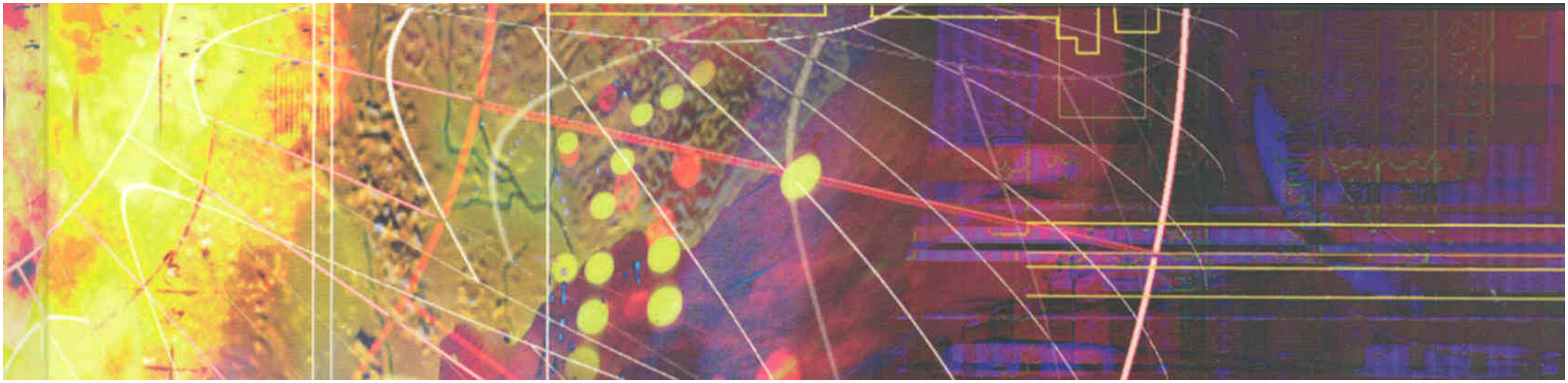
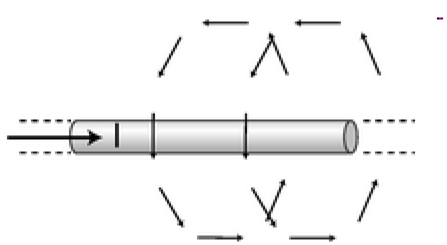


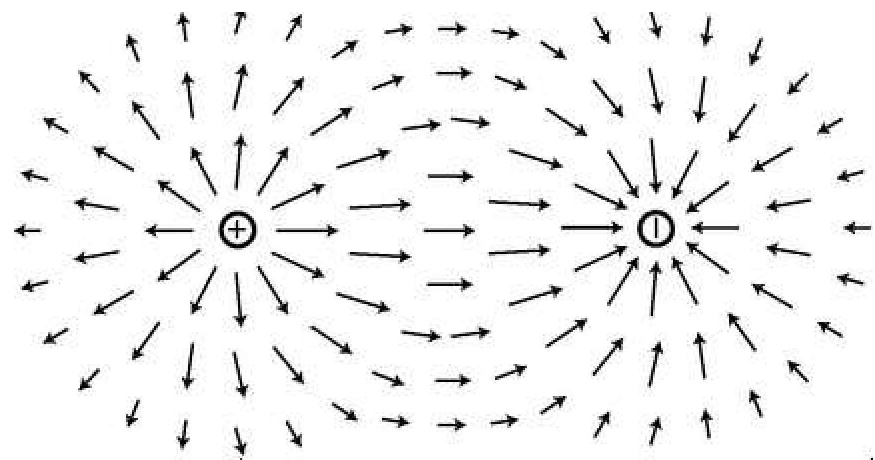
# EE303 Lesson 24: Antenna Fundamentals

# Electromagnetic waves

- An electric field (**E**) exists between any two points with a difference in charge $q$.
- The movement of charge, current ($I = dq/dt$), in a conductor induces a magnetic field (**H**).




Magnetic field (**H**) due to moving charge



Electric field (**E**) due to point charges

# Electromagnetic waves

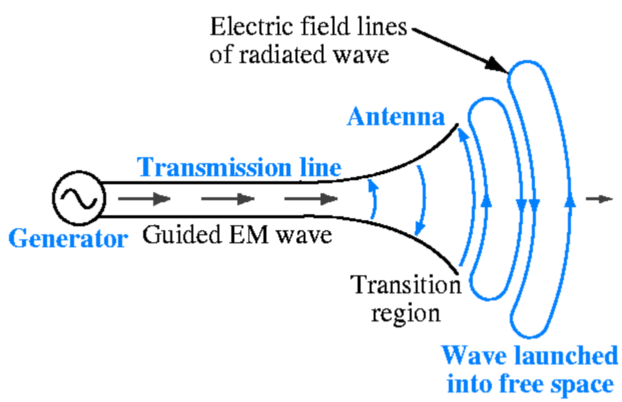
- If the rate of change of charge ($\partial I/\partial t = 0$) is constant, as it is in direct current (dc), then the electric field ($\mathbf{E}$) and the magnetic field ($\mathbf{H}$) are independent of each other.
- When time-varying currents ($\partial I/\partial t \neq 0$) occur such as in alternating-current (ac) sources, then the time-varying $\mathbf{E}$ and $\mathbf{H}$ fields are not independent, but coupled.
- In 1873 James Clerk Maxwell developed the mathematical relationship between the electric and magnetic fields.

$$\nabla \cdot \mathbf{D} = \rho_V \qquad \nabla \cdot \mathbf{B} = 0$$

$$\nabla \times \mathbf{D} = -\frac{\partial \mathbf{B}}{\partial t} \qquad \nabla \times \mathbf{H} = \mathbf{J} + \frac{\partial \mathbf{D}}{\partial t}$$

# Antennas

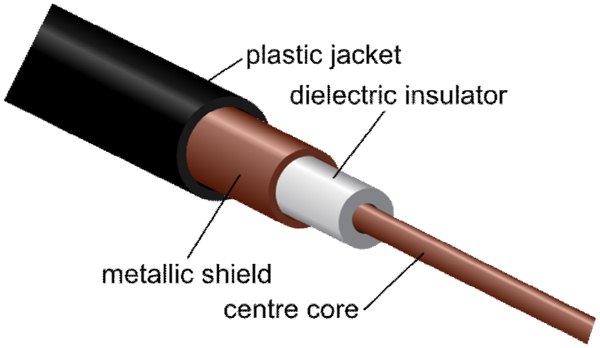
- The coupling between time electric and magnetic fields produces electromagnetic (EM) waves capable of traveling through free space and other media.
- An **antenna** is a device that provides a transition between guided electromagnetic waves and electromagnetic waves in free space.



# Transmission lines

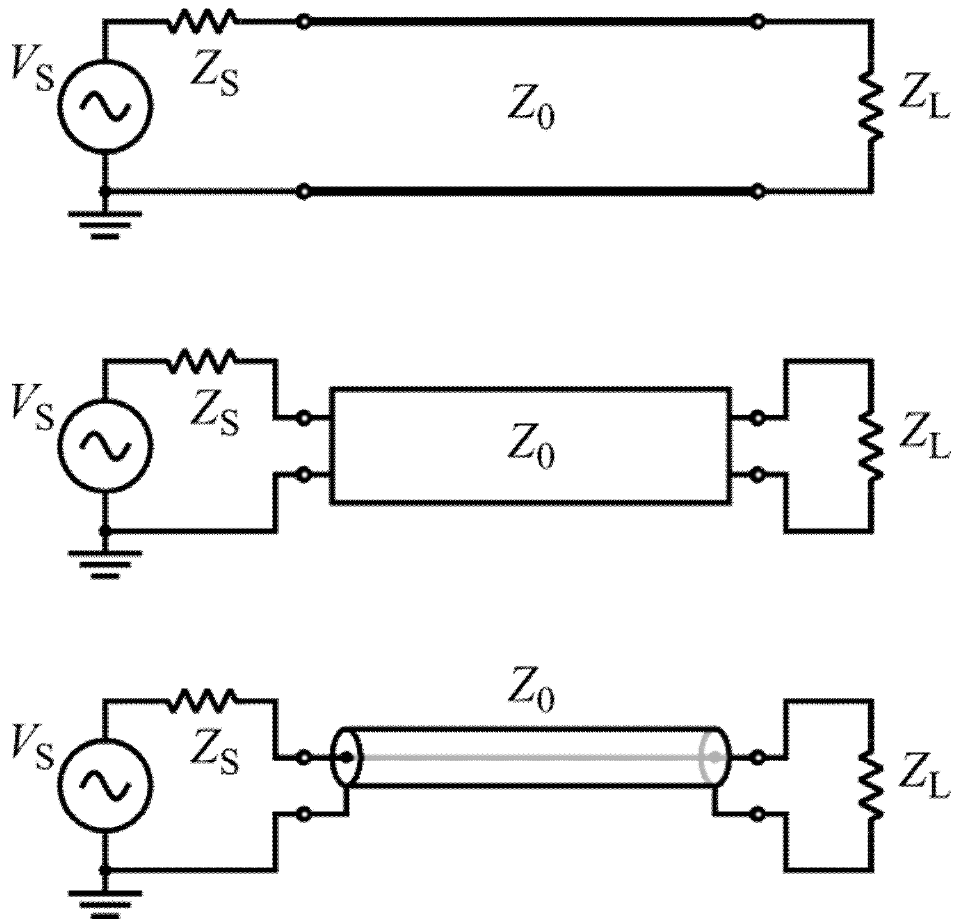
- A transmission line is designed to convey electromagnetic waves from one point to another with
  - With minimum signal attenuation
  - Without radiating the signal into space
- Transmission line examples:
  - Parallel wires
  - Coaxial cable
  - Twisted-pair cable

300 ohm twin-lead




Coaxial cable

# Transmission lines



# Transmission lines

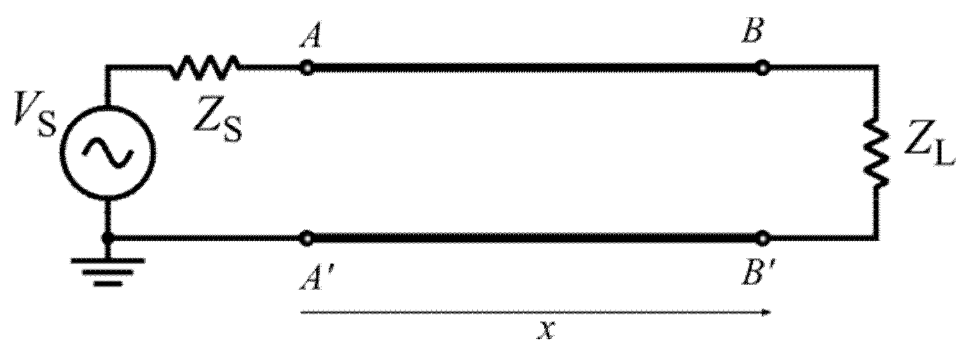
- Normally, for 60-Hz AC power we are not concerned with transmission line characteristics because the frequencies are so low.
  - The length of the conductor is short in relation to 1λ of the signal.
  - For instance, the wavelength of 60-Hz power signal is

$$\lambda = \frac{300,000,000 \text{ m/s}}{60 \text{ Hz}} = 5,000,000 \text{ m}$$

- The voltage at any point on the line is only a function of time *t*.

$$
\begin{aligned}
V_{AA'}(0,t) &= V_0 \cos \omega t \\
V_{BB'}(x,t) &= V_{AA'}(t - x/c) \\
&= V_0 \cos(\omega t - \omega x/c)) \\
&= V_0 \cos(\omega t - \underbrace{\frac{2\pi x}{\lambda}}_{}) ) \\
&\approx V_0 \cos \omega t
\end{aligned}
$$

extremely small for low frequency

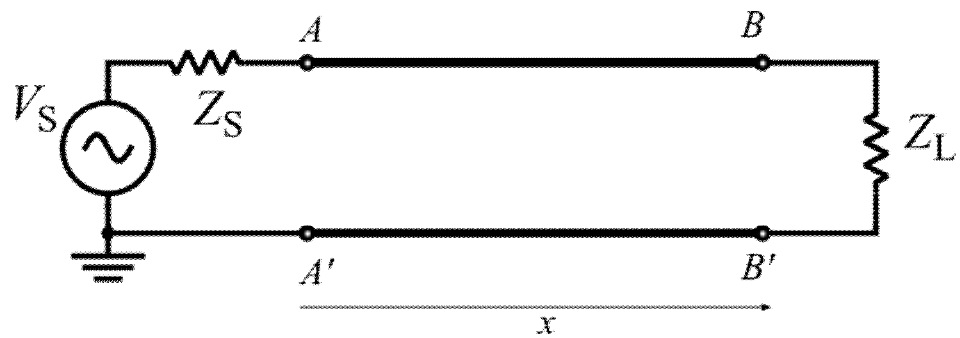


# Transmission lines

- For very high frequencies when the length of the transmission line is of the same order as the wavelength of the signal, we cannot ignore velocity of the propagating wave.
  - We have to consider the voltage as a function of time (*t*) and position (*x*).

$$V_{AA'}(0,t) = V_0 \cos\omega t$$

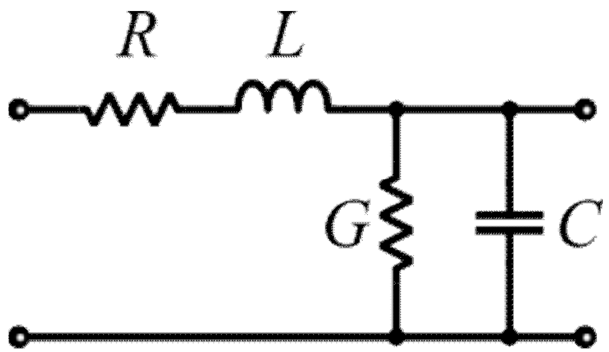
$$\begin{aligned} V_{BB'}(x,t) &= V_{AA'}(t - x/c) \\ &= V_0 \cos(\omega t - \omega x/c)) \\ &= V_0 \cos(\omega t - \underbrace{\frac{2\pi x}{\lambda}}) ) \end{aligned}$$




cannot ignore for high frequency

# Transmission lines

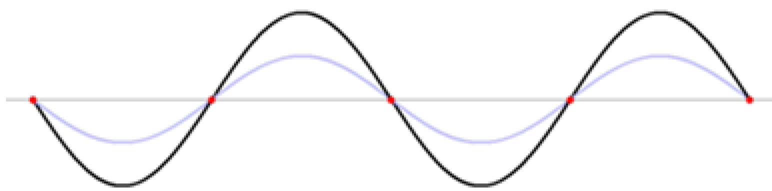
- Electromagnetic wave propagation is governed by Maxwell's equations, but it can be simplified case of propagation over a wires.
- A transmission line can be modeled as an infinite sequence of elementary 2-port components.
- Using this model, the resulting **telegraphers equations** are a pair of linear differential equations which describe the voltage and current on an electrical transmission line with distance and time.



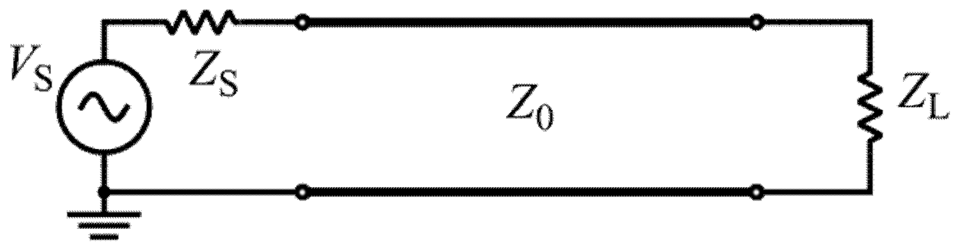

elementary components of a transmission line

# Transmission lines

- Solving telegraphers equations yields traveling wave solutions for voltage ($V$) and current ($I$) waveforms.

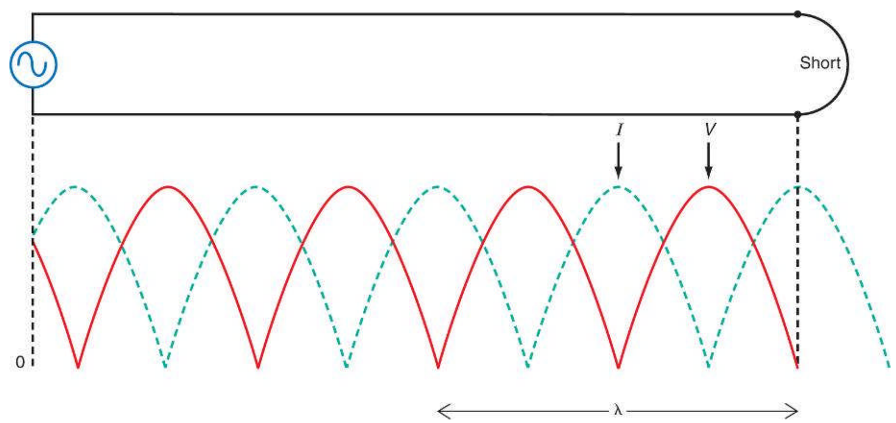


- Depending on the impedance of the load $Z_L$ and the characteristic impedance of the line $Z_0$, these traveling waves can give rise to reflection and standing waves.

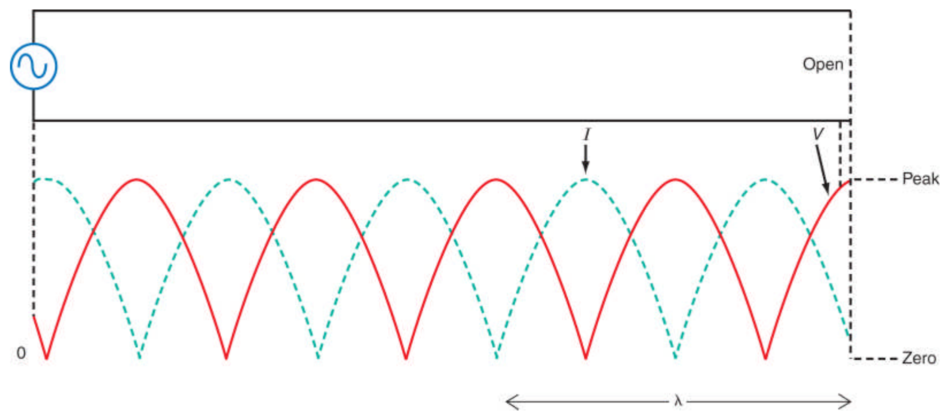


# Transmission lines

- If we short circuit the load ($Z_L = 0$), we get the following standing waves

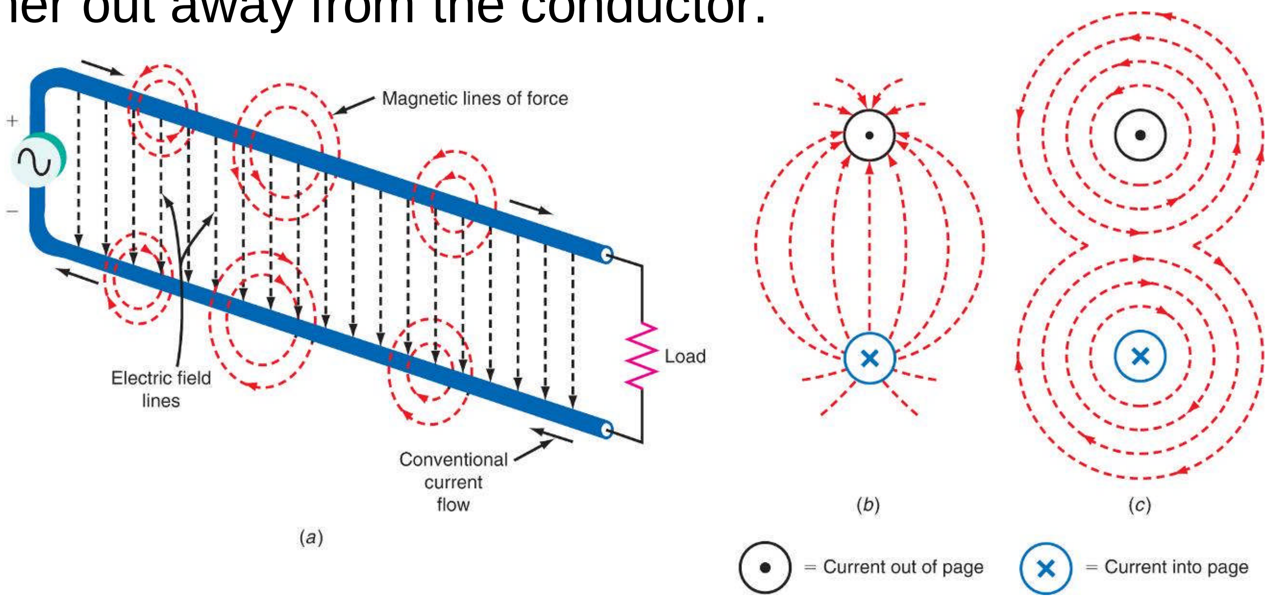



- If the load is open circuit ($Z_L = \infty$), we get



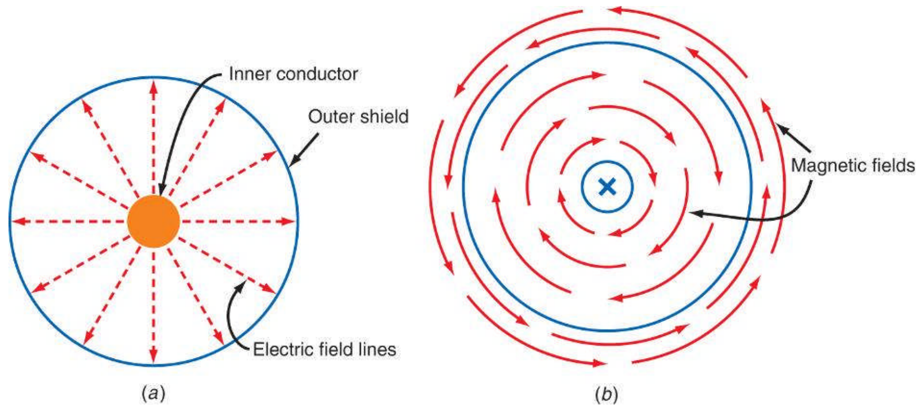
# **E** and **H** fields for transmission lines

- The magnetic and fields for a two-wire transmission line are depicted below.
  - Note that at any instance in time, the wires have opposite polarities thus the direction of the electric field changes once per cycle.
  - Also, the direction of current flow is always opposite so the fields strengthen one other between the conductors but cancel each other out away from the conductor.



# E and H fields for transmission lines

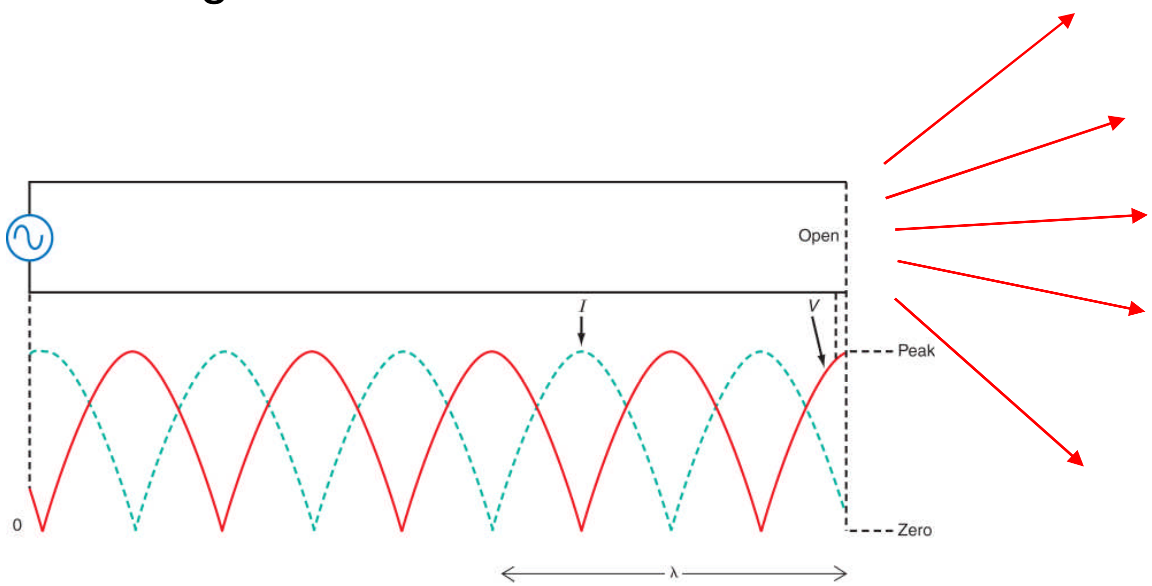
- The illustration below shows the electric and magnetic fields in a coaxial cable.




- Transmission lines, unlike antennas, are designed not to radiate electromagnetic waves but to contain them.

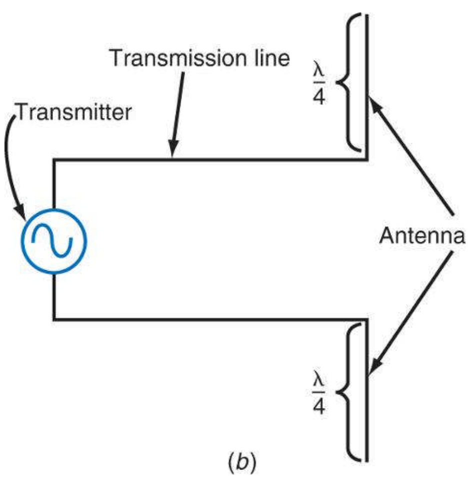
# Antenna operation

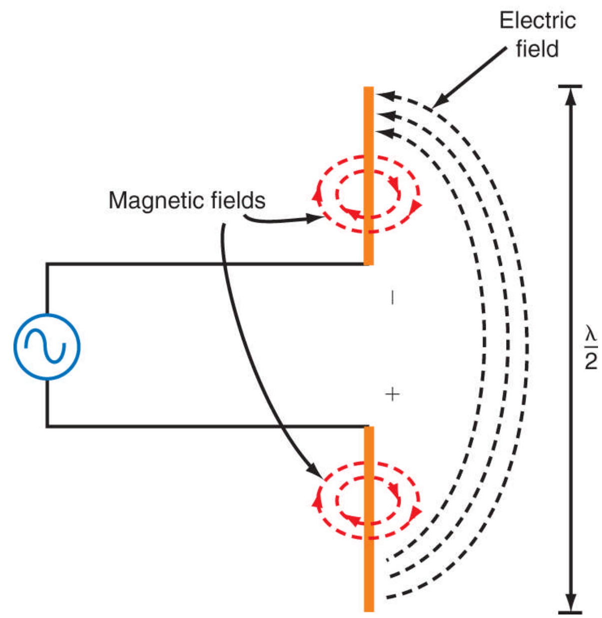
- If a parallel wire transmission line is left open, then electric and magnetic fields do escape from the end of the wire and radiate into space
  - This is rather inefficient because a great deal of cancelation of the electric and magnetic fields still occurs.



# Antenna operation

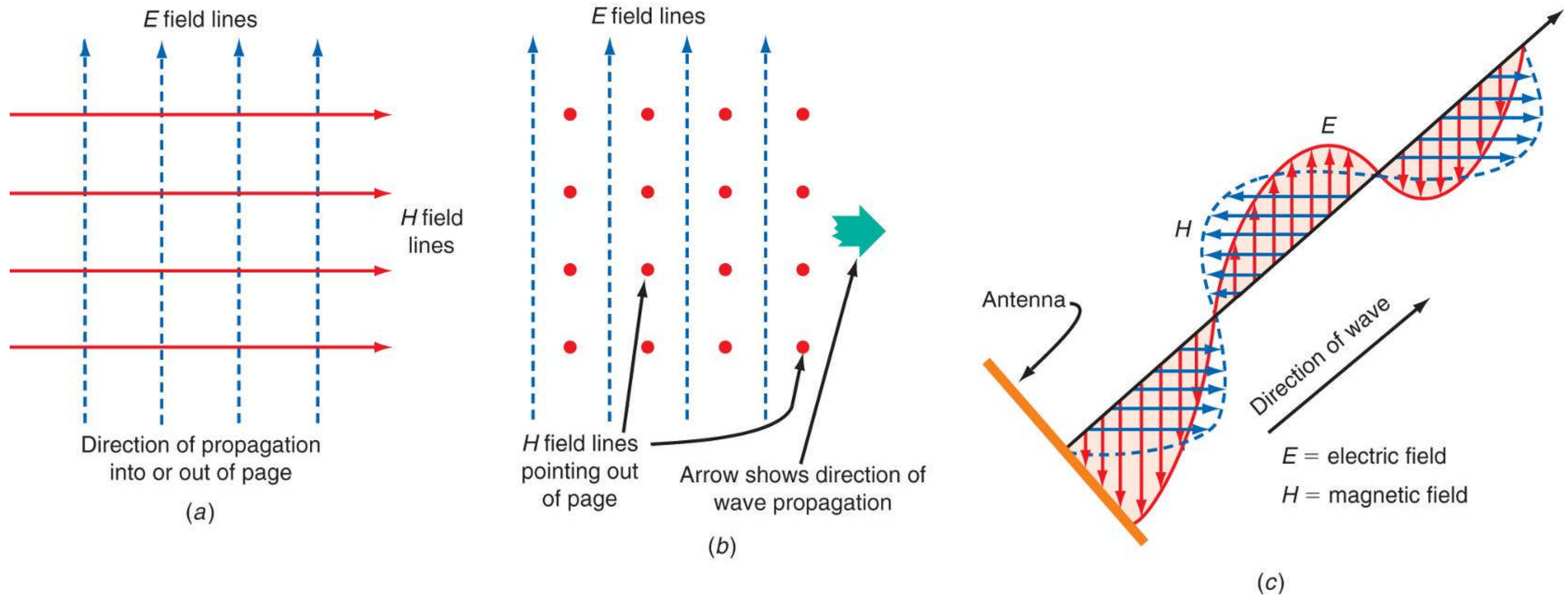
- However, if the last quarter-wavelength ($\lambda/4$) of each conductor is turned at a right angle then
  - The electric fields spread out from the conductor.
  - The magnetic fields reinforce one another.
  - This results in efficient radiation.



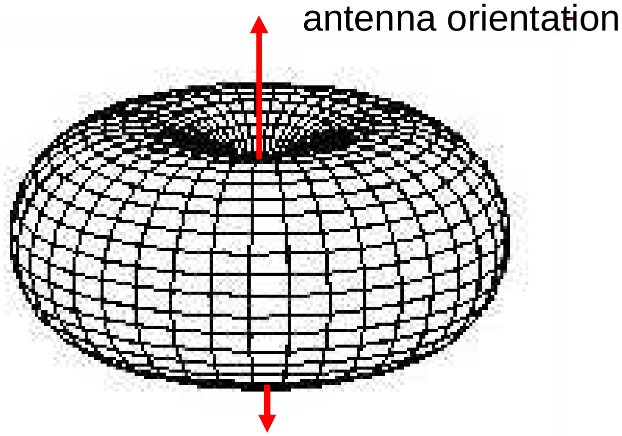
# Antenna operation

- The electric and magnetic fields produced by the antenna are at right angles to one another, and both are perpendicular to the direction of propagation.



# Antenna radiation pattern

- The intensity of the radiated power related to the cross product $\mathbf{E} \times \mathbf{H}$.
- For the case of the half-dipole antenna the radiation pattern is doughnut shaped as depicted




- The radiation pattern shows the strength of the antenna's radiated field as a function of direction.

# Near-field / far-field radiation

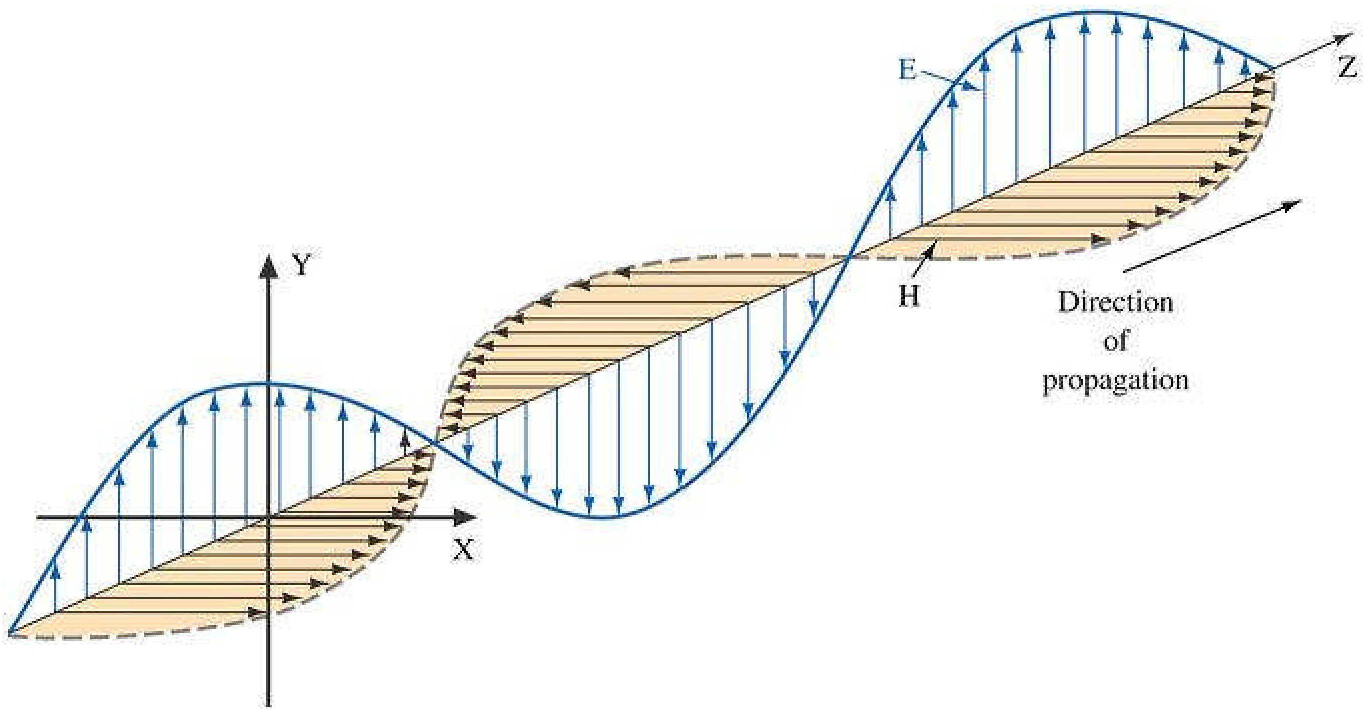
- The cross product $\mathbf{E} \times \mathbf{H}$ typically results in many terms which are proportional to $1/R^2$ and $1/R^3$ where $R$ is the radial distance from the antenna.
  - As distance increases away from the antenna, these terms become negligible.
- In general we will consider distances $\sim 10\lambda$ away from the antenna, and we can ignore these terms.
  - This is called the **far-field approximation** and is what is depicted in most radiation patterns.
- Distances less than $\sim 10\lambda$ are considered **near-field**.

# Example Problem 1

Consider the case of an antenna designed to transmit 2.4 GHz signals. At approximately what distance could we be considered to be in the far-field ?

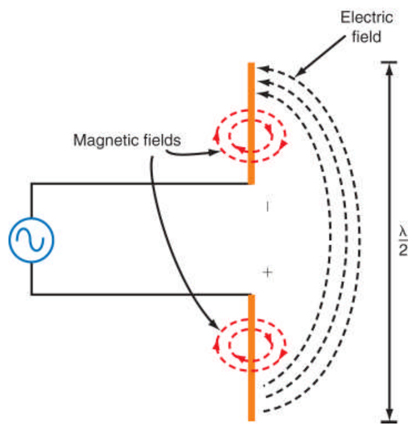
# Antenna polarization

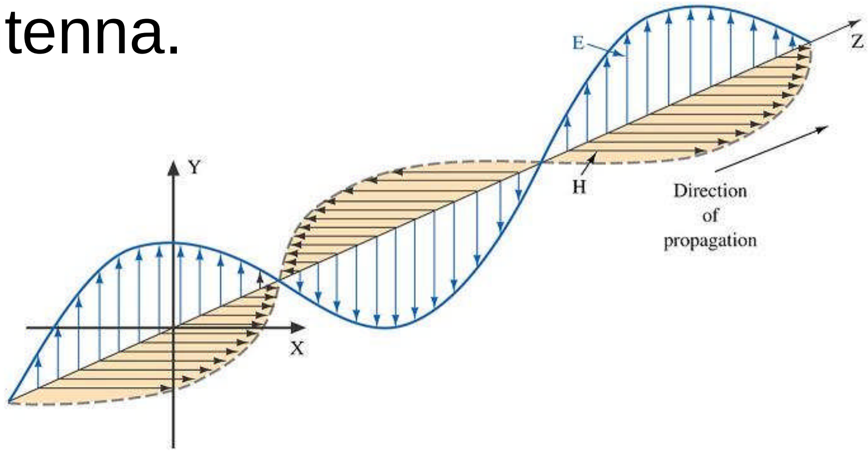
- The polarization of an antenna refers to the direction of the **electric field** it produces.
- Polarization is important because the receiving antenna should have the same polarization as the transmitting antenna to maximize received power.



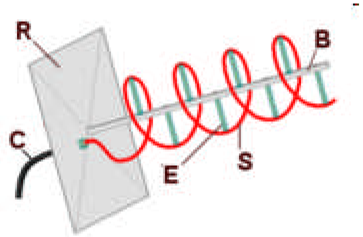
# Antenna polarization

- The half-dipole antenna as depicted is an example of a vertically polarized antenna.



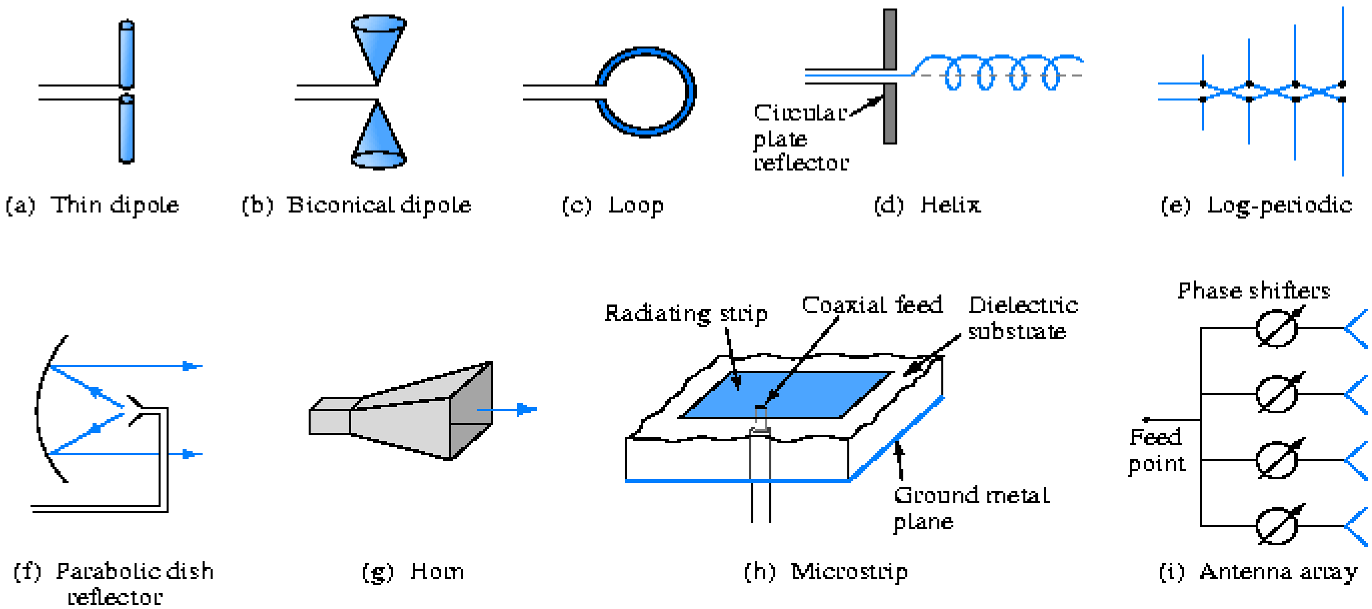

- Other types of polarization include horizontal and circular.




circularly polarized radiation is produced by helical antennas

# Antenna physical characteristics

- The antenna's size and shape largely determines the frequencies it can handle and how it radiates electromagnetic waves.



# Wavelength (λ)

- You may recall from physics that wavelength (λ) and frequency ($f$) of an electromagnetic wave in free space are related by the speed of light ($c$)

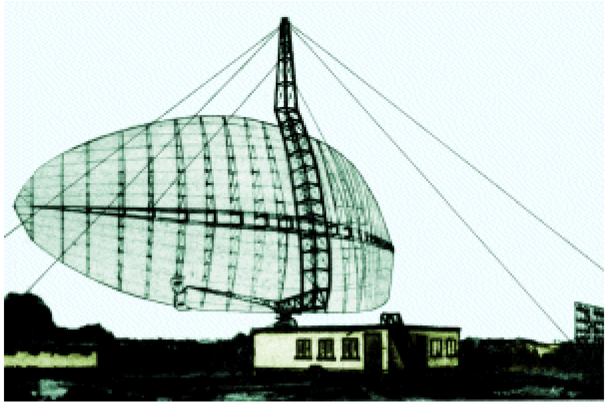
$$c = f\lambda \quad \text{or} \quad \lambda = \frac{c}{f}$$

- Therefore, if a radio station is broadcasting at a frequency of 100 MHz, the wavelength of its signal is given

$$\lambda = \frac{c}{f} = \frac{3.0 \times 10^{8}\ \text{m/s}}{100 \times 10^{6}\ \text{cycle/s}} = 3\ \text{m}$$

# Wavelength and antennas

- The dimensions of an antenna are usually express in terms of **wavelength** ($\lambda$).
- Low frequencies imply long wavelengths, hence low frequency antennas are very large.
- High frequencies imply short wavelengths, hence high frequency antennas are usually small.



# Reciprocity

- Antennas exhibit the same radiation pattern for transmission and reception.
- This property is called **reciprocity**.
- Therefore, if an antenna transmits in direction A with 100 times the power it transmits in direction B, then when used to receive a signal it can be expected to be 100 times as sensitive in direction A relative to B.