



I ILLINOIS

Electrical & Computer Engineering

GRAINGER COLLEGE OF ENGINEERING

Antenna for EMC

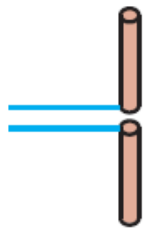
Prof. Victoria Shao

Introduction

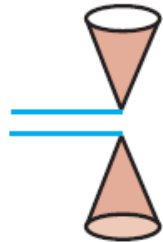
1. Antenna Overview
2. Ideal Dipole (Hertzian Dipole)
3. Antenna parameters
4. Dipole and Monopole
5. Other Antennas
6. Antenna Arrays
7. Antennas in communication systems



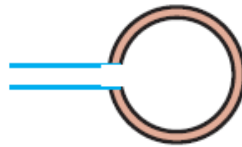
1 Antenna Overview



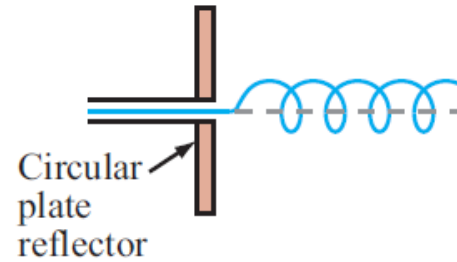
(a) Thin dipole



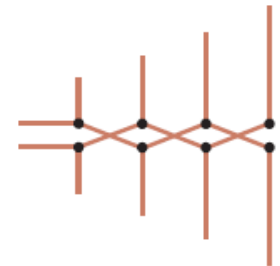
(b) Biconical dipole



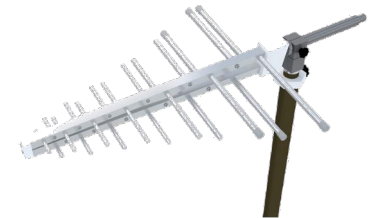
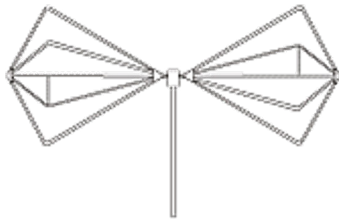
(c) Loop



(d) Helix

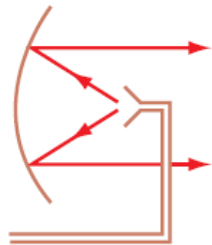


(e) Log-periodic

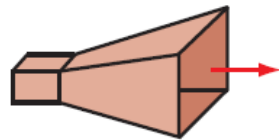


Examples of Antennas

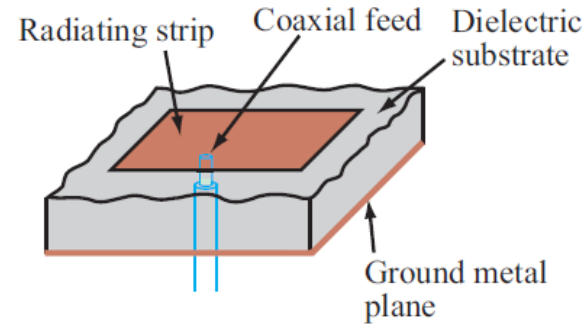
1 Antenna Overview



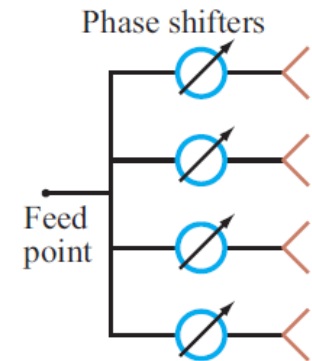
(f) Parabolic dish reflector



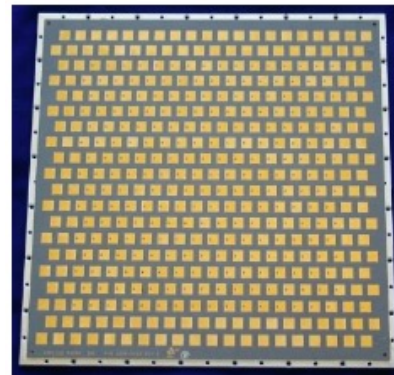
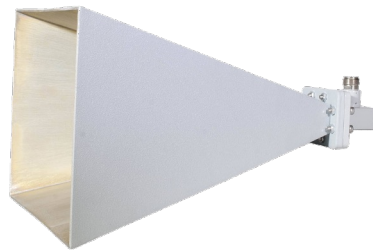
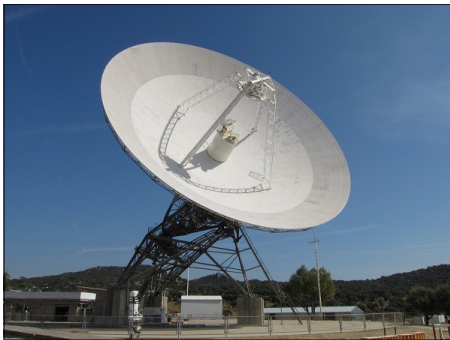
(g) Horn



(h) Microstrip



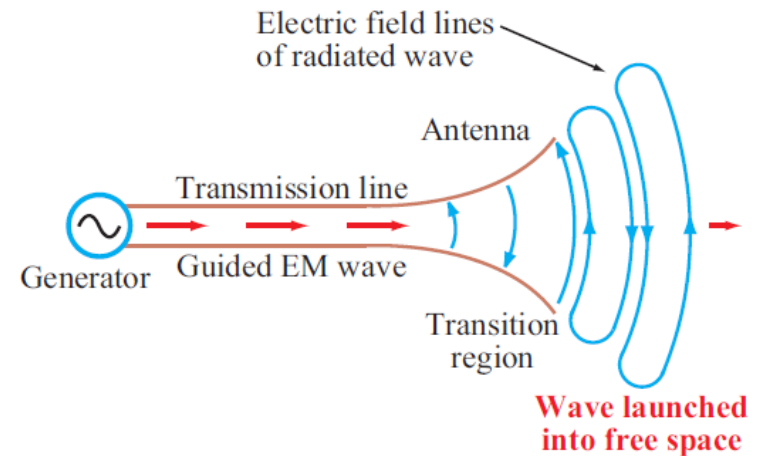
(i) Antenna array



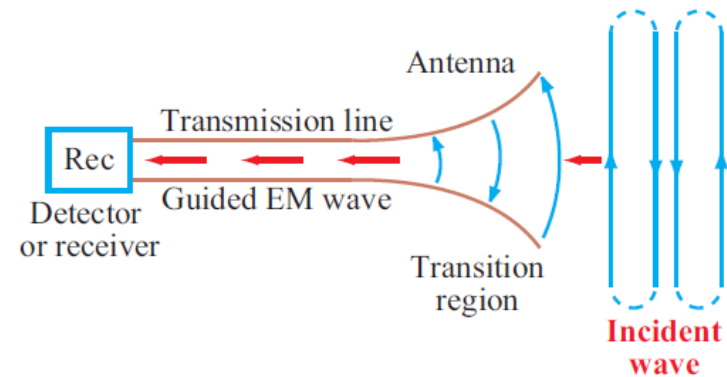
Examples of Antennas

Antenna Properties

1. An antenna is a **transducer** that converts a guided wave propagating on a transmission line into an electromagnetic wave propagating in an unbounded medium (usually free space), or vice versa.
2. Most antennas are **reciprocal devices**, exhibiting the same radiation pattern for transmission as for reception.
3. Being a reciprocal device, an antenna, when operating in the receiving mode, can extract from an incident wave only that component of the wave whose electric field matches the **antenna polarization** state.



(a) Transmission mode

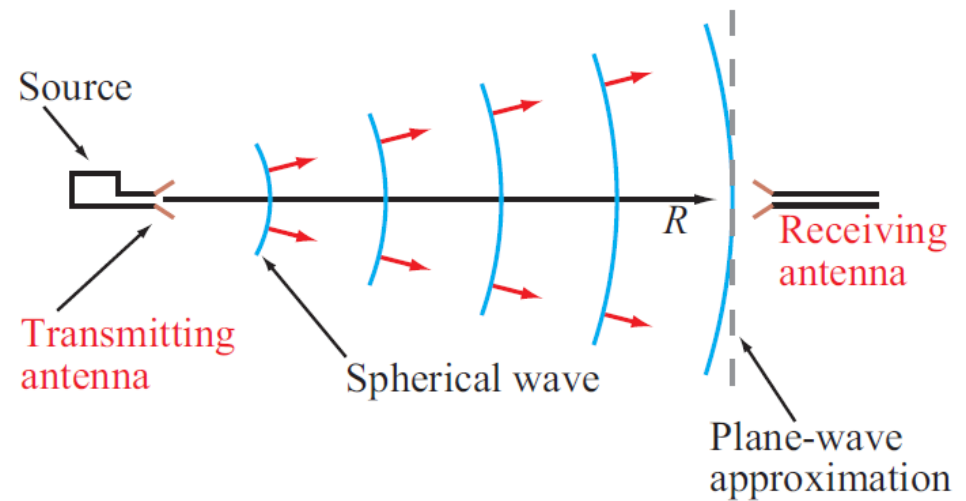


(b) Reception mode

Antenna as a transducer between a guided electromagnetic wave and a free-space wave, for both transmission and reception.

Far-Field Approximation

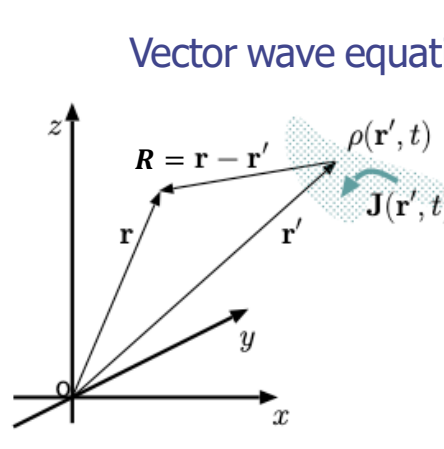
1. In close proximity to a radiating source, the wave is **spherical** in shape, but at a far distance, it becomes approximately a **plane wave** as seen by a receiving antenna.
2. The far-field approximation **simplifies the math**.
3. The distance beyond which the far-field approximation is valid is called the **far-field range** (will be defined later).



Far-field plane-wave approximation.

Steps in evaluation of radiation fields :

(Solution of Maxwell equations for radiation problems)



Vector wave equation →

$$\nabla^2 \vec{A} + \omega^2 \mu \epsilon \vec{A} = -\mu \vec{J}$$

Solution is

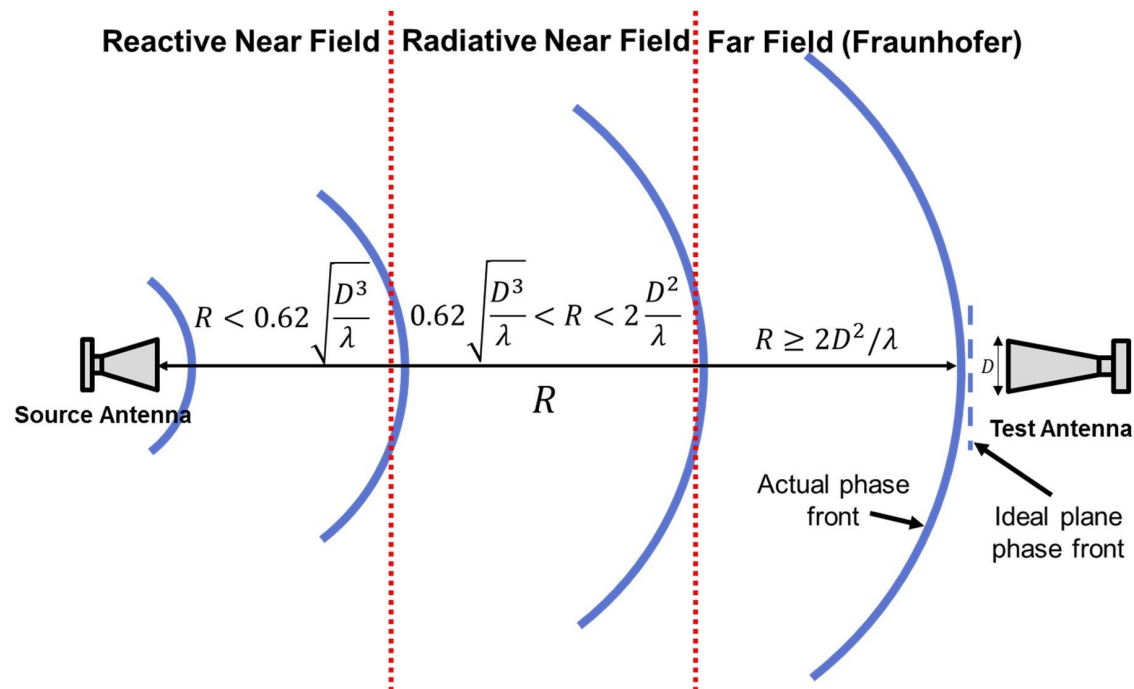
$$\vec{A} = \iiint_{v'} \mu \vec{J} \frac{e^{-j\beta R}}{4\pi R} dv'$$

$$\vec{B} = \nabla \times \vec{A}$$

General approach to solve for radiation problem:

1. Calculate vector potential $\vec{A}$
2. Find magnetic field $\vec{H} = \frac{1}{\mu} \nabla \times \vec{A}$
3. Calculate the $\vec{E}$ field by Ampere's Law $\vec{E} = \frac{1}{j\epsilon\omega} \nabla \times \vec{H}$
Far field (Plane wave) $\vec{E} = \eta \vec{H} \times \hat{k}$

Far-Field Conditions



D is the length of line source

$$r > \frac{2D^2}{\lambda}$$

D is the dimension of surface source

$$r \gg D$$

2 The ideal dipole (Hertzian dipole)

Definition: A *Hertzian dipole* is a thin, linear conductor whose length l is very short compared with the wavelength λ ; l should not exceed $\lambda/50$.

Current along dipole:

$$i(t) = I_0 \cos \omega t = \Re[I_0 e^{j\omega t}]$$

Solution of E and H field at R distance away

$$\begin{aligned}\tilde{H}_\phi &= \frac{I_0 l k^2}{4\pi} e^{-jkR} \left[\frac{j}{kR} + \frac{1}{(kR)^2} \right] \sin \theta, \\ \tilde{E}_R &= \frac{2I_0 l k^2}{4\pi} \eta_0 e^{-jkR} \left[\frac{1}{(kR)^2} - \frac{j}{(kR)^3} \right] \cos \theta, \\ \tilde{E}_\theta &= \frac{I_0 l k^2}{4\pi} \eta_0 e^{-jkR} \left[\frac{j}{kR} + \frac{1}{(kR)^2} - \frac{j}{(kR)^3} \right] \sin \theta\end{aligned}$$

dipole antennas are commonly used for both emission and immunity testing

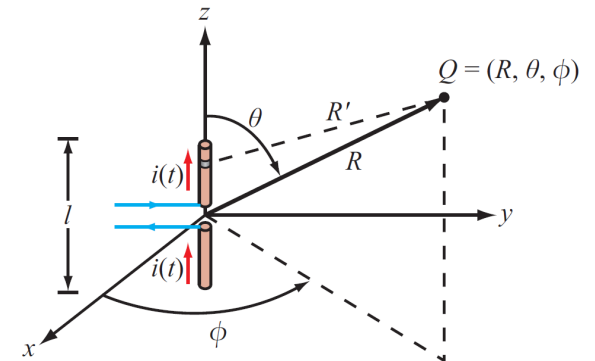


Figure 9-4: Short dipole placed at the origin of a spherical coordinate system.

k or β : wave number $k = \frac{2\pi}{\lambda}$

Hertzian Dipole—Far-Field Approximation

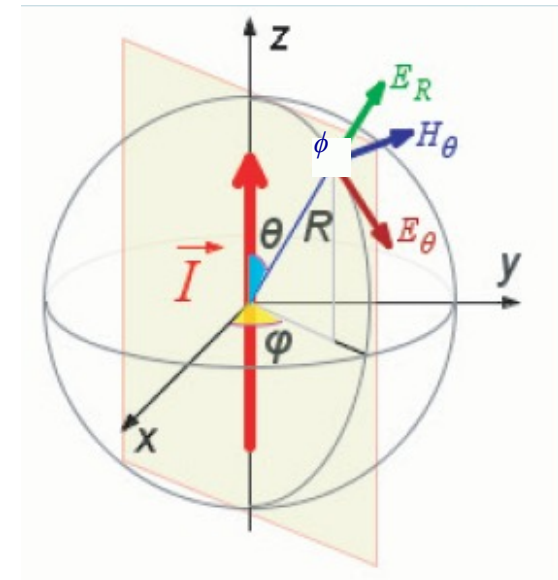
At far field regions

$$\tilde{E}_\theta = \frac{j I_0 l k \eta_0}{4\pi} \left(\frac{e^{-jkR}}{R} \right) \sin \theta \quad (\text{V/m}),$$

$$\tilde{H}_\phi = \frac{\tilde{E}_\theta}{\eta_0} \quad (\text{A/m}),$$

$\frac{e^{-jkR}}{R}$:spherical propagation factor

$\eta_0 = 120\pi \Omega$ intrinsic impedance of the medium
 $\approx 377 \Omega$



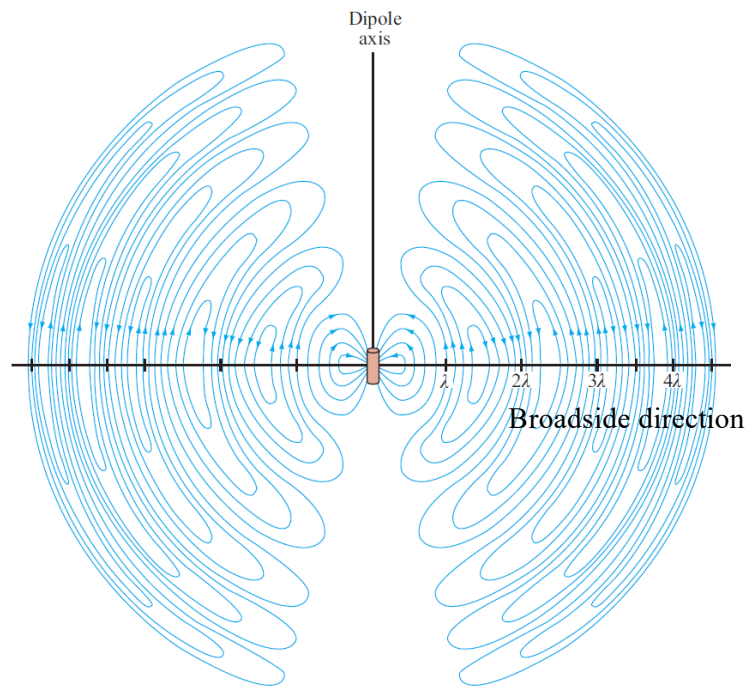
$$\vec{H} = \frac{I \Delta z}{4\pi} j \omega \mu \frac{e^{-j\beta r}}{r} \sin \theta \hat{\phi}$$

$$\vec{E} = \frac{I \Delta z}{4\pi} j \beta \frac{e^{-j\beta r}}{r} \sin \theta \hat{\theta}$$

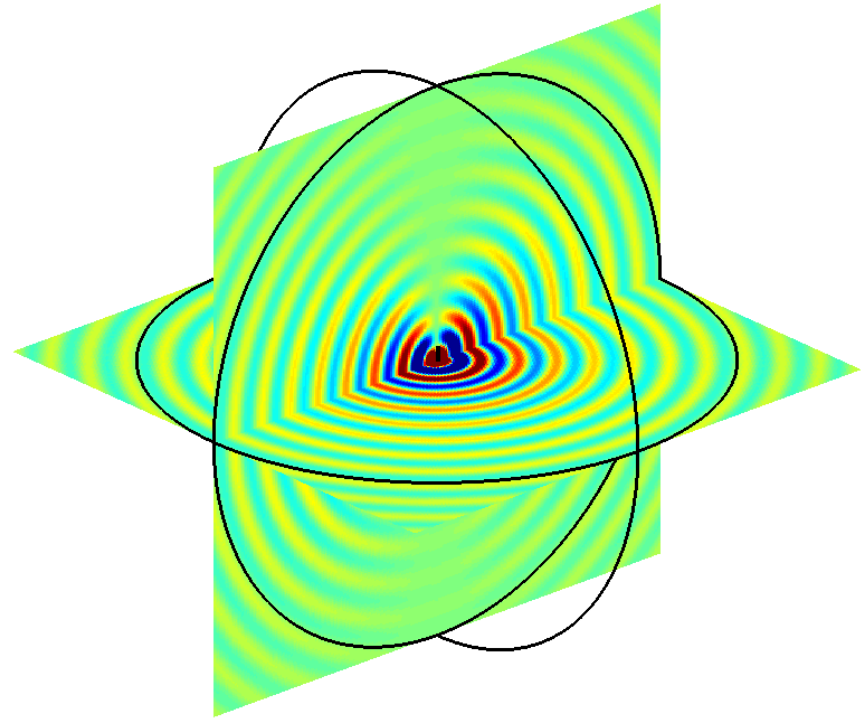
Ω

I

Radiated Electric Field



Electric field lines surrounding an oscillating dipole at a given instant.



The ideal dipole (Hertzian dipole): Far-Field Properties

1. The fields are proportional to $1/r$, $\hat{I}$, dl , and $\sin \theta$.
2. $|\vec{E}_{\text{far field}}|/|\vec{H}_{\text{far field}}| = \eta_0$.
3. $\vec{E}_{\text{far field}}$ and $\vec{H}_{\text{far field}}$ are *locally orthogonal*.
4. $\vec{E}_{\text{far field}} \times \vec{H}_{\text{far field}} = K\vec{a}_r$.
5. A phase term $e^{-j\beta_0 r}$ translates to a time delay in the time domain of $\sin[\omega(t - r/v_0)]$.

$$\vec{H} = \frac{I\Delta z}{4\pi} j\omega\mu \frac{e^{-j\beta r}}{r} \sin\theta \hat{\phi}$$

$$\vec{E} = \frac{I\Delta z}{4\pi} j\beta \frac{e^{-j\beta r}}{r} \sin\theta \hat{\theta}$$

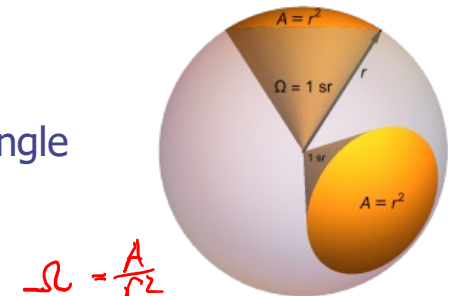
Power flowing density : (Unit : w/m*m)

$$\vec{S} = \frac{1}{2} \vec{E} \times \vec{H}^* = \frac{1}{2} \left(\frac{I\Delta z}{4\pi} \right)^2 \omega\mu\beta \frac{\sin^2 \theta}{r^2} \hat{r} \quad \text{per unit solid angle}$$

Total radiated power (Unit : W)

$$P = \iint \vec{S} \cdot d\vec{s} = \iint \vec{S} r^2 \sin\theta d\theta d\phi$$

$$P = 80\pi^2 \left(\frac{\Delta z}{\lambda} \right)^2 \frac{I^2}{2}$$



$$d\Omega = \frac{dA}{r^2} = \sin\theta d\theta d\phi$$

solid angle



The ideal dipole (Hertzian dipole): Far-Field Properties

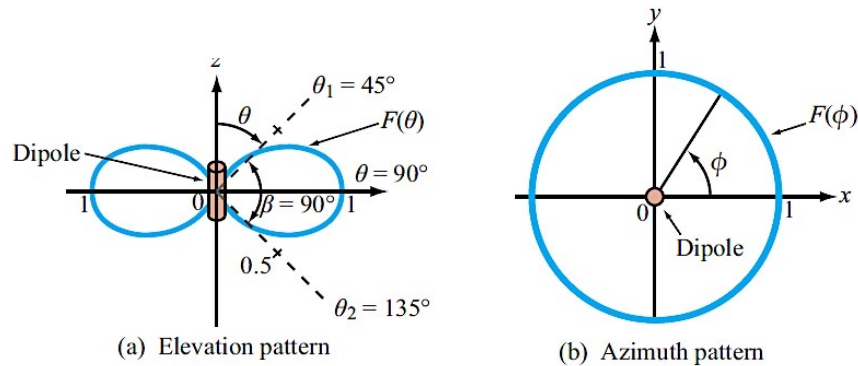
Denoting $\hat{I}/\sqrt{2} = \hat{I}_{\text{rms}}$, we can compute a **radiation resistance**:

$$R_{\text{rad}} = \frac{P_{\text{rad}}}{|\hat{I}_{\text{rms}}|^2} \\ = 80\pi^2 \left(\frac{dl}{\lambda_0} \right)^2 \quad (\text{in } \Omega)$$

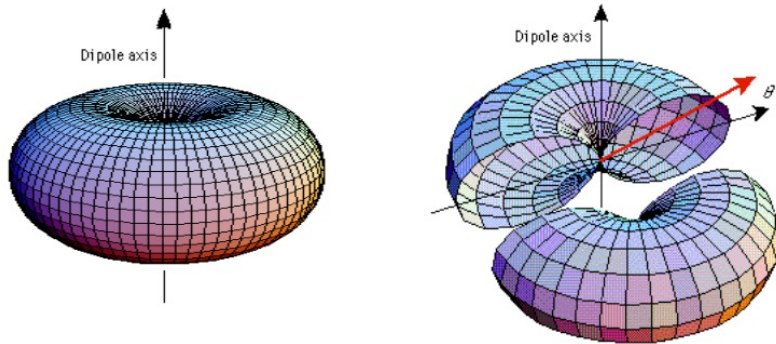
- The **radiation resistance** represents a fictitious resistance that dissipates the same amount of power as that radiated by the antenna when both carry the same value of current.
- The Hertzian dipole is a very ineffective radiator!
 - For example, for a length $dl = 1$ cm and a frequency of 300 MHz ($\lambda_0 = 1$ m), the radiation resistance is 79 m Ω . $\rightarrow$ In order to radiate 1 W of power, we require a (RMS) current of 3.6 A!
 - If the frequency is changed to 3 MHz ($\lambda_0 = 100$ m), the radiation resistance is 7.9 m Ω and the current (RMS) required to radiate 1 W is 356 A!



The ideal dipole (Hertzian dipole): Far-Field Properties



Radiation patterns of Hertzian dipole.



$$F(\theta, \phi) = \sin^2 \theta$$

Normalized Radiation Intensity

- describes the directional pattern of the antenna

$$F(\theta, \phi) = \frac{S(R, \theta, \phi)}{S_{\max}} \quad \text{dimensionless}$$

For Hertzian dipole

$$F(\theta, \phi) = F(\theta) = \sin^2 \theta$$

- No energy is radiated by the short dipole along the direction of the dipole axis
- Maximum radiation ($F=1$) occurs in the broadside direction ($\theta=90^\circ$)

Hertzian Dipole Example

1. Compute the total power radiated by a 1-m long Hertzian dipole at 5 MHz, if the driving current amplitude is 5 A. Assume that the antenna operates in air.

$$\lambda = \frac{c}{f} = \frac{3 \times 10^8}{5 \times 10^6} = 60 \text{ m} = \frac{V_{\text{prop}}}{f}$$

$$P_{\text{rad}} = 40\pi^2 I_0^2 \left(\frac{l}{\lambda} \right)^2 = 40\pi^2 5^2 \left(\frac{1}{60} \right)^2 = 2.74 \text{ W}$$

2. Compute the radiation resistance of the antenna from the previous example.

$$P_{\text{rad}} = \frac{1}{2} I_0^2 R_{\text{rad}}$$

$$R_{\text{rad}} = 80\pi^2 \left(\frac{l}{\lambda} \right)^2 = 80\pi^2 \left(\frac{1}{60} \right)^2 = 0.22 \Omega$$



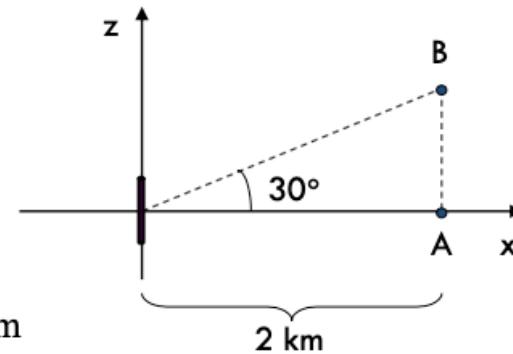
Hertzian Dipole Example

3. Consider the antenna from the previous examples and compute the signal strength (magnitude of the E field amplitude) at points A and B, as shown in the figure.

$$|\vec{E}| = \frac{\eta_0 k l I_0}{4\pi R} \sin \theta = 60\pi \frac{l}{\lambda} I_0 \left(\frac{\sin \theta}{R} \right) = 5\pi \left(\frac{\sin \theta}{R} \right)$$

$$R_A = 2000 \text{ m}, \quad \theta_A = 90^\circ, \quad |\vec{E}_A| = 5\pi \left(\frac{\sin 90^\circ}{2000} \right) = 7.85 \text{ mV/m}$$

$$R_B = \frac{R_A}{\cos 30^\circ} = \frac{2000}{\cos 30^\circ} = 2309.4 \text{ m}, \quad \theta_B = 60^\circ, \quad |\vec{E}_B| = 5\pi \left(\frac{\sin 60^\circ}{2309.4} \right) = 5.89 \text{ mV/m}$$



Magnetic Dipole (Loop)

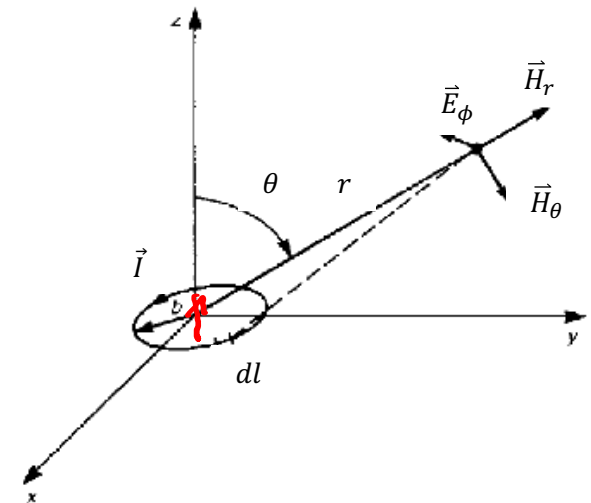
$$\begin{aligned}\nabla \times \vec{E} &= -j\omega\mu\vec{H} - \vec{M} \\ \nabla \times \vec{H} &= j\omega\epsilon\vec{E} + \vec{J}\end{aligned}$$

- A dual to the elemental electric dipole is the *elemental magnetic dipole or current loop*. A very small loop of radius b lying in the xy plane carries a phasor current I . It is assumed that the loop circumference is electrically small, i.e., $2\pi b < \lambda_0/10$. $\rightarrow \frac{\lambda}{50}$
- This loop constitutes a *magnetic dipole moment*

$$\hat{m} = \hat{I}\pi b^2 = \hat{I}A \quad (\text{in } Am^2)$$

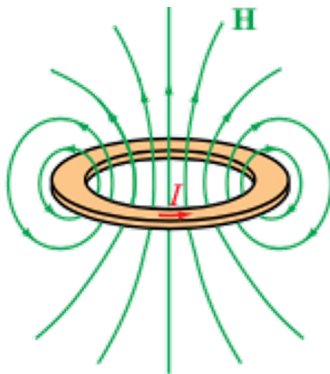
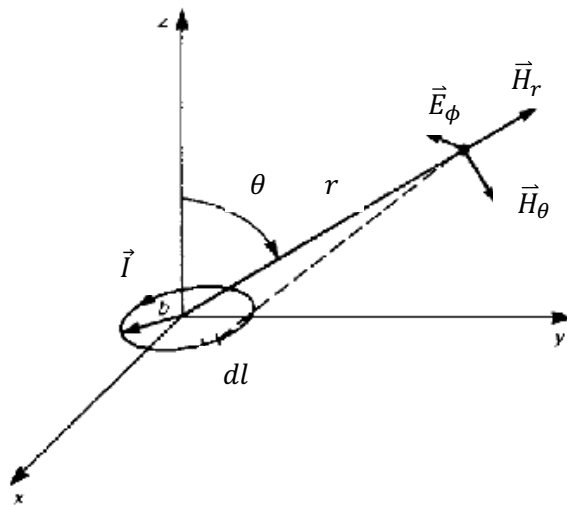
A: Area the loop encloses

$$\vec{M} \Delta z = j\omega\mu IS$$



Loop antenna is used for measuring **magnetic field emissions** and **immunity testing** at lower frequencies

Magnetic Dipole (Loop)



$$\hat{E}_r = 0$$

$$\hat{E}_\theta = 0$$

$$\hat{E}_\phi = -j \frac{\omega \mu_0 \hat{m} \beta_0^2}{4\pi} \sin \theta \left(j \frac{1}{\beta_0 r} + \frac{1}{\beta_0^2 r^2} \right) e^{-j\beta_0 r}$$

$$\hat{H}_r = j2 \frac{\omega \mu_0 \hat{m} \beta_0^2}{4\pi \eta_0} \cos \theta \left(\frac{1}{\beta_0^2 r^2} - j \frac{1}{\beta_0^3 r^3} \right) e^{-j\beta_0 r}$$

$$\hat{H}_\theta = j \frac{\omega \mu_0 \hat{m} \beta_0^2}{4\pi \eta_0} \sin \theta \left(j \frac{1}{\beta_0 r} + \frac{1}{\beta_0^2 r^2} - j \frac{1}{\beta_0^3 r^3} \right) e^{-j\beta_0 r}$$

$$\hat{H}_\phi = 0$$

$$k = \beta_0$$

$$k \text{ or } \beta: \text{ wave number} \quad k = \frac{2\pi}{\lambda}$$

k - wave number
 β_0 - propagation

Hertzian dipole

$$\tilde{H}_\phi = \frac{I_0 l k^2}{4\pi} e^{-jkR} \left[\frac{j}{kR} + \frac{1}{(kR)^2} \right] \sin \theta,$$

$$\tilde{E}_R = \frac{2I_0 l k^2}{4\pi} \eta_0 e^{-jkR} \left[\frac{1}{(kR)^2} - \frac{j}{(kR)^3} \right] \cos \theta,$$

$$\tilde{E}_\theta = \frac{I_0 l k^2}{4\pi} \eta_0 e^{-jkR} \left[\frac{j}{kR} + \frac{1}{(kR)^2} - \frac{j}{(kR)^3} \right] \sin \theta$$

Magnetic Dipole (Loop)

$$\rightarrow \mathcal{M} = I A$$

$$\hat{E}_\phi = -j \frac{\omega \mu_0 \hat{m} \beta_0^2}{4\pi} \sin \theta \left(j \frac{1}{\beta_0 r} + \frac{1}{\beta_0^2 r^2} \right) e^{-j\beta_0 r}$$

$$\hat{H}_r = j 2 \frac{\omega \mu_0 \hat{m} \beta_0^2}{4\pi \eta_0} \cos \theta \left(\frac{1}{\beta_0^2 r^2} - j \frac{1}{\beta_0^3 r^3} \right) e^{-j\beta_0 r}$$

$$\hat{H}_\theta = j \frac{\omega \mu_0 \hat{m} \beta_0^2}{4\pi \eta_0} \sin \theta \left(j \frac{1}{\beta_0 r} + \frac{1}{\beta_0^2 r^2} - j \frac{1}{\beta_0^3 r^3} \right) e^{-j\beta_0 r}$$

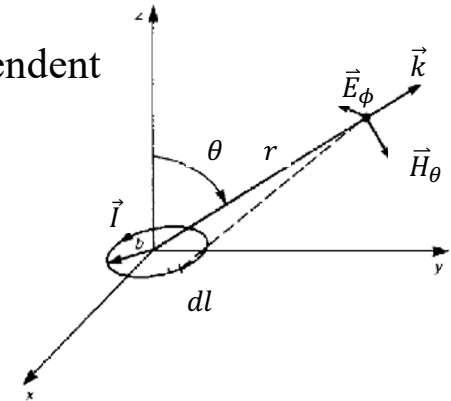
Comparing Magnetic Dipole with the fields of the Hertzian dipole, we see that duality exists between the fields of these structures. Observations about the electric (magnetic) field of the electric dipole apply to the magnetic (electric) field of the magnetic dipole.

Magnetic Dipole (Loop)

The far field of the magnetic dipole is characterized by the $1/r$ -dependent term:

$$\begin{aligned}\vec{E}_{\text{far field}} &= \frac{\omega\mu_0\hat{m}\beta_0}{4\pi} \sin\theta \frac{e^{-j\beta_0 r}}{r} \hat{\phi} \\ &= \frac{\pi^2 f^2 \mu_0 \hat{I} b^2}{v_0} \sin\theta \frac{e^{-j[2\pi(r/\lambda_0)]}}{r} \hat{\phi}\end{aligned}$$

$$\begin{aligned}\vec{H}_{\text{far field}} &= -\frac{\omega\mu_0\hat{m}\beta_0}{4\pi\eta_0} \sin\theta \frac{e^{-j\beta_0 r}}{r} \hat{\theta} \\ &= \frac{\pi^2 f^2 \mu_0 \hat{I} b^2}{\eta_0 v_0} \sin\theta \frac{e^{-j[2\pi(r/\lambda_0)]}}{r} \hat{\theta}\end{aligned}$$



Magnetic dipole is not an efficient radiator!

Radiation resistance of the magnetic dipole

$$R_{\text{rad}} = \frac{P_{\text{av}}}{|\hat{I}_{\text{RMS}}|^2} = 31,170 \left(\frac{A}{\lambda_0^2} \right)^2 \quad A = \pi b^2$$

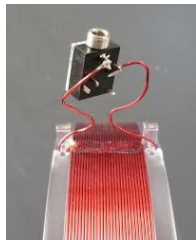
Consider a loop of radius 1 cm. At 300 MHz the radiation resistance is $3.08 \text{ m}\Omega$. In order to radiate 1 W, the loop requires a (RMS) current of 18 A. At 3 MHz the radiation resistance is $3.08 \times 10^{-11} \Omega$, and the (RMS) current required to radiate 1 W is $1.8 \times 10^5 \text{ A}$!



Small loop antenna:



- The small loop antenna is very popular in receiving antenna.
- Multi-turn small loops are popular in AM broadcast receiver.
- Small loop antennas are also used in direction-finding receivers and for EMI field strength probes.



7.3 Antenna Parameters: power pattern

Total Radiated Power P_{rad}

Differential power radiated through dA

$$dP_{\text{rad}} = \mathbf{S}_{\text{av}} \cdot d\mathbf{A} = \mathbf{S}_{\text{av}} \cdot \hat{\mathbf{R}} dA = S dA$$

Differential area

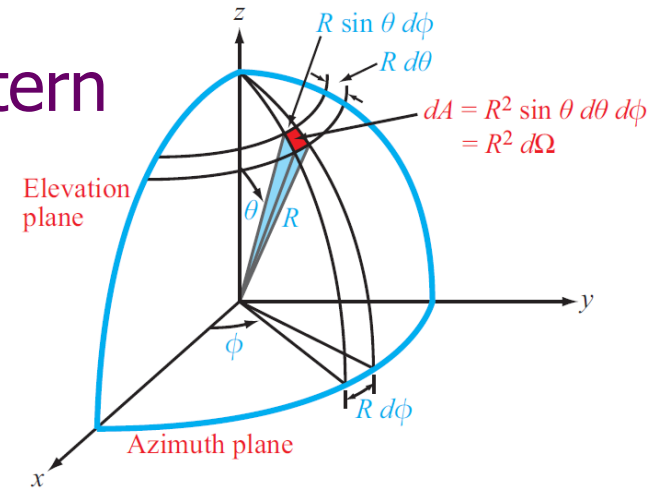
$$dA = R^2 \sin \theta \, d\theta \, d\phi$$

Solid Angle

$$d\Omega = \frac{dA}{R^2} = \sin \theta \, d\theta \, d\phi$$

Power radiated through dA

$$dP_{\text{rad}} = R^2 S(R, \theta, \phi) \, d\Omega$$

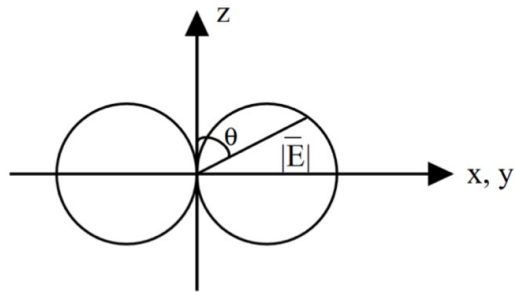


Definition of solid angle $d\Omega = \sin \theta \, d\theta \, d\phi$.

$$\begin{aligned} P_{\text{rad}} &= R^2 \int_{\phi=0}^{2\pi} \int_{\theta=0}^{\pi} S(R, \theta, \phi) \sin \theta \, d\theta \, d\phi \\ &= R^2 S_{\text{max}} \int_{\phi=0}^{2\pi} \int_{\theta=0}^{\pi} F(\theta, \phi) \sin \theta \, d\theta \, d\phi \\ &= R^2 S_{\text{max}} \iint_{4\pi} F(\theta, \phi) \, d\Omega \quad (\text{W}), \end{aligned}$$

Total Radiated Power

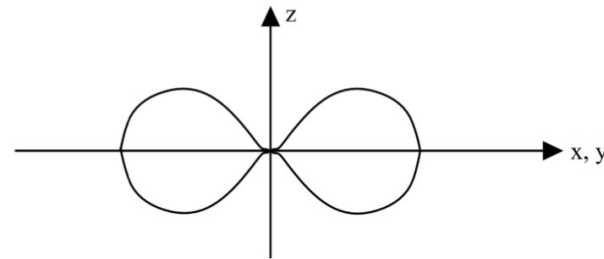
Antenna Parameters: field pattern



Radiation **field pattern** of a Hertzian dipole or small loop antenna.

$$\frac{E_{\theta}}{E_{\theta, \max}} = \sin \theta$$

The field pattern with its maximum value is 1



Radiation **power pattern** of a Hertzian dipole or small loop antenna.

$$F(\theta, \phi) = \sin^2 \theta \quad \text{For power pattern}$$

Example of 3-D Pattern

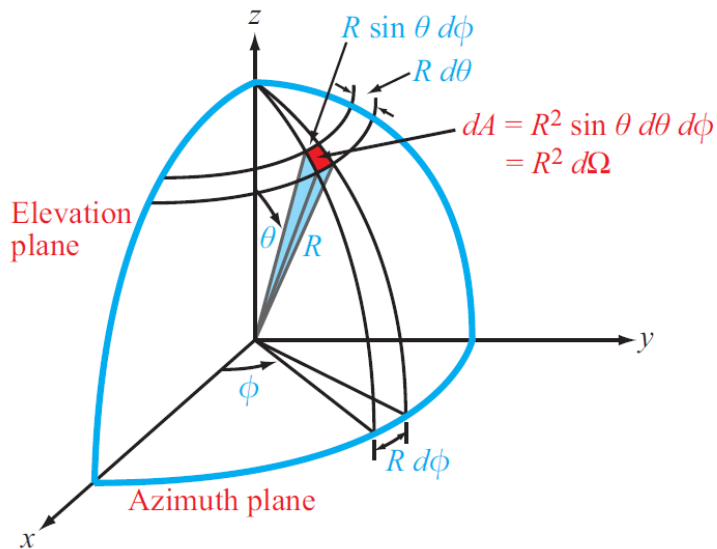
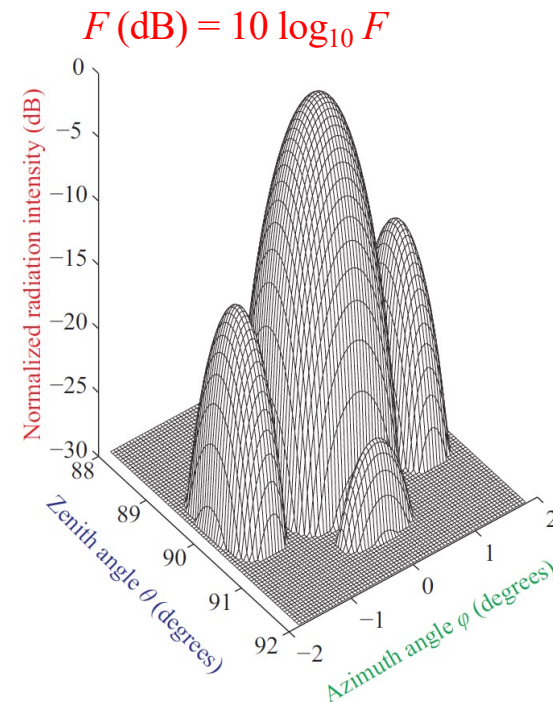


Figure 9-8: Definition of solid angle $d\Omega = \sin \theta \, d\theta \, d\phi$.

Principal planes:

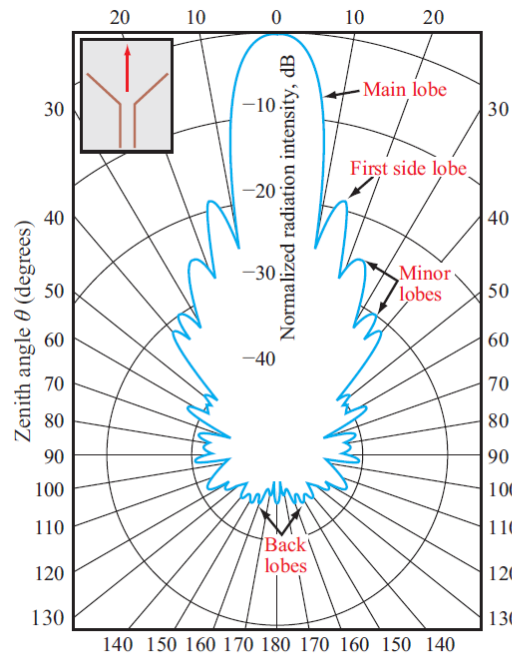
1. **Elevation plane** (x-z and y-z planes, etc.)
2. **Azimuth plane** (x-y plane)

normalized radiation intensity $F(\theta, \phi)$

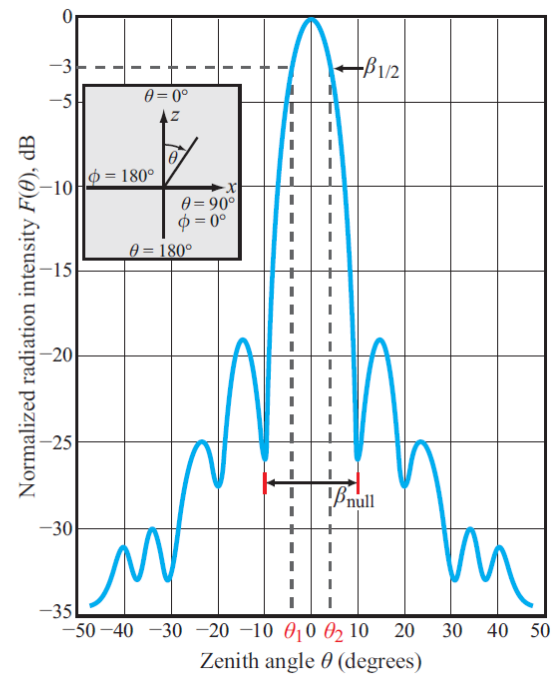


9-9: Three-dimensional pattern of a narrow-beam antenna.

Polar and Rectangular Plots



(a) Polar diagram



(b) Rectangular plot

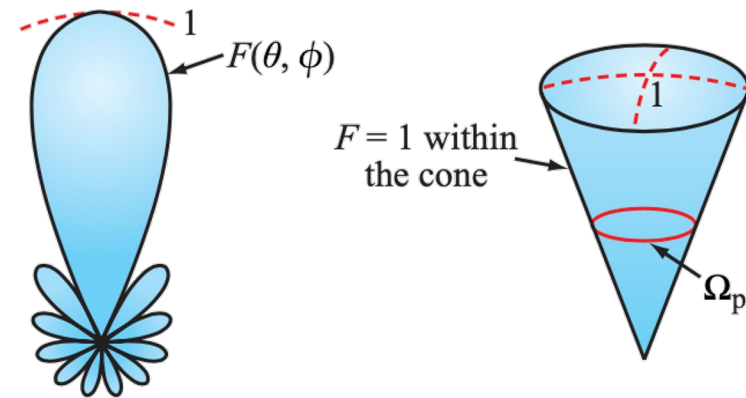
Beam Dimensions

1. Pattern solid angle

$$\Omega_p = \iint_{4\pi} F(\theta, \phi) d\Omega \quad (\text{sr}).$$

the equivalent width of the main lobe

For an isotropic antenna with $F(\theta, \phi) = 1$ in all directions, $\Omega_p = 4\pi$ (sr).



(a) Actual pattern

(b) Equivalent solid angle

The pattern solid angle Ω_p defines an equivalent cone over which all the radiation of the actual antenna is concentrated with uniform intensity equal to the maximum of the actual pattern.

Beam Dimensions

2. Half-power beamwidth

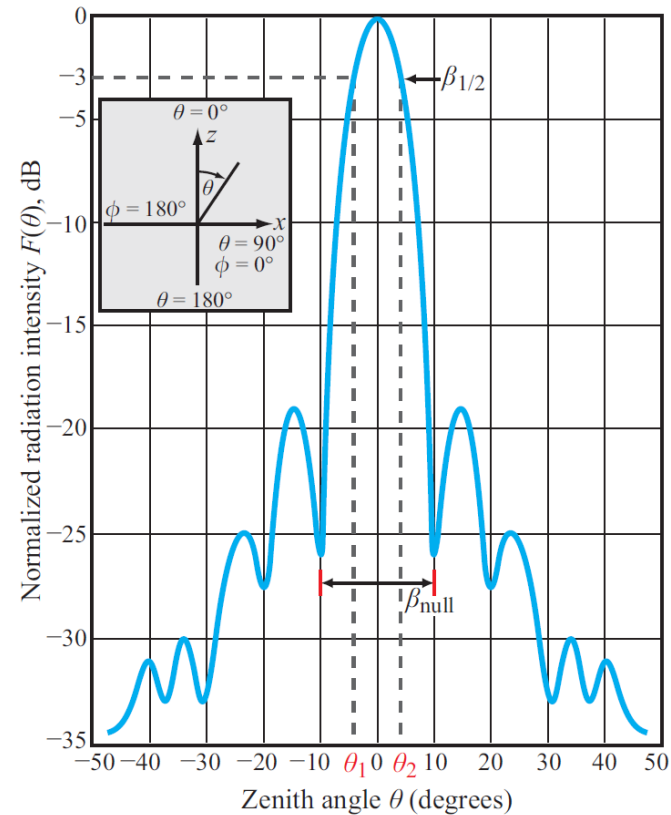
$$\beta = \theta_2 - \theta_1,$$

where θ_1 and θ_2 are the **half-power angles** at which $F(\theta, 0) = 0.5$

Since 0.5 corresponds to -3 dB, the half power beamwidth is also called the 3-dB beamwidth.

For the Hertzian dipole antenna pattern, $F(\theta) = \sin^2 \theta$.

is maximum at $\theta = 90^\circ$, θ_2 is at 135° , and θ_1 is at 45° . So, $\beta = 135^\circ - 45^\circ = 90^\circ$.



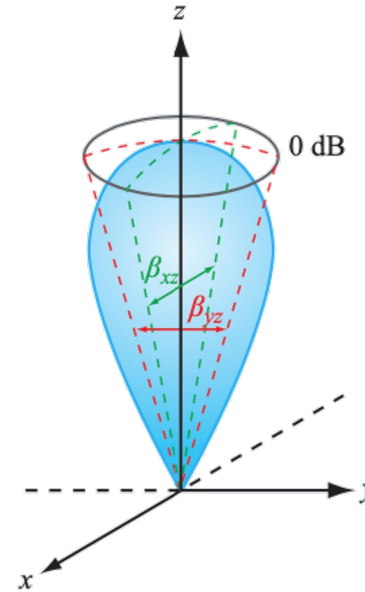
Beam Dimensions

1. Pattern solid angle

$$\Omega_p = \iint_{4\pi} F(\theta, \phi) d\Omega \quad (\text{sr}).$$

the equivalent width of the main lobe

$$\Omega_p \approx \beta_{xz}\beta_{yz}$$



The solid angle of a radiation pattern is approximately equal to the product of the half-power beamwidths in the two principal planes $\Omega_p \approx \beta_{xz}\beta_{yz}$.

Antenna Parameters: Directivity

Directivity

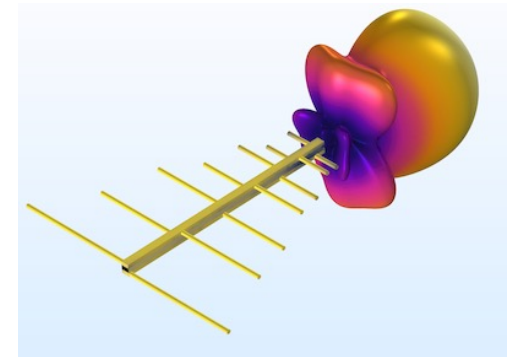
$$D = \frac{F_{\max}}{F_{\text{av}}}$$

$$F(\theta, \phi) = \frac{S(R, \theta, \phi)}{S_{\max}}$$

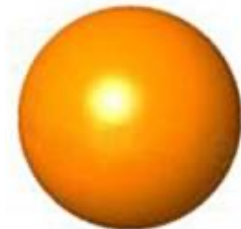
$$= \frac{1}{\frac{1}{4\pi} \iint_{4\pi} F(\theta, \phi) d\Omega}$$

$$= \frac{4\pi}{\Omega_p} \quad (\text{dimensionless})$$

The narrower Ω_p of an antenna pattern is, the greater is the directivity.
For an isotropic antenna, $\Omega_p = 4\pi$; hence, its directivity $D_{iso} = 1$.



Antenna pattern of log-periodic antenna



Antenna pattern of isotropic antenna

Antenna Parameters: Directivity

Directivity

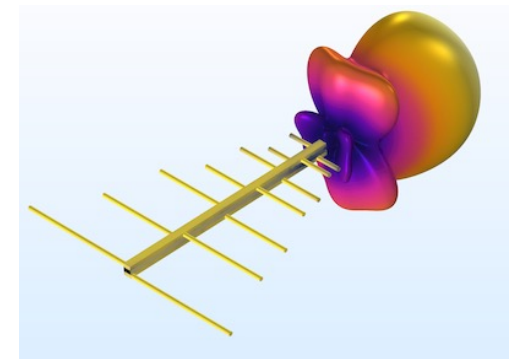
$$D = 4\pi/\Omega_p$$

$$\Omega_p = \iint_{4\pi} F(\theta, \phi) d\Omega \quad (\text{sr}).$$

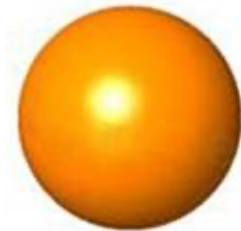
$$P_{rad} = R^2 S_{max} \iint_{4\pi} F(\theta, \phi) d\Omega = R^2 S_{max} \Omega_p$$

$\Rightarrow$

$$D = \frac{4\pi R^2 S_{max}}{P_{rad}} \quad \text{and} \quad P_{rad} = \frac{4\pi R^2 S_{max}}{D}$$



Antenna pattern of log-periodic antenna



Antenna pattern of isotropic antenna

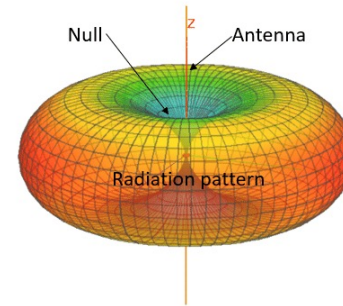
Antenna Parameters: Directivity

Directivity of Hertzian dipole

$$F(\theta) = \sin^2 \theta$$

$$\begin{aligned} D &= \frac{4\pi}{\iint_{4\pi} F(\theta, \phi) \sin \theta \, d\theta \, d\phi} \\ &= \frac{4\pi}{\int_{\phi=0}^{2\pi} \int_{\theta=0}^{\pi} \sin^3 \theta \, d\theta \, d\phi} = \frac{4\pi}{8\pi/3} = 1.5 \end{aligned}$$

or, equivalently, 1.76 dB.



Radiation pattern of Hertzian dipole

Antenna Parameters: efficiency and gain

Radiation efficiency:

$$\xi = \frac{P_{\text{rad}}}{P_t} \quad (\text{dimensionless}). \quad (0 \leq \xi \leq 1) \quad P_t: \text{total transmitter power}$$

Gain: 4π times the ratio of radiation intensity in a given direction to the **total transmitter power of the antenna** from the connected transmitter

$$G = \frac{4\pi R^2 S_{\text{max}}}{P_t}$$



$$D = \frac{4\pi}{\Omega_p} = \frac{4\pi R^2 S_{\text{max}}}{P_{\text{rad}}}$$

- If all input power appeared as radiated power ($P_t = P_{\text{rad}}$), Directivity = Gain.
- In reality, some of the power is lost in the antenna absorbed by the antenna and nearby structures).

$$G = \xi D$$



Antenna Parameters: Loss Resistances , radiation efficiency

- Input impedance

$$Z_{in} = R_{in} + jX_{in}$$

R_{in} : Dissipation = Radiation + Ohmic loss $R_{in} = R_{rad} + R_{loss}$

X_{in} : Power stored near the antenna

$$P_t = P_{rad} + P_{loss} = \frac{1}{2}I_0^2 R_{rad} + \frac{1}{2}I_0^2 R_{loss}$$

R_{rad} : radiation resistance

R_{loss} : loss resistance

- Radiation Efficiency

$$\xi = \frac{P_{rad}}{P_t} = \frac{P_{rad}}{P_{rad} + P_{loss}} = \frac{R_{rad}}{R_{rad} + R_{loss}}$$

Example: Radiation resistance and efficiency of a Hertzian Dipole

A 4-cm-long center-fed dipole is used as an antenna at 75 MHz. The antenna wire is made of copper and has a radius $a = 0.4\text{mm}$. The loss resistance of a circular wire of length l is given by

$$R_{loss} = \frac{l}{\sigma A} = \frac{l}{\sigma 2\pi a \delta} = \frac{l}{2\pi a} \sqrt{\frac{\pi f \mu_c}{\sigma_c}}$$

Where μ_c and σ_c are the magnetic permeability and conductivity of the wire. Calculate the radiation resistance and the radiation efficiency of the dipole antenna.

Solution: a) At 75 MHz $\lambda = \frac{c}{f} = \frac{3 \times 10^8}{7.5 \times 10^7} = 4\text{m}$

The length to wavelength ratio is $l / \lambda = 4\text{cm} / 4\text{m} = 0.01$, so it is a short dipole.

For Hertzian dipole,

$$P_{\text{rad}} = 40\pi^2 I_0^2 \left(\frac{l}{\lambda} \right)^2$$

Example: Radiation resistance and efficiency of a Hertzian Dipole

$$P_{\text{rad}} = 40\pi^2 I_0^2 \left(\frac{l}{\lambda}\right)^2$$

$$P_{\text{rad}} = \frac{1}{2} I_0^2 R_{\text{rad}} \implies R_{\text{rad}} = 80\pi^2 (l/\lambda)^2 \quad (\Omega)$$

$$\text{For } l/\lambda = 4\text{cm} / 4\text{m} = 0.01 \implies R_{\text{rad}} = 0.08 \, \Omega \quad \text{radiation resistance}$$

b) Next, we determine the loss resistance R_{loss} and radiation efficiency.

$$\text{For copper, } \mu_c \approx \mu_0 = 4\pi \times 10^{-7} \text{ H/m} \quad \sigma = 5.8 \times 10^7 \text{ S/m}$$

$$R_{\text{loss}} = \frac{l}{2\pi a} \sqrt{\frac{\pi f \mu_c}{\sigma_c}} = \frac{4 \times 10^{-2}}{2\pi \times 4 \times 10^{-4}} \left(\frac{\pi \times 75 \times 10^6 \times 4\pi \times 10^{-7}}{5.8 \times 10^7} \right)^{1/2} = 0.036 \, \Omega$$

Therefore, the radiation efficiency is

$$\xi = \frac{R_{\text{rad}}}{R_{\text{rad}} + R_{\text{loss}}} = \frac{0.08}{0.08 + 0.036} = 0.69$$

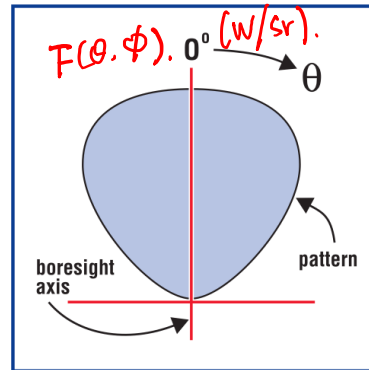
The dipole is 69% efficient.



Basic Antenna Terms Used in EMC Measurement

Antenna Pattern

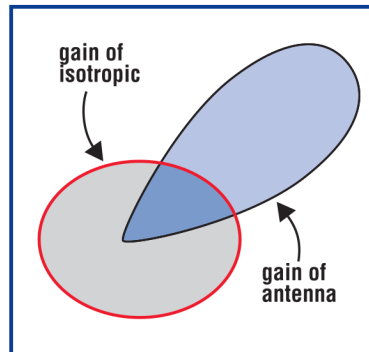
The pattern shows the response of the antenna as the viewing angle is varied.



Gain

Gain is a key performance parameter which combines the antenna's directivity and radiation efficiency.

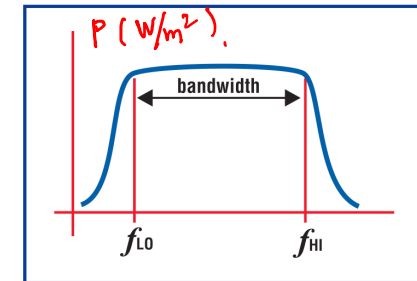
$$G = \xi D$$



Bandwidth

The bandwidth of an antenna is the operating frequency range of the antenna

$$f_{HI} - f_{LO} = 5\%.$$



Beamwidth

the viewing angle of the antenna, in the plane of measurement, when power has fallen by 3dB - HPBW

