Technician Licensing Class Introduction

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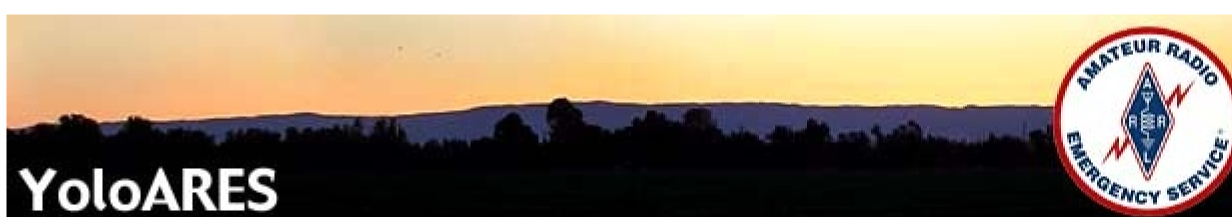
Special thanks to K3DIO

The Plano Amateur Radio Klub (TX)

Some of this material comes from them



Radio Waves

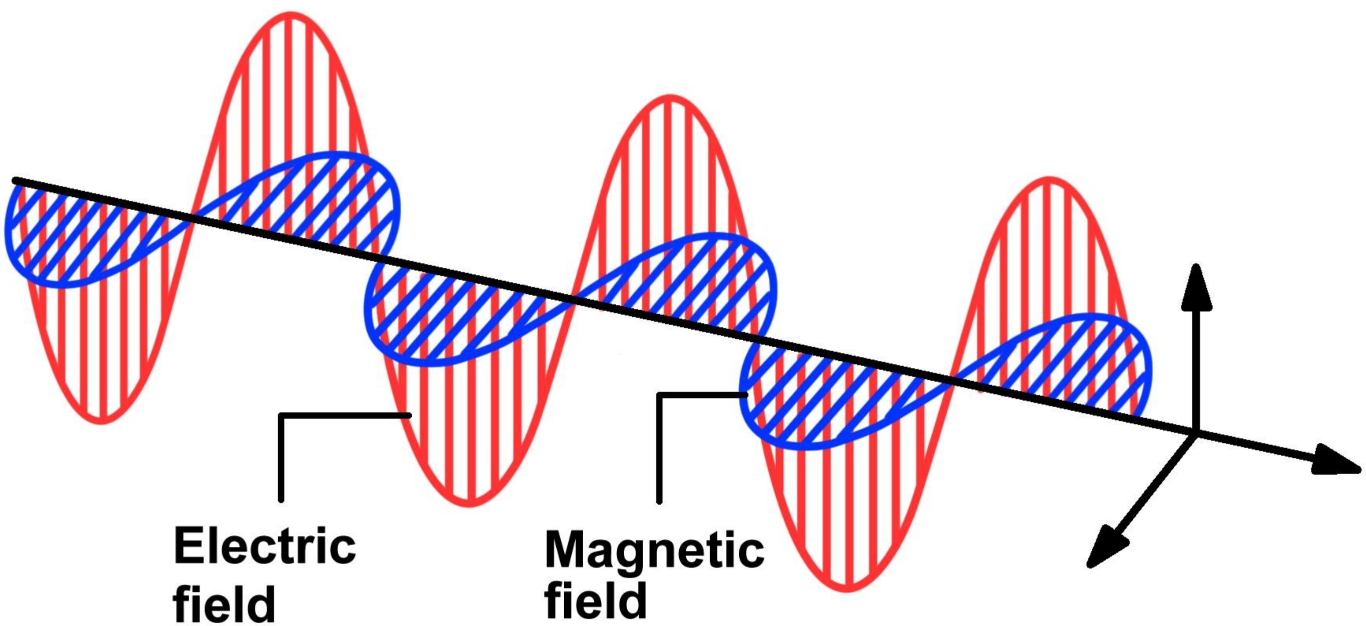
- Electromagnetic Waves
- Frequency
- Polarization
- Antennas
- Feedlines
- Standing Wave Ratios

Electromagnetic (EM) Waves

- Types
  - Light
  - Radio Waves
  - X-Rays
  - etc
- Speed
  - Light is a type of radio wave
  - Radio waves travel at the speed of light
    - True speed of light in **"free space**"
    - Slower through materials, including air
  - Radio waves are waves greater than 20 kHz

Electromagnetic (EM) Waves

- Contain two elements
  - At Right angles from each other
  - An electric component
  - A magnetic component

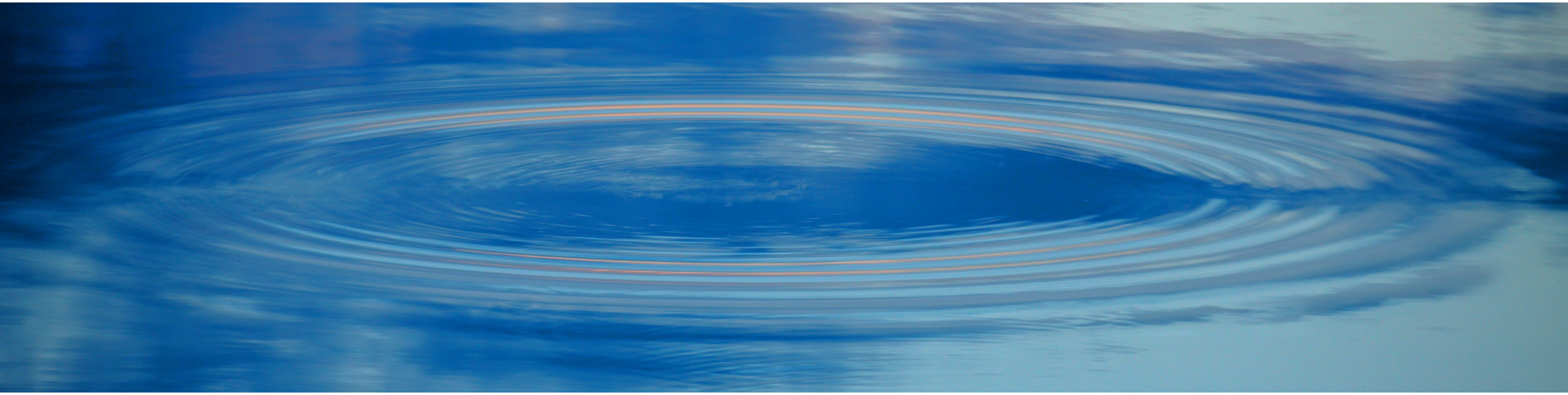


Radio Waves vs Water

- Water waves and ripples
  - Ripple out from the center
  - Loose energy as they travel further
  - Loose energy as they spread out
  - Travel in 2 dimensions
- Radio waves
  - Ripple out from the transmitter
  - Loose energy as they travel further
  - Loose energy as they spread out
  - Travel in 3 dimensions

Waves

- Can vary in size ("**Amplitude**")
  - How tall?
- Can vary in frequency
  - How many waves pass per second?
  - Related to distance between the peaks

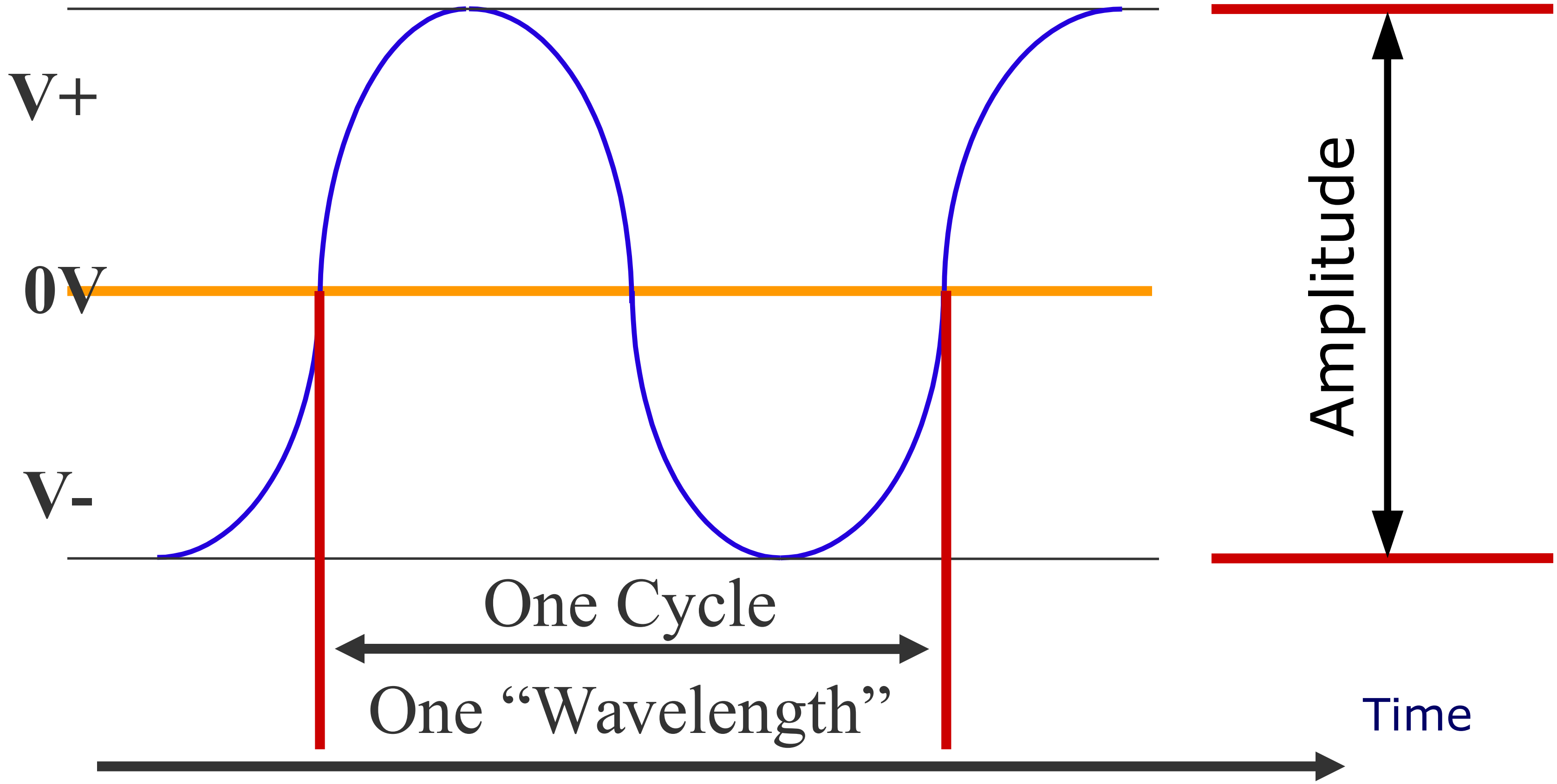


Bigger Waves

Wavelength and Frequency

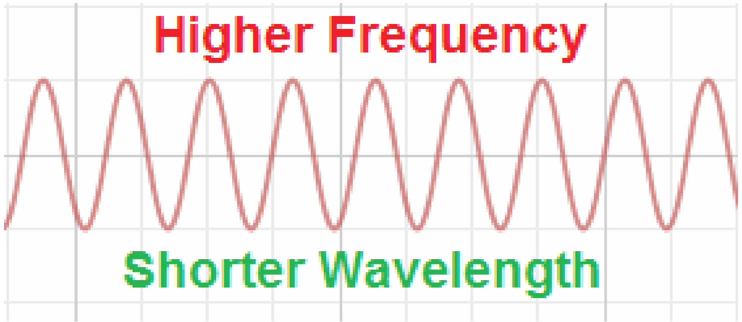
(Diagram is only in 1 dimension!)

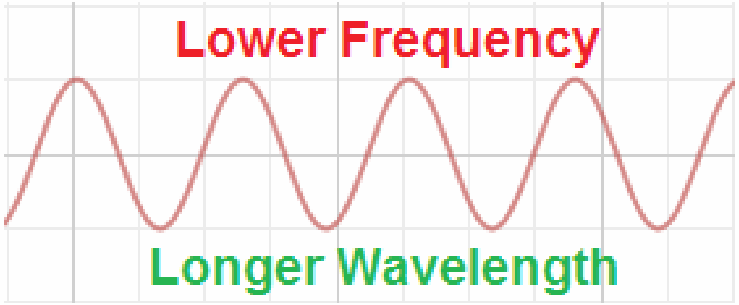
The distance a radio wave travels in one cycle is called wavelength.



Frequency Vs Wavelength

- Frequency goes up:
  - Wavelengths get shorter
- Frequency goes down:
  - Wavelength gets longer





Radio "Wave" Properties

- Radio Frequency – "**RF**"
- Frequency is measured in Hertz ("Hz")
  - The number of "cycles per second"
  - How many times does a peak reach you?
- Example:
  - 5 Hz = The peak gets to you 5 times in 1s
  - Or the trough, or the middle, or...
    - (some reference point)

Radio “Wave” Math

- Symbols
  - F: Frequency
  - S: Distance (It's a physics thing)
- Equations
  - F is always in MHz for these
    - (the **300,000,000 m/s is the speed of light**)
  - Frequency (MHz) = 300 / wavelength (m)
  - F = 300/S
  - Wavelength (m) = 300 / frequency (MHz)
  - **S = 300/F**

Your Turn!   F = 300 / S

- What is the frequency for:
  - 2m national calling: 2.0475 m
  - 70cm national calling: 0.672645 m
  - 6m calling frequency: 5.98503 m
- What is the wavelength of:
  - 802.11 channel: 5240 MHz
  - KXJZ FM: 90.9 MHz
  - KFBK : 1.530 MHz

Frequency Bands

- Radio waves are groups in bands
  (memorize these)
  - HF: 3 - 30 MHz
  - VHF: 30 - 300 MHz
  - UHF: 300 - 3000 MHz

Ham Radio Bands

- Are identified by both frequency and **approximate wavelength**
  - 2m band ~147 MHz
    - Bottom: 144 MHz = 2.083333 m
    - Top: 148 MHz = 2.027027 m
  - 6m band ~50 MHz
  - 160m band ~1.875 MHz
- Note the inverse relationship!
  - One goes up, the other goes down
  - (Guess what's gonna happen to antenna sizes!)

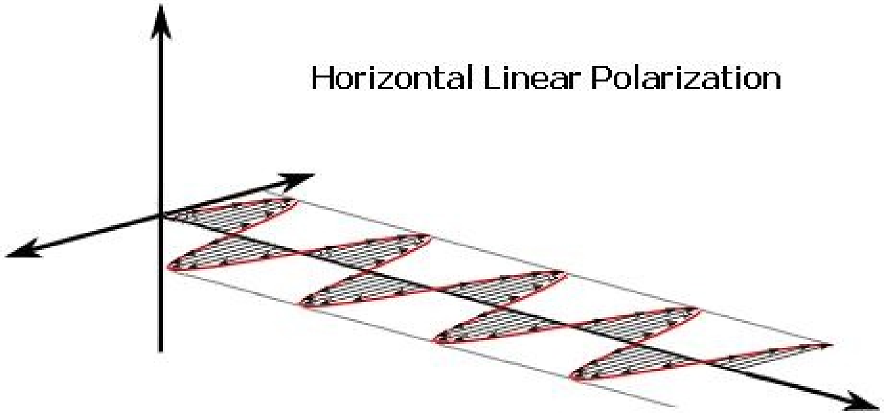
Sound Waves

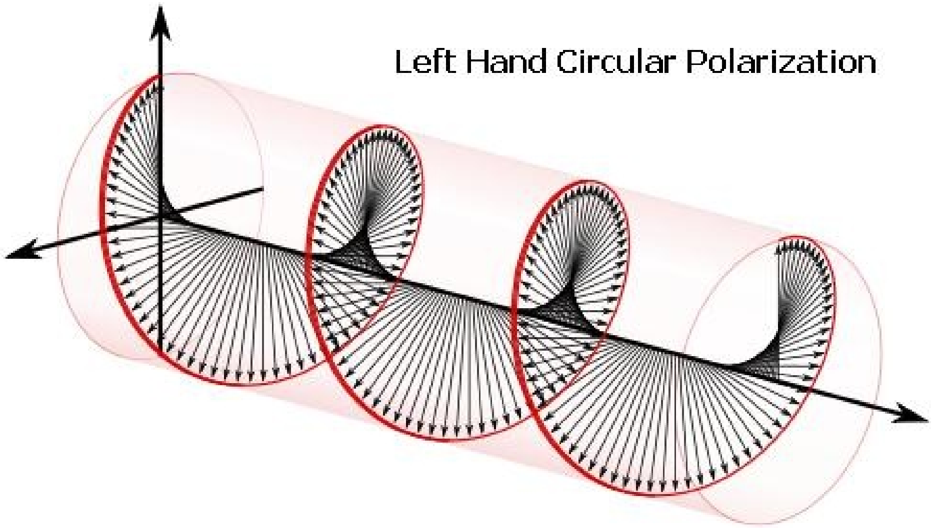
- Sound Waves
  - You hear air being pushed back and forth
  - Atoms bump against each other
  - Causes vibrations in your ear
  - Guess what: the waves have a frequency
- Human hearing: 300 Hz – 3000 Hz
- Electronics convert signals to sound
  - Receivers: receive radio waves, convert them to electricity
  - Speakers: convert electric to sound waves

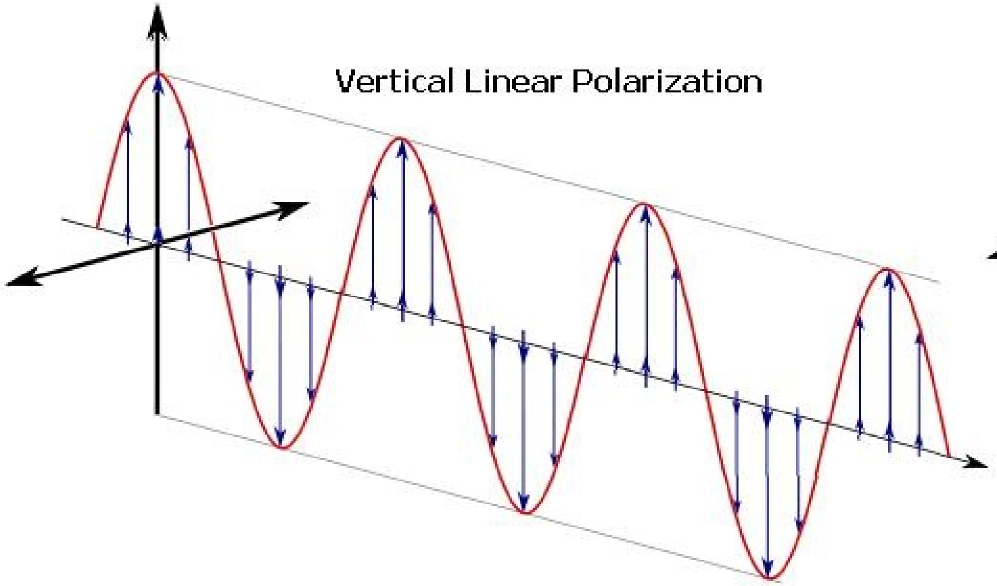
EM Waves - Polarization

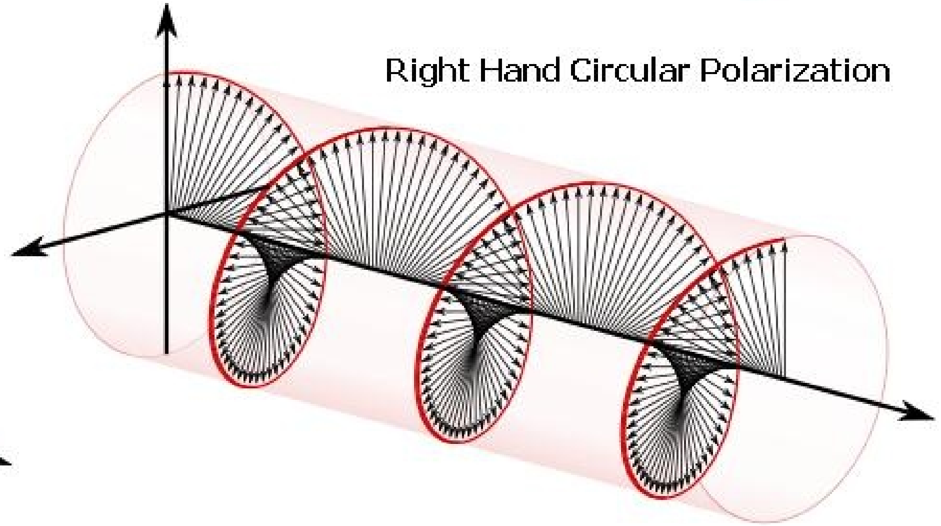
- We think primarily of the electric wave
- It is frequently “Polarized”
  - It moves up and down in one plane
- Polarization Types
  - Horizontal Side-to-side
  - Vertical Up-and-Down
  - Circular Rotates around

EM Waves - Polarization









Polarization Notes

- Repeaters
  - Almost always have vertical antennas
  - Are, thus, vertically polarized
- Horizontal polarization is better:
  - For long distance VHF/UHF
  - For **weak-signal** and **CW** work
- If transceiver and receiver are opposite:
  - **Signals could be significantly weaker**
  - ~20db drop at VHF
  - Hold your HT antenna upright!

How do we create EM waves?

- Move electricity!
  - Electromagic waves are created anytime electricity flows through something
  - Move them at the frequency you want
    - Think of pulsing electrons moving in and out
  - Powerlines are very noisy!
- Bigger, better transmissions
  - Move electricity into an antenna
  - Wires are designed to move electricity
  - Antennas are designed to radiate EM
    - (we'll see that you can make a wire antenna)

Antenna Basics

- Antenna theory is quite complex
- Usually have at least
  - One driven element – where the juice goes
  - One matching ground element
    - EM radiating from an antenna needs a return path to ground
- Usually built in wavelength fractions
  - 1/2-wave dipole
  - 1/4-wave vertical
  - **Frequency goes up: antennas get short**

Simple Antenna Math

- Recall: $S(m) = 300 / F(MHz)$
- 1/2 wave dipole length for 146.520?
  - $S = 300 / 146.520 / 2$: 1.0238m
- The U.S. books frequently use inches
  - 1m ~ 39.37 inches
  - 1.0238m = 40.3in
- Rewriting for inches
  - $S(m) = 39.37 * S(in) = 300 / F(MHz)$
  - $S(in) = 11811 / F(MHz)$

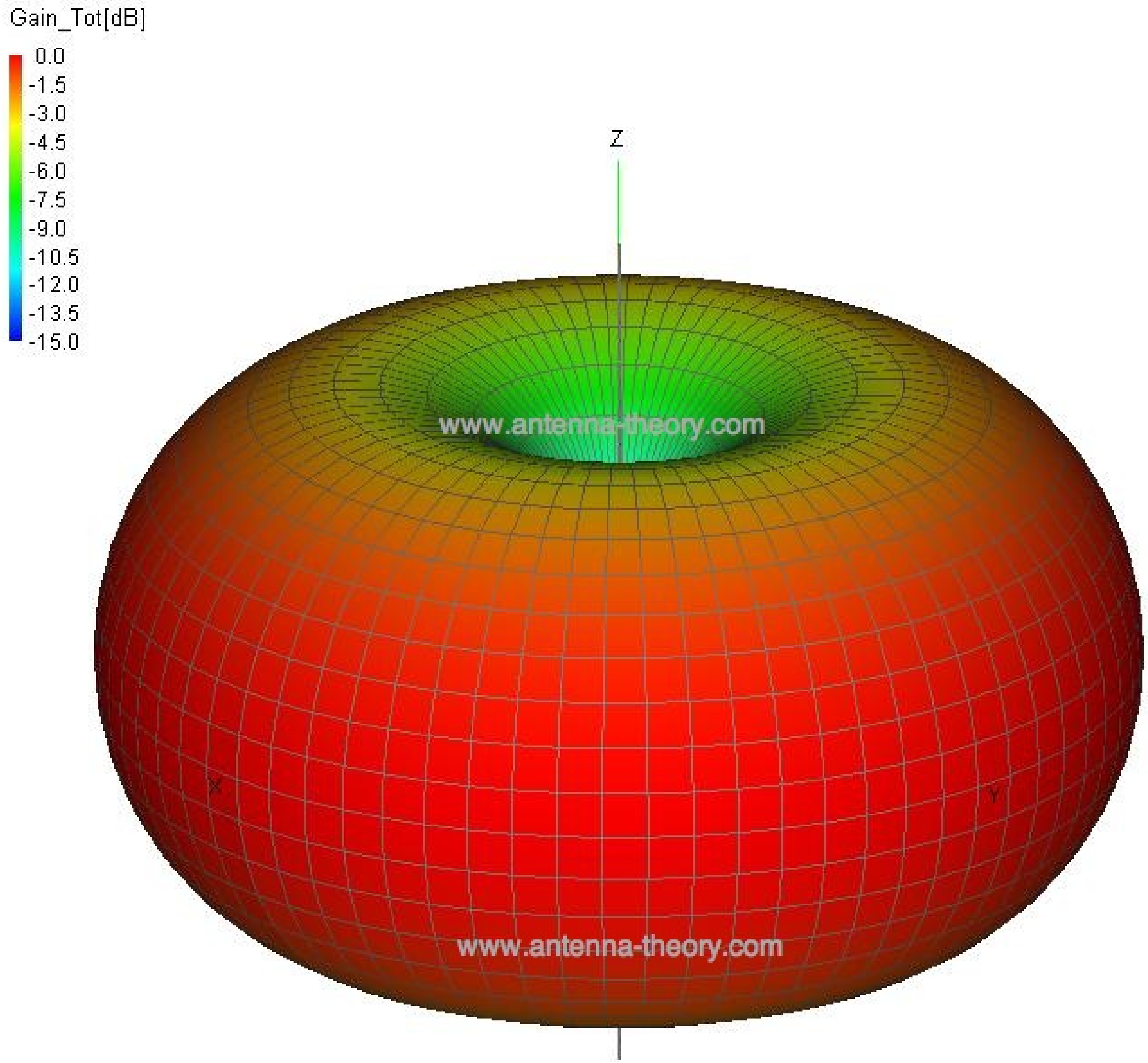
Antenna Math Test Questions

- Equations
  - S(m) = 300 / F(MHz)
  - S(in) = 11811 / F(MHz)
  - 1m = 39.37in
- What is the approximate length, in inches, of a quarter-wavelength vertical antenna for 146 MHz?
- What is the approximate length, in inches, of a 6 meter 1/2-wavelength wire dipole antenna?

Antenna Radiation Patterns

- A perfect reference antenna
  - Would radiate in a perfect sphere
  - Strength in each direction would be equal
- Real antennas
  - Are never perfect in the first place
  - Are usually designed to radiate stronger
    - Stronger signals in some directions
    - Which means weaker in opposite directions
    - The net result must be the same!
- **Gain: increase in signal strength in a direction compared to a reference**

Vertical Antenna Pattern



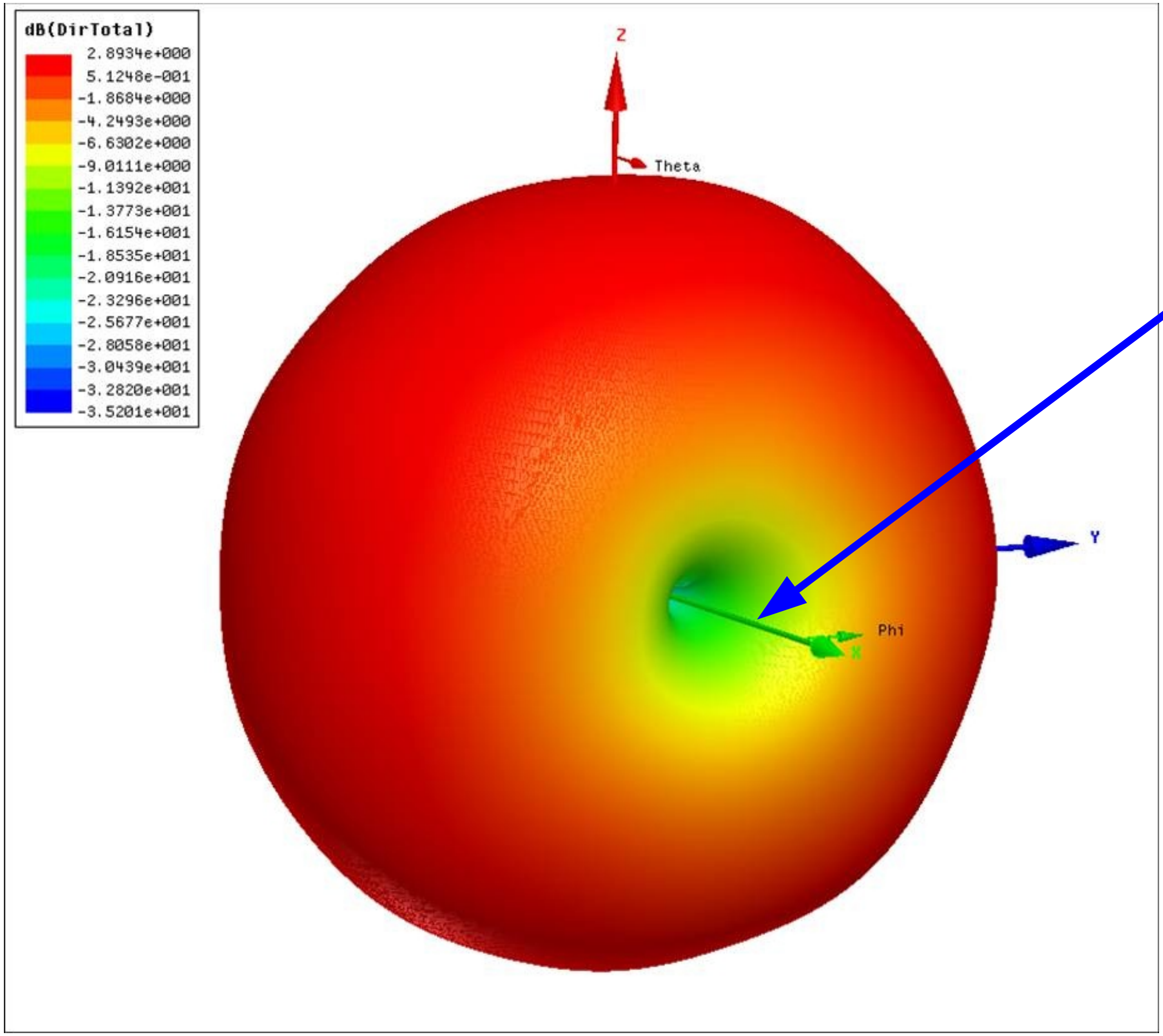
The Simplest Antenna: the Dipole

- “half-wave” dipole antennas
  - Two wires running opposite to each other
  - At just the right length for the frequency
    - 1/4 of the transmission wavelength each

3 “Fanned” Attic Dipoles – WA6MM

160m Dipole (from W1TR)

Dipole Radiation Pattern



The green line is the antenna

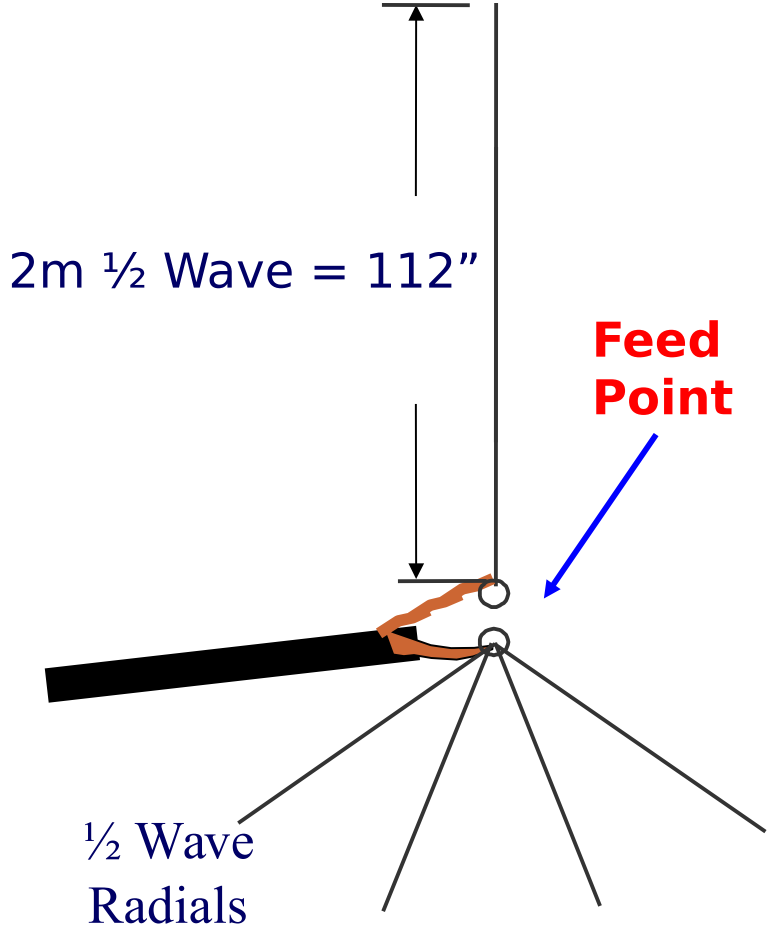
Note: Radiation from a dipole is perpendicular to the wire! (**broadside to the antenna)**

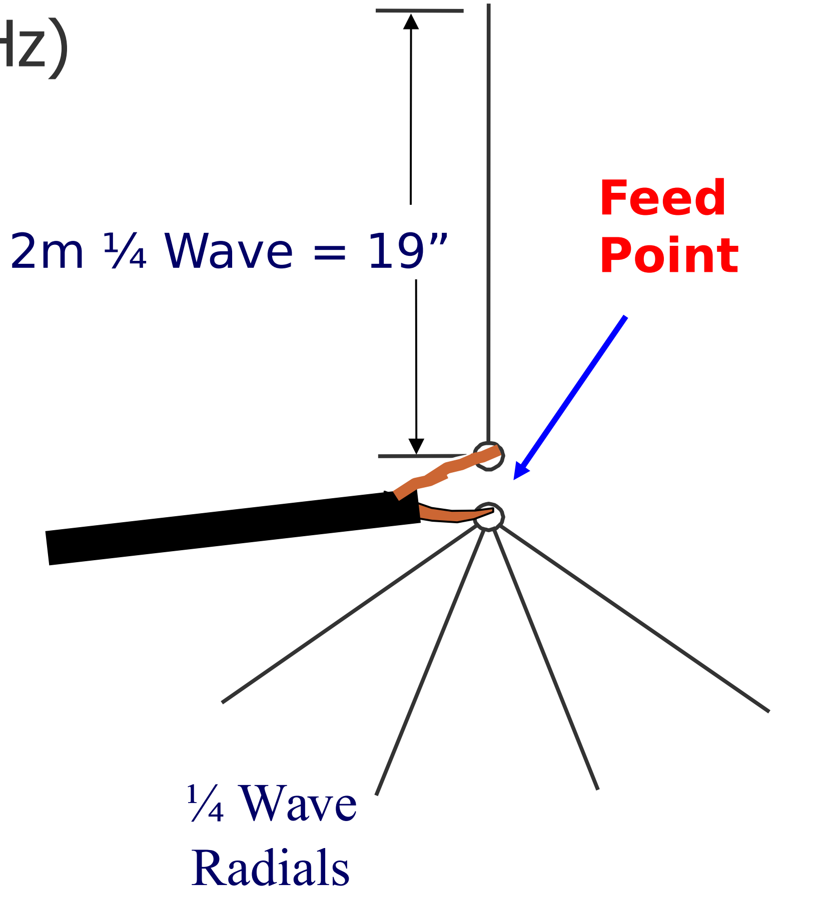
Vertical Antennas

- Also are in multiples of 1/4-waves
  - 1/4-waves are common
  - 1/8-waves are used too
  - For 6m, 2m, 440, etc
    - Longer antennas are easier
    - $5/8^{th}$ wave antennas
    - 1 & 1/4 antennas

Vertical Antennas

$$\text{Length of vertical in feet} = \frac{234}{f\ (\text{MHz})}$$





Antenna Characterstics

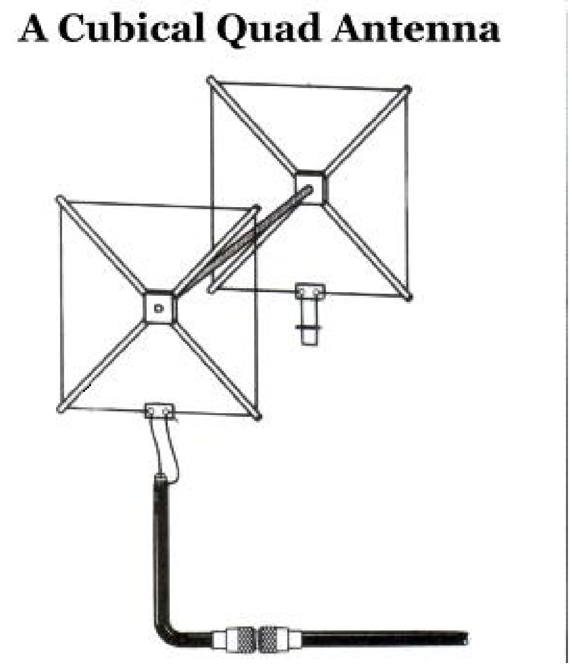
- Vertical antennas produce vertical polarized electric signals
  - **Right angles to the earth**'s surface
- Hand-held's "**rubber duck**" antennas
  - A vertical antenna
  - They're inefficient – **not full sized**
  - **Inside a car** their signal can bounce around and will be **10-20 times weaker**

Antenna Characterstics

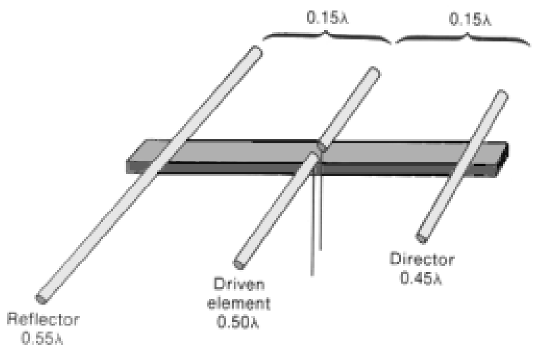
- Can do both horizontal and vertical:
  - Dipoles
  - Yagis
  - Quads
- (depends on how they're mounted)

Directional or “**Beam**” Antennas

- Quads

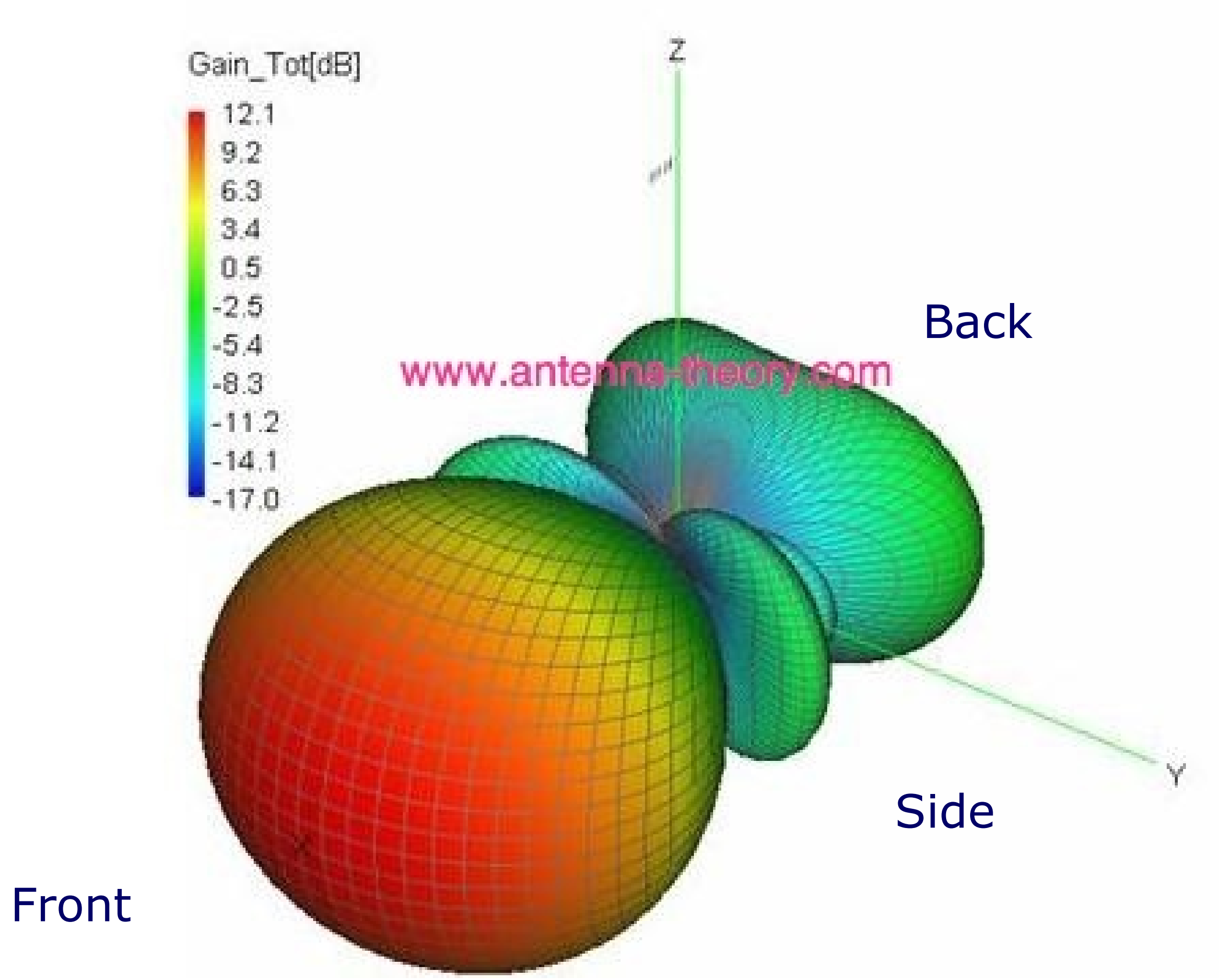


- Yagi



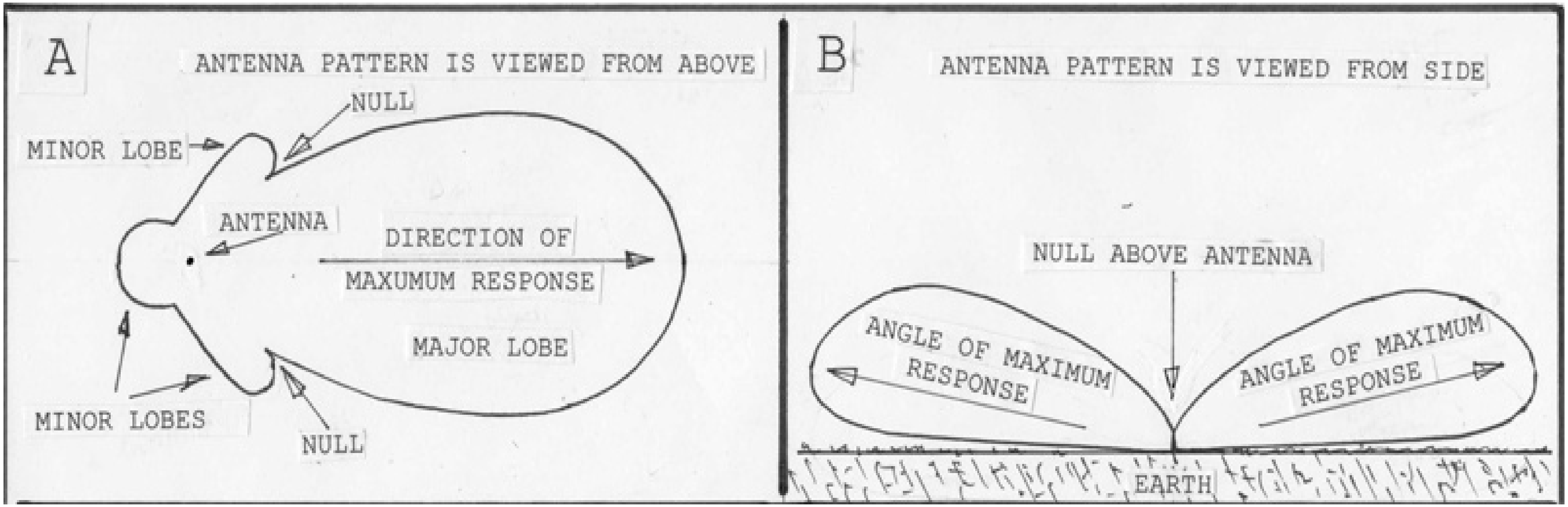
- Dish

Yagi Antenna Pattern – Directional!



2-D Gain Models

- Before 3-D models we only had:



- (these are still very common diagrams)

Antenna Characteristics

- Antennas have “resistance”
  - Most HAM Transmitters expect 50 ohms
  - Resistance varies by frequency!
- Antennas have “capacitance” too
  - Most of the time, you want 0 capacitance
  - Not realistic even when desired
  - Capacitance is a form of resistance
  - Varies by frequency too!
- Antennas also have “inductance”
  - Similar to capacitance

Antenna Characteristics

- Antennas
  - Are designed for a particular frequency
    - They are "**resonate**" at one frequency
    - And close enough really near by
  - Characteristics deviate away from it
    - Resistance goes up or down
    - So does capacitance / inductance
  - You can measure an antenna's performance using an **antenna analyzer**

Putting Up Antennas

- Towers let you get them really high
  - Wear a **hardhat and safety glasses**
  - Wear a **climbing harness**
  - Always have a **helper or observer**
  - Keep them clear of **overhead power**
    - If it falls, ensure a **10 foot clearance**
  - A **gin pole** can help you lift sections
  - Never climb a **crank-up tower unless it is fully retracted**

Putting Up Antennas

- Grounding Towers
  - Use an **8-ft rod for each leg**
    - Bond them to each other and the tower
- Grounding with conducting wires
  - Lightning likes a straight path
  - So help it: **avoid sharp bends**
  - **Keep connections short and direct**
- Grounding requirements are set by
  - **Local electrical codes**

Connecting Antennas

- You can attach a radio directly
  - But it's not always convenient for you
    - You want your antenna as high as possible
    - Like, in a tree
    - Maximum “Radio Horizon”
- A “Feedline” connects them
  - Transfers **RF signals** between **radio and an antenna**
  - Common Types
    - **Coaxial cable** (“Coax”)
    - Ladder Line

Feedline Characteristics

- Feedlines have
  - Resistance
  - capacitance and inductance too
- Needs to carefully match the antenna
  - i.e. You generally want 50ohm coax
  - Your radio will not be happy otherwise
    - (more on this later)

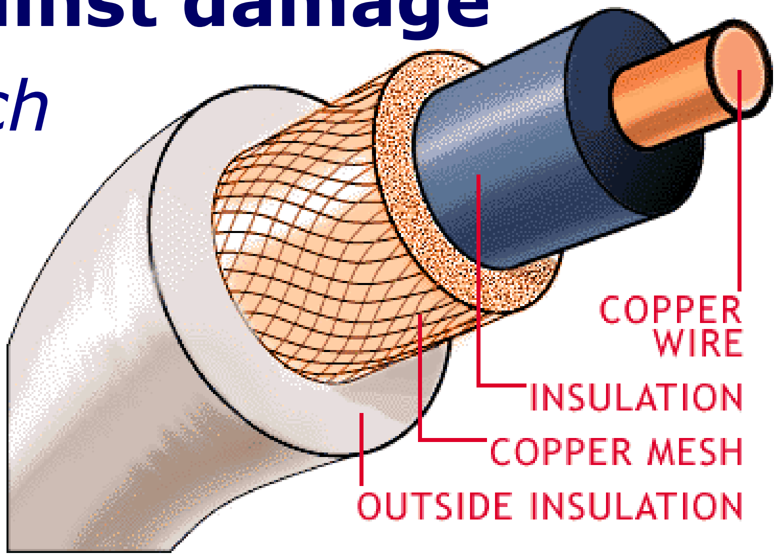
Very simple model of the system

Feedline Characteristics

- Feedlines have different qualities
  - RG58 : Thin, lightweight, and horrible
  - RG8: Thick, heavy, and great
  - Hard-line: Super duper thick and great
- Worse feedlines
  - Lose more power in transmission
  - **Lost power is converted into heat**
  - **Higher frequency → more loss**
    - Make sure your high-frequency antennas have really good feedlines.
    - Optimize for 2m before 160m

Coax Cables

- Are super **easy to use**
- Very susceptible to water damage
    - **Most common reason for failure**
    - **"air core" especially**
    - **Use UV-resistant outer-jacket cables to protect the jackets against damage**
- *More sensitive to a mismatch with the antenna*
- Loss per foot measured in dB

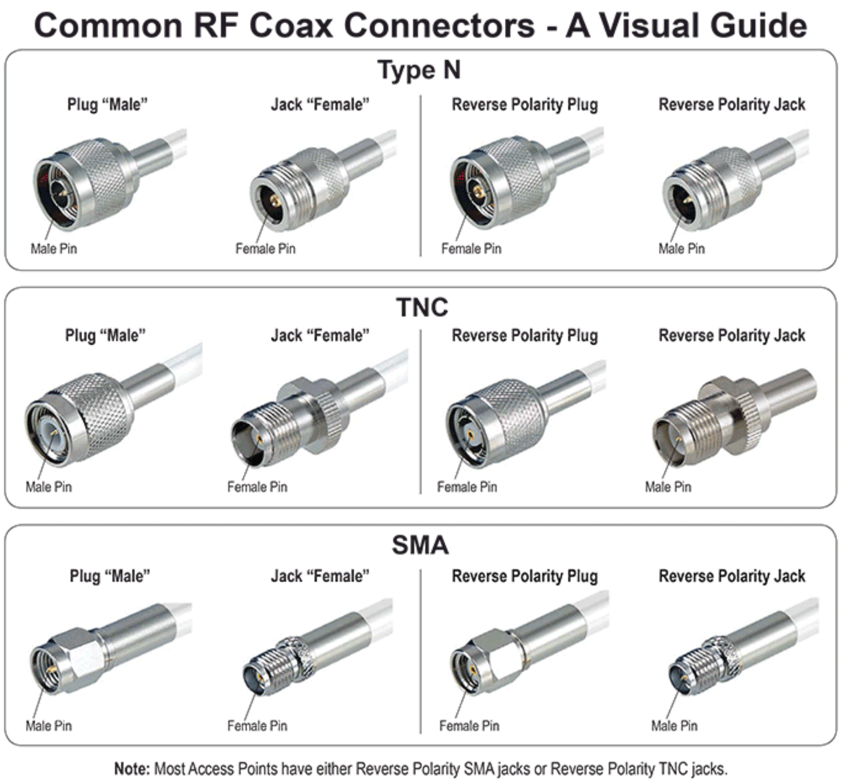


Coax Cable Signal Loss (Attenuation) in dB per 100ft

Loss	RG-174	RG-58	RG-8X	RG-213	RG-6	RG-11	9913	LMR-400
1MHz	**1.9dB**	**0.4dB**	**0.5dB**	**0.2dB**	**0.2dB**	**0.2dB**	**0.2dB**	**0.3dB**
10MHz	**3.3dB**	**1.4dB**	**1.0dB**	**0.6dB**	**0.6dB**	**0.4dB**	**0.4dB**	**0.5dB**
50MHz	**6.6dB**	**3.3dB**	**2.5dB**	**1.6dB**	**1.4dB**	**1.0dB**	**0.9dB**	**0.9dB**
100MHz	**8.9dB**	**4.9dB**	**3.6dB**	**2.2dB**	**2.0dB**	**1.6dB**	**1.4dB**	**1.4dB**
200MHz	**11.9dB**	**7.3dB**	**5.4dB**	**3.3dB**	**2.8dB**	**2.3dB**	**1.8dB**	**1.8dB**
400MHz	**17.3dB**	**11.2dB**	**7.9dB**	**4.8dB**	**4.3dB**	**3.5dB**	**2.6dB**	**2.6dB**
700MHz	**26.0dB**	**16.9dB**	**11.0dB**	**6.6dB**	**5.6dB**	**4.7dB**	**3.6dB**	**3.5dB**
900MHz	**27.9dB**	**20.1dB**	**12.6dB**	**7.7dB**	**6.0dB**	**5.4dB**	**4.2dB**	**3.9dB**
1GHz	**32.0dB**	**21.5dB**	**13.5dB**	**8.3dB**	**6.1dB**	**5.6dB**	**4.5dB**	**4.1dB**
Imped	**50ohm**	**50ohm**	**50ohm**	**50ohm**	**75ohm**	**75ohm**	**50ohm**	**50ohm**

Connectors

- **Type N: high frequencies**
  - **(greater than 400MHz)**
- **PL-259: A bayonet type: for HF**



SO-239 to PL259

BNC

Mismatches

- What happens when they match?
  - All the power goes out the antenna!
  - Yay!
- What happens when they don't?
  - Not all the power goes out the antenna
  - Some is “Transmitted”
  - Some is “Reflected” back down the line
  - So, if your transmits at 5 Watts
    - Only 4 watts may actually go out
- Use a SWR meter or **Directional Wattmeter**

Standing Wave Ratio

The least understood aspect of antenna theory

- The Standing Wave Ratio
  - **how well a load is matched to a transmission line**
  - i.e., A ratio of “real” to “perfect”
  - “one to one” → 1:1
  - A 1:1 ratio is a perfect situation
    - Impossible!
    - At anything other than 1:1
      - There is an “impedance mismatch”
      - you loose power
  - At **2:1 → transmitters reduce power**
    - *The test says 2:1, but I've seen more at 3:1*

Measuring SWR

- Use a:
  - SWR meter
    - Many high-end radios have them built-in now
    - Automatic antenna tuners do too
  - **Use a directional watt meter**
    - Measures forward and reverse power

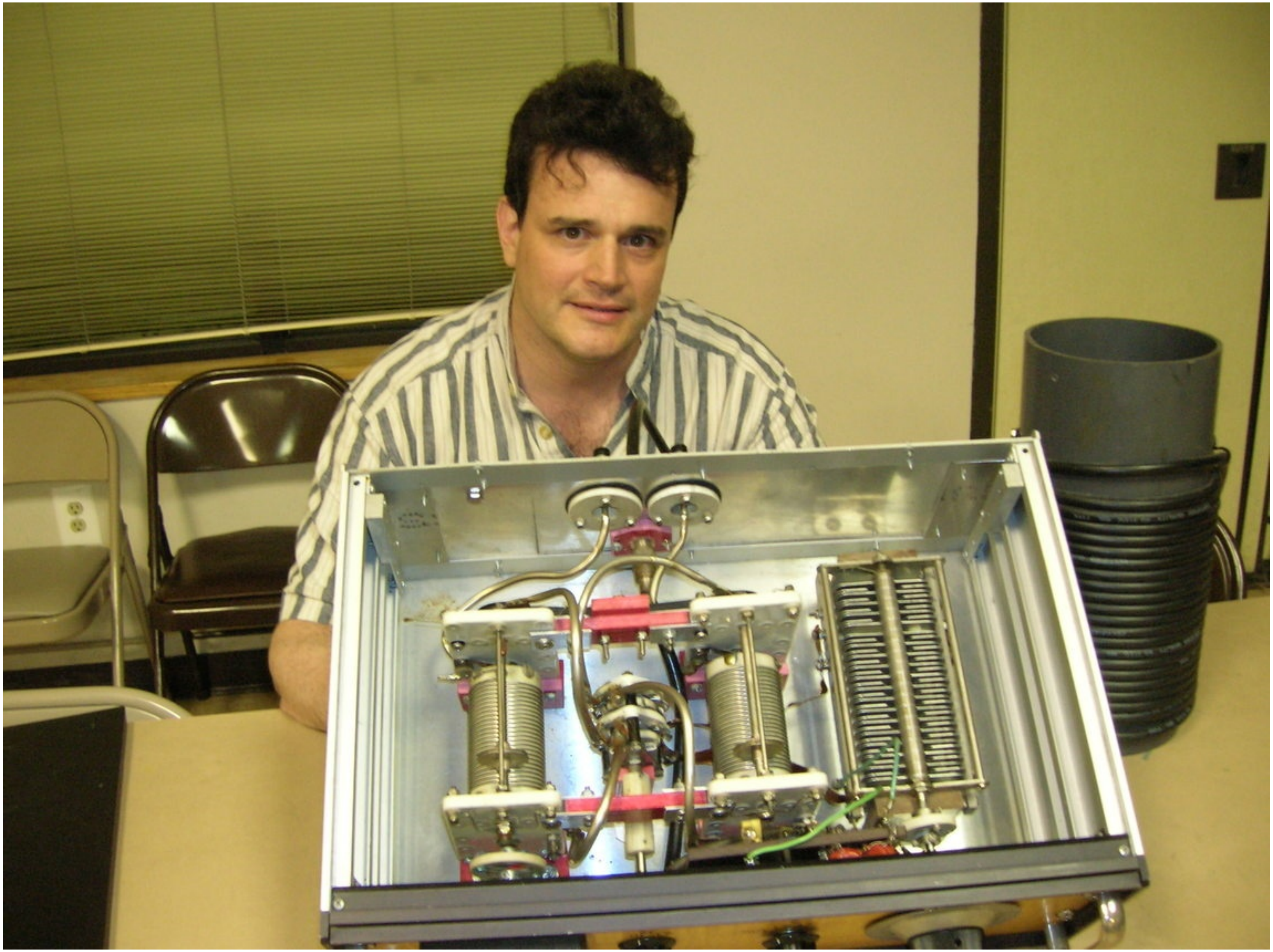
Fixing SWR Issues

- Fix the antenna!
  - Antennas themselves cause issues
    - Getting an exact 50 ohm antenna is hard
- Fix the feedline!
  - Use the right one!
  - Very important at high frequencies
- Fix the connector!
  - If you're getting **erratic readings, it's probably a loose fitting**.

Fixing SWR Issues

- Use an antenna tuner
  - Adds capacitors and inductors
  - Matches the **systems impedance to the transmitters expected impedance**
  - Does not fix the inefficiencies!
    - Just prevents the radio from seeing them
  - Sits as close to the antenna as possible
    - But, most put them right next to the radio
      - (hard to control one at 50ft in the air)

A very big antenna tuner – WB2ICQ



Radio Frequency Radiation

- RF radiation safety is affected by:
  - Power level of the transmitter
  - The frequency of the transmission
    - **Human absorption differs by frequency**
  - Time exposed to the signal
    - "Duty Cycle": **Ratio of on-air time to total operating time**
      - An "**average exposure**" level over time
    - Listening 99% of the time doesn't do much
  - Radiation pattern of the antenna
    - (don't stand in front of a beam antenna)

RF Radiation Guideline

- Generally:
  - Minimize: Power * Time * 1/Distance
- i.e.
  - Reduce power when not needed
  - Reduce transmission time
  - **Move away from the antenna**
    - *Falls off at the distance squared*
    - *i.e. 2x farther away is 4x less radiation*
- As a ham, you can separate the radio from the antenna: which is safer!

RF Radiation

- Dangers
  - Don't touch antennas while transmitting
    - **Painful RF burn**
- FCC Compliance
  - Re-evaluate after an **equipment change**
  - **Acceptable evaluation criteria:**
    - FCC OET Bulletin 65
    - Computer modeling
    - Measurement of field strength using calibrated equipmenth
    - (“all of the above” on the test)

VHF / UHF RF Radiation

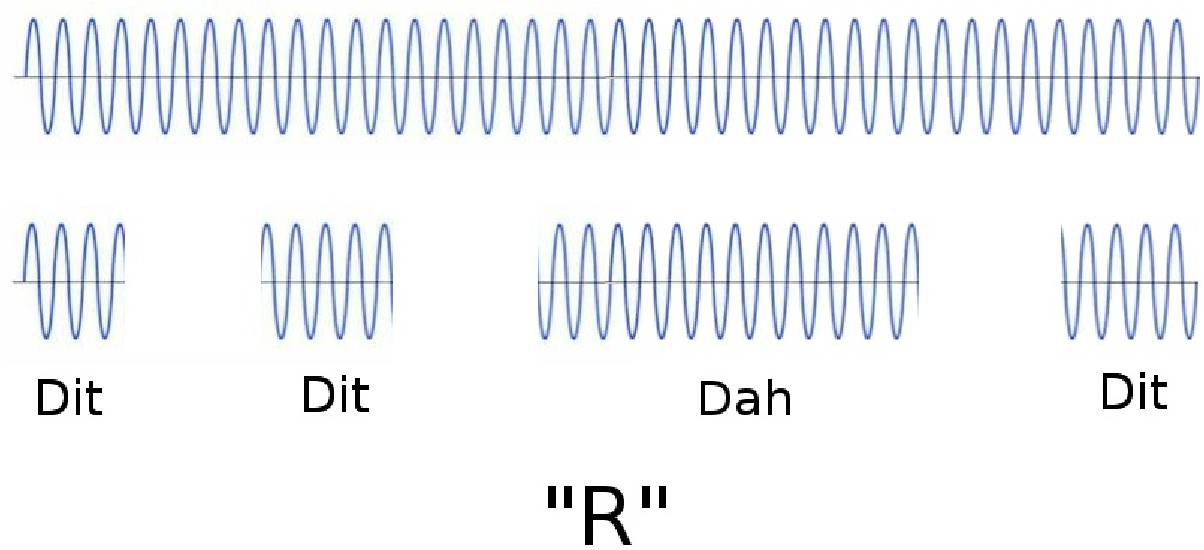
- VHF/UHF radiation is **non-ionizing**
- Maximum VHF RF before evaluation
  - 50 watts PEP at the antenna
  - Many radios don't go higher than that
    - Except for some radios at 6m
- On the test, lowest Maximum Permissible Exposure limit:
  - 3.5 MHz, **50 MHz**, 440 MHz, 1296 MHz
- Longer story
  - http://www.arrl.org/the-fcc-s-new-rf-exposure-regulations

We know how to broadcast... now what?

- What types of signals can we send?
- How do they work?

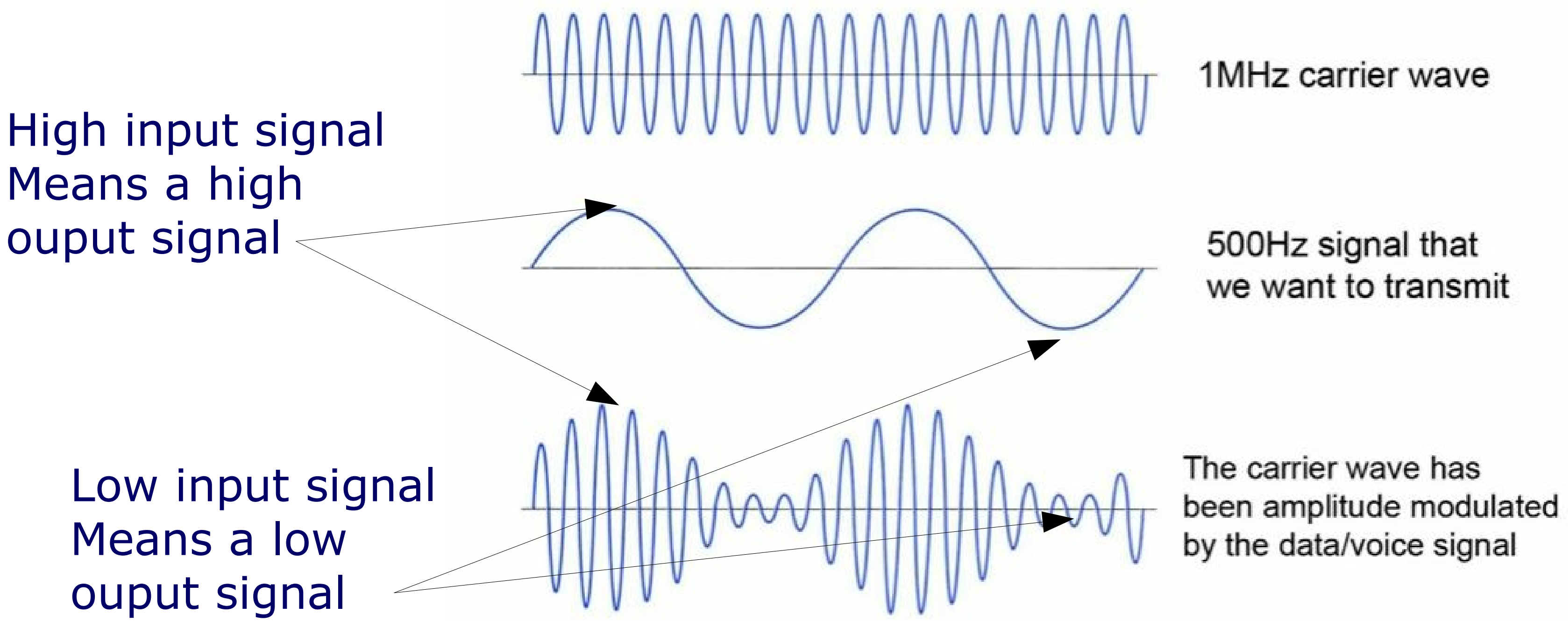
The simplest: A “Carrier Wave” (CW)

- A sinusoidal signal being turned on/off
  - Used to send Morse Code
  - Pushing a button down sends it
    - And letting go of the button stops it
    - A “morse code key”



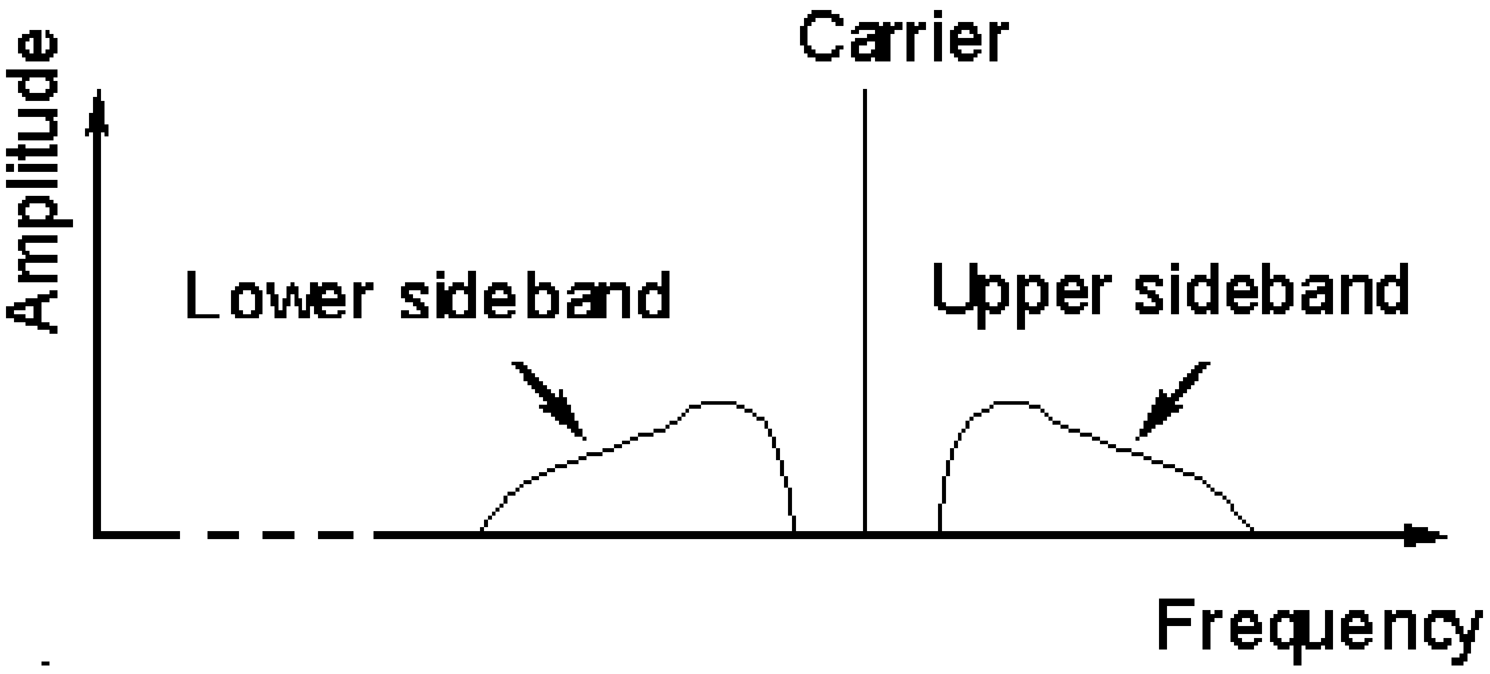
Amplitude Modulation (AM)

- Start with a sine wave (carrier wave)
  - At the frequency we want to transmit at
  - Make the amplitude of it vary
  - An input signal determines the height



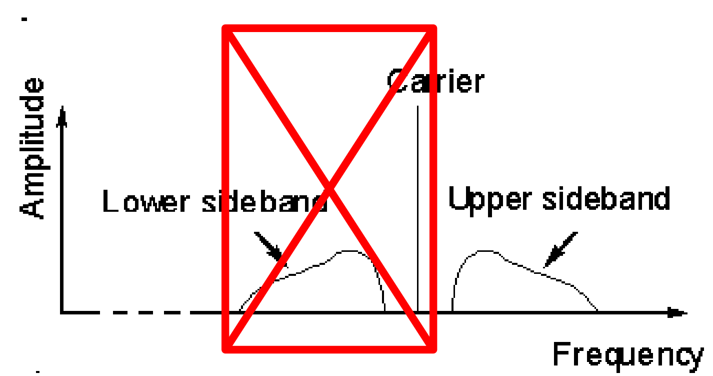
Amplitude Modulation

- In the frequency spectrum it looks like
  - A carrier in the middle
  - And an upper/lower bump, aka “sideband”



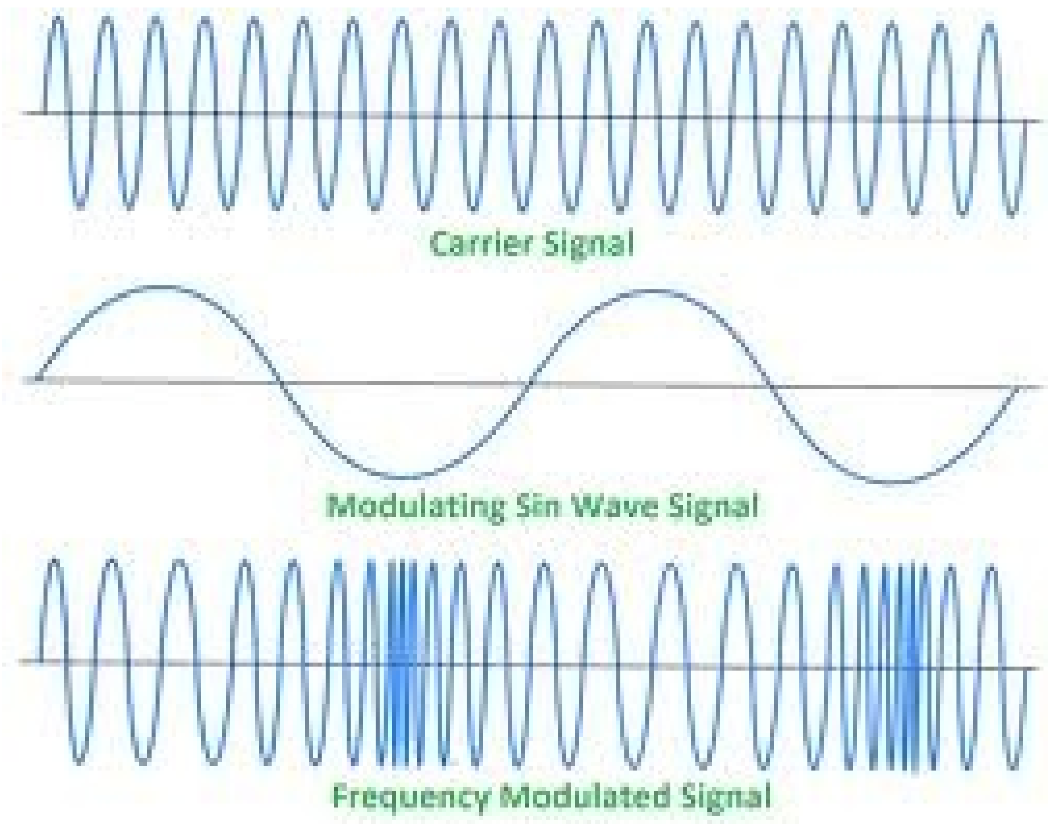
Single Sideband

- Hams got creative.
  - Transmitting the carrier is a waste of power
  - In fact, transmitting both sidebands is too
- The solution: filter them out!
  - Significantly less power to transmit
  - Receiver can still reconstruct the signal
  - Still a form of **Amplitude Modulation**
  - **USB on 20m – 440**
  - LSB on 40m - 160m

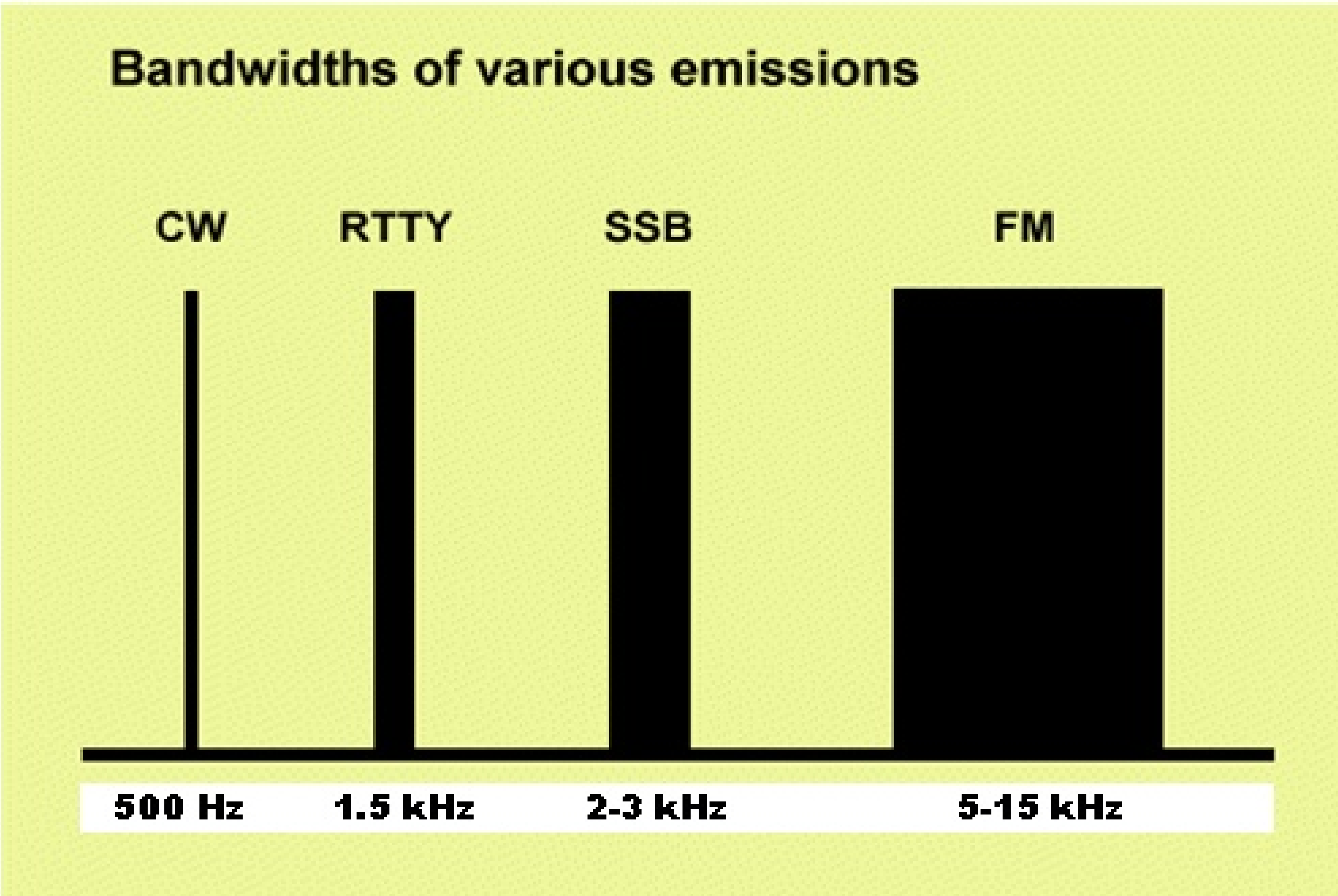


Frequency Modulation

- Modulate the Frequency instead
  - Change it slightly as the input varies

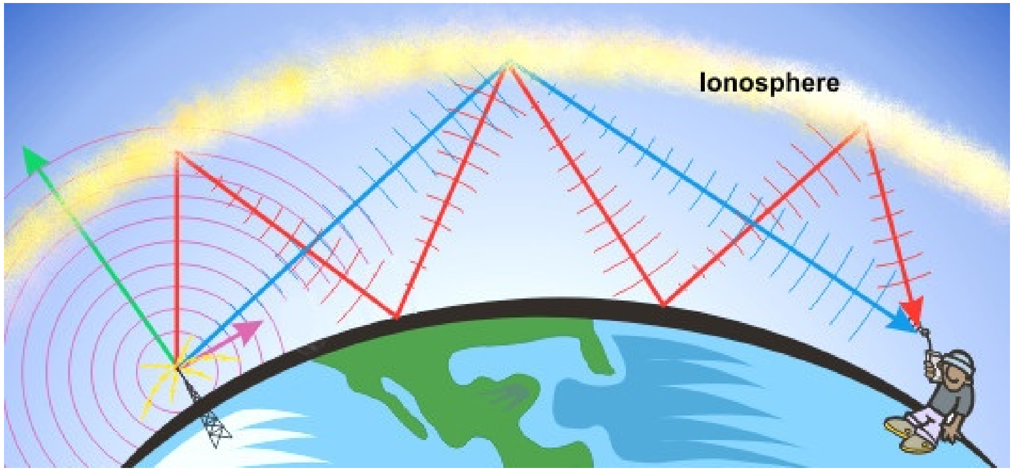


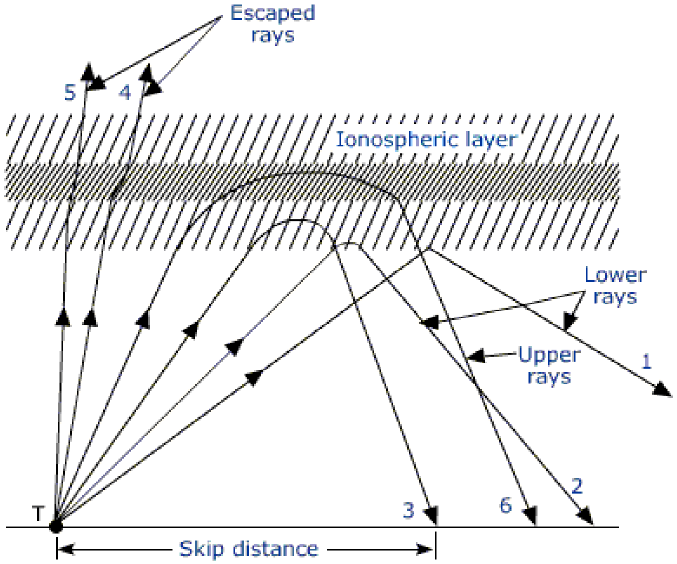
Frequency Space Required



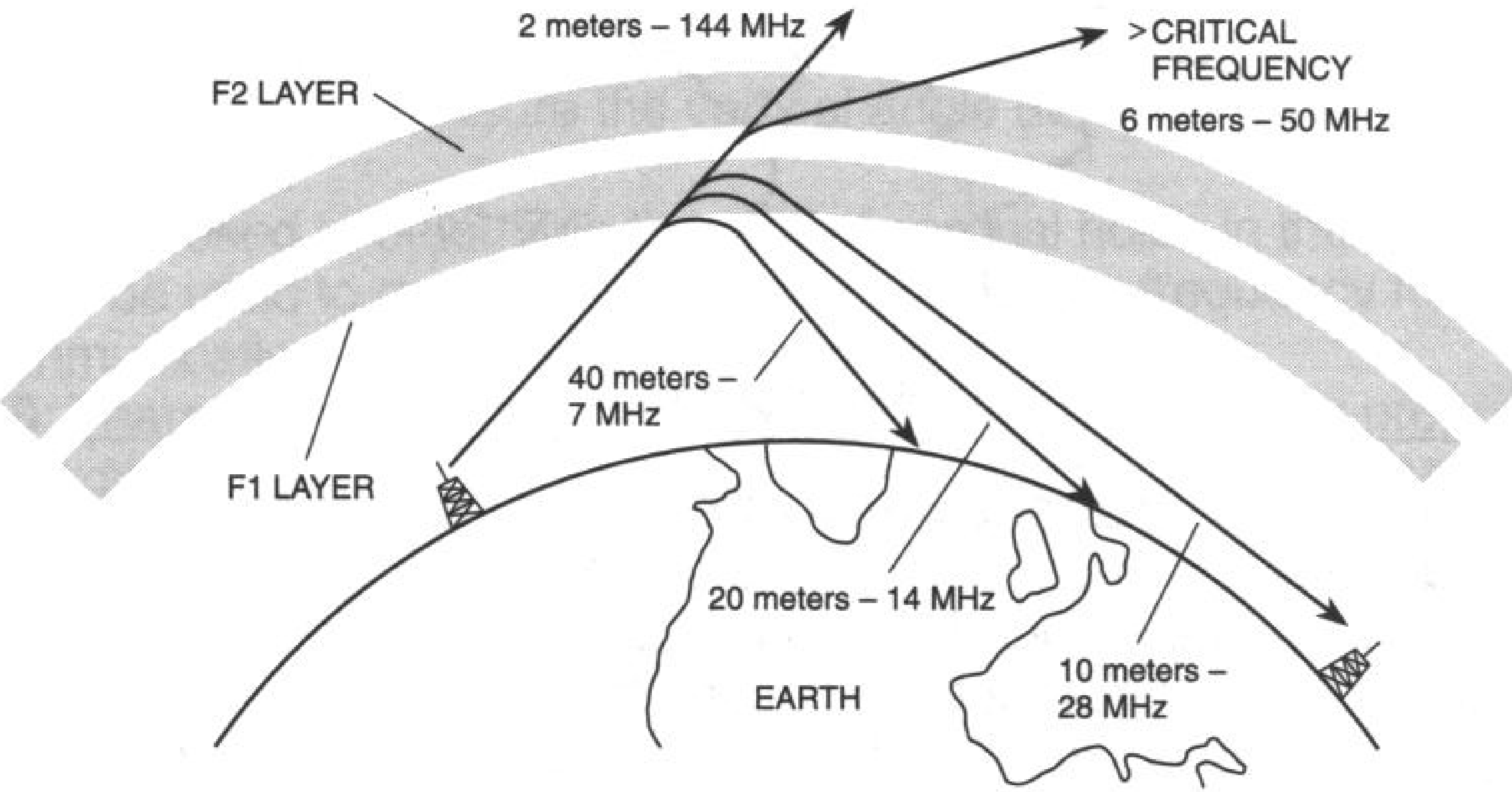
Propegation

- How do signals get around the world?
  - Various ways!
- First, we have to talk about the sky
  - Actually the ionosphere
  - Allows radio signals around the world



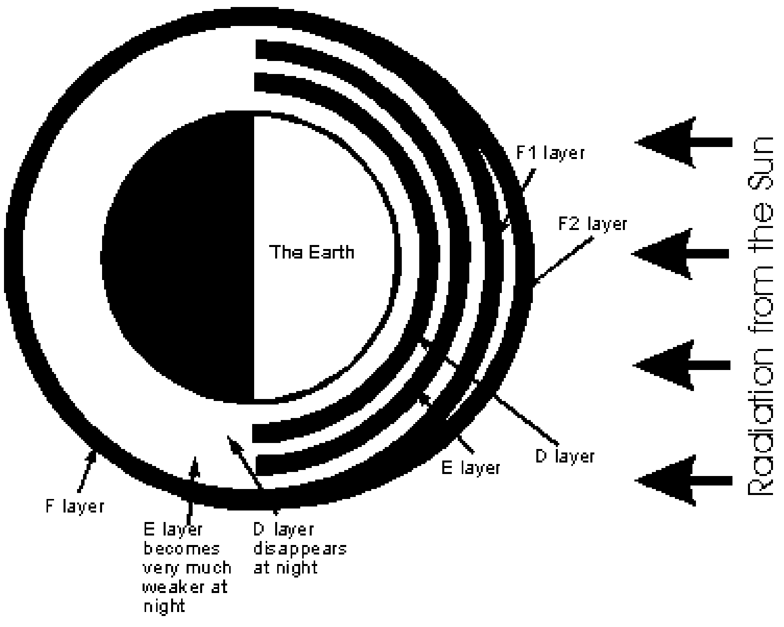


Reflection at different frequencies



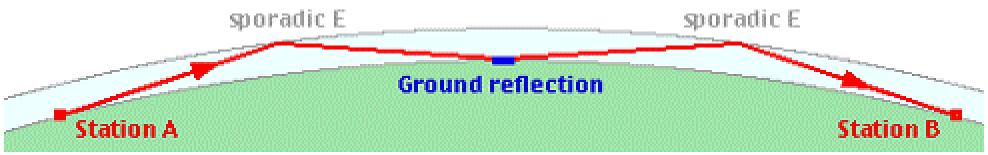
Ionosphere

- Composed of Layers
  - Some exist in the day (F)
  - Some exist only at night (D and E)
- **10m works best during the day**
- Signals bounce off it
  - **Reflected polarization is randomized**



Propegation

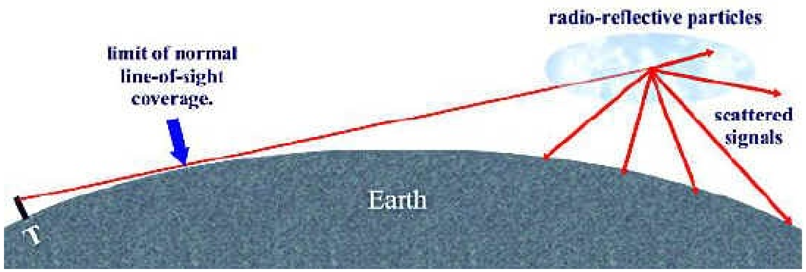
- How do signals get around the world?
  - Various ways!
- UHF and VHF
  - Not normally heard over long distances
  - Sometimes through "sporadic E" reflection



  - Sometimes they bounce off of aurora
    - **rapid fluctuations of strength** and **distort**

Propegation

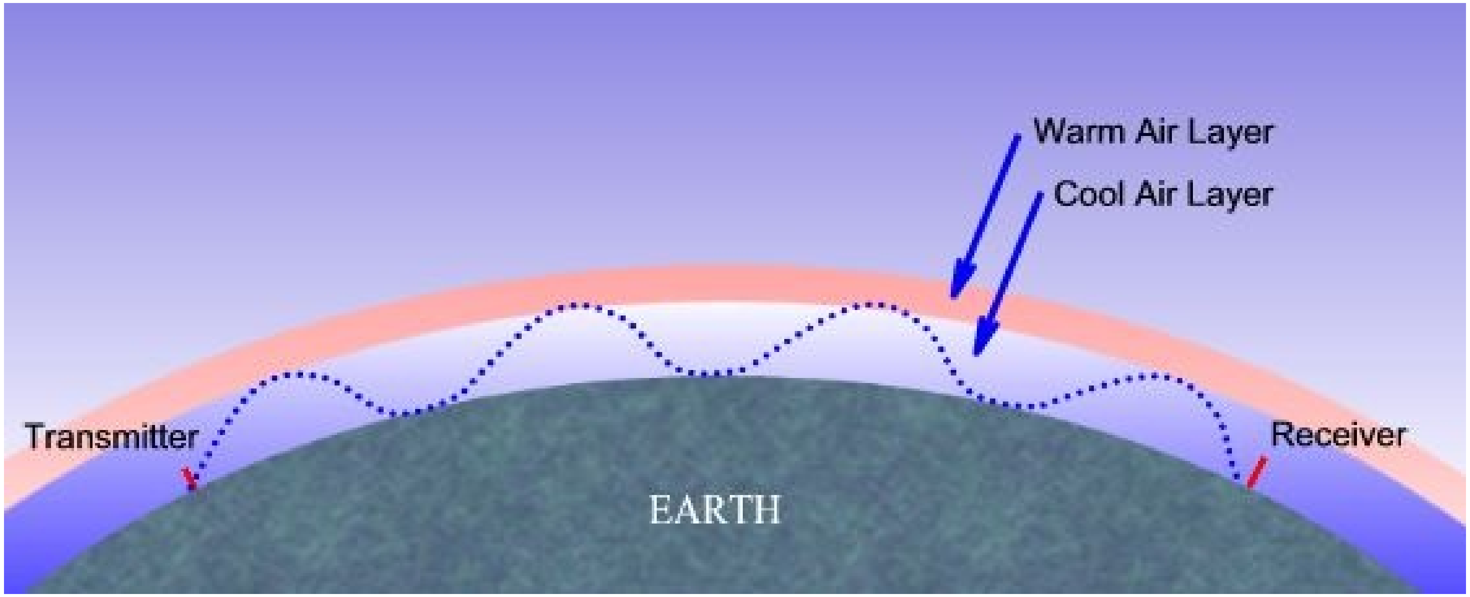
- VHF and UHF sometimes over 300mi!
  - **“Tropospheric scatter”**
  - Radio waves scatter in the troposphere



- Sometimes bouncing off comets
  - “**meteor scatter”**
  - Best on **6m**

Propegation

- VHF and UHF continued still
  - Tropospheric Ducting: **Temperature inversions in the atmosphere**



Satellites

- There are “AMSAT” satellites in orbit
  - Frequently carry 2m or 400 repeaters
  - **LEO: Low Earth Orbit**
- Satellites move very very fast
  - Results in **doppler shift** in frequency
    - Higher as it comes at you
    - Lower as it goes away
    - You have to adjust your transmitter!
- Satellites rotate
  - “Spin Fading” - their antennas rotate

Questions?

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