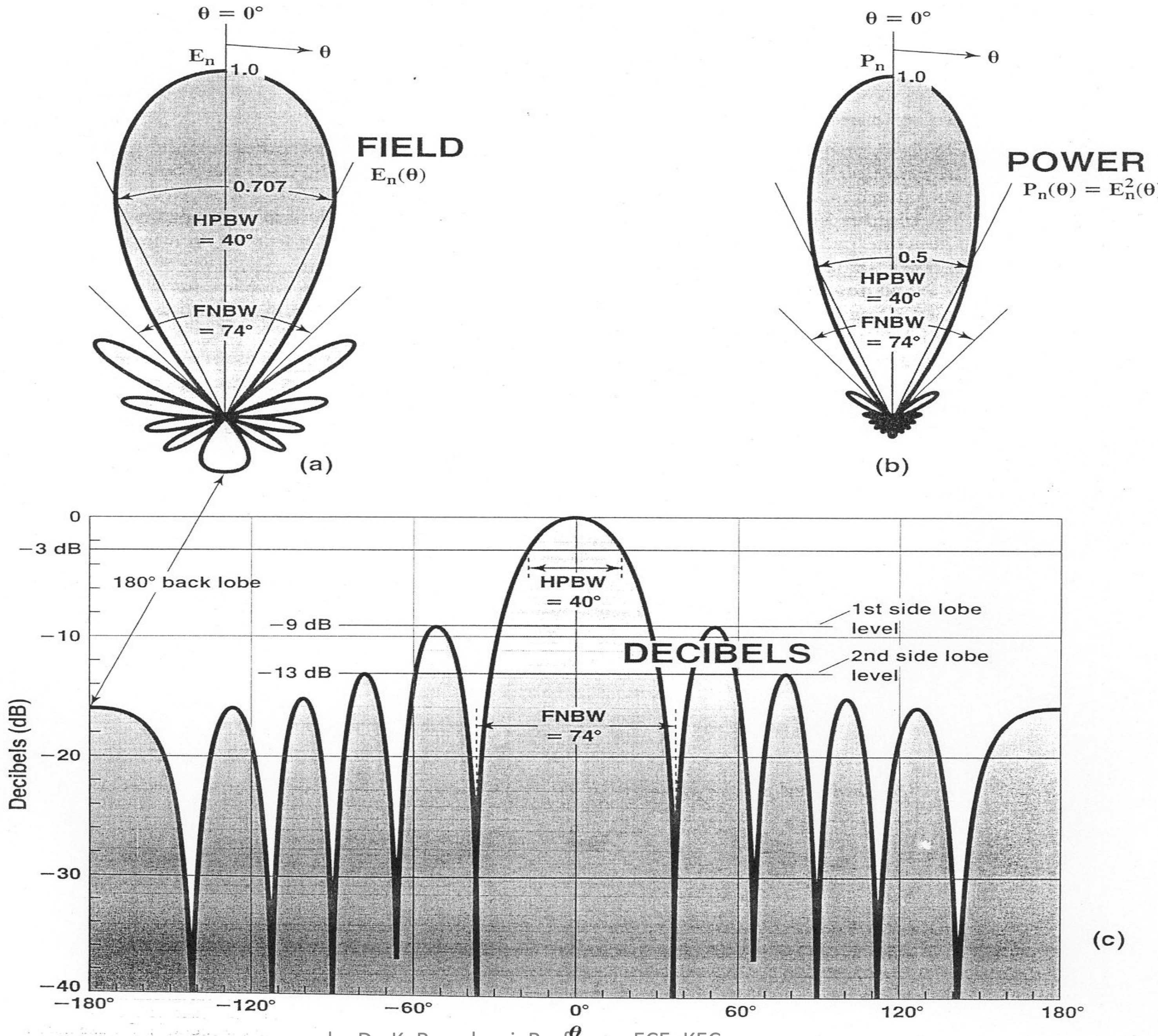
- 3 dB beamwidth (HPBW)
- Sidelobes
- Nulls
- Front-to-back ratio
- Gain (approximate)
- Maximum signal position



Antenna Pattern Parameters




z
Main lobe
axis
θ = 0
P
Field
pattern
θ = 30°
E_φ
Field
components
Main
beam
or main
lobe
E_θ
Field in
θ, φ direction
Side
lobes
Nulls
Back
lobes
x
φ = 0
φ = 85°
y


θ = 0°
θ
E_n
1.0
FIELD
$E_n(\theta)$
0.707
HPBW
= 40°
FNBW
= 74°
(a)
θ = 0°
θ
P_n
1.0
POWER
$P_n(\theta) = E_n^2(\theta)$
0.5
HPBW
= 40°
FNBW
= 74°
(b)
0
−3 dB
180° back lobe
HPBW
= 40°
−9 dB
1st side lobe
level
−10
DECIBELS
−13 dB
2nd side lobe
level
Decibels (dB)
FNBW
= 74°
−20
−30
(c)
−40
−180°
−120°
−60°
0°
60°
120°
180°
θ

Directivity and GAIN

"The ratio of the radiation intensity in a given direction from the antenna to the radiation intensity averaged over all directions."

$$\frac{\text{Max Radiation intensity from subject or test antenna}}{\text{Max Radiation Intensity from reference (Isotropic)antenna}}$$

with same power input.

$G = \eta D$

Directivity and GAIN of an Antenna

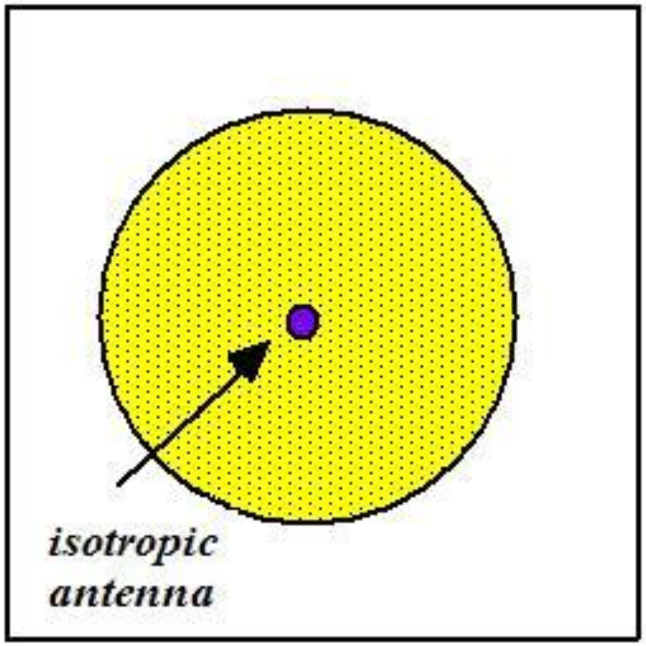
- The ***Directivity*** or ***Gain*** of an antenna is defined as the ratio of the maximum value of the power radiated per unit solid angle to the average power radiated per unit solid angle

- **Directivity** is a fundamental antenna parameter. It is a measure of how '***directional***' an antenna's radiation pattern is. An antenna that radiates equally in all directions would have effectively zero directionality, and the directivity of this type of antenna would be 1 (or 0 dB).

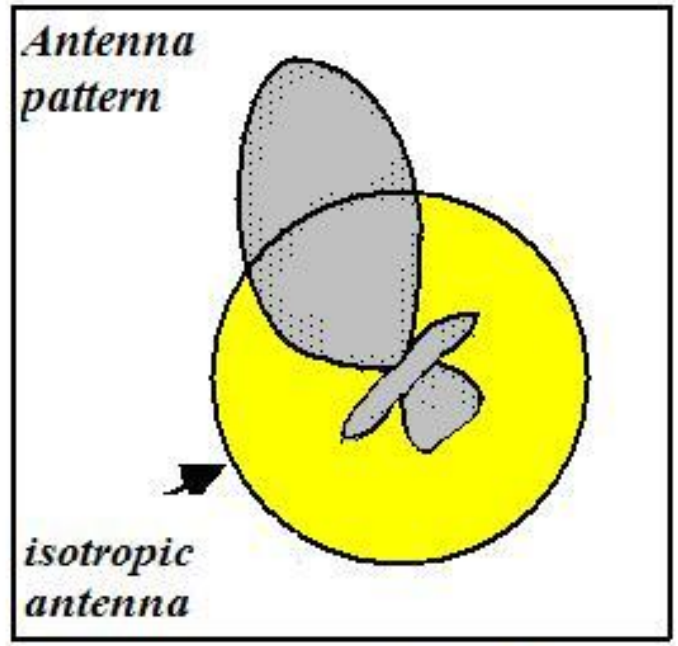
- It measures the power density of the antenna radiates in the direction of its strongest emission, versus the power density radiated by an ideal Isotropic Radiator (which emits uniformly in all directions) radiating the same total power.

- Directivity is a component of its Gain, If lossless antenna, $G = D$

Gain or Directivity



Isotropic Pattern



Comparison of regular antenna pattern with isotripic

An isotropic antenna and a practical antenna fed with the same power. Their patterns would compare as in the figure on the right.

Directivity and Gain

- All practical antennas radiate more than the isotropic antenna in some directions and less in others.
- Gain is inherently directional; the gain of an antenna is **usually measured in the direction which it radiates best**.

"The directivity of an antenna is equal to the ratio of the maximum power density P_{max} to its average value over a sphere as observed in the far field of an antenna"

$$D = D_{\max}(\theta,\phi) = \mathrm{P}_{\max} / \mathrm{P}_{ave} = U_{\max} / U_{ave}$$

Gain or Directivity

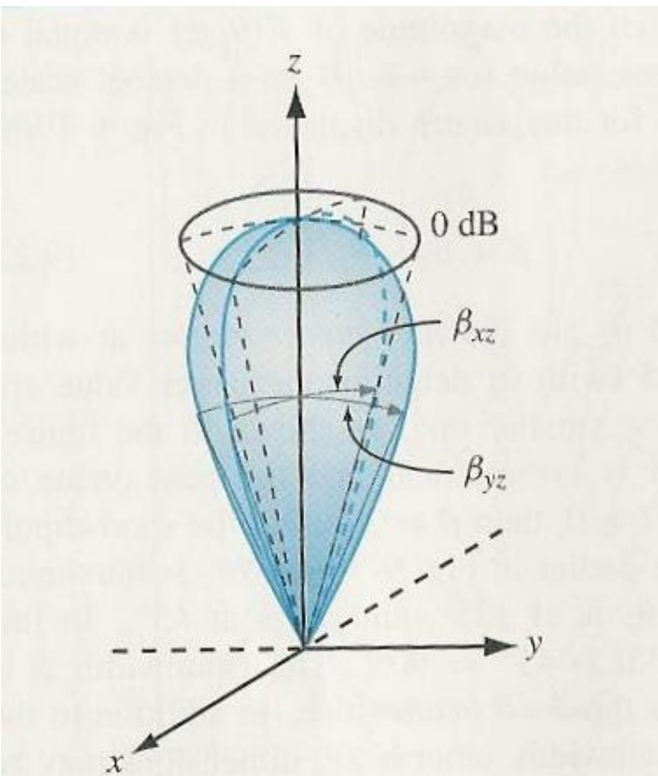
- Gain is measured by comparing an antenna to a model antenna, typically the isotropic antenna which radiates equally in all directions.

$$D(\theta,\phi) = \mathsf{P}/\mathsf{P}_{AVE} = \frac{\mathsf{P}(\theta,\phi)}{\frac{1}{A}\iint \mathsf{P}\, dA} = \frac{4\pi r^2 \mathsf{P}(\theta,\phi)}{P_{rad}}$$

$$D_o = \frac{4\pi U_{\max}}{P_{rad}} = 4\pi/\Omega_{\mathrm{A}} = \Omega_{\mathrm{isotropic}}/\Omega_{\mathrm{A}}$$

Relation b/w Directivity, HPBW, Ω_A

- For an antenna with a single main lobe pointing in the z-direction , Beam area(Ω_A) can be approximated to the product of the HPBW



Beam solid angle

$$\Omega_A \cong \beta_{xz}\beta_{yz}$$

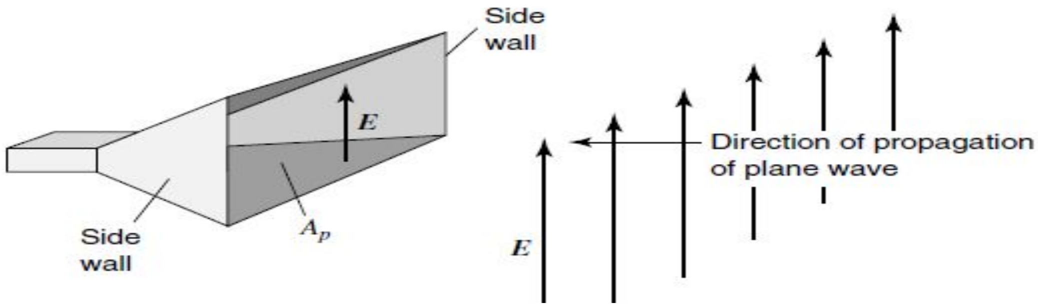
then

The Directivity:

$$D = 4\pi/\Omega_A \cong \frac{4\pi}{\beta_{xz}\beta_{yz}}$$

Effective Aperture

“A useful parameter in calculating the received power of an antenna is the ***effective area*** or ***effective aperture***”



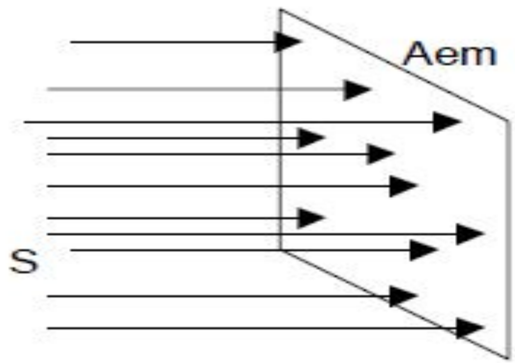
Effective area or Effective aperture (square meters)

The effective area corresponds to the effective absorbance area presented by an antenna to an incident plane wave. For an aperture antenna, it is equal to or smaller than the physical aperture. The relationship between the gain and the wavelength is

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

Effective aperture

In receiving mode, the maximum power received in a receiving antenna is P_{Am}. Consider this power to be that intercepted from the incoming wave by a maximum effective area A_{em}.



If the power density of the incoming wave is S, then $P_{rec} = S\,A_{em}$.

A_{em} is called maximum effective aperture of the antenna.

A_{em} is related to directivety by $D = \frac{4\pi}{\lambda^2} A_{em}$.

Since $G = e_r D = e_r \frac{4\pi}{\lambda^2} A_{em} = \frac{4\pi}{\lambda^2}(e_r A_{em}) = \frac{4\pi}{\lambda^2} A_e$

$A_e = e_r A_{em}$ is called effective aperture of the antenna.

Effective Aperture

It is also defined as the ratio of power received at the antenna load terminal to the poynting vector(or power density)in Watts/meter^2 of the incident wave.
Thus

$$\text{Effective Area} = \frac{\text{Power Received}}{\text{Poynting Vector of incident wave}}$$

$$A_e = W/P$$

Antenna Impedance

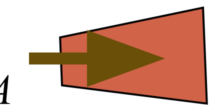
Antenna *Input impedance* is very important because it is generally desired

- to supply maximum available power from the transmitter to the antenna or
- to extract maximum amount of received energy from the antenna.

Antenna Impedance

- An antenna is “seen" by the generator as a load with impedance Z_A, connected to the line.

Z_A

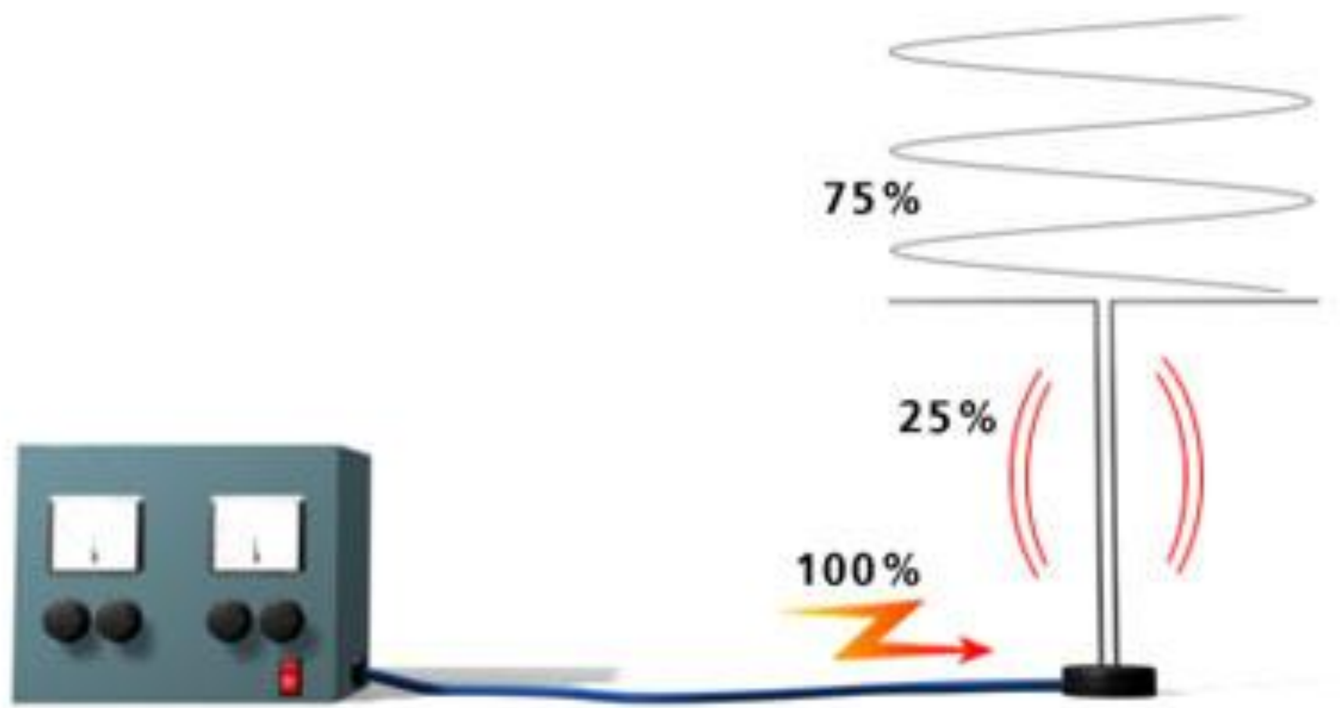


$$Z_A = \left(R_{rad} + R_L\right) + jX_A$$

- **The real part is the radiation resistance plus the ohmic resistance**.
  - Minimizing impedance differences at each interface will reduce SWR and maximize power transfer through each part of the antenna system.
  - Complex impedance, Z_A, of an antenna is related to the electrical length of the antenna at the wavelength in use.
    - The impedance of an antenna can be matched to the feed line and radio by adjusting the impedance of the feed line, using the feed line as an impedance transformer.
    - More commonly, the impedance is adjusted at the load with an antenna tuner, a balun, a matching transformer, matching networks composed of inductors and capacitors, or matching sections such as the gamma match.

Antenna Impedance

The radiation resistance does not correspond to a real resistor present in the antenna but to the resistance of space coupled via the beam to the antenna terminals.



Radiation Resistance

- The antenna is a radiating device in *which power is radiated into space in the form of electromagnetic waves* .Hence there must be power dissipation which may be expressed in usual manner as

$$W=I^2R$$

- If it is assumed that all this power appears as electromagnetic radio waves then this power can be divided by square of current i.e

$$R_r=W/I^2$$

at a point where it is fed to antenna and obtain a fictitious resistance called as ***Radiation resistance***.

Radiation Resistance

- Thus "Radiation Resistance can be defined as that fictitious resistance which when substituted in series with the antenna will consume the same power as is actually radiated".
- Total Power loss in an antenna is sum of the two losses

Total Power Loss = Ohmic Loss + Radiation Loss

$$
\begin{aligned}
W &= W^{'} + W^{''} \\
&= I^2 R_r + I^2 R_l \\
&= I^2 (R_r + R_l) \\
&= I^2 R
\end{aligned}
$$

Radiation Resistance

The value of Radiation Resistance depends on:

- ✔ Configuration of Antenna
- ✔ The Point where radiation resistance is considered
- ✔ Location of antenna with respect to ground and other objects
- ✔ Ratio of length of diameter of conductor used
- ✔ Corona Discharge-a luminous discharge round the surface of antenna due to ionization of air etc.

So , Antenna Input Impedance is

- Input Impedance (resistance + reactance)
- Radiation Resistance (corresponds to energy that is transmitted)
- Loss Resistance

Radiation Resistance

- *Radiation Resistance* is the portion of the antenna's impedance that results in power radiated into space (i.e., the effective resistance that is related to the power radiated by the antenna. Radiation resistance varies with antenna length. Resistance increases as the λ increases

Antenna Bandwidth

- Antenna Bandwidth is the range of frequency over which the antenna maintains certain required characteristics like gain, front to back ratio or SWR pattern (shape or direction), polarization and impedance
- It is the bandwidth within which the antenna maintains a certain set of given specifications.

$$\Delta w = w_2 - w_1 = w_r / Q = Bandwidth$$

$$\Delta f = f_2 - f_1 = f_r / Q$$

$$\Delta f \propto \frac{1}{Q}$$

f_r=Centre or Resonant Frequency

$$Q = 2\pi \frac{\text{Total Energy Stored by antenna}}{\text{Energy Radiated or Dissipated per cycle}}$$

Lower the "Q" of antenna higher is the bandwidth and vice versa

Antenna Bandwidth

Most antenna technologies can support operation over a frequency range that is 5 to 10% of the central frequency

(e.g., 100 MHz bandwidth at 2 GHz)

To achieve wideband operation requires specialized antenna technologies

(e.g., Vivaldi, bowtie, spiral)

Antenna Bandwidth

- The **bandwidth** of an antenna is the range of frequencies over which it is effective, usually centered around the operating or resonant frequency.
  - The bandwidth of an antenna may be increased by several techniques, including using thicker wires, replacing wires with *cages* to simulate a thicker wire, tapering antenna components (like in a feed horn), and combining multiple antennas into a single assembly(Arrays) and allowing the natural impedance to select the correct antenna.

Bandwidth

- For broadband antennas, the bandwidth is usually expressed as the ratio of the upper-to-lower frequencies of acceptable operation. For example, a 10:1 bandwidth indicates that the upper frequency is 10 times greater than the lower.

- For narrowband antennas, the bandwidth is expressed as a percentage of the frequency difference (upper minus lower) over the center frequency of the bandwidth. For example, a 5% bandwidth indicates that the frequency difference of acceptable operation is 5% of the center frequency of the bandwidth.

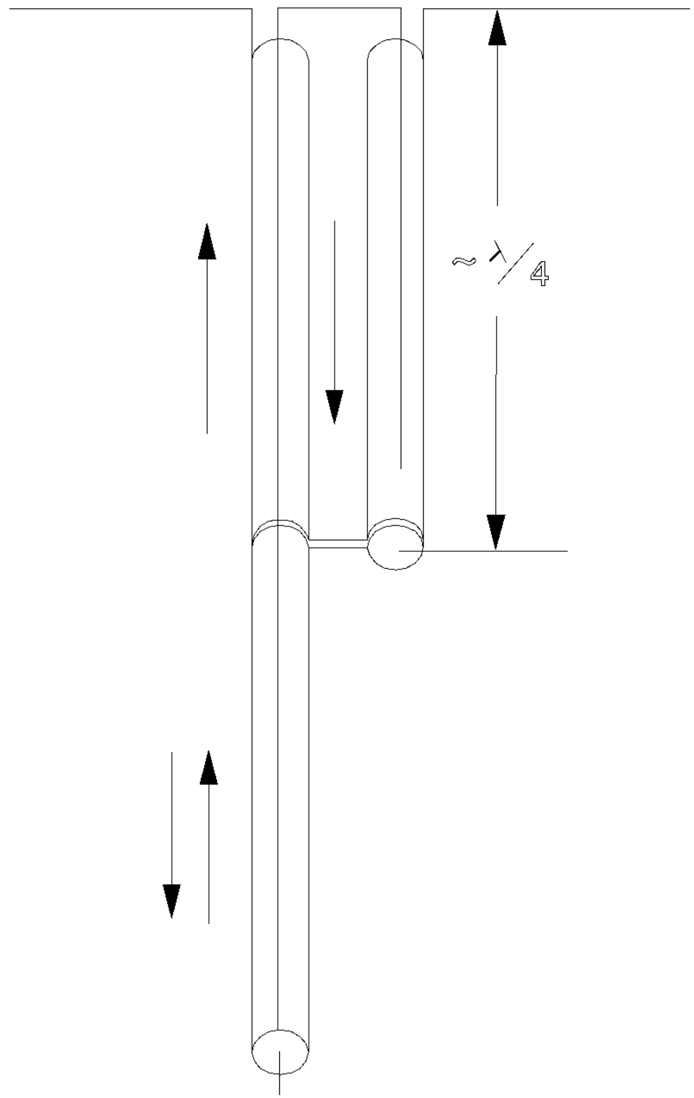
Baluns

- A balun is a device that joins a balanced line (one that has two conductors, with equal currents in opposite directions, such as a twisted pair cable) to an unbalanced line (one that has just one conductor and a ground, such as a coaxial cable).
- So it's used to convert an unbalanced signal to a balanced one or vice versa.
- **Baluns** isolate a transmission line and provide a balanced output.
- A typical use for a **balun** is in television antenna.

Baluns

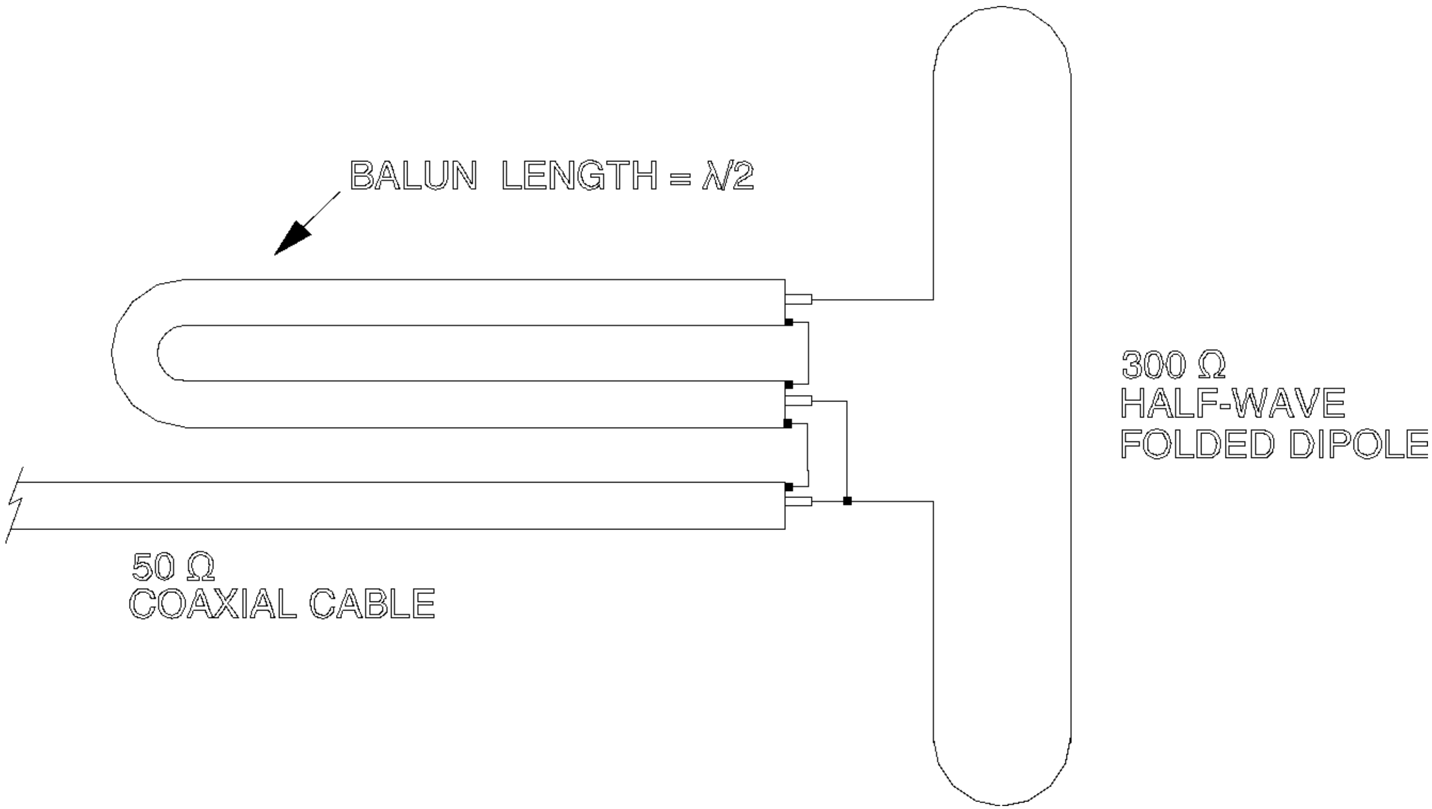
- A **balun** is a type of transformer Used at RF
  - Impedance-transformer baluns having a 1:4 ratio are used between systems with impedances of 50 or 75 ohms (unbalanced) and 200 or 300 ohms (balanced). Most television and FM broadcast receivers are designed for 300-ohm balanced systems, while coaxial cables have characteristic impedances of 50 or 75 ohms. Impedance-transformer baluns with larger ratios are used to match high-impedance balanced antennas to low-impedance unbalanced wireless receivers, transmitters, or transceivers.
- Usually band-limited
- Improve matching and prevent unwanted currents on coaxial cable shields
- As in differential signaling, the **rejection of common mode current** is the most important metric for an antenna feed balun, although performance also requires proper impedance ratios and matching to the antenna.

Baluns

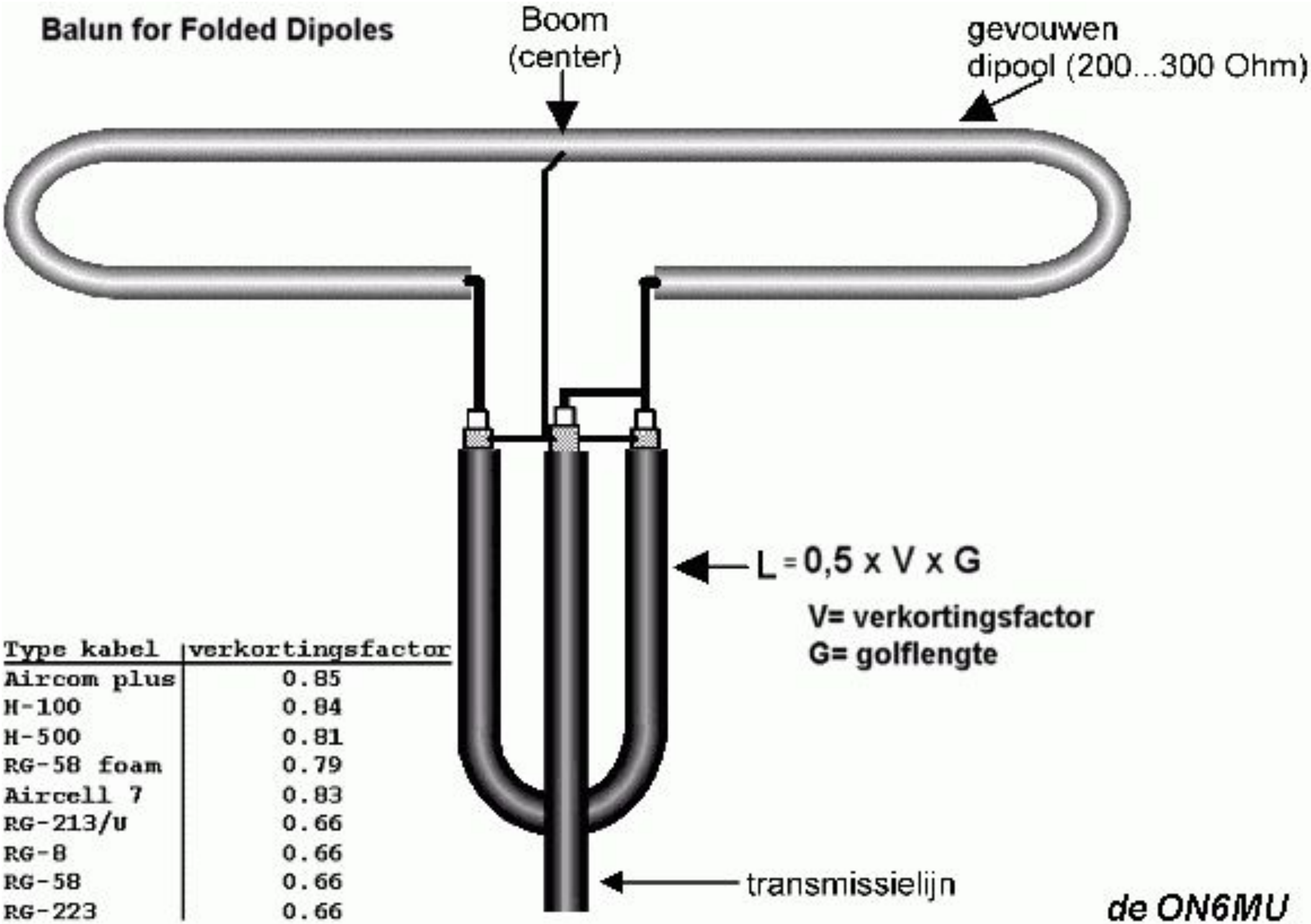


Balun for connecting a center-fed dipole to a coaxial cable

Baluns As Impedance Transformers

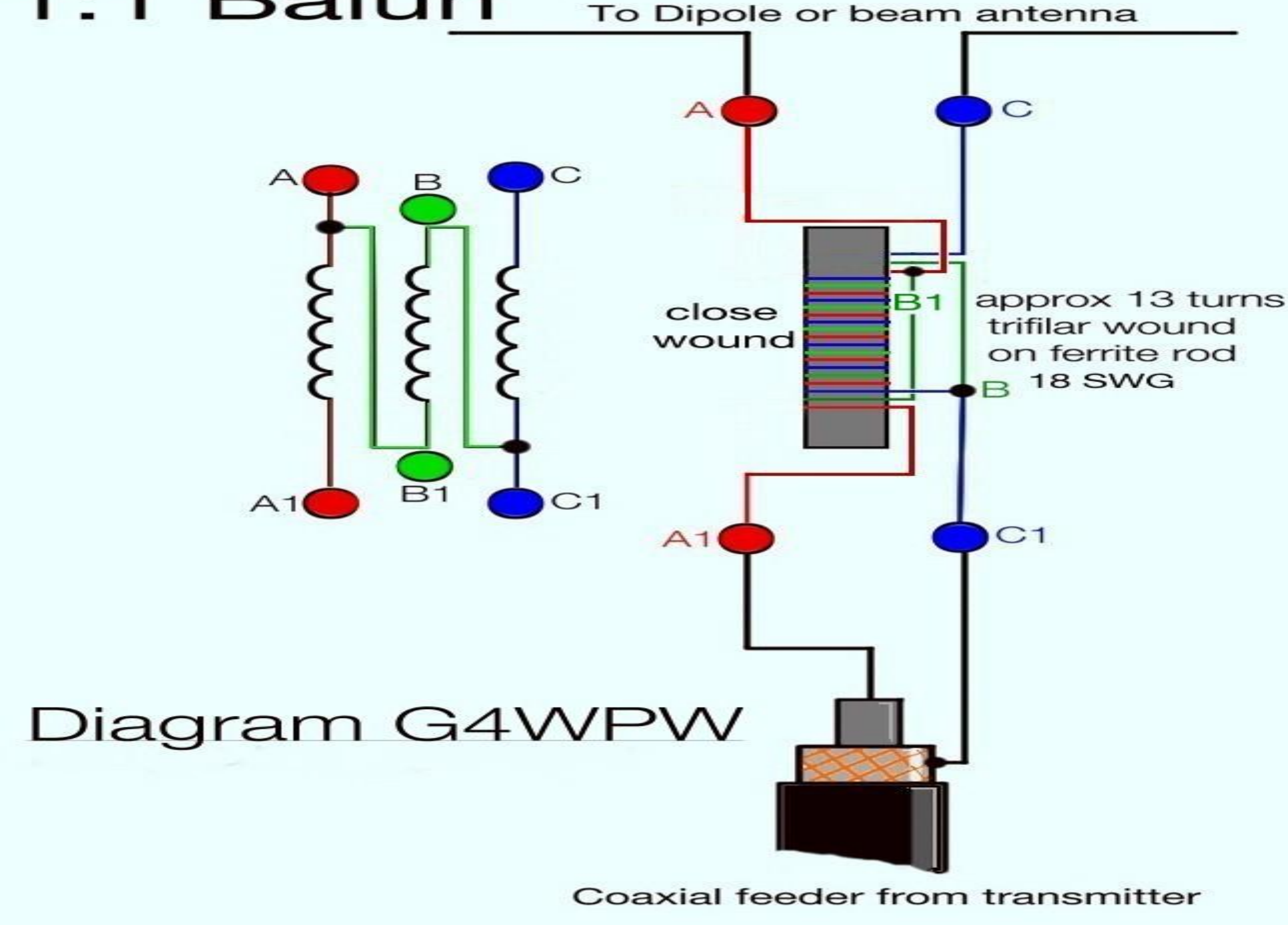


Transition from a 50Ώ coaxial cable to a 300 Ώ half-wave folded dipole through a four-to-one impedance transformation balun



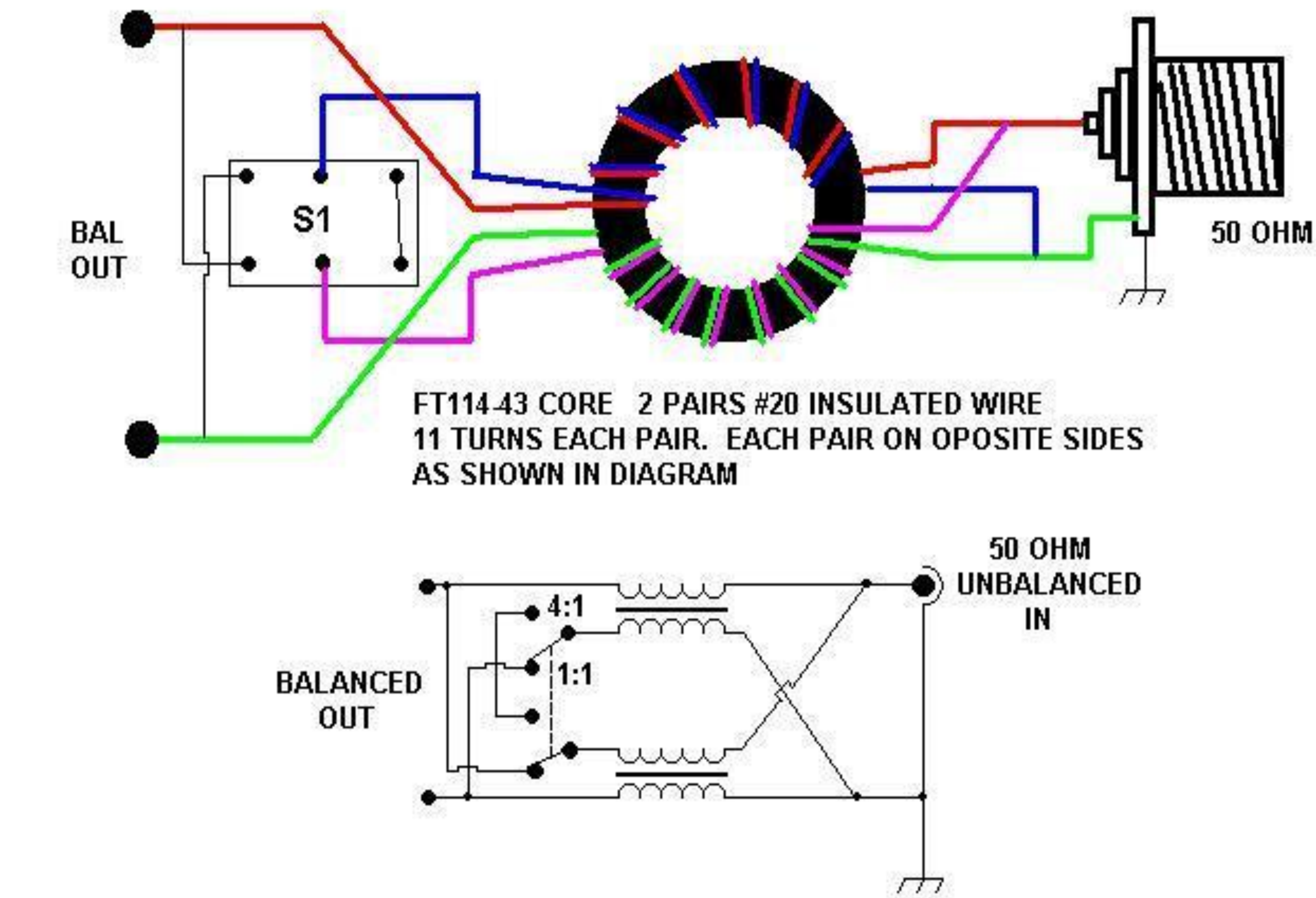
Type kabel	verkortingsfactor
Aircom plus	0.85
H-100	0.84
H-500	0.81
RG-58 foam	0.79
Aircell 7	0.83
RG-213/U	0.66
RG-8	0.66
RG-58	0.66
RG-223	0.66

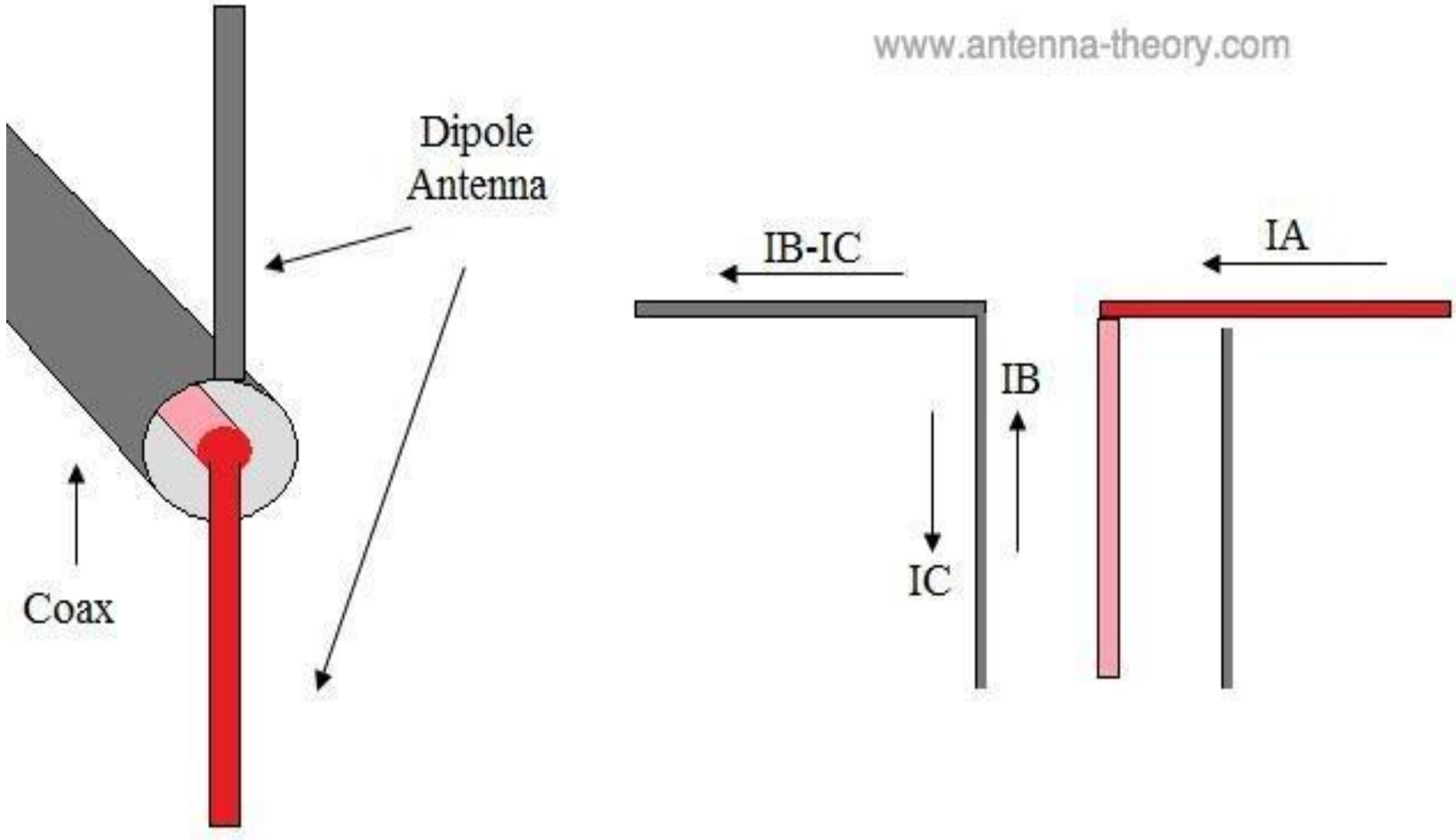
1:1 Balun



To Dipole or beam antenna
A
C
A
B
C
B1
A1
B1
C1
close
wound
approx 13 turns
trifilar wound
on ferrite rod
18 SWG
B
A1
C1
Diagram G4WPW
Coaxial feeder from transmitter

QRP TO 25 WATT, 4:1 - 1:1 SWITCHABLE BALUN

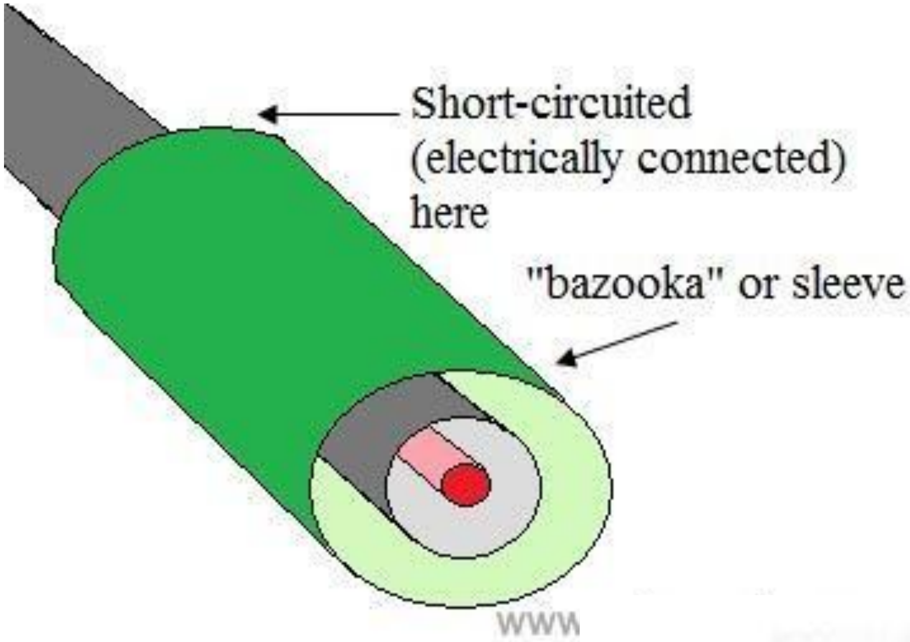




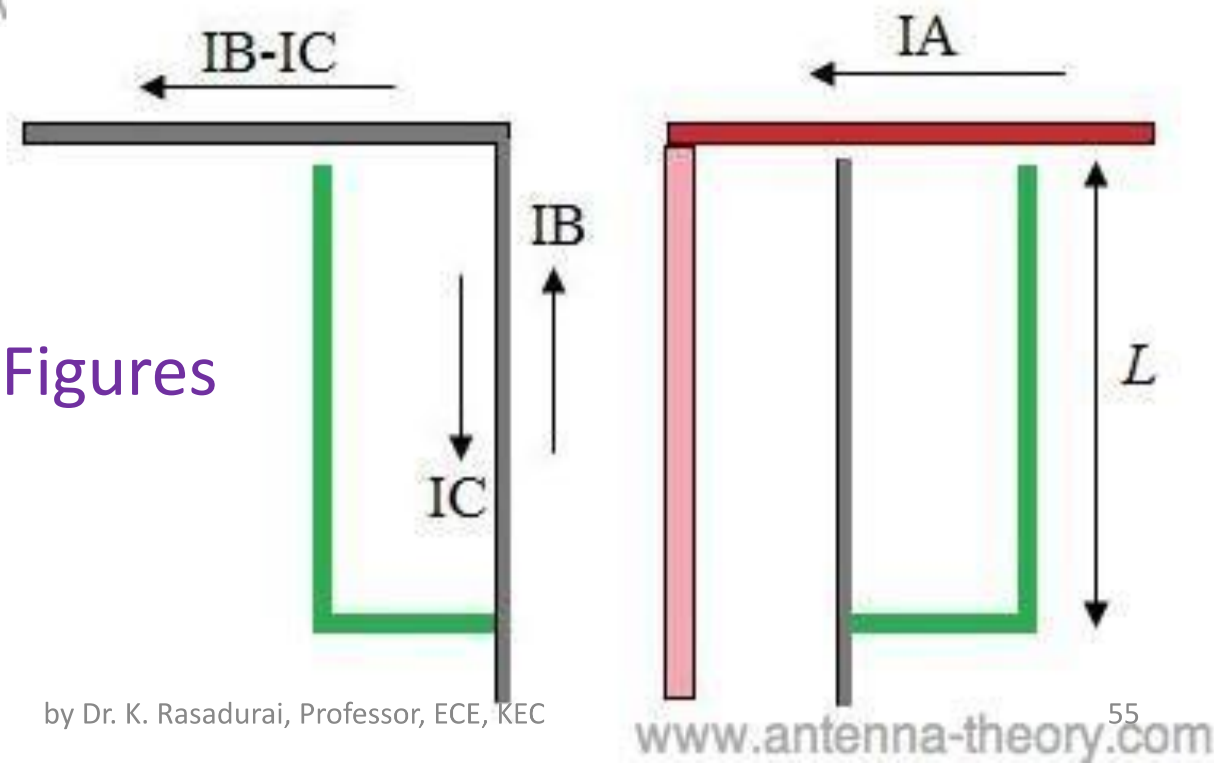
(a) Physical Model

(b) Equivalent View Showing Current Paths

Forcing *IC* to be zero somehow - this is often called choking the current or a current choke is needed.



This <u>balun</u> adds a short-circuited sleeve around the coaxial cable to choke the ***Ic***



The green sleeve in Figures 1 and 2 acts as a transmission line

Balanced	Unbalanced
Television receiver	Coaxial_cable_network
Television receiver	Coaxial antenna system
FM broadcast receiver	Coaxial antenna system
Dipole antenna	Coaxial transmission line
Parallel-wire transmission line	Coaxial transmitter output
Parallel-wire transmission line	Coaxial receiver input
Parallel-wire transmission line	Coaxial transmission line