# BASIC ANTENNAS FOR EXPERIMENTERS

**If you ever experiment with receivers and/or transmitters, you will at some point need to consider the subject of antennas. This is a very large subject and could occupy hundreds of thousands of pages with some pretty advanced mathematics and electromagnetic theory. However, the antennas a casual experimenter will use are generally simple types, such as wires, whip antennas, and dipoles. We will present some basics that will be useful to the experimenter, shortwave or scanner enthusiast, or for use with hobby low power transmitters. A good antenna will do more to improve the performance of a transmitter or receiver than almost anything else. Too often the antenna is an afterthought, with little consideration given to it. You cannot always depend on a length of wire or a pre-packaged plug in whip from an electronics store, if you want the best performance your equipment can deliver. Receivers may perform poorly, and transmitters can even be damaged by improper antenna systems. A little knowledge about antennas can be very useful. We will not go into the more complex types, such as yagis and log periodic arrays, as much more space would be needed than is available in this article.**

**An antenna can be any structure that is used to radiate or to receive electromagnetic energy. Almost any conducting structure can be used to radiate or receive energy. How well this is done depends on the size, geometry, frequency or wavelength to be used, and the location of the antenna, as well as surrounding environmental factors. Antennas come in all sizes. Inch long antennas and smaller are used as parts of microwave antenna systems operating at 1000 to 100,000 Mhz. One inch to foot long antennas are used for UHF and cell phone work. Antennas one to ten feet long are used for FM, TV, and VHF communications work. Hundred foot long wire antennas are used for shortwave and AM radio. The largest antennas are giant arrays of thousand foot towers, topped by miles of cables and occupying hundreds of acres of ground. These monsters are used for VLF (very low frequency) work at frequencies as low as 10 kHz. Fortunately, the frequencies and antennas needed by experimenters lie between these extremes, typically short whip antennas a few feet long, up to wire antennas 50 to 200 feet or so in length. We will concern ourselves with antennas in this practical category. Frequencies typically will range from lowest used AM broadcast (150 kHz) to UHF (around 1000 MHz). Antennas can be operated either horizontally or vertically with respect to ground. Each antenna has its advantages and disadvantages, both mechanical and electrical.**

**Antenna structures appear as electrical loads (to transmitters) or electrical sources (to receivers) and they have equivalent impedances that vary with antenna size and frequency. In the case of a receive antenna, the source also has a voltage equal to that picked up by the antenna. In the general case, there are many discrete frequencies as well as noise components present. Voltages may range from microvolts (weak signals) to volts (from very strong nearby AM broadcast stations) Occasionally voltages with 60 Hz components from power lines and audio voltages are picked up, from both man made and natural sources. Ideally, an antenna will**

**radiate all power delivered to it or deliver all the power it extracts from a passing wave to a load, generally a receiver. This comes close to reality with some types of antennas, but generally this is not always the case. For easy matching, an antenna should be of a length that is one half of a wavelength at the received or transmitted frequency. A half wave antenna length is usually calculated from the formula:**

**Length in feet = 468 / F (MHz)**

**This is about 5 percent shorter than an actual theoretical half wavelength, and practically works very well. The shortening takes into consideration and compensates for "end effects" caused by the supporting insulators and masts, proximity to ground and other structures, and the fact that the wire is of finite thickness. It works well up to the lower VHF range (50 MHz or so). At higher frequencies element thickness is more significant and this formula is best used as a starting point. Impedance is ideally 72 ohms, although practical antennas will show 30 to 80 ohms, depending on antenna height above ground, so a 50Ω cable is often used to feed half wave antennas. Half wave antennas such as dipoles work better if mounted a quarter wavelength (half the antenna length) or more above ground. Dipoles for lower frequencies (2MHz or lower) are often somewhat ineffective as to performance, owing to the difficulty of mounting them at the quarter wave heights needed for good performance (over 100 feet at 2 MHz). They are seldom used below about 1.8 MHz for transmission purposes. Vertical antennas are more suited to lower frequency operation. Antennas longer than ½ wave are also commonly used, and antennas several wavelengths in length have desirable properties for some uses.**

**A quarter wave antenna can also be used if a suitable ground is available. The effect of the ground is to act as an electrical "reflection", this reflection "supplying" the missing half of the half wave antenna. This is called the "ground plane" as it ideally is a perfectly conducting plane infinite in extent. Realistic ground planes are the earth, car or airplane bodies, ships, arrays of mesh or wire, lengths of wire or rod ( called radials), metal structures, or sea water. A quarter-wave antenna in theory looks like a 36Ω impedance, although 25 to 50 ohms is typical, depending on ground plane and surroundings. A good, low resistance ground plane or ground is very important with this type of antenna. This antenna will have a length given by:**

**Length in feet = 234 / F (MHz)**

**Quarter wave antennas are usually operated as vertical antennas. A vertical antenna requires little real estate and only one vertical support, but needs a location relatively clear of obstructions and a good ground system for optimum results. A small quarter wave antenna system can be mounted on a pole up in the air, with a radial ground system under the antenna. These radials are usually 4 to 8 in number and are made from the same rod as the radiating element, and are also a quarter wave in length. These antennas are called ground plane antennas and are commonly seen on fire, police, airport, and commercial service antenna towers. Due**

**to size and mechanical limitations, ground plane antennas are usually used at VHF ferquencies above 25 MHz, although in theory there is no lower frequency limit, and much lower frequency ones have been constructed by radio amateurs for 7 MHz and 3.5 MHz operation.**

**An antenna extracts energy from a passing electromagnetic wave and the amount of energy is proportional to its aperture. Simply put, for practical purposes, this is the effective area that the antenna presents to the passing wave, as a large barrel will catch more rainwater than a small barrel. Antenna gain is generally measured in dB with respect to an isotropic radiator. An isotropic radiator radiates equally well in all directions, as an ideal point source and has a gain defined as zero dB. An unshielded clear light bulb mounted in a socket with no reflector would be an equivalent optical example. A gain antenna such as a yagi or parabolic dish would be equivalent to the same light bulb mounted with a reflector. Note that a gain antenna does not increase radiated power, it simply radiates the power fed to it mainly in one direction, so the signal is stronger in that direction at the expense of other directions. By contrast, an active antenna has a built in amplifier and actually amplifies the signal fed to or received by the antenna. This produces an effective gain figure. An active antenna requires a power supply to run the amplifier in it. Active antennas are used more often for reception purposes than transmission purposes. At lower frequencies, such as 100 KHz up to the lower shortwave (HF) range up to to 30 MHz, the larger antennas used capture plenty of energy. At UHF and microwave, antennas are measured in inches and capture less energy, so larger antenna arrays are used at these frequencies relative to wavelength. As an example, a typical amateur radio antenna used on the 7 MHz band (40 meters) is a simple half wave dipole about 66 feet long, mounted about 25 to 35 feet above ground. This antenna has little gain as compared to an isotropic radiator. A typical amateur radio antenna used on the 430 MHz band is a multi-element Yagi consisting of ten or more half wave elements, with 10 dB or more gain, mounted on a tower 50 ft high or more. A simple dipole would almost never be used on this band. It would be about a foot long and capture little signal. Microwave antennas are almost always parabolic dish, horn, or other gain types physically many wavelengths in size. Satellite TV antennas for C-band (4 GHz) are 10 feet in diameter and exhibit around 40 dB gain. The actual "antenna" in these systems is a tiny probe built into the LNB assembly mounted at the focus of the dish. The dish merely gathers signal and focuses it on the probe antenna in the LNB assembly.**

**The current flowing in an antenna varies along its length , being zero at the end, the voltage here being a maximum. Current is maximum somewhere along its length, or at the end that is fed with power in some cases. This varies with frequency. This current and voltage distribution will determine the feed impedance to be expected at a particular feed point. Power can be fed into or taken from the antenna anywhere along its length by the use of a transmission line (feedline) of the proper impedance. A half wave dipole is fed at its center where the current is a maximum, and the impedance here is around 50 to 70 ohms. A quarter wave antenna is fed at its end, usually the lowest point, called the base. Impedances here**

**are lower, usually 30 to 50 ohms. Random length antennas are usually fed at one end through an impedance matching network, but also can be fed at almost any point with suitable feedlines. These feedlines are commonly high impedance 300 to 600 ohm two conductor feedlines, which look like ladders. These lines are made of two conductors spaced 3 to 6 inches apart and fastened together with plastic or ceramic spacers that look like ladder rungs.**

**Antennas that are small electrically (Less than a quarter wavelength at the frequency in consideration) will appear as a capacitive reactance (several hundred ohms) in series with a small resistance (a few ohms). The resistance is made up of losses, both in the ground, and surroundings, and conductor losses, and losses from radiation of power. The power lost in radiation is often expressed as that power lost in a fictitious resistance called the "radiation resistance". This is ideally as high as possible compared to the total antenna resistance, as the higher it is relative to losses, the larger the fraction of the power fed to the antenna is radiated. In efficient antennas this is 80 - 90 percent or more of the total antenna resistance. Lower values of less than 5 ohms can be hard to match efficiently without excessive losses. Very high values (several thousand ohms) can also present difficulties. Reactance values due to L or C can be zero to several thousand ohms. These values all depend on frequency and antenna surroundings, as well as antenna configuration and size. For example, an 102 inch CB type whip antenna for 27 MHz use is a quarter wave long and will appear as about a 36 ohm resistance to the CB transmitter. But, consider using this antenna at the frequency of 1650 KHz, the high end of the AM broadcast band. Here it appears as a 0.1 Ω resistor in series with a capacitor of 4700 Ω reactance (20 pf), approximately. A little thought will show that this is a difficult impedance to match with reasonable efficiency to a transmitter needing a 50 Ω load impedance. This is the classic short antenna problem … feeding it power so it will radiate efficiently. Short antennas with low losses and excellent grounds often present very low feed impedances of only a few ohms. A short vertical antenna system with no matching circuit and a feed impedance that is higher (30 to 50 ohms) probably has high losses, especially if the radiation resistance of the antenna a few ohms or less**

**Half or quarter wave long antennas allow easy transfer of power to and from the antenna. The antenna is resonant at that frequency and behaves much like a tuned circuit. This also helps in reducing radiation of spurious signal components, and in the case of reception, favors the received frequency. However, with auxiliary inductors and/or capacitors, a matching network can be made up to couple any random length antenna to a receiver or transmitter. In the case of receivers often this is not critical. This is especially true in the shortwave and AM frequency ranges, where the large (25 to 200 ft typically) antenna picks up plenty of energy and external noise interference is the limiting factor in weak signal reception. In this case no matching network may be needed. The typical 50 to 100 foot long wire antenna connected directly to the antenna terminals of a receiver is an example of this. In most cases satisfactory reception will be obtained, with no matching needed. (Reception of weak signals will generally be improved with one, however.) This**

**antenna will appear as a complex impedance, with around 10 to 600 ohms resistance and plus or minus reactance values up to about 1000Ω, depending on frequency. Most shortwave receivers will handle this mismatch with little difficulty, although some of the newer solid state models like to see 50 Ω, and an antenna tuner will improve reception a little in these cases. But, with transmitters, power from the transmitter must be delivered to the antenna so it can be radiated efficiently. Also, since most transmitters are generally designed to operate into a specified load impedance (Usually 50 to 75 ohms) some form of matching network will be required in cases where a random length antenna will be used. Also, the use of the same antenna over a wide range of frequencies (2 to 30 MHz coverage using only one antenna is commonly required) necessitates a matching network of some kind.**

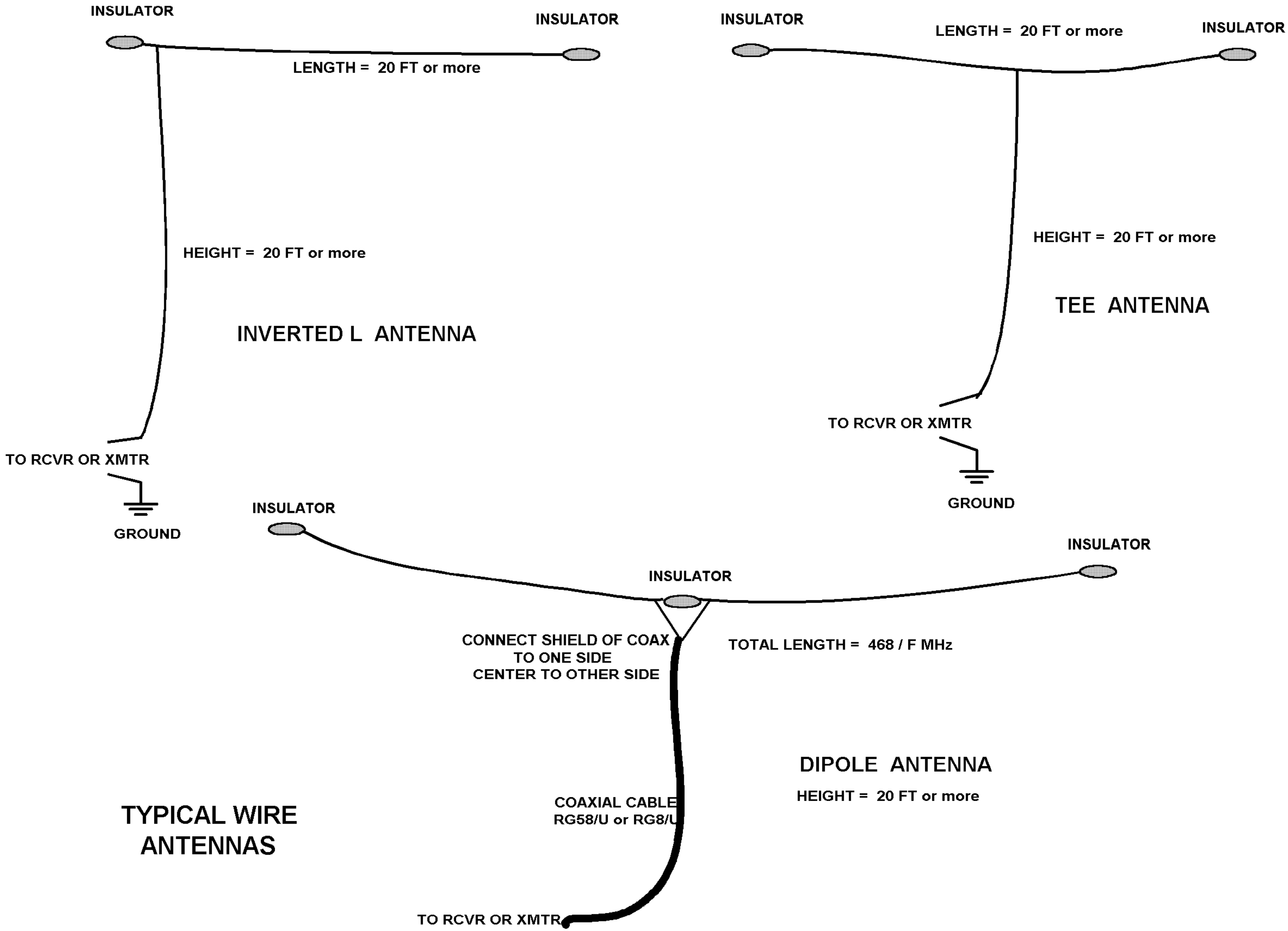
**In a practical situation, individuals may have several options or be severely limited in erecting an antenna for experimentation. Those experimenters living in a private home in a rural area usually can erect almost any reasonable kind of antenna needed, and the only limitations are financial or esthetic. Those living in apartments, condominiums, or deed restricted housing situations may not be able to put up or use any kind of outside antenna, or be limited to something small and not visible. It is a sad fact of life that antenna performance is directly proportional at any frequency, all things equal, to relative size, height, and clearance from nearby structures. A 10 element yagi (big) will outperform a dipole or quarter wave whip (small) at a given frequency. An antenna 100 feet high above ground will be superior to the same antenna mounted 10 feet above ground. An antenna outside a building mounted on a roof will usually vastly outperform the same antenna located inside a building. A good ground under the antenna is important and much better than a poor ground or no ground, especially with those antennas needing a good ground (Vertical antennas and long wire antenna systems). These contrasts in performance could range from a few dB to as much as 40 dB. There is no magic here. Bigger is better, higher is better, outside is better than inside. If you come up with a very tiny antenna that performs as well as a full size antenna, many companies will want to buy your idea. The armed services have done much research on small antennas for tactical communications, but the laws of physics do not allow something for nothing. The small, portable antenna giving performance like a big one is still a wish and a dream. No magic circuits can substitute for a poor antenna either. There are a number of "magic"small antennas advertised in magazines, on the web, and in other places. They are sold for radio, TV, and shortwave use, promising all kinds of performance, some claiming to eliminate the need for a good antenna system. These are mostly wishes and prayers, and inevitably will prove disappointing if one expects the advertised claims about performance. A good active receiving antenna system often will provide better reception than a wire antenna several times its size. But, active antennas have to be mounted outdoors away from buildings and noise to really work well. This is often not an option for many would be users of these antennas. Indoors, they are too shielded and buried in the ambient noise present in most multiple dwellings to show much improvement, especially at frequencies below 5 to 10 MHz.**

**These practical limitations may dictate the kind of antenna one is forced to use. In practice, the random length wire antenna, fed at one end, is probably the most practical choice. It can be made of very fine wire (#28 or even #30) as to be nearly invisible, hidden in trees or run along building surfaces and under eaves, or even attached to a flagpole and disguised as a rope. Care must be taken to avoid the possibility of accidental contact with power and utility wires. Antennas should be ideally be mounted FAR AWAY and at right angles to utility wires, and NEVER NEAR, OVER, OR UNDER them. There is always the possibility that a broken wire can fall and contact power lines. This precaution avoids shock hazard and also very important, unwanted pickup of noise and interference often present on utility wires.**

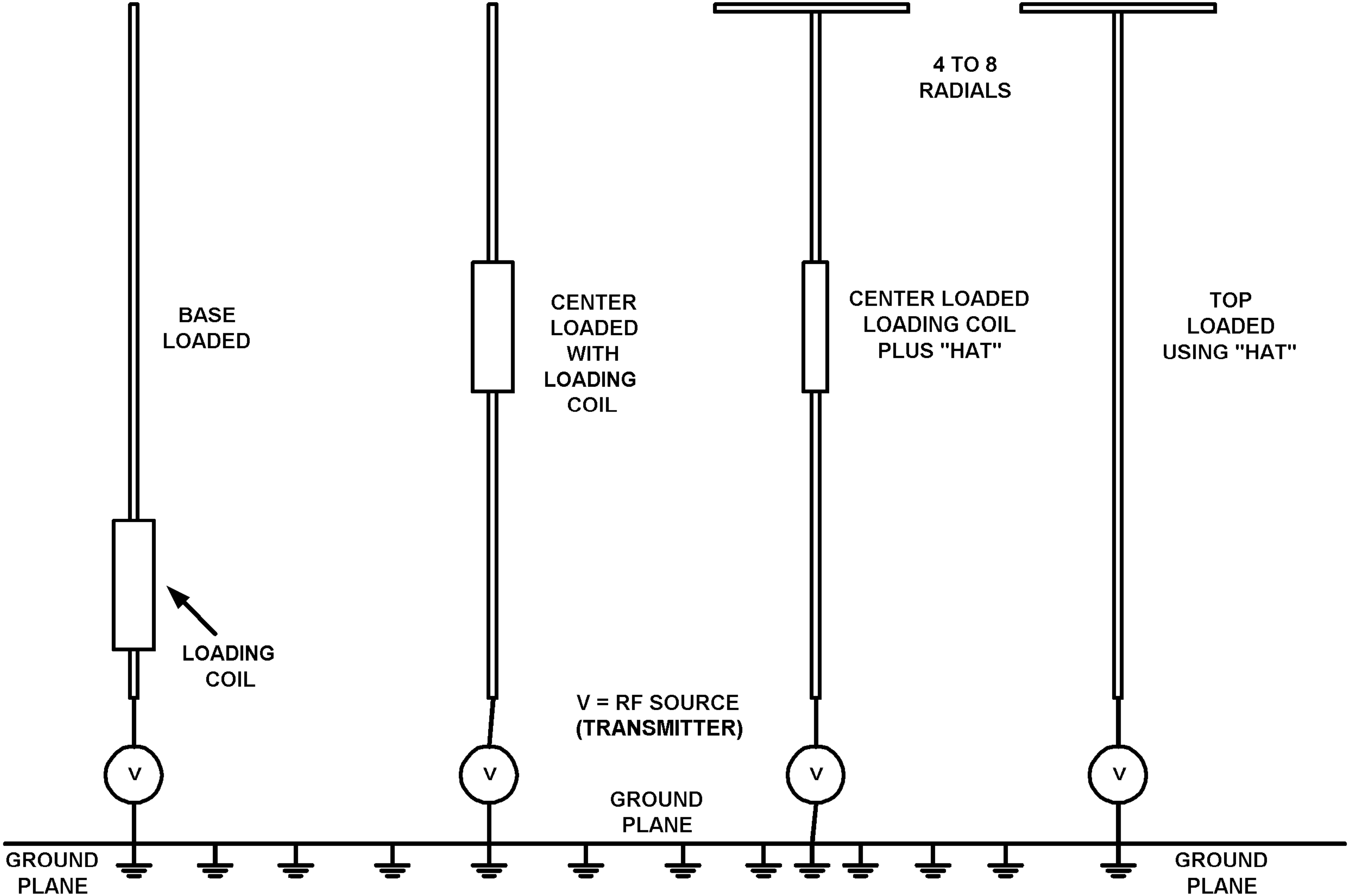
**Several antennas are shown in the figures. All will provide good results if carefully built and placed as far away as possible from obstructions and utility lines. There are no magic "tricks" to getting these antennas to work. If they used only for reception, nothing is very critical. For use with a transmitter, the antenna should be cut to length as needed and/or a matching network should be used to make sure the transmitter is operation into its designed impedance. For best results a dipole should be mounted broadside to the desired direction of best reception or transmission, although this is also dependent on height and operating frequency. For most all practical uses, all these antennas can be regarded as approximately omnidirectional, as surroundings, height, and environmental factors such as ground resistance all play a part in determining the antenna pattern. You will notice several dB variation in certain directions, depending again on frequency and orientation. A Tee antenna can be considered as similar to a top loaded vertical antenna, as the top section connects at the center of its length to the vertical downlead (feeder). The top section, or "flat top" acts as a capacitive hat and the vertical feed wire actually does most of the radiating. Tee antennas are sometimes called "Marconi" antennas. A variation of this is the Windom antenna, which uses a resonant flat top and a vertical feeder connected at a point off center, depending on application. The inverted "L" is a mixture of horizontal and vertical, depending on geometry of the antenna. It is probably the most widely used long wire antenna configuration, and is very dependable for good performance over a wide frequency range. It often is the easiest antenna to install. The flat top section of an inverted "L" connects to the vertical feeder at one end. Note that vertical, tee, and inverted L types require some sort of ground connection for best results. A single 8 foot ground rod driven into the earth is often used for this connection. It will be found to not be as good a ground as you may think. While this will do for draining off static electricity, it will have little effect for RF, unless you live in a salt marsh or on a large metal platform. A good RF ground is a large conducting metal plane, and this is usually simulated with a large number of buried wires (radials) a few inches below the soil surface. The more metal buried in the ground the better. A ground to a cold water pipe also helps. DO NOT use power or telephone grounds. Losses in ground resistance are often the main loss components in antenna systems, especially with short antennas used at low and medium frequencies. But, real life situations are seldom ideal, and some ground is better than no ground, so just do the best you can. Depending on your particular application, you may get away with surprisingly little. See the figures for typical**

**configurations. Crystal set experimenters and AM DX fans will do best with one of the wire antennas such as the inverted L or Tee, as long and as high as possible. Shortwave fans can use any of the antennas shown. A dipole cut for your favorite frequencies will probably be your best bet. You can parallel several different dipoles cut for favorite frequencies if you wish. Should your interest be in LP transmitters, only a very short indoor antenna should be used. You might get cited by the FCC should your LP transmitter cause interference to any licensed services or interfere with radio or TV reception.**

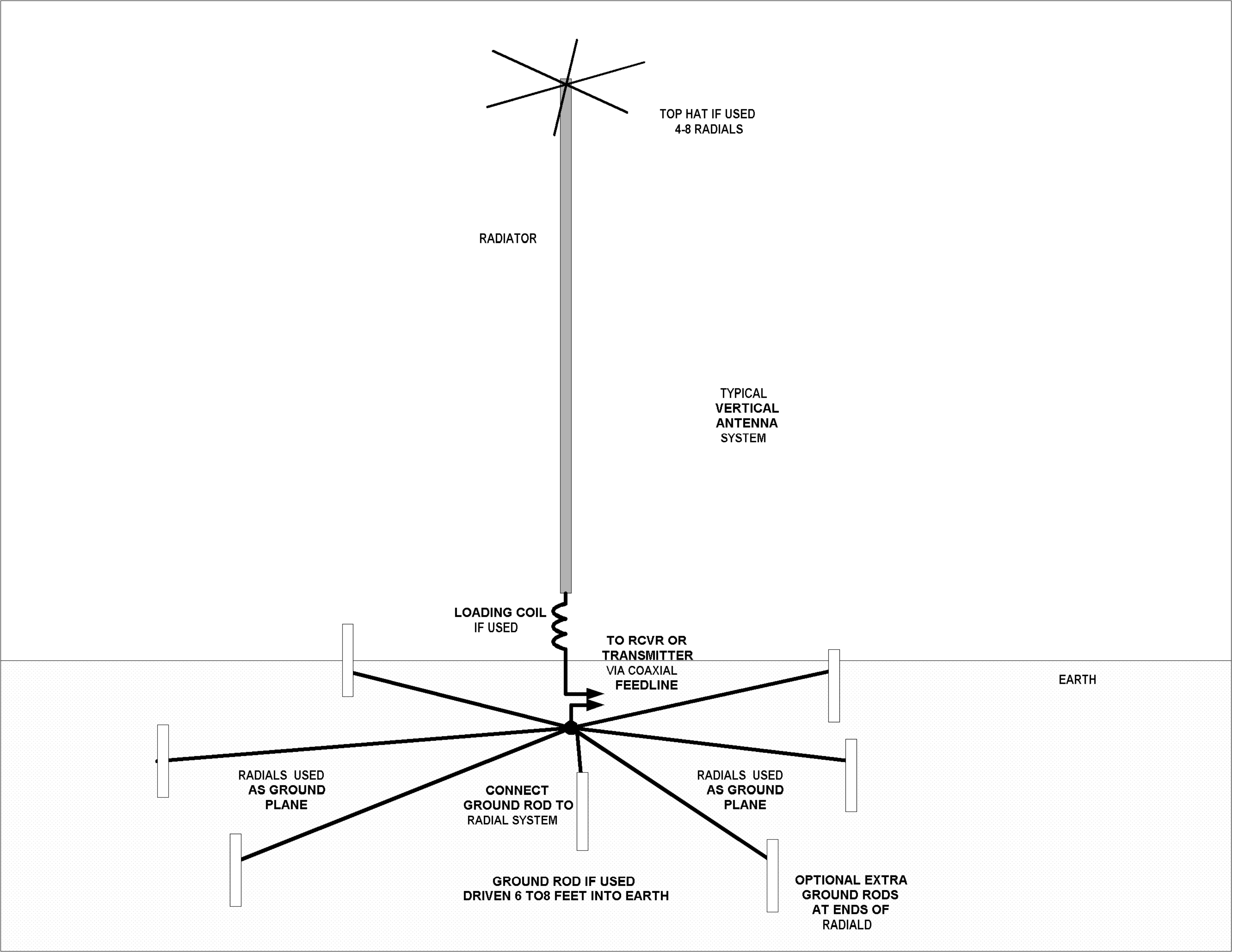
**If you live in an apartment or condominium and cannot erect an outdoor antenna, at least try to get some wire outside the building, even if only a few feet long. As mentioned, fine insulated or magnet wire of gauges as small as #28 or #30 can be used. Discarded lengths of multiconductor telephone or computer cable have many suitable lengths of such wire inside and can sometimes be obtained for free. A shorter wire run along the outside of a building is often much better than a longer one inside. This way, the building will act as a shield that attenuates inside RF interference, instead of attenuating desired RF signals. As much as 20 to 40 dB improvement can result. An outside antenna is always desirable. It is not only because the outside antenna picks up more signal strength. Most modern receivers have more sensitivity than you really need, and will perform very well with a small antenna. Indeed, is actually possible to have too much signal strength, resulting in receiver overload, interference and generally degraded performance. The real advantage of an outside antenna is that it can be located far away from household noise sources. Modern appliances using microcontrollers, displays, and triac devices, as well as entertainment equipment, often generate a lot of spurious unwanted noises. Getting an antenna away from all this stuff works wonders in improving reception. Keep the wire as far as possible away from electrical lines and devices. A good active antenna will prove valuable in these situations, as long as it can be mounted outside the building. If you can get hold of the Aug 1997 issue of Popular Electronics, an excellent active antenna was described in detail. A kit to build this antenna is available from the source mentioned at the end of this article. This antenna is 2 to 4 feet long, weatherproof, easily concealed, operates from 100 kHz to 30 MHz, and performs as well as a 25 to 50 ft long wire in most situations. You can also check out the website mentioned at the end of this article for more information.**




TYPICAL WIRE ANTENNAS




TYPES OF VERTICAL
ANTENNAS SUITABLE
FOR LOW POWER
TRANSMITTERS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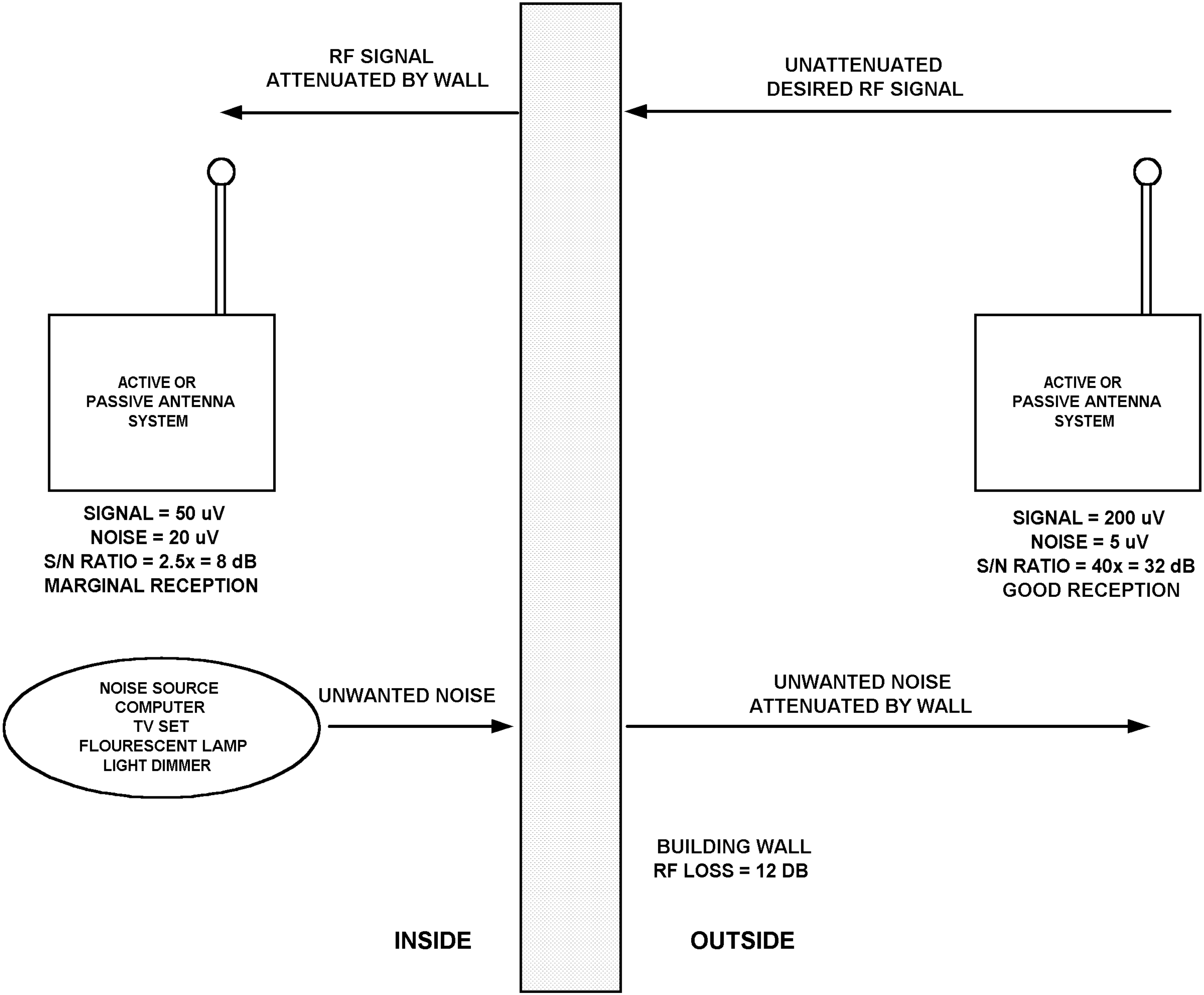


**WHY AN OUTSIDE ANTENNA IS BETTER THAN AN INSIDE ANTENNA**