A DISCUSSION OF ANTENNA THEORY

by Paul Graham (K9ERG)

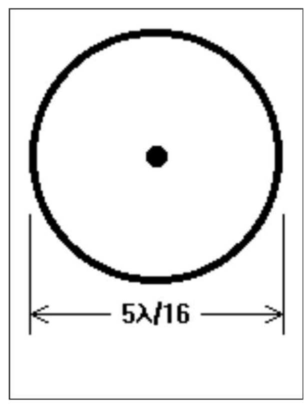
1. ANY piece of conducting material will work as an antenna on any frequency.

Even a straightened paper clip will work on 160 Meters. All we have to do is properly match the the transmitter to the the paper clip, and the paper clip will radiate ALL of the power fed to it! The aperture of this antenna will have a radius of 5/32 wavelength (.079 sq. wavelengths cross section area); essentially this is close to the theoretical "Isotropic" source. If this antenna is located in "free space", the radiation will be almost equal in all directions.

2. The ONLY reason for building sophisticated antennas is to allow us to CONTROL THE RADIATION PATTERN.

The radiation pattern is controlled by focusing the radiated energy. The geometry of the antenna and the proximity of near-by objects are the main controlling factors.

The total amount of energy radiated remains constant for a given transmitter output power. When this energy is focused, the energy radiated in one or more directions will be increased, and the energy radiated in other directions will decrease. This is what gives an antenna "gain".



3. An antenna has an aperture similar to that of a camera lens. The aperture of an isotropic source is a circle with a diameter of 5/16 wavelength.

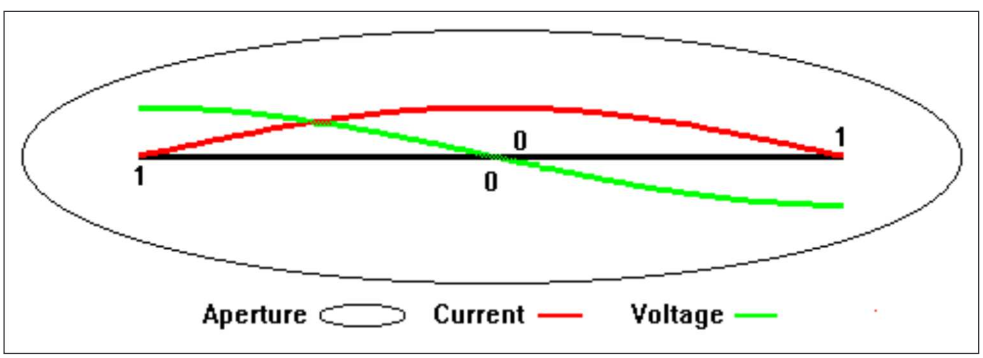
The aperture of a dipole antenna is roughly the shape of a rugby ball (elliptical) when viewed from a point 90 degrees from the line of the conductor.

The cross section area of the aperture of a dipole is 1.64 times that of an isotropic source.

When A1 = aperture of a dipole and A2 = aperture of an Isotropic Source:

$$\text{Gain} = 10 \log(A1/A2) = 10 \log(1.64/1) = 2.15 \text{ dB.}$$

4. The Dipole antenna.



Contrary to popular belief, the dipole is so named because it has two electrical poles, not two physical poles; it also has two zeros and could have been called a di-zero antenna. When the length is such that the poles are at ends of the conductor and the zeros are at the center, the antenna will be exactly 1/2 wavelength long.

Therefore:
A dipole antenna is exactly 1/2 wavelength long.

A dipole is most commonly fed at the center, where it presents a pure resistive, balanced, 68 Ohm (R68j0) load to the feed line (this is why the popular misconception of two physical poles).

A dipole can be fed anywhere along its length, however CENTER FED and END FED are the most common, and the easiest.

5. The effects of APERTURE INTERFERENCE.

Anything that enters into the aperture of an antenna will affect the operation of the antenna. The effects are pattern distortion, skewing of balance, change of feed impedance and resonant frequency shift; in other words - everything we want to control.

Sometimes it is desirable to cause intentional aperture interference. Placing other conductors into the aperture will cause severe pattern distortion. This can be beneficial when this distortion takes place in such a manner as to focus the radiated energy into a tight beam. This is the basic operating principle of parasitic beam antennas.

6. Ground mounted vertical antennas.

One common practice is to mount one half of a dipole vertically on a conducting surface (ground plane). This reduces the size of the aperture by 50%, resulting in a 3 dB loss. As we have seen, a dipole has 2.15 dB gain over an isotropic source; if a 1/4 wavelength antenna on a ground plane has 3 dB loss as compared to a dipole, that means that the "1/4 wave" antenna has 0.85 dB loss as compared to an isotropic source. Some antenna manufacturers express the gain of their products as "gain over a 1/4 wave". An antenna advertized as having 3 dB gain over a 1/4 wave is the same as as an antenna having 2.15 dBi gain or 0 dBd gain. It's the same antenna - the bigger numbers are just that - bigger numbers!

A somewhat less common practice is to mount a vertical dipole directly on the ground. This practice is fraught with problems. A portion of the aperture is beneath the ground. This induces large currents into the ground surrounding the antenna. With the high (and uncontrollable) ground resistance, these currents result in substantial voltage drops. The power lost to heating the ground does nothing more than make the worms uncomfortable. These losses can be reduced to acceptable levels by installing an extensive ground system (90 - 1/2 wavelength long radial wires placed on the ground at 4 degree spacing is about minimum). The severe aperture interference also causes the antenna to exhibit a high angle of radiation. It would be easier (and cheaper) to elevate the antenna far enough so that the aperture does not touch the ground.

7. Elevated vertical antennas:

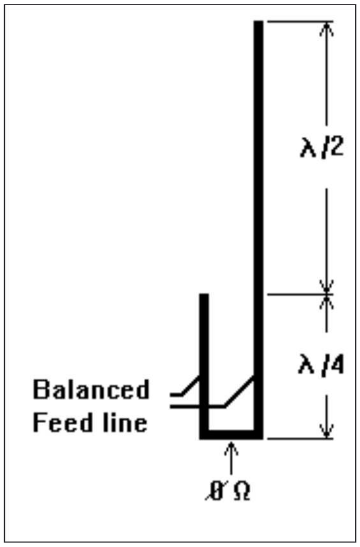
One attempt at elevating a dipole antenna resulted in what is commonly known as the 5/8 wavelength vertical antenna. The theory goes something like this:

> "If we elevate a dipole antenna 1/8 wavelength above ground, the aperture will just touch (or just miss) the ground. We can feed the antenna with 1/8 wavelength of high impedance feed line (a single wire should work) and the ground loss and radiation angle problems will disappear."

Actual construction of these antennas is such that the antenna conductor is continued on down to the ground, where a matching network transforms the high impedance of the 1/8 wavelength long, single conductor, feed line to the low impedance of the line running to the transmitter. The resulting structure is 5/8 wavelength high (hence the common name).

Alas, it does not perform as expected. There is considerable mismatch between the antenna and the high impedance, single conductor feed line, resulting in radiation from that line. This would not be all bad except that this radiation is in the wrong direction (30-45 degrees up depending on ground conductivity). This approach also did not eliminate the need for an extensive grounding system. Because this antenna does exhibit some gain (approx. 2.9 dB) over a 1/4 wave whip, it has become a sort of de-facto standard for VHF and UHF mobile operation.

Another approach to the problem is the "J-Pole" antenna. In this design, the antenna is elevated at least 1/4 wavelength above ground, thus eliminating the ground losses and "normalizing" the radiation pattern. The Impedance matching between the low impedance feed line and the high impedance of the end of the dipole is accomplished with an open wire stub matching network. A shorting bar is placed at one end of a 1/4 wavelength of open wire line, the dipole is then connected to the open end, and the feed line is connected at the point where the impedance of the feed line matches the impedance of the stub. If Co-axial cable feed line is to be used, a BalUn MUST be used. Attempts to feed this antenna directly with co-ax have met with disastrous results. The 0 Ohms reference point is at the center of the short, NOT somewhere up the side of the "J".



Yet another workable solution to the problem is to use a co-axial stub matching network. The advantages of this approach are that it can be fed directly with co-axial cable, a large reduction in wind resistance making it suitable for mobile operation and its total independence from ground. The major disadvantage is the extreme difficulty of construction. Unless special (expensive) tooling and fixturing is available, it is almost impossible to assemble the matching network! Although it can be done, this antenna is easier (and much cheaper) to purchase (mass produced) than it is to build just one!

8. The PROPER and COMPLETE match.

The match between an antenna and its feed line is only proper and complete when the following conditions are met:

a. The antenna impedance is matched to the feed line impedance. The only "right way" to do this is to use a matching network between the feed line and the antenna. ANY adjustments made to the antenna in order to achieve impedance matching will change the radiation pattern of the antenna.

> There is one notable exception to this: When we want to achieve an impedance transformation, we can insert a short (usually 1/4 wavelength long) piece of feedline that will have a VSWR greater than 1:1.

b. The antenna balance is matched to the feed line balance. When feeding a balanced antenna, a balanced feed line MUST be used. Conversely, when feeding an unbalanced antenna, an unbalanced feed line MUST be used. When it is necessary to mix balances, a BalUn MUST be used. This can be incorporated into the design of the matching network.

9. 1:1 VSWR does NOT indicate resonance.

The Voltage Standing Wave Ratio (VSWR) is only 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 co-axial cable, and connect a transmitter and SWR meter at the other end, the VSWR will be 1:1. The resistor is NOT, by any means, resonant.

If we connect a resonant antenna that has a feed impedance of 272 Ohms to the end of that piece of co-ax (ignoring any resonance effects of the co-ax), the VSWR will be 5.44:1.

It is possible to cut a piece of feed line to just the right length, and measure a 1:1 VSWR at the transmitter end of that feed line -- the actual VSWR on this line is (infinity):1.

The only practical way to measure the resonant frequency of an antenna is to use a DIP METER at the antenna.

10. High VSWR does NOT cause feed line radiation.

Most radiation from co-axial cable is caused by terminating this unbalanced feed line with a balanced load. The remainder of the radiation is due to other problems such as: dis-continuities in the outer conductor (braid corrosion is a major factor), improperly installed connectors and signal pickup caused by routing the feed line too close to, and parallel to the antenna.

Contrary to popular belief, properly terminated and installed open wire line does not radiate. Even with infinite SWR, the fields surrounding each wire cancel each other at a distance roughly equal to the wire spacing distance away from the line. 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.

11. Antenna Gain Information.

There are four ways of expressing antenna gain. These are:

dBi	Gain over an isotropic source (a theoretical antenna having no dimensions: a geometric point).
dBd	Gain over a dipole (0 dBd = 2.15 dBi).
dBq	Gain over a quarter wavelength whip (bigger numbers than dBi).
dBadv	LARGE RANDOM numbers generated by the advertizing and marketing departments at some antenna companies. These departments are sometimes known as the "S and M" (Smoke and Mirrors) groups.

Sad to say, but the advertized gain claims of most large antenna companies are out and out fraudulent. Because most users of antennas can't separate the real numbers from the phony, they wind up paying big money for junk and the honest antenna companies suffer. With lower sales, the honest companies have smaller R&D budgets. New and better products don't get produced. Everyone loses.

This antenna gain chart shows the maximum theoretical (minus a small allowance for system losses) gain achievable from arrays of closely spaced co-linear dipole elements. Dimensions shown are for elements almost touching; the actual heights may be slightly more due to phasing networks used between the dipole elements.

Number of Co-Linear Elements	Gain dBd	Gain dBi	Overall Height 2 Meters Meters	Overall Height 2 Meters Feet	Overall Height 70 Centimeters Meters	Overall Height 70 Centimeters Feet
1	0.00	2.15	0.98	3.2	0.32	1.0
2	2.15	4.25	1.95	6.4	0.64	2.1
4	4.25	6.35	3.90	12.8	1.28	4.2
8	6.35	8.45	7.81	25.6	2.56	8.4
16	8.45	10.55	15.62	51.2	5.11	16.8

32	10.55	12.65	31.23	102.5	10.22	33.5
64	12.65	14.75	62.47	204.9	20.45	67.1
128	14.75	16.85	124.93	409.9	40.90	134.2
256	16.85	18.95	249.86	819.8	81.79	268.4
512	18.95	21.05	499.73	1639.5	163.59	536.7
1024	21.05	23.15	999.45	3279.0	327.17	1073.4