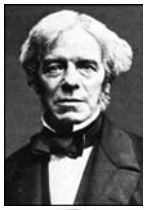
## L 30 Electricity and Magnetism [7]

**ELECTROMAGNETIC WAVES**

- Faraday laid the groundwork with his discovery of electromagnetic induction
- Maxwell added the last piece of the puzzle

LIGHT

Heinrich Hertz made the experimental discovery in 1886



## James Clerk Maxwell (1831-1879)

- Faraday showed that a changing magnetic field can generate a current.
- Another way to look at this is to say that **a changing magnetic field can create an electric field**
- Maxwell argued that **a changing electric field should then also create a magnetic field.**

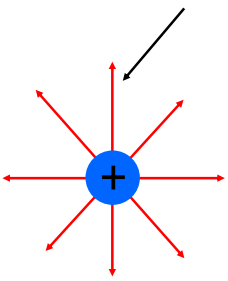
## Electromagnetic (EM) waves

- A wave is a disturbance that propagates in a *medium*
  - transverse waves on a string
  - longitudinal sound waves in air
- *an electromagnetic wave is an electric and magnetic disturbance that propagates through space (even vacuum) at the speed of light 299,792,458 m/s or 186,000 miles/s. No medium is required!*
- EM waves include radio, microwaves, x-rays, light waves, gamma rays . . . . . .

## Electric and Magnetic Fields

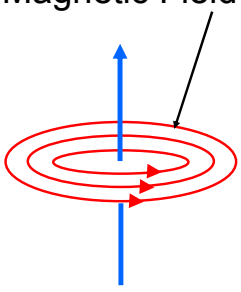
- electric charges produce electric fields (Coulomb's Law)
- electric currents (moving charges) produce magnetic fields (Ampere's Law)
- *an electromagnetic wave is a combination of electric and magnetic fields that vibrate together in space and time in a synchronous fashion*

## Electric Field



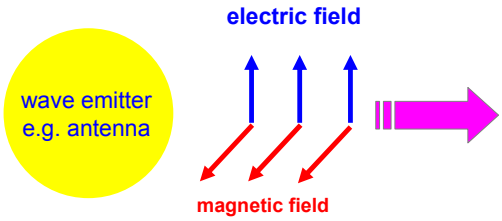
electric field of a positive charge

## Magnetic Field



magnetic field of a current in a wire

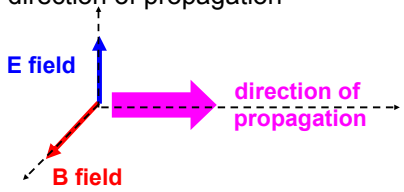
## the generation of an electromagnetic wave




The time varying electric field generated the time varying magnetic field which generates the time varying electric field and so on and so on . . . .

## EM waves: transverse

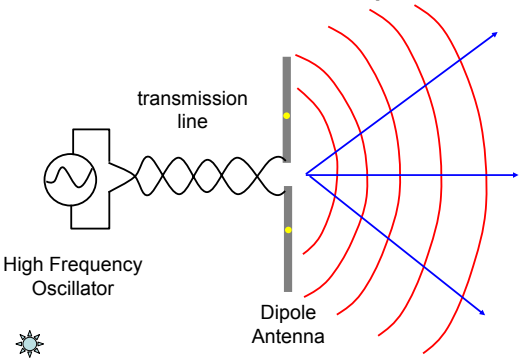
- the electromagnetic wave is a *transverse wave*, the electric and magnetic fields oscillate in the direction perpendicular to the direction of propagation



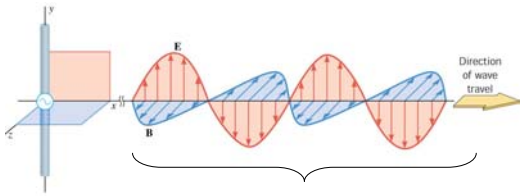

## Electromagnetic waves

- the EM wave propagates because the electric field recreates the magnetic field and the magnetic field recreates the electric field
- an oscillating voltage applied to the antenna makes the charges in the antenna vibrate up and down sending out a synchronized pattern of electric and magnetic fields
- *an **electromagnetic** wave must have both an electric and magnetic field component*

## How radio waves are produced



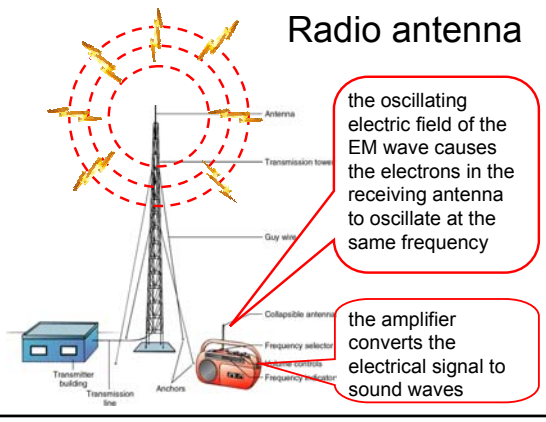

## Electromagnetic Waves




Antenna: emits waves

EM WAVE: electric and magnetic fields moving through space at the speed of light 186,000 miles/sec

## Radio antenna




the oscillating electric field of the EM wave causes the electrons in the receiving antenna to oscillate at the same frequency

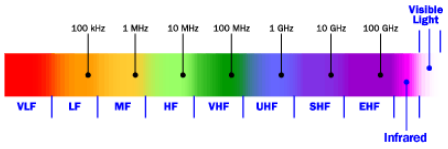
the amplifier converts the electrical signal to sound waves

## Common frequency bands

1 Hertz (Hz) = 1 vibration per second
1 KHZ (kilohertz) = 1000 Hz
1 MHZ (megahertz) = 1,000,000 Hz

**AM radio** - 535 KHZ to 1.7 MHZ
**Short wave radio** - bands from 5.9 to 26.1 MHZ
**Citizens band (CB) radio** - 26.96 to 27.41 MHZ
**Television stations** - 54 to 88 MHZ for channels 2 through 6
**FM radio** - 88 to 108 MHZ
**Television stations** - 174 to 220 MHZ for channels 7 through 13

# Frequency Bands




# Other common bands

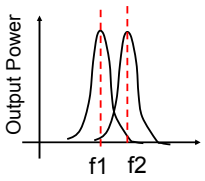
1. Garage door openers, alarm systems, etc. - Around 40 megahertz
2. Standard cordless phones: Bands from 40 to 50 megahertz
3. New 900-MHz cordless phones: around 900 megahertz!
4. Baby monitors: 49 megahertz
5. Radio controlled airplanes: Around 72 megahertz
6. Radio controlled cars: Around 75 megahertz
7. Wildlife tracking collars: 215 to 220 megahertz
8. space station: 145 megahertz and 437 megahertz
9. Cell phones: 824 to 1900 Megahertz
10. Air traffic control radar: 960 to 1,215 megahertz
11. Global Positioning System: 1,227 and 1,575 megahertz

# What is Bandwidth?

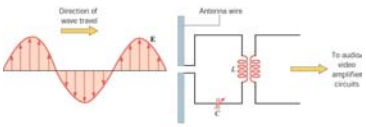
- the term "bandwidth" has two common meanings that are related
  - range within a band of frequencies, e.g. the bandwidth between 40.1 MHZ and 40.2 MHZ is 0.1 MHZ
  - the amount of data that can be transmitted in a fixed amount of time – measured in bits per second or bps.

# the bandwidth problem

- the FCC allocates bandwidth for commercial broadcasters.
- the problem is how many stations can broadcast within a given band
- each station is allotted a frequency, but the output of one station may overlap a bit with another station
- better technologies allow more channels within a band without interference




# Detecting (receiving) the Wave



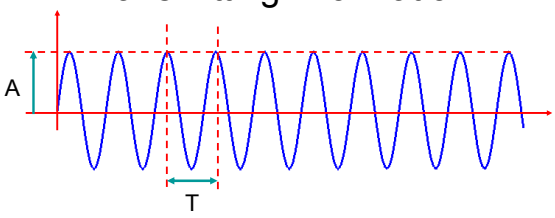
# The golden rule applies to electromagnetic waves

- the golden rule: $c = \lambda f$
  **speed = wavelength × frequency**
  applies to electromagnetic waves.
- the speed **c** is roughly 300,000,000 m/s
- for example, the wavelength of a 1 MHZ radio wave is:

  wavelength = speed/frequency

  = 300,~~000,000~~/1,~~000,000~~ = 300 meters

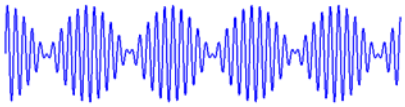
## Transmitting information




- a signal like the one above does not transmit any information – it just goes up and down, up and down
- both the amplitude (A) and the period (T) or frequency f = 1 / T never change

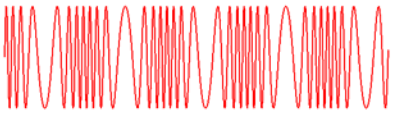
## Amplitude Modulation (AM)

- with AM the amplitude of the wave signal (carrier) is modulated (changed).
- the information is coded into the way that the amplitude is modulated

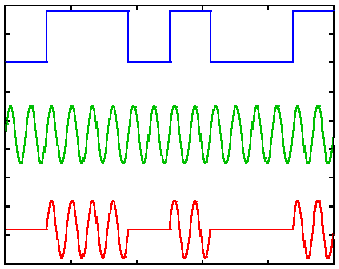


## Frequency modulation (FM)

- with FM signals the frequency of the signal is modulated
- information is coded into the way that the modulation frequency is varied

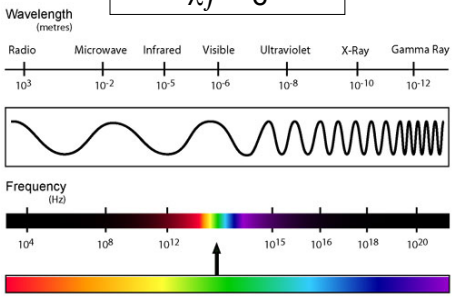


## FM



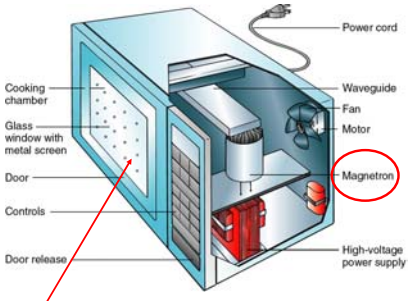
## Electromagnetic spectrum

$$\lambda f = c$$




## Microwaves

- are in the frequency range of a few billion Hz or wav… the sam…
- How…
- Rem… a posi…
- The… onto thes… a few billi…
- all th… making the water hotter and hotter.




the metal screen on the door allows you to see in but does not let the microwaves out

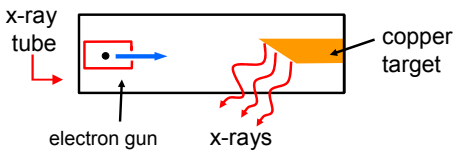
## No metal in the microwave!

- if you have ever accidentally left a fork in the microwave you know that you get a spectacular array of arcs inside.
- The microwaves can cause charges to build up on the sharp edges of the fork
- If enough charge builds up, an arc can occur
- The metal walls of the microwave are smooth and act to reflect the microwaves back into the food where they belong!

## X-RAYS

- x-rays are very short wavelength electromagnetic waves
- how short? 0.00000001 m = $10^{-8}$ m
- by contrast, a 100 MHZ radio wave has a wavelength of 3 meters
- x-rays and radio waves are both electromagnetic waves that differ only in wavelength and frequency

## How are x-rays produced?




- when electrons that have been accelerated through about 50,000 volts slam into a piece of copper, some of the electron energy is converted to x-rays
- x-rays are energetic enough to penetrate through soft tissue and thin metal foils