Tech Notes

Ground/Radial Systems

GROUND MOUNTING

A vertical antenna in its simplest form, is electrically equivalent to one-half of a dipole antenna stood on end. When the antenna is mounted close to the ground, the earth below takes the place of the "missing" half of the dipole. If ground conductivity is fair to good, a short metal stake or rod may provide a sufficiently good ground connection for resonant and low SWR operation on the bands for which the antenna is designed. This basic arrangement is shown in figure 1.

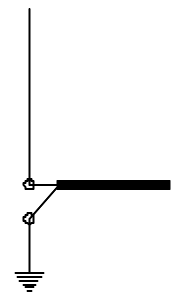


Figure 1

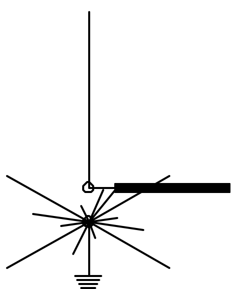


Figure 2

The way it works is that the capacitance between the vertical radiator and the ground causes *return* currents to flow along the earths surface back to the transmitter. If they have to come back along untreated lossy earth thy get back to the source greatly attenuated. This *return* loss is like a resistor in series with the antenna radiation resistance and will therefore affect the feed point impedance.

In almost every case the efficiency of a vertical antenna will be greater if radial wires are used to improve ground conductivity as in figure 2. It's important to note that there's no point in cutting radials to any particular length when ground mounting because the earth will detune them anyway. All you want to do is make the surface of the earth around the antenna more conductive than it is ordinarily.

If you can't copper-plate the backyard, the best approach is to run out as many radials as possible, each as long as possible around the antenna in all directions. Radials may be left on top of the ground however they should be buried for the sake of pedestrians and lawnmowers.

How long should radials be? A good rule is no shorter than the antenna is tall because 50% of your losses will occur in the first 1/4 8 out from the antenna. If you have more than a dozen radials, they must be longer to get the most out of them which is why the FCC specifies 113 wires each .4 8 for AM broadcast stations—the equivalent of a zero-loss ground plane. Obviously, for most ham work this would be overkill.

In some cases wire mesh (i.e. chicken wire) may be used as a substitute for radial wires and/or a ground connection, the mesh or screen acting as one plate of a capacitor to provide coupling to the earth beneath the antenna.

It should be noted that a ground rod is useful only as a d.c. ground or as a tie point for radials. It does little or nothing to reduce ground losses at r.f. regardless of how far it goes into the ground.

Bare wire, insulated, any gauge, it doesn't matter. The current coming back along any one wire won't amount to that much.

EFFICIENCY

The importance of reducing losses in the ground system can be seen from an examination of a vertical antenna's feedpoint impedance which at resonance consists of three components: antenna radiation resistance; conductor loss resistance; and earth loss resistance. An unloaded quarter-wave vertical antenna has a radiation resistance of about 35 ohms with negligible ohmic or conductor loss, but ground loss resistance may be very great if no measures are taken to reduce it, and in some cases ground loss R may even exceed the antenna radiation resistance. These three components may be added together to arrive at the feedpoint **impedance** of a **resonant** (no reactance) antenna. For the sake of illustration, assume that the ground loss beneath a quarter wavelength vertical antenna is 15 ohms, that conductor loss resistance is zero, and that the radiation resistance is the textbook figure of 35 ohms. The feedpoint impedance would then be 15 + 0 + 35 = 50 ohms, and the antenna would be perfectly matched to a 50 ohm coaxial line. Since the radiation resistance is an index of the amount of applied power that is consumed as useful radiation rather than simply lost as heat in the earth or in the conductor, the radiation resistance must be kept as high as possible in relation to the total feedpoint impedance for maximum efficiency. Efficiency, expressed as a percentage, may be found by dividing the radiation resistance by the total feedpoint impedance of a resonant antenna, so under the conditions assumed above our vertical antenna would show an efficiency of 35/50 = 70%. As a vertical antenna is made progressively shorter than one-quarter wavelength the radiation resistance drops rapidly and conductor losses from the required loading inductors increase. A one-eighth wave inductively loaded vertical would have a radiation resistance of something like 15 ohms and coil losses (or trap losses for multiband antennas) would be in the range of 5 ohms. Assuming the same value of ground loss resistance (15 ohms), the feedpoint impedance would become 15 + 5 + 15 = 35 ohms and the efficiency would be 15/35 = 43%. From the above calculations it is clear that the shorter a vertical antenna must be the less efficient it also must be for a given ground loss resistance. Or to state the matter another way, more elaborate ground or radial systems must be used with shorter verticals for reasonable efficiency. If the ground loss of resistance of 15 ohms from the preceding example could be reduced to zero ohms, it is easy to show that the efficiency of our one-eighth wavelength loaded vertical would increase to 75%. Unfortunately, more than 100 radials each one-half wavelength long would be required for zero ground loss, so lower efficiencies with shorter radials must usually be accepted for the sake of convenience. In spite of their limitations, short vertical antennas over less than ideal ground systems are often more effective DX performers than horizontal dipoles which must be placed well above the earth (especially on the lower bands) to produce any significant radiation at the lower elevation angles. Verticals, on the other hand, are primarily low-angle radiators on all bands.

ABOVE GROUND (ELEVATED) INSTALLATIONS (rooftop, tower, mast. etc.)
The problem of ground loss resistance may be avoided to some extent by mounting a vertical antenna some distance above the earth over an artificial ground plane consisting of resonant (usually 1/4 8) radial wires. Four resonant radials are considered to provide a very low-loss ground plane system for vertical antennas at base heights of 1/2 8 or more. This arrangement contrasts favorably with the more than 100 radials for zero ohms loss resistance at ground level, and since 1/2 8 is only about thirty-five feet at 20 meters, very worthwhile improvement in vertical antenna performance can be realized, at least on the higher bands, with moderate pole or tower heights. At base heights below 1/2 8 more than four radials will be required to provide a ground plane of significantly greater conductivity than the lossy earth immediately below the antenna: even so, a slightly elevated vertical with relatively few radials may be more effective than a ground-level vertical operating over a larger number of radials if only because the former is apt to be more in the clear. Resonant radial lengths for any band may be calculated from the formula:

$$Length\ (ft) = \frac{240}{Frequency\ (MHz)}$$

Figure 3 shows the basic ground plane system for elevated verticals. Radials may slope downward as much as 45 degrees without any significant effect on operation or performance. Radials for different bands should be separated as much as possible and the far end of each radial insulated from supporting wires. Figure 4 shows a ground plane system that uses four resonant radials for 40 meters, another set of four for 20 meters, and a third set for 10 meters. A separate set for 15 meters is not ordinarily required because the 40 meter radials operate as resonant 3/4 8 radials on that band. At the lower heights the separate wires of this system may provide enough capacitance to ground to permit low SWR operation on 80/75 meters as well, but it is probable that at least one resonant radial will be required for low SWR on that band. It's important to note that cutting each conductor of rotator cable to a specific frequency will not work unless you separate it, angling each conductor away for most of its length because the longer ones will detune the shorter ones.

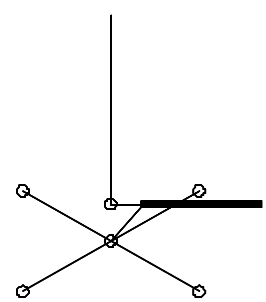


Figure 3

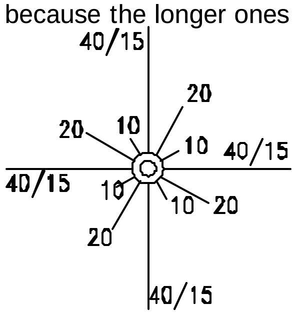


Figure 4

The 12-radial system of Figure 4 is a very good one, but it requires at least 12 tie-off points. Butternut has developed a multiband radial made of 300-ohm ribbon that resonates simultaneously on 40, 20, 15 and 10 meters. Four such radials offer essentially the same ground plane performance as the system of Figure 4 but require only 4 supports. These multiband radials plus additional wire for an 80 meter radial are available separately (our STR-II kit) or as part of the Butternut roof mounting kit (RMK-II).

There are times when physical restrictions will dictate the use of fewer than four radials, and at least one

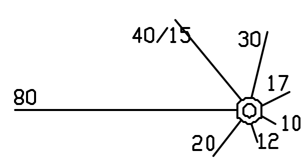


Figure 5

manufacturer recommends 2 radials per band, the radials for each band running 180 degrees away from each other. A simpler (and no doubt less effective) system is shown in Figure 5. Since only one resonant radial is used per band the antenna will radiate both vertically and horizontally polarized energy, and the pattern will not be completely omnidirectional. For true ground plane action and predominantly vertical polarization no fewer than three equally-spaced radials should be used.

Figure 6 illustrates the construction of a multi-band radial which is resonant on 40, 20, 15 and 10 meters. Good quality 300 ohm TV ribbon lead should be used (velocity factor is critical), and the conductors should employ at least one strand of steel wire to support the weight of the radial. Four such radials will be the practical equivalent of the system shown in figure four for operation on 40 through 10 meters.

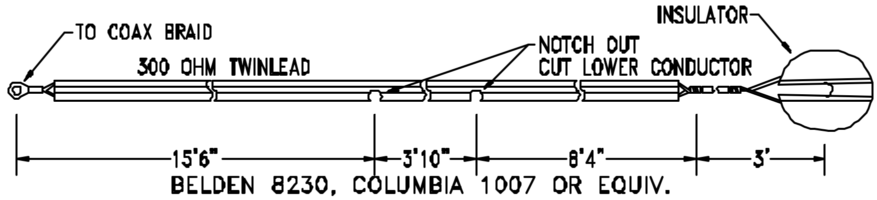


Figure 6

Regardless of the number of radials used in either elevated or ground level systems, all radials should be attached to the ground connection at the antenna feedpoint by the shortest possible leads. An elaborate radial system at ground level, for example, cannot be used with a vertical antenna on a rooftop or on a tall tower, for the length of the ground lead would effectively become part of the antenna, thus detuning the system on most or all bands.

METAL TOWERS AND MASTS

If a metal mast or tower is used to support a vertical antenna all radials should be connected to the mast or tower at the ground connection of the antenna feedline. This is because one of the functions of a resonant radial is to detune a supporting metal structure for antenna currents that might otherwise flow on the structure and thus turn the vertical antenna system into a vertical long wire with unwanted high-angle radiation.

OTHER MOUNTING SCHEMES

In cases where a resonant vertical antenna may neither be ground mounted nor used with an elevated ground plane, operation may still be possible if connection can be made to a large mass of metal that is directly connected or capacitively coupled to the ground, e.g., central air conditioning systems or structural steel frames of apartment buildings. Some amateurs have reported good results with vertical antennas extended horizontally or semi-vertically from metal terraces which serve as the ground connection. Alternatively, a quarterwave vertical may be window mounted if a short ground lead to a cold water pipe or radiator can be used. If a long lead must be used, tuned radials may be required for resonance on one or more bands. Great care should be exercised in such installations to avoid power lines and to keep the antenna from falling onto persons or property.

MOBILE HOME AND RV INSTALLATION

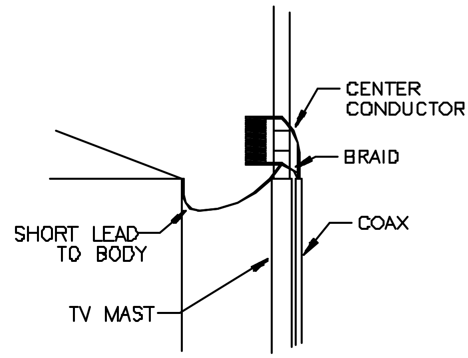
The principles of vertical antenna installations for use on mobile homes or RV's are the same as for other installations, and they all boil down to two main considerations. The first is that of erecting the vertical in the clearest possible spot, away from obstacles (including the MH or RV) that can interfere with radiation from the antenna. The second is that of installing the beat possible ground system beneath the antenna in order to minimize losses from r.f. currents flowing in the earth below the antenna. Fortunately, the metal bodies of both MHz and RVs can be used as highly conducting ground planes for vertical antennas in exactly the same way that automobile bodies, etc., provide the ground system for shorter vertical antennas for mobile operation. The metal body of an automobile, MH or RV may be viewed as one plate of a capacitor. Since the surface area of even a small automobile is quite large and in close proximity to the earth, its body is tightly coupled to the earth below and may be considered simply as an extension of the earth itself—a kind of hill as far as radio frequencies are concerned, but one having higher conductivity than the earth itself. RVs and especially MHz, having much greater surface area, will therefore provide a more extensive and effective ground system than a large number of radial wires occupying the same space as the MH or RV.

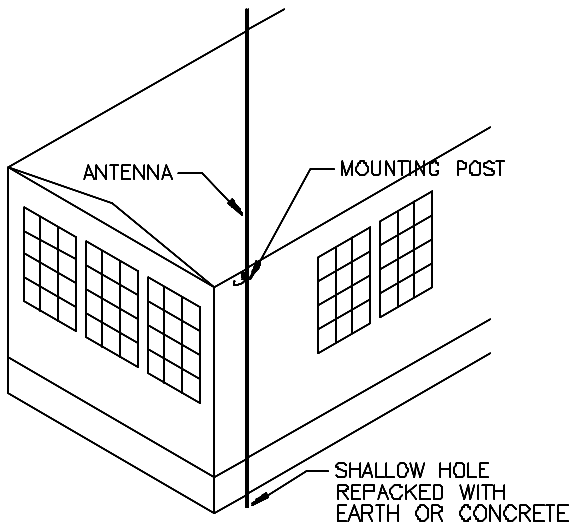
As in mobile installations, a vertical antenna may be mounted almost anywhere on the body of the vehicle or MH and made to operate with reasonably low VSWR, but it is generally considered that the best possible location for a mobile antenna is in the middle of the roof of the vehicle, i.e., at the center of the vehicle's ground plane and at a point where the antenna will not be in the "shadow" of any part of the vehicle. It is not usually convenient, or even practical to install a relatively tall vertical on the roof of an RV or MH for any number of reasons, so the next best procedure would be to install a vertical antenna with its base at the same level as the roof, preferably near the middle of one of the longer sides.

The exact way in which this may be done is a matter of convenience, but a short mast extending from ground level to the roof of the MH and RV and placed alongside the building or RV would provide a stable and sturdy support with a minimum of mounting brackets and other modifications to the RV or MH. For portable operation such a mast could simply be lashed alongside the RV with the base in a shallow hole in the ground for additional support, and there would be no harm in extending the mast a few inches above the roof level to permit attachment of ropes which could be used to hold the mast firmly against the side of the vehicle and to prevent side sway.

This system has been used successfully with various types of RVs, travel trailers and even passenger automobiles during portable operation. For "L" shaped mobile homes a vertical antenna should be placed in the corner of the "L" so that the metal roof will provide groundplane coverage over 270 degrees.

In all cases the base of the vertical antenna should not be more than a few inches away from the MH or RV so that the shortest possible lead may be run from the ground connection of the antenna to the metal body, as the length of this ground lead will effectively lengthen the antenna itself on all bands, and detuning can occur in some cases. A good electrical connection between the body of the RV or MH and the antenna is important, and in the case of mobile homes it would be a good idea to make sure that good electrical contact exists between the different parts of the metal body. Discontinuities can often lead to the production of harmonic radiation and TVI. The essential circuit connections are shown in the diagram above.





For permanent installations the bottom of the mast may be set deeper in the ground, and concrete may be used for greater strength and stability. The upper portion of the mast should be securely attached to the side of the building. Steel TV mast sections are readily available in lengths of ten feet and the mounting posts of Butternut HF verticals will slide into those which have an outside diameter of 1 1/4 inches and a wall thickness of .058 inches. Other vertical antennas may use different mounting techniques and requirements, so be sure to select a mast that will be suited to the particular situation. The main point to keep in mind is that the mast should not extend more than a few inches above the level of the roof so that the ground lead may be kept short.

LIGHTNING PROTECTION

Modern solid state amateur equipment is particularly vulnerable to damage from lightning or static induced transients that may appear on transmission lines, and conventional air-gap lightning protectors may provide no real protection at all for solid state gear. A line of very effective lightning and static protectors has been developed by ALPHA DELTA COMMUNICATIONS, P.O. Box 571, Centerville, Ohio 45459, for use with solid state equipment, and since these devices feature much faster transient discharge times than earlier designs, they should be investigated for possible use with all vertical and other antenna systems.