Basic Antenna Parameters

Radiation Pattern

$$\overline{W}_{AVE} = \frac{1}{2} \operatorname{Re}\left[\bar{E} \times \bar{H}^*\right]\Big|_{r = \text{constant}} = P(\theta, \phi)$$

is called "antenna pattern" - <u>without further specification this refers to power, as above</u> - Often given in dB, relative watts/m^2

Either

$$\bar{E}, \bar{H}\Big|_{r=\text{constant}} \qquad \bar{E}(\theta,\phi), \bar{H}(\theta,\phi)$$

is called "field pattern" of antenna

volts/m or amps/m

Isotropic Radiator

$$P(\theta,\phi) = \text{constant}$$

hypothetical, not physically realizable!

Omni-antennas*.

$$P(\theta,\phi) = P(\theta) \text{ or } P(\phi)$$

pattern varies in one-direction only.

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* sometimes omni-directional

Directional Antennas

Usually by design

$P(\theta, \phi)$ varies with some well-defined

P_{MAX}

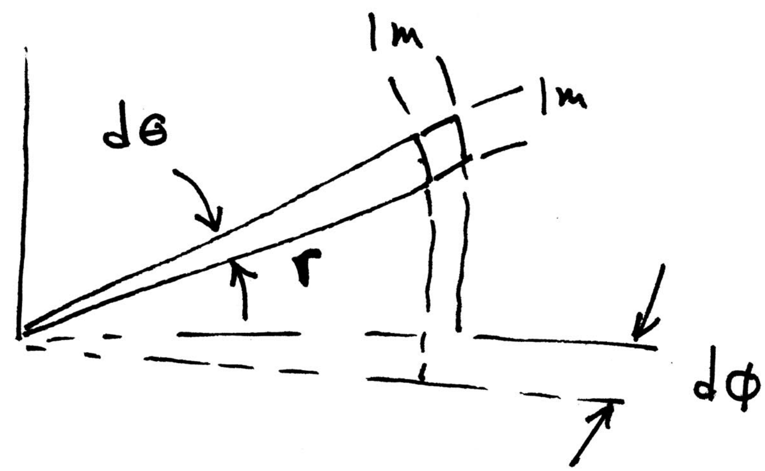
Radiation Intensity

$$\bar{U} = r^2 \, \bar{W}_{AVE} = \frac{r^2}{2}\left[\bar{E} \times \bar{H}^*\right] \xrightarrow{r \to \infty} \bar{U}(\theta, \phi)$$

Ind. of r for $kr >> 1$

$P(\theta,\phi) \propto U(\theta,\phi)$

watts / steradian (in the far field.)



Directivity of Antenna

Often means maximum directive gain

$$D(\theta, \phi) = \frac{U}{U_0} = \frac{U}{\frac{P_{rad}}{4\pi}} = \frac{4\pi U}{P_{rad}} = \frac{\text{Power in some } \theta, \phi}{\text{Power for isotropic radiator}}$$

P_{rad} = radiated power

$$D_0 = \left.\frac{U}{U_0}\right|_{MAX}$$

; Isotropic source $D = 1$

Ideal Dipole

$$\bar{U} = r^2 \bar{W}_{Ave} = \frac{\eta}{8}\left(\frac{I \Delta z}{\lambda}\right)^2 \sin^2\theta \; \bar{a}_r$$

$$= \left[\frac{3}{8}\frac{1}{\pi}\sin^2\theta\right] P_{rad} \; ; \; P_{rad} = \eta\frac{\pi}{3}\left[\frac{I \Delta z}{\lambda}\right]^2$$

$$D(\theta,\phi) = \frac{4\pi U}{P_{rad}} = \frac{3}{2}\sin^2\theta$$

[pattern is a doughnut w/o a hole!]

Note $\quad U = D \cdot \frac{P_{rad}}{4\pi} \quad ; \quad W = \frac{D}{r^2}\frac{P_{rad}}{4\pi}$

Example of omni-antenna

Measurement Based Definitions

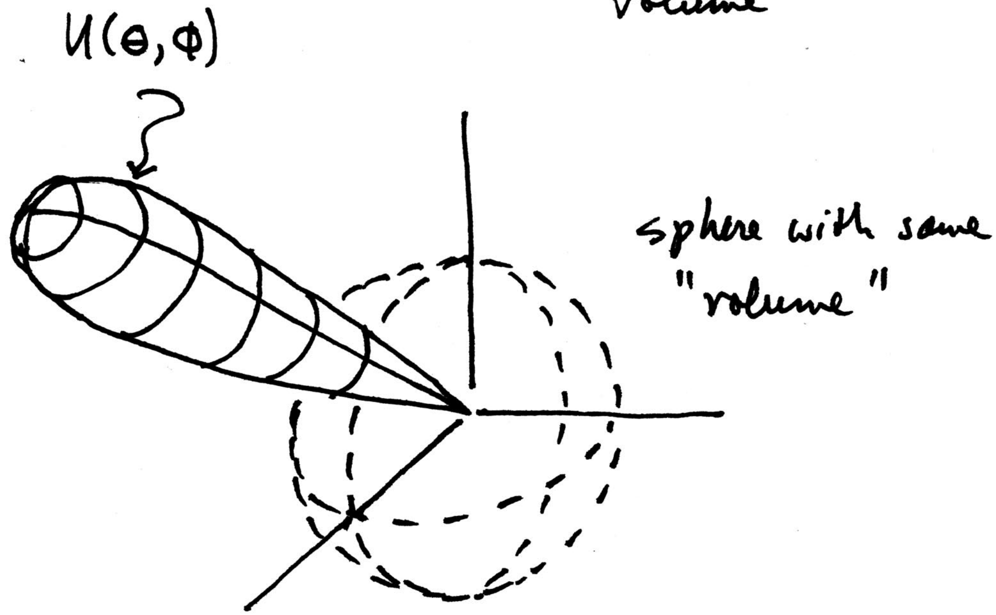
Often functional form of $P(\theta, \phi)$ is not known

$$P_{rad} = \int_0^{2\pi} \int_0^{\pi} \tilde{U}(\theta, \phi) \sin\theta \, d\theta \, d\phi$$

$$D(\theta, \phi) = \frac{4\pi \, \tilde{U}(\theta, \phi)}{\int_0^{2\pi} \int_0^{\pi} \tilde{U}(\theta, \phi) \sin\theta \, d\theta \, d\phi}$$

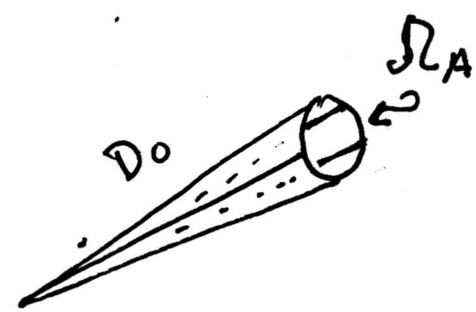
$\tilde{U}$ is obtained from data

$$D(\theta,\phi) = U \Big/ \iint_{4\pi} \underbrace{\underbrace{U(\theta,\phi)}_{\text{"length"}} \; \underbrace{\sin\theta \, d\theta \, d\phi}_{\text{"area"}}}_{\text{"volume"}} \Big/ 4\pi$$



$$D_0 = \frac{4\pi}{\int_{4\pi} U(\theta,\phi) \sin\theta \, d\theta \, d\phi \Big/ U_{MAX}} = \frac{4\pi}{\Omega_A}$$

$$\Omega_A = \frac{\int U(\theta,\phi) \, d\Omega}{U_{MAX}}$$



Beam solid angle $\times D_0$ — as though all energy flows through Ω_A = Effective solid angle

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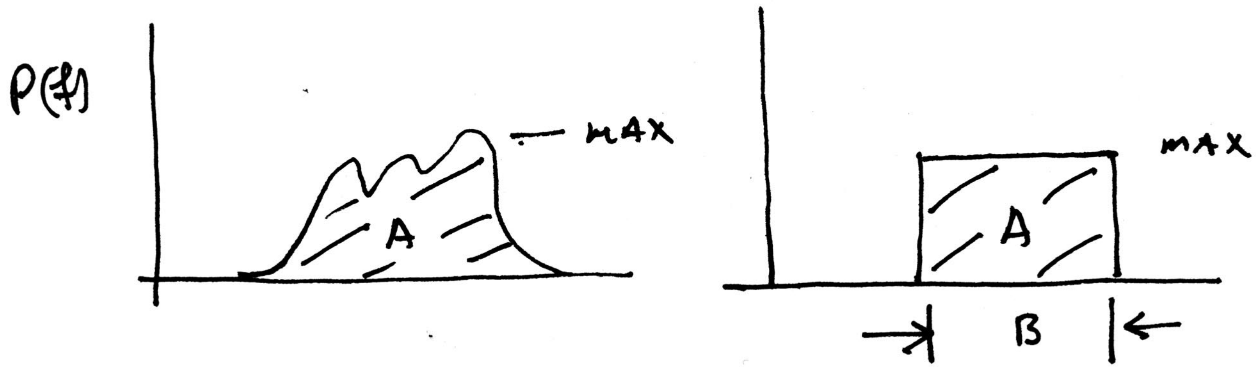
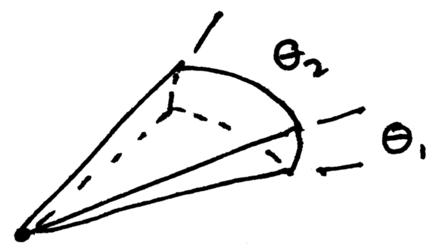
In same sense that

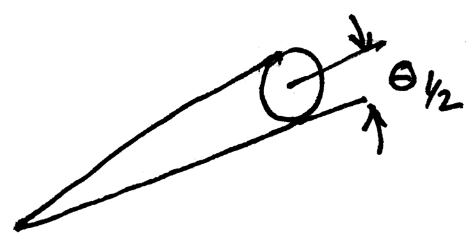


$$B = \frac{\int g(f)\,df}{g_{MAX}}$$ is equivalent width of a filter.

$$D_0 = \frac{4\pi}{\Omega_A} = \frac{4\pi}{\theta_1 \theta_2} = \frac{41253}{(\theta_1 \theta_2)_{\text{degrees.}}}$$



$$D_0 = \frac{4\pi}{\pi (\theta_{1/2})^2} = \frac{4\pi}{\pi \frac{\theta^2}{4}} = \frac{16}{\theta^2} = \frac{52524}{\theta^2_{\text{deg.}}}$$



GAIN DEFINED

P_{watts}.

P_{watts} is input, not radiated

Isotropic Radiator

(referenced to lossless case)

$$\frac{P_{watts}}{4\pi r^2} = \frac{watts}{m^2}$$ at distance r (expected average)

For real antennas and $kr \ggg 1$, $\frac{2D^2}{\lambda} < r$

$$P(\theta,\phi,r) = \left(\frac{P_{watts}}{4\pi r^2}\right) g(\theta,\phi) \;;\quad g = \text{gain}$$

Gain incorporates both the concentration of energy in space-direction and antenna losses.

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<u>Formally</u>,

$$G(\theta,\phi) = \frac{U(\theta,\phi)}{\frac{P_{input}}{4\pi}} = \frac{4\pi\, U(\theta,\phi)}{P_{input}}$$

(or $g(\theta,\phi)$)

$$= \frac{\text{Radiation intensity in some direction } \theta,\phi}{\text{Radiation intensity if all the } \underline{\text{input}} \text{ power were radiated isotropically}}$$

So $\quad D(\theta,\phi) \geq G(\theta,\phi)$

Often "gain" $\Rightarrow$ maximum gain.

For a lossless ideal dipole the gain and the directivity are the same.

$$|W| = P_{rad} \frac{1}{4\pi r^2} \frac{3}{2} \sin^2\theta \quad \text{watts}/m^2$$

the gain in any (θ, ϕ) is $\frac{3}{2} \sin^2\theta$,

but the "gain" is often refered to as

$$G = \frac{3}{2} \quad \text{or} \quad 1.76 \text{ dBi},$$

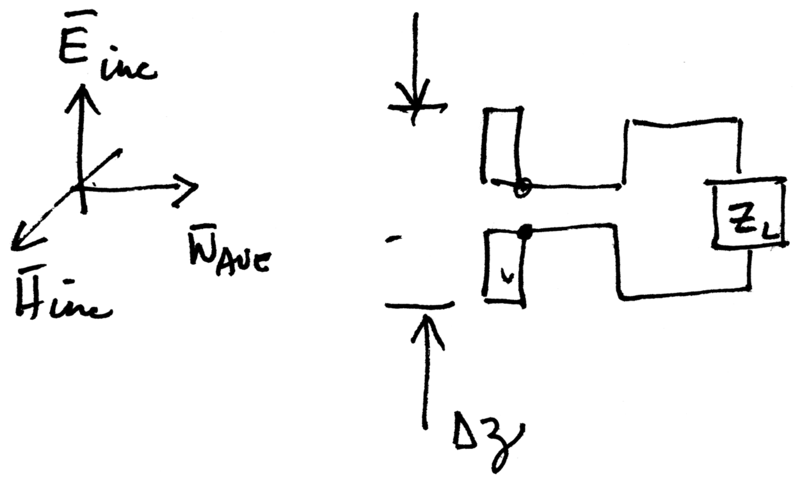
which refers to the maximum gain.

(dBi is decibels w.r.t. an isotropic antenna)

Basic Antenna Parameters (cont.)

<u>What about receiving case</u> ?

Consider Infinitesimal or Ideal Dipole, again!



How much power can we extract ?

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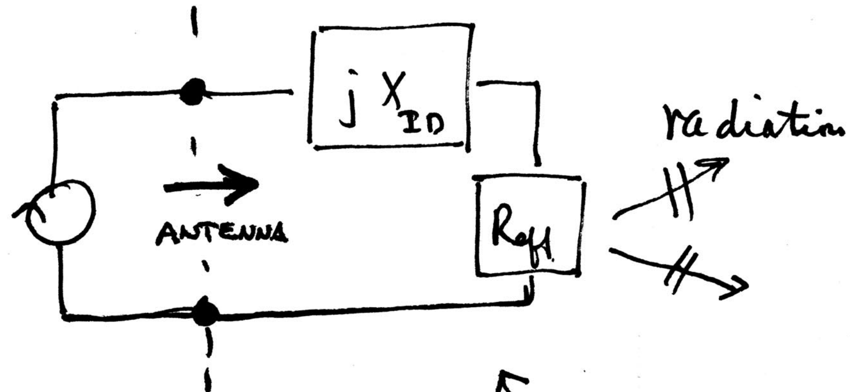
Already know that when excited by some source

$$V = \left(R_{eff} + j X_{I.D.}\right) I$$

$$R_{eff} = \frac{2}{3}\pi\eta\left[\frac{\Delta z}{\lambda}\right]^2$$



So we know equivalent circuit of dipole

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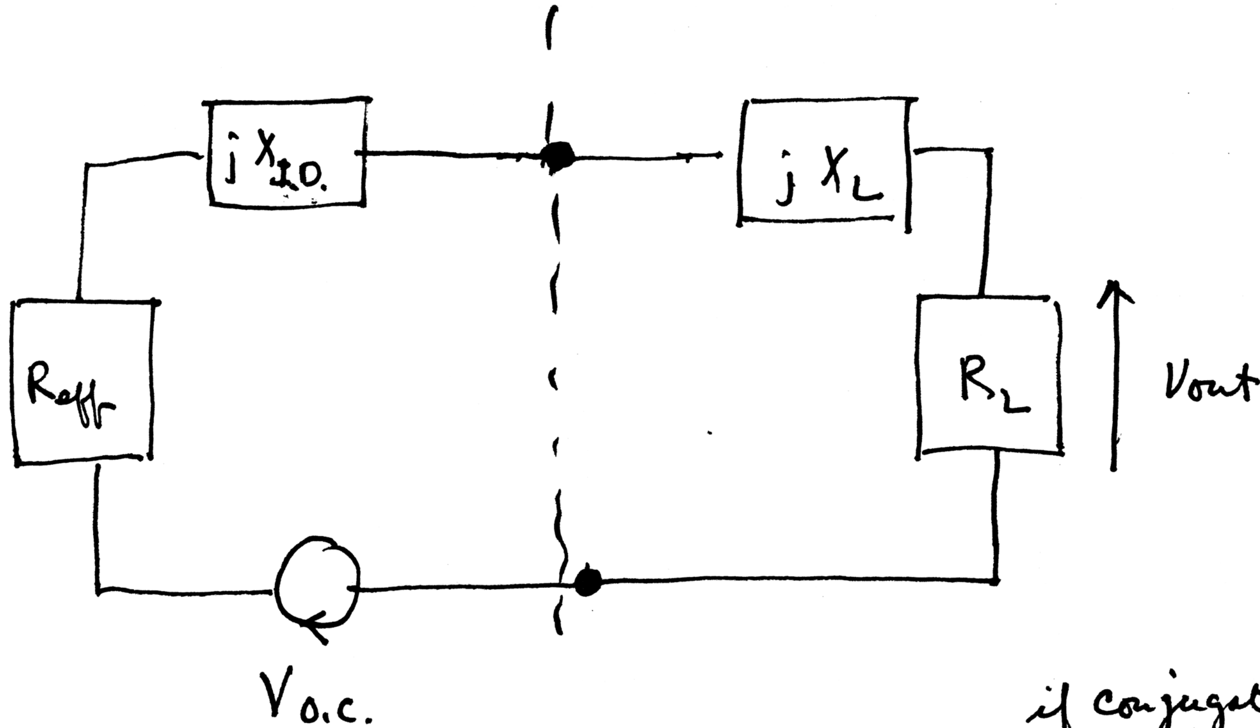
when connected to a load, circuit must be



if conjugate match

$$V_{out} = \frac{R_L}{(R_{eff} + j\,X_{I.O.}) + (R_L + j\,X_L)}\,V_{o.c} \longrightarrow \frac{V_{o.c}}{2}$$

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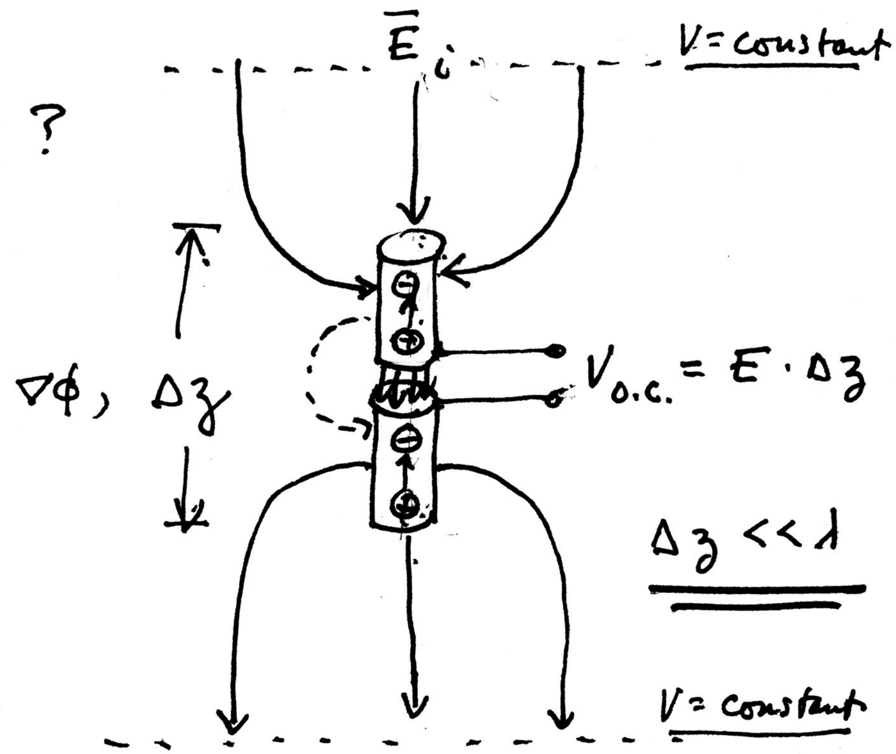
$V_{o.c.} = ?$

$V_{out\,(MAX)} = \frac{E\Delta z}{2}$



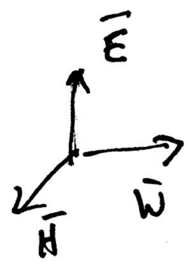
In order to satisfy B.C. on conductor - charge moves immediately to produce an internal field that cancels E_i, so $E_{tan} = 0$! Original $E_i \cdot \Delta z$ appears across the gap.

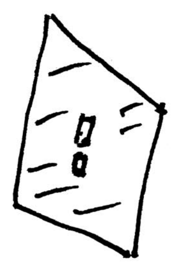
Effective aperture of receiving antenna

$$|\bar{W}_i| \cdot A_{eff} = P_{Received} = P_R$$

$$P_r = \frac{|V_{out}|^2}{2R_{eff}} = \frac{|E_{inc}\Delta z|^2}{8}\,\frac{1}{\frac{2}{3}\pi\eta\left(\frac{\Delta z}{\lambda}\right)^2} = \frac{|E_{inc}|^2}{2\eta}\left(\frac{3\lambda^2}{8\pi}\right)$$

$$P_r = |W_{ave}| \cdot A_{eff} \; ; \quad A_{eff} = \frac{3\lambda^2}{8\pi}$$

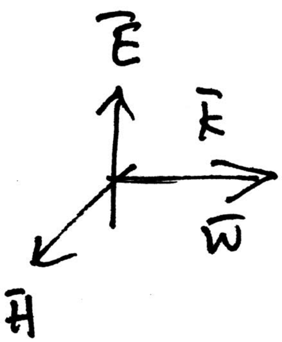




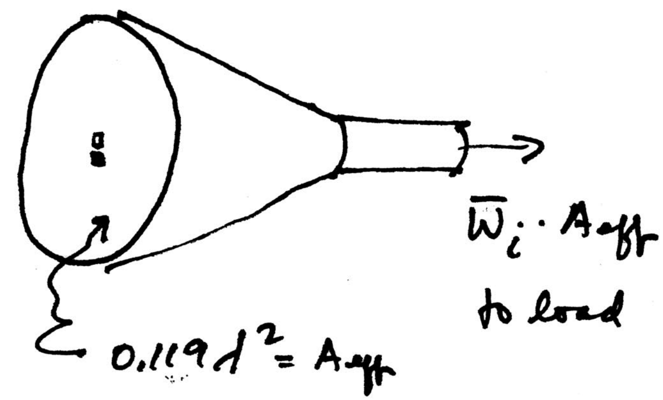
$\frac{3\lambda^2}{8\pi}$ independant of Δz !!

Lossless, ideal Dipole

So, Ideal Dipole behaves like an EM-wave collector of size $A_{eff} = 0.119\lambda^2$, independent of Δz for $\Delta z \ll \lambda$.



Ant. as a funnel!

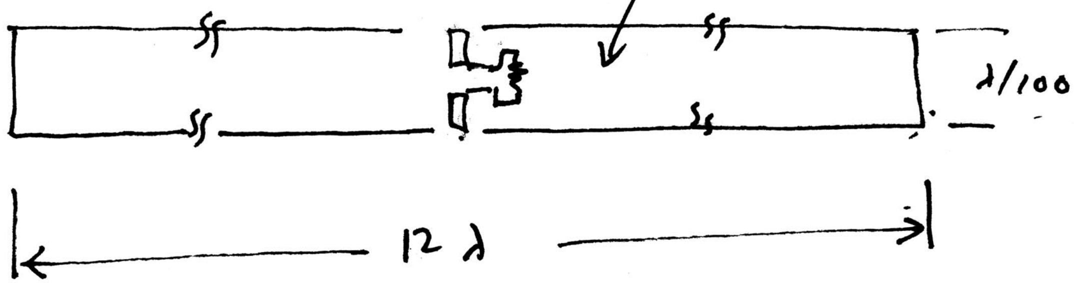


Dipole scoops up power over A_{eff} and delivers it to load.

Assume, for example, that $\Delta z = \lambda/100$

$$\frac{3\lambda^2}{8\pi} \Big/ \lambda/100 = \frac{300\lambda}{8\pi} \cong 12\lambda$$

area $= \dfrac{3\lambda^2}{8\pi} = [0.35\lambda]^2$



A_{eff} is much larger than physical size!