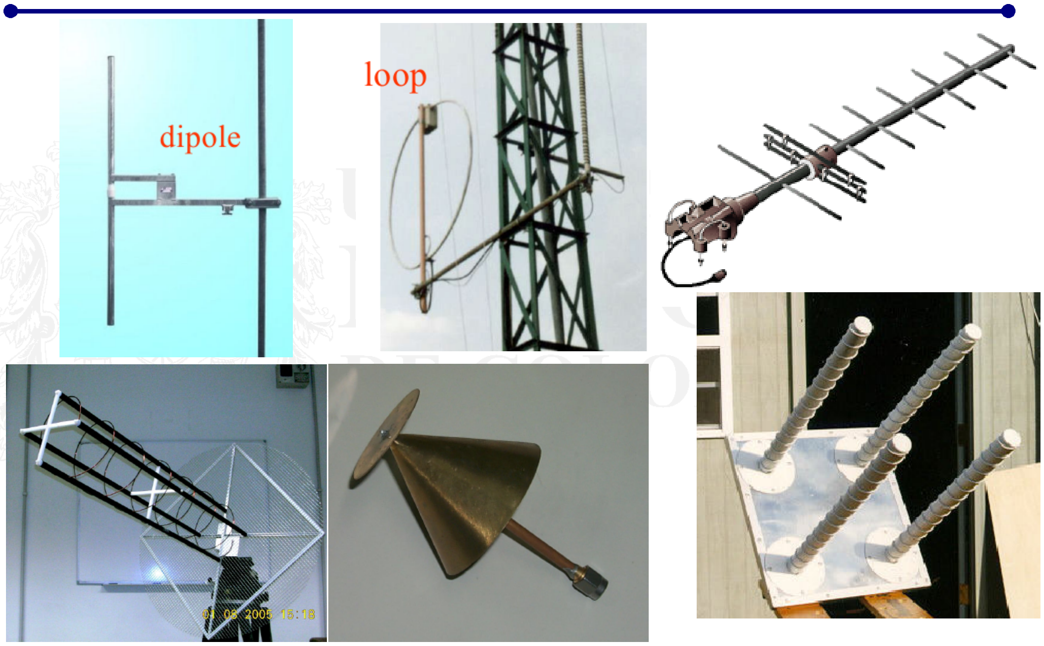
Wire antennas

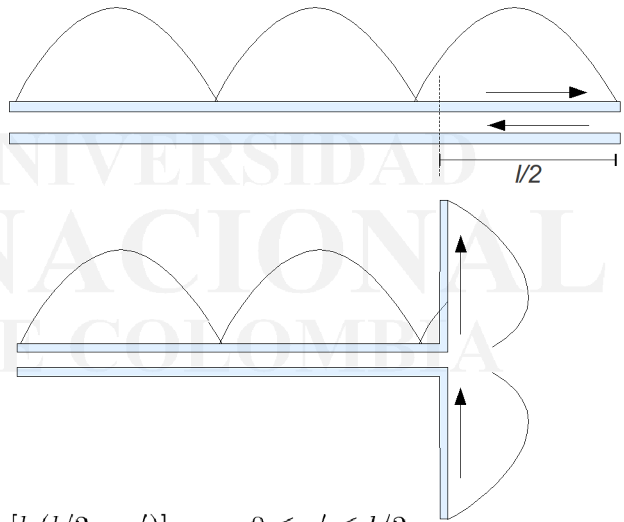
Javier Leonardo Araque Quijano
Associate Professor
Electrical and Electronics Engineering Department
Universidad Nacional de Colombia
jlaraqueq@unal.edu.co

Wire antenna examples



Finite length dipole

Assuming infinitely thin conductors, its current can be approximated by that on a transmission line whose (open-circuit) termination has been "opened up"



$$\mathbf{I_e}\left(x'=0, y'=0, z'\right)=\begin{cases}\hat{\mathbf{z}} I_0 \sin\left[k\left(l/2-z'\right)\right] & 0 \leq z' \leq l/2 \\ \hat{\mathbf{z}} I_0 \sin\left[k\left(l/2+z'\right)\right] & -l/2 \leq z' \leq 0\end{cases}$$

Far field

Superposition is used to add the contributions due to infinitesimal elements along the two "poles" of the antenna. The T.L. Portion in principle does not radiate since contribution from the two wires cancel out.

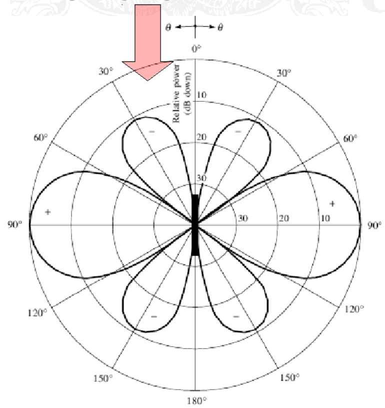
$$E_\theta = \int_{-l/2}^{+l/2} dE_\theta = j\eta \frac{ke^{-jkr}}{4\pi r}\sin\theta\left[\int_{-l/2}^{+l/2} I_e(x', y', z')e^{jkz'\cos\theta}\, dz'\right]$$

$$E_\theta \simeq j\eta \frac{I_0 e^{-jkr}}{2\pi r}\left[\frac{\cos\left(\frac{kl}{2}\cos\theta\right)-\cos\left(\frac{kl}{2}\right)}{\sin\theta}\right]$$

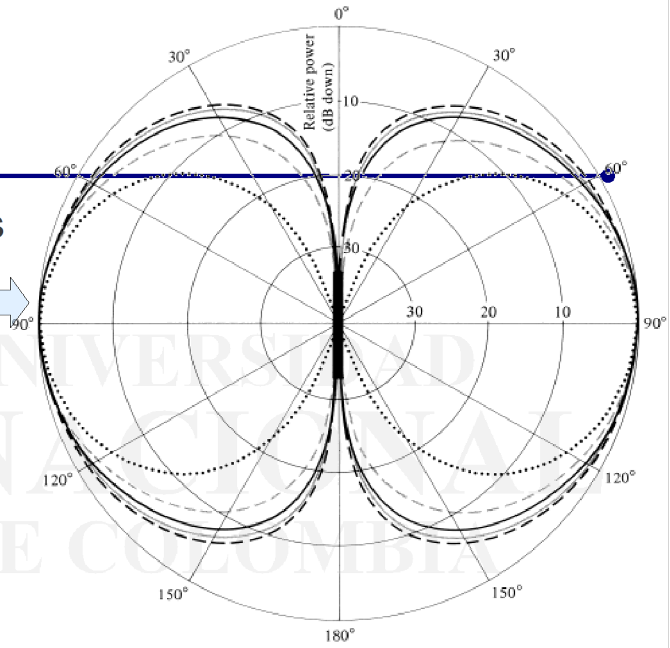
$$H_\phi \simeq \frac{E_\theta}{\eta} \simeq j\frac{I_0 e^{-jkr}}{2\pi r}\left[\frac{\cos\left(\frac{kl}{2}\cos\theta\right)-\cos\left(\frac{kl}{2}\right)}{\sin\theta}\right]$$

Far field (2)

- In principle, pattern is more directive with increasing length, however ...



l=1.25 lambda



$l = \lambda/50$	$l = \lambda/50$	3-dB beamwidth = 90°
$l = \lambda/4$	$l = \lambda/4$	3-dB beamwidth = 87°
$l = \lambda/2$	$l = \lambda/2$	3-dB beamwidth = 78°
$l = 3\lambda/4$	$l = 3\lambda/4$	3-dB beamwidth = 64°
$l = \lambda$	$l = \lambda$	3-dB beamwidth = 47.8°

Radiated Power and Radiation Resistance

$$P_{\rm rad} = \int_0^{2\pi}\int_0^{\pi} W_{\rm av} r^2 \sin\theta \, d\theta \, d\phi$$

$$= \eta \frac{|I_0|^2}{4\pi}\int_0^{\pi} \frac{\left[\cos\left(\frac{kl}{2}\cos\theta\right) - \cos\left(\frac{kl}{2}\right)\right]^2}{\sin\theta} d\theta$$

$$R_r = \frac{2P_{\rm rad}}{|I_0|^2} = \frac{\eta}{2\pi}\{C + \ln(kl) - C_i(kl)$$

$$+ \tfrac{1}{2}\sin(kl) \times [S_i(2kl) - 2S_i(kl)]$$

$$+ \tfrac{1}{2}\cos(kl) \times [C + \ln(kl/2) + C_i(2kl) - 2C_i(kl)]\}$$

$$C_i(x) = -\int_x^{\infty} \frac{\cos y}{y} dy$$

$$S_i(x) = \int_0^{x} \frac{\sin y}{y} dy$$

$$C = 0.5772 \text{ (Euler's constant)}$$

$$R_{in} = \frac{R_r}{\sin^2\left(\frac{kl}{2}\right)}$$

To obtain the usual input resistance, current must be substituted by the current at antenna input terminals (not max along TL).
This analysis does not allow to obtain the imaginary part of the input impedance: total reactive power depends critically on the integration surface chosen: need to consider explicitly wire radius (see later on).

Antenna Directivity

$$D_0 = 4\pi \frac{F(\theta,\phi)|_{\max}}{\int_0^{2\pi}\int_0^{\pi} F(\theta,\phi)\sin\theta \, d\theta \, d\phi}$$

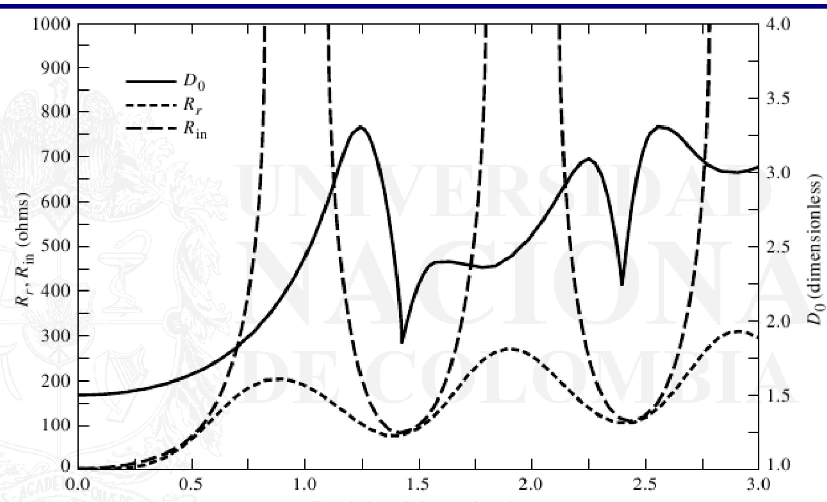
F is the radiation intensity (here normalized):

$$F(\theta) = \left[\frac{\cos\left(\frac{kl}{2}\cos\theta\right) - \cos\left(\frac{kl}{2}\right)}{\sin\theta} \right]^2$$

$$D_0 = \frac{2F(\theta)|_{\max}}{Q}$$

$$Q = \{C + \ln(kl) - C_i(kl) + \tfrac{1}{2}\sin(kl)[S_i(2kl) - 2S_i(kl)] + \tfrac{1}{2}\cos(kl)[C + \ln(kl/2) + C_i(2kl) - 2C_i(kl)]\}$$

Antenna resistance and directivity

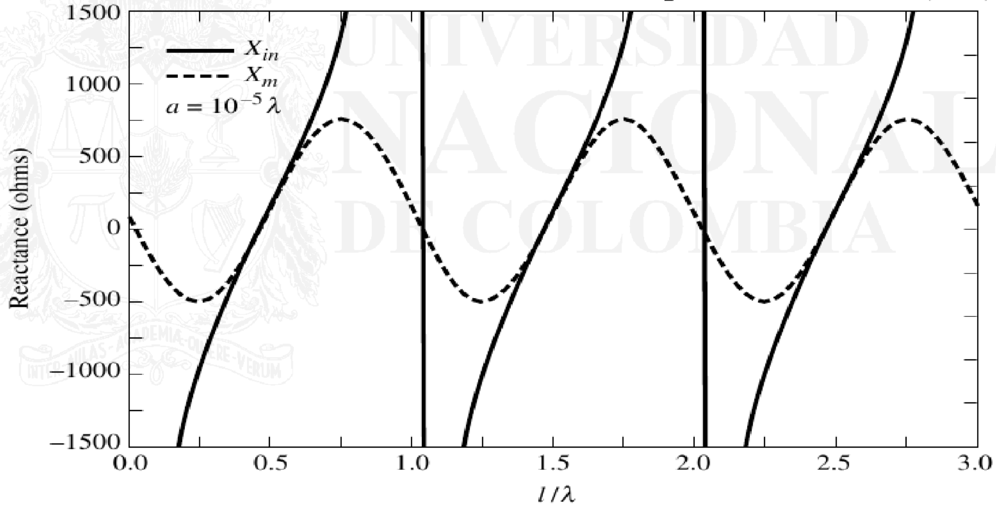


We are interested in Rin above, which is the radiation resistance referred to antenna input terminals. Rrad in these curves is referred to current maximum, which is not necessarily located at antenna terminals (not so useful).

Antenna reactance

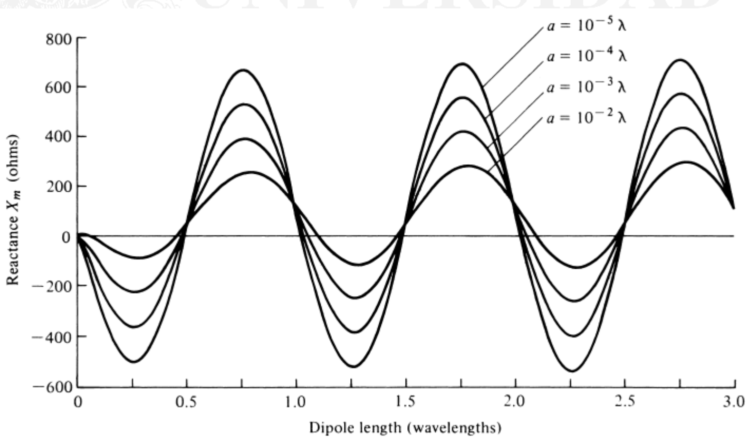
- Can be computed considering the complex Poynting vector (need to consider a finite wire radius a):

$$X_m = \frac{\eta}{4\pi}\left\{2S_i(kl) + \cos(kl)[2S_i(kl) - S_i(2kl)] - \sin(kl)\left[2C_i(kl) - C_i(2kl) - C_i\left(\frac{2ka^2}{l}\right)\right]\right\}$$



Effect of wire thickness

- Thicker wires lead to smoother reactance curves → improved bandwidth since total input impedance changes more slowly.



Half-wavelength dipole

$$E_\theta \simeq j\eta \frac{I_0 e^{-jkr}}{2\pi r}\left[\frac{\cos\left(\frac{\pi}{2}\cos\theta\right)}{\sin\theta}\right]$$

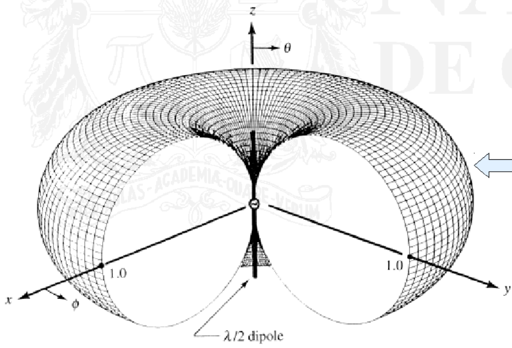
$$H_\phi \simeq j \frac{I_0 e^{-jkr}}{2\pi r}\left[\frac{\cos\left(\frac{\pi}{2}\cos\theta\right)}{\sin\theta}\right]$$

$$Z_{in} = 73 + j42.5$$

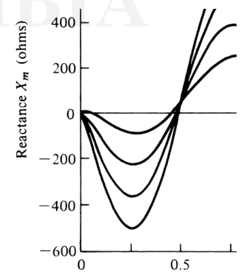
$$D_0 = 4\pi \frac{U_{\max}}{P_{\text{rad}}} = 4\pi \frac{U|_{\theta=\pi/2}}{P_{\text{rad}}} = \frac{4}{C_{in}(2\pi)} = \frac{4}{2.435} \simeq 1.643$$

$$A_{em} = \frac{\lambda^2}{4\pi} D_0 = \frac{\lambda^2}{4\pi}(1.643) \simeq 0.13\lambda^2$$

Actually l< lambda/2 to make reactance zero:
thicker → shorter

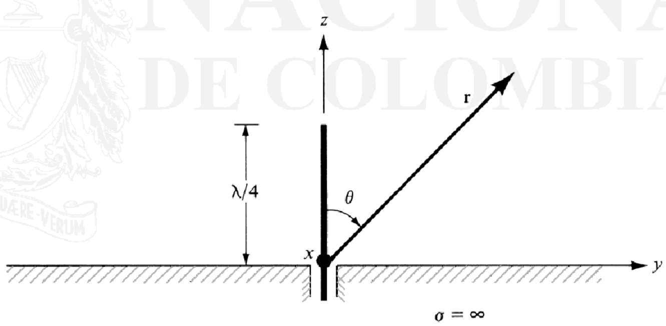


E is well approximated by sin(theta)^1.5



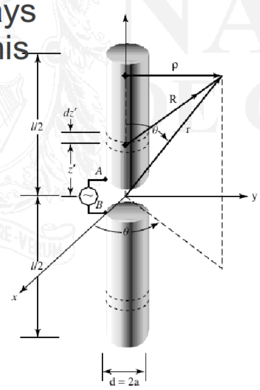
Monopole above PEC plane

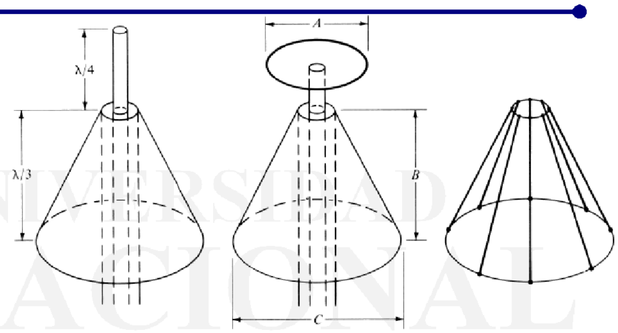
- Image theory → Fields on top hemisphere are the same as with the dipole.
- Input impedance is half that of dipole.



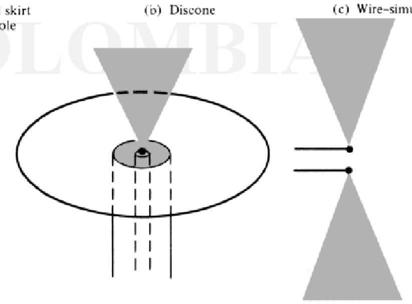
Variations for broad band operation

By increasing the effective volume of the antenna its bandwidth can be enhanced. Common ways to achieve this are:



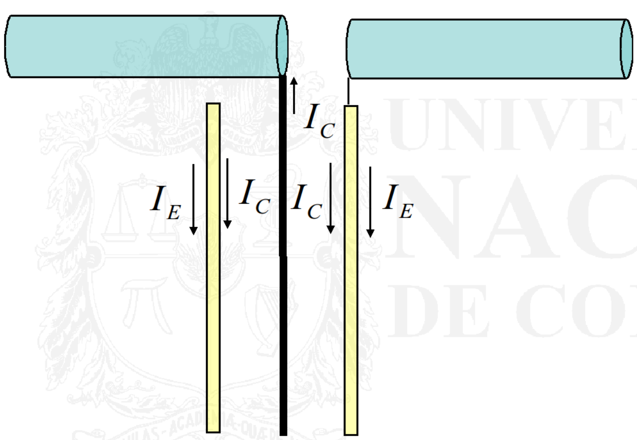


(a) Conical skirt monopole (b) Discone (c) Wire-simulation



(a) Triangular sheet (b) Bow-tie

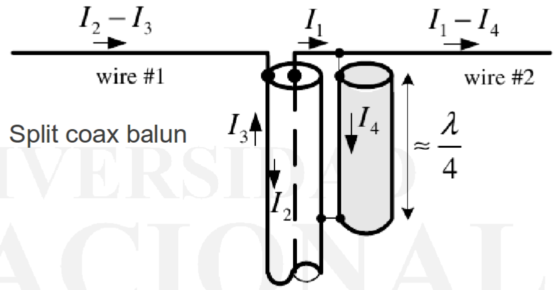
Balancing - BALUN



- Interaction with coax jacket induces currents on it that:
  - Disturb pattern.
  - Modify input impedance, it now depends on distance to source and surrounding elements.

Balun realizations

Lambda/2 line
for balancing



Transformer