Whither Vertical Antenna Design?
(Trap and Loading Coil Losses With Vertical Antennas)

By Donald R. Newcomb, W0DN

In an earlier piece we talked about earth losses and their baleful effect on vertical antenna performance. In spite of much nonsense to the contrary, the only way to avoid earth losses is to make the earth below and around a ground level installation far more conductive than it is normally. As a practical matter this entails installing a number of radial wires on or slightly under the earth. 120 such radials, each 1/28 long and more or less uniformly distributed are supposedly ideal. As you might imagine, as the radials are made shorter and less numerous earth losses increase and the system becomes less efficient. The ARRL Antenna Book (16th Edition) sums it up well enough:

> "It has also been found that as the number of radials is reduced, the *length* required for optimum results with a particular *number* of radials also decreases; in other words, if only a small number of radials can be used, there is no point in extending them out l/28 . With 15 radials, for example, a length of 1/8 is sufficient. With as few as two radials the length is almost unimportant, but the efficiency or a 1/48 antenna with such a grounding system is only about 25% (It will be considerably lower with shorter antennas [Ch.3-36])."

Note in particular the remark about antennas physically shorter than .25 8. Some of the popular no-radial vertical types are touted as electrical "half waves," although the same manufacturer may produce an even taller quarter wave for the same bands. But how can a quarter wave be taller than a half wave? Easy! An *electrical* half wave is *not* necessarily the same as a physical half wave, and if you don't yet understand the difference it might a good idea to review some basic definitions. A *physical* wavelength in free space is always so many feet and inches and is never less than 964 feet divided by the frequency in mHz. A physical wavelength at 7 mHz is therefore 984/7 = 140.6 ft. and a mere half wave is only a little over 76 ft. An *electrical* half wave may be as tall as a *physical* half wave (70 ft.) or as short as anyone dares make it before the antenna stops radiating altogether. Know the difference! It's an unfortunate fact of modern life that new amateurs look for enlightenment in the Newspeak of antenna ads and that some of the experts who review these for technical accuracy and misleading statements don't blow the whistle loud enough to be heard by the advertising crew. Make it a point to insist on explanations for statements that don't seem to make sense or seem to contradict basic theory! If the manufacturer can oblige, fine. If not, seek elsewhere.

So much for earth losses and dimensions except to add that an antenna that is *physically* much shorter than .258 without any radial system at all will probably show so little radiation resistance that it will be a poor performer in most installations

At times we may have little choice. An antenna for 75 meter mobile work just can't be 60 ft. tall, so we load it seven ways from Sunday, accept the resulting low efficiency, and don't lose much sleep over it. But we expect somewhat better performance from a much taller fixed antenna. And if we can run out a few good radials we may be able to do much better than the worst-case situation cited above. If we're using one of the “no-radial” so-called half waves we're probably out of luck because radials supposedly de-tune the antenna on some or all bands, in which case we’ll probably need some kind of expensive antenna tuner to deal with the higher SWR. At this point we have to start to worry about loading and trap losses, especially if we're already losing some 75% of our applied power to earth losses, so just what magnitude or additional loss are we talking about? It's hard to be precise, because of the wide variation in materials and dimensions used in most trap and loading-coil construction, but at least one expert (G4ZU) has reckoned that each trap in one of the popular so-called “half wave” designs contributes 1.0 dB or so of loss resistance on the band for which it's designed. That may not sound like much, but let’s take that as a starting point and start tallying up all our lost dBs. Most trap coils are wound on small diameters and use fairly light wire (typically #12 or smaller). Worse, their diameter/length ratio is usually poor, larger coil diameters being preferred (see the ARRL Handbook for a more thorough discussion of trap Q in relation to loss). Most trap and loading coils used in commercial designs are long and skinny low-Q (typically 100 or less) affairs, so perhaps 1.0 dB of loss per trap is overly generous.

Most vertical antennas are physically shorter than .258 at the lowest operating frequency and use less than a quarter-wavelength of the available radiator on any band, the traps for the higher frequency bands acting as loading coils on all lower frequency bands. A 25-ft. radiator, for example uses only the lower 6 ft. or so of the antenna to produce radiated field on 10 meters while the rest of the antenna above the 10 meter trap goes along for the ride and contributes nothing. It might seem a bit wasteful to have most of the antenna waving about uselessly, but that's one of the prices that some of us are willing to pay for low SWR operation on more than a single band. The 10 meter trap acts as a loading coil on 12 meters, so we can’t use a full quarter wavelength or the radiator on that band either. This necessary shortening entails a slight reduction in the radiation resistance on that band, so the next trap (for 15 meters) has to be inserted at an even lower point on the antenna in terms of wavelength. And so it goes, right down to the lowest frequency of operation on 80 meters where all seven (!) traps contribute both loss resistance and inductive reactance to the antenna circuit even as the progressive radiator shortening necessitates a progressive decrease in radiation resistance. Remember, the only part of an antenna's feed point impedance that does us a bit of good is the *radiation resistance*, which is called a “resistance” at all only because that designation provides a convenient way to account for power “lost” as radiation instead of heat. All other components of the feed point impedance represent power that is truly lost and can never become available for radiation. Therefore, if we start out with 100 watts into such an antenna we should assume that ve’ll lose a good 6 dB to earth losses and another 1.0 to 7 dB to trap and loading losses, depending on the frequency of operation. Luckily, all traps don't come into play on all eight bands, so the loss may not be too noticeable above 21 mHz where only the first two traps are “active”. At 14 mHz however, cumulative trap and loading loss from the 10, 12 and 17 meter traps could exceed 3 dB, in which case the loss could become quite noticeable.

Assume too that we're using one of the ultra-short no-radial types that ignore earth losses. Earth losses will probably cut our 100 watts down to 25 watts or less before our signal leaves our property, and if we take 3 dB or more from what's left for trap and loading losses we’re down to only a dozen watts or so. Grim? Perhaps, and it only gets worse as we QSY down to 30, 40 or 80 meters. Another disturbing thought! Some of the no-radial designs use more than one trap per band to form what looks to be a single short and heavily loaded radial which can do next to nothing to reduce earth losses, but will certainly give us a few more dBs of loss to work into our calculations.

There is no simple device such as a SWR bridge or analyzer that will allow us to separate antenna radiation resistance from loss resistance, something that must be done if we are to say anything meaningful about antenna efficiency. If we know the physical height of a vertical, however, it's a simple matter to find the radiation resistance from Chapter 3 of the Antenna Book, and measure the antenna SWR at the feed point with an accurate instrument. That done, we then calculate the total feed point impedance at resonance. If, for example, we find that our vertical is 1/88 tall (45° or about 18 ft at 7 mHz), we'll see that it should have a radiation resistance of about 7 ohms. If our SWR measures 1.5 we'll know that the total feed point impedance is 1.5 X 56 or 75 ohms. That’s everything: earth loss, trap loss, loading loss and maybe even a fair amount of feed line loss that won't show up on the SWR meter if we're using long runs of ancient coax. That's why it's a good idea to measure SWR as close to the antenna as possible. Our 7 ohms of radiation resistance is in there too, so the other 68 ohms of feed point impedance are down the drain forever. To calculate the efficiency of our poor little antenna we have to pull out our precious 7 ohms of radiation resistance and divide it by the total feed point impedance. That's 7/75 or 9.3333%. In other words less than one watt in 10 ever gets radiated.! But cheer up! Efficiency may be a little better above 7 mHz and, alas, a lot worse below 7 mHz as the antenna becomes ever shorter in terms of physical wavelength At 14 mHz the same antenna would use nearly a full 1/4 of the available radiator for a radiation resistance approaching 35 ohms and the trap and loading losses should waste only about half of our 100 watts. Earth losses would probably stay about the same, but overall efficiency might rise quite a bit. The same 16 ft. antenna would probably not be designed to play on 80 meters because the radiation resistance would drop to only 2 ohms or so and efficiency would be no more than about 5% because of the additional required loading and its accompanying loss.

It seems that multi-band vertical antenna design in recent years has proceeded along several paths, all of which are ultimately dead ends. The multiple-trap design approach of the 50's has just about run its course. Before 1980 or so there were three fewer HF bands to worry about, so we could often swallow several dB of trap loss in exchange for the convenience of operating on four or five bands with a single antenna and when conditions were good often no one was the wiser. Along came three WARC bands in the early 80's and three more trap circuits with another few dB of loss resistance and what was formerly tolerable became much less so as the sunspots petered out.

It could not have come as a surprise to any designer or manufacturer that additional traps for additional bands would necessarily mean additional loss and generally inferior performance, but most of them had been plodding down the same old road for years, so it was probably an easy decision to stick with what had always worked (sort of) and hope for the best. Is there nothing that can be done to reduce trap and loading losses? There certainly is and an obvious first step would be to get rid of traps altogether or at least reduce their number to the point where they won't soak up half our applied power. Oddly enough, one of the designs from the late 70's took this design approach with a five-band (80-10 M) vertical that used only three tuned circuits, only one of which functioned as a trap. More remarkable still, the Q of the two non-trap circuits was well over 300, and because neither choked off current flow on any amateur band and thus allowed the entire antenna to operate on all bands but 15 meters where, however, it still functioned as a full physical .258 radiator. The improvement in 20 meter radiation resistance, in particular, was striking: from less than 35 ohms for a loaded quarter wave to over 100 ohms for the whole 26-ft. radiator. It's risky to make predictions concerning the kind of aerial that anyone will want in five or ten years, but I think it safe to say that in a few years virtually everyone will want something that incorporates the main features of this design which is now the property of the Bencher Inc. of Chicago, IL. Traps may still have a place in multi band antenna design, but they’re increasingly recognized as an unnecessary source of loss.

Another design approach (from the mid 80's) purported to have realized the same objectives (increased radiation resistance and decreased loss resistance). This design showed some promise in that it avoided traps entirely in favor of linear circuit elements and used a sufficiently tall radiator (31.5 ft) for good radiation resistance on most bands, but, paradoxically, treated earth loss as a minor inconvenience that could safely be ignored because the antenna feed point (not the antenna itself) had been elevated some 18 ft. This simple expedient, it is claimed, “virtually eliminated” earth losses so that only three short (25 ft.) radials would permit a ground-mounted antenna to play with an efficiency of “about 96%”. We have not seen such a startling claim since the heyday of CB, so we perhaps should examine this one carefully. What is earth loss and where does it reside? Earth loss is simply the resistance offered to RF as it flows along or through the earth. Conductive earth favors current flow and lossy (highly resistive) earth opposes current flow at RF. At any rate, that's what all the textbooks have been saying for nearly a century, so to ask where we encounter earth loss is akin to asking who is buried in Grant's tomb. Yet, we're asked to believe that earth loss is somehow concentrated in the antenna conductor and that we can reduce or eliminate it by changing the feed point! Eagerly, we search the promotional and other literature for a key to unlock the mystery of this extraordinary breakthrough, but it seems to have passed almost unnoticed!

In a review article in Radio Communications in December 1991 G3SJX examines this design, accepting the claim for reduced earth losses largely at face value. Apart from minor problems involving RF on the feed line (for which the manufacturer suggests an additional 65 feet of coaxial feed line as a cure) assembly was straightforward, and comparative tests could begin against a much shorter antenna, an 8-band version of the "no- trap" design discussed earlier over a dozen short (1/8 to 1/48) radials.

The results? G3SJX reported the following: on 80 meters the taller antenna's bandwidth was 130 kHz between the 2:1 SWR points compared to 32 kHz for the shorter antenna. However, signals were as much as 1-1/2 S-units below those from the shorter antenna, a situation that he attributes to the “lower Q inductive loading” provided by a quarter wave coaxial stub and capacitor arrangement for 3.5 mHz stuffed inside the radiator. Apart from the external tuning rods the internal stub and capacitor appear to be the only loading device used in this antenna which supposedly operated at approximately 90% efficiency, or roughly the performance that one might expect from a ground-level antenna over 100 + long radials. A 31.5 ft. antenna should deliver at least the same performance as a shorter one, particularly if it's operating at that level of efficiency. Clearly, something was wrong, at least on 80 meters! GSSJX tends to blame a lossy loading stub and capacitor. This is disappointing, for it does little good to get rid of lossy traps only to replace them with even lossier circuit elements.

G3SJX continues, observing that “on 7, 14 and 24 mHz there was no perceptible difference between the antennas." The obvious question here is why not? The taller antenna, supposedly operating at 90% efficiency, ought to have been markedly superior to the shorter one on these bands, but it wasn't. G3SJX again:

> "On 21 mHz the [taller antenna] was 1 to 2 S-points down and on 28 mHz generally similar but up to 1/2 S-point down on some signals. These results were remarkably consistent and independent of direction or whether the signals were local or DX (p. 53)."

Perhaps it's time to consider the basic assumptions that underlie this particular design. That they're unusual is something of an understatement in the light of all that has been written about earth loss and vertical antennas over the last 60 years. What is really odd is that those assumptions have largely gone unchallenged, until recently. VE2CV's long Technical Note in QST for January 1995 is perhaps a long-overdue step in the right direction, for this design was widely bally-hooed as the ne plus ultra of vertical design. Quoth VE2CV:

> "The purpose of this technical note is to clarify some of the statements made about the performance of vertical antennas. Some companies claim outstanding or amazing DX performance, low radiation angle, low noise, no ground loss and other attention-grabbing text in their product advertisements. Some of these need to be examined carefully. I'll comment particularly on the following statements: Elevated feed reduces--even eliminates--earth loss; Raising the antenna off the ground improves performance; A vertical's DX performance is superior to that of a horizontal dipole at a practical height. It's my opinion that the first statement is *not true*. The second and third statements need qualification...(p.76) Although a great fuss is made about reducing ground loss with elevated feed, such a claim, as I've discussed earlier, is not true. To improve performance, *the entire antenna* has to be lifted off the ground by a significant amount, *not just the feed point* (p.79)"

For this design to show appreciable gain over a ground-mounted base-fed antenna VE2CV suggests antenna heights of 50 ft. or more for 14.150 mHz and notes that for equivalent performance at 7 mHz the antenna should be twice as tall, further noting that:

> "A grounded vertical antenna with an elevated feed makes a better multi-band DX antenna than does a vertical antenna with base feed, but this is not because ground induced losses are reduced, but

> because the antenna's current distribution is changed, as is the radiation pattern. For multi band performance, judged by pattern change with change in frequency, the feed point should be at a height of about 1/3 the total height (h) of the radiator and the height of the radiator should not be greater than 1 wavelength (8) at the highest frequency used (p. 78)."

At any rate, we should not imagine that an elevated feed point will do anything at all to reduce earth losses or that efficiency can begin to approach 90% in most installations. Moreover, we might suspect that the unexpectedly poor results that G35JX noted on 21 and 28 mHz were due to changes in current distribution along the radiator. Suffice it to say that the elevated-feed design in question still has problems with earth and loading losses (even after eliminating all traps) and that a good deal of re-design will be required before it can live up to the startling claims that have been made for it.

In general, we might say that over the last dozen years or so antenna design has tended to stress compactness, ease of installation and overall convenience at the expense of more basic design considerations. That's certainly understandable enough from the manufacturer's point of view, because he's merely reacting to market pressures: if enough customers want a 160 meter DX antenna that will fit inside a basement broom closet and put S-9 + 40 dB signals into Nepal 24 hours per day (no ground radials needed, of course) you may be sure that someone will offer one. True, it may not work very well, but creative advertising has been conquering the laws of mere physics for longer than any of us have been alive.

Unfortunately, what works (or seems to work) well during periods of maximum sunspot activity may not work at all as the same sunspot cycle declines. If you're willing to sacrifice 90% of your power to earth and trap losses because you're too lazy or too decrepit to run out a few pieces of wire under the nose of the neighborhood antenna Gestapo, there's probably no hope for you to begin with, in which case we have to wonder why anyone would want to blow a small fortune on an overpriced dummy load in hopes of daily miracles. Years ago, H.L. Menoken once observed that no one ever went broke under-estimating the intelligence of the American public. And Menoken didn't even have a ham ticket!

We can only guess what commercial vertical HF aerials for HF will look like in coming years, but if we extrapolate from current design trends the outlook is worse than bleak. Perhaps it will be possible to add still more traps for still more bands, although that road is not only rutted but heavily mined, particularly where it merges with the highway leading to tinier and tinier radiators for ever lower values of radiation resistance and efficiency. It's clear that we can't count on Cycle 23 for any relief at this point because it won't even begin for another two years and

10 meters may not open regularly for another year or two after that. Perhaps the people with the “90% efficient” design will discover ground systems and low-loss loading? Perhaps others will drop some of their traps and start using taller radiators. Don't bet on it!

One hopeful sign of a possible change of heart comes from Kurt Sterba's favorite BFAC (Big Famous Aerial Company). They've announced a “special” 36 ft. tall vertical for 80/75 meters that sports a huge capacitive hat at the top. That's still not a full physical quarter-wave, so presumably the black box at the base houses some sort of loading coil. It's strictly an 80/75 meter affair, but that's all to the good because we don't need a string of traps for higher-frequency bands sucking up power that might otherwise help us to establish a commanding presence in the next hemisphere. And, wonder of wonders, this BFAC has the audacity to recommend that we use *radials* with it! Daring? You bet! When did you last see an ad for something that *requires* radials? Have these people started to worry about performance all of a sudden? Are conditions really that bad? Someone must think so!

Anyway they're to be complimented for seeking to make something a little better rather merely smaller and lossier. It would certainly be ironic if the QRMing masses, having been taught by the BFAC’s to look upon “ground radials” with undisguised horror, decide to give this one a miss! Too bad, but that's one of the risks that go with dancing out on the cutting edge of aerial design!