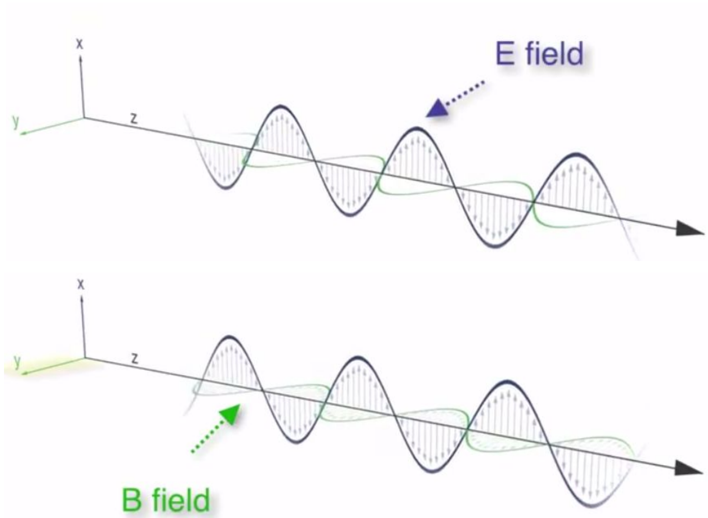
1. *Electromagnetic Waves*

a. **Fuente.** *NotreDameX*: EG240x Understanding Wireless: Technology, Economics, and Policy
    i. Exploring Electromagnetic (EM) Waves

First, the **EM wave propagates** along the z-axis from the transmitting antenna to the receiving antenna. Second, the E field oscillates up and down along the x-axis. We can think of this E field as being induced by an electric current that moves charges back and forth in the transmitting antenna, Third, the B field oscillates back and forth along the y-axis perpendicular to the E field.



It's worth emphasizing that there is a beautiful mathematical equation that governs the simplified solution to Maxwell's equations. **We introduce this equation to highlight some key parameters of the propagating EM wave**. The planar wave equation is shown here, focusing on the variation of the E field. We see that the EM wave is oscillating, both as a function of space, in this case along the z-axis, and time, the t-axis. The particular type of oscillation is called sinusoidal. The two key parameters of the EM wave are how fast it oscillates in these two dimensions. The wavelength is the length of one full cycle in space, when we take a fixed snapshot in time, and is often measured in units of meters. The frequency is the number of oscillations per unit time when we look at a particular point in space. Frequency is measured in units of Hertz, named after the famous physicist who experimented with EM waves. It turns out that frequency and wavelength have to relate to one another because the EM wave propagates at the speed of light, 3 times 10 to the 8th meters per second.

Planar Wave Solution

$$\vec{E}(x,y,z,t) = A\cos\left(\frac{2\pi}{\lambda}z - 2\pi ft + \theta\right)\vec{x}$$

λ : wavelength in meters

f : frequency in cycles/sec (Hertz)

$f\lambda = c = 299,792,458$ m/s, speed of light!

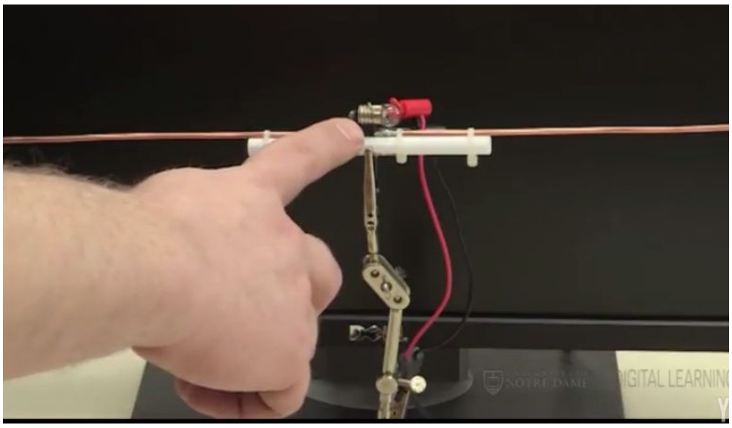
HEINRICH HERTZ

http://en.wikipedia.org/wiki/Heinrich_Hertz#/media/File:Heinrich_Rudolf_Hertz.jpg

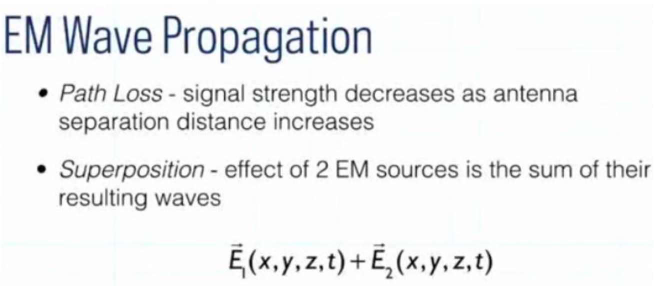
Example Frequencies & Wavelengths

Application	f	λ
FM Radio	88 MHz	3.4 m
GPS	1.575 GHz	0.19 m
Cellular	1.8 GHz	0.17 m
WiFi	2.4 GHz	0.125 m

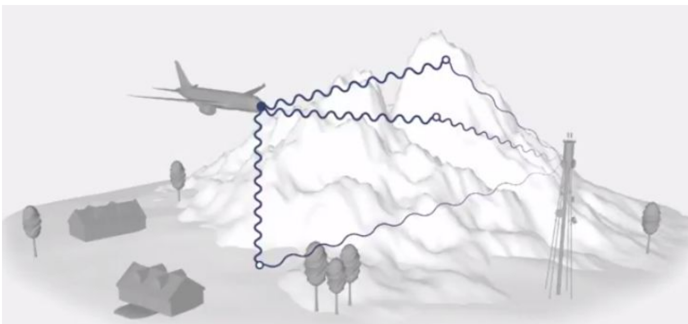
Here we have a simple transmitter which is generating a current back and forth in this dipole antenna.And here we have a similar dipole antenna that is connected by a flashlight bulb. If a strong enough EM wave impinges upon this receive antenna, it should generate a current back and forth in the antenna and light the bulb.

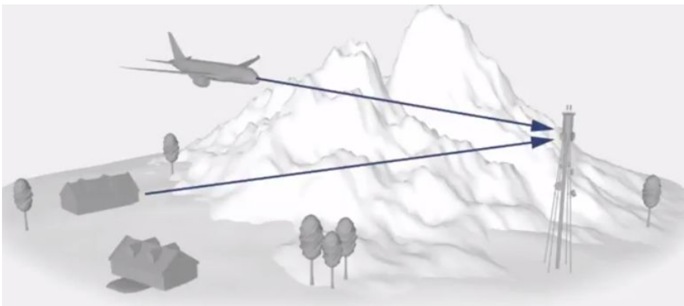


From the experiment



Superposition leads to some major challenging issues in wireless technology. As one example, when a signal propagates from an antenna, it can bounce off of objects in the medium and result in multiple copies of the signal with different gains and time delays at the receiver. This effect, called multi-path propagation, results from a transmitted signal interfering with itself because of superposition. Another example is two different transmitters, whose signals are close together in frequency and therefore interfering with one another.






Interference Challenges in Wireless
Multipath Propagation - reflections cause a signal to interfere with itself
Crosstalk - two or more transmitters close in space and frequency interfere with each other's signals at a receiver
Have been tackled from technical, economic, & regulatory perspectives

2. vvv