Tech Notes

Why Radials?

PART I

There are few subjects in amateur radio that are so clouded in mystery as radials and ground systems for vertical antennas. That this should be so is itself something of a mystery, for countless books and articles have examined this subject in considerable detail over the last 50 years. The basic points are quite well known by now EXCEPT, it seems, among the amateur community.

Why so much confusion? Some people will tell you that vertical antennas REQUIRE them for effective operation or even for low SWR, but you'll see ads stating (a) that a particular vertical antenna works like a bomb with no radials at all, (b) that another doesn't need any radials because it's a “half-wave” tall on one or another band and remotely tuned, another (c) that THEIR antenna can get by with a greatly abbreviated radial system because its feedpoint is a few feet above ground, and our favorite (d) is the one that claims that only a few 14 foot radials will allow it to deliver MAXIMUM operating efficiency.

The ARRL Antenna Book tells us that more than 100 much longer radials would be needed for that kind of efficiency on most amateur bands, even though the advertisements say otherwise! And what is meant by "ground" anyway? Much of the misunderstanding can be laid at the door of over-zealous dream merchants who prefer to gloss over unpleasant truths. Let's review the basics and try to separate the facts from the hype.

What is a ground? It can be a connection to the earth itself and often is. At power frequencies, the earth is usually a good conductor, and most electrical codes dictate a copper-plated steel rod driven into the earth to a depth of six feet or more. Unfortunately, such a ground connection is next to worthless at radio frequencies, although it's useful in preventing shocks. Too many amateurs have been electrocuted when they contacted the "ground" side of a feedline connected to ungrounded (or poorly grounded) station equipment while standing on damp earth'. Be especially leery of old two-conductor house wiring, and don't count on the newer three-conductor wiring to take the place of a good earth ground to all station equipment that plugs into the power outlets in the shack!' An ungrounded chassis can be lethal whether the unit is switched on or not, so drive that copper-plated steel rod into the flower bed and connect a heavy wire between it and all station equipment while everything is still unplugged.

But why should a ground connection that serves quite well at 60 Hz not also suffice into the megahertz range? And why do we even worry about it? Consider a vertical radiator installed at ground level and fed through the usual coaxial feedline, the braided outer conductor connected to the inevitable copper-plated ground stake. What is not so obvious is that the “business” end of a vertical antenna is also “connected” to the earth through the capacitance of the vertical radiator to the earth itself. True, this capacitance won't be

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very great, but it'll be great enough to cause current to flow in or along the earth all around the antenna out to a distance greater than the length of the vertical radiator. These "return" currents make their way back to the feedpoint to complete the circuit and can be seriously attenuated if they must pass along or through lossy earth. Even the most conductive earth is fairly lossy at radio frequencies, and the “return” losses can be severe unless an extensive radial system is used to provide a number of low-loss paths back to the feed point.

But what kind Of losses are we talking about in the average case? The ARRL Antenna Book (any edition) suggests that 120 radials equally spaced and each a halfwave long would make an essentially lossless ground system at R.F., and the FCC mandates such ambitious systems for stations operating in the AM broadcast band. A lossless ground system means that all power applied to a vertical antenna apart from conductor and loading losses (usually only a few percent) will be radiated instead of being lost in the earth as heat.

Amateurs must usually make do with much shorter and many fewer radials, particularly on the lower frequencies, but one can often reduce the length of radials and their number considerably without incurring significant loss. Still, the Antenna Book observes that with only two 1/8-wavelength radials (about 17 feet on 40 meters) overall efficiency is not likely to exceed 25%, in which case the difference between a bare-minimum ground system and an “ideal” one might amount to a whopping six decibels or more. Much depends on the natural conductivity of local soil. Sandy, arid regions are probably the worst, but the best is none too good compared to seawater. It's worth noting that what matters is conductivity at or near the SURFACE of the earth. If your R.F. has to fight its way through several feet of high resistance sand or rock to find a low-resistance path back to the antenna feedpoint you've probably lost the battle already. Subsurface mineral deposits and high water tables don't help much either, for these are usually too far down to do much good. Fresh water, by the way, is not a very good conductor at R.F. , so don't look for any great benefit from nearby lakes, ponds, rivers, creeks or swimming pools.

Some people imagine that they have a wonderful ground system because they're connected to a well casing that goes down several hundred feet. Not so, alas! Remember that your return currents will be flowing all around the antenna on or slightly under the surface, so even a six-inch casing won't provide much surface area along which current can flow. In other words, your well casing could go down 15 feet or 1500 feet or all the way to China without doing much to reduce your earth losses in the HF range.

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Some practical considerations, however, before we take a close look at some fairly typical installations and draw some rough conclusions: the PERFECT ground system for a vertical antenna operating in the HF range is probably out of the question on most residential lots, but that doesn't at all mean that nothing can be done to reduce earth losses and turn more of your applied power into useful radiation rather than heat. The most important thing to keep in mind as we go along is that some of your precious R.F. will be radiated straight-away (good), a relatively small amount will be lost forever in feed line, traps, loading coils and the like (not so good, but we can usually live with it), and a fair amount will come raining down from the vertical radiator onto your lossy real estate. Your main task will be to help this last portion of R.F. to work its way back to the antenna feed point with as little wear and tear as possible so that most of it will be available to run up the radiator again on the next cycle. How to do it? Copper-plate your backyard? Hardly practical, but you can do quite a bit with plain old wire (bare or insulated) in any gauge heavy enough to stay in one piece if stepped on or if ground between rocks during a hard freeze. Many radial wires emanating from the base of the antenna will offer a number of low-resistance paths back to the feed point. These radial wires can be buried an inch or two under the sod to protect them from lawnmowers and foot traffic, or they can simply be draped on the earth. There's no point in burying them any deeper than is necessary to get them out of the way. Space them more or less uniformly over 360 degrees (not always possible, but that's the goal).

HOW MANY WIRES? That depends on how long they are. HOW LONG SHOULD THEY BE? Answer: The longer the better. The hitch is that as the wires become longer more of them are required to take full advantage of their greater length. This is because a longer wire will intercept current on the surface out to a greater distance than will a shorter wire (good), but for a given number of wires the separation between adjacent wires necessarily increases as the wires become longer, in which case currents on the surface between two highly-conductive wires must cross an ever-greater stretch of lossy earth to encounter a low-loss path home (not so good). Of course, four 1/2-wave radials will do a better job of reducing ground losses than will four 1/4-wave radials, but the difference may not be very great for the reason just given and because the intensity of currents flowing out near the end of the wires will be much less than that of currents closer to the antenna.

It's generally reckoned that approximately half the ground loss encountered occurs within a circle having a radius equal to the antenna's height and that most (though not all) of the remaining loss resistance occurs in the next quarter wavelength out from the antenna as the capacitance between the vertical radiator and the earth rapidly decreases. In any case, it's clear that for a given amount of wire it pays to lay down a larger number of radials when they have to be short, although some have pushed. this sound principle to ridiculous lengths, cutting 120 ONE-FOOT radials (covering approximately the same surface area as a garbage can lid) when a dozen 10-footers would have done a much better job.

Perhaps you've heard or read that all radials should be some particular resonant length, say a quarter wavelength, before they're draped on the earth or buried slightly under the sod. Resonant radials have their uses (as we'll see shortly), but within a few feet of the earth any practical length of wire in the HF range will have enough capacitance to the earth to be tightly coupled to it and thus be detuned considerably, much as a horizontal wire dipole at very low heights will be detuned from the formula lengths for resonance by the earth. Luckily, radials at ground level need not be resonant at all, so at ground level your only problem is to make the earth around the antenna more conductive than it is to start with. In practice that means putting down as many radials as possible and making each one of them as long as possible.

In essence, all we're talking about is efficiency. If you put 100 watts into an antenna, how much of that leaves the antenna as useful radiation and how much is lost as heat? Some of the quantities we have to deal with are elusive and usually can be measured only indirectly, but with a little theory and seventh grade math we can begin to evaluate things more or less logically and usually come up with useful insights into the probable effectiveness of a proposed vertical installation.

The first basic concept we have to deal with, a RADIATION RESISTANCE. This term is a misnomer in that it doesn't denote a real resistance, but R F. energy that is “lost” by radiation--just what we want. In fact, we can say that radiation resistance is "good" resistance as opposed to “bad” ground and conductor resistance which represent a total loss.

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Let's assume that the antenna is a full quarter wave tall and resonant or nearly so (the usual case) so that we don't have to worry about any inductive or capacitive reactance components or losses in loading coils or matching networks. Of all the several “resistances” the radiation resistance is the easiest to estimate because that's largely a matter of radiator height (length) and to a lesser extent, diameter. Conductor resistance is usually negligible for radiators constructed of tubing, but loading losses can increase rapidly as the structure is made much shorter and as the loading coils require more inductance to bring the antenna to resonance, and the various trap circuits required for multi-band operation add their own losses. Some of these are lossier than others, so one should refer to the ARRL Handbook or other publications for a more thorough understanding of such concepts as “Q” and “form factor”.

But ground losses can easily exceed combined conductor, loading, and trap losses if no measures are taken to reduce them. Let's consider a 1/4-wave vertical at ground level with only a 6 ft rod for a ground system (a fairly typical installation, regrettably). Because a quarter-wave is a resonant length we can forget about loading and trap losses, and the conductor losses will usually be low enough to ignore.

Therefore, we can assume that whatever feed point impedance we encounter will consist of the antenna radiation resistance plus the ground loss resistance and little else, so we attach our 50 ohm cable and measure the SWR at the antenna feedpoint. Measurements made at the transmitter end of the line may be much less accurate. Hmm. The lowest SWR in the center of the band is 2:1! What does that tell us? First, we know that a SWR of 2:1 on 50-ohm line means a feedpoint impedance of either 100 or 25 ohms. Which is it? Luckily, we also know that a 1/4-wave vertical has a radiation resistance of approximately 35 ohms, so there's no way our total feed point impedance can drop BELOW that value, Our feed point impedance at resonance, then, is 100 ohms, and we now have enough information to say something about the efficiency of this antenna and its ground system. If our radiation resistance is 35 ohms we must also have some 65 ohms of pure ground loss resistance that's doing us no good at all.

Efficiency (the ratio of power radiated by the antenna to the total power fed to it and expressed as a percentage) can be easily calculated by dividing the radiation resistance by the total impedance of the antenna circuit (i.e., radiation resistance + ground loss resistance + conductor, trap and loading losses of all kinds). In this little example we've assumed a resonant quarter-wave antenna to simplify matters, so we can now say that the efficiency is equal to the radiation resistance (35 ohms) divided by the same radiation resistance (35 ohms) and ground and other losses (65 ohms) or 35/100 = 35%, meaning that a little more that one watt out of every three applied to the antenna goes anywhere.

Suppose, however, that we put down a half dozen radials and find that our SWR drops to 1:1? (It may or may not!) That would mean that the feed point impedance has dropped to 50 ohms, and since our radiation resistance is still 35 ohms we can assume that the ground loss component is down to only 15 ohms. Our efficiency, however, is up to 35/50 or 70%--a notable improvement for a dollar or two worth of wire additional increases in efficiency will come more slowly and require much more wire, of course, but from zero radials to a half-dozen or so there's probably no easier or less expensive way to make your signal louder. Just how much improvement you can expect from adding radials to a system that previously included none is hard to predict because we don't usually know what the local R.F. ground loss resistance is to start with, and the technique of working back from the SWR with no radials at all permits only a rough estimate if we have an approximate idea of the radiation resistance of the antenna. If the antenna is much shorter than 1/4 wave and has to be loaded to resonate on a given band (the usual case with multi-band vertical antennas) the radiation resistance will be lower still and the overall efficiency reduced, particularly if the loading or trap coils are lossy, as they usually are, though you're not going to find this mentioned in any of the ads of those concerns who sell them.

Most commercial multi-band vertical antennas stand less than 30 ft tall (a bit less than 1/4-wave at 7 MHz) and worse, the use of traps to decouple sections of the radiator for resonance on the higher-frequency bands means that less than 1/4-wavelength of the available radiator will come into play on all but the highest-frequency band (usually 10 meters). This, in turn, means that the radiation resistance will reach 35 ohms only on that hand because the first trap, inserted at the 1/4-wave point for the highest frequency band, acts as a loading coil on each lower frequency band and progressively reduces the length of the radiator required for resonance. In other words, the 10 meter trap “loads” 15 meters, the 10 and 15 traps load 20 meters, the 10, 15 and 20 meter traps load 40 meters, and so on, each trap adding its own little bundle of loss resistance and helping to reduce the radiation resistance at the lower frequencies where the antenna is already “short” and thus has relatively low values of radiation resistance to start with.

Consider a vertical antenna having the same physical height as a quarter wave but now loaded to resonate at half-frequency over our original no-radial ground system. If the antenna is 1/4 wavelength on, say, 40 meters, its physical height is about 33 ft. A 1/4-wave resonant vertical for 80 or 75 meters would have to be some 60 ft tall, so what order of radiation resistance can we expect from something half as tall? Probably something in the range of 12 ohms, and we can assume that our ground loss resistance won't be any worse on 80/75 than it was on 40 meters because ground losses tend to increase with frequency. Anyway, if we apply a little power to it we'll probably read SWR = 3:1 or so at resonance. With 50-ohm line we know that the total feed point impedance at resonance must be either 3 x 50 ohms or 50 ohms/3, either 150 ohms or 16.6 ohms. Again, it's almost certainly the higher value because our 12 or so ohms of radiation resistance subtracted from the lower value would leave only 4.6 ohms for any ground and loading coil loss resistance. If we met with 60+ ohms of ground loss on another band we'll probably have nearly as much to contend with on 80 or even 160 meters. Further, we shouldn't completely ignore possible loss resistance in the loading coil, so figure maybe 5 ohms of our total feed point impedance for that.

Efficiency, then, would be approximately 12/150 = 8%! If we put back our six radials and observe that the SWR at resonance has dropped to 1.5 we can assume that the total feed point impedance has dropped to only 75 Ohms and that our efficiency has gone up to 16%. That may not sound like much compared to a full-size dipole operating at 90% efficiency or more, but don't be misled, for it still amounts to a signal gain of 3 dB! Most low-band dipoles can't be put high enough above the earth to produce much low-angle radiation for DX operation, and even an “inefficient” vertical will often out-perform a low dipole on 80 or 40 meters when the path length exceeds a few thousand miles. Longer and more numerous radials would further reduce the ground loss resistance and increase efficiency, and if you managed to string out 100 + radials for zero ground loss resistance would you ever arrive at even 90% efficiency? Probably not, because of the loss resistance in the loading coil or in the traps that contribute to the loading. The total feed point impedance would consist of the antenna radiation resistance (12 Ohms), loading coil loss resistance (5 Ohms) and zero ground loss resistance, 17 ohms in all, so 12/17 = 70% efficiency at best. Your signal would be stronger by same 6 decibels, equivalent to quadrupling the transmitter power, and your SWR would be up to 3:1 again, but a simple matching device can take care of that. Have we really gained anything? Yes, we certainly have. It's much easier and less expensive to match the feed line to the antenna than to use an amplifier!

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Several important points emerge from this last discussion. The first is that one should try to keep the radiation resistance as high as possible in relation to the circuit loss resistance for the sake of efficiency. Unfortunately, the radiation resistance largely depends on the height of the vertical structure, so as a practical matter all we can hope to do is to reduce the ground loss resistance through the use of radials and the loading losses through the use of high-Q loading inductors of large diameter. The slim loading coils and traps of light wire encased in metal that one sees in today's commercial designs are NOT what is needed.

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Consider standing wave ratio, or SWR. Doesn't a low value of SWR ALWAYS mean that an antenna is operating efficiently? No, it means nothing of the kind. Over the last 30 years or so low SWR has become an end in itself, especially since most no-tune solid- state transceivers won't deliver full power into 50-ohm lines that aren't almost perfectly matched to the antenna circuit. But what about line losses because of high SWR? The truth is that even a perfectly matched 100 ft length of good coax will have a built-in loss of approximately one decibel at 30 MHz, and increasing the SWR to 3:1 or so would cause only negligible additional loss that would be even more negligible at lower frequencies.

How can we account for all the superstitions that have grown up around SWR? We've all heard of the fellow who raised and lowered his beam until he found the exact height that produced the lowest SWR reading in the shack. That his beam might have worked much better at a slightly greater height with only a slight increase in SWR didn't interest him at all because SWR was the only thing that mattered, Similarly, some poor misguided souls have ripped up excellent radial systems because they found that increased SWR was too great a price to pay for greatly improved performance. Silly? It certainly is, but it points up a dirty little “secret” that most manufacturers would rather not reveal, namely, that they depend on your having a fair amount of ground loss for their vertical antennas to operate with tolerable SWR on some or all bands.

We said a bit earlier that a vertical antenna's radiation resistance depends almost entirely on its physical height or length. For obvious practical reasons, this height is usually between 25 and 30 feet, much shorter than the 60-odd feet needed for a quarter wave length on 60/75 meters or even on 40 meters, so the antennas radiation resistance never reaches the 35 ohms that we read about in the literature. In fact, the multiple-trap design approach most often means that the radiation resistance won't reach 35 ohms on ANY band except 10 meters where only the lower eight feet or so of the antenna is being used. Feed such an antenna with 50-ohm cable over a good ground system and the SWR should be no better than 1.5 on any band--barely acceptable in these days of no-tune solid state finals. But if we can count on a few dozen ohms of ground loss resistance the total feedpoint impedance comes closer to 50 Ohms and the SWR moves closer to 1.1! All is right with the world, at least if you don't worry about efficiency. One final example to illustrate:

A popular multiband trap vertical has a total height of some 25 feet, all of which is used on 80 meters. On 40 meters, however, only about 20 ft of it is used because a 40 meter trap is inserted at that point to block current flow on that band and to provide enough inductance for resonance on 80 meters. The normal physical length for a resonant quarter wavelength on 40 meters is still approximately 33 feet, so the fact that this antenna needs to be only 22 ft. tall suggests that the trap circuits for the higher-frequency bands contribute a fair amount of loading on 40 meters. But, as we’ve seen, shortening the antenna can lower the antenna's radiation resistance quite a bit, to, maybe 20 ohms on 40

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meters in this instance. When a 50-ohm feed line is connected what will the SWR be? Absent significant ground and loading losses it should be roughly 50/20 or 2.5:1 at best. Happily, however, most people will drive a stake in the ground, run out a short radial or two, accept another 25 ohms or so of ground loss resistance and end up with a SWR of 1.5 or less, not realizing that more than half their power is being lost in the ground connection. Luckily for all concerned, very little radiated power is required for effective communication over great distances under most conditions, as the QRP crowd has amply demonstrated over the years, so no one is the wiser. When you hear someone describe a vertical antenna as a “dummy load on a stick” or as “one that radiates equally poorly in all directions” these remarks should probably be directed at the whole installation, including the ground system rather than at the vertical radiator and its circuits.

But what about the poor fellow who read the ARRL Antenna Book and installed a good ground system? Is he stuck with his 2.5 SWR or must he remove radials until his SWR (and his signal) drop below some magic number? Must he buy an expensive “antenna tuner?” Not at all! It's a simple and inexpensive job to come up with a “cheap and dirty” matching device that will cover all the HF bands, and one is included with every Butternut HF vertical.

Radiation resistance, remember, is not a real resistance, but we have to account for any power fed to the antenna circuit that disappears through useful radiation as well as any loss resistance that simply consumes power to no purpose, but there's no harm in treating it as “lost” for our simple calculations so long as we recognize what's happening in the real world.

Remember too that our various calculations, simple as they are, don't begin to explain in detail just what is happening in all cases with all antennas, useful as they might be for a general understanding of what is involved.

PART IV

So far, we've been talking about vertical antennas operating with and without radial systems at ground level. Can't we simply raise the antenna a few feet above ground and forget about radials and losses as some of the ads suggest? Not really, unless we’re willing to forget about efficiency too, and in the case of most base-fed vertical antennas we'll probably need resonant radials to get low SWR if we raise the antenna more than about 10feet above ground level. A physical 1/4-wave radiator, recall, can operate in a resonant condition because the earth, even lossy earth, provides a “mirror image” of the “missing” half of a 1/2-wave dipole. The lower end of such an antenna is at a low-voltage/high-current point and has a feedpoint impedance of about half that of a dipole, or 35 ohms plus ground loss resistance, and if the feedpoint is quite close to the earth such an antenna will also be resonant. If, however, the antenna is elevated more than a foot or so the length of any vertical lead to the ground connection will become part of the vertical radiator and the antenna will no longer be resonant on one or more bands. For the same reason an elaborate radial system at ground level will do little or nothing for a vertical antenna atop a tall tower. Any radial or other ground system should enter the picture right at the antenna feedpoint of a base-fed antenna.

We know that it takes about 100 radials at ground level to overcome all our ground losses (bearing in mind that very few amateurs have either the real estate or the ambition required for 100 radials) and that four quarter-wavelength radials will provide about the same efficiency at antenna base heights of a half-wavelength or so. As the height above ground decreases the number of radials required for the same efficiency naturally increases, so at heights of a quarter-wavelength a dozen or more resonant radials might still be required for an essentially lossless ground system. Then there's another problem to solve: that of finding a tower or mast to support the antenna (how much are you willing to spend to accomplish what?)

Apart from reducing the number of radials needed for reducing the ground loss resistance to some minimum level, is there really any great advantage to mounting a vertical on a tall tower or mast? Maybe, maybe not. If the antenna is in a dense forest full of leafy trees that can soak up vertically polarized r.f. energy or in an urban canyon of apartment buildings it makes sense to elevate a vertical in order to be clear of local obstructions, particularly on the higher-frequency hands. If, on the other hand, the antenna is in the clear at ground level--and if you have the room for radials--it's unlikely that the cost of a tall tower could be justified. The vertical angle radiation pattern of a vertical antenna at ground level is essentially the same as that of the same antenna fifty feet above ground where initial adjustment will be more tedious and hazardous. The main difference between above-ground and ground level vertical installations if both are in the clear is that more radials will be needed at ground level to overcome the earth loss resistance.

But what about the no-radial designs with or without a remote matching device at the lower end? One ad asks us to believe that a 17-ft. radiator is a “half wave” or at least plays like one on 20 meters, although a half wavelength on 20 meters is closer to 33 feet. Still, 17 feet is tall enough for relatively high radiation resistance on 20 meters, and the loading from the traps for the higher frequency bands probably don't introduce too much loss resistance. But how well would this antenna play on that band at ground level or even a few feet off the ground? Probably no better or worse than our plain-vanilla quarter-wave radiator because the ground loss resistance will still be there waiting to gobble up most of your power. “No ground radials” perhaps sounds alluring, but until we can make claims for “no ground LOSSES” the world will remain a dangerous place for R.F. from vertical antennas operating in the HF range! “Ground radials”, one must assume, are lengths of wire that are to be buried in the earth or draped on the surface. Why these should be more annoying than, say, “counterpoise radials,” the kind that are NOT to be buried, is a bit unclear, One "no ground radial" antenna seems to employ a “counterpoise” system of greatly shortened radials (so it uses radials after all!) though perhaps not as the ad-writer imagined.

At this point we should probably make a detour for a few definitions in order to make better sense of what follows. For years the terms “ground radials”, “ground plane” and “counterpoise” have been used almost interchangeably until their separate meanings have been all but lost.

The ARRL Antenna Book (15th edition) offers the following definitions:

Ground plane–-A system of conductors placed beneath an elevated antenna to serve as an earth ground. Also see counterpoise.

Counterpoise–A wire or group of wires mounted close to the ground, but insulated from ground, to form a low-impedance, high capacitance path to ground. Used at MF and HF to provide an RF ground for an antenna. Also see ground plane.

A counterpoise, then, depends on a fair amount of capacitance to ground for proper operation, and that means (a) that the counterpoise must be near the earth in terms of wavelength and (b) that the counterpoise must cover enough surface area to develop the necessary capacitance between it and the earth below, if you view the counterpoise as one plate of a capacitor and the earth as the other it's obvious that the capacitance between the two will diminish as the separation between them increases.

Counterpoises are most often used with vertical antennas for the lower-frequency bands when buried radials are out of the question, and the conductors that make it up often take the form of a spider web for the sake of increased capacitance. They're seldom placed any higher above earth than is necessary to permit unimpeded foot traffic, about seven feet or so. At much greater heights where capacitance to earth is not a consideration elevated 1/4-wave radials will suffice. And don't overlook the possibility that a set of resonant radials for one band may also provide an effective counterpoise system on one or more lower- frequency bands. Four 1/4-wave radials for 40 meters, for example, should provide enough capacitive coupling to earth to function as a capacitive counterpoise on 80/75 and 160 meters when antenna base heights don't exceed about 25 feet. This height represents less than 1/10 wavelength on 160 meters and twice that on 75/80 meters, and it is within this approximate range that counterpoises can be expected to work without becoming much larger. Keep this point in mind as we resume our discussion of the “no radial” vertical antenna.

It should be apparent that most mobile antennas operate according to the counterpoise principle, the metal body of the vehicle providing the capacitive coupling to the earth itself.

In the case of our “no radial” antenna that uses an abbreviated “counterpoise radial” system we might well wonder what its precise function is. Near the ground the short radials won't do much to reduce the ground loss resistance--certainly no more than the same number of ordinary wire radials of the same or greater length--and at even greater heights it's not at all clear how the vestigial radial system will take the place of the dozen-odd 1/4 wave radials we'd need for a real dent in the ground loss resistance once the antenna is raised to a 1/4 wavelength or so above the earth on 20 meters. The remote tuning/matching device takes the place of resonant radials as far as overall resonance and SWR are concerned, but will do nothing about ground losses. Elevated radials are usually 1/4 wavelength because it's a convenient resonant length, but even longer radials would be desirable if they didn't make the overall antenna system reactive. The function of a “ground plane” radial system (see above definition) is the same as that of “ground radials” or “counterpoise radials”: to provide low-loss “return” paths for currents that might otherwise prefer to flow on or along the lossy earth, and once again “the more wire the better” is a safe principle to follow, The makers of the “no radial” antenna have recently introduced a slightly taller 7-band version that claims “electrical half-wave length” operation, although its physical height falls well short of that required for even a quarter wavelength on 40 meters. How well this “no radial” vertical may be expected to play under competitive conditions an 40 meters where the short “counterpoise radials” will be even less effective in reducing ground losses at any height than they are on 20 meters is probably a fair question that deserves an answer, particularly since the manufacturer insists on this antenna's “independence of ground”. That's going a bit too far, perhaps, because its performance will depend on the same factors that affect more conventional vertical antennas that use messy, unsightly, inconvenient and totally inexpensive “ground” radials to deal with ground losses. Independent of ground in that the remote tuner/matcher provides low SWR? Okay, no quarrel with that. But low SWR by itself tells us next to nothing about how well the antenna is performing. Independent of ground as far as efficiency is concerned? NO WAY!

Suffice it to say that any vertical that will play close to the earth with no radials at all will play MUCH better over a good radial or counterpoise system and whether a particular system is a good one depends largely on how much surface area it covers and how many wires are used to cover it. A simple “no-radial” multi-band vertical may be easily constructed for next to nothing if one already has an “antenna tuner” and a handy tree limb. If the vertical wire is made about 25 feet long its performance should be roughly equivalent to that of any commercially available “no-radial” vertical antenna of the same general length (height) on 40 through 10 meters and occupying the same space, the longer wire lengths tending to favor the lower bands and the shorter lengths the higher bands, SWR at the feedpoint may reach 20:1 or more, but “ladder-line” has very low loss to begin with, so the additional losses because of very high SWR are unimportant. The difference in performance between this simple vertical wire and the commercial “no-radial” vertical will not be worth examining in the average case, and either can be made to outperform the other by laying out a GOOD radial or counterpoise system at the antenna's feedpoint, especially when the antenna is near the earth. Earth losses are the major limiting factor to vertical antenna performance, and no remote tuner or matcher can do anything about that.

Obviously, there are a number of trade-offs involved in every antenna installation, and there is no single antenna type or particular installation that will be ideal for everyone on every band. Before you blow your lunch money for the next six months you should probably become familiar with the most basic types and understand their characteristics. If you have an ARRL Antenna Book read it. Most of the answers to your questions are there, though you have to dig a little to find them. It's well worth it.

If you retain nothing from the foregoing discussion but a vague awareness that radials are somehow FUNDAMENTAL to the successful operation of vertical antennas you've grasped the main point. Even those vertical antennas that supposedly “don't need” radials will always operate more efficiently over a good radial system than over no radials at all. Radials may or may not affect the SWR of elevated or ground-level vertical antennas, but that's incidental to their primary function, which is to reduce the ground losses that might otherwise keep the vertical from operating more efficiently.

ADDENDUM

But hasn't anyone ever come up with a better, more effective and above all EASIER way to reduce earth losses than by stringing out radials? It seems not. Lossy earth is a constant, so the only thing one can do to protect vertically polarized RF flowing along it is to make it more conductive, and radial wires are by far the most effective and least expensive way to do that. FCC still requires AM broadcasters to install some 113 radials, each nearly a halfwavelength, in order to reduce earth losses to zero so that other station and antenna measurements can be made more accurately, and the latest edition of the ARRL Antenna Book still specifies 120 such radials for loss-free ground systems. These lengths and numbers hearken back to the results of a series of exhaustive tests conducted by RCA in New Jersey in 1937, and the resulting data are quoted or at least mentioned in every serious treatment of the subject ever since.

What? You don’t have the room for such a system? Hardly anyone does. Luckily, the first half-dozen radials are the most important, and if they can't each be a half wavelength long? So be it! Run out whatever you can. Hundred-foot towers are more desirable than 40-footers and 5Kw linears will make louder noises than 100-watters, so what else is new? The great question for which there's no hard and fast answer is what constitutes a MINIMAL radial system for amateur purposes. In most parts of the Midwest one can often get by with no radials at all, as a “cheap and dirty” ground rod will often suffice for low SWR on most bands. In desert or rocky regions SOME radials are usually needed, especially if something more than just “getting by” is desired.

ADDENDUM

The story on radials and earth losses has been told and re-told countless times in the last fifty years. The people who make no-radial vertical antennas have solved (or ducked) the earth loss problem by ignoring it, but in the amateur magazines (even in ARRL's OST, alas) we can find ads proclaiming marvelous new breakthroughs in the unending struggle against the evil forces of earth loss. One of these advertisments in particular is remarkable for its startling claims of “virtually NO earth loss” with only three short radials and higher radiation resistance than the conventional quarter-wave base-fed vertical. What's the big secret? There isn't any; someone has merely decided to feed a vertical quarter-wave in the center and to tell us that this “revolutionary technology” knocks out earth losses, boosts radiation resistance and allows a quarter-wave “stick” to operate at “approximately 90% efficiency!” Like WOW! Unfortunately, in order to believe these claims we must also believe other things that just aren't true, namely, that the conductivity of the local earth can be improved or modified in any way by doing something or anything at all to the vertical radiator and that we can feed a quarter-wave in the center as a loaded halfwave and keep the higher radiation resistance associated with a dipole. Does any of this make sense?

Stop and think for a moment. Where do we find earth losses? Surprise! They're to be found in and under the earth around a vertical radiator out to a distance of a wavelength or more. Feed the radiator at the bottom, top or in the center and the earth loss resistance will still be there waiting to devour any vertically polarized RF that dares to come along. It'll still be there if you platinum-plate the radiator, paint it green or yank it up and store it in your attic, so what can they be talking about? If earth losses resided in the radiator they'd probably be called by a different name, we’d have had an entirely different theory of vertical antenna operation all these years, and FCC (probably) would not have had the BC broadcasters invest so heavily in copper wire. This part of the new “revolutionary technology” is so much technobabble, and one can only wonder how it slipped past the wizards at QST/ARRL.

But what about the big increase in radiation resistance? We said earlier that efficiency depends on keeping the radiation resistance as high as possible in relation to any loss resistance in the antenna circuit, so maybe they're ahead on that count? In another ad the “revolutionary technology” people deride the “conventional” (base-fed) vertical as “the most inefficient antenna available for amateur use.” A quarter-wave base-fed vertical, recall, has a radiation resistance of about 35 ohms, so how much greater is that of the center-fed job? The ARRL Antenna Book (16th edition, p. 2-43) tells us that a center-fed antenna having an overall length of a quarter-wavelength has a radiation resistance of 14 ohms. What? Less than HALF the radiation resistance of “the most inefficient antenna available for amateur use?” Could THEIRS be even more inefficient? Assuming a feedpoint impedance of 50 ohms (which is what they claim) and only 14 ohms of radiation resistance, efficiency = 14/50 or about 28%--quite a bit less than 90% claimed! Back to the drawing board? Probably not, though they have NOT eliminated earth losses by redesigning the radiator. When you see the BC stations ripping up their zero-loss radial systems to sell as scrap you'll know that someone has come up with something that works better than radials. Not before.

Another “no-radial” vertical for 40 through 6 meters has come on the market. This one stands all of 12 ft. tall, but it's called a “halfwave” in our modern Antenna Newspeak, and it supposedly operates with MAXIMUM efficiency and requires no radials, counterpoises or ground planes because “you don't have the kind of ground losses that's [sic] common with a quarter-wave vertical.” Again, ground/earth losses “go with the turf” in a very literal sense; they won't disappear simply because you don't want to bother with radials or because the manufacturer doesn't think you'll notice the difference (at times you may not).

ADDENDUM

Even if we ignore earth losses (assume for the moment that they don't even exist) what does "maximum efficiency" mean in Antenna Newspeak? A halfwave antenna on 40 meters (length about 66 ft. or 180 electrical degrees) will have a radiation resistance of about 70 ohms; a 12-ft. vertical (33 electrical degrees) will have a radiation resistance of less than 4 ohms, according to the ARRL Antenna Book. Assuming a perfect match to 50-ohm line the efficiency should be in the range of 4/50 = 8%! Unfortunately, earth losses DO exist, and we have yet to take them into account, so you can expect to offer up about half of your remaining power to Mother Earth in most near-ground installations--perhaps not too bad if you like to operate QRP with 100 watts!

A quarter-wave vertical, on the other hand would have no more earth loss to contend with than our magic 12-ft. "halfwave," but its much higher radiation resistance (35 vs. 4 ohms) would allow it to operate more efficiently in any setting. Even a run-of-the-mill multiband vertical bristling with traps and top hats can muster about 15 ohms of radiation resistance on 40 meters, so if we assume 35 ohms of earth loss resistance (not uncommon) and a perfect match we'd still be operating at about 15/50 or 30% efficiency with the taller antenna. That may not be much, but it's a lot better than 8% (or less, if you allow for earth losses), and if you want to run out a few wires you can probably do even better. On the higher-frequency bands, of course, the shorter "halfwave" antenna won't be so bad because the vertical portion starts to look a bit more like a REAL halfwave or even a real quarterwave, but any improvement because of increased radiation resistance and decreased loading losses won't affect the earth loss situation, whatever it might be. Is it possible to add radials to the no-radial or few-radial designs to improve efficiency? In general, it seems not, but one should ask the manufacturer.

None of the foregoing is in any way profound or original. It's an old, old story that bears almost constant retelling, especially when the sunspots are heading south again and when new amateurs are coming to the hobby and grappling with basic concepts for the first time, to say nothing of such pseudo- concepts as "halfwaves" that are only .18 wavelengths tall. Indeed, one manufacturer offers a no-radial "halfwave" that's several feet SHORTER than than his own trapped and loaded "quarterwave." Confusing? You bet; it's supposed to be! Even a Newspeak "halfwave" concurs up visions of greater radiation resistance, efficiency and bandwidth than is possible with a mere real-world "quarterwave," although the opposite is more likely to be the case. In one of Kurt N. Sterba's recent "Aerial" columns in WORLDRADIO we can read (among other juicy tidbits) that

... the typical quarter-wave vertical is NOT an end-fed antenna--it's a center-fed antenna. The high current is right there at the feedpoint. It is the center of a dipole that goes one quarter-wave vertically and the other half of the dipole which is made up of the ground and/or ground radials (May, 1993, page 71)

True enough, and most of the standard reference texts tell essentially the same story. Electrically, the no-radial Newspeak "halfwave" and the real-world quarterwave are not too different, though the quarterwave with quarter-wave (or longer) radials will be much more effective in reducing earth losses than no radials at all, at least at heights of a half wavelength or less. Remember that getting rid of unsightly and inconvenient radials will NOT get rid of power-robbing ground loss, far from it. So then, why radials? To make a vertical antenna play more efficiently by reducing some or all of the inevitable earth loss, Q.E.D.