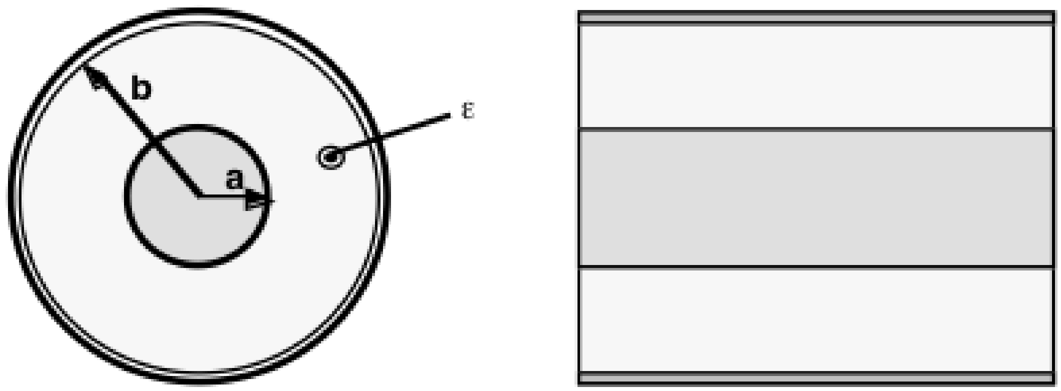
Velocity and losses in a coaxial transmission line

Consider a coaxial transmission line consisting of inner and out low-loss conductors separated by a low-loss dielectric having dielectic constant ε.



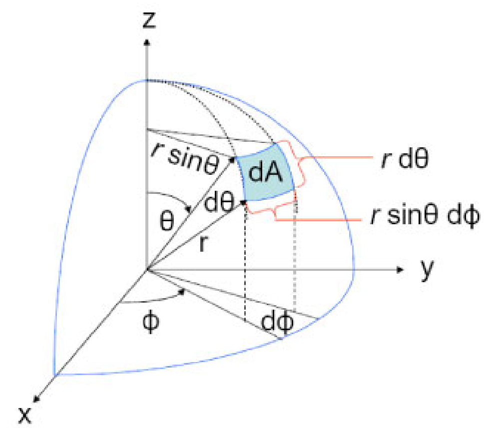
1. What is the velocity of propagation in such a transmission line?

2. What can you say about skin depth in the conductors, as a function of conductivity and frequency?

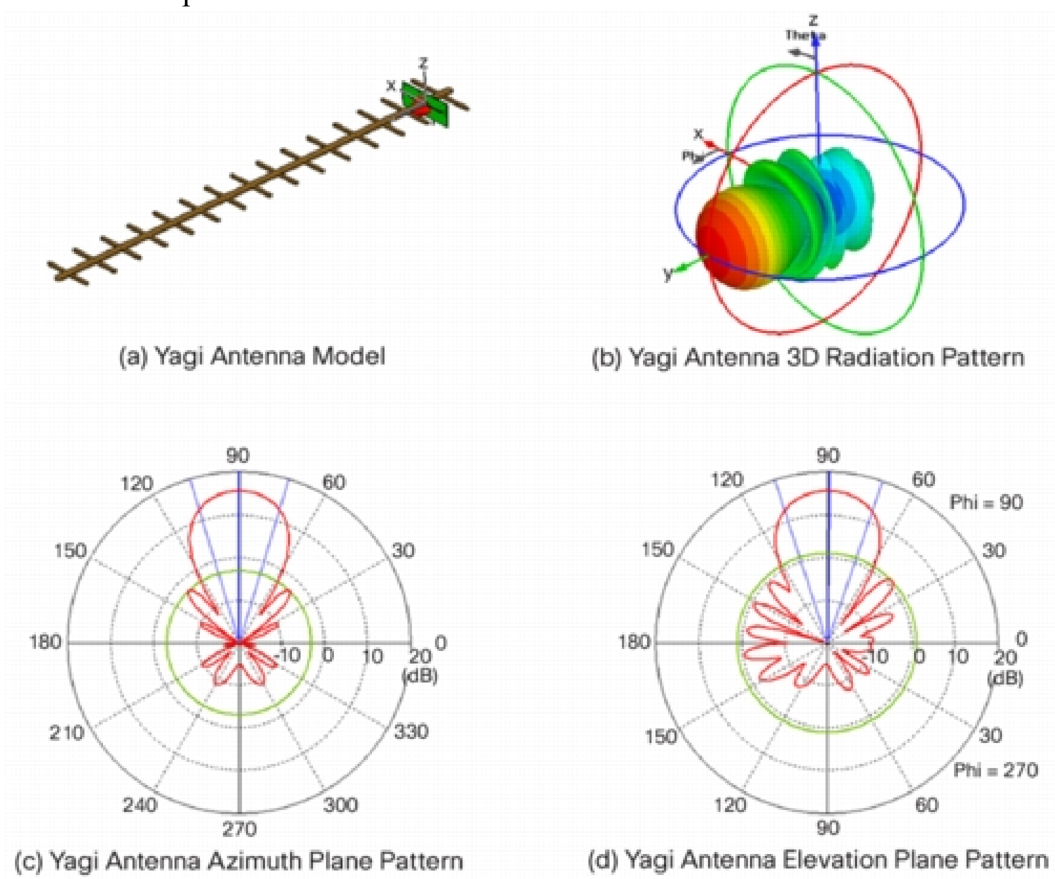
3. For a non-ideal transmission line (non-zero conductive and dielectric losses), what can you say about the behavior of conductive and dielectric losses as a function of frequency?

Power density of a radiating antenna

1. Consider a free-space radiator of electromagnetic waves. Show that the power flux (power per unit area) at a distance **r** is proportional to the inverse of the square of the distance, that is, $\mathbf{1/r^2}$. Use spherical coordinates.



2. An isotropic radiator radiates equal power in all directions. A directive antenna enhances power in a desired direction by reducing transmission in other directions. Directivity is defined as the ratio $D=P_{dir}/P_{iso}$, as shown by directive radiation patterns such as this example:



(a) Yagi Antenna Model

(b) Yagi Antenna 3D Radiation Pattern

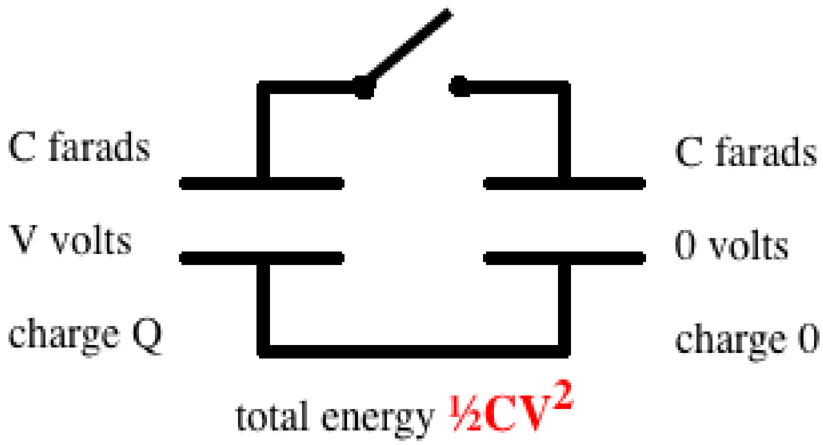
(c) Yagi Antenna Azimuth Plane Pattern

(d) Yagi Antenna Elevation Plane Pattern

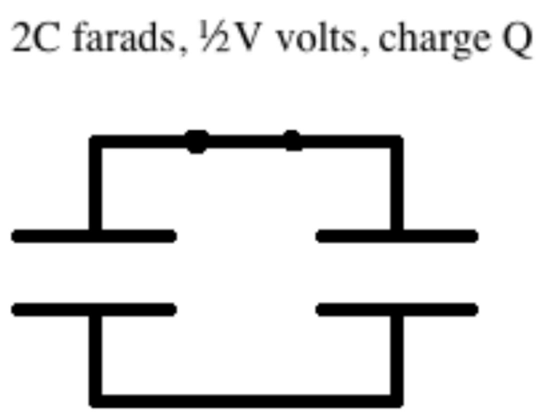
What is the integral over all azimuth and elevation angles of the directivity of an isotropic antenna, and of a directive antenna?

The capacitor paradox:

Consider a capacitor C charged to a voltage V. The charge stored in the capacitor is $Q = CV$ and the energy stored in the capacitor is $1/2CV^2$.



1. Now close the switch to share the charge with the second, equal capacitor. Since charge is conserved and the voltage on both capacitors must be equal, what is the resulting voltage?



2. Now what is the total energy stored in both capacitors?

3. If this is not equal to the original stored energy, what might be some reasons for the difference?

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<u>Coaxial transmission line</u>:

$v_p = c/\sqrt{\varepsilon}$

$\delta = \sqrt{(2/\mu\sigma\omega)}$

Conductive loss α $\sqrt{f}$

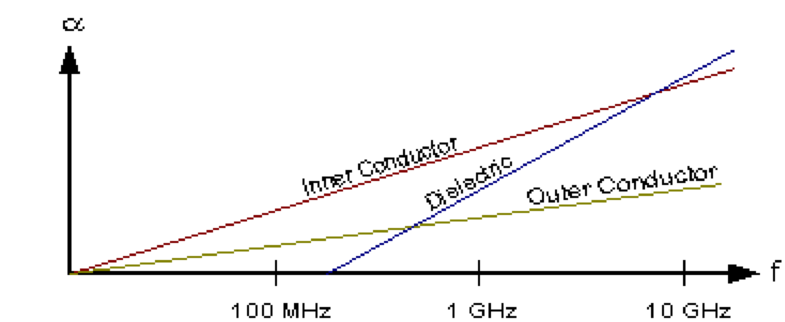
Dielectric loss α f

Cable attenuation is the sum of the conductor losses and the dielectric losses per the following equations.

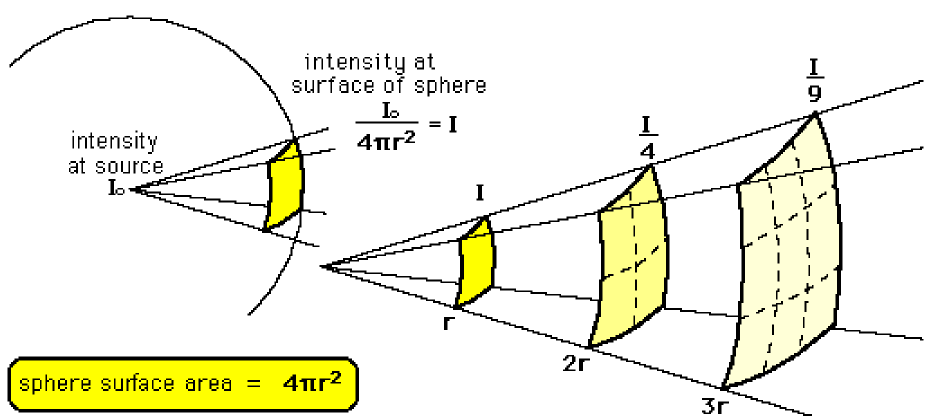
$$\alpha_{conductors} = \alpha_c = \frac{11.39}{Z} * \sqrt{f} * \left| \frac{\sqrt{\rho_{rd}}}{d} + \frac{\sqrt{\rho_{rD}}}{D} \right| \quad \frac{dB}{m}$$

$$\alpha_{dielectric} = \alpha_{diel} = 90.96 * f * \sqrt{\varepsilon_r} * \tan(\delta) \quad \frac{dB}{m}$$

ρ_r = 1 for copper, 10 for steel



<u>Inverse square law and directivity</u>:



Directivity integrated over a full sphere is *unity* for all antennas, isotropic or directive (no power is generated in the antenna).

<u>Capacitor paradox</u>:

Total initial energy is $\frac{1}{2}CV^2$. After switch is closed, charge is divided equally between capacitors, so voltage is $\frac{1}{2}V$ and stored energy is $\frac{1}{4}CV^2$. The remaining energy is either *dissipated* in the resistance of the circuit or the switch, or if the circuit is lossless, is *radiated* from the circuit because of the current pulse, or is *stored* in magnetic fields of the connecting wires.