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
  - Hertz made the experimental discovery


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 per second.
- EM waves include radio, microwaves, x-rays, light waves, gamma rays

Electric and Magnetic Fields

- electric charges produce electric fields
- electric currents (moving charges) produce magnetic fields
- an electromagnetic wave is a pattern of electric and magnetic fields that vibrate together in space and time in a synchronous fashion

Electric Field       Magnetic Field

- 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

**Direction of Propagation**

E field

B field

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

- High Frequency Oscillator
- Dipole Antenna

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

**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

1 KHZ (kilohertz) = 1000 Hz
1 MHZ (megahertz) = 1,000,000 Hz
**Frequency 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. **MIR space station**: 145 megahertz and 437 megahertz
9. **Cell phones**: 824 to 1500 megahertz
10. **Air traffic control radar**: 960 to 1,215 megahertz
11. **Global Positioning System**: 1,227 and 1,575 megahertz

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**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.

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**Detecting (receiving) the Wave**

- The golden rule: 
  \[ c = \lambda \times f \]
  
  - Speed = Wavelength \times 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:
    \[ \text{wavelength} = \frac{\text{speed}}{\text{frequency}} = \frac{300,000,000}{1,000,000} = 300 \text{ meters} \]
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

Electromagnetic spectrum

\[ \lambda f = c \]

Microwaves

- are in the frequency range of a few billion Hz or wavelengths of about several cm (about the same range as radar, the "Radarange"
- How do microwaves heat water?
- Remember that the water molecule has a positive end and a negative end.
- The electric field of the microwave grabs onto these charges and shakes them violently a few billion times each second
- all this shaking energizes the molecules making the water hotter and hotter.
No metal in the microwave!

- If you have ever accidently 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? \(0.00000001 \text{ m} = 10^{-8} \text{ m}\)
- 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.