Radio Frequency Principles

Crowley - 3

Objectives

- Compare and contrast radio frequency (RF) principles and characteristics
- List major radio propagation principles
- Identify different antenna types and characteristics

Radio Frequency Fundamentals

- A radio wave is an electromagnetic wave of a frequency between about 10^4 and 10^{12} Hz as used for communications.
- As a transmission media, radio works at OSI layer 1, the physical layer.
- Part of the electromagnetic (EM) spectrum, which comprises a wide range of electromagnetic radiation and energies with different characteristics, including infrared, visible, and ultraviolet light, and microwaves, X-rays, and many others.

Electromagnetic (EM) Spectrum

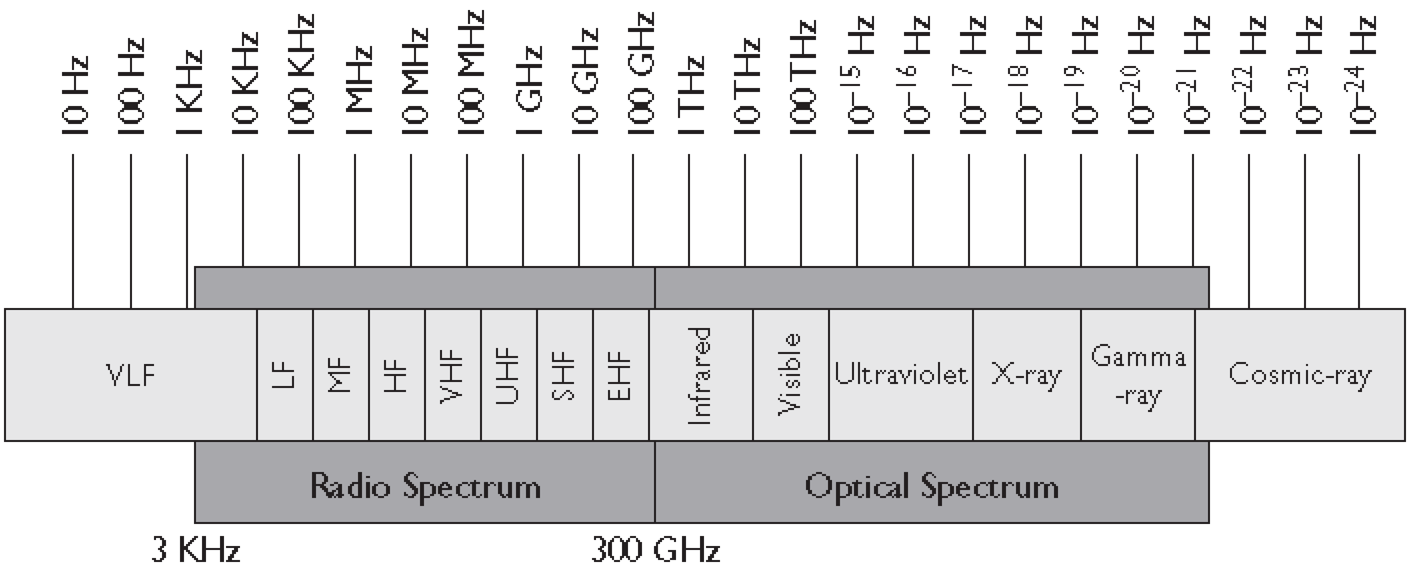


Figure 3-1 The electromagnetic (EM) spectrum

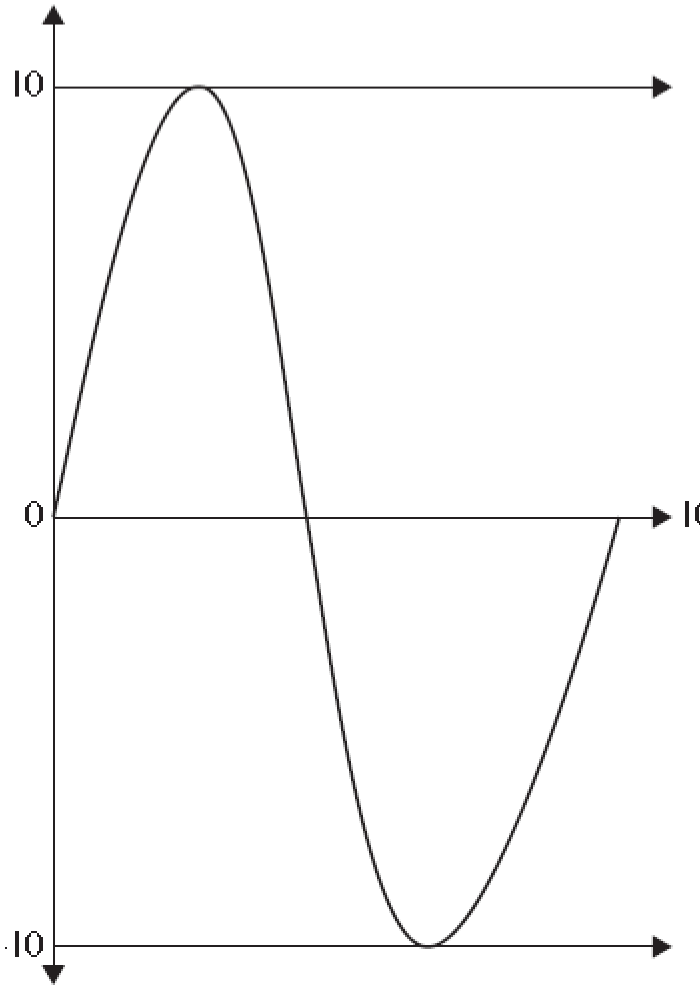
- Radio takes up a portion of the EM spectrum in the lower frequency ranges.

Radio Frequency Concepts and Characteristics

- By definition, alternating current, changes direction.
- Information is sent on a wire using this alternating current and then transmitted via an antenna to a receiver.

Frequency

- RF signal is a sine wave, which is shown as an electrical current changing voltage uniformly over a defined time period.
- If you could visualize this, you'd see something similar to what is illustrated on next slide.
- As the wave changes direction, it does this over a measured length of time.



Hertz (Hz)

- Complete change back and forth is called a cycle.
- By convention, accepted time period is one second.
- How many times in one second the direction changes, or how many cycles per second.
- A signal that changes only once over one second is said to have a frequency (designated by f) of one cycle per second.
- Cycles per second is measured by a unit called a Hertz.

Hz

- Typical radio communication frequencies measured in:
  - Thousands of cycles per second, or kilohertz (abbreviated KHz);
  - Millions of cycles per second, or megahertz (MHz);
  - Billions of cycles per second, or gigahertz (GHz).
- While the frequency is measured in cycles per second, actual radio wave physical length can also be measured.

Wavelength

- Wavelength of a radio wave, designated by the Greek letter lambda (λ), is the distance of one complete cycle from beginning to end.
- Wavelengths measured in terms of centimeters, meters, or even kilometers.
- Typically expressed in very small numbers—the wavelength of an average Ultra High Frequency (UHF) TV signal can be anywhere from 10 centimeters to 1 meter in length, for example.

Higher Frequencies, Shorter Wavelengths

- Now, consider that as number of waves increases in a given period of time, wavelengths become shorter.
- Higher frequencies have shorter wavelengths.
- Lower frequencies have longer ones.
- Where:

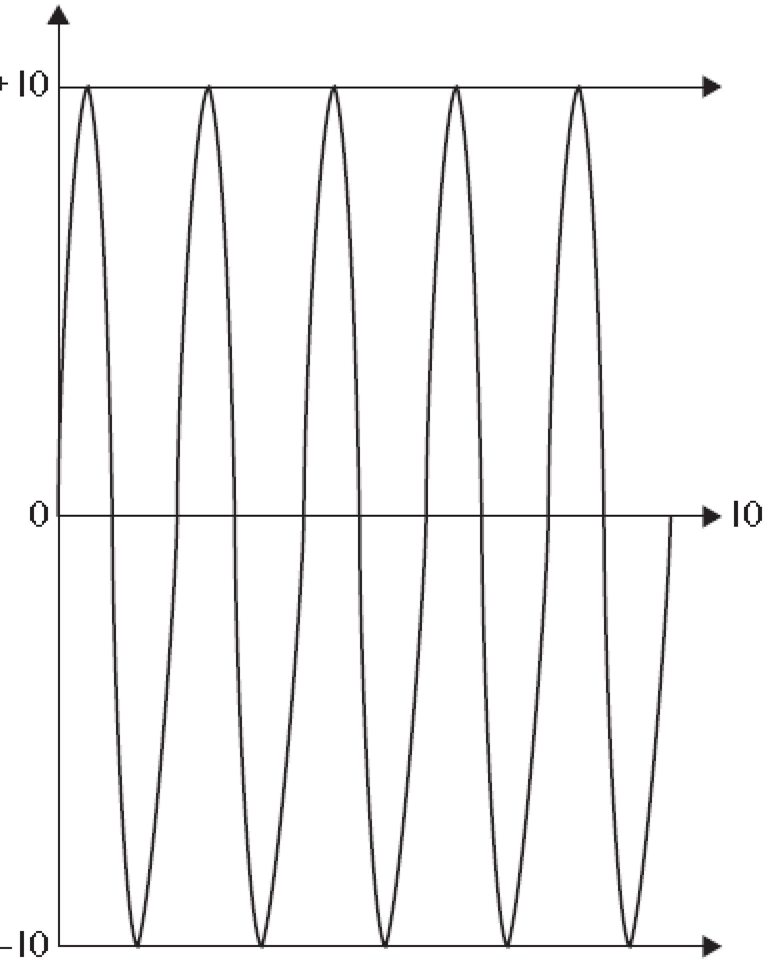
lambda = wavelength, v= frequency, and c=$3x10^8$ m/s

$$\nu = \frac{c}{\lambda} \quad , \quad \lambda = \frac{c}{\nu}$$

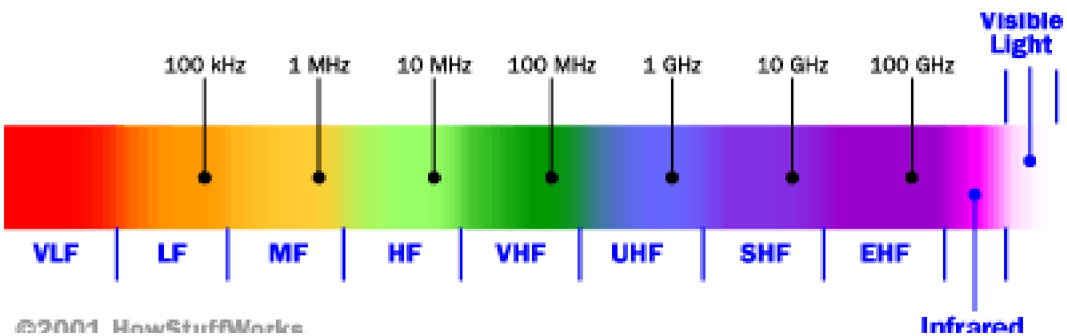
Energy

- As you move through the EM spectrum, some energies, like X-rays, are high-frequency and low wavelength, and others, such as radio, are the opposite—lower frequencies and longer wavelengths.
- Energy with shorter wavelengths (and higher frequencies) tends to be more powerful, but is more limited in distance.
- Energy with higher wave-lengths (and lower frequencies) can travel longer distances, but is less powerful.

Radio Frequency Ranges



- Radio frequency ranges in the EM spectrum are from around 3 KHz to about 300 GHz.
- Categorized with names such as low, medium, and high frequencies….
- Note wave-lengths decrease as frequencies increase.

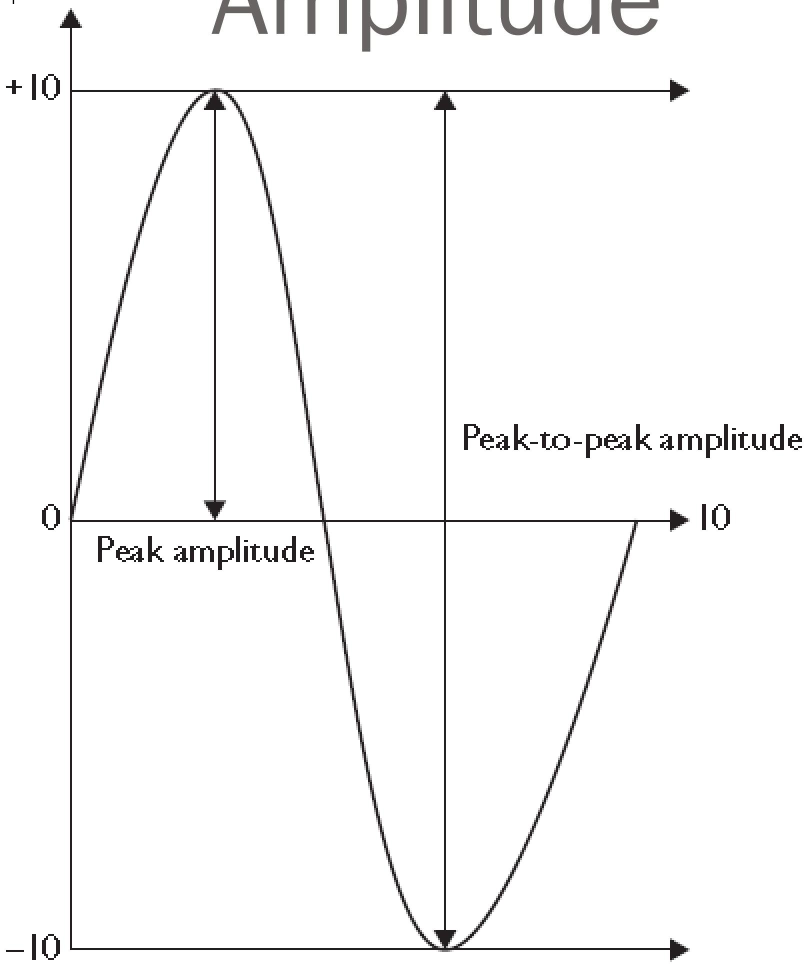


Frequency Band	Frequency	Wavelength
Extremely low frequency (ELF)	3–30 Hz	10^5–10^4 kilometers (km)
Super Low Frequency (SLF)	30–300 Hz	10^4–10^3 km
Ultra Low Frequency (ULF)	300–3000 Hz	1000–100 km
Very Low Frequency (VLF)	3–30 KHz	100–10 km
Low Frequency (LF)	30–300 KHz	10–1 km
Medium Frequency (MF)	300 kHz–3 MHz	1 km–100 meters (m)
High Frequency (HF)	3–30 MHz	100–10 m
Very High Frequency (VHF)	30–300 MHz	10–1 m
Ultra High Frequency (UHF)	300 MHz–3 GHz	1 m–10 centimeters (cm)
Super High Frequency (SHF)	3–30 GHz	10 cm–1 cm
Extremely High Frequency (EHF)	30–300 GHz	1 cm–1 millimeter (mm)
Tremendously High Frequency (THF)	300 GHz–3000 GHz	1 mm–0.1 mm

Table 3-1 RF Frequency Range

- In Table 3-1, full RF frequency range; along with the names, called frequency bands, as well as their wavelengths.

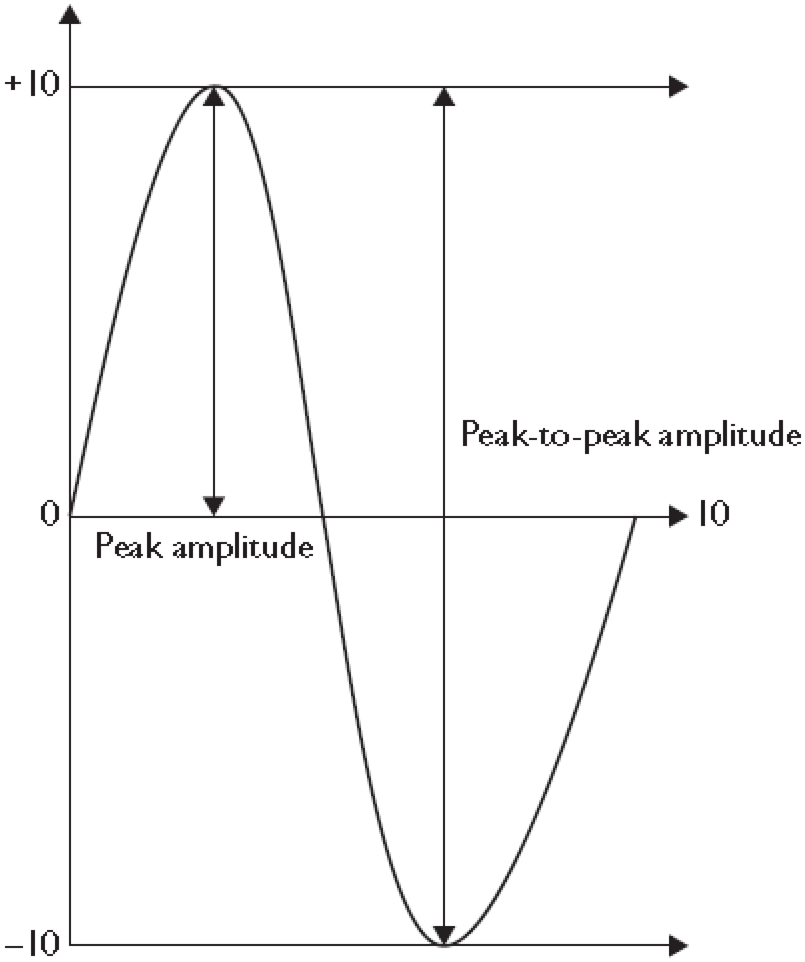
Amplitude



- If wavelength is the actual length or period of a wave measured, then it makes sense that you can also measure a wave’s height.
- Called the amplitude of a wave.
- As you can see, there are a different ways to measure amplitude.

Peak Amplitude.

- A simple measurement of the height of the wave (in positive numbers) from the zero axis, or starting point, to the highest level.
- It's really the absolute value of the height (shown using the mathematical symbol for absolute value, or | |; for example, the absolute value for both –6 and +6 is |6|).
- Peak-to-peak amplitude, on the other hand, is the measure of the entire range of movement of the wave, from its peak (the highest point) to its trough (its lowest point).



- Various Measurements of Amplitude

Amplitude

- Amplitude relates proportionally to both the strength of a signal and its power.
- Weaker signals have lower amplitude.
- Stronger, more powerful signals tend to have higher amplitude.

Bandwidth

- Bandwidth is a range of frequencies,(sometimes called a frequency band) measured in Hertz (Hz).
  - A frequency band can be 20 Hz wide, for example, and could reside at any part of the spectrum.
- Frequency range between given lower and higher frequencies.
  - Let's say that you have a lower frequency of 20 MHz and an upper frequency of 45 MHz.
  - The bandwidth, then, is 25 MHz, which is essentially the difference between the two.

Modulation

- AM amplitude modulation.
- FM frequency modulation.
- Signal itself is called a carrier wave, and, with nothing else done to it, it's just a wave of energy.
- In order to make the radio wave meaningful as data, you have to change its characteristics.
- This is what modulation is—the process of changing or varying properties of a wave or signal.

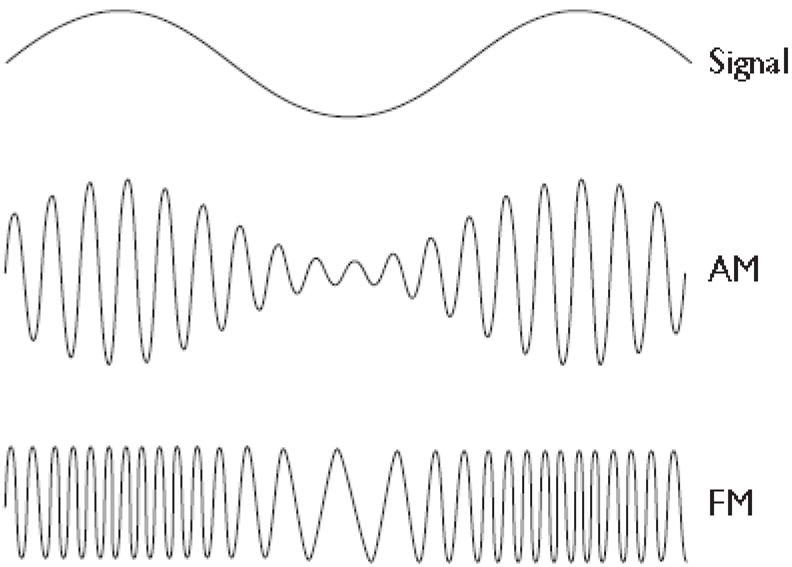
Modulation

- Radio signals can be modulated several ways.
- Some, like AM and FM, are analog, and some are digital.
- The properties you usually modify using analog methods are either the amplitude or the frequency of the signal.
- The carrier wave or signal is changed (modulated) by another signal in such a way that it can represent data.
- Based upon the method of modulation, the signal can represent 1s and 0s (binary data) or other types of data.

Modulation

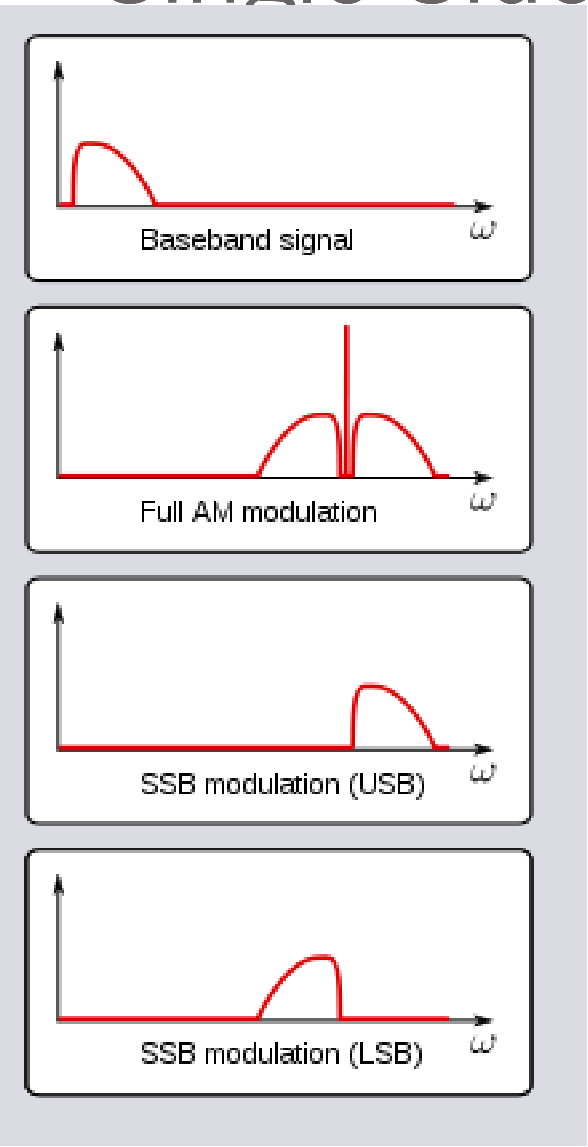
- Amplitude modulation changes the amplitude of each wave.
- The changes can be made in a discernible pattern, which can represent data.
  - AM is typically used in lower frequency ranges (below 30 MHz)
  - Can be found in commercial radio, aircraft communications, and other shortwave applications.
- Frequency modulation is the more modern method of analog modulation.
  - The two basic types of FM, FM Narrow (FMN) and FM Wide (FMW), can be found in commercial broadcast (FMW) and two-way radio systems (FMN), and are typically found in the range above 30 MHz.

AM and FM



- Both amplitude and frequency modulation with an unmodulated carrier wave.

Single Sideband (SSB)



- Another analog modulation method.
- Primarily used in amateur (ham) radio, as well as marine (commercial fishing/shipping and private boating) applications.
- Evolution of AM
- A shortwave radio technology that operates below 30 MHz.

Digital modulation

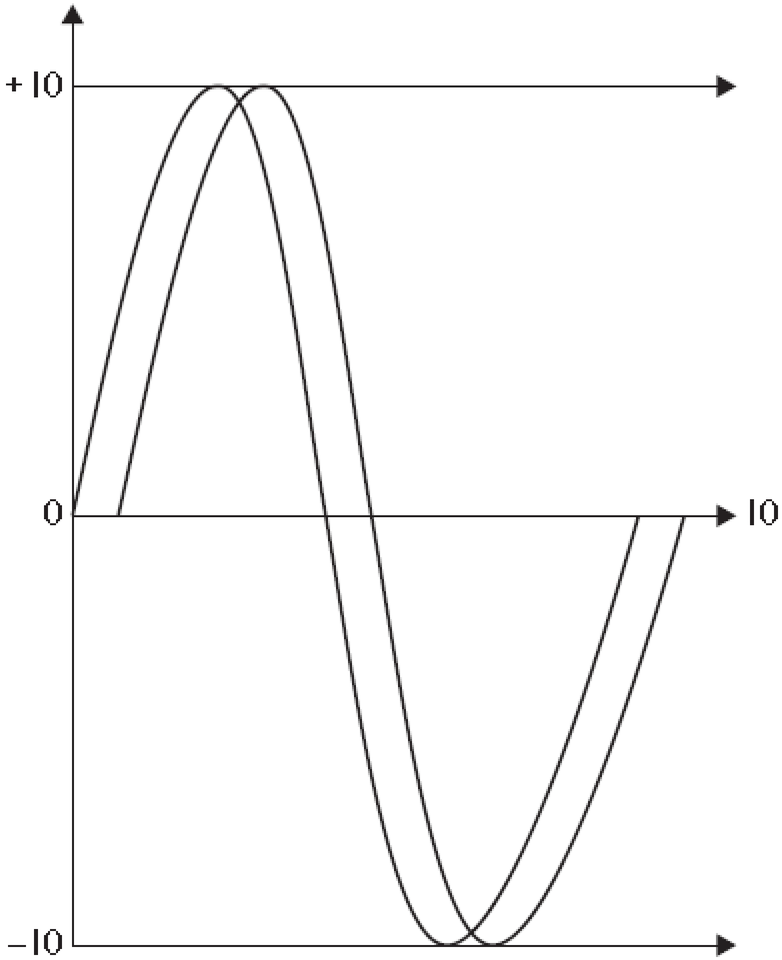
- A more modern method of signal modulation.
- Can make better use of available bandwidth by compressing data.
- Can be used to get a better, higher-fidelity signal, which is necessary for data with higher quality-of-service (QoS) requirements.
- Digital modulation can perform error-checking, and offers the ability to “clean up” a signal on the receiving end.

Spread Spectrum

- Spread spectrum allows a signal to be transmitted over the entire bandwidth of the frequencies within the spectrum.
- Accomplished by a variety of methods, including frequency hopping (rapidly changing frequencies within the bandwidth range).
- This method, appropriately called frequency hopping spread spectrum (FHSS), is used by a wide variety of wireless devices, including cordless phones, baby monitors.
- Another common method of modulation using spread spectrum is direct sequence spread spectrum (DSSS).
- In DSSS, the data is randomly spread over types of wireless networks.

Phase

- Phase refers to the difference, if any, between two sine waves.
- Let's suppose that a wave starts at a particular instance, and a second wave, of the same frequency, starts immediately after.
- There is a delay in both distance and time between the two waves, and they are said to be out of phase with each other.
- As a result of a phase difference, the waves could overlap with each other and cause distortion in their respective signals.
- They could also cancel each other out completely.

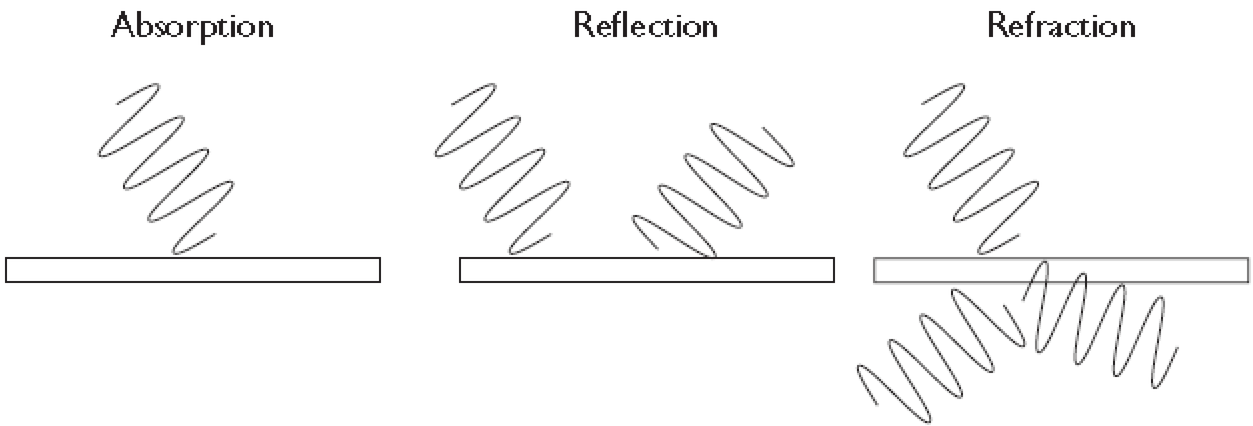


Phase

- Actually measured as an angle, not a time (frequency) or distance (wavelength) difference.
- Angle is determined by the difference in wavelengths of the two signals.
- If the second sine wave starts at a quarter of the length of the first wave, it is 90 degrees out of phase with the first wave, at a half-length, 180 degrees, and so on.
- Phase difference can be measured from 0 to 360 degrees.

RF Propagation

- Radio waves have different characteristics, depending upon frequency, amplitude, wavelength…
  - Some radio waves travel longer distances.
  - Some have the ability to penetrate solid objects.
  - Some bounce off solid objects.
- Tendency of radio waves (and other EM energies) to react in these ways is called propagation.
  - Propagation describes how easily radio waves travel through objects, or are absorbed by them, refracted, or reflected off of them.
- Some transmissions require line of-sight (LOS).
  - Require a path fairly free of obstacles.



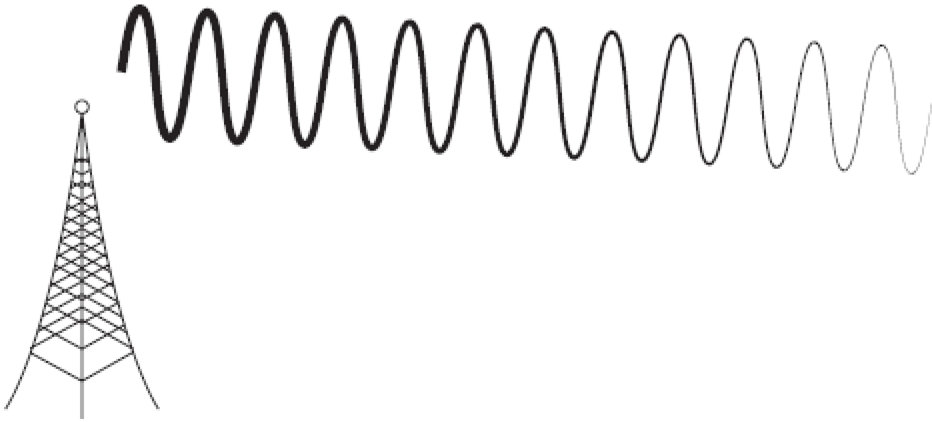
- Refraction is different from diffraction in that the RF signal passes through the material and is bent, while in diffraction, the RF signal bends around the material.

Reflection

- Reflection means that an RF signal “bounces” off of the surface of an object.
- The surface is usually one that does not lend itself to absorption or refraction.
- RF signals can bounce off of many objects, and too much bounce can cause loss of signal, poor performance, and a decrease in throughput.

RF Attenuation

- All EM energy attenuates over distance.
  - Farther the energy travels from the source, the weaker it gets.
- Some energies are able to travel extremely large distances with little or insignificant attenuation, while others attenuate after only a few feet.
- Sound waves, for example, attenuate such that if you were to stand at one end of a field and yell to a friend on the other end, they may not hear you clearly because the sound simply weakens over the distance.
- Both wired networks and wireless networks also suffer from attenuation because of the gradual degradation of the signal due to loss of energy over distance.



- Attenuation does not take into account obstacles that may cause absorption, reflection, or refraction, nor does it include any factors such as antenna gain, or limitations of the receiver and transmitter.
- It’s all about signal loss in free (unobstructed) space over distance.

Interference

- Interference is signal distortion that outside elements, such as other electromagnetic energies, weather conditions, and so on, have on an RF signal.
  - Sometimes called noise.
- Can come from a wide variety of sources, including other radio transmitters.
  - Could also come from heavy machinery, electrical appliances, or anything else close by that generates an electromagnetic field.
- Term signal-to-noise ratio (SNR) describes strength of an RF signal compared to the noise level.

Antennas

- Antennas transmit and receive radio frequency signals.
- Some antennas are used to transmit or receive in one direction only, while others transmit and receive in all directions.
- The particular type of RF technology used, such as microwave, cellular, and radio, also directly affects the type and design of the antenna.

Basic Concepts

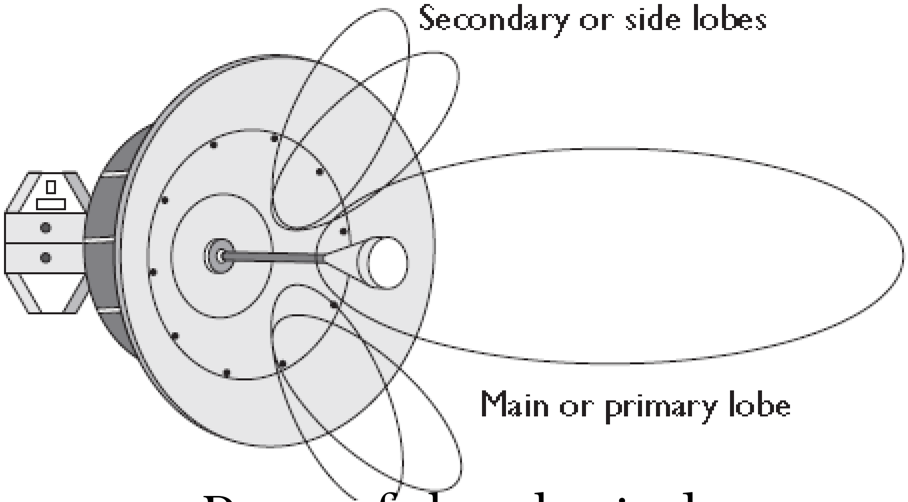
- Antennas are essentially conductors.
- On the transmission side, antennas are the part of the radio system that takes the electrical signals produced by the transmitter and turns them into radio waves that are propagated through the air to a receiver.
- The receiver side also has an antenna that receives the RF signal and converts it back to an electrical signal understood by the receiving equipment.
- Because of the wide variety of RF signals, the many uses of RF, and the different types of transmitters and receivers, many different types of antennas are available.
- Factors that influence which antenna you might use for a given setup include frequency range, distance, outdoor or indoor use, antenna height, location.

Antenna Characteristics

- Some antennas are more appropriate for long distances, others for shorter distances.
- Antennas generally used for a particular frequency range and power level.
- Regardless of type of signal or frequency range, however, there are some technical characteristics of antennas that most share.
- Including lobes, beamwidth, azimuth and elevation, gain, and polarization in the next few pages.

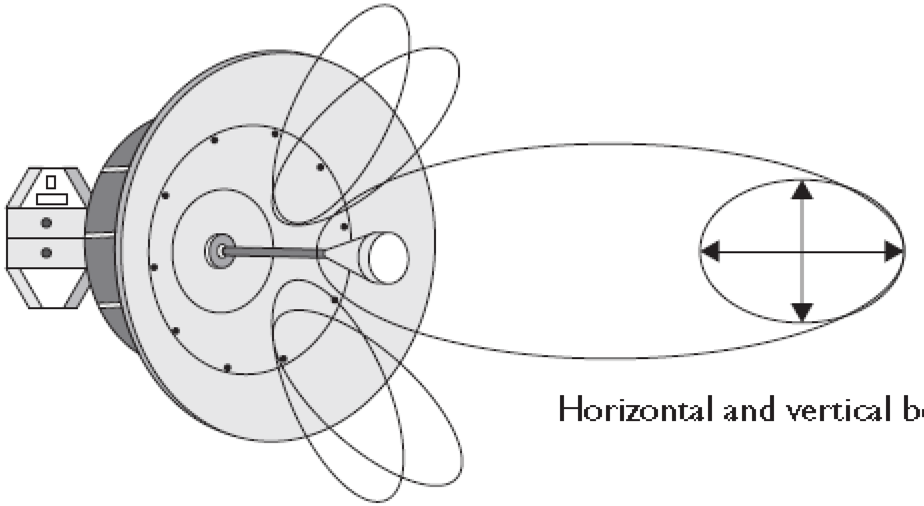
RF Lobes

- RF lobes, or patterns, are the shapes the RF energy takes when emitted from an antenna.
- We tend to think of radio waves as having the two-dimensional shape and pattern that we see in simple drawings and in ponds when we drop a stone into them, but that isn't necessarily how they would look if we were able to actually see them as they come from the antenna.
- RF signals are emitted in three dimensions and have shapes peculiar to their specific characteristics, as well the design of the antenna itself.



Lobes

- Parts of the physical pattern and shape of the lobe may be useable by the transmitter and receiver, while other parts of it may not be.
- The "primary" part of the lobe may be what extends out for a distance and is usually the main receivable part of the transmission pattern, while there may be secondary parts that extend sideways or in different directions and may not be useable due to weaker signal strength.



Beamwidth

- Beamwidth refers to the angle of measurement of part of the antenna pattern, or lobe, which is measured as the half-way point of the main lobe, usually at half power.
- Sometimes called the Half Power Beamwidth (HPBW)
  - Is the point where the signal power drops to 50 percent (about –3 dB) from the center or peak of the main lobe.
- An angular measurement, beamwidth is expressed in degrees and can be either a horizontal or vertical measurement.

Beamwidth

- Beamwidth measurements and physical pattern, like RF lobes, vary with the physical construction and design of the antenna.
- One function in designing a wireless system is determining the appropriate beamwidths (both horizontal and vertical) for an antenna to ensure the right RF signal coverage.

RF Power Measurements

- Radio signal power is measured in watts (abbreviated W),
  - Milliwatts (mW, or 1/1000 of a watt)are typically used to describe smaller power levels.
- Watts are a way of measuring absolute power output.
- We also, however, use decibels to describe relative changes in power.

Decibel

- Fundamental unit of measure abbreviated as dB, which relates to the difference between two signal levels.
- Can be express increases or decreases (changes) in power levels.
- When used this way, we express it as a dBm, which is a decibel compared to 1 milliwatt (mW) of power, the standard reference power level.
- There is a mathematical relationship between decibels and milliwatts, based upon logarithmic functions.

Relationship

- Base of the relationship, 0 dBm = 1 mW.
- As power levels change, the dBm measurement changes as well.
- A proportional change that isn't linear (a one-for-one change, if you will).
- You can use the following formula to compute dBm:

- dBm=10×log (signal÷reference)

- … an example: 100 mW is 20 dBm, but doubling the power to 200 mW is only an increase of +3 dB, to 23 dBm.

Logarithmic Relationship

- You can see that an increase of +3 dB doubles signal power.
- Other changes result in similar proportional changes.

- So, in the previous discussion about beamwidth, the –3 dB difference accounts for the half-power signal loss that describes the beamwidth.
- Decibels can also be used to help describe antenna power.

Azimuth and Elevation

- Azimuth is the horizontal RF coverage pattern;
  - Can be visualized by thinking of how you would look at a three-dimensional lobe from the top.
- Elevation, on the other hand, is the vertical RF coverage pattern.
  - Visualized by looking at it from a side view.
- If you were to stand next to a tall building, you'd see its elevation as height, from the bottom of the building to its top floor.
- Beamwidths are sometimes referred to as azimuth and elevation beamwidths.

Gain

- Gain is a measure of how much of the signal's input power is concentrated in a particular direction.
- It is usually discussed in the context of an omnidirectional antenna, which radiates equally in all directions.
- Gain is an amplification of the RF signal, and is measured in decibels isotropic (dBi).

Two types of gain Passive and Active.

- Passive gain is a function of antenna design and is used to focus the signal by changing the vertical and horizontal beamwidths (signal patterns) to be narrower.
  - An increase in gain results in a narrower beamwidth.
  - As gain decreases, the beamwidth widens.
- Exception is omnidirectional antenna, which, because it has a horizontal beamwidth that extends in a full circle (360 degrees), does not decrease its horizontal bandwidth as gain increases, but it still can provide more coverage.
- Passive gain can be changed by changing antennas, or, in some cases, changing characteristics of an antenna's shape .
- Active gain, on the other hand, is achieved by increasing the signal strength, usually through an amplifier, to the radio transmitter.
  - Remember that gain doesn't necessarily come from changing power levels; it's more of a function of focusing the signal.

Polarization

- Polarization of an antenna refers to its horizontal or vertical orientation.
  - The placement of an antenna, horizontal or vertical, can affect how RF waves are both transmitted and received.
- Normally, the antennas for a given type of radio signal (such as UHF or Wi-Fi, for example) should be similar in design, construction, and use so that the transmitter and receivers are compatible.
- If a transmitter antenna is horizontally polarized (oriented), for example, the receiving antenna should also be oriented horizontally.
- If you've used a computer on a wireless network, for example, with an external antenna that has been moved around or side-to-side, you may have experienced a signal loss due to the antenna orientation changing from vertical to horizontal (or vice versa).
- This is because a change in polarization of an antenna from what it should be usually decreases the RF signal.

Antenna Power Levels

- In addition to the radiated RF signal power, decibels can also be used to describe antenna power levels.
- There are two ways that decibels are used in terms of antenna power.
- The first applies to isotropic antennas, and is abbreviated dBi. Isotopic antennas broadcast signals in all directions equally, in the pattern of a sphere.
- This is a theoretical scenario because there's no "perfect" isotropic antenna.

dBi

- The dBi measurement is a relative power measurement and is used to further define the antenna's dBm power level, taking into account other factors as well, such as power loss from the antenna itself, cables, connectors, and so on.
- This adjusted power measurement, if you will, is called Equivalent Isotropically Radiated Power (EIRP).
- The second way applies to dipole antennas and is less common.
- Most of the time, you see dBi measurements used in wireless networks.
- The abbreviation for dipole antenna power measurement is dBd, and can be converted to dBi if needed.

Types of Antennas

- The two general categories of antennas discussed are omnidirectional and directional.

Omnidirectional

- A "true" omnidirectional would be almost like the "perfect" isotropic antenna discussed previously; that is, it would be able to transmit/receive in all directions.
- If you could visualize the RF signal pattern coming from an omnidirectional antenna, it would appear to be in the shape of a doughnut surrounding the top of the antenna, rather than a perfect sphere.
- This means that it does transmit and receive in all directions, but only in a given plane (usually horizontal).

Point to Multipoint

- Omnidirectional antennas are used in point-to-multipoint systems, meaning they transmit in all horizontal directions to multiple receivers.
- An omnidirectional antenna usually comes in the discone, whip, and dipole (think of older TV "rabbit ears" as an example of dipole) varieties.
- You've likely seen examples of omnidirectional antennas in your home and business wireless network equipment, or attached to cars for mobile radio equipment.

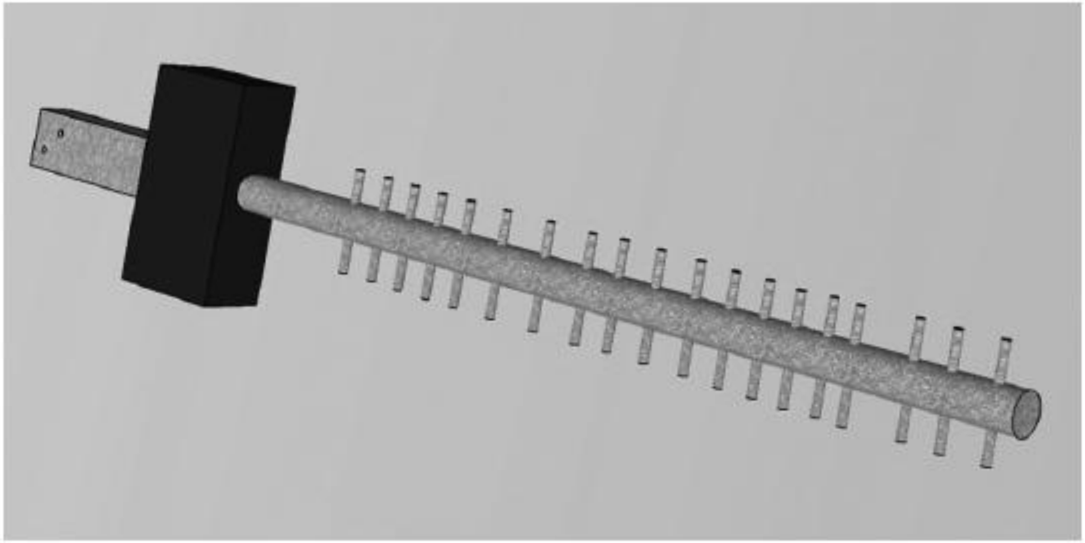
- Examples of omnidirectional antennas commonly found in 802.11 wireless networks.

Semi-directional

- A semi-directional antenna can transmit and receive signals more focused in a particular direction (or, in some cases, two discrete directions).
- This may be the case when you are trying to ensure coverage for a particular transmitter and receiver, in a point-to-point setup.
- Directional antennas come in a wide variety of flavors, including planar, sector, and Yagi (discussed shortly).
- Planar antennas are flat panels (also sometimes called patch or panel antennas) and can have a horizontal beamwidth as much as 180 degrees, but it is usually less.
- Sector antennas can cover a particular angle with their RF patterns (think about a slice of pie) and may be mounted in array of several (three or four) antennas on a tower to give a sort of omnidirectional coverage, albeit highly focused in each sector for each antenna in the array.
- Sector antennas usually have a wide horizontal beamwidth, but a narrow vertical beamwidth.

Bi-directional

- Bi-directional antennas are a form of directional antennas that transmit or receive in two discrete directions, as opposed to omnidirectional (all directions) or semi-directional (one direction that may be very narrow or very wide).
- Usually, this is accomplished by actually having two separate antennas constructed together that can send high gain RF signals in two separate (and usually opposite) directions.



Yagi

- Yagi antenna is a directional antenna.
- If you remember the days of television before cable was common, the old-fashioned TV antennas on the top of a house were typically a type of Yagi antenna.
- Most of these antennas operated in the UHF and VHF ranges for television reception, although other types of Yagi antennas can operate in other frequency ranges as well.

Parabolic Dish

- Likely, you’ve seen variants of this type of antenna before; it is the most commonly used antenna in TV and Internet services from satellite providers.
- You’ll also see it mounted on various kinds of cellular and microwave towers.
- A parabolic dish is considered a highly directional antenna, meaning that is has very narrow vertical and horizontal beamwidths.
- It’s usually used for longer range communications, up to several miles in most cases, depending upon environmental conditions such as weather and terrain, as well as gain.
- The RF pattern begins very narrow from the antenna but disperses or spreads very wide over long distances.

Faraday Cages

- An enclosure created by using conductive materials and used to prevent electrical interference.
- Faraday cages can be very large, surrounding an entire room, or be very small and surround a particular piece of equipment.
- In addition to preventing electrical interference, Faraday cages can prevent or suppress RF signal leakage.
- An example of a Faraday cage would be a structure surrounding a secure room that would block incoming or outgoing RF signals, such as cellular phones or other transmitting/receiving devices.
- Another example, on a smaller scale, might be a box that shields devices from radio frequency interference or from RF leakage.
- Still another example of Faraday cages may be shielding built into the device itself, in the form of hardened cases, linings, and suppressors, to perform the same functions on a device-by-device basis.
- If you want to see a common use of a Faraday cage, look no further than your kitchen's microwave oven!

Questions???