Communications Electronics

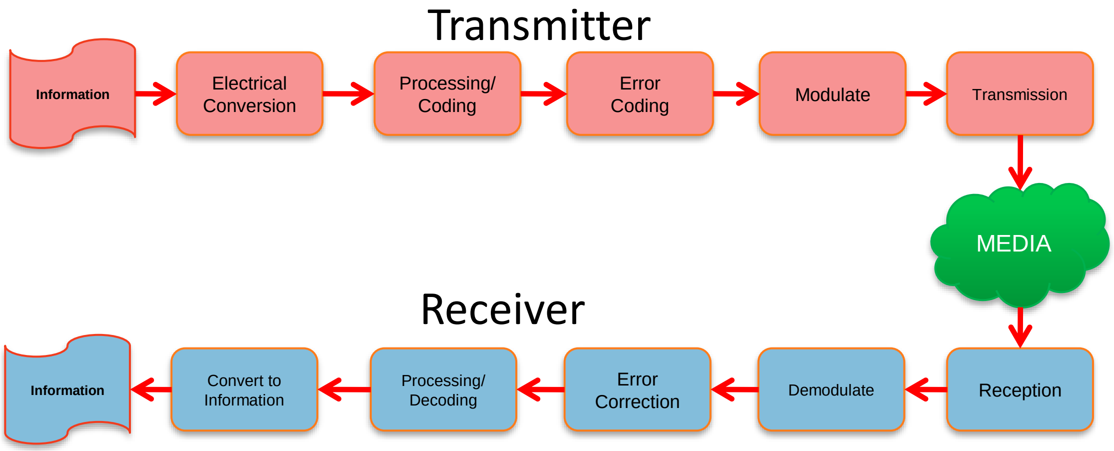
Electromagnetic Waves
The Electromagnetic Spectrum
&
Bandwidth

Today's Objectives

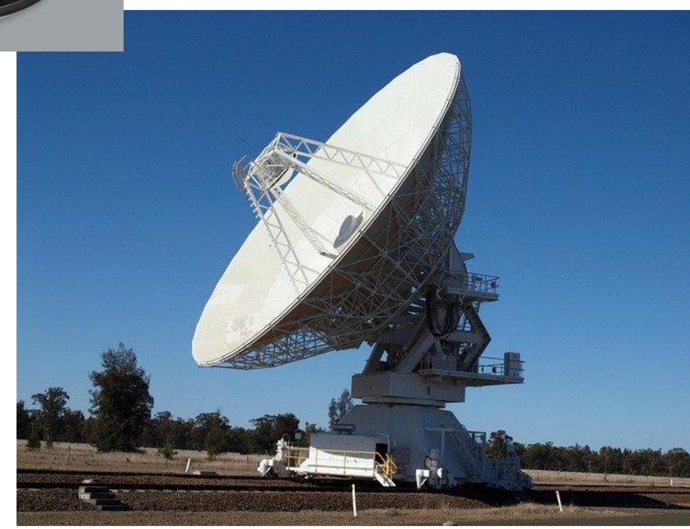
- Describe why an RF carrier signal is needed to transmit over a media channel
- Compute the frequency from wavelength and the wavelength from frequency in free space
- Compute the time that it takes for a signal in free space to go a specified distance

Purpose of Communications Systems

- Transfer information from one point to another
- System fundamentally consist of three elements
  - Transmitter, Receiver and a Channel



Communications Systems Examples



https://store.google.com/us/product/nest_learning_thermostat_3rd_gen?hl=en-US

Image by becuffin from Pixabay

https://www.linksys.com/us/c/wireless-routers/

Modulation Process

- The information signal cannot be transmitted directly
  - Too low of a frequency (e.g. voice signal 20 – 3000 Hz)
  - Requires too long of an antenna
  - Requires a great deal of power to transmit

- Modulation process takes the information and puts onto a “carrier” signal that is more easily transmitted

Why do I need a Carrier? A Snail Mail Example

- I want to tell my brother about some good news
- I put the information in a letter that I write and put it in an envelope
- I could get in the car and drive it to the destination but that is not efficient and costly
- I give the letter to the mail “carrier”
- The letter gets delivered efficiently (along with other mail, mostly junk) to my brother’s house.
- He opens the letter and reads the good news that I want to convey
    - “Happy Birthday”!

Why do I need a Carrier? A Snail Mail Example

- The “good news” is the information that I want to send
- Writing the letter and putting in an envelope and giving it to the mail person is like modulating the signal onto the carrier at the transmitter
- The massive postal system is like the “channel”
- Receiving the letter, opening the envelope and reading is like a receiver and demodulation

Why do I need a Carrier?

- If I wanted to transmit an electrical signal with audio (20 to 3000 Hz) it would require an antenna 100's to 1000's of miles long
  - And *lots* of power

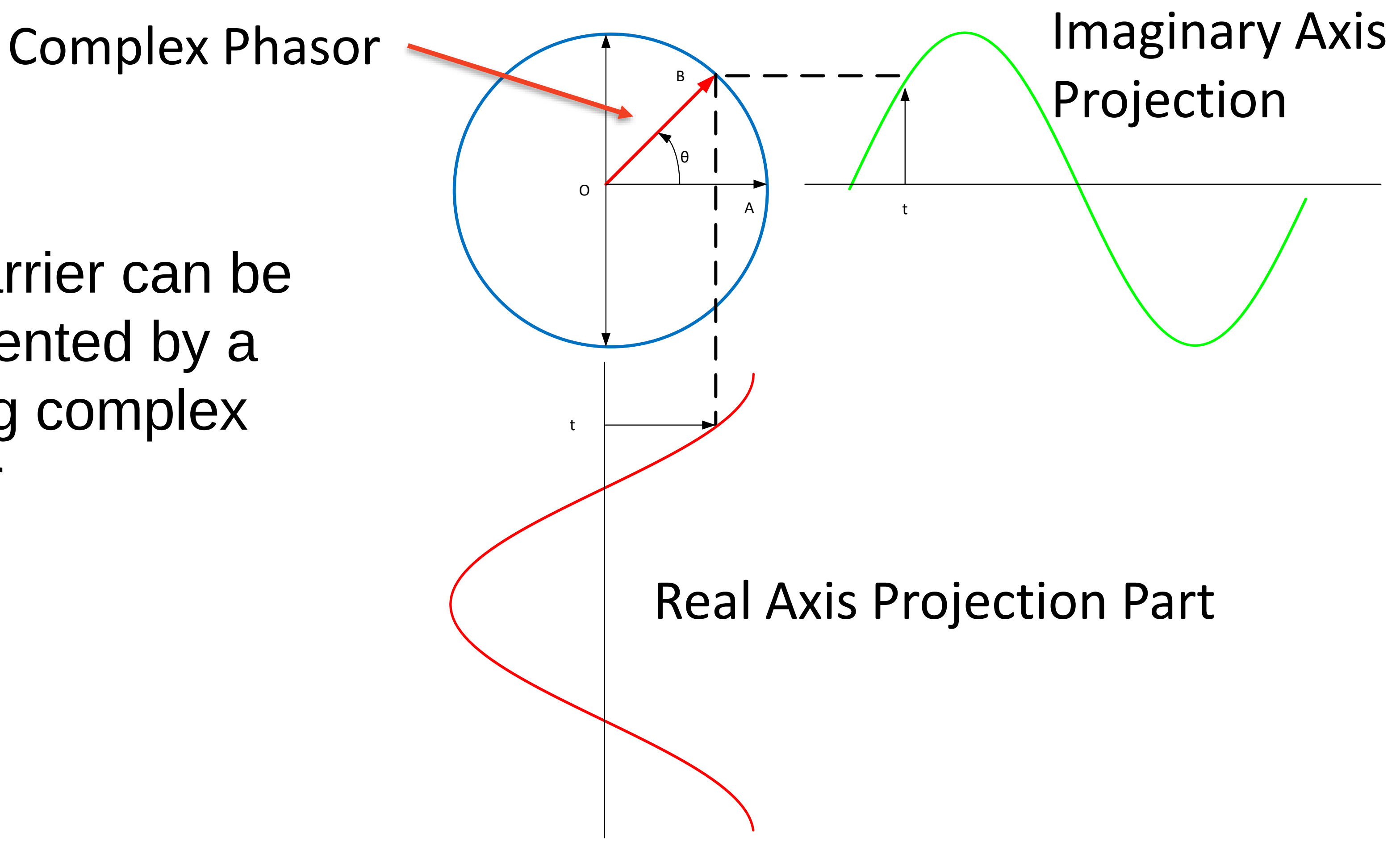
- Higher frequency signals travel (propagate) better
  - Require shorter length antennas

Example Carrier Signals?

- A carrier is a sinusoidal signal at a frequency higher than the information signal

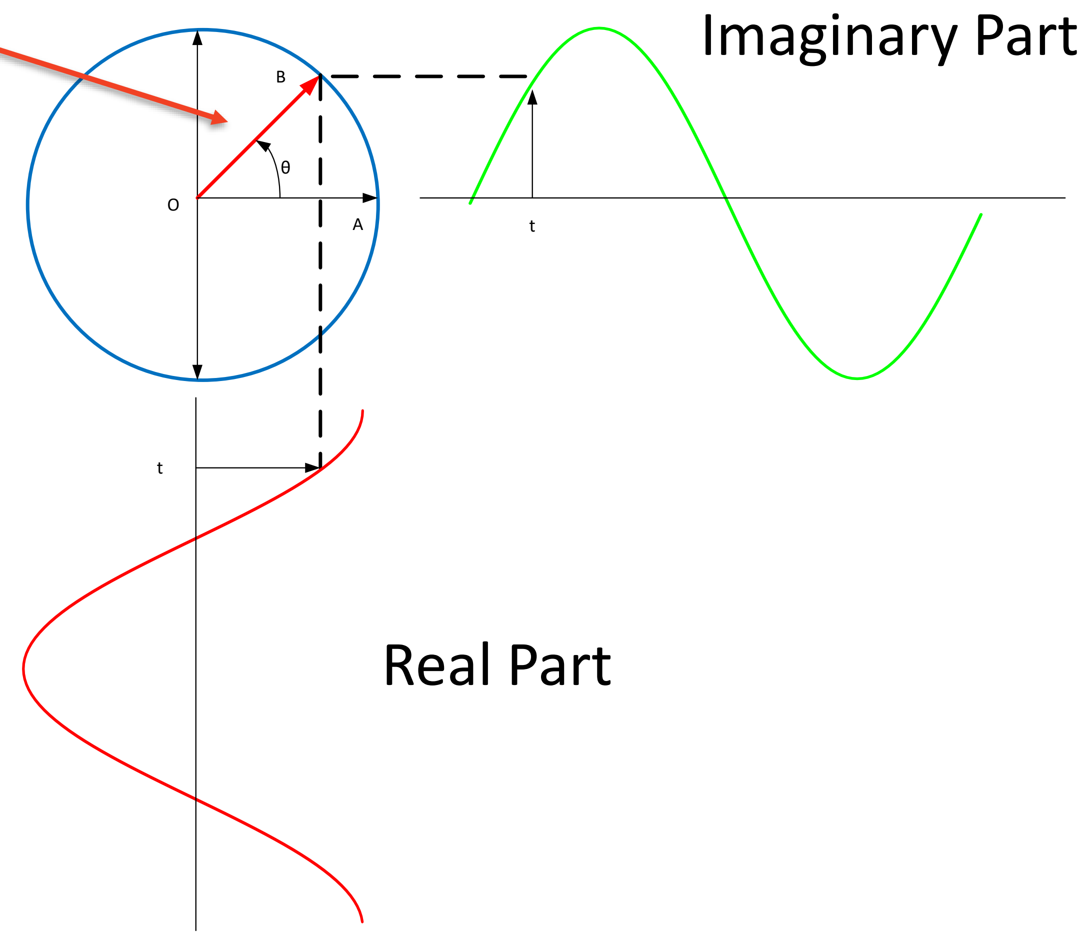
- Example Carrier signals
  - WITR FM Broadcast at 89.1 MHz
  - 5G WiFi transmissions at 5.180 GHz
  - BBC World Service at 1323 kHz
  - GPS at 1575.42 MHz
  - Monroe County Sheriff Dispatch – 460.750 MHz
  - Bluetooth -- ~2.480 GHz

What is a Carrier Signal?



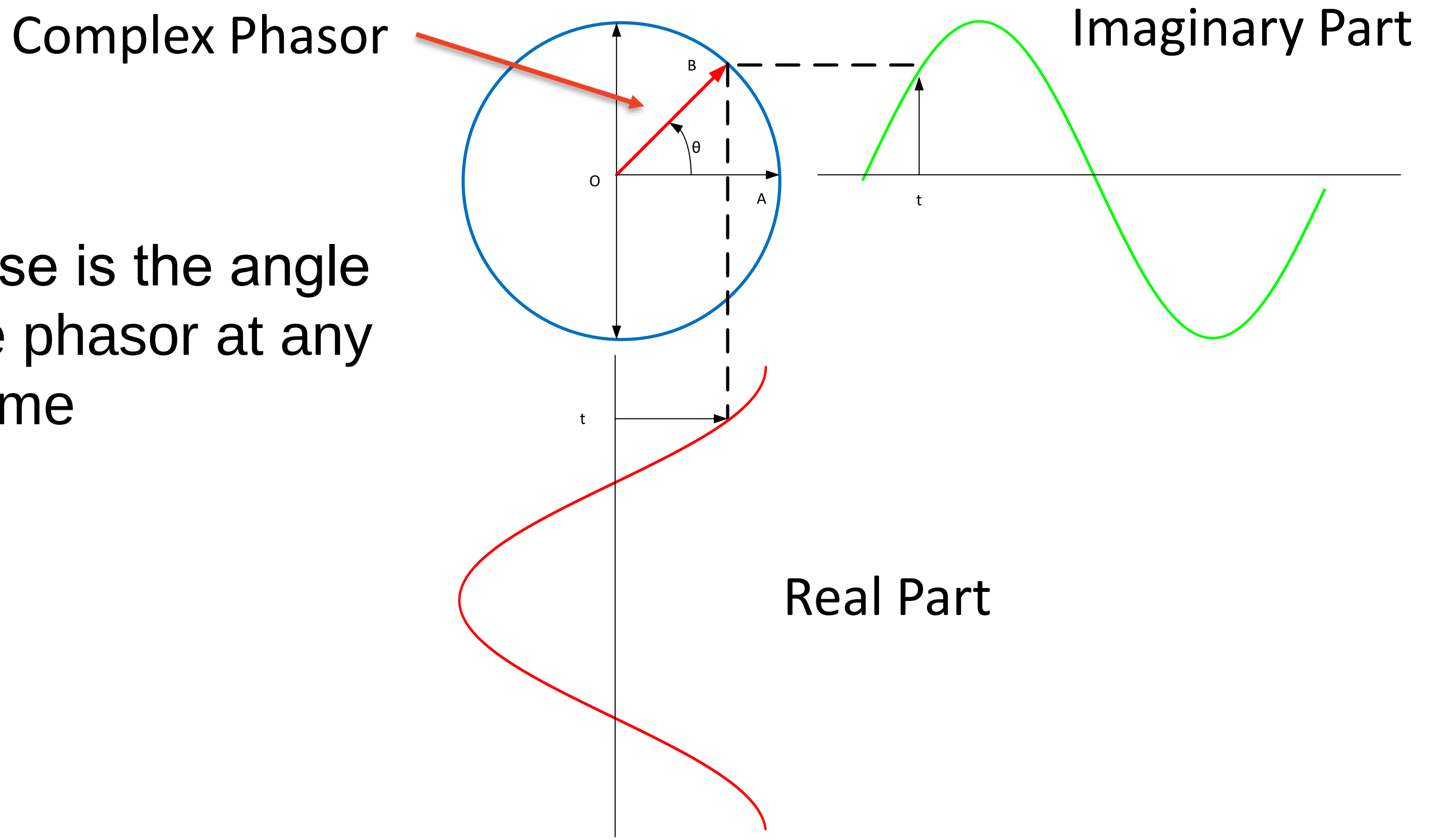
- The carrier can be represented by a rotating complex phasor

What is a Carrier Signal?



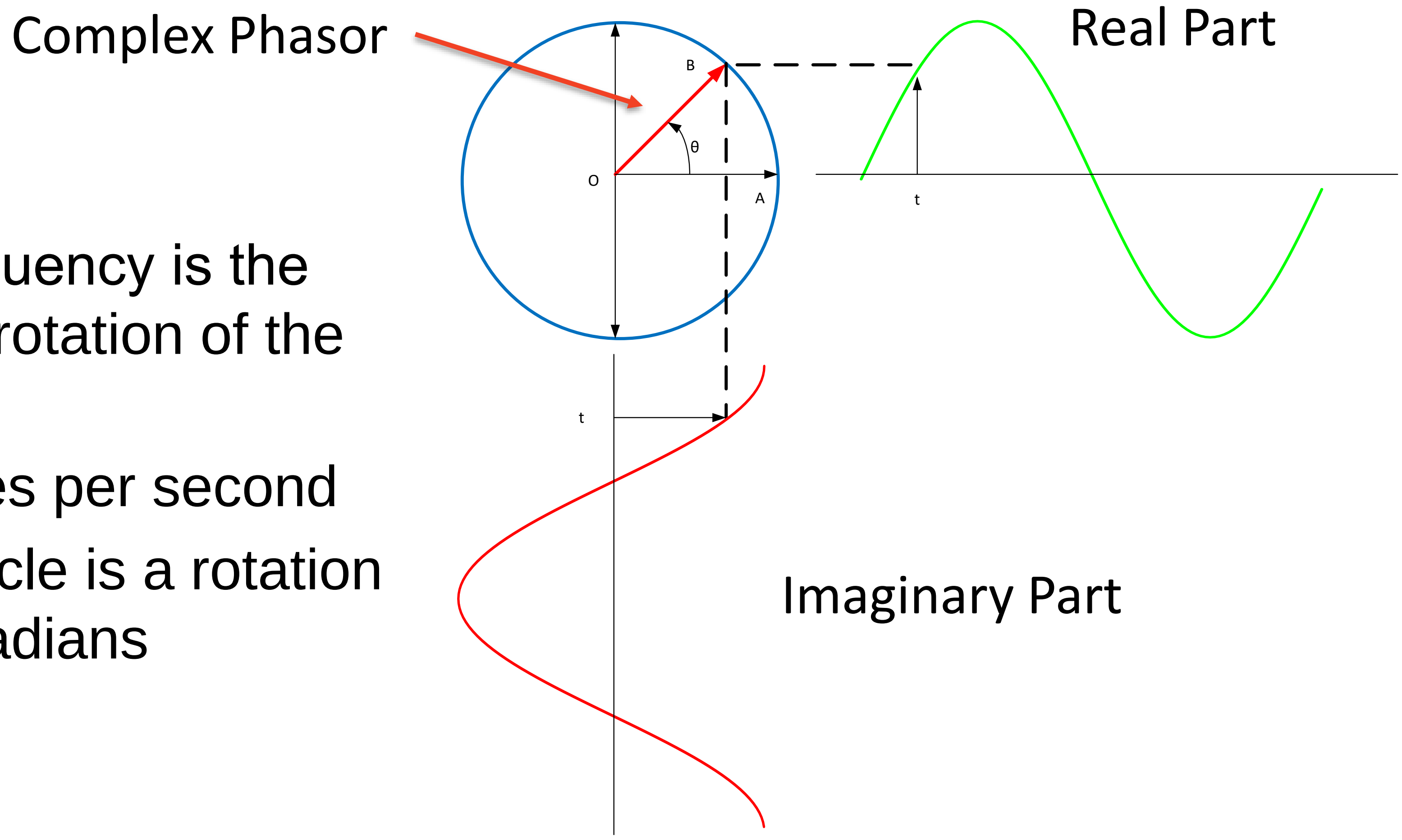
- It's magnitude is the magnitude of the phasor
- Peak Magnitude of the real and imaginary parts

What is a Carrier Signal?



- It's phase is the angle θ of the phasor at any given time

What is a Carrier Signal?



- It's frequency is the rate of rotation of the phasor
- In cycles per second
- One cycle is a rotation of 2π radians

What Properties Can We Change / Modulate?

- The carrier by itself contains no information

- Modify the magnitude (Amplitude modulation)
- Modify the phase (Phase/Angle modulation)
- Modify the frequency (Frequency modulation)

- Can also modify a combination of these (Phase and amplitude or QAM modulation)

Characteristics of Modulation

- Mathematically represent the carrier with time varying components, both phase and magnitude

Let $\theta(t)$ be the time varying phase

- The time varying signal can be written as a complex exponential

$$v(t) = V_p(t)e^{j\theta(t)}$$ Time varying magnitude and phase

Expanding the exponential (euler's)

$$v(t) = V_p(t)cos(\ \theta(t)\ ) + jV_p(t)sin(\ \theta(t)\ )$$

Characteristics of Modulation

- The complex signal is conceptual. Let's consider just the real part

$$v(t) = V_p(t)cos(\,\theta(t)\,) + jV_p(t)sin(\,\theta(t)\,)$$

$$v_r(t) = V_p(t)cos(\,\theta(t)\,)$$

- If the phase term is linear in time, then the frequency is constant

$$\theta(t) = \omega t + \phi = \ 2\pi f t + \phi$$

$$v_r(t) = V_p(\mathrm{t})\cos(2\pi f t + \phi)$$

ω is angular velocity ${}^{rad}/_{sec}$

f is frequency in cycles/sec

ϕ is a fixed phase term

Characteristics of Modulation

- Remember the only characteristics of the carrier that can be modulated (changed) are:
  - Amplitude
  - Frequency
  - Phase

- No matter how complex the modulation scheme may be these characteristics are what are being changed

How Does the Carrier Propagate? Electromagnetic Waves

- An electromagnetic wave consists of:
  - A time-varying electric field and a time-varying magnetic field
- Both fields vary sinusoidally
  - Their field intensities vary sinusoidally out of phase with one another
- Energy travels or propagates in electromagnetic waves

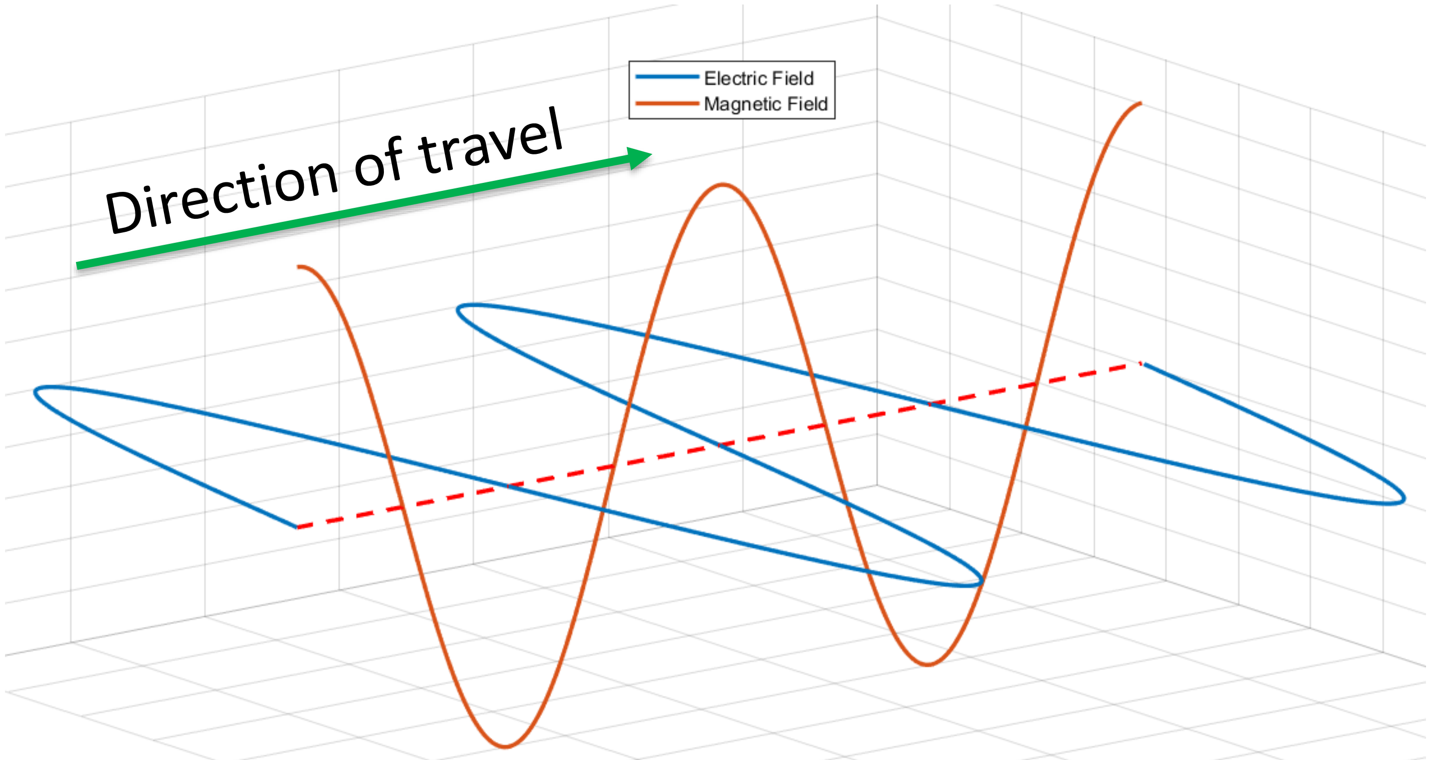
How does the Signal Travel?

- A current in a conductor creates a magnetic field
- A voltage potential creates an electric field

- Current flow and electric fields on a transducer (like an antenna) give rise to electric and magnetic fields
- This results in electromagnetic waves that propagate in free space

Electromagnetic Waves

- Electric and Magnetic fields vary out of phase with one another and are at right angles



21

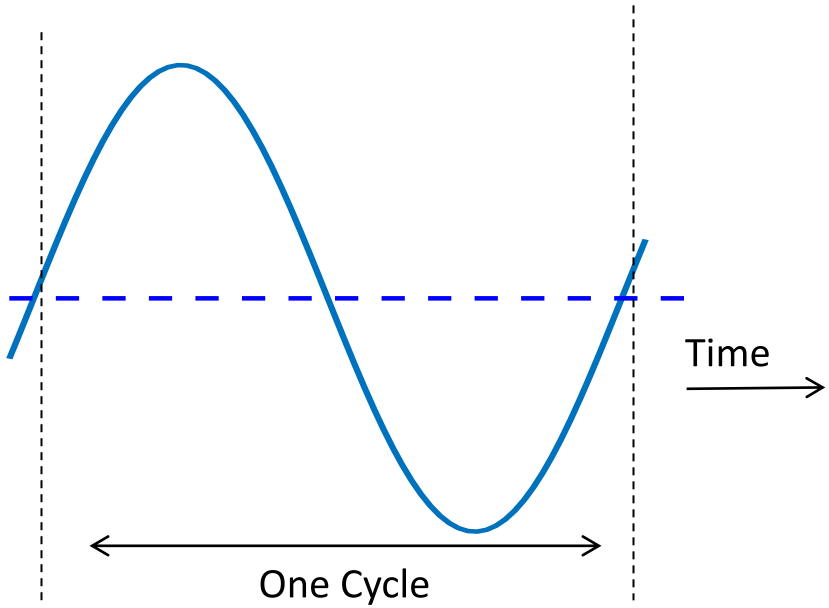
Electromagnetic Waves

- At the transmitter currents in the antenna create electromagnetic waves that are radiated into free space

- At the receiver electromagnetic waves arriving at the antenna induce currents in the antenna that are applied to the receiver input

Electromagnetic Wave Frequency and Wavelength

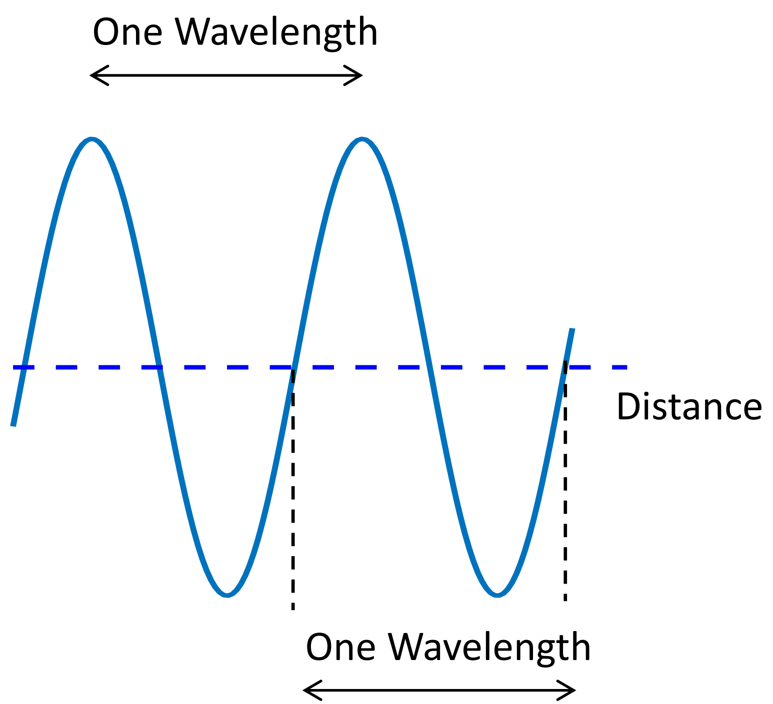
- The frequency of variation is measured in cycles per second
  - Cycles per Second – Hertz
  - Named for Heinrich Hertz



23

Electromagnetic Wave Frequency and Wavelength

- The distance traveled in the time of one cycle is called one wavelength



The Speed of an Electromagnetic Wave

- In Free Space an electromagnetic wave travels at the speed of light, c.

$$c = 3x10^8 \; meters/sec$$

$$c = 186{,}000 \; miles/sec$$

- The wavelength is represented by the Greek letter λ.
- In other media they may travel slower
  - Coax cable for example ~66% of the speed in free space

The Wavelength of an Electromagnetic Wave

- If the frequency of the wave is f then:

$$\lambda = c/f$$

For example: WITR broadcasts at a frequency of 89.7 MHz. The wavelength of its transmissions is:

$$\lambda = \frac{3x10^8\ m/sec}{89.7x10^6\ cycles/sec} = 3.345\ meters$$

Travel Time

- How long does it take for a radio wave to travel from Rochester to Buffalo??

- What would you guess?

Example – Travel Time

- The distance from Rochester to Buffalo "as the crow flies" is 67 miles or 107.8 kM

- In free space an electromagnetic wave travels $v = 3 \times 10^8\, m/sec$ the speed of light

$$t = \frac{d}{v} = \frac{107.8 \times 10^3 m}{3 \times 10^8\ m/sec} = 359.3\mu Sec$$

28

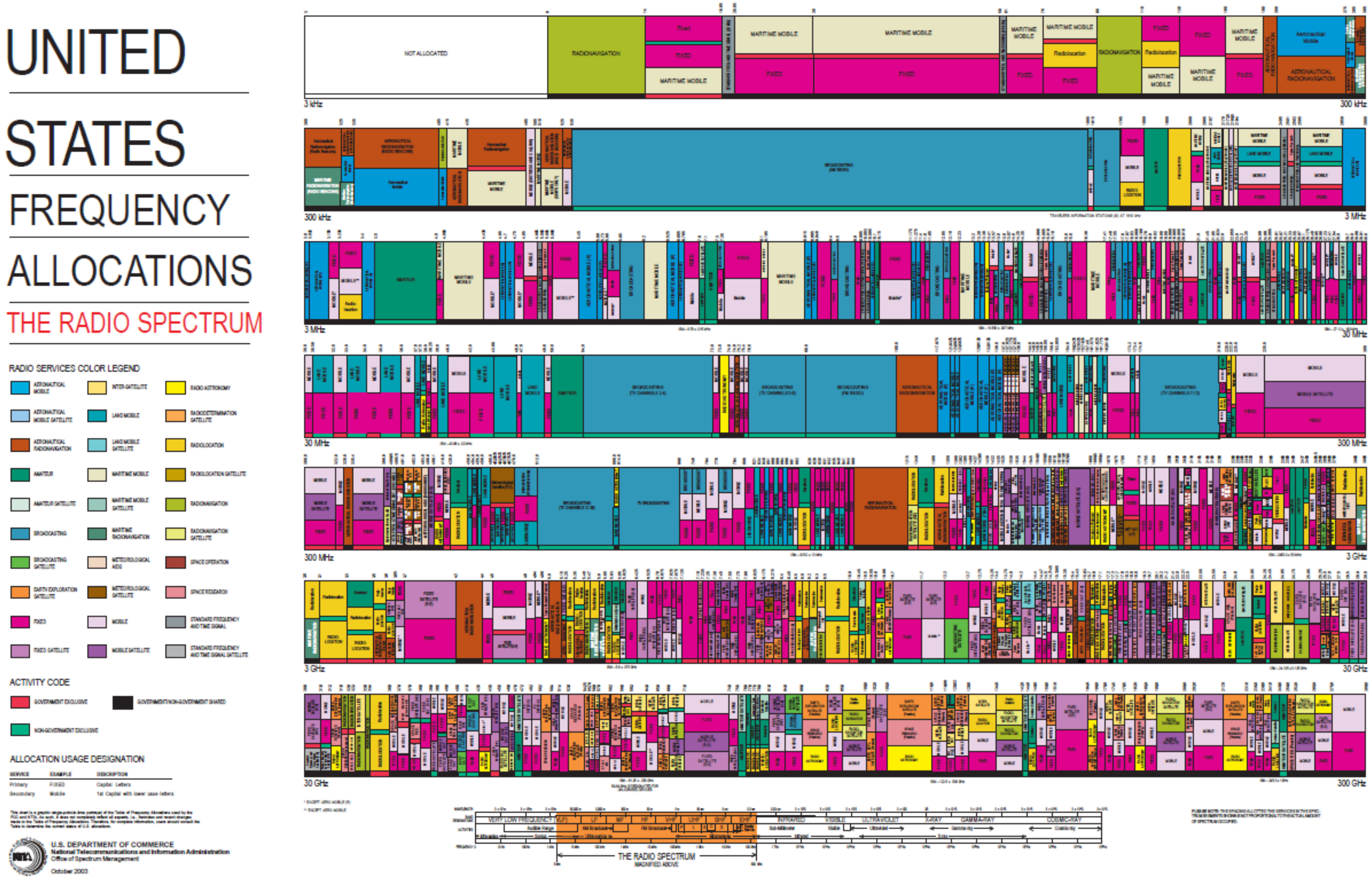
Frequency Spectrum and Uses

- Sound Waves
  - Subsonic <25 Hz
  - Audio 5-20 kHz
  - Ultrasound >20 kHz
- Electromagnetic Waves
  - ELF 30-3 kHz Sub communications
  - VLF 3k-30 kHz Sub Comms, Geolocation
  - LF 30k-300 kHz LORAN, Broadcasting
  - MF 300k-3 MHz AM Radio
  - HF 3M-30 MHz Long distance commuinications
  - VHF 30M-300 MHz FM, TV, Line of sight
  - UHF 300M-3 GHz TV, Cordless Phone, Satellite, Cellular, Bluetooth

Frequency Spectrum and Uses

- Electromagnetic Waves (cont.)
  - SHF 3G-30 GHz WLAN, Radar
  - EHF 30 GHz - 300 GHz Satellite Comms
  - IR 0.3T-300 THz TV remotes, short range
  - Visible 0.3P-3 PHz
  - UV 3P-30 PHz
  - X-Ray 30P-300 PHz
  - Gamma Ray 0.3E-3 EHz (exa)
  - Cosmic Ray >3 EHz

US Frequency Allocations



Source: http://www.ntia.doc.gov/osmhome/allochrt.html