Using the Half-Square Antenna For Low-Band DXing

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Can't put up a really high horizontal antenna for 80-meter DXing? Maybe the vertically polarized "Half-Square" might be the antenna for you.

Antennas widely used by amateurs have a few basic characteristics in common. They provide modest performance and good efficiency, are simple in design, inexpensive to fabricate and very flexible with regard to height, shape and construction materials. There is a very wide range of differences between QTHs, resources and personal circumstances. It is vital that the basic performance of an antenna be preserved even for significant variations in dimensions and materials if it is to be widely useful.

The dipole antenna fits these requirements admirably and is probably the most widely used antenna of all. Unfortunately, on the low frequency bands (80 and 160 meters) it is increasingly difficult to get good DX performance from a dipole due to the problem of getting the antenna high enough (in terms of wavelength). The landmark work by N6BV on HF propagation clearly illustrates this.[1, 2] **Fig 1** shows one of his graphs to illustrate the range of radiation angles most likely to be usable on an 80-meter path from New England to Europe. Over 90% of the time the angles are between 17· and 24·. Other longer paths (and those from different locations) show similar patterns, except that the longer paths have lower peak angles, in the range of 10· to 18·. For DX work on 80 meters, the desirable radiation angles are generally between 10· and 20·.

Also shown in Fig 1 are the radiation patterns for dipoles at 100 feet and 200 feet. At 200 feet the pattern is great, but lowering the antenna to 100 feet reduces radiation at the desired angles significantly. For most hams 100-foot dipoles are not possible and 200-foot dipoles not even a fantasy.

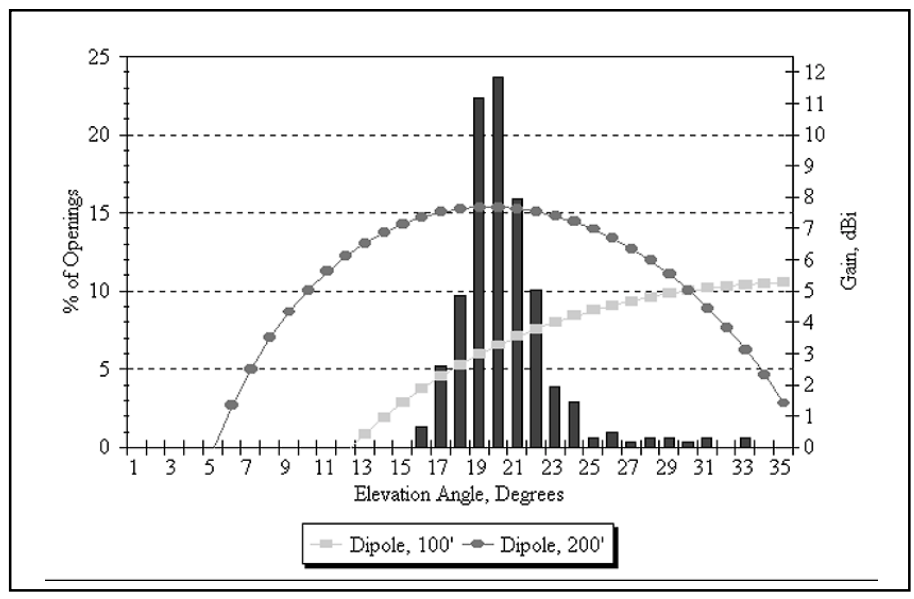

Fig 1—80-meter graph of the percentage of all openings from New England to Europe versus elevation angles, together with overlay of elevation patterns over flat ground for dipoles at two different heights. The 200-foot high dipole clearly covers the necessary elevation angles better than does the 100-foot high dipole. (*From The ARRL Antenna Book, 17th edition, Fig 30.)*

Heights in the range of 40 to 80 feet are much more typical, with the emphasis more towards 40 than 80 feet. This further degrades performance.

Another problem with low dipoles, from a DXing point of view, is that they have great response at high angles. This brings in local and US stations S9+ while you are trying to copy an S3 DX station.

Is there a way to improve on the dipole's DX performance while retaining most of its practical advantages? The answer is "Yes." The half-square antenna can provide 3 to 10 dB of improvement at angles between 10° and 20°, depending on the available height and soil conductivity in the ground reflection zone. In addition, the high-angle radiation can be suppressed. The shape, dimensions and feed point options are also more flexible than previous descriptions have indicated.

The half-square and its close cousin, the "bobtail curtain," have been known to amateurs for nearly 50 years.[3] For the most part, articles describing the half-square have been relatively brief and have not attempted to examine many of the finer points.[4, 5, 6] This very simple antenna has many subtle details and more than a few surprises. You can get very good results without great effort, but it is also possible to obtain very poor performance if moderate care is not taken!

The purpose of this article is to take a careful look at this antenna including:

- Comparison to a dipole at comparable heights, over different grounds.
- The effect of changing shape and dimensions on performance.
- Useful bandwidth, including both impedance and pattern effects.
- Different feed and matching schemes.
- Multiband operation

Modeling Notes

Much of the work presented here was done using computer modeling. Because these antennas are close to ground (in terms of wavelengths) and different parts of the antenna are at different heights, *NEC2* rather than *MININEC* modeling programs were used.[7,8,9] To maximize the accuracy, I included the wire losses and all wires connected at a corner used segment tapering. I assumed real ground, using the high accuracy (Norton-Sommerfeld) ground model. I carefully observed the proscription against grounding wires directly to a real ground. The accuracy of the modeling should be very good.

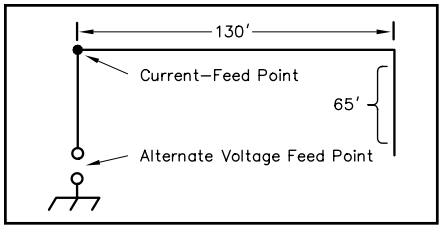

Fig 2—Typical 80-meter half-square, with λ/4-high vertical legs and a λ/2-long horizontal leg. The antenna may be fed at the bottom or at a corner. When fed at a corner, the feed point is a low-impedance, current-feed. When fed at the bottom of one of the wires against a small ground counterpoise, the feed point is a high-impedance, voltage-feed.

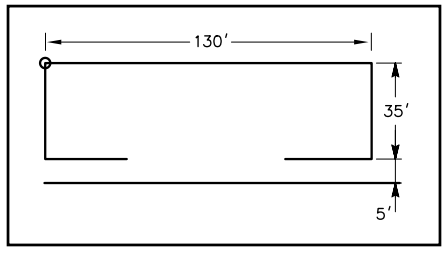

Fig 3—An 80-meter half-square configured for 40-foot high supports. The ends have been bent inward to reresonate the antenna. The performance is compromised surprisingly little.

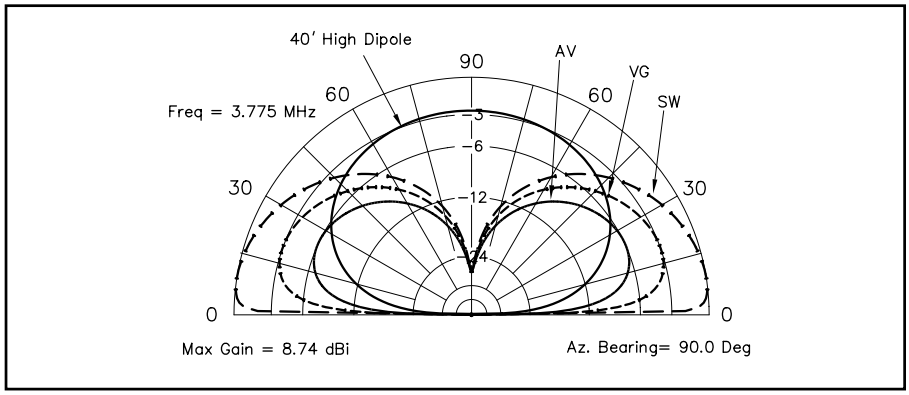

Fig 4—Comparison of 80-meter elevation response of 40-foot high, horizontally polarized dipole over average ground and a 40-foot high, vertically polarized half-square, over three types of ground: average (conductivity σ = 5 mS/m, dielectric constant ε = 13), good (σ = 30 mS/m, ε = 20) and saltwater (σ = 5000 mS/m, ε = 80). The quality of the ground clearly has a profound effect on the low-angle performance of the half-square. However, even over average ground, the half-square outperforms the low dipole below about 32°.

The Half-Square Antenna

A simple modification to a dipole would be to add two λ/4 vertical wires, one at each end, as shown in **Fig 2**. This is a *half-square antenna*. The antenna can be fed at one corner (low impedance, current fed) or at the lower end of one of the vertical wires (high impedance, voltage fed). Other feed arrangements are also possible.

The "classical" dimensions for this antenna are λ/2 (131 feet at 3.75 MHz) for the top wire and λ/4 (65.5 feet) for the vertical wires. However, there is nothing sacred about these dimensions! You can vary them over a wide range and still obtain nearly the same performance.

This antenna is two λ/4 verticals, spaced λ/2, fed in-phase by the top wire. The current maximums are at the top corners. The theoretical gain over a single vertical, for two in-phase verticals, is 3.8 dBi.[10] An important advantage of this antenna is that it does not require the extensive ground system and feed arrangements that a conventional pair of phased λ/4 verticals would.

Comparison To A Dipole

In the past, one of the things that has turned off potential users of the half-square on 80 and 160 meters is the perceived need for λ/4 verticals. This forces the height to be > 65 feet on 80 meters and > 130 feet on 160 meters. That's not really a problem. If you don't have the height there are several things you can do. For example, just fold the ends in, as shown in **Fig 3**. This compromises the performance surprisingly little.

Let's look at the examples given in Figs 2 and 3, and compare them to dipoles at the same height. For this comparison I have selected two heights, 40 and 80 feet, and average, very good and sea-water grounds. I have also assumed that the lower end of the vertical wires had to be a minimum of 5 feet above ground.

At 40 feet the half-square is really mangled, with only 35 foot high (≈ λ/8) vertical sections. The comparison between this antenna and a dipole of the same height is shown in **Fig 4**. Over average ground the half-square is superior below 32° and at 15° is almost 5 dB better. That is a worthwhile improvement. If you have very good soil conductivity, like parts of the lower Midwest and South, then the half-square will be superior below 38° and at 15° will be nearly 8 dB better. For those fortunate few with saltwater-front property the advantage at 15° is 11 dB! Notice also that above 35°, the response drops off rapidly. This is great for

DX but is not good for local work.

If we push both antennas up to 80 feet (**Fig 5**) the differences become smaller and the advantage over average ground is 3 dB at 15°. The message here is that *the lower your dipole and the better your ground, the more you have to gain by switching from a dipole to a half-square*. The half-square antenna looks like a good bet for DXing. However, there are a few other things to consider before replacing your dipole.

Changing the Shape

Just how flexible is the shape? We'll look now at several distortions of practical importance. Some have very little effect but a few are fatal to the gain. Suppose you have either more height and less width than called for in the standard version or more width and less height, as shown in **Fig 6A**.

The effect on gain from this type of dimensional variation is given in **Table 1**. For a top length (L_T) varying between 110 and 150 feet, where the vertical wire lengths (L_v) readjusted to resonate the antenna, the gain changes only by 0.6 dB. For a 1 dB change the range of L_T is 100 to 155 feet, a pretty wide range.

Another variation results if we vary the length of the horizontal top wire and readjust the vertical wires for resonance, while

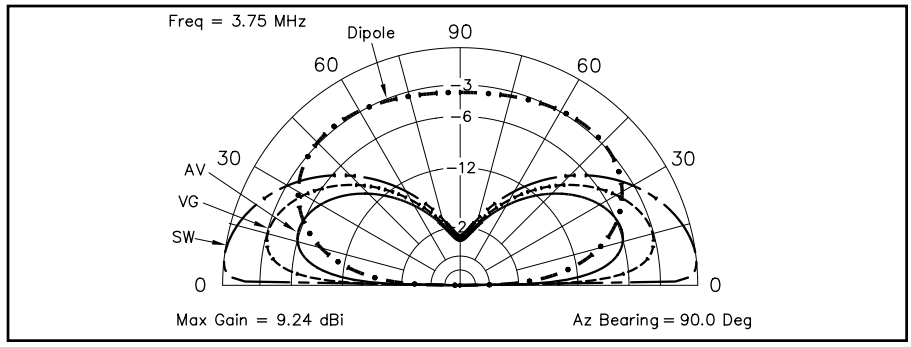

Fig 5—Comparison of 80-meter elevation response of 80-foot high, horizontally polarized dipole over average ground and an 80-foot high, vertically polarized half-square, over same three types of ground as in Fig 4: average, good and saltwater. The greater height of the dipole narrows the gap in performance at low elevation angles, but the half-square is still a superior DX antenna, especially when the ground nearby is saltwater! For local, high-angle contacts, the dipole is definitely the winner, by almost 20 dB when the angle is near 90°.

Table 1

Variation in Gain with Change in Horizontal Length, with Vertical Height Readjusted for Resonance. See Fig 6A.

L_T (feet)	L_V (feet)	Gain (dBi)
100	85.4	2.65
110	79.5	3.15
120	73.7	3.55
130	67.8	3.75
140	61.8	3.65
150	56	3.05
155	53	2.65

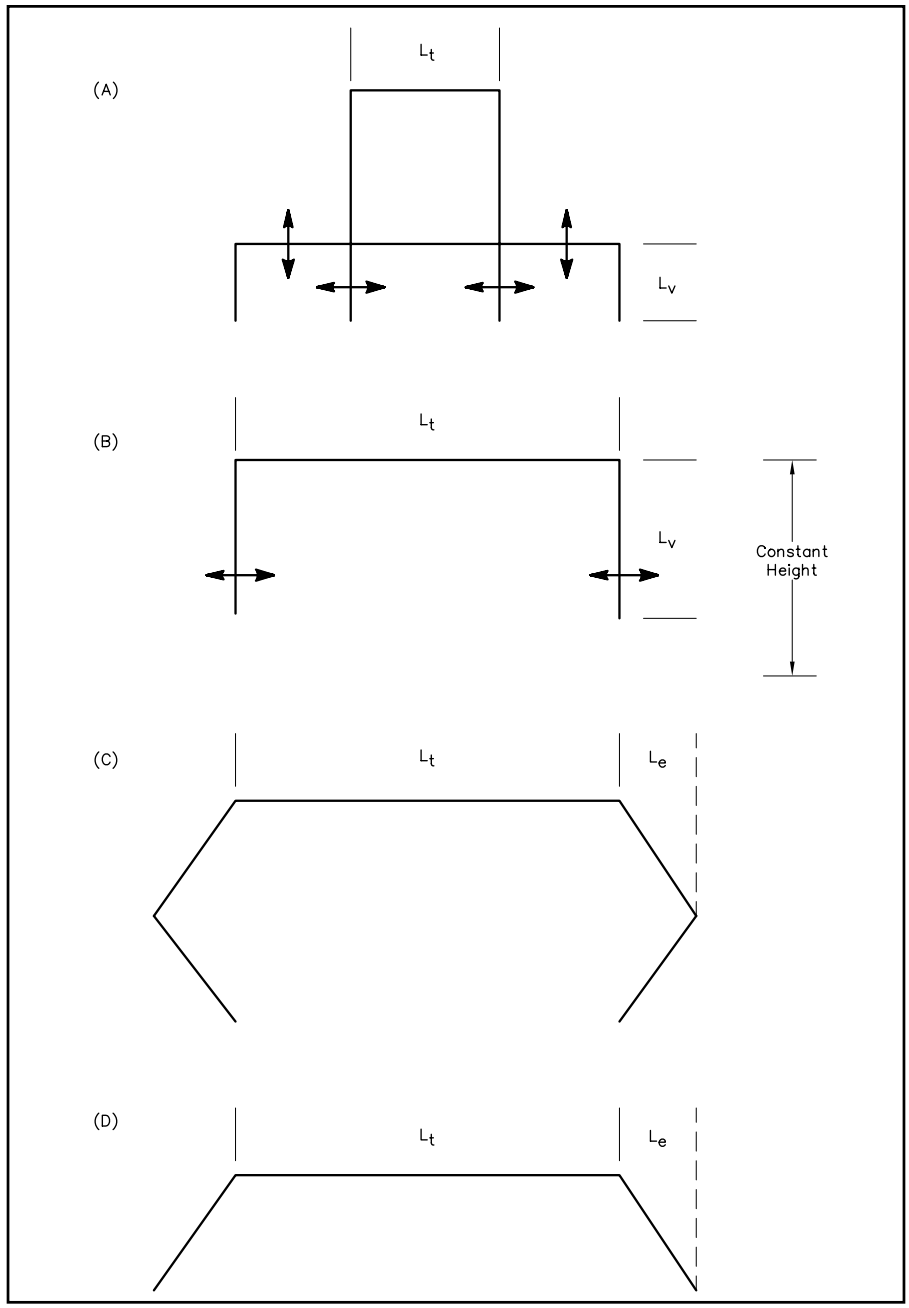

Fig 6—Varying the horizontal and vertical lengths of a half-square. At A, both the horizontal and vertical legs are varied, while keeping the antenna resonant. At B, the height of the horizontal wire is kept constant, while its length and that of the vertical legs is varied to keep the antenna resonant. At C, the length of the horizontal wire is varied and the legs are bent inwards in the shape of "vees." At D, the ends are sloped outwards and the length of the flattop portion is varied. All these symmetrical forms of distortion of the basic half-square shape result in small performance losses.

Table 2

Variation in Gain with Change in Horizontal Length, with Vertical Length Readjusted for Resonance, but Horizontal Wire Kept at Constant Height. See Fig 6B.

L_T (feet)	L_V (feet)	Gain (dBi)
110	78.7	3.15
120	73.9	3.55
130	68	3.75
140	63	3.35
145	60.7	3.05

Table 3

Gain for Half-Square Antenna, Where Ends Are Bent Into V-Shape. See Fig 6C.

Height ⇒	H=40′	H=40′	H=60′	H=60′
L_T (feet)	L_e (feet)	Gain (dBi)	L_e (feet)	Gain (dBi)
40	57.6	3.25	52.0	2.75
60	51.4	3.75	45.4	3.35
80	45.2	3.95	76.4	3.65
100	38.6	3.75	61.4	3.85
120	31.7	3.05	44.4	3.65
140	-	-	23	3.05

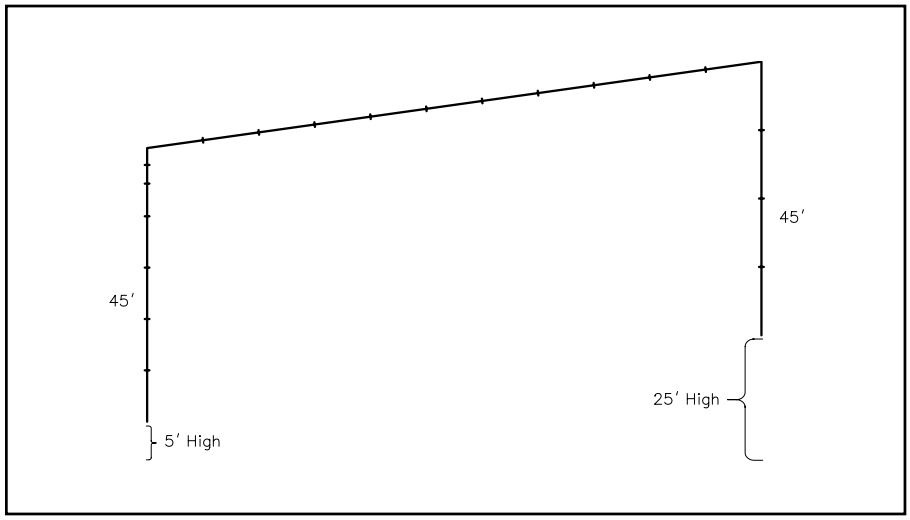

Fig 7—An asymmetrical distortion of the half-square antenna, where the bottom of one leg is purposely made 20 feet higher than the other. This type of distortion does affect the pattern!

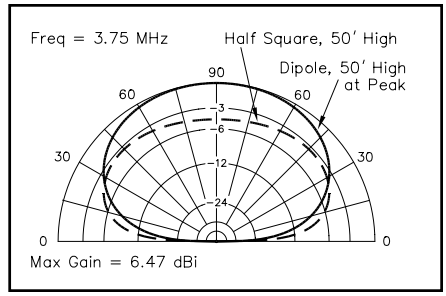

Fig 8—Elevation pattern for the asymmetrical half-square shown in Fig 7, compared with pattern for a 50-foot high dipole. This is over average ground, with a conductivity of 5 mS/m and a dielectric constant of 13. Note that the zenith-angle null has filled in and the peak gain is lower compared to conventional half-square shown in Fig 5 over the same kind of ground.

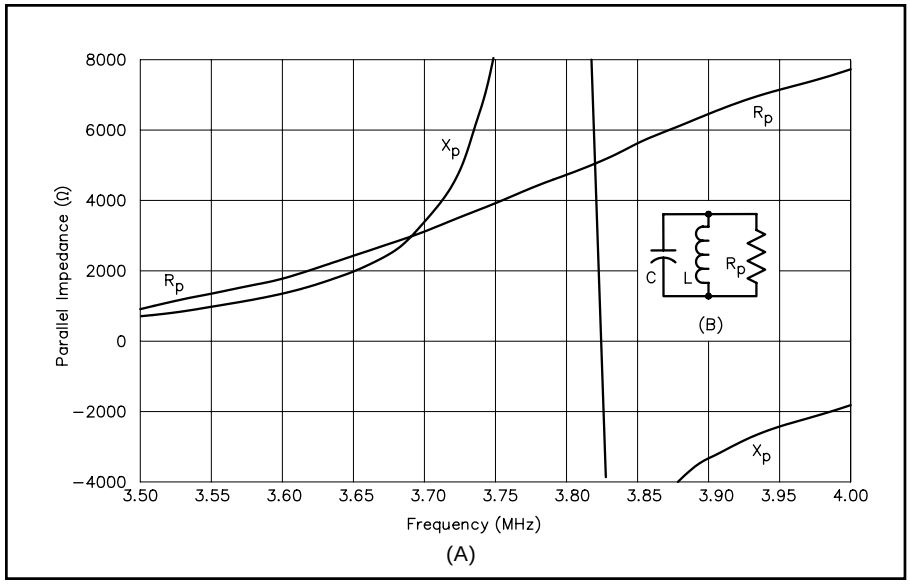

Fig 9—At A, graph of feed point shunt resistance and shunt reactance versus frequency for a half-square with voltage-feed at bottom corner. At B, equivalent parallel circuit of this antenna. This particular half-square is resonant at about 3.820 MHz, where its feed point resistance is about 5000 Ω.

keeping the top at a constant height. See Fig 6B. **Table 2** shows the effect of this variation on the peak gain. For a range of L_T= 110 to 145 feet, the gain changes only 0.65 dB.

The effect of bending the ends into a V shape, as shown in Fig 6C, is given in **Table 3**. The bottom of the antenna is kept at a height of 5 feet and the top height (H) is either 40 or 60 feet. Even this gross deformation has only a relatively small effect on the gain! Sloping the ends outward as shown in Fig 6D and varying the top length also has only a small effect on the gain. While this is good news because it allows you to dimension the antenna to fit different QTHs, not all distortions are so benign.

Suppose the two ends are not of the same height, as illustrated in **Fig 7**, where one end of the half-square is 20 feet higher than the other. The radiation pattern for this antenna is shown in **Fig 8** compared to a dipole at 50 feet. This type of distortion does affect the pattern. The gain drops somewhat and the zenith null goes away. The nulls off the end of the antenna also go away, so that there is some end-fire radiation. In this example the difference in height is fairly extreme at 20

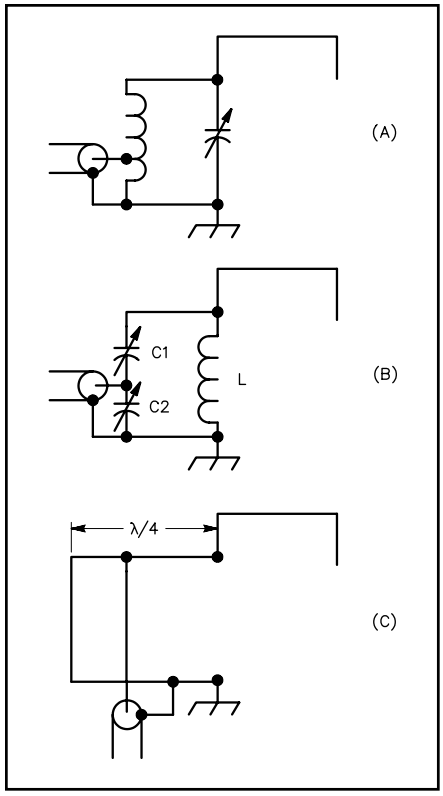

Fig 10—Typical matching networks used for voltage-feeding a half-square antenna.

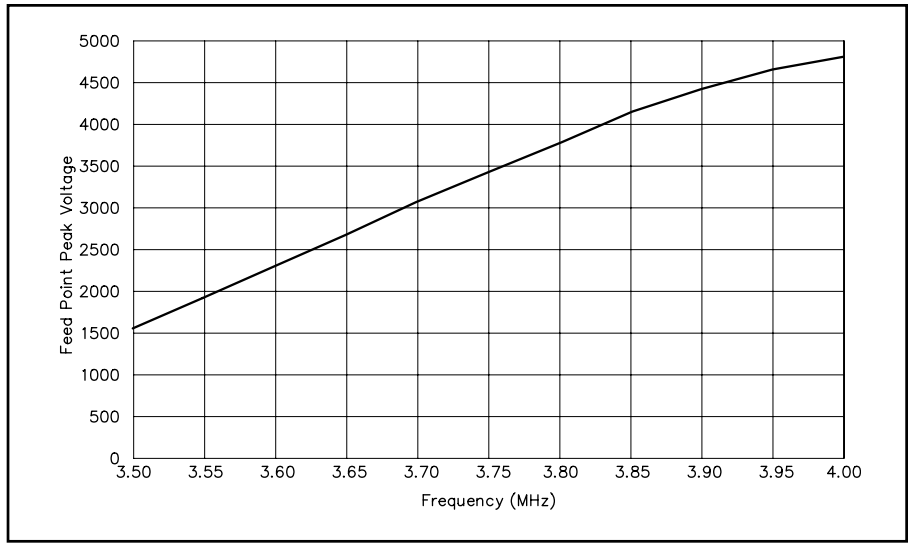

Fig 11—Graph of peak RF voltage at feed point of voltage-fed half-square antenna with 1500 W power.

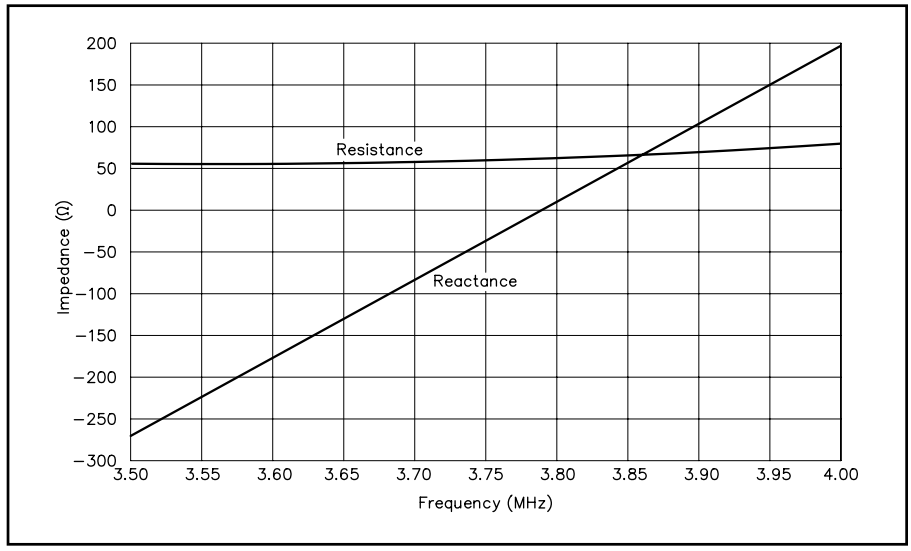

Fig 12—Graph of feed point series resistance and reactance versus frequency for a half-square with current-feed at one corner. Note that the resistive component changes slowly with frequency. This particular antenna is resonant at just under 3.8 MHz.

feet. Small differences of 1 to 5 feet do not affect the pattern seriously.

If the top height is the same at both ends but the length of the vertical wires is not the same, then a similar pattern distortion can occur. The antenna is very tolerant of *symmetrical* distortions but it is much less accepting of *asymmetrical* distortion.

What if the length of the wires is such that the antenna is not resonant? Depending on the feed arrangement that may or may not matter. We will look at that issue later on, in the section on patterns versus frequency. The half-square antenna, like the dipole, is very flexible in its proportions.

Feed-Point Impedance

There are many different ways to feed the half-square. Traditionally the antenna has been fed either at the end of one of the vertical sections, against ground, or at one of the upper corners as shown in Fig 2.

A typical example of the impedance variation for voltage feed is shown in **Fig 9A**. The impedance generated from the modeling program represents the parallel-equivalent impedance (Fig 9B) when driven at one end. This form is most informative when using a parallel L-C matching network, such as the one shown in **Fig 10**.

In addition to the variation in reactance (X_p), the resistance (R_p) varies from 1200 to 5700 Ω. This very high impedance means that the voltage at the feed point will be quite high. A graph of peak voltage for 1.5 kW drive power is given in **Fig 11**. The feed point voltage will be over 4 kV! This must be kept in mind when designing matching networks. Because of the large range of impedances, simple matching schemes yield relatively narrow SWR bandwidths.

For current feed, the impedance is much lower, as shown in **Fig 12**. The resistive component doesn't change very much but the reactive component does. This is a relatively high-Q antenna ($Q \approx 17$). **Fig 13** shows the SWR variation with frequency for this feed arrangement. Again, the bandwidth is quite narrow. An 80-meter dipole is not particularly wideband either, typically exhibiting an SWR range of about 6:1 over the whole band. A dipole will have less extreme variation in SWR than the half-square.

Patterns Versus Frequency

Impedance is not the only issue when defining the bandwidth of an antenna. The effect on the radiation pattern of changing frequency is also a concern. For an end-fed half-square, the current distribution changes with frequency. For an antenna resonant near 3.75 MHz, the current distribution is nearly symmetrical. However, above and below resonance the current distribution increasingly becomes asymmetrical. In effect,

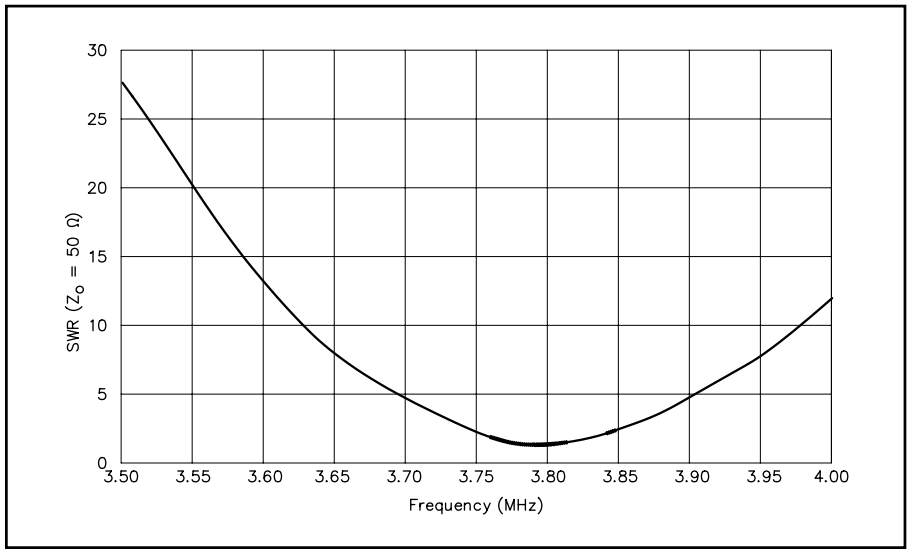

Fig 13—Variation of SWR with frequency for current-fed half-square antenna. The SWR bandwidth is quite narrow.

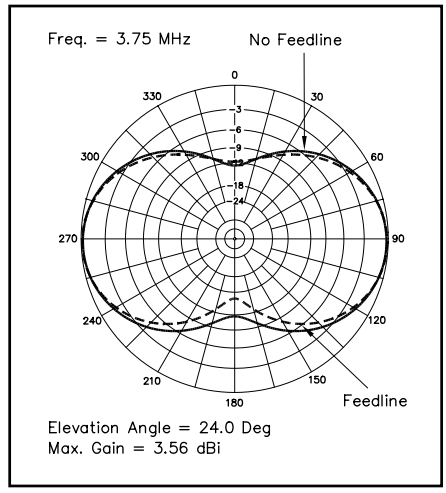

Fig 14—Effect of feed line on azimuth radiation pattern for current-fed half-square antenna. The feed line introduces only small distortions in symmetrical radiation pattern. The coaxial feed line was modeled as being brought out straight for 30 feet from the corner, then brought down close to ground level and led away for 50 feet more, where it was grounded.

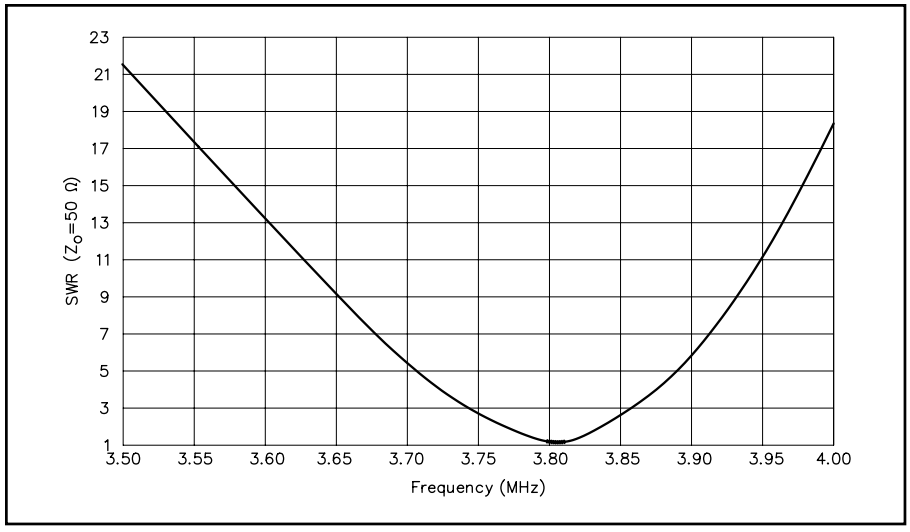

Fig 15—SWR versus frequency for voltage-fed half-square antenna, using matching network shown in Fig 10B, with L = 15 μH, C_1 = 125 pF and C_2 = 855 pF. The SWR bandwidth is less than 100 kHz at the 2:1 SWR points.

the open end of the antenna is constrained to be a voltage maximum but the feed point can behave less as a voltage point and more like a current maxima. This allows the current distribution to become asymmetrical.

The effect is to reduce the gain by –0.4 dB at 3.5 MHz and by –0.6 dB at 4 MHz. The depth of the zenith null is reduced from –20 dB to –10 dB. The side nulls are also reduced. Note that this is exactly what happened when the antenna was made physically asymmetrical. Whether the asymmetry is due to current distribution or mechanical arrangements, the antenna pattern will suffer. In my model, I used four ground wires, 10 feet long. These represent an adequate ground for the antenna when operated not too far from resonance. Even shorter wires could be used.

When corner-feed is used, the asymmetry introduced by off-resonance operation is much less, since both ends of the antenna are open circuits and constrained to be voltage maximums. The resulting gain reduction is only –0.1 dB. It is interesting that the sensitivity of the pattern to changing frequency depends on the feed scheme used!

Of more concern for corner feed is the effect of the transmission line. The usual instruction is to simply feed the antenna using coax, with the shield connected to vertical wire and the center conductor to the top wire. Since the shield of the coax is a conductor, more or less parallel with the radiator, and is in the immediate field of the antenna, you might expect the pattern to be seriously distorted by this practice. This arrangement seems to have very little effect on the pattern!

A number of different feed-line arrangements were modeled. An example of the patterns for one of them is shown in **Fig 14**. The wire, representing the outside of the coax feeding the antenna at the corner, was brought out straight for 30 feet, then brought down close to ground and led away for 50 feet more and grounded. The effect at resonance was barely detectable, as shown in Fig 14. At 3.5 MHz the gain was down by –0.5 dB and at 4 MHz was actually up by +0.1 dB. Other lengths and feed-line arrangements were tried with similar lack of effect. The greatest effect came when the feed-line length was near λ/2. Such lengths should be avoided.

Frankly, this result came as a considerable surprise. There are at least two possible explanations. First, the feed line is connected to a low-voltage point. Second, the feed line is located off the end of the antenna, where the field is canceled to some extent by the phasing of the radiators. Whatever the reason, this is very good news. It means that the antenna can be kept just as simple as a dipole.

Of course, you may use a balun at the feed point if you desire. This might reduce the coupling to the feed line even further but it doesn't appear to be worth the trouble. In fact, if you use an antenna tuner in the shack to operate away from resonance with a very

high SWR on the transmission line, a balun at the feed point would take a beating.

Voltage-Feed at One End of Antenna: Matching Schemes

Several straightforward means are available for narrow-band matching. However, broadband matching over the full 80-meter band is much more challenging. Voltage feed with a parallel-resonant circuit and a modest local ground, as shown in Fig 10, is the traditional matching scheme for this antenna. Matching is achieved by resonating the circuit at the desired frequency and tapping down on the inductor in Fig 10A or using a capacitive divider (Fig 10B). It is also possible to use a 1/4λ transmission-line matching scheme, as shown in Fig 10C.

If the matching network shown in Fig 10B is used with L = 15 μH, C_1 = 125 pF and C_2 = 855 pF, you will obtain the SWR characteristic shown in **Fig 15**. At any single point the SWR can be made very close to 1:1 but the bandwidth for SWR < 2:1 will be very narrow at <100 kHz. Altering the L-C ratio doesn't make very much difference. This antenna has a well-earned reputation for being narrowband. If you only want to DX on phone or CW then that may be acceptable, but most users want to do both.

It is possible to change the capacitors or tune the inductor, either with switches, manual adjustment or a motor drive. However, that level of complexity is unacceptable, especially since we are trying to replace a dipole with something equally simple. It is also possible to design wideband matching networks with multiple elements, but again that approach is relatively complex.

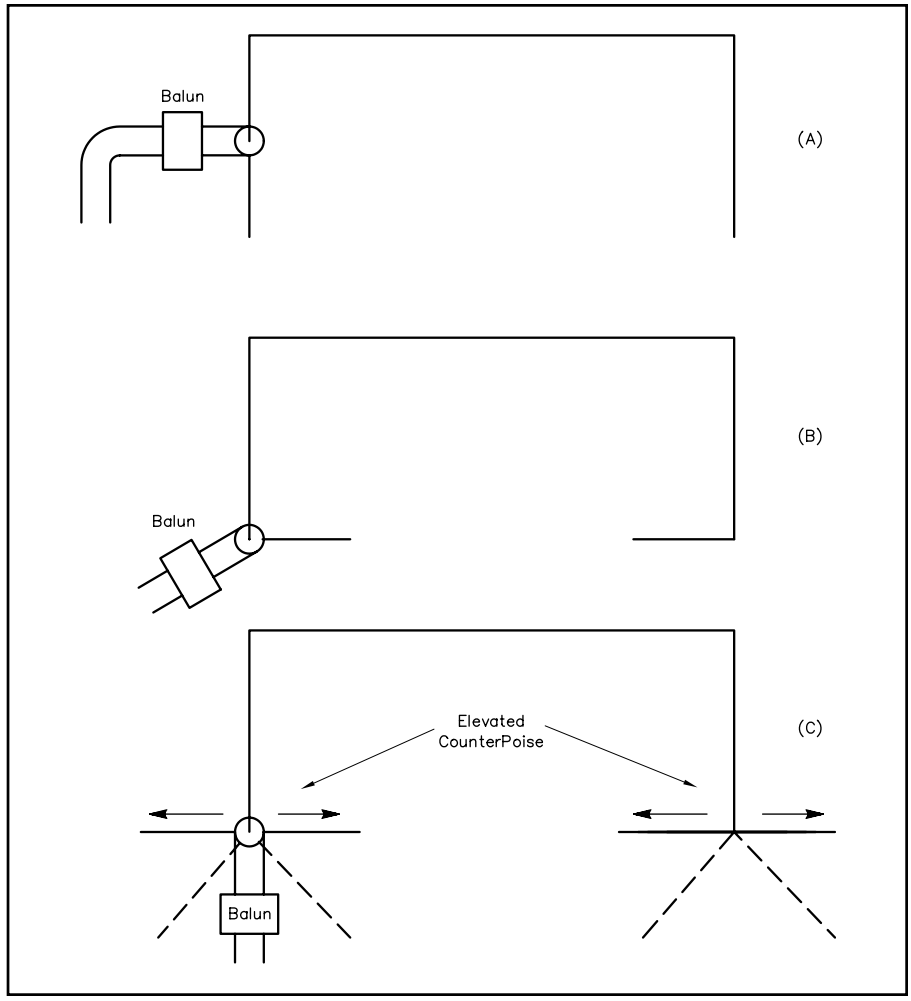

Fig 16—Possible methods for current-feeding of half-square antenna at points other than the upper corners. At A, a balun is used to decouple the feed line from the feed point at the center of one of the vertical legs of the antenna. At B, the ends of the vertical legs are both bent back horizontally to provide a feed point. At C, an elevated counterpoise is used to provide a feed point at the bottom of a vertical leg.

Current-Feed: Matching Schemes

The antenna can be current-fed at points other than the upper corners. Some possibilities are shown in **Fig 16**. As the feed point is moved away from the current maxima, the voltage increases and it becomes necessary to use a balun to decouple the transmission line. For narrowband use or if there is a matching network at the feed point this may be acceptable and may result in a more convenient feed point. As shown in Fig 16A, the feed point can be moved down the vertical wire to a higher impedance point and a 4:1 or 9:1 balun used. If the ends of the antenna are bent back toward the center, then a convenient feed point would be the lower corner, as shown in Fig 16B. By making the ends symmetrical as shown in Fig 16C even better decoupling could be obtained and the symmetry of the antenna is maintained.

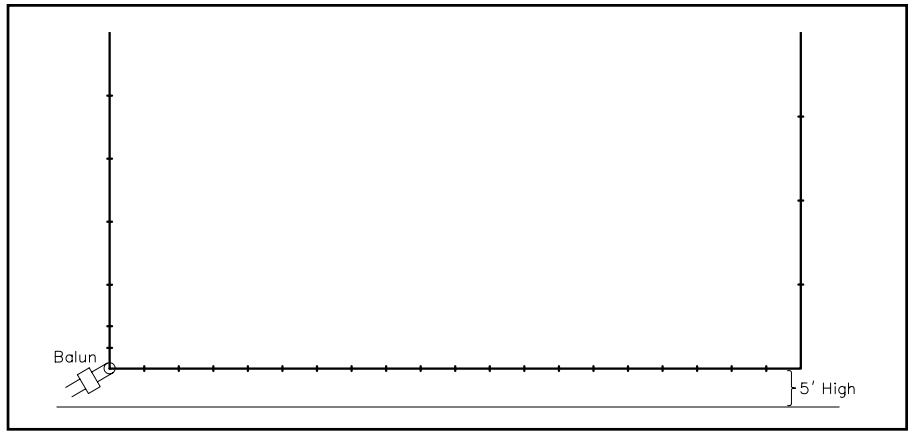

Fig 17—An "inverted half-square" antenna, current-fed at a lower corner. The losses in this configuration are excessive unless the ground under the antenna is exceptionally good, RF-wise.

Another possibility that has been used in the past is to invert the antenna, as shown in **Fig 17** and feed it at a lower corner. The problem with this approach is that the losses are higher because the current maxima are close to ground. A comparison between a normal half-square and an inverted one, 5 feet over average ground, is made in **Fig 18**. The difference is over 2 dB. For greater height or better ground, the loss would be lower. The killer antenna built by Tom

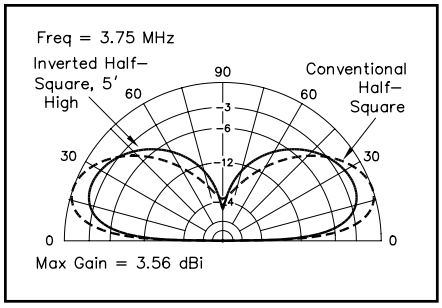

Fig 18—Elevation pattern for a conventional half-square, compared with an "inverted half-square" whose horizontal wire is located 5 feet over average ground. The difference is more than 2 dB.

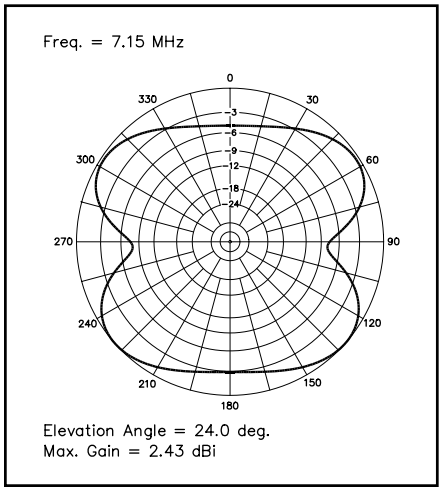

Fig 19—An attempt to load an 80-meter half-square antenna on 7 MHz. The pattern is badly distorted. The half-square is a monoband antenna!

Erdmann, W7DND, used this configuration but it was installed over a saltwater beach.[11] As a consequence the losses were very low and the feed point very conveniently located.

Multiband Operation

An 80-meter half-square can be used on other bands but the pattern and the drive-point impedance will change. A current-fed, 80-meter half-square will have a radiation pattern like that shown in **Fig 19** when driven at 7.15 MHz. On 40 meters the pattern has four lobes and the feed-point impedance is approximately 3300 + *j* 1500 Ω. If end-feed is used, the impedance will be in the region of 450 + *j* 110 Ω. With end-feed, the pattern will be somewhat asymmetric.

If the antenna is used on 20 meters the pattern will have eight lobes and the impedance at 14.2 MHz will ≈ 1100 + *j* 900 Ω. If a tuner is available this antenna can be used at higher frequencies but it will have a multi-lobed pattern typical of a harmonic antenna.

On the higher bands (40 meters and up), the height in wavelengths is greater for a given physical antenna height. Over average ground, the advantage of the half-square over a typical dipole thus becomes smaller and the half-square may even become inferior to the dipole. When the antenna is installed over very good ground or seawater, then the half-square may still be a contender on the higher bands.

Conclusion

The half-square antenna has some definite advantages. It is a simple and effective alternative to a typical dipole on the 80 and 160-meter bands, where the half-square radiates a stronger signal at the low angles most appropriate for DX work. The height and shape of the antenna are quite flexible and can be tailored to fit the needs of a given QTH. As a DX receiving antenna, it has the advantage of discriminating against strong high-angle signals arriving from stations within 1500 miles.

One disadvantage of the half-square is that it is more narrowband than a dipole—for DX work this may not be a serious disadvantage, since the ranges of frequencies for the DX "windows" are quite small. The antenna is also vertically polarized, which means more noise pickup when receiving.

Notes and References

[1] *The ARRL Antenna Book*, 17th edition (ARRL, Newington: 1994), Chapter 23.

[2] Dean Straw, N6BV, *All The Right Angles*,1993, Published by LTA, PO Box 77, New Bedford, PA.

[3] Woodrow Smith, W6BCX, "Bet My Money On A Bobtail Beam," *CQ*, Mar 1948, pp 21-23, 92.

[4] Ben Vester, K3BC, "The Half-Square Antenna," *QST*, Mar 1974, pp 11-14.

[5] Paul Carr, N4PC, "A Two Band Half-Square Antenna With Coaxial Feed," *CQ*, Sep 1992, pp 40-45.

[6] Paul Carr, N4PC, "A DX Antenna For 40 Meters," *CQ*, Sep 1994, pp 40-43.

[7] *EZNEC* is available from Roy Lewallen, W7EL, PO Box 6658, Beaverton, OR 97007.

[8] *NEC-Wires* is available from Brian Beezley, K6STI, 3532 Linda Vista Drive, San Marcos, CA 92069, tel 619-599-4962.

[9] *NEC-WIN Basic* is available from Paragon Technology, 200 Innovation Blvd, Suite 240, State College, PA 16803, tel 814-234-3335.

[10] *The ARRL Antenna Book*, 17th edition (ARRL: Newington), Chapter 8, p 8-6.

[11] Jerrold Swank, W8HXR, "The S-Meter Bender," *73*, Jun 1978, pp 170-173.