Antennas

Most basic antenna is a quarter wave vertical. It is a quarter wavelength long and is a vertical radiator. They radiate electromagnetic radiation. Typical examples are installed on motor vehicles.

Technically the most basic antenna is an isotropic radiator. Mythical antenna radiates in all directions. Standard against which we compare some other antennas.

This type of antenna relies upon an artificial ground of either drooping radials or a car body to act as ground. Sometimes the antenna is worked against an actual ground. What does this mean? It works against the ground (earth).

Polarization

Orientation of electromagnetic waves far from the source. Depending on how antenna oriented physically determines its polarization.

Linear: vertical, horizontal, and oblique.

Circular: circular right hand (RHCP), circular left hand (LHCP, elliptical right hand and elliptical left hand. Clockwise rotation of electromagnetic wave is right-hand polarization, counterclockwise rotation is left-hand.

Antenna erected vertically is vertically polarized. Antenna erected horizontally is horizontally polarized. Other specialized antennas exist with cross polarization, having both vertical and horizontal components and we can have circular polarization.

Polarization has to do with the electric portion of the electromagnetic field.

Important if trying to get maximum performance from antennas. Best performance when match polarization of transmitting antenna and receiving antenna(s). Get good separation with 90 degree separation with QAM, light polarization, magnetics (put audio track at 90 degree difference to video track). If there is a chance of co-channel interference, the license may stipulate polarization. When a signal is transmitted at one polarization but received at a different polarization there will be a lot of loss.

Antennas are actually tuned circuits. Resonant rise of voltage gives the receiver more voltage out of an antenna.

Power Gain

For an antenna, it is the ratio of power input to antenna to the power output from the antenna. Measured in decibels. This gain is most often referred to with the units of dBi, logarithmic gain relative to an isotropic antenna. An isotropic antenna has a perfect spherical radiation pattern and a linear gain of one.

Directivity

The directive gain of an antenna is a measure of the concentration of the radiated power in a particular direction. How is this done? What kind of antenna is obviously directional? A satellite dish (parabolic).

Antenna Types

Many different types.

- Dipole
- Multiple Element Dipole
- Yagi
- Flat Panel
- Parabolic Dish
- Slotted
- Microstrip – printed onto the circuit board of the cell phone

Dipole Antenna

Generalized radiation pattern. Best used to transmit/receive from broad side of the antenna (orienting the antenna perpendicular to the direction of the transmitted signal); need the larger area of the broad side in order to induce voltage in the antenna. Sensitive to any movement away from perfectly vertical position. Can move about 45 degrees from perfect vertical before performance of antenna degrades by more than half.

A wire is a tuned circuit. What makes up a tuned circuit? Inductor and capacitor. Where is the inductor and capacitor? Capacitance between antenna and ground/earth. Inductance is the actual wire.

From the azimuth pattern, you find that the antennas work equally well in a full 360 degrees around then antenna. Physically, dipole antennas are cylindrical in nature. Usually fed through an input coming up to the bottom of the antenna but can be fed into the center of the antenna as well. Radiation pattern is $\sin^2$ theta.

Half Wave Dipole

Antenna is balanced, coax is unbalanced, so need balun between them. Diagram 1.

Becomes common where space permits. Mostly horizontal for practical reasons.

Left and right halves are ¼ wave sections. Input impedance nominally 50 ohms. That's why there is 50 ohm coax. 50 ohm coax used for radio, and this is why.

Height above ground and proximity to other large objects plays important part. Can hang one in attic with fine gauge wire.

Azimuth pattern and elevation pattern. Elevation pattern (z vs. y) has the two lobes typical of a dipole. Azimuth pattern (x vs. y) has a single circle in the middle.

Lambda means wavelength. Lambda over 2 means half-wave.

Folded Dipole Antenna

Only ever seen as a TV antenna (or FM antenna). 300 ohm impedance. Wide bandwidth (one octave); need this for TV. Mainly used in conjunction with yagi antennas. FM frequency range 88-108 MHz.

Pick a frequency somewhere in between.

Multiple Element Dipole Antennas

Same general characteristics as dipole. Similar elevation radiation pattern and azimuth pattern. Biggest difference is directionality in elevation pattern, and increased gain from multiple elements. Can configure with different amounts of gain.

Elevation Pattern

Diagram 2.

Yagi

More for receiving antennas. Direction forced by phasing on transmitting antennas.

Array of independent antenna elements, with only one of the elements driven to transmit electromagnetic waves. Has elements including driven element, reflector(s), and director(s). Number of elements (specifically number of directors) determines the gain and directivity. The elements are all those The rest of the antenna is at ground potential; the driven element is off ground.

Not as directional as parabolic dish antennas but more directional than flat panel antennas.

Bandwidth decreases as number of elements increases.

Yagi-Uda

Developed by Japanese scientists in 1930's. Half-wave dipole, rear reflector and zero, one or more directors.

UHF Yagi

19 elements, 17 directors, fancy folded dipole with low-noise mast head amplifier, and reflector. Vertically polarized. Photo presented.

Stacked half wave dipole or collinear array

Consist of four sets of half-wave dipole and reflector only but mounted one above another. Used when just had VHF TV. Wires connected to each dipole done in a phased way, comprising a collinear antenna array and so arranged for improved gain.

Loop Antennas

Comes in amazing number of configurations. Small space antenna, extremely inefficient. Works on differences in voltages induced by current flowing in sides of antenna. Usually requires associated amplifier for low voltages. Responds well to signals arriving in one direction (coplanar to the loop) and not at 90 degrees off. If come from perpendicular, equal signal currents cancel each other out. Technically speaking, loop antenna responds to magnetic field rather than the electric field.

Rather than being omnidirectional, loop antenna responds to cosine of angle between its face and direction of arrival of electromagnetic wave. Produces figure 8 pattern; no problem for receiving. Addition of small whip antenna in conjunction with proper phasing allows direction ambiguity to be resolved and we have an antenna relatively ideal for direction finding.

In AM radio, huge coil of fine wire around a ferrite core. Quarter or half wave at AM frequencies is huge. Wind wire around core, called a loop stick antenna. This is most common loop antenna you will encounter. Ferrite rod for greater efficiency and size reduction. Could be circular or rectangular. If rotate through 360 degrees, should notice two points 180 degrees apart where signals strongest, and two other points 180 degrees apart where signals weakest (these are called *nulls*). Useful for radio direction finding.

Flat Panel

Configured in patch type format in shape of square or rectangle. Most of power radiated in one direction in both vertical and horizontal planes. Can provide excellent directivity and considerable gain.

Parabolic Dish

Use physical features and multiple elements for extremely high gain and sharp directivity. Use a reflective dish in parabolic shape to focus all received electromagnetic waves on the antenna to a single point. Also works to catch all energy radiated from the antenna and focus it in a narrow beam when transmitting.

Slotted

Similar radiation characteristics to dipole. Consists only of narrow slot cut into ground plane. Little gain, low directionality. Easy to build and integrate, low cost.

Microstrip

Made to emulate many different styles of antennas. Made with PCB traces on PC boards, so small and lightweight. Can't handle much output power, made for very specific frequency ranges. Not well suited for wideband communications systems.

Comparison Chart

Chart	*Radiation Patterns*	*Power Gain*	*Directivity*	*Polarization*
Multi Element	Broadside	Low	Low	Linear
Dipole	Broadside	Low/Medium	Low	Linear
Flat Panel	Broadside	Medium	Medium/High	Linear/Circular
Parabolic Dish	Broadside	High	High	Linear/Circular
Yagi	Endfire	Medium/High	Medium/High	Linear
Slotted	Broadside	Low/Medium	Low/Medium	Linear
Microstrip	Endfire	Medium	Medium	Linear

Effective radiated power (**ERP**) is the input power multiplied by the antenna gain. If use circular polarization, can transmit with twice the power.

HAAT – height above average terrain.

Antenna Impedance

Ratio at any given point in antenna of voltage to current. Depending on height above ground, influence of surrounding objects and other factors, a quarter wave antenna with near perfect ground exhibits a nominal input impedance of around 36 ohms. A half wave dipole antenna is nominally 75 ohms while a half wave folded dipole is nominally 300 ohms. This indicates why we have 75 ohm coaxial cable and 300 ohm ribbon line for TV antennas. Quarter wave antenna with drooping quarter wave radians exhibits nominal 50 ohms impedance, one reason for existence of 50 ohm coax cables. Antenna design drove cable impedance.

Baluns

Transmission line transformer for converting balanced input to unbalanced output or vice versa. May or may not provide wide frequency range impedance transformation depending upon configuration used. Earlier days, extensive use made of 300 ohm twin lead ribbon cable to feed signals to TV receiver. When color TV introduced ribbon cable often created problems which could be rectified by use of coaxial cable. Since not twisted pair, things happen between the two lines at slightly different times, so noise doesn't quite cancel, and found out that it affected the color. Used coax, but that resulted in need to connect balanced with unbalanced. Now, balun built into the TV receiver and we bring coax to the receiver.

Wavelength

Originally in radio, custom to refer to wavelength not frequency. Radio waves travel at light speed (300 million meters/second). Wavelength = 300/Frequency in MHz. As frequencies increased, by about the 1930's term short-wave came about due to decreased wavelength.

What is Impedance?

A simple example. Assume have 4 items on workbench: series of 8 AA 1.5V batteries for 12V supply, 12 heavy duty car battery fully charged (capable of lots of current), small 12v bulb of very very low wattage, very high wattage car high-beam headlight (probably 65 or 80 watts).

Low wattage bulb + AA cells = works.

High wattage headlight + car battery = works

Both are sort of matched: light duty to light duty, heavy duty to heavy duty.

What happens if AA batteries on headlight, or low wattage bulb on car battery? Headlight doesn't even light up on AA batteries.

Heavy duty battery capable of delivering large amounts of power, series AA batteries capable of delivering only relatively minimal power. Car battery is a low impedance source, other is high impedance source. On other hand, high beam headlight capable of consuming large amounts of power (low impedance load), but little bulb capable of consuming only minimal amounts of power (high impedance load).

Impedance Expression

Applied to any electrical entity which impedes the flow of current. Could denote resistance, reactance, or complex combination of both. Leads us to Q.

What is Q?

Important property of both inductors and capacitors; it is dimensionless. The Q of capacitors is generally so high as to be ignored however it is the Q of inductors we mainly concern ourselves with.

All inductors exhibit some extra resistance to AC or RF. Q is the reactance of the inductor divided by the resistance. Formula: Q = (2 * pi * f * L) / R. This factor Q largely determines the sharpness of the resonant circuits. The actual resistance of wire to AC or RF is often far greater than the DC resistance.

What can substitute for the resistance of the winding that I can use to affect Q? Put a resistor in parallel with the tank circuit. Diagram 3. Q means quality which is dimensionless. Increased resistance will widen the curve. Diagram 4.

At lower frequencies (say 500 kHz) the Q is materially improved by using Litz wire to reduce RF resistance. Litz wire is bunched wire strands of almost minute wire size. 220 strands of #44 wire (each strand 2 mils diameter) wound on toroid to produce extremely high Q of over 500 at 250 kHz. That is unloaded Q.

#44 wire has cross sectional area of 3.1416 mils squared. With 220 strands, total cross sectional area is 601 mils squared or about 30 mils diameter. The nearest equivalent wire size for a similar cross sectional area is #20 wire.

Had toroid been wound with same number of turns of the #20 wire, the inductance would probably have been about the same but the Q would certainly been far, far less.

Skin Effect and Q

Perimeter of circle is pi * diameter. For #20 wire (32 mils), above equivalent is 30 mils, total perimeter for RF to travel on of pi * diameter = 94 mils. On other hand, #44 diameter of 2 mils, just 6.2832 mils of perimeter but multiplied by 220 times it is 1382 mils instead of 94 mils. This is a huge distance. This is why using Litz wire to vastly improve Q. Negligible above 2 MHz.

Why Q Important?

Bandwidth of filter determined mainly by loaded Q. Limitation on design Q is available inductor Q. Usually design Q cannot exceed about 1/5 the available inductor Q else circuit losses become prohibitive. Typical inductor Q of 100, loaded Q is 20. Filter bandwidth will be center frequency divided by 20. At 7.0 MHz is 350 MHz wide. At lower frequencies such as 455 kHz it would be 22 kHz. Channel spacing is 10 kHz for AM stations, so 22 kHz is a bit wide, so use special wire to only pass 10 kHz.

Why Insulators are Built that Way

The insulator wire holes are oriented 90 degrees differently from each other. Also, each wire runs through channels along the length of the insulator to go through the holes on the opposite side of the direction from which the wire came. This ensure that if the insulator breaks, the wires will still be connected together, maintaining physical stability.

Why there are Multiple Insulators in Guy Wires

Break up the guy wires so that none of the segments are lengths that are a multiple of ¼ wavelength.

Break

Projects