Antennas and Propagation

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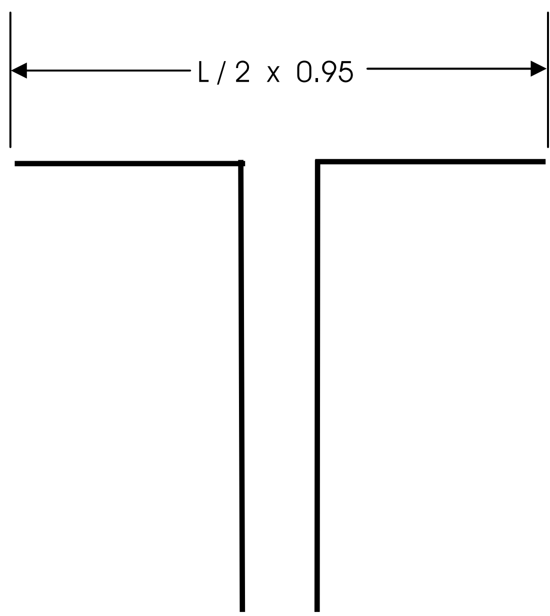
Any conducting material can act as an antenna. Designers go to "great lengths" to design antennas in order to control their radiation pattern and gain. The two main factors in antenna design and operation are the geometry of the antenna and the proximity of the antenna to nearby objects.

The Half Wave Dipole

Each half of the half wave dipole is 1/4 wavelength. Together they make up 1/2 wavelength.

The free space wavelength of an electromagnetic wave is: L = c / f (Hz), where c = 300,000,000 meters/second (velocity of light) or L (meters) = 300 / f (MHz).

The velocity of a wave along an antenna or transmission is slower than it is in free space, usually about 95 % of c. Therefore, a half wave dipole is 5 % shorter than it's free space wavelength.

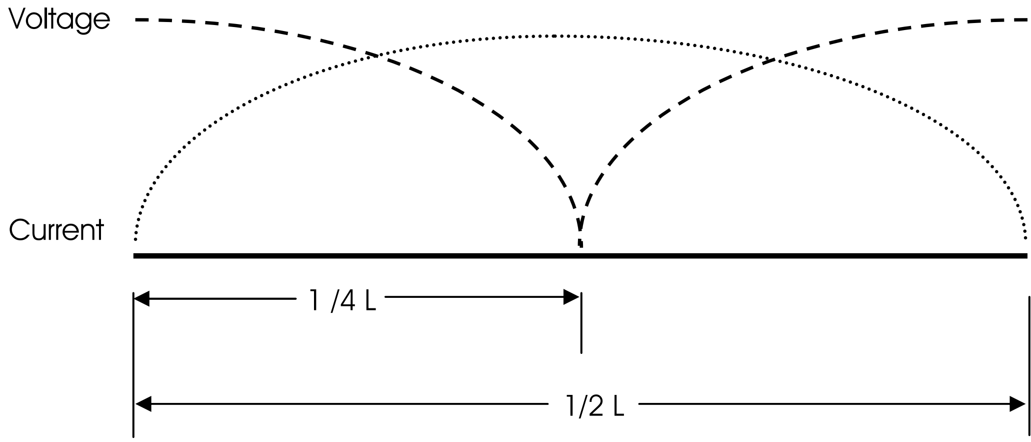


A 7 MHz. half wave dipole length = (c / f) x 0.95 x 0.5 meters

A 7 MHz. half wave dipole length = (300 / 7) x 0.95 x 0.5 = 20.36 meters

A 7 MHz. half wave dipole length = ((c / f) x 0.95 x 0.5) x 3.2808 feet

A 7 MHz. half wave dipole length = ((300 / 7) x 0.95 x 0.5) x 3.2808 = 66.79 feet



The voltage and current waves of an antenna are 90 degrees out of phase with each other.

If the current is high and the voltage is low, the impedance will be low (R = E/I). The impedance is the lowest at the center of a half wave dipole (72 ohms). At the ends, the impedance is the highest (2,000-3,000 ohms).

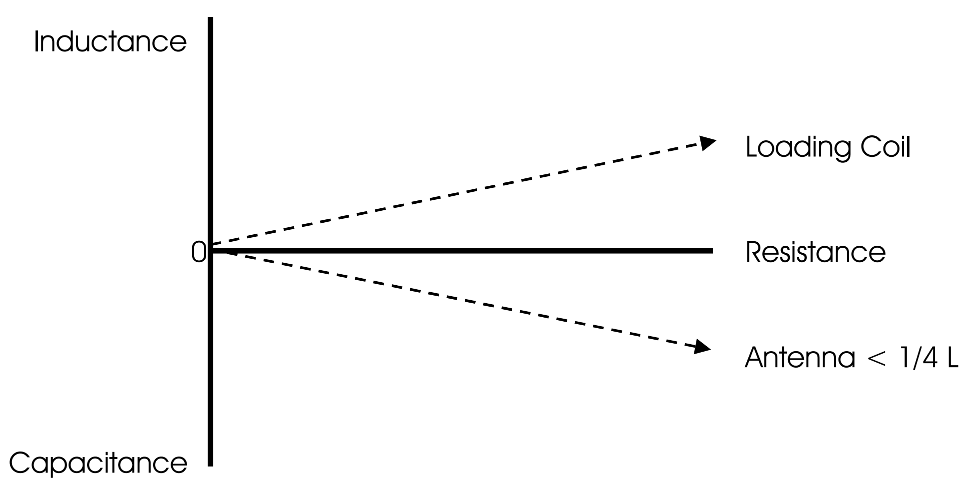
The half wave dipole is resonant when the length is made such that the mid point yields the lowest voltage and highest current.

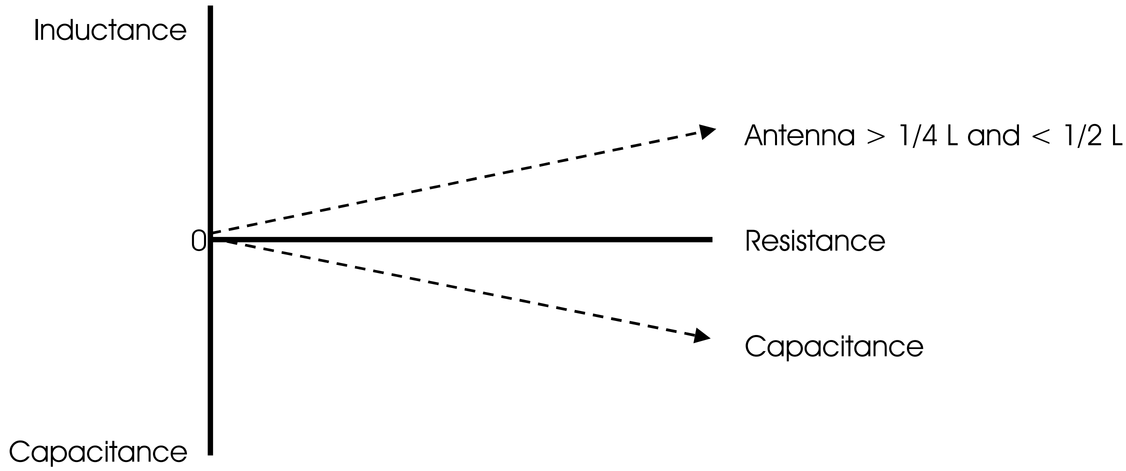
A 1/4 wavelength antenna or an antenna of multiple 1/4 wavelengths is a resonant antenna.

Any circuit is resonant when the inductive reactance and capacitive reactance are equal. At resonance, inductive reactance and capacitive reactance are 180 degrees apart and when equal, cancel each other, leaving only the resistance component. The shortest length of wire that can be resonant is a quarter wavelength.

If the antenna is shorter than a quarter wavelength, it will have a capacitive reactance. It will require the addition of an inductive reactance (loading coil) to cancel the capacitive reactance and become resonant.

If the antenna is longer than a quarter wavelength and shorter than a half wavelength, it will have an inductive reactance. It will require the addition of a capacitive reactance (capacitor) to cancel the inductive reactance and become resonant.





The Five-Eighth Wave Ground Plane Antenna

Normally, a 5/8 L antenna cannot be resonant because it is not a multiple of a 1/4 L. However they are commonly found as vertical antennas. The vertical section is 5/8 L, which has a capacitive reactance because it is longer than two 1/4 L's. An inductive loading coil is added somewhere along the length of the vertical to cancel the capacitive reactance. The 5/8 wave antenna is actually tuned to 3/4 L by the addition of the loading coil making it effectively a 3/4 wavelength antenna. The four horizontal radials are 1/4 wavelength each.

The Quarter Wave Ground Plane Antenna

The quarter wave ground plane antenna is often used with radials or installed on a flat conducting surface, such as the roof of a car. It is simply a reflector whereby some of the radiation will be reflected by the ground plan and interact with the incident wave from the antenna. This kind of antenna provides an omni directional pattern.

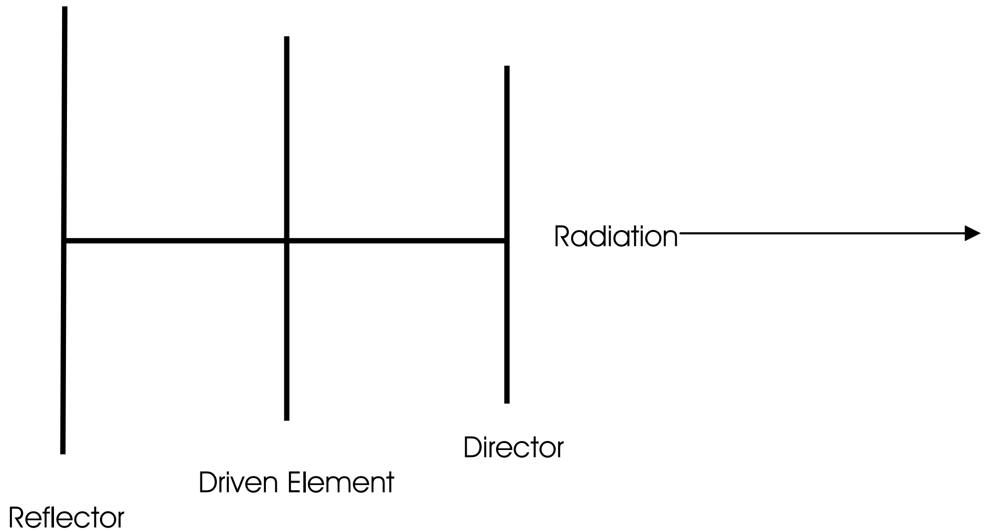
The Yagi Antenna

A Yagi antenna has one driven element, a dipole, and at least one other parasitic element. The parasitic dipoles receive radiation from the main dipole and re-radiate it. The energy is radiated from the main driven element and after a short delay, energy is picked up and re-radiated by the parasitic elements. The antenna can be made to radiate in one direction by controlling the spacing and length of the parasitic elements to yield a greater gain.

The three element Yagi has: a driven element, a reflector element, and a director element. The primary direction of radiation is in the direction of the driven element to director element. The driven element length is determined by equations used to calculate the dipole antenna. The reflector is 5% longer than the driven element and the director is 5% shorter than the driven element. The spacing between the elements are usually between 0.15 to 0.2 wavelengths (0.18 for maximum forward gain).

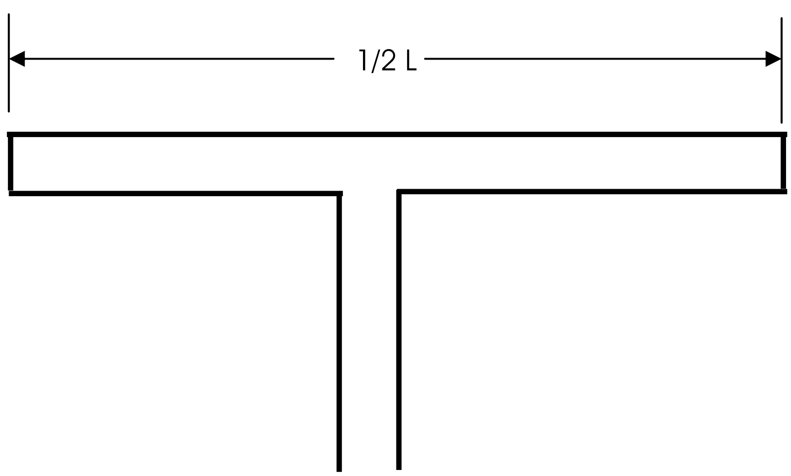
Propagation delays caused by the spacing of the elements, causes wave cancellation towards the rear of the antenna and wave reinforcement towards the front of the antenna. The gain is usually about 6-8.5 dB over a dipole.

Additional elements can be added to a Yagi to increase the power gain. Additional elements are always directors placed in front of the driven element. Doubling the number of directors, will increase the gain by about 3 dB. Adding parasitic elements to a Yagi decreases the antenna bandwidth.



The Folded Dipole Antenna

The folded dipole antenna is an antenna that consists of two dipoles connected in parallel. Folding the dipole increases the feed point impedance. Two dipoles folded, the feed point resistance increases by 2 squared (4), which is equal to 300 ohms. Three parallel dipoles increases by 2 cubed (8). The dipole forming the driven element of a Yagi antenna is often folded to increase the feed point impedance by 4.



Trapped Antennas

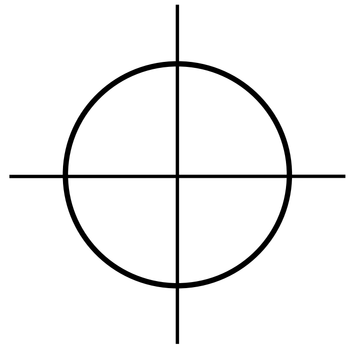
Traps are parallel tuned circuits used on HF antennas that have high impedances used to switch different sections of the antenna in and out of resonance. When the traps are not used at their resonant frequencies, they become loading coils and shorten the effective length of the antenna wire needed.

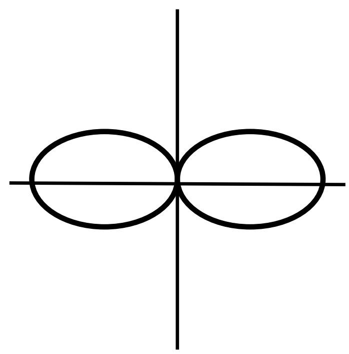
Isotropic and Practical Antennas

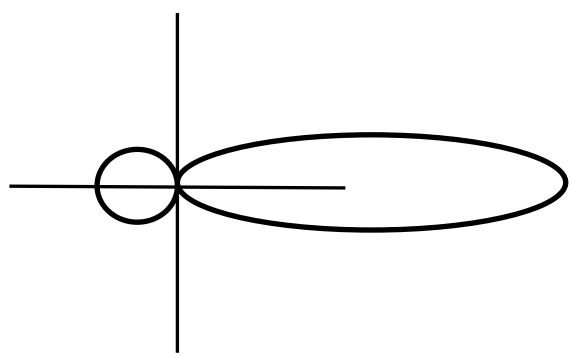
The isotropic antenna is a theoretical antenna that radiates equally in all directions and serves as a reference. A half wave dipole antenna has a gain of 2.14 dB above an isotropic antenna. Rubber duck antennas have a loss of several dB below an isotropic antenna.

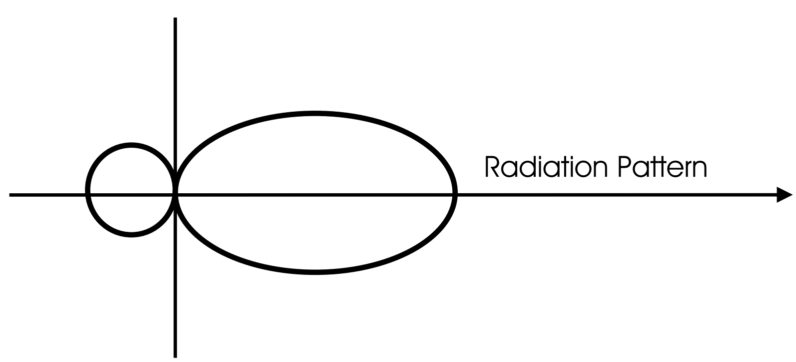
An antenna that directs most of the electromagnetic radiation in one direction has a power advantage over an omni directional antenna. The power gain of an antenna is the ratio of the power radiated in its primary direction as compared to the isotropic antenna. A gain of 6 dB is a factor of 4 and 1 "S" point on the S-meter.

The area of a dipole's radiation pattern (A1) is 1.64 times that of the isotropic's pattern (A2). Therefore, the gain can be calculated as Gain = 10 Log (A1/A2) = 10 Log (1.64/1) = 2.15 dB


Isotropic
Radiation Pattern


Dipole
Radiation Pattern


Folded Dipole
Radiation Pattern


Yagi
Radiation Pattern

Voltage Standing Wave Ratio (VSWR)

The Voltage Standing Wave Ratio (VSWR) is the ratio between the impedances of the feed line and the load. If we connect a 50 Ohm resistor at one end of a piece of 50 Ohm coaxial cable, and connect a transmitter and SWR meter at the other end, the VSWR will be 1:1. The resistor is not resonant. However, if we connect a resonant antenna that has an impedance of 144 Ohms to the end of that piece of cable, the VSWR will be 2.88:1 (VSWR = Antenna Impedance / Feed Line Impedance).

If a feed line is cut to a length that creates a VSWR measurement of 1:1 at the transmitter end of that feed line, the actual VSWR on this line is (infinity):1. Using VSWR is not the best method for tuning an antenna. The best method to measure the resonant frequency of an antenna is to use an antenna bridge at the antenna.

High VSWR does not cause feed line radiation. Most of the radiation from a coaxial cable is caused by terminating an unbalanced feed line with a balanced load. The remainder of the radiation is due to other problems such as, braid corrosion, improperly installed connectors, and signal pickup caused by routing the feed line too close to, and parallel to the antenna.

A properly terminated and installed open wire line does not radiate. Even with infinite SWR, the fields surrounding each wire cancel each other out. Terminating the line in an unbalanced load, or causing anything to come within the "field space" will cause unbalance in the line, thus allowing the line to radiate.

Propagation

The ionosphere is a layer in the Earth's atmosphere that lies in a range of 80 to 300 miles above the Earth's surface that reflects radio waves. As the sun shines on the ionosphere it changes composition and height, which affects the propagation characteristics. In general signals below 30 MHz bounce off this layer and return to Earth while signals above 30 MHz go through the layer into outer space. Radio signals that are bounced or refracted off the ionosphere are also affected by the time of day and season of the year.

During the 24-hour cycle the ionosphere changes in height above the Earth and bounces some signals while absorbing others. During the day the higher frequencies (above 10 MHz) tend to propagate while lower frequencies are absorbed. At night the reverse happens. There are many exceptions to this but it is a good general guideline.

Seasons also affect propagation. Summertime in the northern hemisphere means that higher frequencies have better propagation while in the winter the lower frequencies improve. An interesting time of the year for propagation is when the seasons change from fall to winter and from winter to spring. This is often when the best DX can be found. Because the seasonal change is occurring in both hemispheres but in the opposite direction DX from North American to Australia or southern Africa can be at its best.

Another phenomenon that affects radio propagation is the 11-year sunspot cycle. A peak occurred during the year 2000 and the next peak will occur around 2011. A sunspot low occurs at the midpoint of this cycle. When the sunspots are at their maximum propagation is at its best. At this time the higher shortwave frequencies exhibit the best propagation extending to 6 meters, which becomes quite popular during this time of the cycle. 10 meters can easily work stations worldwide with low power (even qrp) and a modest antenna.

Band (meters)	Frequency (MHz)	Use (band conditions vary for many reasons)
160	1.8 – 2.0	Night
80	3.5 – 4.0	Night and Local Day
40	7.0 – 7.3	Night and Local Day
30	10.1 – 10.15	CW and Digital
20	14.0 – 14.350	World-wide Day and Night
17	18.068 – 18.168	World-wide Day and Night
15	21.0 – 21.450	Primarily Daytime
12	24.890 24.990	Daytime During Sunspot Highs
10	28.0 – 29.7	Daytime During Sunspot Highs
6	50 – 54	Local to World-wide
2	144 – 148	Local and Medium Distance
70 cm	430 – 440	Local

Near Vertical Incidence Sky wave Antennas

NVIS propagation is a propagation pattern that uses antennas with high-angle radiation (almost 90 degrees, vertical) and low operating frequencies for a range of about 0-300 miles.

Long distance propagation uses radio waves that are reflected from the ionosphere and return to earth at some distance away. Radio waves that are radiated at a very low angle, travel a long distance to reach the ionosphere at a very shallow angle and return to earth far away. When the angle of radiation increases, the radio waves reach the ionosphere at a greater angle, and return to earth closer to their point of origin. Signals that reach the ionosphere at a higher angle of incidence will not be reflected at all, but will continue out into space. The area of reflection that would have occurred is the "skip zone". Depending on operating frequencies, antennas, and propagation conditions, this skip zone can start at roughly 12 to 18 miles and extend out to several hundred miles, preventing communications.

NVIS antennas are designed to minimize the ground wave (low takeoff angle) radiation and maximize the sky wave (very high takeoff angle, 60-90 degrees). Essentially, the NVIS antenna radiates a wave almost straight up, then bounces from the ionosphere and returns to the Earth in a circular pattern around the transmitter. Because of the near-vertical radiation angle, there is no skip zone. Communications are continuous out to several hundred miles from the transmitter. The nearly vertical angle of radiation requires the use of lower frequencies, usually 2-10 MHz. This type of propagation is excellent when communicating over hills and mountains. These frequencies are the same frequencies that contain a lot of atmospheric noise, such as distant thunderstorms. The NVIS antenna is optimized for listening to signals from nearby areas, and minimizes the reception of signals from distant sources.

One of the most effective antennas for NVIS is a dipole that is mounted from 0.1 to 0.25 wavelengths above ground. When a dipole is brought very close two ground, the angle of radiation increases. In the range of 0.1 to 0.25 wavelengths above ground, vertical and nearly vertical radiation reaches a maximum. A dipole can be used at even lower heights, resulting in some loss of vertical gain, but often, a more substantial reduction in noise and interference from distant regions. Heights of 5 to 10 feet above ground are not unusual for NVIS operation.

During a test by WOIPL, they used a 75-meter dipole at a height of 30 feet. They found the communications to be difficult. They set up a second dipole at a height of 8 feet. The background noise went from S7 to S3 and the communications with stations 25 miles and further, greatly improved. Many people find the 10 to 15 foot height to be ideal. Field tests have proven that the maximum NVIS efficiency is obtained at the 10 to 15 foot height for frequencies in the 40 meter to 75 meter range.

Skip Zones

A skip zone is the area that is not covered by sky wave radiation. In other words, the sky wave angle is such that the sky wave travels a long distance before reaching earth. The distance between the transmitting antenna and the point where the sky wave reaches the earth is the skip zone.

The "take-off angle" is the angle at which a wave leaves the transmitting antenna.

Nomograph for determining primary skip zone (one hop) as a function of radiation angle.

For a 2 or 3 element yagi at HF (7 to 14 Mhz) approx heights are:
(assuming average soil conductivity = 5 mS / meter   dielectric constant = 13)

TO Angle (degress)	Height (feet)	Distance F2 Layer (miles)
45	20	400-800
40	27	450-900
30	32	650-1,300
20	37	950-1,700
15	45	1,200-2,000
12	50	1,300-2,300
10	60	1,400-2,400

For a 2 or 3 element yagi at HF (21 to 28 Mhz) approx heights are:
(assuming average soil conductivity = 5 mS / meter   dielectric constant = 13)

TO Angle (degress)	Height (feet)	Distance F2 Layer (miles)
45	20	200-400
40	27	225-450
30	32	325-650
20	37	475-850
15	45	600-1,000
12	50	675-1,150
10	60	700-1,200