

Antenna Basics

Definition

An Antenna is a transducer (i.e. a wire or a piece of metal that sends or receives radio waves.) It converts electrical signals into electromagnetic waves.

In radio communications, they are used to send energy waves (radio waves) through the air so that radios may communicate with each other without the need of a wire line.

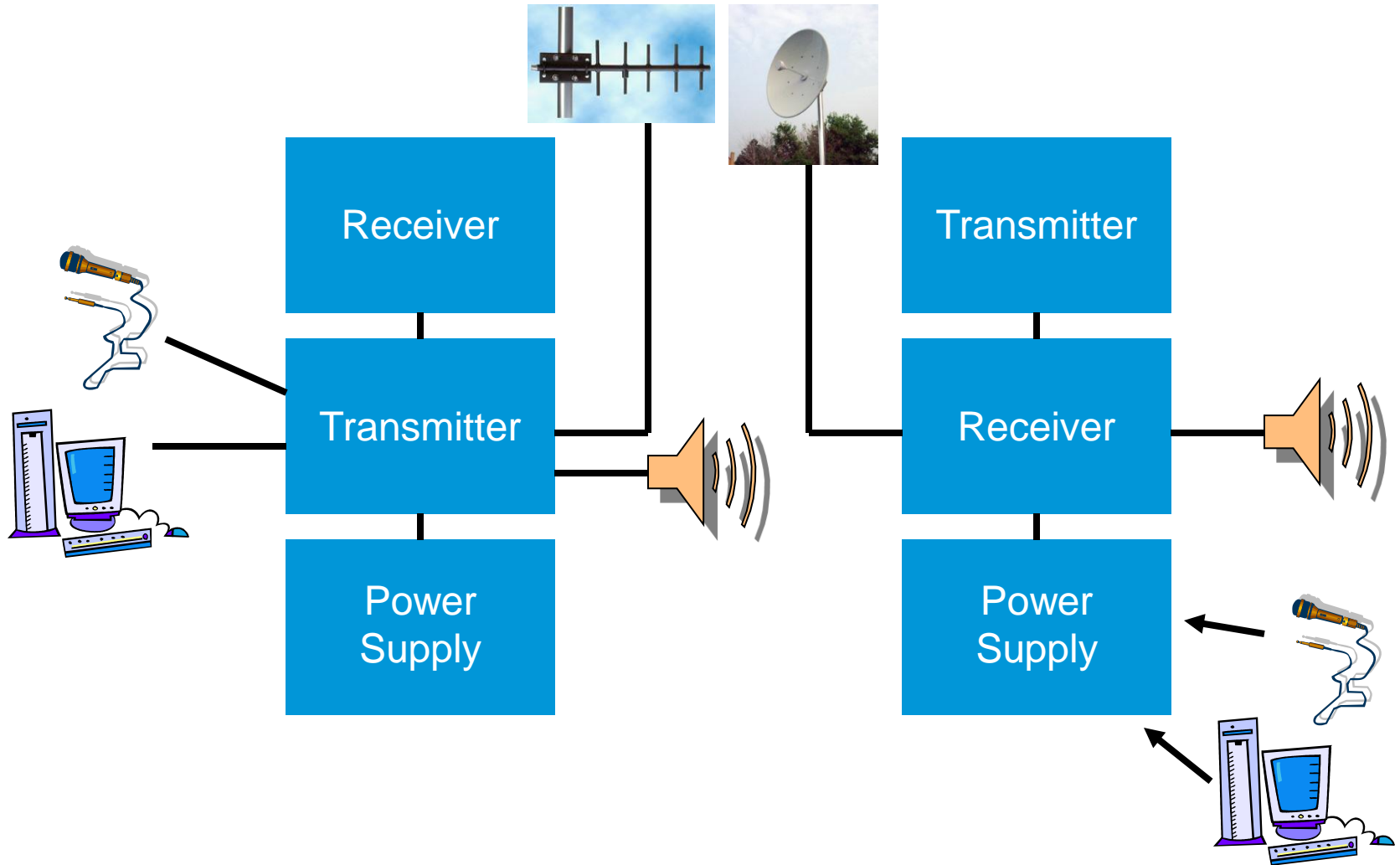


Antenna Functions

1. Transmit or capture the airborne signal.
2. Increase the signal received, or transmitted.
3. Provide directivity.
4. Provide polarized selectivity.



How a Radio Works



Important Concepts

- **Radio Wave**

A combination of electric and magnetic fields varying at the radio frequency, and capable of traveling through space at the speed of light. It is produced by feeding the output of a radio transmitter to a transmitting antenna.

- **Frequency**

Refers to the number of times a radio wave is repeated over a one second time span.

- **Spectrum**

A range of frequencies within which radiation has some specified characteristics, such as the audio-frequency spectrum, ultraviolet spectrum, or radio spectrum.

- **Radio Frequency**

The part of the general frequency spectrum between the audio and infrared light regions (about 10 kHz to 10,000,000 MHz); abbreviated as “RF”.

Important Concepts

- **Hertz**

The basic measure of frequency with which an electromagnetic wave completes a full cycle from its positive to its negative pole and back again. Each unit is equal to one cycle per second. A Megahertz (MHz) is equal to one million Hertz. A Gigahertz (GHz) is equal to one billion Hertz. MAXRAD measures frequencies below 1000 MHz in MHz, and above 1000 MHz in GHz (i.e. Microwave).

- **Frequency Range**

Refers to the portion of the radio wave spectrum that a given antenna is designed to operate most efficiently within. Antennas can be tuned to be resonant (most efficient) at different points within a designated frequency range. This happens below the stated VSWR.

- **Bandwidth**

The frequency range over which an antenna remains resonant (efficient) below the stated VSWR.

Important Concepts

- **Band**

Frequencies which are allocated for a specified purpose. In the Land Mobile Radio Spectrum radios operate in Low Band, High Band, UHF, VHF, 700 MHz, 800 MHz and 900 MHz bands of frequencies.

- **Wavelength**

The physical length of a radio wave. The higher the frequency, the shorter the wavelength.

- **Attenuation**

A measurement, in decibels (dB), of signal loss.

- **Radiation Pattern**

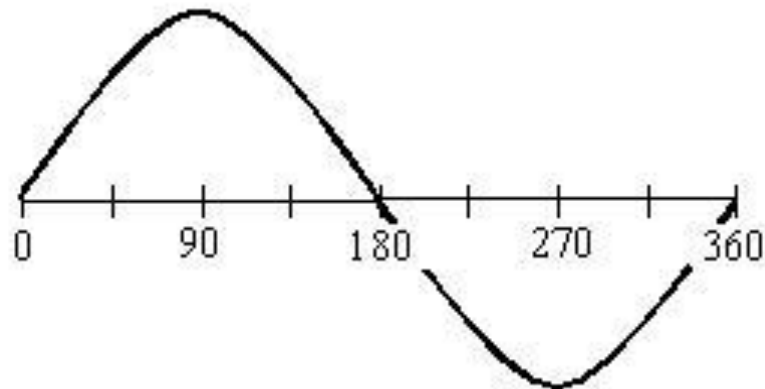
The shape taken by the radio energy radiated from an antenna. A pair of antennas must be within each other's radiation patterns in order to communicate effectively.

Antenna Basics

- A **radio wave** (electrically a sine wave) consists of 2 pulses of energy of equal strength and opposite charge (polarity).
- Each pulse is $\frac{1}{2}$ wavelength long. For a rod type antenna to effectively make the conversion of electrical signals to radio waves, the antenna must set up a field around the antenna called a “**standing $\frac{1}{2}$ wave**”. A standing $\frac{1}{2}$ wave is $\frac{1}{2}$ a wavelength long.

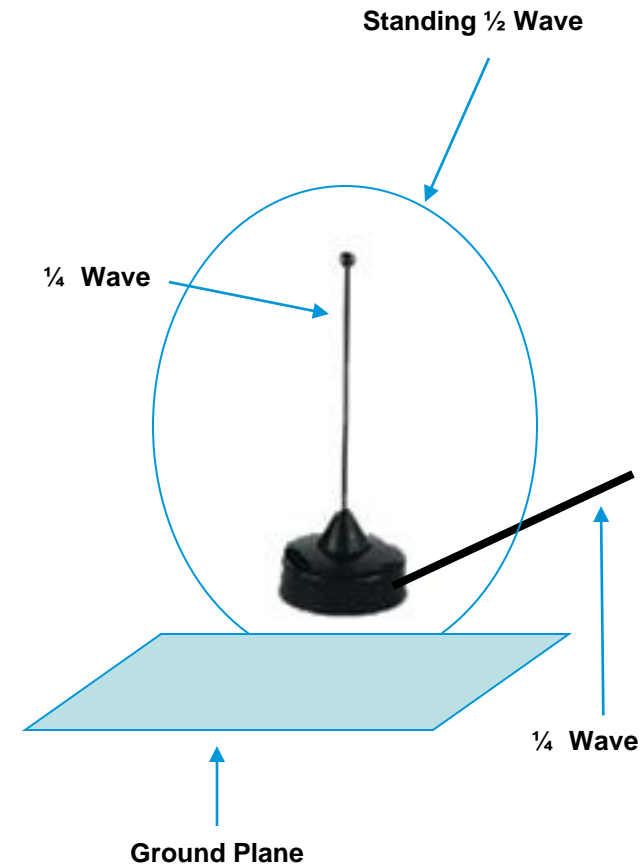
Antenna Basics

- As the antenna radiates, a $\frac{1}{2}$ wavelength long pulse of positively polarized energy is immediately followed by a $\frac{1}{2}$ wavelength pulse of negatively polarized energy. If an antenna were to emit an entire wave at once, the 2 opposite polarized $\frac{1}{2}$ wave pulses would cancel each other out.



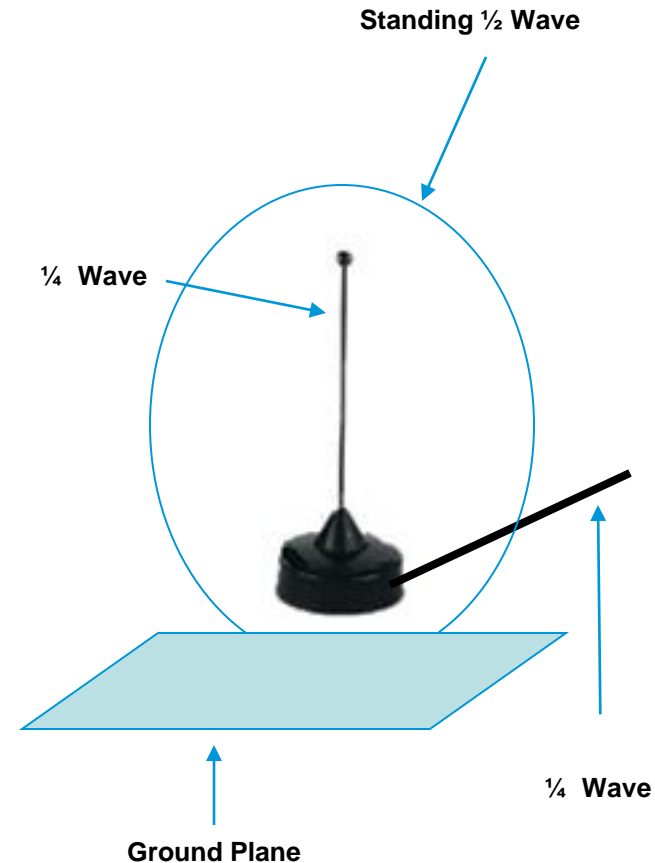
Antenna Basics

- A $1/2$ wave dipole consists of two $1/4$ wave elements with each element electrically connected to a shielded feed line (usually coax).
- Usually, one $1/4$ wave element (the antenna rod) is electrically connected to the coax center conductor; the other $1/4$ wave element (the ground plane) is electrically connected to the coax braid.
- When RF energy is applied through the coax, a standing $1/2$ wave is created across the entire dipole.



Antenna Basics

- To be most effective, the ground plane must be equivalent to a $\frac{1}{4}$ wavelength and should uniformly surround the rod.
- Some antennas are designed to operate without a ground plane. Their base coil circuitry allows the antenna to set-up a standing $\frac{1}{2}$ wave over the length of the antenna with a 50 Ohm impedance.



Antenna Basics

All antennas are grouped according to their operating frequency. Frequency is measured in Megahertz (MHz).

Frequency is closely related to the antenna's physical length, or its wavelength. The higher the frequency, the lower the wavelength, and the shorter the antenna.

$$\text{Wavelength} = \text{Speed of Light} / \text{Frequency}$$

(Radio waves travel at the speed of light)



2.4 GHz ISM Antenna



146 MHz VHF Antenna

Antenna Basics

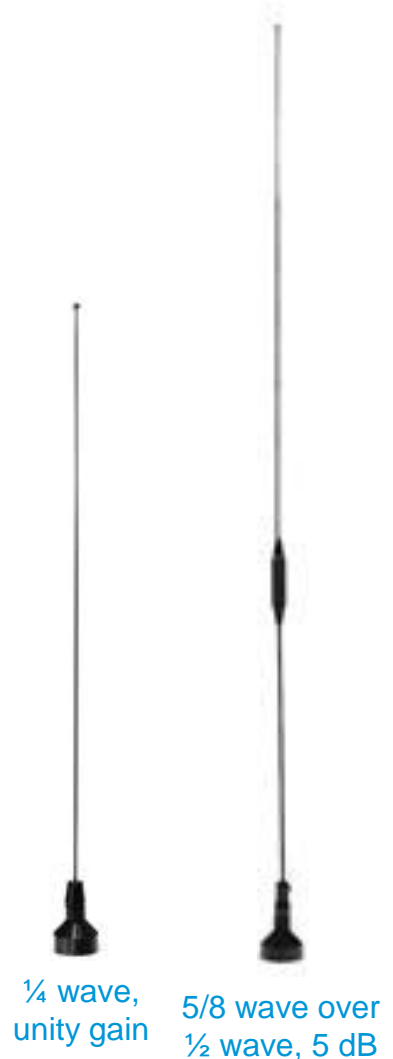
Gain

- **Gain** is a measurement of the strength of a radio signal as it passes through an antenna. The higher the gain number, the stronger the signal emitted.
- Ordinarily reference to an isotropic radiator (dBi).
- Gain is measured in Decibels (dB).
- A quarterwave antenna can be rated as having no gain (0 dB or unity gain) over itself.
- Sometimes referenced to a dipole (dBi vs dBd).
- Other antennas are rated against the unity gain quarterwave. For example, a base loaded 5/8 wave antenna has a 3 dB increase in signal strength relative to a quarterwave.

Antenna Basics

Gain

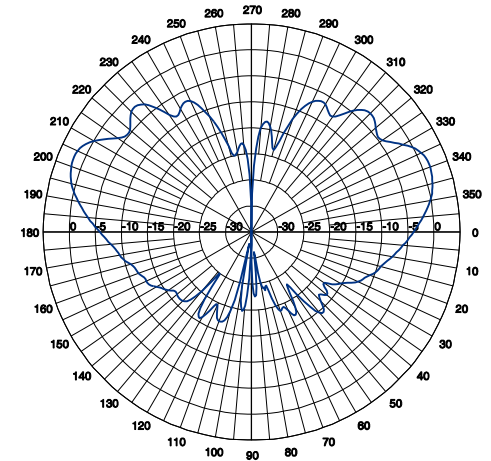
- Gain can be achieved by stacking $\frac{1}{2}$ wave sections that are “in phase” with each other. Two $\frac{1}{2}$ wave sections stacked directly on top of each other will create two standing $\frac{1}{2}$ waves of opposite polarity and will cancel each other out.
- The phasing coil is used to nullify the energy of one of the standing $\frac{1}{2}$ waves so that the next standing $\frac{1}{2}$ wave formed on the next rod section is of the same polarity as the standing $\frac{1}{2}$ wave formed on the first rod section.
- As these $\frac{1}{2}$ wave pulses are emitted from the antenna, in some directions the waves will join together and increase the signal strength (the gain) in that direction.



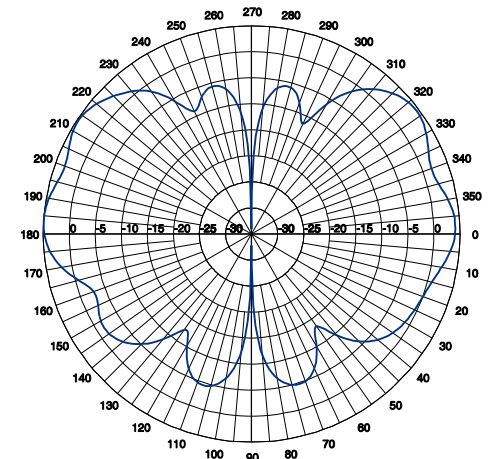
Antenna Basics

Gain

- In other directions, the waves slip out of phase and actually cancel each other out. The pattern formed by the waves adding together and canceling each other out is called the **Radiation Pattern**. It is the shape of the radiated energy from the antenna.
- In order for antennas to communicate well with each other, they must both be located within each other's radiation pattern.
- The shape of the radiation pattern together with the amount of energy radiated can be focused in a particular direction; its size and shape determines the gain.



3 dB Gain Antenna Elevation Pattern

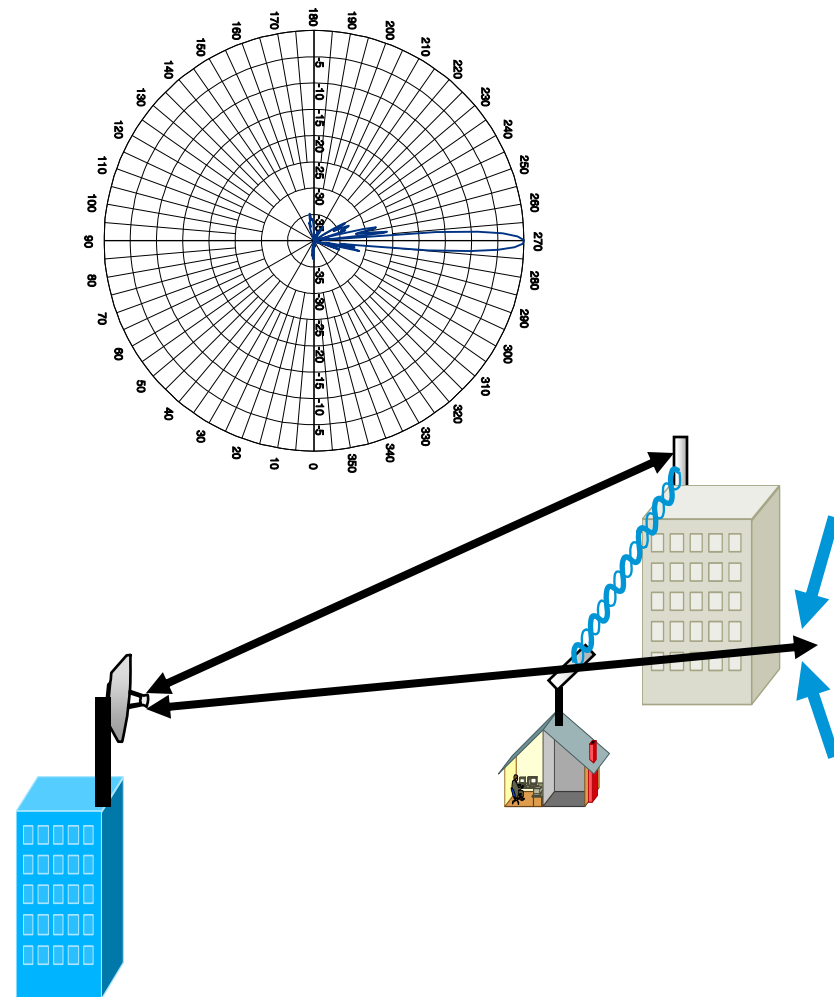


5 dB Gain Antenna Elevation Pattern

Antenna Basics

Gain

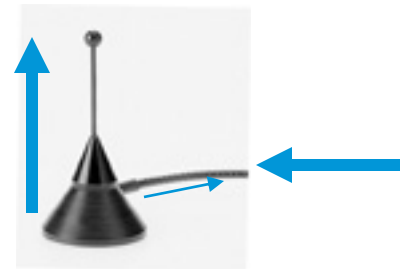
- Antenna gain is achieved (increased) by concentrating the radiation pattern of the antenna. This is done by narrowing the vertical elevation or horizontal azimuth pattern.
- If communicating over long distances, high gain antennas are recommended. However, if the transmitting antenna, and the receiving antenna are close to each other, a high gain antenna may cause the signal to spread far beyond the receiver antenna, resulting in poor performance and causing possible interference with other radio communications.



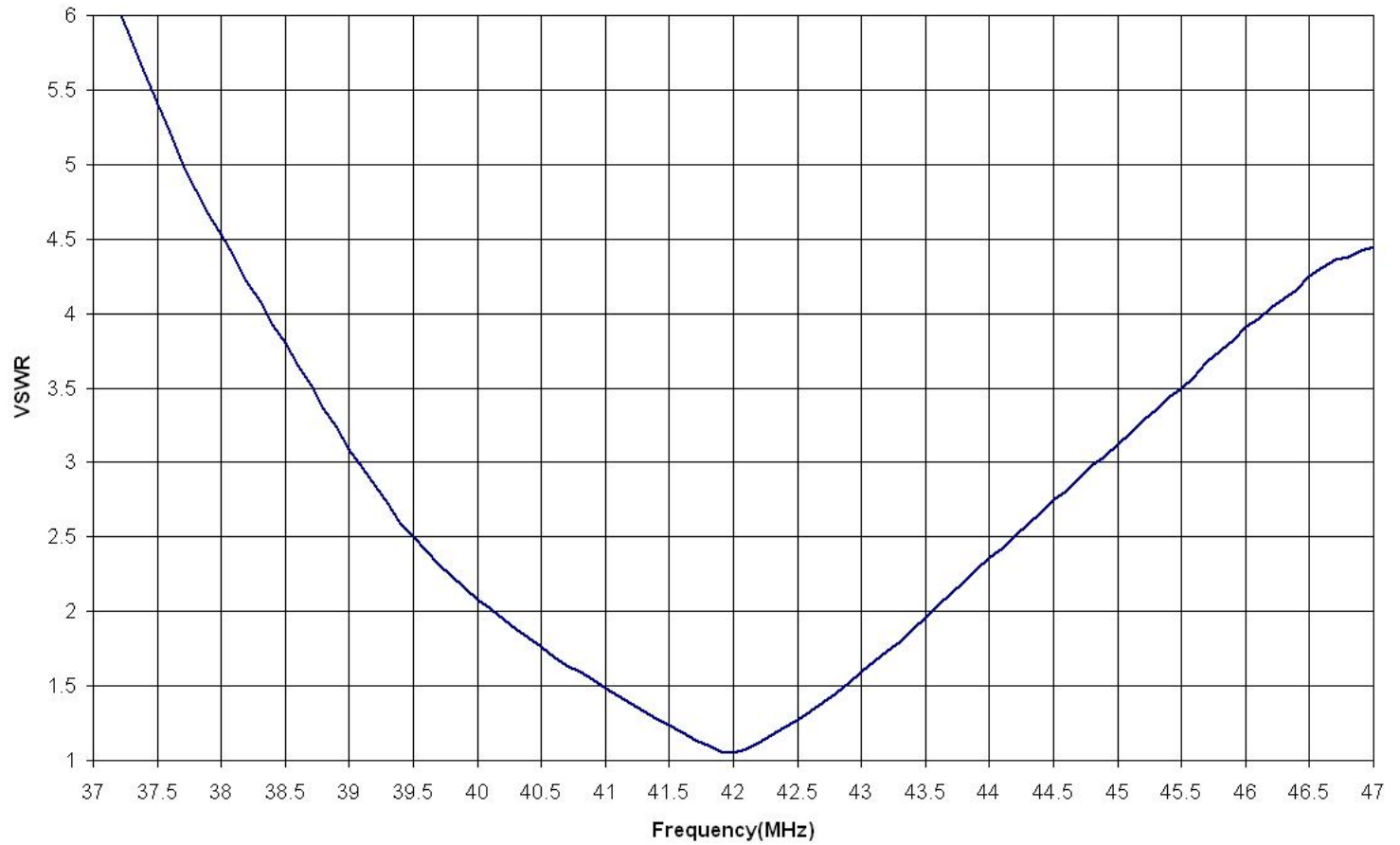
Antenna Basics

VSWR

- The VSWR indicates how efficiently an antenna allows energy to pass through it to be received by another antenna.
- If the antenna has a poor VSWR value, the energy will be reflected back through the coaxial cable in the opposite direction of the energy coming from the radio.
- The antenna's **resonant point** is where the maximum amount of energy passes through the antenna with the least amount of energy reflected back through the coaxial cable. It is the value at which the antenna operates most efficiently.
- The optimal VSWR ratio is 1:1 (100% efficiency); a VSWR of 2:1 indicates that 89% of the energy is radiated by the antenna, and 11% is being reflected back through the coax. **It is considered the highest ratio for acceptable performance.**



VSWR Chart



Antenna Basics

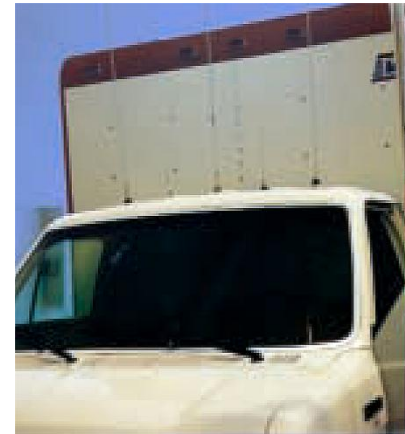
Remember!

- Gain, radiation pattern and efficiency are closely related. Changing one will most likely affect the other two.
- When looking for an antenna solution, it is important to take these three variables together into consideration in order to judge how effectively the antenna will radiate.

Antenna Types

- **Mobile Antennas**

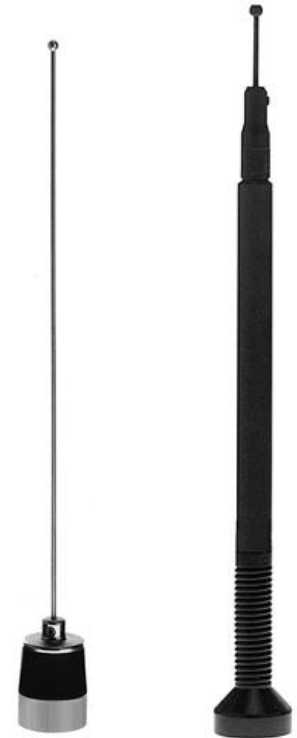
- Used on automobiles, trucks, buses, trains and other vehicles
- Have moderate gain – typically unity, 3 dB or 5 dB
- Communicate with other mobile antennas or to a fixed base (base station) antenna
- Medium range capacity
- Low frequencies/tall
- High frequencies/short



Antenna Types

- **Mobile Antennas**

- The basic mobile antenna is the $\frac{1}{4}$ wave over a ground plane
- It resonates at 50 ohms impedance
- It is $\frac{1}{4}$ wave long, but requires $\frac{1}{4}$ wavelength of ground plane
- The ground plane should be of equal size all around the antenna for it to radiate properly.
- It is the unity gain reference
- Some antennas are designed to operate **without** a ground plane (used on vehicles with fiberglass or composite plastic roofs.)
- No ground plane antennas utilize a base loaded coil and capacitor combination to achieve the ground plane necessary for operation.
- Elevated feed antennas do not require a ground plane. They are center fed $\frac{1}{2}$ wave dipoles (one $\frac{1}{4}$ wave element is the rod above the base, and the other $\frac{1}{4}$ wave element is the brass tube in the base).



Choosing the Proper Mobile Antenna

- **Size:**
 - Frequency of operation and gain of the antenna determine the size. Consider your space limitations (overhead clearance)
- **Ground Plane:**
 - Ground plane for mobile antennas must be at least one-quarter wavelength radius around the antenna. Consider the ground plane size before you choose an antenna or its location.

<u>Frequency</u>	<u>Radius / ¼ wavelength</u>
27 MHz	109"
40 MHz	73-1/2"
430 MHz	6-7/8"
450 MHz	6-1/2"
835 MHz	3-1/2"

- **Mount:**
 - Optimal location is the center of the roof. Ordinarily, a ¾ hole mount is very efficient. Antenna height may become a problem in some cases – consider other mount options
 - Permanent type mounts are most common. Magnetic base mounts and windshield tape mounts are other options.

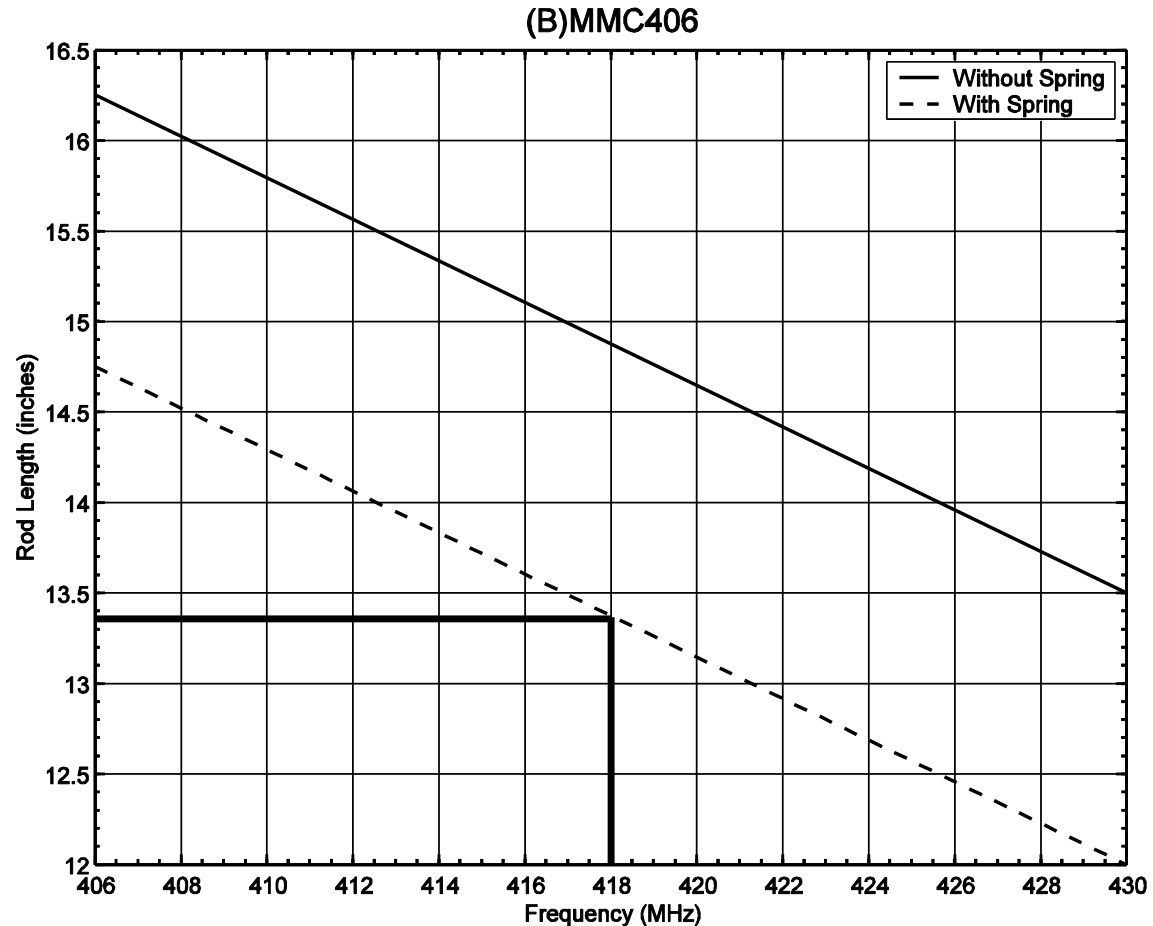
Choosing the Proper Mobile Antenna

- **Gain:**
 - To increase gain, the antenna has to be made longer. The mounting requirements of your application will help determine the maximum desired length of the antenna.
- **Radiation Pattern:**
 - Antenna gain is achieved by concentrating the radiation of the antenna at an angle perpendicular to the antenna (i.e. the horizon). The resulting radiation pattern must be reached by another antenna's radiation pattern in order to communicate. Too much gain may prevent this.
- **Bandwidth:**
 - This is the range of frequencies where the VSWR of the antenna is less than 2:1. This is a function of both gain and frequency; as gain increases, the bandwidth will decrease. This should be considered if coverage of more than one frequency is desired.

Cutting Charts

- Since the resonant frequency of the antenna is determined by its overall length, if the length of the antenna is changed, the resonant frequency will change. This can be done by shortening the antenna rod.
- A cutting chart is a graph of frequency versus rod length for a particular antenna. It can be used to determine the proper length for the antenna rod. It is suggested that a rod be cut slightly longer than the cutting chart suggests. Then test the reflected power and cut more if needed. Avoid cutting too short.

Cutting Chart Example



The dark line indicates that the approximate length for a rod tuned to 418MHz is 13.375 inches.

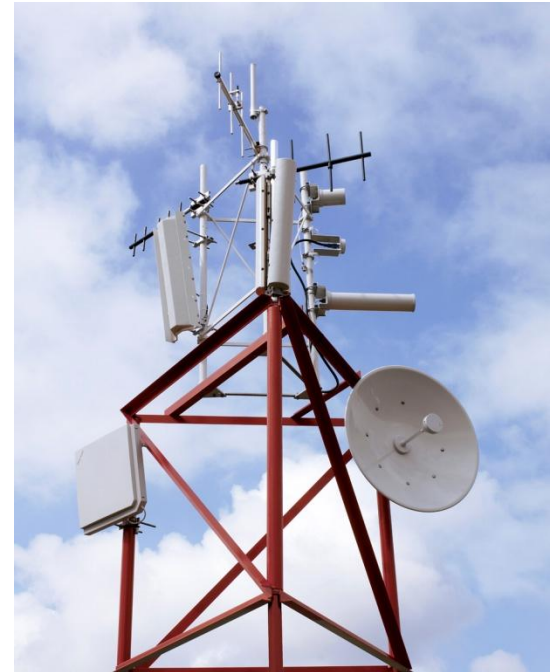
Antenna Types

- Portable “Rubber Duck” Antennas
 - Used on small hand-held telephones, radios or scanners to communicate with each other
 - Made of soft, flexible, spring-like material that does not break easily
 - Available with a variety of connector options and mechanical features
 - They require a ground plane
 - Typically low gain – unity, 2 dB or 3 dB
 - Short range capability
 - To choose a model, consider the mechanical features required (swivel, knuckle rotation, etc.) and the desired frequency and connector



Antenna Types

- **Base Station Antennas**
 - Typically installed on towers or building tops
 - Used to transmit strong signals at a distance to other mobile, portable or base station antennas
 - Heavily built to survive wind, rain and ice
 - Can be mounted vertically or horizontally
 - Two types: directional or omnidirectional



Antenna Types

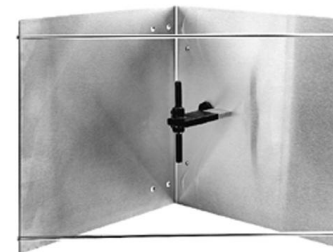
- Base Station Antennas
 - The basic base station antenna is the $\frac{1}{2}$ wave dipole
 - When tuned, it resonates at 50 ohms impedance
 - Physically $\frac{1}{2}$ wavelength long
 - Requires no ground plane
 - Unity gain reference



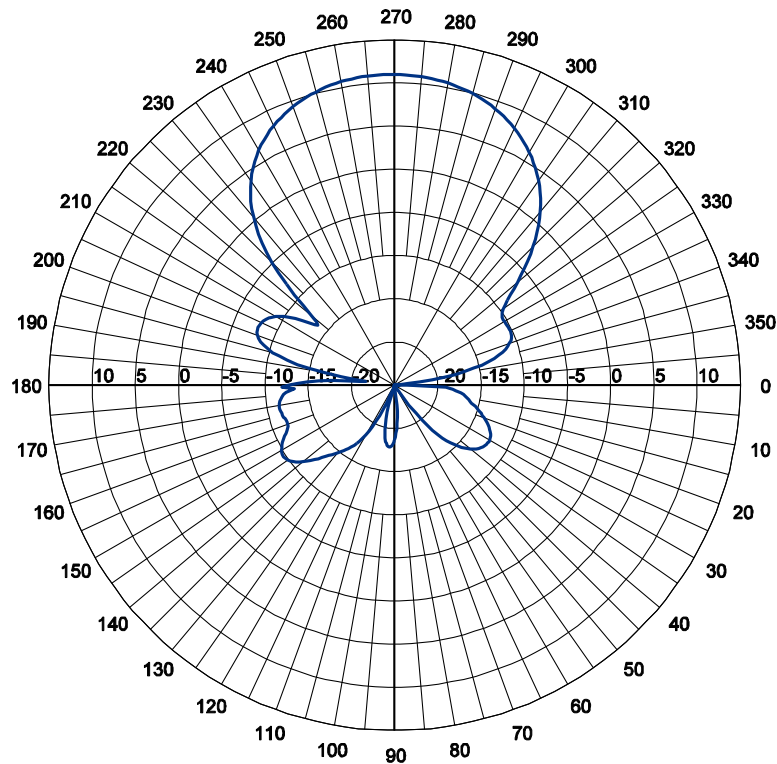
Antenna Types

- Base Station Antennas
 - Directional

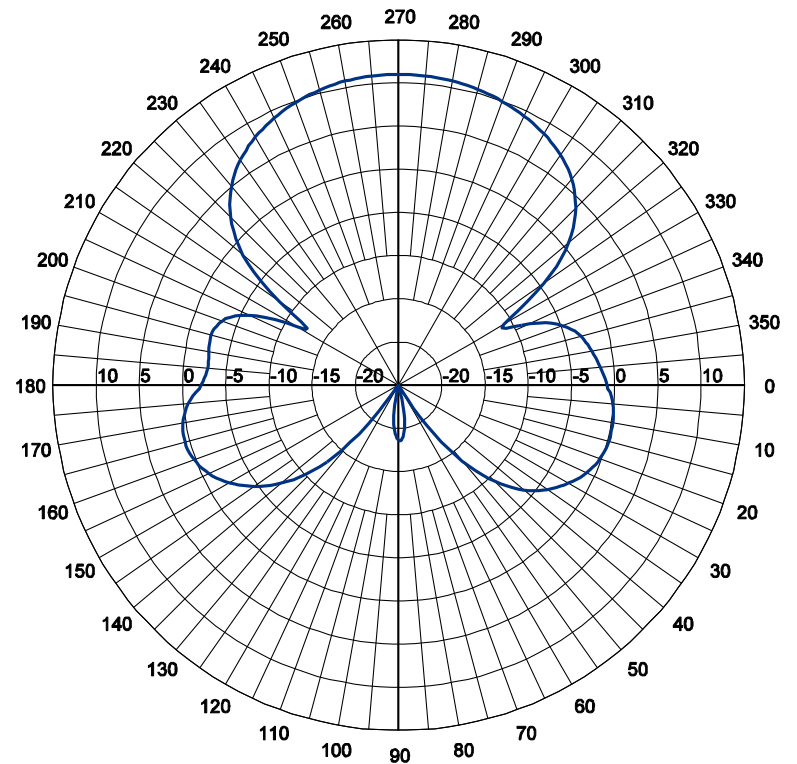
- Focus all of the radiated signal towards a targeted area
- Usually higher gain
- Directional yagi, corner reflector, parabolic dishes, sectors and panel antennas are the most common
- Typically mast mounted (panels can be wall mounted), these antennas are used for long range communications, or where the customer has strict pattern requirements



Directional Radiation Patterns



Elevation Pattern -
Yagi



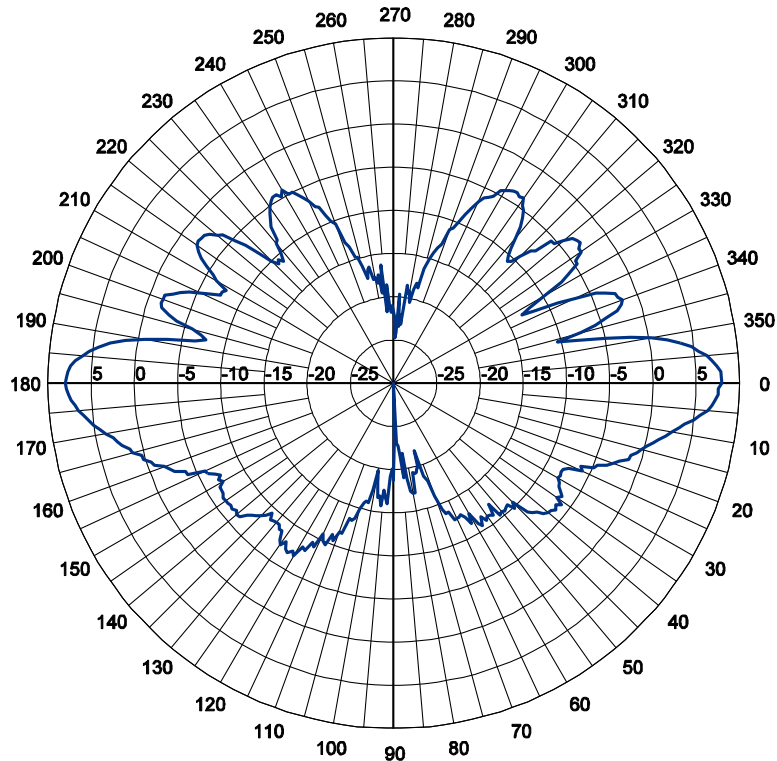
Azimuth Pattern -
Yagi

Antenna Types

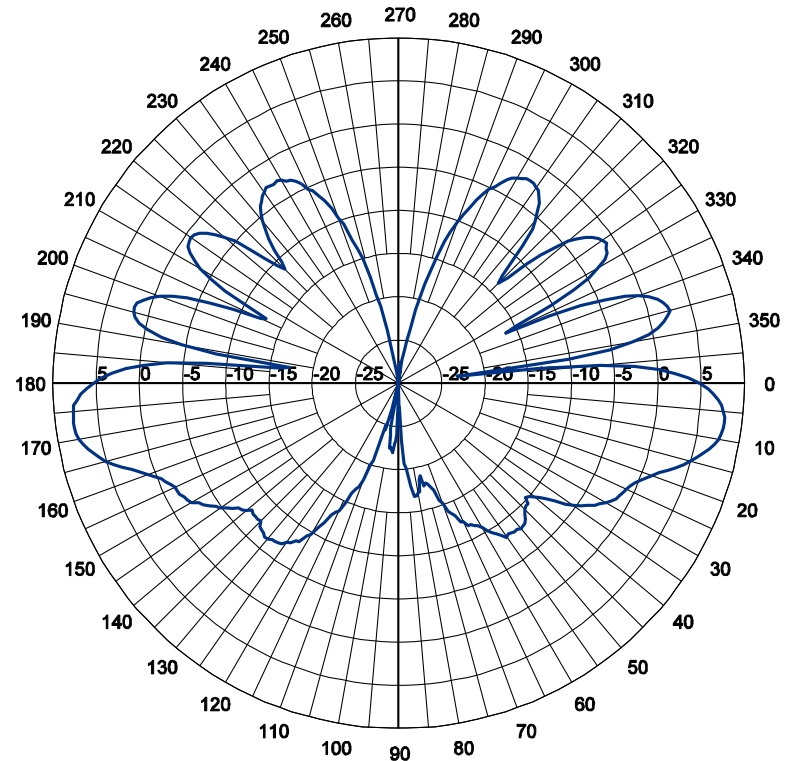
- Base Station Antennas
 - Omnidirectional
 - Emit signals in all directions toward the horizon and are usually lower in gain than directional antennas
 - Antennas are encased in tubing housing, usually made of fiberglass, aluminum or plastic.
 - Typically mast mounted



Omnidirectional Radiation Patterns



Elevation Pattern -
Omni



Elevation Pattern – Omni
With 7 dB electrical downtilt

Transmission Lines Cable

- Much like the antenna, the transmission components (i.e. cable and connectors) have a direct impact on the performance of the communications system.
- Cable quality is commonly rated according to the following criteria:
 - **Characteristic impedance:** the ratio of voltage to current in a cable of infinite length - commonly to 50 or 75 Ohms.
 - **Power rating:** the maximum power that it will endure without causing electrical problems. Measured in Watts.
 - **Attenuation:** signal loss in a given length of cable, at a given frequency. It is a function of cable size and length, for longer runs a high performance, low loss cable is recommended. Measured as dB/100ft.
 - **Velocity of propagation:** transmission speed of an electrical signal traveling a length of cable, as compared with the speed of light in free space. Measured in percentages.
 - **Shielding efficiency:** depends on the construction of its outer conductor. Usually single (85%-90% coverage) or double braid (95%-98% coverage.)



Transmission Lines Connectors

- Cables are used to connect two points.
- To connect a cable to a radio and to an antenna, connectors are used.
- Connectors are specified by their mechanical construction, by their characteristic impedance, which should be chosen to match the cable's, and by the materials used in their construction.
- They are usually crimped or soldered to the cable.
- When choosing a connector, its electrical and mechanical features, as well as the frequency for which it is specified should be examined.



Radio Spectrum

These are some of the useful radio waves as classified into bands by the Federal Communications Commission.

Band	Abbreviation	Frequency Range
High Frequency	HF	27-29.9 MHz (includes CB and 10M Ham)
Very High Frequency	VHF	30-144 MHz 144-174 MHz 174-328.6 MHz
700 MHz Band		764-776 MHz & 794-806 MHz (Public Safety)
Ultra High Frequency	UHF	328.6-450 MHz (includes TETRA) 450-470 MHz 470-512 MHz (Two-way Radio) 806-824 (Two-way Radio) 851-869 MHz (Two-way Radio) 896-901 MHz (Two-way Radio) 935-940 MHz (Two-way Radio) 1000-1999 MHz (Includes GPS, DCS and PCS) 2000-2999 MHz (Includes WCS, ISM, UNII, WiMAX, MMDS)
Super High Frequency	SHF	3000-6000 MHz (Includes UNII and ISM)