Chapter 6

Low-Frequency Antennas

In theory there is no difference between antennas at 10 MHz and up and those for lower frequencies. In reality however, there are often important differences. It is the size of the antennas, which increases as frequency is decreased, that creates practical limits on what can be realized physically at reasonable cost.

At 7.3 MHz, 1λ = 133 feet and by the time we get to 1.8 MHz, 1 λ = 547 feet. Even a λ/2 dipole is very long on 160 meters. The result is that the average antenna for these bands is quite different from the higher bands, where Yagis and other relatively complex antennas dominate. In addition, vertical antennas can be more useful at low frequencies than they are on 20 meters and above because of the low heights (in wavelengths) usually available for horizontal antennas on the low bands. Much of the effort on the low bands is focused on how to build simple but effective antennas with limited resources. This section is devoted to antennas for use on amateur bands between 1.8 to 7 MHz.

The Importance of Low Angles for Low-Band DXing

In Chapter 3, The Effects of Ground, we emphasized the importance of matching the elevation response of your antennas as closely as possible to the range of elevation angles needed for communication with desired geographic areas. **Fig 1** shows the statistical 40-meter elevation angles needed over the entire 11-year solar cycle to cover the path from Boston, Massachusetts, to all of Europe. These angles range from 1° (at 9.6% of the time when the 40-meter band is open to Europe) to 28° (at 0.3% of the time).

Fig 1 also overlays the elevation pattern response of a 100-foot high flattop dipole on the elevation-angle statistics, illustrating that even at this height the coverage is hardly optimum to cover all the necessary elevation angles. While Fig 1 is dramatic in its own right, the data can be viewed in another way that emphasizes even more the importance of low elevation angles. **Fig 2** plots the the *cumulative distribution function*, the total percentage of time 40 meters is open from Boston to Europe, at or below each elevation angle. For example, Fig 2 says that 40 meters is open to Europe from Boston 50% of the time at an elevation angle of 9° or less. The band is open 90%

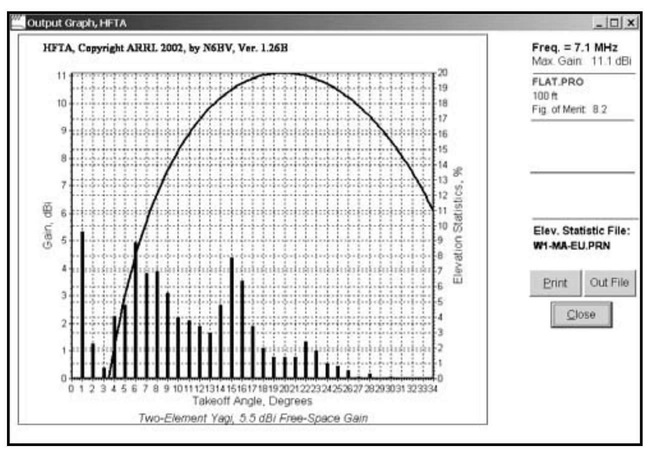

Fig 1—Screen capture from *HFTA* (HF Terrain Assessment) program showing elevation response for 100-foot high dipole over flat ground on 7.1 MHz, with bar-graph overlay of the statistical elevation angles needed over the whole 11-year solar cycle from New England (Boston) to all of Europe. Even a 100-foot high antenna cannot cover all the necessary angles.

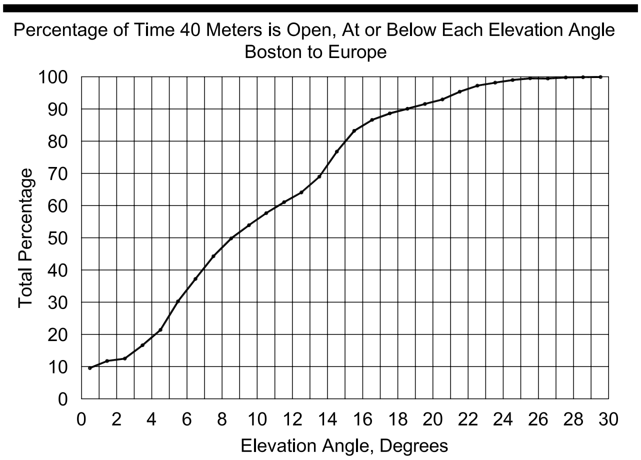

Fig 2—Another way of looking at the elevation statistics from Fig 1. This shows the percentage of time the 40-meter band is open, at or below each elevation angle, on the path from Boston to Europe. For example, the band is open 50% of the time at an angle of 9° or lower. It is open 90% of the time at an angle of 19° or lower.

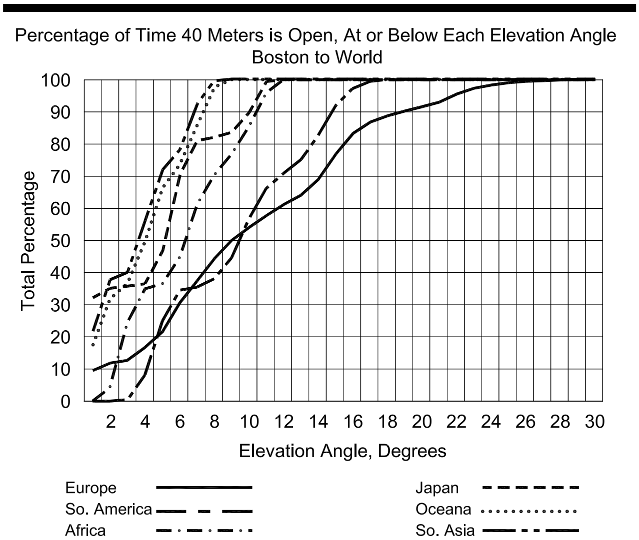

Fig 3—The percentage of time the 40-meter band is open, at or below each elevation angle, for various DX paths from Boston: to Europe, South America, southern Africa, Japan, Oceania and south Asias. The angles are predominantly quite low. For example, on the path from Boston to Japan, 90% of the time when the 40-meter band is open, it is open at elevation angles less than or equal to 10°. Achieving good performance at these low takeoff angles requires very high horizontally polarized antennas, or efficient vertically polarized antennas.

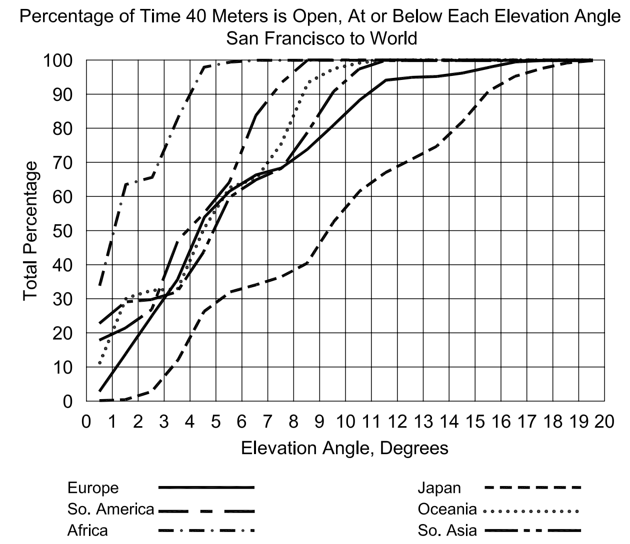

Fig 4—The 40-meter statistics from the West Coast: from San Francisco to the rest of the DX world. Here, 90% of the time the path to Europe is open, it is at takeoff angles less than or equal to 11°. No wonder the hams living on mountain tops do best into Europe from the West Coast.

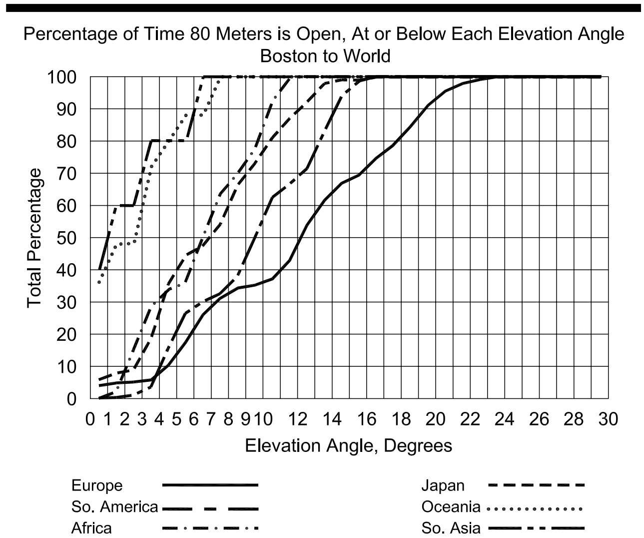

Fig 5—The situation on 80 meters from Boston to the rest of the DX world. Into Europe, 90% of the time the elevation angle is less than or equal to 20°. Into Japan from Boston, 90% of the time the angle is less than or equal to 12°.

of the time at an elevation angle of 19° or less.

Fig 3 plots the 40-meter elevation-angle data for six major geographic areas around the world from Boston. In general, the overall range of elevation angles for far-distant locations is smaller, and the angles are lower than for closer-in areas. For example, from Boston to southern Asia (India), 50% of the time the takeoff angles are 4° or less. On the path to Japan from Boston, the takeoff angles is less than or equal to 6° about 70% of the time. These are low angles indeed.

Fig 4 shows similar data for the 40-meter band from San Francisco, California, to the rest of the world. The path to southern Africa from the US West Coast is a very long-distance path, open some 65% of the time it is open at angles of 2° or less! The 40-meter path to Japan involves takeoff angles of 10° or less more than 50% of the time. If you are

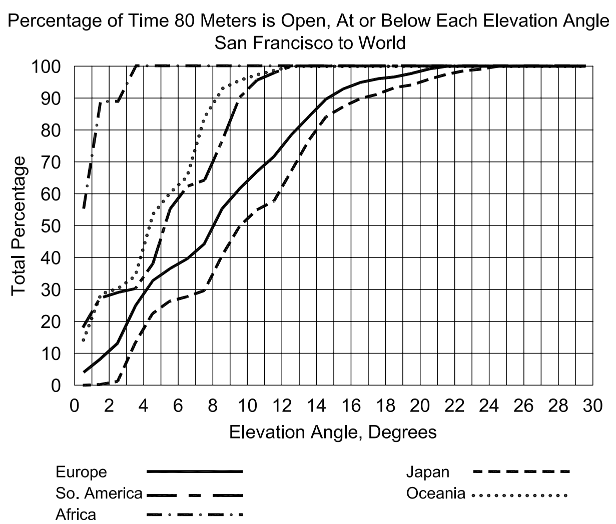

Fig 6—From San Francisco to the rest of the world on 80 meters: 90% of the time on the path to Japan, the takeoff angle is less than or equal to 17°; 50% of the time the angle is less than or equal to 10°; 25% of the time the angle is less than or equal to 6°. A horizontally polarized antenna would have to be 600 feet above flat ground to be optimum at 6°!

fortunate enough to have a 100-foot high flattop dipole for 40 meters, at a takeoff angle of 10° the response would be down about 3 dB from its peak level at 20°. At an elevation angle of 5° the response would be about 8 dB down from peak. You can see why the California stations located on mountain tops do best on 40 meters for DXing.

Fig 5 shows the same percentage-of-time data for the 80-meter band from Boston to the world. Into Europe from Boston, the 80-meter elevation angle is 13° or less more than 50% of the time. Into Japan from Boston, 90% of the time the band is open is at a takeoff angle of 13° or less. (Note that these elevation statistics are computed for "undisturbed" ionospheric conditions. There are times when the incoming angles are affected by geomagnetic storms, and generally speaking the elevation angles rise under these conditions.)

Fig 6 shows the 80-meter data from San Francisco to the world. Low elevation angles dominate in this graph and high horizontal antennas would be necessary to optimal coverage. In fact, 50% of the time for all paths, the elevation angle is less than 10°.

In the rest of this chapter, we'll often compare horizontally polarized antennas at practical heights with vertically polarized antennas, usually at takeoff angles of 5° or 10°, angles useful for DX work. But first, let us look at situations where *high* takeoff angles are most useful.

Short/Medium-Range Communications

Not all hams are interested in working stations thousands of miles from them. Traffic handlers and rag chewers may, in fact, only be interested in *nearby* communications—perhaps out to 600 miles from their location.

For example, a ham in Boston may want to talk with his brother-in-law in Cleveland, OH, a path that is just over 550 miles away. Or an operator in Buffalo, NY, may be the net control station (NCS) for a regional net involving the states of New York and New Jersey. She needs to cover distances up to about 300 miles away.

Depending on the time of day, the most appropriate ham frequencies needed for nearby communications are the 40 and 80/75-meter bands, with 160 meters also a possibility during the night hours, particularly during low portions of the sunspot cycle. The elevation angles involved in such nearby distances are usually high, even almost directly overhead for distances beyond ground-wave coverage (which may be as short as a few miles on 40 meters). For example, the distance between the Massachusetts cities of Boston and Worchester is about 40 miles. On 40 meters, 40 miles is beyond ground-wave coverage. So you will need sky-wave signals that use the ionosphere to communicate between these two cities, where the elevation angle is 83°—very nearly straight up.

Hams using vertical antennas for communications with nearby stations may well find that their signals will be below the noise level typical on the lower bands, especially if they aren't running maximum legal power. Such relatively short-range paths involve so-called *NVIS*, "Near Vertical Incidence Skywave," a fancy name for HF communication systems covering nearby geographic areas. The US military discusses NVIS out to about 500 miles, encompassing the territory a brigade might cover. Elevation angles needed to cover distances from 0 to 500 miles range from about 40º to 90º. This also covers the circumstances involved in amateur communications, particularly in emergency situations.

The following section is adopted from the article "What's the Deal About NVIS?" that appeared in December 2005 *QST*. This article used an example of a hypothetical earthquake in San Francisco to analyze HF emergency communication requirements.

HAM RADIO RESPONSE IN NATURAL DISASTERS

One of San Francisco's somewhat less endearing nicknames is "the city that waits to die." When the *Big Earthquake* does come, you can be assured that all the cell phones and the land-line telephones will be totally jammed, making calling in or out of the San Francisco Bay Area virtually impossible. The same thing occurred in Manhattan on September 11, 2001. The Internet will also be severely affected throughout northern California because of its trunking via the facilities of the telephone network. Commercial electricity will be out in wide areas because power lines will be down. It's virtually certain that water mains will be out of commission too.

If the repeaters on the hills around the San Francisco Bay Area haven't been damaged by the shaking itself, there will be some ham VHF/UHF voice coverage in the intermediate area, at least until the backup batteries run down. But connecting to the dysfunctional telephone system will be difficult at best through amateur repeaters.

With little or no telephone coverage, an obvious need for ham radio communications to aid disaster relief would be from San Francisco to Sacramento, the state capital. Sacramento is 75 miles northeast of the Bay Area, well outside VHF/UHF coverage, so amateur HF will be required on this radio circuit. On-the-ground communications directly between emergency personnel (including the armed-forces personnel who will be brought into the rescue and rebuilding effort) will often be difficult on VHF/UHF since San Francisco is a hilly place. So HF will probably be needed even for short distance, operator-to-operator or operator-to-communications center work. Throughout the city, portable HF stations will have to be quickly set up and staffed to provide such communications.

Hams used to half jokingly call short range HF communications on 40 and 80 meters "cloud warming." This is an apt description, because the takeoff angles needed to launch HF signals up into the ionosphere and then down again to a nearby station are almost directly upwards. **Table 1** lists the distance and takeoff angles from San Francisco to various cities around the western part of the USA. The distance between San Francisco and Sacramento is about 75 miles, and the optimum takeoff angle is about 78°. Launching such a high-angle signal is best done using horizontally polarized antennas mounted relatively close to the ground.

GEOGRAPHIC COVERAGE FOR NVIS

Figure 7A shows the geographic area coverage around San Francisco for a 100-W, 7.2-MHz station using an inverted V dipole. The center of this antenna is 20 feet above flat

Table 1
Average Elevation Angles for Target Destinations from San Francisco

Location	*Distance Miles*	*Average Elevation Angle, Degrees*
San Jose, CA	43	80
Sacramento, CA	75	78
Fresno, CA	160	63
Reno, NV	185	60
Los Angeles	350	44
San Diego	450	42
Portland, OR	530	30
Denver, CO	950	18
Dallas, TX	1500	8

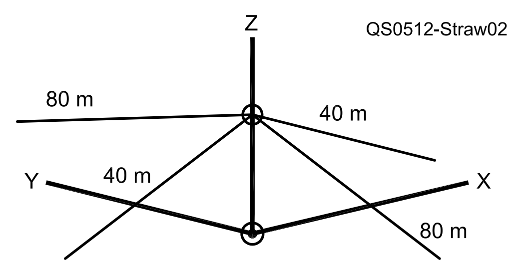

Fig 8—Layout for two band inverted V dipoles for 40 and 80 meters. The two dipoles are fed together at the center and are laid out at right angles to each other to minimize interaction between them. Each end of both dipoles is kept 8 feet above ground for personnel safety.

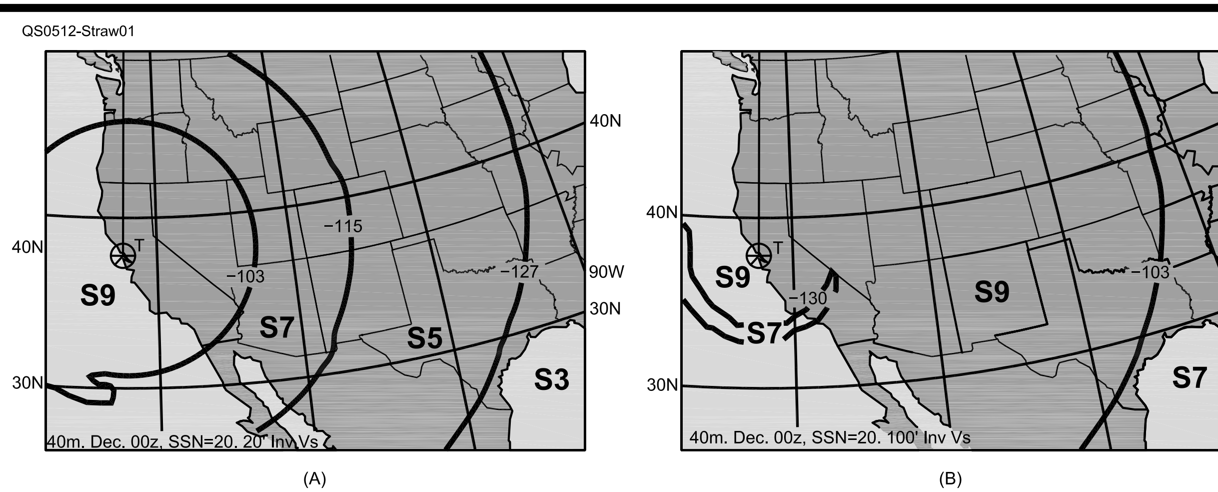

Fig 7—At A, Predicted 40 meter geographic coverage plot for a 100 W transmitter in December at 0000 UTC (near sunset), for a SSN (Smoothed Sunspot Number) of 20. The antennas used are 20 foot-high inverted V dipoles. At B, 40 meter coverage for same date and time, but for 100 foot-high flattop dipoles. Most of California is well covered with S9 signals in both cases, but there is more susceptibility in the higher dipole case to thunderstorm crashes coming from outside California, for example from Arizona or even Texas. Such noise can interfere with communications inside California.

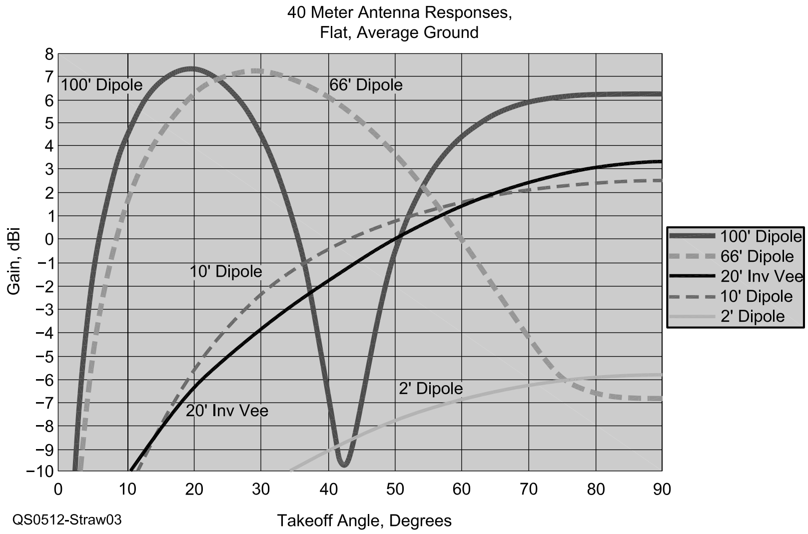

Fig 9—Elevation plots for different 40 meter antennas above flat ground with average ground characteristics (5 mS/m conductivity and dielectric constant of 13). The 10 foot-high flattop dipole and the 20 foot-high inverted V dipoles both have close to the same characteristics. Note that there is a null in the response of the 100 foot-high flattop dipole at a 42° elevation angle. The gain there is roughly that of a 2 foot-high dipole!

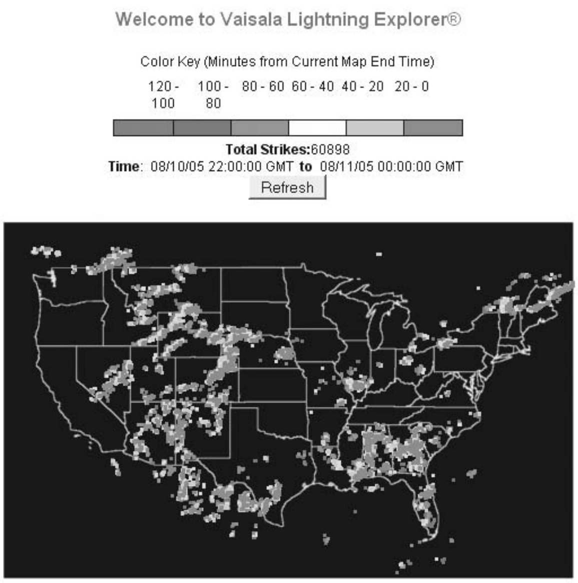

Fig 10—The distribution of lightning strikes across the USA for August 10, 2005 from 2200 to 0000 UTC, in the afternoon California time. There are lots of lightning strikes in the US during the summer—60,898 of them in this two-hour period! (*Courtesy Vaisala Lightning Explorer.*)

ground and the ends are 8 feet high. An actual implementation of such an antenna could be as an 80-meter inverted V, fed in parallel with a 40-meter inverted V dipole at a 90° angle. See **Fig 8**. The 8-foot height puts the ends high enough to prevent RF burns to humans (or most animals). The low height of the antenna above ground means that the azimuthal pattern is omnidirectional for high elevation angles.

Fig 7 was generated using the *VOAAREA* program, part of the *VOACAP* propagation-prediction suite, for the month of December. This was for 0000 UTC, close to sundown, for a low period of solar activity (Smoothed Sunspot Number, SSN of 20). The receiving stations were also assumed to be using identical inverted-V dipoles.

You can see that almost the whole state of California is covered with S9 signals, minus only a thin slice of land near the Mexican border in the southeast portion of the state, where the signal drops to S7. Signals from Texas are predicted to be only S5 or less in strength. Signals (or thunderstorm static) coming from, say, Louisiana would be several S units weaker than signals from central Texas.

Now take a look at Fig 7B. Here, the date, time and solar conditions remain the same, but now the antennas are 100-foot high flattop dipoles. California is still blanketed with S9 signals, save for an interesting crescent-shaped slice near Los Angeles, where the signal drops down to S7. Close investigation of this intriguing drop in signal strength reveals that the necessary elevation angle, 44°, from San Francisco to this part of southern California falls in the first null of the 100-foot high antenna's elevation pattern. See **Fig 9**, which shows the elevation patterns for five 40-meter antennas at different heights. In the null at a 44° takeoff angle, the 100-foot high dipole is just about equal to a 2-foot high dipole. We'll discuss 2-foot high dipoles in more detail later.

For most of California, the problem with 100-foot high 40-meter antennas is that interfering signals from Texas, Colorado or Washington State will *also* be S9 in San Francisco. So will static crashes coming from thunderstorms all over the West and much of the Gulf Coast. (Ed Farmer, AA6ZM, joked once that the Army doesn't have any problem with interfering signals—they just call in an airstrike. We hams don't generally have this ability, although we occasionally call in the FCC.) See **Fig 10**, which shows a typical distribution of thunderstorms across the US in the late afternoon, California time, in mid-August. There certainly are a lot of thunderstorms raging around the country in the summer.

The signal-to-noise and signal-to-interference ratios for a 20-foot high inverted V dipole will be superior for medium-

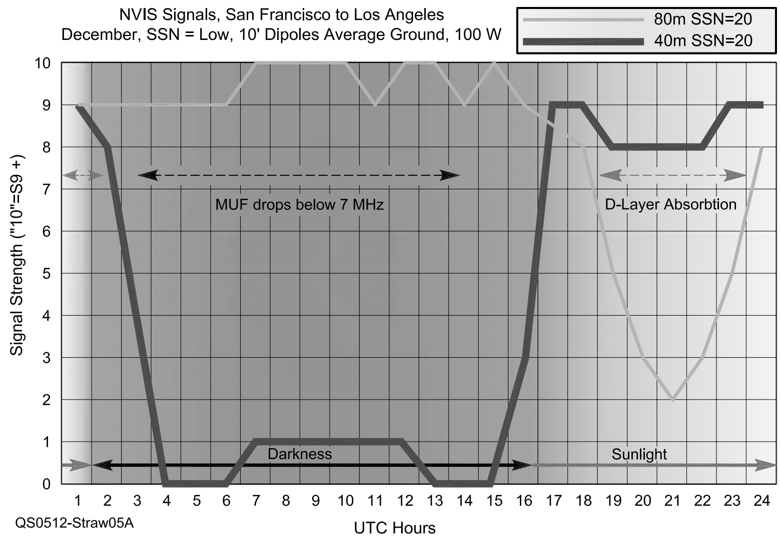

Fig 11—VOACAP calculations for a 350 mile path from San Francisco to Los Angeles, using 10 foot-high flattop dipoles. This plot shows the signal strength in S Units ("S10" = S9+10) for a worst-case month/SSN combination—winter solstice, in December, for a low level of solar activity (SSN = 20). The 40-meter signal drops to a very low level during the night because the MUF drops well below 7.2 MHz. The 80-meter signal drops in the afternoon because of D-layer absorption. For 24-hour communications on this path, the rule of thumb is to select 40 meters during the day and 80 meters during the night.

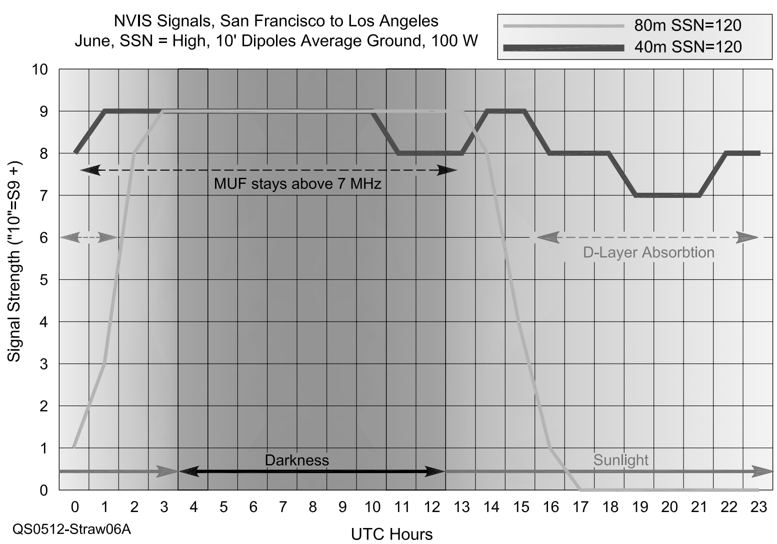

Fig 12—Signal strengths for the San Francisco to Los Angeles path for a worst-case month/SSN combination—summer solstice, in June, for a high level of solar activity (SSN = 120). Now 80 meters drops out more dramatically during the daylight hours, due to increased D-layer absorption. At this high level of solar activity, 40 meters remains open 24 hours with reasonable signal levels. However, the NVIS rule-of-thumb still holds: Use 40 meters during the day; 80 meters at night.

range distances, say out to 500 miles from the center, compared to a 100-foot high antenna. The 20-foot high antenna can discriminate against medium-angle thunderstorm noise in the late afternoon coming from the Arizona desert, although it wouldn't help much for thunderstorms in the Sierra Nevada in central Nevada, which are arriving in San Francisco at high angles, along with the desired NVIS signals.

This is the essence of what NVIS means. NVIS exploits the difference in elevation pattern responses of low horizontally polarized antennas compared to higher horizontal antennas, or even verticals. Over the years, many hams have been lead to believe that higher is always better. This is not quite so true for consistent coverage of medium or short distance signals!

If NVIS only involved putting up a low horizontally polarized antenna on 40 meters the story would end here. However, real cloud warming is more complicated. It also involves the intelligent choice of more than just one operating frequency to achieve reliable all day, all-night communications coverage.

Fig 11 shows the signal strength predicted using *VOACAP* for the 350-mile path from San Francisco to Los Angeles for the month of December for a period of low solar activity (SSN of 20). The antennas used in this case are 10-foot high dipoles, just for some variety. These act almost like 20-foot high Inverted V dipoles. December at a low SSN was chosen as a worst-case scenario because the *winter solstice* occurs on December 21. This is the day that has the fewest hours of daylight in the year. (Contrast this with the *summer solstice*, on June 21, which has the most hours of daylight in the year.) Note that the upper signal limit in Fig 11 is "S10"—a fictitious quantity that allows easier graphing.

S10 is equivalent to S9+, or at least S9+10 dB.

The 40-meter curve in Fig 11 shows that the MUF (maximum usable frequency) actually drops below the 7.2 MHz amateur band after sunset. The signal becomes quite weak for about 14 hours during the night, from about 0300 to 1700 UTC. In a period of low solar activity the 40-meter band thus becomes strictly a *daytime band* on this medium-distance path.

The 80-meter curve in Fig 11 shows strong signals after dusk, through the night and up until about an hour after sunrise. After sunrise, 80 meters starts to suffer absorption in the D layer of the ionosphere and hence the signal strength drops. Here, 80 meters is a true *nighttime band*.

Let's see what happens from San Francisco to Los Angeles during a period of high solar activity (SSN of 120) during the summer solstice in June. **Fig 12** shows that 40 meters now stays open all hours of the day due to the greater number of hours of sunlight in June and because the ionosphere becomes more highly ionized by higher solar activity. Meanwhile, 80 meters still remains a nighttime band during these conditions on this path.

Now, let's look at a shorter-distance path—our 75-mile emergency communications path from San Francisco to Sacramento. We'll again use June during the summer solstice, at a high level of solar activity (SSN of 120) because this represents another worst-case scenario. **Fig 13** shows that 40 meters remains open on this path all day, dropping to a lower signal level just before sunrise. At sunrise, the MUF drops close to 7.2 MHz. 80 meters is still mainly a nighttime band to Sacramento, even though it does yield workable signal levels even during the daylight hours. However, 40 meters is better from 1200 to 0400 UTC, so 40 would be still the right daytime band for this path during the day.

CHOOSING THE RIGHT NVIS FREQUENCY

You can see that a pattern is developing here for efficient NVIS short/medium-distance communications out to 500 miles:

- You should pick a frequency on 40 meters during the day.
- You should pick a frequency on 80 meters during the night.
- You should choose an antenna that emphasizes moderate to high elevation angles, from 40° to almost directly overhead at 90°.

"What about 60 meters?" you might ask. The characteristics on 60 meters fall in-between 40 and 80 meters, although it resembles 40 meters more closely. With characteristics close to that of 40, but with only five channels available and a 50-W power limit, the 60-meter band is of low utility for serious NVIS use.

What about 160 meters? For 100-W level radios, even at the worst-case month or during low solar activity, the critical frequency doesn't fall below 3.8 MHz often enough to destroy the ability to communicate, even for short distances. That is a relief, considering that installing a 160-meter half-wave dipole involves a 255-foot wingspan, and it would need to be elevated at least 30 feet in the center. A short loaded vertical such as a 160-meter mobile whip would have poor response at the high elevation angles needed for NVIS. You could probably put a monster 160-meter horizontal dipole up at a permanent location, but hauling such a thing around in the field would not be an easy task.

SOME OTHER OBSERVATIONS ABOUT NVIS—STRATEGY

You could pose the question about whether NVIS is an operating *mode* or whether it is actually an operating *strategy*. We maintain that NVIS is a strategy. It involves choosing both appropriate frequencies and then appropriate antennas for those frequencies. Fig 13 does show that on short-distance

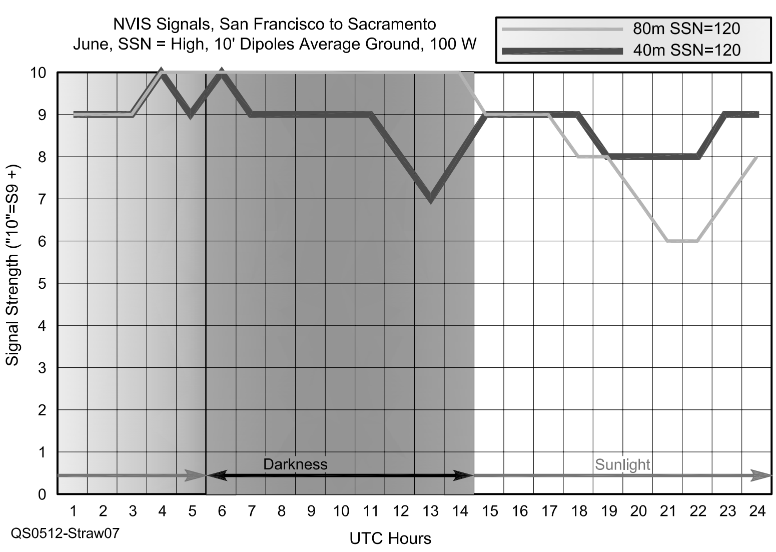

Fig 13—Signal strengths for a 75 mile path—San Francisco to Sacramento. This is for June and SSN = 120. Either band could be used successfully over the full 24-hour period because signal levels are always higher than S6. But the simple NVIS rule-of-thumb still holds: Use 40 meters during the day; 80 meters at night. This simplifies giving instructions to operators unaccustomed to the use of HF.

paths, such as between San Francisco and Sacramento, you could stay on 80 meters all day and night. But if you have to give a single rule-of-thumb to operators who are not very experienced at operating HF, we would tell them to operate on the higher frequency band during the day and on the lower frequency band at night.

SOME OTHER OBSERVATIONS ABOUT NVIS—ANTENNA HEIGHT

Some NVIS aficionados have advocated placing dipoles only a few feet over ground, something akin to saying, "If low is good for NVIS, then lower must be even better." Now we are not claiming that a very low antenna *won't* work in specific instances—for example, covering a small state such as Rhode Island or even just the San Francisco Bay Area.

It certainly is convenient to mount a 40-meter dipole on some 2-foot high red traffic cones! You should be very skeptical, however, about the ability of such antennas to cover all of a large state, such as California or Texas, especially on 80 meters. **Fig 14** shows the computed elevation responses for a number of 80-meter antennas, including a 2-foot-high dipole.

Fig 15B shows the 80 meter geographic coverage plot for 2-foot-high flattop dipoles, compared with the plot in Fig 15A for 20-foot-high inverted V dipoles on both ends of the path. The 2-foot-high dipoles produce about two S-units less signal across all of California than the 20-foot-high inverted V dipoles, at 0300 UTC in December, with an SSN of 20. The reason is that a low dipole will suffer more losses in the ground under it.

The differential between California signals and possible interfering signals from, say, New Mexico, is predicted to be four S-units, the same as it is for the higher inverted V dipole

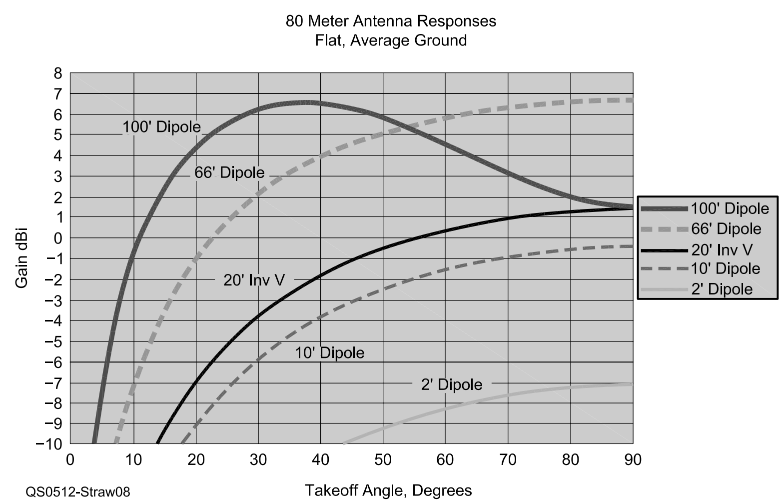

Fig 14—Elevation response patterns for 80 meter antennas over average soil. The shapes track each other rather well, remaining parallel for heights from 2 to 66 feet over flat ground. The 2 foot dipole is substantially down, about 9 dB, from the 20 foot inverted V dipole at all angles.

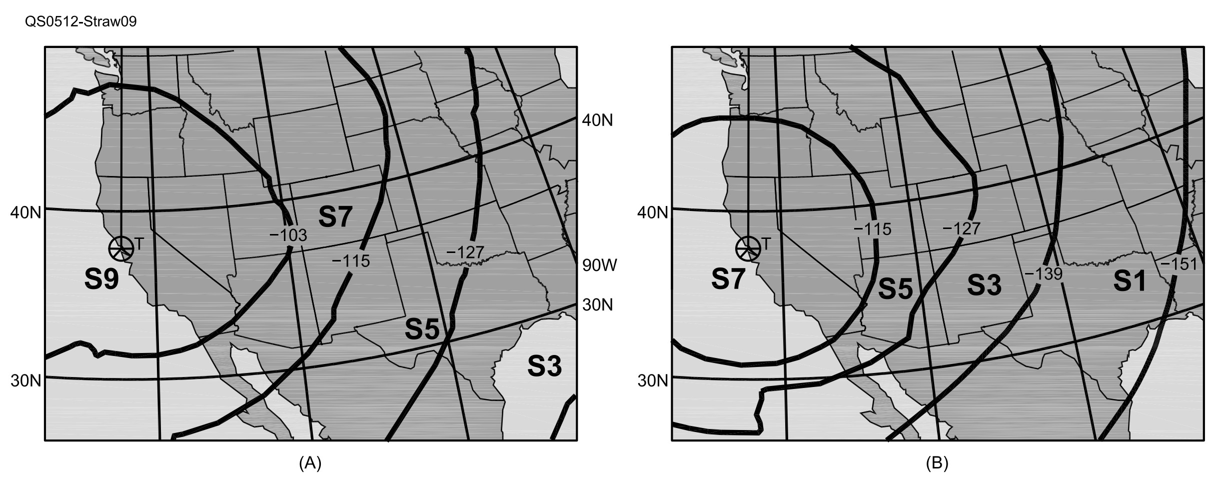

Fig 15—Geographic coverage plots for December, SSN = 20, 0300 UTC. At A, antennas are 20 foot-high inverted V dipoles over Average soil. At B, antennas are 2-foot-high flattop dipoles over Average soil. The response for the 2-foot-high antennas is down about 2 S Units, 8 to 12 dB for a typical communications receiver.

at 20 feet. Thus there is no real advantage in terms of signal-to-interference ratio or signal-to-noise ratio (for thunderstorm static crashes) for either height. This is because the shape of all the response curves in Fig 14 below 20 feet essentially track each other in parallel.

However, the lower the antenna, the lower the transmitted signal strength. Physics remain physics. And if you are in an emergency situation operating on batteries, you could reduce power from 100 W to 10 W with a 20-foot high inverted-V antenna and still maintain the same signal strength as a 2-foot high dipole at 100W.

LOW NVIS ANTENNAS AND LOCAL POWERLINE NOISE

Some advocates of really low antennas have stated that the received noise is much lower than that received from higher antennas, and this therefore leads to better signal-to-noise ratios (SNR). How much this is true depends on the source of the noise. If the noise comes from distant thunderstorms, then the SNR advantage going to a 2-foot antenna from a 20-foot-high one is insignificant, as Fig 15 indicates.

If noise is from an arcing insulator on a HV power line half a mile away, that noise will arrive at the antenna as a ground-wave signal. We calculate that the 2-foot antenna receives 4.4 dB less noise by groundwave than a 20-foot-high inverted V dipole. However, at an incoming elevation angle of 45º—suitable for a signal going from Los Angeles to San Francisco—the signal would be down 7.1 dB on the low dipole compared to the higher antenna. The net loss in SNR for the 2-foot-high dipole is thus 7.1– 4.4 or 2.7 dB. Close, but no cigar. Summarizing about really low NVIS antennas:

- A 2-foot-high dipole yields weaker signals, but without an SNR advantage compared to its more elevated brethren.
- A 2-foot-high dipole is a lot easier to trip over at night. We would call this a "knee biter" (or maybe an "ankle biter" if you're really tall).
- You (and your dog) can easily get RF burns from an antenna that is only 2 feet off the ground.

This is not a winning strategy to make friends or QSOs, it seems. But still, a really low dipole may serve your short-range communication needs just fine. But remember, that just as "higher is better" isn't universally true for NVIS (or even longer range) applications, "lower is better" isn't a panacea either.

ELEVATION ANGLES FOR MODERATE DISTANCES ON 75/80 METERS

Fig 16 shows the elevation angles statistics for a 75-meter, 550-mile path from Boston to Cleveland, together with overlays of the elevation patterns for several different types of antennas. These elevation statistics cover all parts of the 11-year solar cycle for this path. The responses for the popular G5RV antenna (described later in this chapter) are shown for two different heights above flat ground: 50 and 100 feet. An 80-meter half-wave sloper ("full sloper") and an 80-meter ground-plane antenna are also shown. All antenna patterns are for "average ground" constants of 5 mS/m conductivity and a dielectric constant of 13.

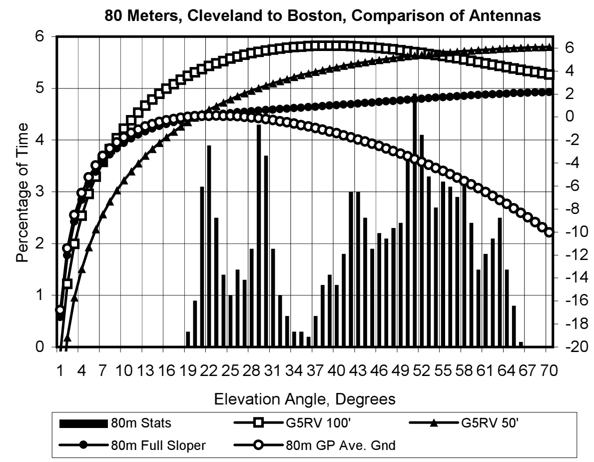

Fig 16—80/75-meter elevation statistics for all portions of the 11-year solar cycle for the path from Cleveland, Ohio, to Boston, Massachusetts, together with the elevation responses for four different multiband antennas. The 100-foot high horizontally polarized G5RV performs well over the entire range of necessary takeoff elevation angles.

At the statistically most significant takeoff angles around 50°, the two horizontally polarized G5RV antennas are about equal. At the second-highest elevation peak near 30°, the 100-foot G5RV has about a 4-dB advantage over its lower counterpart. The full sloper has comparable performance to the 100-foot high G5RV from 1° to about 20° and then gradually rises to its peak at angles higher than 70°. The full sloper is superior to the 50-foot horizontal G5RV at low takeoff elevation angles. The 80-meter ground plane has a deep null directly overhead. At an elevation angle of 70° it is down some 16 dB compared to the 50-foot high horizontal G5RV.

The advantage of antennas suitable for high-angle radiation was vividly demonstrated during a 75-meter QSO one fall evening between N6BV/1 in southern New Hampshire and W1WEF in central Connecticut. This involved a distance of about 100 miles and W1WEF was using his Four Square vertical array. Although W1WEF's signal was S9 on the Four Square, N6BV/1 suggested an experiment. Instead of connecting the so-called "dump power" connector on his Comtek ACB-4 hybrid phasing coupler to a 50-Ω dummy load (the normal configuration), W1WEF switched the dump power to his 100-foot high 80-meter horizontal dipole. W1WEF's signal came up more than 20 dB! The approximately 100-W of power that would otherwise be "wasted" in the dummy load was converted to useful signal.

ELEVATION ANGLES FOR MODERATE DISTANCES ON 40 METERS

Fig 17 shows the situation for the 40-meter band, from Boston to Cleveland, together with the same antennas used for 80 meters in Fig 16. Note that the 100-foot high horizontally

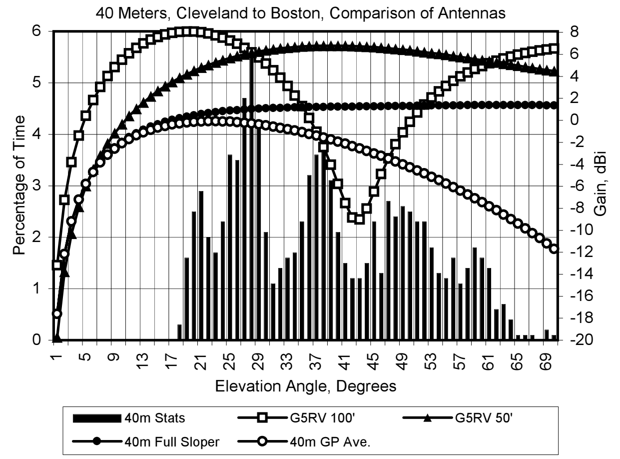

Fig 17—40-meter elevation statistics for the Cleveland to Boston path, together with elevation patterns for four antennas. Here, the 100-foot high horizontally polarized G5RV would have a null in the middle of the range of elevation angles needed for consistent performance on this path. For multiband use on this path to relatively nearby stations, the 50-foot high horizontal antenna would be a better choice than the 100-foot high antenna.

polarized G5RV has about a 16-dB null at an elevation angle of 43°. This doesn't affect things for low elevation angles, but it certainly has a profound effect on signals arriving between about 30° to 60°, especially when compared to the 50-foot high horizontal G5RV. The 40-meter full sloper beats out the high horizontal antenna from about 35° to 50°. And the ground plane is obviously not the antenna of choice for this moderate-range path from Boston to Cleveland, although it is still a good performer on longer-distance paths, with their low takeoff angles.

A 100-foot high multiband dipole is about ⅜-λ high on 75/80 meters. It is an excellent antenna for general-purpose local and DXing operation. But the same dipole used on 40 meters becomes ¾-λ high. At that height, the nulls in its elevation pattern give large holes in coverage for nearby 40-meter contacts. Many operators have found that a 40- to 50-foot high dipole on 40 meters gives them far superior performance for close-in QSOs, when compared to a high dipole, or even a high 2-element 40-meter Yagi.

NVIS SUMMARY

The use of NVIS strategies to cover close-in and intermediate distance communications within about 600 miles involves the intelligent choice of low HF frequencies. As a rule-of-thumb for ham band NVIS, 40 meters is recommended for use during the day; 80 meters during the night.

NVIS involves the choice of antennas suitable for this strategy. Horizontally polarized dual-band 80 and 40-meter flattop dipoles that are mounted higher than about 10 feet high will work adequately for portable operations. Dual-band 80 and 40-meter inverted V dipoles supported 20 feet above the ground at the center can also work well in portable operations.

Single-band 40-meter flattop antennas about 30 feet high and 80-meter flattop antennas about 60 feet high can do a good job for fixed locations.

Horizontal Antennas for the Low Bands

As shown in Chapter 3, The Effects of Ground, and here, radiation angles from horizontal antennas are a very strong function of the height above ground in wavelengths. Typically for DX work heights of λ/2 to 1 λ are considered to be a minimum. As we go down in frequency these heights become harder to realize. For example, a 160-meter dipole at 70 feet is only 0.14 λ high. This antenna will be very effective for local and short distance QSOs but not very good for DX work. Despite this limitation, horizontal antennas are very popular on the lower bands because the low frequencies are often used for short range communications, local nets and rag chewing. Also horizontal antennas do not require extensive ground systems to be efficient.

DIPOLE ANTENNAS

Half-wave dipoles and variations of these can be a very good choice for a low band antenna. A variety of possibilities are shown in **Fig 18**. An untuned or "flat" feed line is a logical choice on any band because the losses are low, but this generally limits the use of the antenna to one band. Where only single-band operation is wanted, the λ/2 antenna fed with open-wire line is one of the most popular systems on the 3.5 and 7-MHz bands.

If the antenna is a single-wire affair, its impedance is in the vicinity of 60 Ω, depending on the height and the ground characteristics. The most common way to feed the antenna is with 50- or 75-Ω coaxial line. Heavy coaxial lines present support problems because they are a concentrated weight at the center of the antenna, tending to pull the center of the antenna down. This can be overcome by using an auxiliary pole to take at least some of the weight of the line. The line should come away from the antenna at right angles, and it can be of any length.

Folded Dipoles

A folded dipole (Fig 18B and C) has an impedance of about 300 Ω, and can be fed directly with any length of 300-Ω line. The folded dipole can be made of ordinary wire spaced by lightweight wooden or plastic spacers, 4 or 6 inches long, or a piece of 300 or 450-Ω twin-lead or ladder line.

A folded dipole can be fed with a 600-Ω open wire line with only a 2:1 SWR, but a nearly perfect match can be ob-

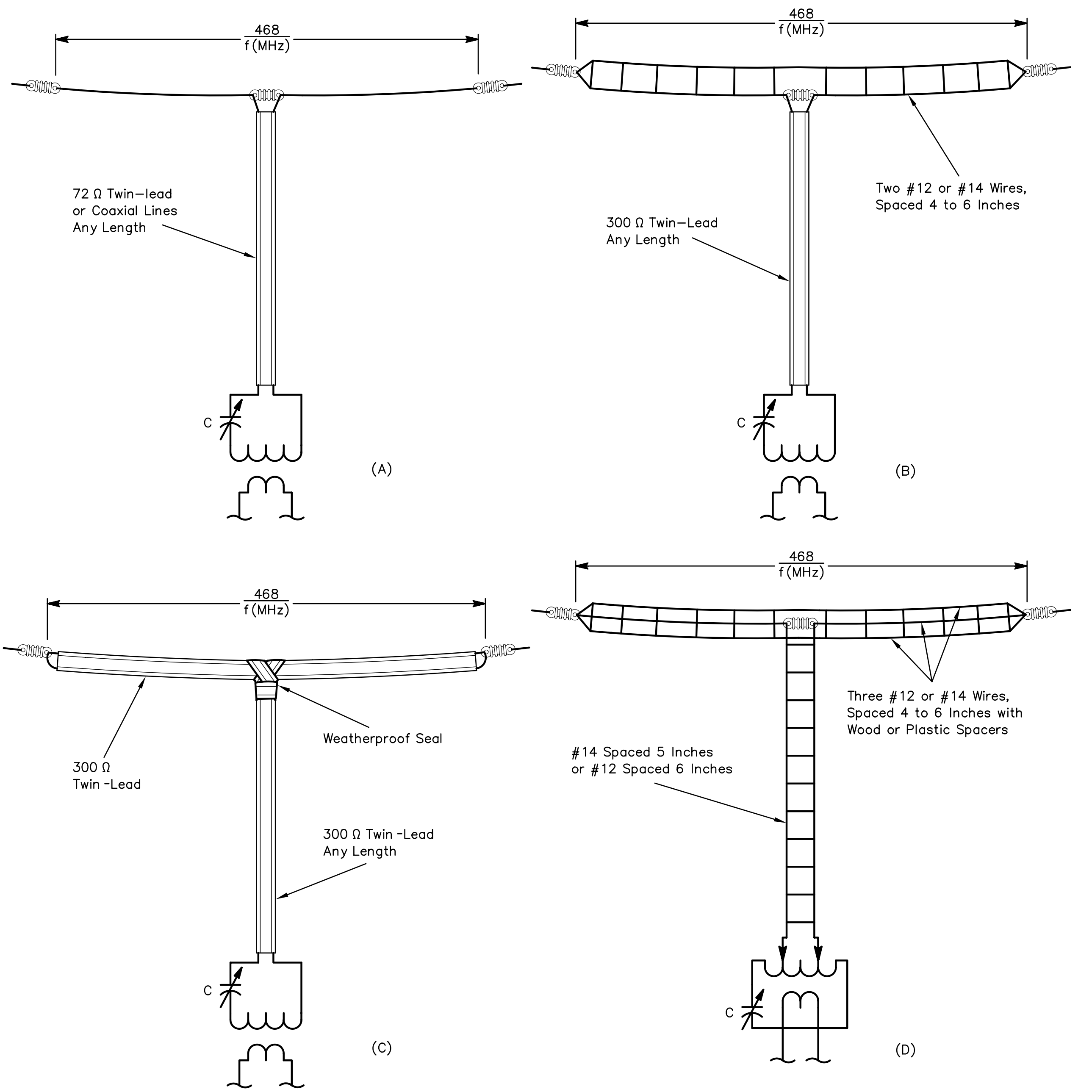

Fig 18—Half-wavelength antennas for single band operation. The multiwire types shown in B, C and D offer a better match to the feeder over a somewhat wider range of frequencies but otherwise the performances are identical. The feeder should run away from the antenna at a right angle for as great a distance as possible. In the coupling circuits shown, tuned circuits should resonate to the operating frequency. In the series-tuned circuits of A, B, and C, high L and low C are recommended, and in D the inductance and capacitance should be similar to the output-amplifier tank, with the feeders tapped across at least ½ the coil. The tapped-coil matching circuit shown in Chapter 25 can be substituted in each case.

tained with a three-wire dipole fed with either 450-Ω ladder line or 600-Ω open wire line. One advantage of the two- and three-wire antennas over the single wire is that they offer a better match over a wider band. This is particularly important if full coverage of the 3.5-MHz band is contemplated.

Inverted-V Dipole

The halves of a dipole may be sloped to form an inverted V, as shown in **Fig 19**. This has the advantages of requiring only a single high support and less horizontal space. There will be some difference in performance between a normal horizontal dipole and the inverted V as shown by the radiation patterns in **Fig 20**. There is small loss in peak gain and the pattern is less directional.

Sloping of the wires results in a raising of the resonant frequency and a decrease in feed-point impedance and

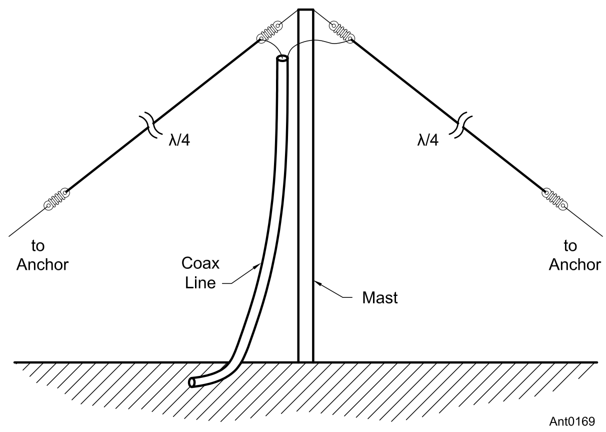

Fig 19—The inverted-V dipole. The length and apex angle should be adjusted as described in the text.

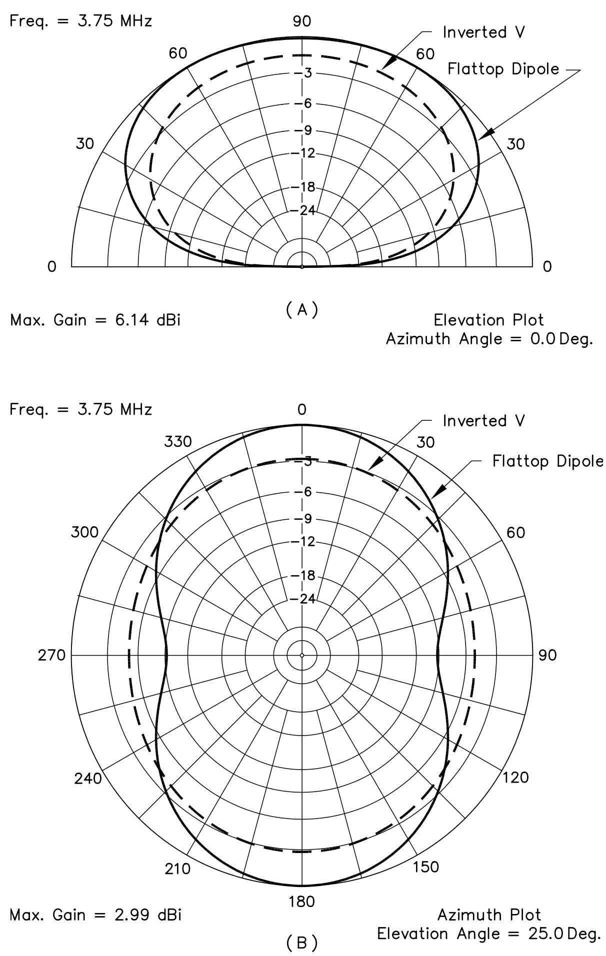

Fig 20—At A, elevation and at B, azimuthal radiation patterns comparing a normal 80-meter dipole and an inverted-V dipole. The center of both dipoles is at 65 feet and the ends of the inverted V are at 20 feet. The frequency is 3.750 MHz.

bandwidth. Thus, for the same frequency, the length of the dipole must be increased somewhat. The angle at the apex is not critical, although it should probably be made no smaller than 90°. Because of the lower impedance, a 50-Ω line should be used. For those who are dissatisfied with anything but a perfect match, the usual procedure is to adjust the angle for lowest SWR while keeping the dipole resonant by adjustment of length. Bandwidth may be increased by using multiconductor elements, such as a cage configuration.

PHASED HORIZONTAL ARRAYS

Phased arrays with horizontal elements, which provide some directional gain, can be used to advantage at 7 MHz, if they can be placed at least 40 feet above ground. At 3.5 MHz heights of 70 feet or more are needed for any real advantage.

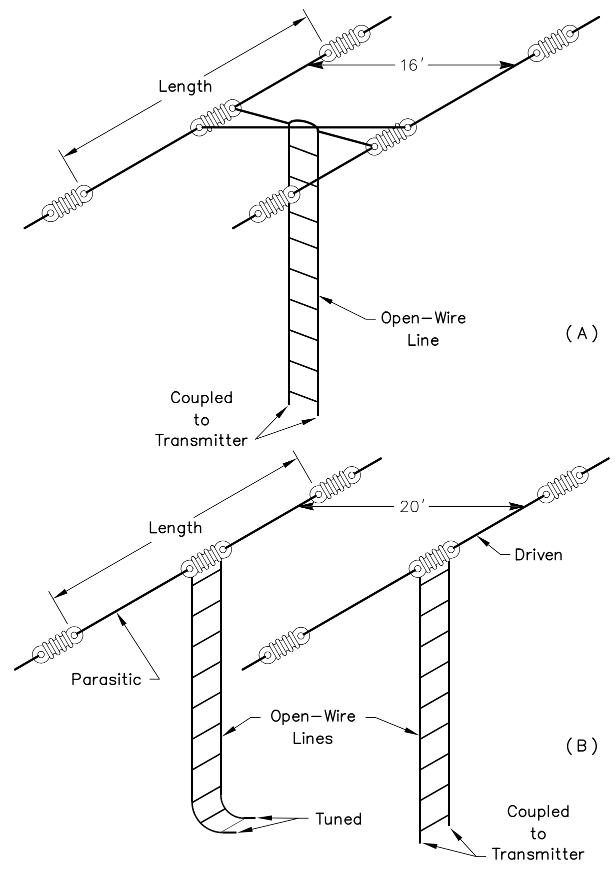

Fig 21—Directional antennas for 7 MHz. To realize any advantage from these antennas, they should be at least 40 feet high. At A, system is bidirectional. At B, system is unidirectional in a direction depending upon the tuning conditions of the parasitic element. The length of the elements in either antenna should be exactly the same, but any length from 60 to 150 feet can be used.
If the length of the antenna at A is between 60 and 80 feet, the antenna will be bidirectional along the same line on both 7 and 14 MHz. The system at B can be made to work on 7 and 14 MHz in the same way, by keeping the length between 60 and 80 feet.

Many of the driven arrays discussed in Chapter 8 and even some of the Yagis discussed in Chapter 11 can be used as fixed directional antennas. If a bidirectional characteristic is desired, the W8JK array, shown in **Fig 21A**, is a good one. If a unidirectional characteristic is required, two elements can be mounted about 20 feet apart and provision included for tuning one of the elements as either a director or reflector, as shown in Fig 21B.

The parasitic element is tuned at the end of its feed line with a series or parallel-tuned circuit (whichever would normally be required to couple power into the line), and the proper tuning condition can be found by using the system for receiving and listening to distant stations along the line to the rear of the antenna. Tuning the feeder to the parasitic element can minimize the received signals from the back of the antenna. This is in effect adjusting the antenna for maximum front-to-back ratio. Maximum front-to-back does not occur at the same point as maximum forward gain but the loss in forward gain is very small. Adjusting the antenna for maximum forward gain (peaking received signals in the forward direction) may increase the forward gain slightly but will almost certainly result in relatively poor front-to-back ratio.

A MODIFIED EXTENDED DOUBLE ZEPP

If the distance between the available supports is greater than λ/2 then a very simple form of a single wire collinear array can be used to achieve significant gain. The *extended double Zepp* antenna has long been used by amateurs and is discussed in Chapter 8, Multielement Arrays. A simple variation of this antenna with substantially improved bandwidth can be very useful on 3.5 and 7.0 MHz. The following material has been taken from an article by Rudy Severns, N6LF, in *The ARRL Antenna Compendium Vol 4*.

The key to improving the characteristics of a standard double-extended Zepp is to modify the current distribution. One of the simplest ways to do this is to insert a reactance(s) in series with the wire. This could either be an inductor(s) or a capacitor(s). In general, a series capacitor will have a higher Q and therefore less loss. With either choice it is desirable to use as few components as possible.

As an initial trial at 7 MHz, only two capacitors, one on each side of the antenna, were used. The value and position of the capacitors was varied to see what would happen. It quickly became clear that the reactance at the feed point could be tuned out by adjusting the capacitor value, making the antenna look essentially like a resistor over the entire band. The value of the feed-point resistance could be varied from less than 150 Ω to over 1500 Ω by changing the location of the capacitors and adjusting their values to resonate the antenna.

A number of interesting combinations were created. The one ultimately selected is shown in **Fig 22**. The antenna is 170 feet in length. Two 9.1 pF capacitors are located 25 feet out each side of the center. The antenna is fed with 450-Ω transmission line and a 9:1 three-core Guanella balun used

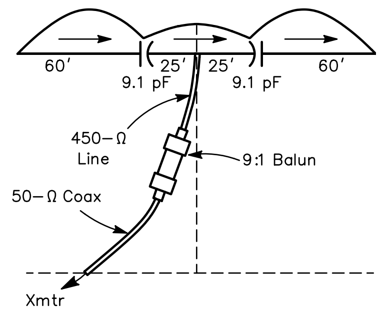

Fig 22—Schematic for modified N6LF Double Extended Zepp. Overall length is 170 feet, with 9.1 pF capacitors placed 25 feet each side of center.

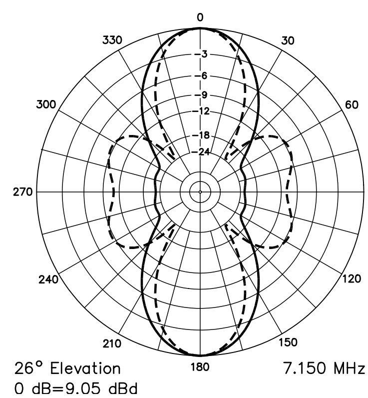

Fig 23—Azimuth pattern for N6LF Double Extended Zepp (solid line), compared to classic Double Extended Zepp (dashed line). The main lobe for the modified antenna is slightly broader than that of the classic model, and the sidelobes are suppressed better.

at the transmitter to convert to 50 Ω. The transmission line can be any convenient length and it operates with a very low SWR.

That's all there is to it. The radiation pattern, overlaid with that for a standard DEZepp for comparison, is shown in **Fig 23**. The sidelobes are now reduced to below 20 dB. The main lobe is now 43° wide at the 3-dB points, as opposed to 35° for the original DEZepp. The antenna has gain over a dipole for > 50° now and the gain of the main lobe has dropped only 0.2 dB below the original DEZepp.

Experimental Results

The antenna was made from #14 wire and the capacitors were made from 3.5-inch sections of RG-213, shown in **Fig 24A**. Note that great care should be taken to seal out moisture in these capacitors. The voltage across the capacitor for 1.5 kW will be about 2000 V so any corona will quickly destroy the capacitor.

A silicon sealant was used and then both ends covered

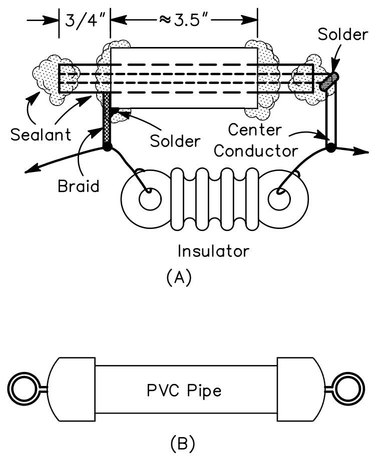

Fig 24—Construction details for series capacitor made from RG-213 coaxial cable. At A, the method used by N6LF is illustrated. At B, a suggested method to seal capacitor better against weather is shown, using a section of PVC pipe with end caps.

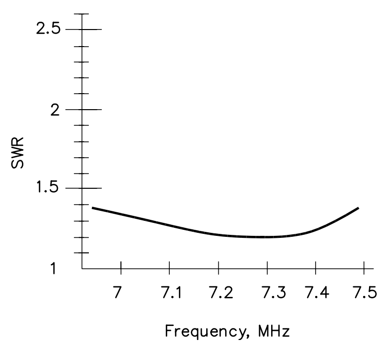

Fig 25—Measured SWR curve across 40-meter band for N6LF DEZepp.

with coax seal, finally wrapping it with plastic tape. The solder balls indicated on the drawing are to prevent wicking of moisture through the braid and the stranded center conductor. This is a small but important point if long service out in the weather is expected. An even better way to protect the capacitor would be to enclose it in a short piece of PVC pipe with end caps, as shown in Fig 24B.

Note that all RG-8 type cables do not have exactly the same capacitance per foot and there will also be some end

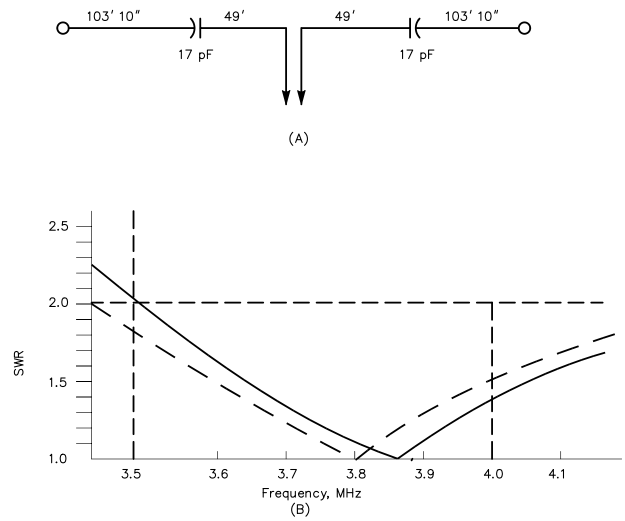

Fig 26—75/80-meter modified Double Extended Zepp, designed using *NEC Wires*. At A, a schematic is shown for antenna. At B, SWR curve is shown across 75/80-meter band. Solid line shows measured curve for W7ISV antenna, which was pruned to place SWR minimum higher in the band. The dashed curve shows the computed response when SWR minimum is set to 3.8 MHz.

effect adding to the capacitance. If possible the capacitor should be trimmed with a capacitance meter. It isn't necessary to be too exact—the effect of varying the capacitance ±10% was checked and the antenna still worked fine.

The results proved to be close to those predicted by the computer model. **Fig 25** shows the measured value for SWR across the band. These measurements were made with a Bird directional wattmeter. The worst SWR is 1.35:1 at the low end of the band.

Dick Ives, W7ISV, erected an 80-meter version of the antenna, shown in **Fig 26A**. The series capacitors are 17 pF. Since he isn't interested in CW, Dick adjusted the length for the lowest SWR at the high end of the band, as shown in the SWR curve (Fig 26B). The antenna could have been tuned somewhat lower in frequency and would then provide an SWR < 2:1 over the entire band, as indicated by the dashed line.

This antenna provides wide bandwidth and moderate gain over the entire 75/80-meter band. Not many antennas will give you that with a simple wire structure.

Vertical Antennas

On the low bands quarter-wave high vertical antennas become increasingly attractive, especially for DX work, because they provide a means for lowering the radiation angle. This is especially true where practical heights for horizontally polarized antennas are too low. In addition, verticals can be very simple and unobtrusive structures. For example, it is very easy to disguise a vertical as a flagpole. In fact an actual flagpole may be used as a vertical. Performance of a vertical is determined by several factors:

- Height of the vertical portion of the radiator
- The ground or counterpoise system efficiency, if one is used
- Ground characteristics in the near- and far-field regions
- The efficiency of loading elements and matching networks

THE HALF-WAVE VERTICAL DIPOLE (HVD)

The simplest form of vertical is that of a half-wave vertical dipole, an HVD. This is a horizontal dipole turned 90º so that it is perpendicular to the ground under it. Of course, the top end of such an antenna must be at least a half wave above the ground or else it would be touching the ground. This poses quite a construction challenge if the builder wants a free-standing low-frequency antenna. Hams fortunate enough to have tall trees on their property can suspend wire HVDs from these trees. Similarly, hams with two tall towers can run rope catenaries between them to hold up an HVD.

A vertical half-wave dipole has some operational advantages compared to a more-commonly used vertical configuration—the quarter-wave vertical used with some sort of above-ground counterpoise or an on-ground radial system. See **Fig 27** and 27B, which shows the two configurations discussed here. In each case, the lowest part of each antenna is 8 feet above ground, to prevent passersby from being able to touch any live wire. Each antenna is assumed to be made of #14 wire resonant on 80 meters.

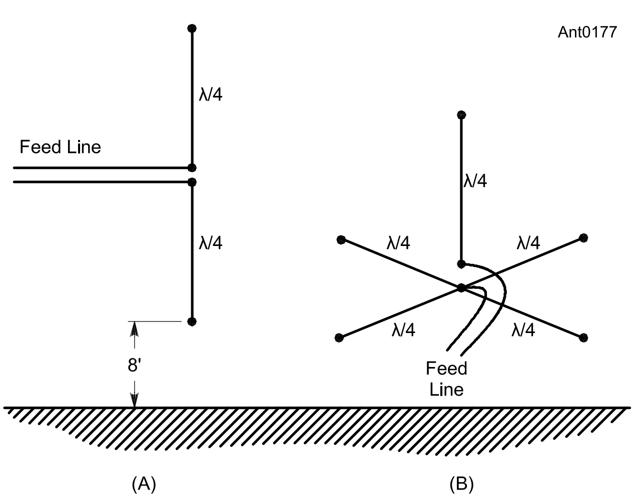

Fig 27—At A, a 80-meter half-wave vertical dipole elevated 8 feet above the ground. The feed line is run perpendicularly away from the dipole. At B, a "ground plane" type of quarter-wave vertical, with four elevated resonant radials. Both antennas are mounted 8 feet above the ground to keep them away from passersby.

Feeding a Half-Wave Vertical Dipole

Fig 28 compares elevation patterns for the two antennas for "average ground." You can see that the half-wave vertical dipole has about 1.5 dB higher peak gain, since it compresses the vertical elevation pattern down somewhat closer to the horizon than does the quarter-wave ground plane. Another advantage to using a half-wave radiator besides higher gain is that less horizontal "real estate" is needed compared to a quarter-wave vertical with its horizontal radials.

The obvious disadvantage to an HVD is that it is taller than a quarter-wave ground plane. This requires a higher support (such as a taller tree) if you make it from wire, or a longer element if you make it from telescoping aluminum tubing.

Another problem is that theory says you must dress the feed line so that it is perpendicular to the half-wave radiator. This means you must support the coax feed line above ground for some distance before bringing the coax down to ground level. A question immediately arises: How far must you go out horizontally with the feed line before going to ground level to eliminate common-mode currents that are radiated onto the coax shield? Such common-mode currents will affect the feed-point impedance as well as the radiation pattern for the antenna system. Quite a bit of distortion in the azimuthal pattern can be created if common-mode currents aren't suppressed, usually by using a common-mode choke, also known as a current balun.

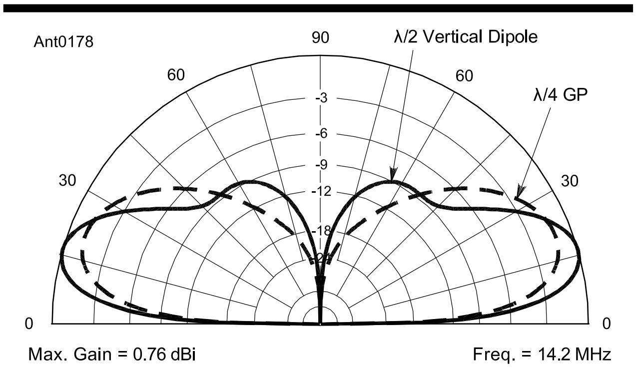

Fig 28—A comparison of the elevation patterns for the two antennas in Fig 27. The peak gain of the HVD is about 1.5 dB higher than that for the quarter-wave ground-plane radiator with radials.

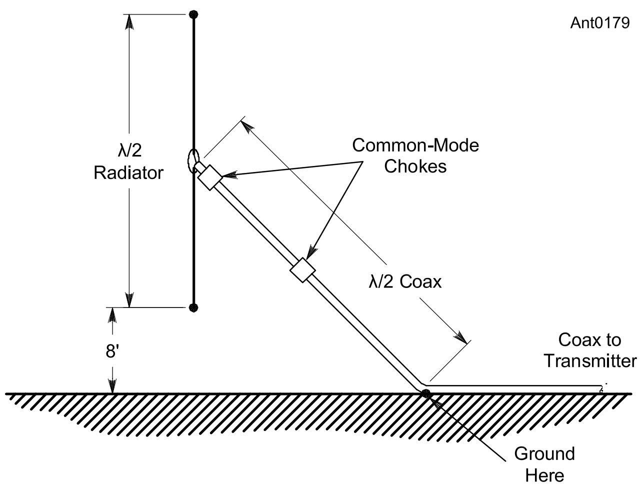

Fig 29—A 20-meter HVD whose bottom is 8 feet above ground. This is fed with a λ/2 of RG-213 coax. This system uses a common-mode choke at the feed point and another λ/4 down the line. The resulting azimuthal radiation pattern is within 0.4 dB of being perfectly circular. The "wingspan" of this antenna system is 27 feet from the radiator to the point where the coax comes to ground level.

Constructing such a common-mode choke is very simple: Three large ferrite beads are slipped over the coax (before the connectors are soldered on or else they won't fit!) and taped in place. The only problem with this scheme is that an additional support (some sort of "skyhook") is required to support the coax horizontally. Let's try to simplify the installation, by slanting the feed-line coax down to ground from the feed point at a fairly steep angle of about 30º from vertical. See **Fig 29**.

Note that the bottom end of the coax in Fig 29 is grounded to a ground rod. This serves several purposes—this serves as a mechanical connection to hold the coax in place and it provides some protection against lightning strikes. Now, as a purely practical matter, just how picky are we being here? What if we skip the second common-mode choke and just use one at the feed point? The computer models predicts that there will be some distortion in the azimuthal pattern—about 1.1 dB worth. Whether this is serious is up to you. However, you may find other problems with common-mode currents on the coax shield—problems such as RF in the shack or variable SWR readings depending on the way coax is routed in the shack. The addition of three extra ferrite beads to suppress the common-mode currents is cheap insurance.

Later in this chapter we'll discuss shortened vertical antennas, ones arranged both as vertical dipoles and as vertical monopoles with radial systems.

MONOPOLE VERTICALS WITH GROUND PLANE RADIALS

For best performance the vertical portion of a ground-plane type of antenna should be λ/4 or more, but this is not an absolute requirement. With proper design, antennas as short as 0.1 λ or even less can be efficient and effective. Antennas shorter than λ/4 will be reactive and some form of loading and perhaps a matching network will be required.

If the radiator is made of wire supported by nonconducting material, the approximate length for λ/4 resonance can be found from:

$$\ell_{\text{feet}} = \frac{234}{f_{\text{MHz}}} \qquad \text{(Eq 1)}$$

For tubing, the length for resonance must be shorter than given by the above equation, as the length-to-diameter ratio is lower than for wire (see Chapter 2, Antenna Fundamentals). For a tower, the resonant length will be shorter still. In any case, after installation the antenna length (height) can be adjusted for resonance at the desired frequency.

The effect of ground characteristics on losses and elevation pattern is discussed in detail in Chapter 3, The Effects of Ground. The most important points made in that discussion are the effect of ground characteristics on the radiation pattern and the means for achieving low ground-loss resistance in a buried ground system. As ground conductivity increases, low-angle radiation improves. This makes a vertical very attractive to those who live in areas with good ground conductivity. If your QTH is on a saltwater beach, then a vertical would be very effective, even when compared to horizontal antennas at great height.

When a buried-radial ground system is used, the efficiency of the antenna will be limited by the loss resistance of the ground system. The ground can be a number of radial wires extending out from the base of the antenna for about λ/4. Driven ground rods, while satisfactory for electrical safety and for lightning protection, are of little value as an RF ground for a vertical antenna, except perhaps in marshy or beach areas. As pointed out in Chapter 3, many long radials are desirable. In general, however, a large number of short radials are preferable to only a few long radials, although the best system would have 60 or more radials longer than λ/4. An elevated system of radials or a ground screen (*counterpoise*) may be used instead of buried radials, and can result in an efficient antenna.

ELEVATED RADIALS AND COUNTERPOISES

Elevated radials, isolated from ground, can be used in place of an extensive buried radial system. Work by Al Christman, K3LC (ex-KB8I), has shown that 4 to 8 elevated radials can provide performance comparable to a 120 λ/4-long buried wires. This is especially important for the low bands, where such a buried ground system is very large and impractical for most amateurs. An elevated ground system is sometimes referred to as a *ground plane* or *counterpoise*. **Fig 30** compares buried and elevated ground systems, showing the difference in current flow in the two systems.

An elevated ground can take several forms. A number of wires arranged with radial symmetry around the base of the antenna is shown in Fig 30B. Four radials are normally

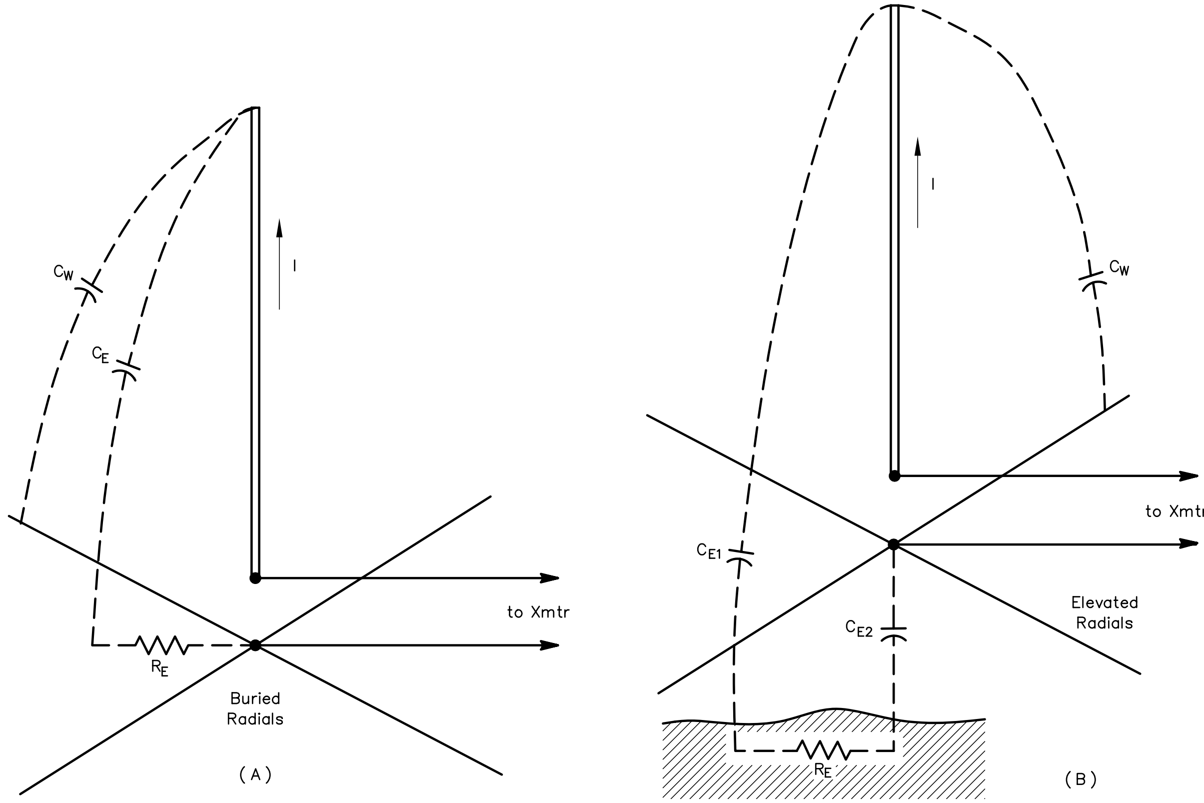

Fig 30—How earth currents affect the losses in a short vertical antenna system. At A, the current through the combination of C_E and R_E may be appreciable if C_E is much greater than C_W, the capacitance of the vertical to the ground wires. This ratio can be improved (up to a point) by using more radials. By raising the entire antenna system off the ground, C_E (which consists of the series combination of C_{E1} and C_{E2}) is decreased while C_W stays the same. The radial system shown at B is sometimes called a *counterpoise*.

used, but as few as two, or as many as eight, can be used. For a given height of vertical, the length of the radials can be adjusted to resonate the antenna. For a λ/4 vertical, the radials are normally λ/4 long.

In the case of a multiband vertical, two or more sets of radials, with different lengths, may be interleaved. The radials associated with each band are adjusted for resonance on their associated band.

A counterpoise is most commonly a system of elevated radials, where the radial wires are interconnected with jumpers, as shown in **Fig 31**. As illustrated in Fig 30, the purpose of the elevated-ground system is to provide a return path for the displacement currents flowing in the vicinity of the antenna. The idea is to minimize the current flowing through the ground itself, which is usually very lossy. By raising the radials above ground most of the current will flow in the radials, which are good conductors. This allows a simple radial system to provide a very efficient ground. However, there is a price to be paid for this.

The ground system now has a direct effect on the feed-point impedance, introducing reactance as well as resistance, and is relatively narrow band. For a given vertical height, the

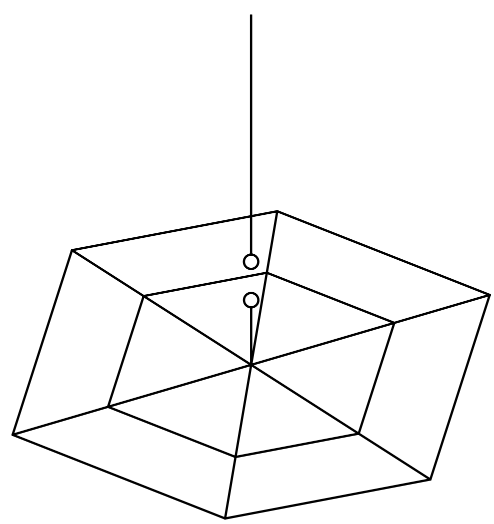

Fig 31—Counterpoise, showing the radial wires connected together by cross wires. The length of the perimeter of the individual meshes should be < λ/4 to prevent undesired resonances. Sometimes the center portion of the counterpoise is made from wire mesh.

Table 2

Illustration of the effect of variable vertical height (L_1) on elevated radial length (L2) and R_R. #12 wire, elevated 5 feet over average ground at 3.525 MHz.

L_1 (λ)	L_1 (feet)	L_2 (feet)	R_R (Ω)
0.225	62.8	94	28.8
0.25	69.8	67	38.4
0.27	75.0	45	51.0
0.3	83.7	24	75.9

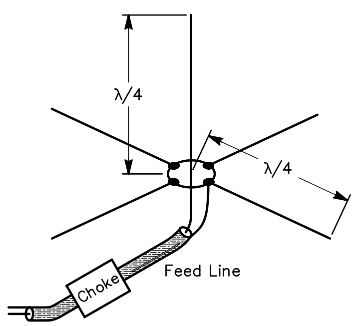

Fig 32—The ground-plane antenna. Power is applied between the base of the vertical radiator and the center of the ground plane, as indicated in the drawing. Decoupling from the transmission line and any conductive support structure is highly desirable.

radial length must be adjusted to resonate the antenna. The length of the radials must be readjusted for each band if a multiband vertical is used. As pointed out above, this usually means the installation of a set of radials for each band. To minimize current flowing in the ground, the antenna, ground plane and feed line must be isolated from ground for RF. More on this later.

The height of the vertical does not have to be exactly λ/4. Other lengths may be used and the antenna may be resonated by adjusting the length of the radials. **Table 2** gives a comparison between three different vertical lengths in an antenna using four elevated radials at 3.525 MHz.

An important feature of Table 2 is the dramatic reduction in radial length (L_2) with even a small increase in vertical height (L_1). For example, increasing the height by 5 feet reduces the radial length by 22 feet on 80 meters. On the other hand even a small decrease in L_1 can cause a substantial increase in L_2. This would be very undesirable, since the area required by the radials is already considerable. Notice also that the small increase in height raises R_R to 51 Ω. This trick of increasing the height slightly to reduce the size of the elevated ground system and to increase the input resistance can be very useful. In a following section the use of *top loading* for short antennas will be discussed. Top loading can also be used on a λ/4 vertical to achieve the same effect as increasing the height—the ability to use shorter radials and a better match.

GROUND-PLANE ANTENNAS

The ground-plane antenna is a λ/4 vertical with four radials, as shown in **Fig 32**. The entire antenna is elevated above ground. A practical example of a 7-MHz ground-plane antenna is given in **Fig 33**. As explained earlier, elevating the antenna reduces the ground loss and lowers the radiation angle somewhat. The radials are sloped downward to make the feed-point impedance closer to 50 Ω.

The feed-point impedance of the antenna varies with the height above ground, and to a lesser extent varies with the ground characteristics. **Fig 34** is a graph of feed-point resistance (R_R) for a ground-plane antenna with the radials parallel to the ground. R_R is plotted as a function of height above ground. Notice that the difference between perfect ground and average ground (ε=13 and σ = 0.005 S/m) is small, except when quite close to ground. Near ground R_R is between 36 and 40 Ω. This is a reasonable match for 50-Ω feed line but as the antenna is raised above ground R_R drops to approximately 22 Ω, which is not a very good match. The feed-point resistance can be increased by sloping the radials downward, away from the vertical section.

The effect of sloping the radials is shown in **Fig 35**. The

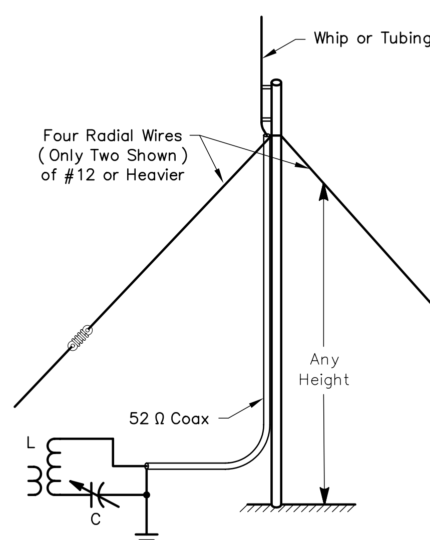

Fig 33—A ground-plane antenna is effective for DX work on 7 MHz. Although its base can be any height above ground, losses in the ground underneath will be reduced by keeping the bottom of the antenna and the ground plane as high above ground as possible. Feeding the antenna directly with 50-Ω coaxial cable will result in a low SWR. The vertical radiator and the radials are all λ/4 long electrically. Contrary to popular myth, the radials need not necessarily be 5% longer than the radiator. Their physical length will depend on their length-to-diameter ratios, the height over ground and the length of the vertical radiator, as discussed in text.

graph is for an antenna well above ground (> 0.3 λ). Notice that R_R = 50 Ω when the radials are sloped downward at an angle of 45°, a convenient value. The resonant length of the antenna will vary slightly with the angle. In addition, the resonant length will vary a small amount with height above the ground. It is for these reasons, as well as the effect of conductor diameter, that some adjustment of the radial lengths is usually required. When the ground-plane antenna is used on the higher HF bands and at VHF, the height above ground is usually such that a radial sloping angle of 45° will give a good match to 50-Ω feed line.

The effect of height on R_R with a radial angle of 45° is shown in **Fig 36**. At 7 MHz and lower, it is seldom possible to elevate the antenna a significant portion of a wavelength and the radial angle required to match to 50-Ω line is usually of the order of 10° to 20°. To make the vertical portion of the antenna

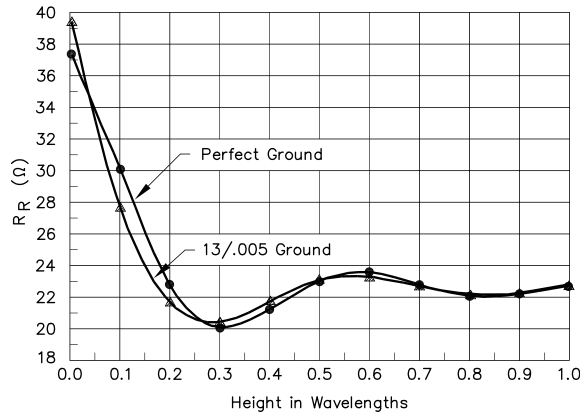

Fig 34—Radiation resistance of a 4-radial ground-plane antenna as a function of height over ground. Perfect and average ground are shown. Frequency is 3.525 MHz. Radial angle (θ) is 0°.

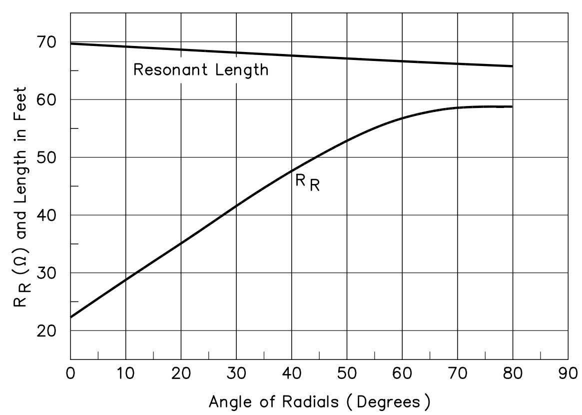

Fig 35—Radiation resistance and resonant length for a 4-radial ground-plane antenna > 0.3 λ above ground as a function of radial droop angle (θ).

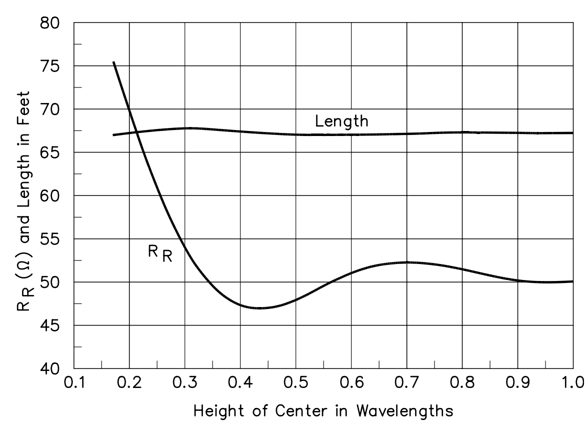

Fig 36—Radiation resistance and resonant length for a 4-radial ground-plane antenna for various heights above average ground for radial droop angle θ = 45°.

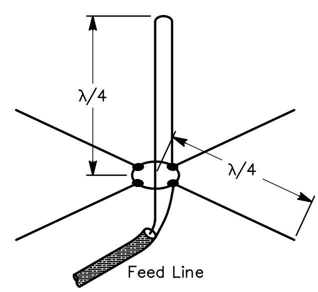

Fig 37—The folded monopole antenna. Shown here is a ground plane of four λ/4 radials. The folded element may be operated over an extensive counterpoise system or mounted on the ground and worked against buried radials and the earth. As with the folded dipole antenna, the feed-point impedance depends on the ratios of the radiator conductor sizes and their spacing.

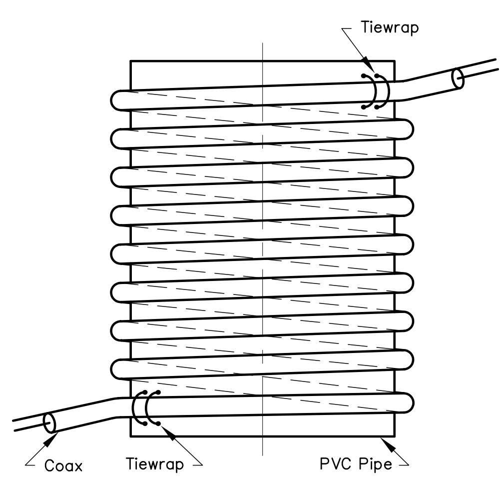

Fig 38—A choke balun with sufficient impedance to isolate the antenna properly can be made by winding coaxial cable around a section of plastic pipe. Suitable dimensions are given in the text.

as long as possible, it may be better to accept a slightly poorer match and keep the radials parallel to ground.

The principles of the folded dipole (Fig 18) can also be applied to the ground-plane antenna, as shown in **Fig 37**. This is the *folded monopole* antenna. The feed-point resistance can be controlled by the number of parallel vertical conductors and the ratios of their diameters.

As mentioned earlier, it is important in most installations to isolate the antenna from the feed line and any conductive supporting structure. This is done to minimize the return current conducted through the ground. A return current on the feed line itself or the support structure can drastically alter the radiation pattern, usually for the worse. For these reasons, a balun (see Chapter 26, Coupling the Line to the Antenna) or other isolation scheme must be used. 1:1 baluns are effective for the higher bands but at 3.5 and 1.8 MHz commercial baluns often have too low a shunt inductance to provide adequate isolation. It is very easy to recognize when the isolation is inadequate. When the antenna is being adjusted while watching an isolated impedance or SWR meter, adjustments may be sensitive to your touching the instrument. After adjustment and after the feed line is attached, the SWR may be drastically different. When the feed line is inadequately isolated, the apparent resonant frequency or the length of the radials required for resonance may also be significantly different from what you expect.

In general, an isolation choke inductance of 50 to 100 µH will be needed for 3.5 and 1.8-MHz ground-plane antennas. One of the easiest ways to make the required isolation choke is to wind a length of coaxial cable into a coil as shown in **Fig 38**. For 1.8 MHz, 30 turns of RG-213 wound on a 14-inch length of 8-inch diameter PVC pipe, will make a very good isolation choke that can handle full legal power continuously. A smaller choke could be wound on 4-inch diameter plastic drain pipe using RG-8X or a Teflon insulated cable. The important point here is to isolate or decouple the antenna from the feed line and support structure.

A full-size ground-plane antenna is often a little impractical for 3.5-MHz and quite impractical for 1.8 MHz, but it can be used at 7 MHz to good advantage, particularly for DX work. Smaller versions can be very useful on 3.5 and 1.8 MHz.

EXAMPLES OF VERTICALS

There are many possible ways to build a vertical antenna—the limits are set by your ingenuity. The primary problem is creating the vertical portion of the antenna with sufficient height. Some of the more common means are:

- A dedicated tower
- Using an existing tower with an HF Yagi on top
- A wire suspended from a tree limb or the side of a building
- A vertical wire supported by a line between two trees or other supports
- A tall pole supporting a conductor
- Flagpoles
- Light standards
- Irrigation pipe
- TV masts

If you have the space and the resources, the most straightforward means is to erect a dedicated tower for a vertical. While this is certainly an effective approach, many amateurs do not have the space or the funds to do this, especially if they already have a tower with an HF antenna on the top. The existing tower can be used as a top-loaded vertical, using shunt feed and a ground radial system. A system like this is shown in **Fig 39B**.

For those who live in an area with tall trees, it may be possible to install a support rope between two trees, or between a tree and an existing tower. (Under no circumstances should you use an active utility pole!) The vertical portion of the antenna can be a wire suspended from the support line to ground, as shown in Fig 39C. If top loading is needed, some or all of the support line can be made part of the antenna.

Your local utility company will periodically have older power poles that they no longer wish to keep in service. These are sometimes available at little or no expense. If you see a power line under reconstruction or repair in your area you might stop and speak with the crew foreman. Sometimes they will have removed older poles they will not use again and will have to haul them back to their shop for disposal. Your offer for local "disposal" may well be accepted. Such a pole can be used in conjunction with a tubing or whip extension such as that shown in Fig 39A. Power poles are not your only option. In some areas of the US, such as the southeast or northwest, tall poles made directly from small conifers are available.

Freestanding (unguyed) flagpoles and roadway illumination standards are available in heights exceeding 100 feet. These are made of fiberglass, aluminum or galvanized steel. All of these are candidates for verticals. Flagpole suppliers are listed under "Flags and Banners" in your Yellow Pages. For lighting standards (lamp posts), you can contact a local electrical hardware distributor. Like a wooden pole, a fiberglass flagpole does not require a base insulator, but metal poles do. Guy wires will be needed.

One option to avoid the use of guys and a base insulator is to mount the pole directly into the ground as originally intended and then use shunt feed. If you want to keep the pole grounded but would like to use elevated radials, you can attach a cage of wires (four to six) at the top as shown in Fig 39D. The cage surrounds the pole and allows the pole (or tower for that matter) to be grounded while allowing elevated radials to be used. The use of a cage of wires surrounding the pole or tower is a very good way to increase the effective diameter. This reduces the Q of the antenna, thereby increasing the bandwidth. It can also reduce the conductor loss, especially if the pole is galvanized steel, which is not a very good RF conductor.

Aluminum irrigation tubing, which comes in diameters of 3 and 4 inches and in lengths of 20 to 40 feet, is widely available in rural areas. One or two lengths of tubing con-

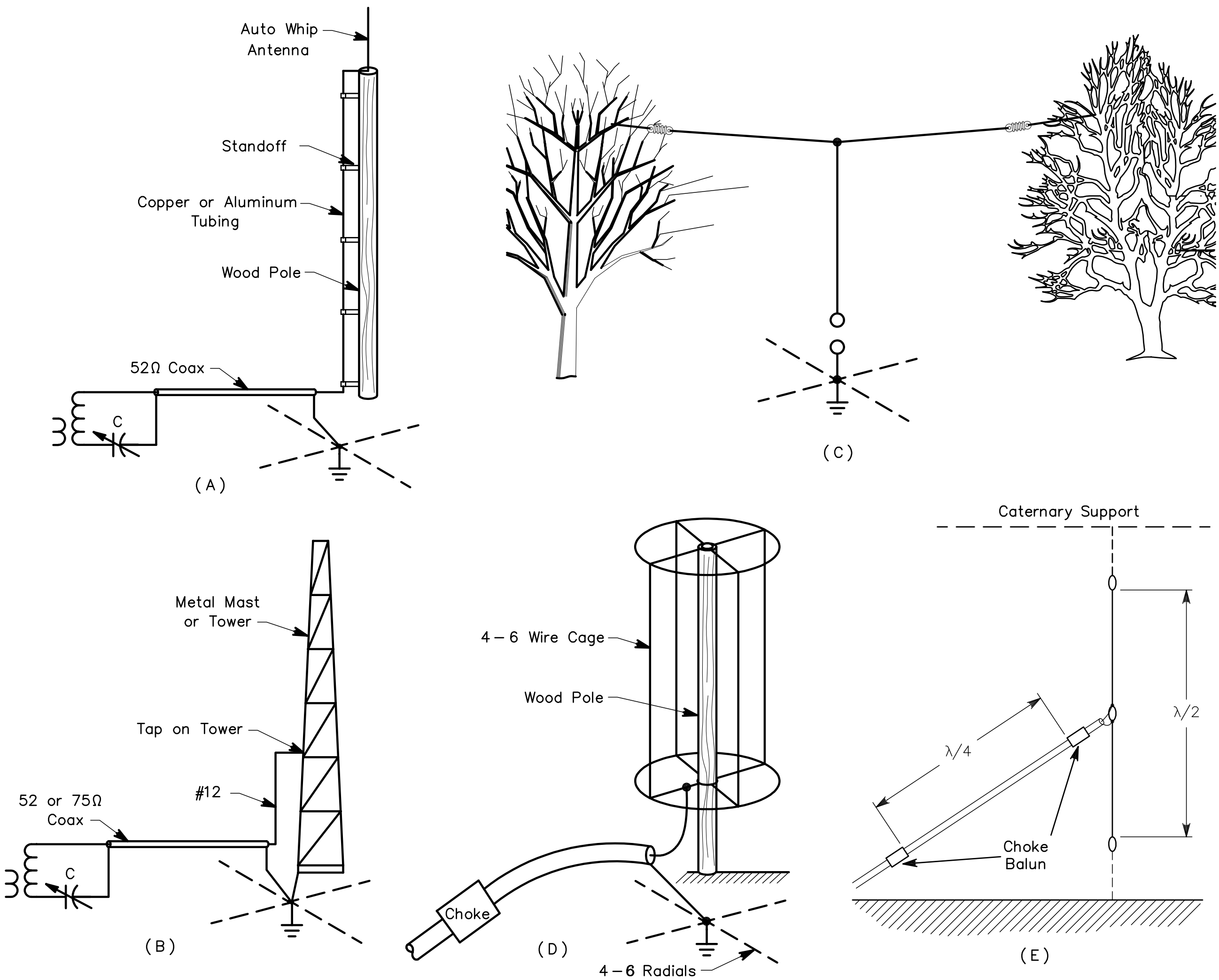

Fig 39—Vertical antennas are effective for 3.5- or 7-MHz work. The λ/4 antenna shown at A is fed directly with 50-Ω coaxial line, and the resulting SWR is usually less than 1.5 to 1, depending on the ground resistance. If a grounded antenna is used as at B, the antenna can be shunt fed with either 50- or 75-Ω coaxial line. The tap for best match and the value of C will have to be found by experiment. The line running up the side of the antenna should be spaced 6 to 12 inches from the antenna. If tall trees are available the antenna can be supported from a line suspended between the trees, as shown in C. If the vertical section is not long enough then the horizontal support section can be made of wire and act as top loading. A pole or even a grounded tower can be used with elevated radials if a cage of four to six wires is provided as shown in D. The cage surrounds the pole which may be wood or a grounded conductor.

nected together can make a very good vertical when guyed with non-conducting line. It is also very lightweight and relatively easy to erect. A variety of TV masts are available which can also be used for verticals.

1.8 TO 3.5-MHz VERTICAL USING AN EXISTING TOWER

A tower can be used as a vertical antenna, provided that a good ground system is available. The shunt-fed tower is at its best on 1.8 MHz, where a full λ/4 vertical antenna is rarely possible. Almost any tower height can be used. If the beam structure provides some top loading, so much the better, but anything can be made to radiate—if it is fed properly. W5RTQ (now K6SE) uses a self-supporting, aluminum, crank-up, tilt-over tower, with a TH6DXX tribander mounted at 70 feet. Measurements showed that the entire structure has about the same properties as a 125-foot vertical. It thus works quite well as an antenna on 1.8 and 3.5 MHz for DX work requiring low-angle radiation.

Preparing the Structure

Usually some work on the tower system must be done before shunt-feeding is tried. If present, metallic guys should be broken up with insulators. They can be made to simulate top loading, if needed, by judicious placement of the first insulators. Don't overdo it; there is no need to "tune the radiator to resonance" in this way since a shunt feed is employed. If the tower is fastened to a house at a point more than about one-fourth of the height of the tower, it may be desirable to insulate the tower from the building. Plexiglas sheet, ¼-inch or more thick, can be bent to any desired shape for this purpose, if it is heated in an oven and bent while hot.

All cables should be taped tightly to the tower, on the inside, and run down to the ground level. It is not necessary to bond shielded cables to the tower electrically, but there should be no exceptions to the down-to-the-ground rule.

A good system of buried radials is very desirable. The ideal would be 120 radials, each 250 feet long, but fewer and shorter ones must often suffice. You can lay them around corners of houses, along fences or sidewalks, wherever they can be put a few inches under the surface, or even on the earth's surface. Aluminum clothesline wire may be used extensively in areas where it will not be subject to corrosion. Neoprene-covered aluminum wire will be better in highly acid soils. Contact with the soil is not important. Deep-driven ground rods and connection to underground copper water pipes may be helpful, if available, especially to provide some protection from lightning.

Installing the Shunt Feed

Principal details of the shunt-fed tower for 1.8 and 3.5 MHz are shown in **Fig 40**. Rigid rod or tubing can be used for the feed portion, but heavy gauge aluminum or copper wire is easier to work with. Flexible stranded #8 copper wire is used at W5RTQ (now K6SE) for the 1.8-MHz feed, because when the tower is cranked down, the feed wire must come down with it. Connection is made at the top, 68 feet, through a 4-foot length of aluminum tubing clamped to the top of the tower, horizontally. The wire is clamped to the tubing at the outer end, and runs down vertically through standoff insulators. These are made by fitting 12-inch lengths of PVC plastic water pipe over 3-foot lengths of aluminum tubing. These are clamped to the tower at 15- to 20-foot intervals, with the bottom clamp about 3 feet above ground. These lengths allow for adjustment of the tower-to-wire spacing over a range of about 12 to 36 inches, for impedance matching.

The gamma-match capacitor for 1.8 MHz is a 250-pF variable with about ⅙-inch plate spacing. This is adequate for power levels up to about 200 W. A large transmitting or a vacuum-variable capacitor should be used for high-power applications.

Tuning Procedure

The 1.8-MHz feed wire should be connected to the top of the structure if it is 75 feet tall or less. Mount the standoff insulators so as to have a spacing of about 24 inches between wire and tower. Pull the wire taut and clamp it in place at the bottom insulator. Leave a little slack below to permit adjustment of the wire spacing, if necessary.

Adjust the series capacitor in the 1.8-MHz line for minimum reflected power, as indicated on an SWR meter connected between the coax and the connector on the capacitor housing. Make this adjustment at a frequency near the middle of your expected operating range. If a high SWR is indicated, try moving the wire closer to the tower. Just the

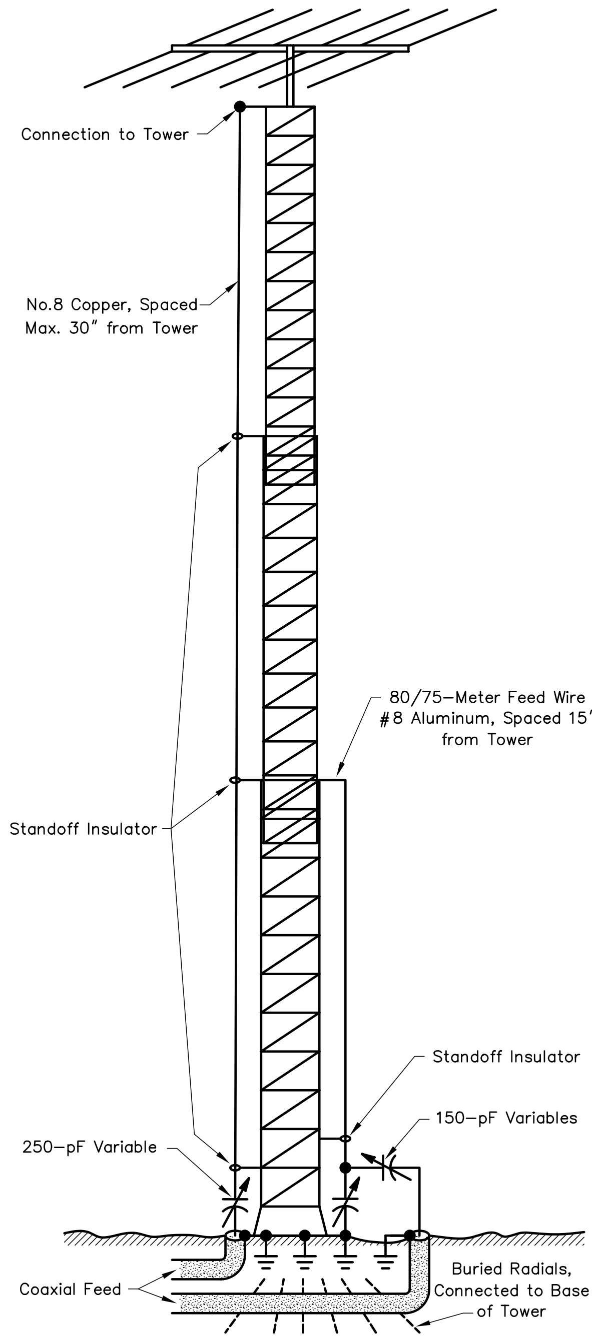

Fig 40—Principal details of the shunt-fed tower at W5RTQ (now K6SE). The 1.8-MHz feed, left side, connects to the top of the tower through a horizontal arm of 1-inch diameter aluminum tubing. The other arms have standoff insulators at their outer ends, made of 1-foot lengths of plastic water pipe. The connection for 3.5-4 MHz, right, is made similarly, at 28 feet, but two variable capacitors are used to permit adjustment of matching with large changes in frequency.

lower part of the wire need be moved for an indication as to whether reduced spacing is needed. If the SWR drops, move all insulators closer to the tower, and try again.

If the SWR goes up, increase the spacing. There will be a practical range of about 12 to 36 inches. If going down to 12 inches does not give a low SWR, try connecting the top a bit farther down the tower. If wide spacing does not make it, the omega match shown for 3.5-MHz work should be tried. No adjustment of spacing is needed with the latter arrangement, which may be necessary with short towers or installations having little or no top loading.

The two-capacitor arrangement in the omega match is also useful for working in more than one 25-kHz segment of the 1.8-MHz band. Tune up on the highest frequency, say 1990 kHz, using the single capacitor, making the settings of wire spacing and connection point permanent for this frequency. To move to the lower frequency, say 1810 kHz, connect the second capacitor into the circuit and adjust it for the new frequency. Switching the second capacitor in and out then allows changing from one segment to the other, with no more than a slight retuning of the first capacitor.

SIMPLE, EFFECTIVE, ELEVATED GROUND-PLANE ANTENNAS

This section describes a simple and effective means of using a grounded tower, with or without top-mounted antennas, as an elevated ground-plane antenna for 80 and 160 meters. It first appeared in a June 1994 *QST* article by Thomas Russell, N4KG.

From Sloper to Vertical

Recall the quarter-wavelength sloper, also known as the *half sloper*. [The half sloper is covered later in this chapter in more detail.—*Ed.*] It consists of an isolated quarter wavelength of wire, sloping from an elevated feed point on a grounded tower. Best results are usually obtained when the feed point is somewhere below a top-mounted Yagi antenna. You feed a sloper by attaching the center conductor of a coaxial cable to the wire and the braid of the cable to the tower leg. Now, imagine four (or more) slopers, but instead of feeding each individually, connect them together to the center conductor of a single feed line. Voilà! Instant elevated ground plane.

Now, all you need to do is determine how to tune the antenna to resonance. With no antennas on the top of the tower, the tower can be thought of as a fat conductor and should be approximately 4% shorter than a quarter wavelength in free space. Calculate this length and attach four insulated quarter-wavelength radials at this distance from the top of the tower. For 80 meters, a feed point 65 feet below the top of an unloaded tower is called for. The tower guys must be broken up with insulators for all such installations. For 160 meters, 130 feet of tower above the feed point is needed.

What can be done with a typical grounded-tower-and-Yagi installation? A top-mounted Yagi acts as a large capacitance hat, top loading the tower. Fortunately, top loading is the most efficient means of loading a vertical antenna.

The examples in **Table 3** should give us an idea of how much top loading might be expected from typical amateur antennas. The values listed in the *Equivalent Loading* column tell us the approximate vertical height replaced by the antennas listed in a top-loaded vertical antenna. To arrive at the remaining amount of tower needed for resonance, subtract these numbers from the non-loaded tower height needed for resonance. Note that for all but the 10-meter antennas, the equivalent loading equals or exceeds a quarter wavelength on 40 meters. For typical HF Yagis, this method is best used only on 80 and 160 meters.

Construction Examples

Consider this example: A TH7 triband Yagi mounted on a 40-foot tower. The TH7 has approximately the same overall dimensions as a full-sized 3-element 20-meter beam, but has more interlaced elements. Its equivalent loading is estimated to be 40 feet. At 3.6 MHz, 65 feet of tower is needed without loading. Subtracting 40 feet of equivalent loading, the feed point should be 25 feet below the TH7 antenna.

Ten quarter-wavelength (65-foot) radials were run from a nylon rope tied between tower legs at the 15-foot level, to various supports 10 feet high. Nylon cord was tied to the insulated, stranded, #18 wire, without using insulators. The radials are all connected together and to the center of an exact half wavelength (at 3.6 MHz) of RG-213 coax, which will repeat the antenna feed impedance at the other end. **Fig 41** is a drawing of the installation. The author used a Hewlett-Packard low-frequency impedance analyzer to measure the input impedance across the 80-meter band. An exact resonance (zero reactance) was seen at 3.6 MHz, just as predicted. The radiation resistance was found to be 17 Ω. The next question is, how to feed and match the antenna.

One good approach to 80-meter antennas is to tune them to the low end of the band, use a low-loss transmission line, and switch an antenna tuner in line for operation in the higher portions of the band. With a 50-Ω line, the 17-Ω radiation resistance represents a 3:1 SWR, meaning that an antenna tuner should be in-line for all frequencies. For short runs, it

Table 3
Effective Loading of Common Yagi Antennas

Antenna	*Boom Length (feet)*	*S (area, ft²)*	*Equivalent Loading (feet)*
3L 20	24	768	39
5L 15	26	624	35
4L 15	20	480	31
3L 15	16	384	28
5L 10	24	384	28
4L 10	18	288	24
3L 10	12	192	20
TH7	24	—	40 (estimated)
TH3	14	—	27 (estimated)

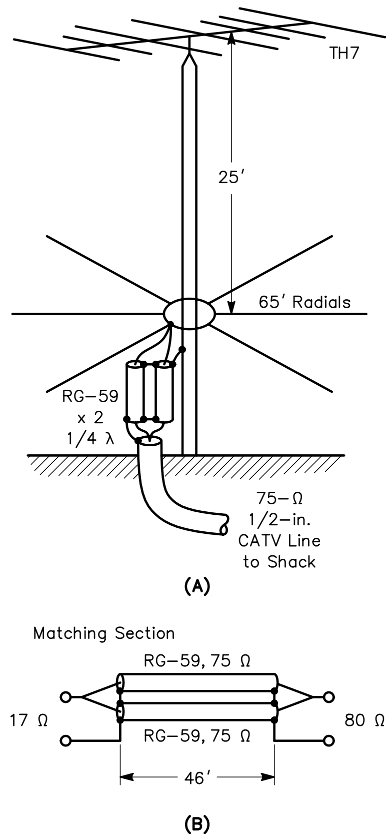

Fig 41—At A, an 80-meter top-loaded, reverse-fed elevated ground plane, using a 40-foot tower carrying a TH7 triband Yagi antenna. At B, dimensions of the 3.6-MHz matching network, made from RG-59.

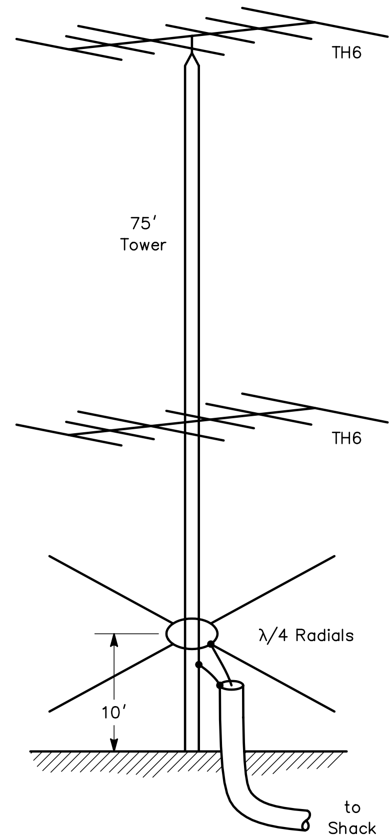

Fig 42—A 160-meter antenna using a 75-foot tower carrying stacked triband Yagis.

would be permissible to use RG-8 or RG-213 directly to the tuner. If you have a plentiful supply of low-loss 75-Ω CATV rigid coax, you can take another approach.

Make a quarter-wave (70 feet × 0.66 velocity factor = 46 feet) 37-Ω matching line by paralleling two pieces of RG-59 and connecting them between the feed point and a run of the rigid coax to the transmitter. The magic of quarter-wave matching transformers is that the input impedance (R_i) and output impedance (R_o) are related by:

$$Z_0^2 = R_i \times R_o \qquad \text{(Eq 2)}$$

For R_i = 17 Ω and Z_0 = 37 Ω, R_o = 80 Ω, an almost perfect match for the 75-Ω CATV coax. The resulting 1.6:1 SWR at the transmitter is good enough for CW operation without a tuner.

160-Meter Operation

On the 160-meter band, a resonant quarter-wavelength requires 130 feet of tower above the radials. That's a pretty tall order. Subtracting 40 feet of top loading for a 3-element 20-meter or TH7 antenna brings us to a more reasonable 90 feet above the radials. Additional top loading in the form of more antennas will reduce that even more.

Another installation, using stacked TH6s on a 75-foot tower, is shown in **Fig 42**. The radials are 10 feet off the ground.

PHASED VERTICALS

Two or more vertical antennas spaced apart can be operated as a single antenna system to obtain additional gain and a directional pattern. There is an extensive discussion of phased arrays in Chapter 8, Multielement Arrays. Much of the material in Chapter 8 is useful for low-band antennas.

The Half-Square Antenna

The *half-square* antenna is a very simple form of vertical two-element phased array that can be very effective on the low bands. The following section was originally presented in *The ARRL Antenna Compendium Vol 5*, by Rudy Severns, N6LF.

A simple modification to a standard dipole is to add two λ/4 vertical wires, one at each end, as shown in **Fig 43**. This makes 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).

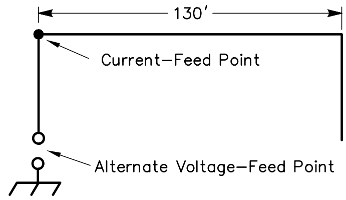

Fig 43—Typical 80-meter half-square, with λ/4-high vertical legs and a λ/2-long horizontal leg. The antenna may be fed at the bottom or at a corner. When fed at a corner, the feed point is a low-impedance, current-feed. When fed at the bottom of one of the wires against a small ground counterpoise, the feed point is a high-impedance, voltage-feed.

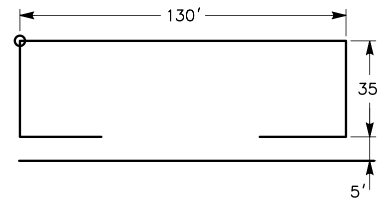

Fig 44—An 80-meter half-square configured for 40-foot high supports. The ends have been bent inward to reresonate the antenna. The performance is compromised surprisingly little.

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! They can vary 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 is 3.8 dB. 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 vertical sections. 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 44**. This compromises the performance surprisingly little.

It is helpful to compare the examples given in Figs 43 and 44 to dipoles at the same height. Two heights, 40 and 80 feet, and average, very good and sea water grounds, were used for this comparison. It is 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 long (≈ λ/8) vertical sections. The elevation-plane comparison between this antenna and a dipole of the same height is shown in **Fig 45**. 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 frontal 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.

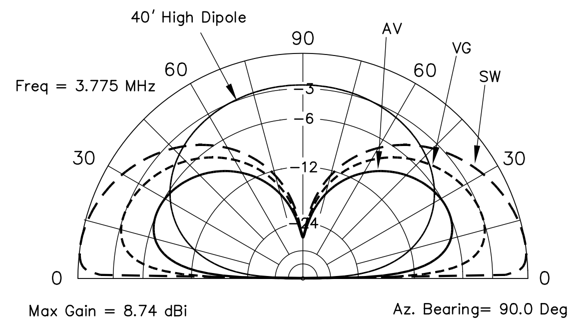

Fig 45—Comparison of 80-meter elevation response of 40-foot high, horizontally polarized dipole over average ground and a 40-foot high, vertically polarized half-square, over three types of ground: average (conductivity σ = 5 mS/m, dielectric constant ε = 13), very good (σ = 30 mS/m, ε = 20) and salt water (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. Even over average ground, the half-square outperforms the low dipole below about 32°.

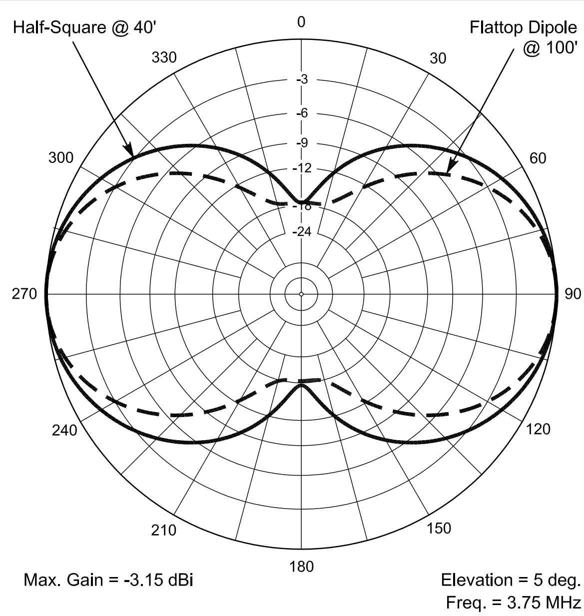

Fig 46—80-meter azimuth patterns for shortened half-square antenna (solid line) shown in Fig 44, compared with flattop dipole (dashed line) at 100 feet height. Average ground is assumed for these cases.

Fig 46 shows the azimuthal-plane pattern for the 80-meter half-square antenna in Fig 44, but this time compared with the response of a flattop horizontal dipole that is 100 feet high. These comparisons are for average ground and are for an elevation angle of 5°. 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.

Changing the Shape of the Half Square

Just how flexible is the shape? There are several common 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 47A**.

The effect on gain from this type of dimensional variation is given in **Table 4**. 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 keeping the top at a constant height. See Fig 47B. **Table 5** 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 47C, is given in **Table 6**. 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 47D and varying the top length also has only a small effect on the gain. While this is good news because it allows you dimension the antenna to fit different QTHs, not all distortions are so benign.

Table 4
Variation in Gain with Change in Horizontal Length, with Vertical Height Readjusted for Resonance (see Fig 47A)

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

Table 5
Variation in Gain with Change in Horizontal Length, with Vertical Length Readjusted for Resonance, but Horizontal Wire Kept at Constant Height (see Fig 47B)

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

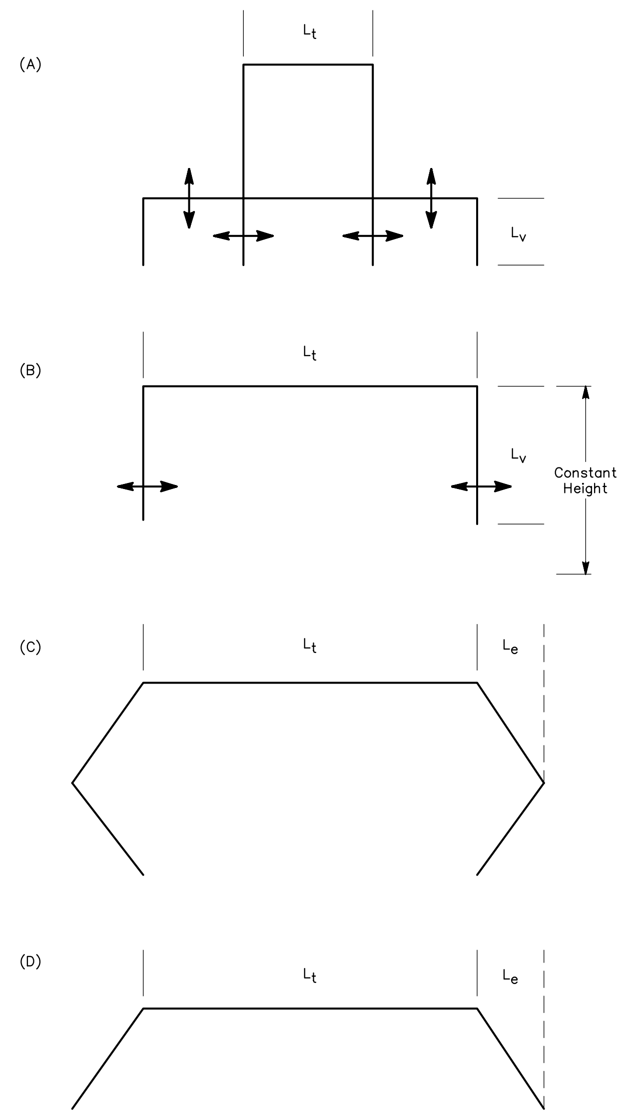

Fig 47—Varying the horizontal and vertical lengths of a half-square. At A, both the horizontal and vertical legs are varied, while keeping the antenna resonant. At B, the height of the horizontal wire is kept constant, while its length and that of the vertical legs is varied to keep the antenna resonant. 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 outward 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. At E, a "halfwave vertical dipole" (HVD) with the feed coax isolated with common-mode choke baluns to keep RF current off the coax shield.

Table 6

Gain for Half-Square Antenna, Where Ends Are Bent Into V-Shape (see Fig 47 C)

Height ⇒	*H=40 feet*	*H=40 feet*	*H=60 feet*	*H=60 feet*
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

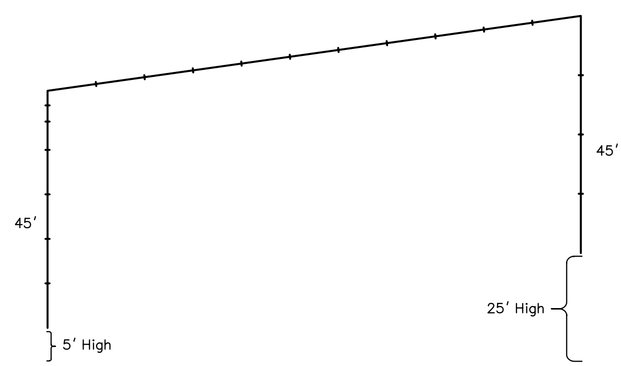

Fig 48—An asymmetrical distortion of the half-square antenna, where the bottom of one leg is purposely made 20 feet higher than the other. This type of distortion does affect the pattern!

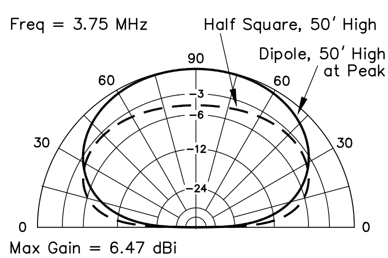

Fig 49—Elevation pattern for the asymmetrical half-square shown in Fig 48, compared with pattern for a 50-foot high dipole. This is over average ground, with a conductivity of 5 mS/m and a dielectric constant of 13. Note that the zenith-angle null has filled in and the peak gain is lower compared to conventional half-square shown in Fig 43 over the same kind of ground.

Suppose the two ends are not of the same height, as illustrated in **Fig 48**, where one end of the half-square is 20 feet higher than the other. The elevation-plane radiation pattern for this antenna is shown in **Fig 49** 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 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.

Half-Square 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 43.

For voltage feed at the bottom against ground, the impedance is very high, on the order of several thousand ohms. For current feed at a corner, the impedance is much lower and is usually close to 50 Ω. This is very convenient for direct feed with coax.

The half-square is a relatively high-Q antenna ($Q \approx 17$). **Fig 50** shows the SWR variation with frequency for this feed arrangement. An 80-meter dipole is not particularly wideband either, but 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 a voltage-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, 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.

When current-feed at a corner 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

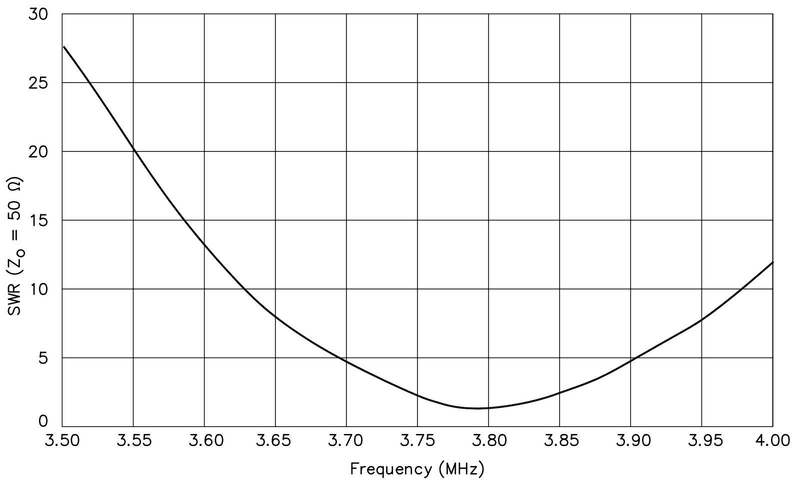

Fig 50—Variation of SWR with frequency for current-fed half-square antenna. The SWR bandwidth is quite narrow.

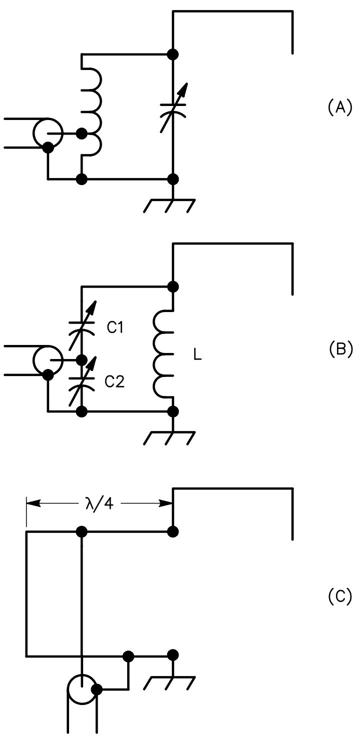

Fig 51—Typical matching networks used for voltage-feeding a half-square antenna.

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. The greatest effect is when the feed line length was near a multiple of λ/2. Such lengths should be avoided.

Of course, you may use a choke 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 51**, 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 51A or using a capacitive divider (Fig 51B). It is also possible to use a λ/4 transmission-line matching scheme, as shown in Fig 51C.

If the matching network shown in Fig 51B is used, typical values for the components would be: L = 15 µH, C1 = 125 pF and C2 = 855 pF. 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. The half-square antenna has a well-earned reputation for being narrow-band.

Short Vertical Antennas

On the lower frequencies it becomes increasingly difficult to accommodate a full λ/4 vertical height and full-sized λ/4 radials, or even worse, a full-sized half-wave vertical dipole (HVD). In fact, it is not absolutely necessary to make the antenna full size, whether it is an HVD, a grounded monopole antenna or a ground-plane type of monopole antenna. The size of the antenna can be reduced by half or even more and still retain high efficiency and the desired radiation pattern. This requires careful design, however. And if high efficiency is maintained, the operating bandwidth of the shortened antenna will be reduced because the shortened antenna will have a higher Q.

This translates into a more rapid increase of reactance away from resonance. The effect can be mitigated to some extent by using larger-diameter conductors. Even doing this however, bandwidth will be a problem, particularly on the 3.5 to 4-MHz band, which is very wide in proportion to the center frequency.

If we take a vertical monopole with a diameter of 2 inches and a frequency of 3.525 MHz and progressively shorten it from λ/4 in length, the feed-point impedance and efficiency (using an inductor at the base to tune out the capacitive reactance) will vary as shown in **Table 7**. In this example perfect ground and conductor are assumed. Real ground will not make a great difference in the impedance but will introduce ground loss, which will reduce the efficiency further. Conductor loss will also reduce efficiency. In general, higher R_R will result in better efficiency.

The important point of Table 7 is the drastic reduction in radiation resistance R_R as the antenna gets shorter. This combined with the increasing loss resistance of the inductor (R_L) used to tune out the increasing base reactance (X_C) reduces the efficiency.

BASE LOADING A SHORT VERTICAL ANTENNA

The base of the antenna is a convenient point at which to add a loading inductor, but it is usually not the lowest loss point at which an inductor, of a given Q, could be placed. There is an extensive discussion of the optimum location of the loading in a short vertical as a function of ground loss and inductor Q in Chapter 16 for mobile antennas, which by necessity are electrically and physically short. This information should be reviewed before using inductive loading.

On the accompanying CD-ROM is a copy of the program *MOBILE.EXE*. This is an excellent tool for designing short, inductively loaded antennas. In most cases, where top loading (discussed below) is not used, the optimum point is near or a little above the middle of the vertical section. Moving the loading coil from the base to the middle of the vertical antenna can make an important difference, increasing R_R and reducing the inductor loss. For example, in an antenna operating at 3.525 MHz, if we make L_1 = 34.9 feet (0.125 λ) the amount of loading inductor placed at the center is 25.2 µH. This resonates the antenna. In this configuration R_R will increase from 6.8 Ω (base loading) to 13.5 Ω (center loading). This substantially increases the efficiency of the antenna, depending on the ground loss and conductor resistances.

Instead of a lumped inductance being inserted at some point in the antenna, it is also possible to use "continuous loading," where the entire radiator is wound as a small diameter coil. The effect is to distribute the inductive loading all along the radiator. In this version of inductive loading the coil is the radiator. An example of a short vertical using this principle is given later in this chapter.

OTHER WAYS OF LOADING A SHORT ANTENNA FOR RESONANCE

Inductive loading is not the only, or even the best, way to compensate for reduced antenna height. *Capacitive top loading* can also be used as indicated in **Fig 52** to bring a vertical monopole to resonance. **Table 8** gives information on a shortened 3.525-MHz vertical using top loading. The vertical portion (L_1) is made from 2-inch tubing. The top loading is also 2-inch tubing extending across the top like a T. The length of the top loading T (±L_2) is adjusted to resonate the

Table 7
Effect of Shortening a Vertical Radiator Below λ/4 Using Inductive Base Loading.
Frequency is 3.525 MHz and for the Inductor Q_L = 200. Ground and conductor losses are omitted.

Length (feet)	*Length (λ)*	*R_R (Ω)*	*X_C (Ω)*	*R_L (Ω)*	*Efficiency (%)*	*Loss (dB)*
14	0.050	0.96	–761	3.8	20	–7.0
20.9	0.075	2.2	–533	2.7	45	–3.5
27.9	0.100	4.2	–395	2.0	68	–1.7
34.9	0.125	6.8	–298	1.5	82	–0.86
41.9	0.150	10.4	–220	1.1	90	–0.44
48.9	0.175	15.1	–153	0.77	95	–0.22
55.8	0.200	21.4	–92	0.46	98	–0.09
62.8	0.225	29.7	–34	0.17	99	–0.02

Table 8
Effect of Shortening a Vertical Using Top Loading

L_1 (feet)	*L_2 (feet)*	*Length (λ)*	*R_R (Ω)*
14.0	48.8	0.050	4.0
20.9	38.6	0.075	8.5
27.9	30.1	0.100	14.0
34.9	22.8	0.125	19.9
41.9	17.3	0.150	25.5
48.9	11.9	0.175	30.4
55.8	7.0	0.200	33.9
62.8	2.4	0.225	35.7

antenna. Again, the ground and the conductors are assumed to be perfect in Table 8.

For a given vertical height, resonating the antenna with top loading results in much higher radiation resistance R_R—2 to 4 times. In addition, the loss associated with the loading element will be smaller. The result is a more efficient antenna for low heights. A comparison of R_R for both capacitive top loading and inductive base loading is given in **Fig 53**. For heights below 0.15 λ the length of the top-loading elements becomes impractical but there are other, potentially more useful, top-loading schemes.

A multiwire system such as the one shown in **Fig 54** has more capacitance than the single-conductor arrangement, and thus does not need to be as long to resonate at a given frequency. This design does, however, require extra supports for the additional wires. Ideally, an arrangement of this sort should be in the form of a cross, but parallel wires separated by several feet give a considerable increase in capacitance

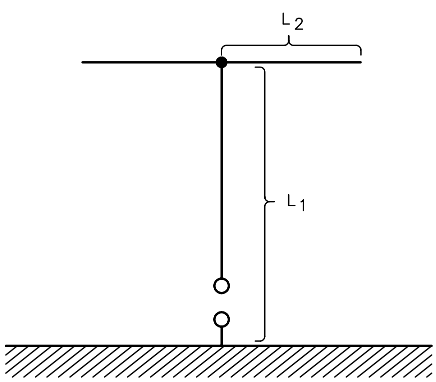

Fig 52—Horizontal wire used to top load a short vertical.

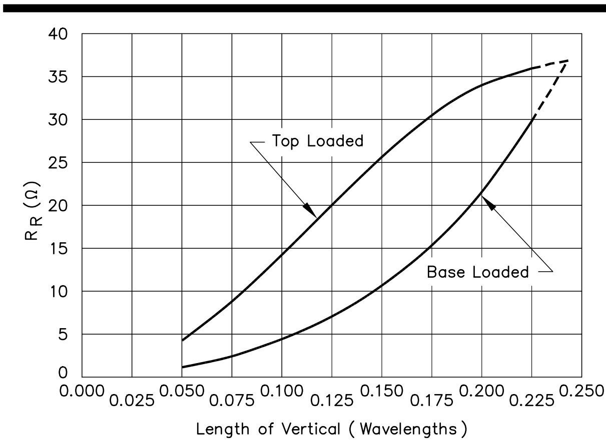

Fig 53—Comparison of top (capacitive) and base (inductive) loading for short verticals. Sufficient loading is used to resonate the antenna.

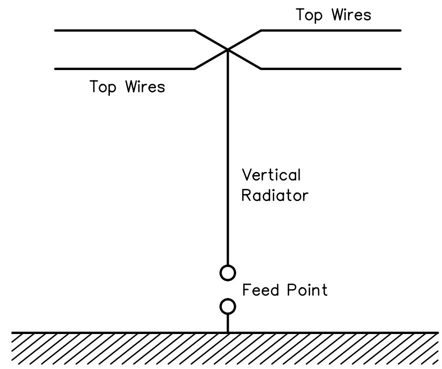

Fig 54—Multiple top wires can increase the effective capacitance substantially. This allows the use of shorter top wires to achieve resonance.

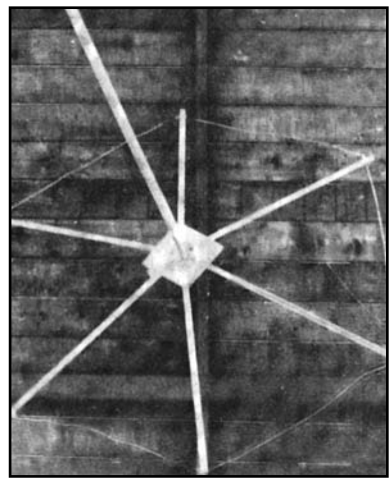

Fig 55—A close-up view of the capacitance hat for a 7-MHz vertical antenna. The ½-in. diameter radial arms terminate in a loop of copper wire.

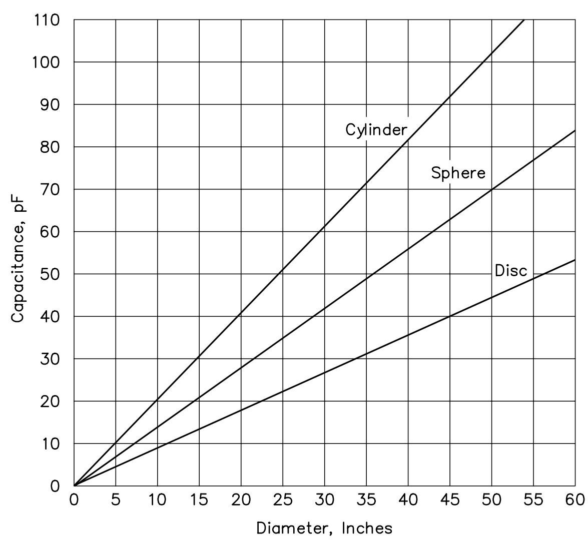

Fig 56—Capacitance of sphere, disc and cylinder as a function of their diameters. The cylinder length is assumed equal to its diameter.

over a single wire.

The top loading can be supplied by a variety of metallic structures large enough to have the necessary self-capacitance. For example, as shown in **Fig 55**, a multi-spoked structure with the ends connected together can be used. One simple way to make a capacitance hat is to take four to six 8-foot fiberglass CB mobile whips, arrange them like spokes in a wagon wheel and connect the ends with a peripheral wire. This arrangement will produce a 16-foot diameter hat that is economical and very durable, even when loaded with ice. Practically any sufficiently large metallic structure can be used for this purpose, but simple geometric forms such as the sphere, cylinder and disc are preferred because of the relative ease with which their capacitance can be calculated.

The capacitance of three geometric forms can be estimated from the curves of **Fig 56** as a function of their size. For the cylinder, the length is specified equal to the diameter. The sphere, disc and cylinder can be constructed from sheet metal, if such construction is feasible, but the capacitance will be practically the same in each if a "skeleton" type of construction with screening or networks of wire or tubing are used.

Finding Capacitance Hat Size

The required size of a capacitance hat may be determined from the following procedure. The information in this section is based on a September 1978 *QST* article by Walter Schulz, K3OQF. The physical length of a shortened antenna can be found from:

$$h_{inches} = \frac{11808}{F_{MHz}} \quad \text{(Eq 3)}$$

where h = length in inches.

Thus, using an example of 7 MHz and a shortened length of 0.167 λ, h = 11808/7 × 0.167 = 282 inches, equivalent to 23.48 feet.

Consider the vertical radiator as an open-ended transmission line, so the impedance and top loading may be determined. The characteristic impedance of a vertical antenna can be found from

$$Z_0 = 60 \left(\ln\left(\frac{4h}{d}\right) - 1 \right) \quad \text{(Eq 4)}$$

where

ln = natural logarithm

h = length (height) of vertical radiator in inches (as above)

d = diameter of radiator in inches

The vertical radiator for this example has a diameter of 1 inch. Thus, for this example,

$$Z_0 = 60 \left(\ln\left(\frac{4 \times 281}{1}\right) - 1 \right) = 361\ \Omega$$

The capacitive reactance required for the amount of top loading can be found from

$$Z_0 = 60\ \ln\left(\frac{4 \times 281}{1}\right) - 1 = 361\ \Omega \quad \text{(Eq 5)}$$

where

X = capacitive reactance, ohms

Z_0 = characteristic impedance of antenna (from Eq 4)

θ = amount of electrical loading, degrees.

This value for a 30° hat is 361/tan 30° = 625 Ω. This capacitive reactance may be converted to capacitance with the following equation,

$$C = \frac{10^6}{2\pi f X_C} \quad \text{(Eq 6)}$$

where

C = capacitance in pF

f = frequency, MHz

X_C = capacitive reactance, ohms (from above).

For this example, the required C = $10^6/(2\,\pi \times 7 \times 625)$ = 36.4 pF, which may be rounded to 36 pF. A disc capacitor is used in this example. The appropriate diameter for 36 pF of hat capacitance can be found from Fig 56. The disc diameter that yields 36 pF of capacitance is 40 inches.

The skeleton disc shown in Fig 55 is fashioned into a wagonwheel configuration. Six 20-inch lengths of ½-inch OD aluminum tubing are used as spokes. Each is connected to the hub at equidistant intervals. The outer ends of the spokes terminate in a loop made of #14 copper wire. Note that the loop increases the hat capacitance slightly, making a better approximation of a solid disc. The addition of this hat at the top of a 23.4-foot radiator makes it quarter-wave resonant at 7 MHz.

After construction, some slight adjustment in the radiator length or the hat size may be required if resonance at a specific frequency is desired. From Fig 53, the radiation resistance of a 0.167-λ high radiator is seen to be about 13 Ω without top loading. With top loading Rr ≈ 25 Ω or almost double.

THE COMPACT VERTICAL DIPOLE

A variation on the HVD (half-wave vertical dipole) theme is the *compact vertical dipole*, or CVD. The CVD uses capacitance-hat loading on each end of a shortened vertical radiator, as shown in **Fig 57C**. Some call this "top hat" and "bottom hat" loading. Les Moxon, G6XN, called this method of loading a shortened antenna simply "end loading." The vertical wire for his 40-meter CVD is 25 feet high, with 15-foot long horizontal loading wires on each side, top and bottom.

K8CH Compact Vertical Dipole

The top loading wires needn't be perpendicular to the vertical radiator, although that is convenient if you construct the antenna from aluminum tubing. K8CH described a wire 30-meter CVD in the 2006 Edition of *The ARRL Handbook.* This used #14 wire throughout, with sloping top loading wires. It was designed to be suspended from a tree at least

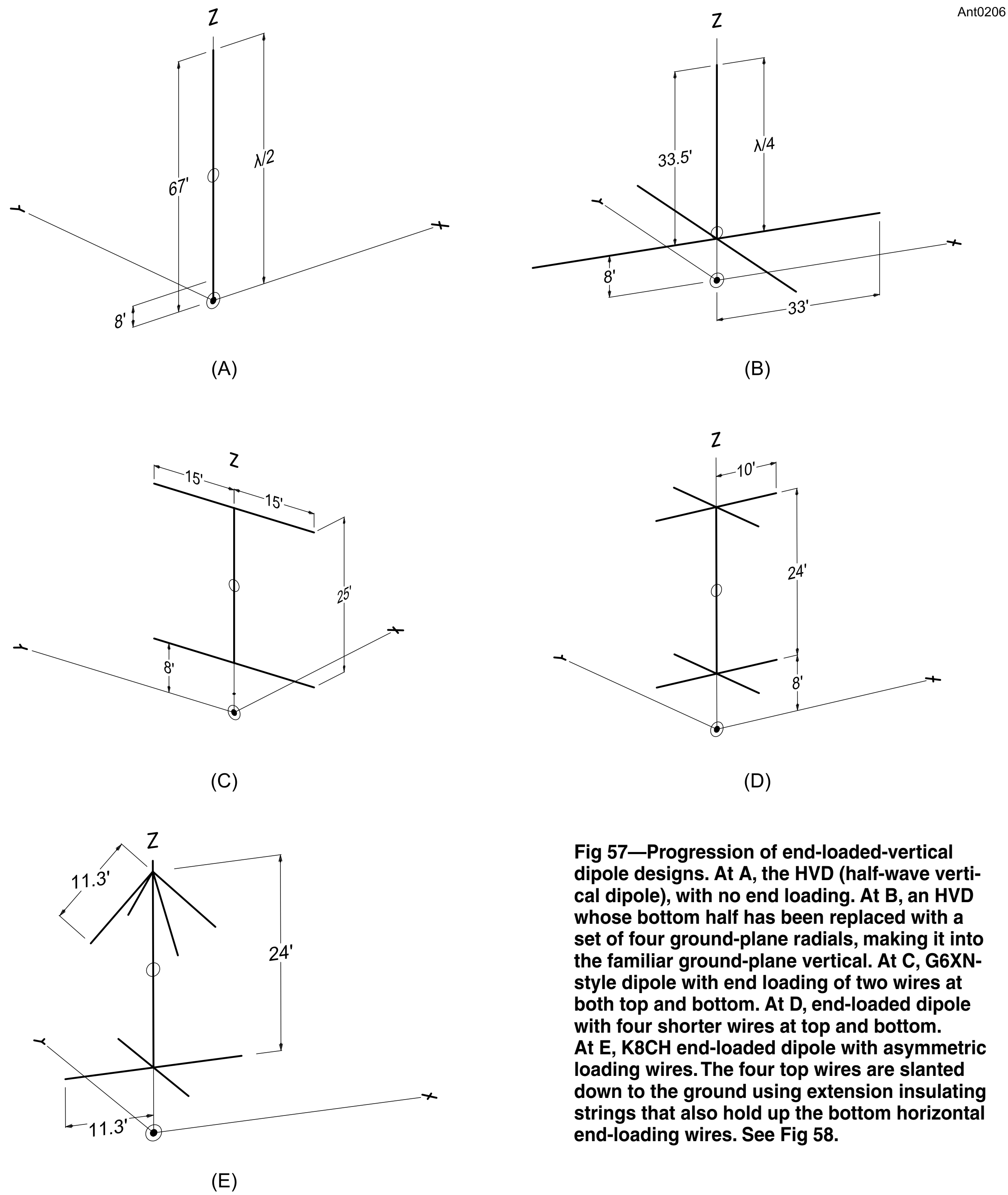

Fig 57—Progression of end-loaded-vertical dipole designs. At A, the HVD (half-wave vertical dipole), with no end loading. At B, an HVD whose bottom half has been replaced with a set of four ground-plane radials, making it into the familiar ground-plane vertical. At C, G6XN-style dipole with end loading of two wires at both top and bottom. At D, end-loaded dipole with four shorter wires at top and bottom. At E, K8CH end-loaded dipole with asymmetric loading wires. The four top wires are slanted down to the ground using extension insulating strings that also hold up the bottom horizontal end-loading wires. See Fig 58.

32 feet high to keep all wires 8 feet or more above humans and animals. The vertical radiating wire is 24 feet long, and the eight top and bottom end-loading wires are all 5 feet 9 inches long. See Fig 57E and **Table 9**, CVD 1.

The top loading wires slant at an angle of 45º down to the ground, using insulating strings that also support the ends of the bottom loading wires, holding them out so that they are horizontal. See **Fig 58**. There is a small loss of gain because of the "umbrella" shape of the top loading wires, and the 2:1 SWR bandwidth is diminished slightly from the horizontal case. This isn't a problem on a narrow band like 30 meters.

A 40-meter version of this antenna, CVD 6, also uses a 24-foot long vertical radiator, 8 feet high at its bottom. It uses 11.3-foot long radial wires made of #14 wire, again with the top four slanted down at 45º. This CVD has a 2:1

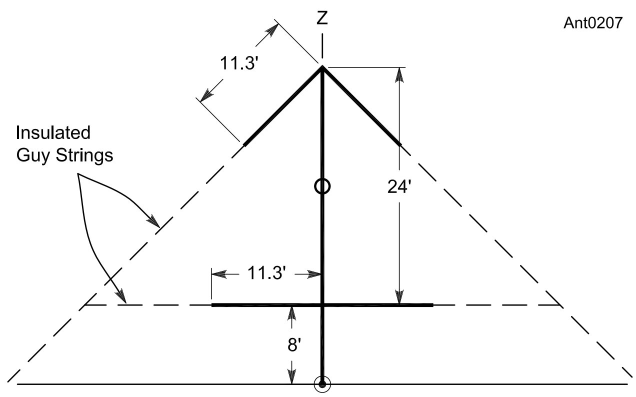

Fig 58—Layout of CVD made using #14 wire suspended from a tree branch.

SWR bandwidth of 250 kHz. It is directly fed with 50-Ω coax with ferrite-core common-mode choke baluns in the middle of the vertical radiator. An additional choke balun is used where the coax reaches ground level in order to knock down common-mode currents that might otherwise radiate onto the coax shield.

You should note the comparison of 40-meter ground-plane vertical antennas in Table 9. GP 1 is for horizontal radials that are 8 feet off the ground, while GP 2 has its radials only 2 feet high. There is some loss in gain because of the proximity of the lossy ground. The 40-meter CVD 1 and CVD 2 cases illustrate the same effect of being close to the lossy ground.

Some of the cases in Table 9 require Center Load coils to bring the antenna to resonance. Where the loading coil inductance is equal to the "Hairpin Coil" inductance, the loading coil also serves as a hairpin matching coil. Where the amount of Hairpin Coil inductance is less than the Load Coil inductance, a match is achieved by tapping the Center Load Coil symmetrically out from the center.

80-Meter CVD

The size of a CVD becomes a real challenge on 80 meters, requiring either very tall support structures or multiple loading methods to keep the vertical radiator to a reasonable length. The CVD 2 design in Table 9 shows a K8CH-style CVD wire antenna whose vertical radiator is 46.5 feet long. It requires a 54.5-foot high tree to keep the bottom end of the vertical radiator 8 feet above ground for safety. Compare this to an HVD that requires a 143-foot support of some sort to keep it 8 feet off the ground at the bottom. The CVD 2 sacrifices some 0.7 dB in gain for this difference in size, and about 75 kHz in 2:1 SWR bandwidth.

The CVD 2 would require retuning when going from

Table 9
Variations on a Vertical Center-Fed Dipole

Name	*Style Fig 57*	*Vertical Length feet*	*Spoke Length feet*	*Min. Ht feet*	*Max. Gain dBi*	*2:1 SWR kHz*	*Hairpin Coil µH*	*Center Load µH*
20 Meters								
GP	B	17.53	16.53	8	0.29	400	—	—
CVD 1	C	13	7.57	8	0.12	625	—	—
CVD 2	D	12	5.1	8	0.00	550	0.68	0.68
CVD 3	E	12.15	5.6	8	–0.01	450	0.5	0.5
30 Meters								
GP	B	24.54	23.14	8	0.04	400	—	—
CVD 1	E	24	5.33	8	–0.2	500	—	—
CVD 2	E	17	7.60	8	–0.36	400	0.82	0.82
40 Meters								
HVD	A	66	—	8	0.13	450	—	—
GP 1	B	35	33	8	–0.12	325	—	—
GP 2	B	34.5	33	2	–0.37	400	—	—
CVD 1	C	25	15	8	–0.42	450	—	—
CVD 2	C	24	15	2	–1.09	400	—	—
CVD 3	D	24	10	8	–0.55	425	—	0.25
CVD 4	D	24	5	8	–0.85	225	—	8.7
CVD 5	D	16	8	8	–1.18	175	0.94	6.8
CVD 6	E	24	11.3	8	–0.59	250	—	—
80 Meters								
HVD	A	135	—	8	0.19	225	—	—
GP	B	65.5	61	8	0.11	200	—	—
CVD 1	C	48.3	30	8	–0.27	200	—	—
CVD 2	E	46.5	21.9	8	–0.50	150	—	—

CW to phone, probably by changing the length of the four bottom horizontal wires equally.

LINEAR LOADING

Another alternative to inductive loading is *linear loading*. This little-understood method of shortening radiators can be applied to almost any antenna configuration—including parasitic arrays. Although commercial antenna manufacturers make use of linear loading in their HF antennas, relatively few hams have used it in their own designs. Linear loading can be used to advantage in many antennas because it introduces relatively little loss, does not degrade directivity patterns, and has low enough Q to allow reasonably good bandwidth. Some examples of linear-loaded antennas are shown in **Fig 59**.

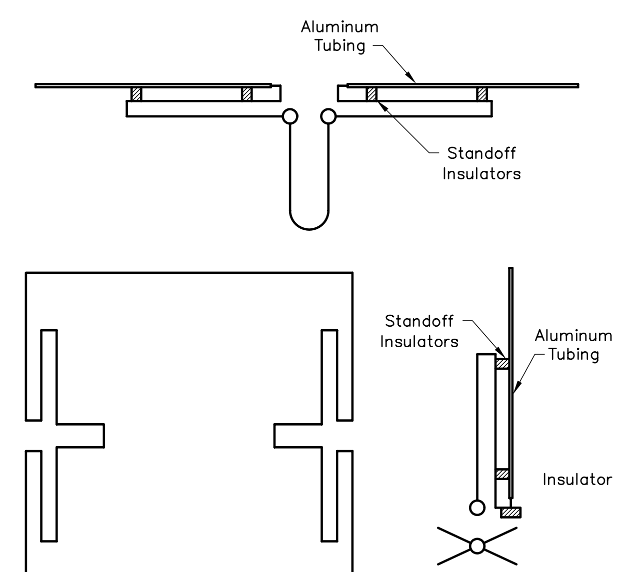

Fig 59—Some examples of linear loading. The small circles indicate the feed points of the antennas.

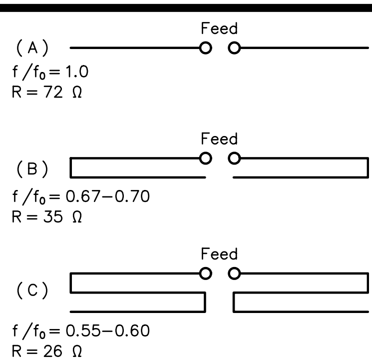

Fig 60—Wire dipole antennas. The ratio f/f_0 is the measured resonant frequency divided by frequency f_0 of a standard dipole of same length. R is radiation resistance in ohms. At A, standard single-wire dipole. At B, two-wire linear-loaded dipole, similar to folded dipole except that side opposite feed line is open. At C, three-wire linear-loaded dipole.

Since the dimensions and spacing of linear-loading devices vary greatly from one antenna installation to another, the best way to employ this technique is to try a length of conductor 10% to 20% longer than the difference between the shortened antenna and the full-size dimension for the linear-loading device. Then use the "cut-and-try" method, varying both the spacing and length of the loading device to optimize the match. A hairpin at the feed point can be useful in achieving a 1:1 SWR at resonance.

Linear-Loaded Short Wire Antennas

More detail on linear loading is provided in this section, which was originally presented in *The ARRL Antenna Compendium Vol 5* by John Stanford, NNØF. Linear loading can significantly reduce the required length for resonant antennas. For example, it is easy to make a resonant antenna that is as much as 30 to 40% shorter than an ordinary dipole for a given band. The shorter overall lengths come from bending back some of the wire. The increased self-coupling lowers the resonant frequency. These ideas are applicable to short antennas for restricted space or portable use.

Experiments

The results of the measurements are shown in **Fig 60** and are also consistent with values given by Rashed and Tai from an earlier paper. This shows several simple wire antenna configurations, with resonant frequencies and impedance (radiation resistance). The reference dipole has a resonant frequency f_0 and resistance R = 72 Ω. The f/f_0 values give the effective reduced frequency obtained with the linear loading in each case. For example, the two-wire linear-loaded dipole has its resonant frequency lowered to about 0.67 to 0.70 that of the simple reference dipole of the same length.

The three-wire linear-loaded dipole has its frequency reduced to 0.55 to 0.60 of the simple dipole of the same length. As you will see later, these values will vary with conductor diameter and spacing.

The two-wire linear-loaded dipole (Fig 60B) looks almost like a folded dipole but, unlike a folded dipole, it is open in the middle of the side opposite where the feed line is attached. Measurements show that this antenna structure has a resonant frequency lowered to about two-thirds that of the reference dipole, and R equal to about 35 Ω. A three-wire linear-loaded dipole (Fig 60C) has even lower resonant frequency and R about 25 to 30 Ω.

Linear-loaded monopoles (one half of the dipoles in Fig 60) working against a radial ground plane have similar resonant frequencies, but with only half the radiation resistance shown for the dipoles.

A Ladder-Line Linear-Loaded Dipole

Based on these results, NNØF next constructed a linear loaded dipole as in Fig 60B, using 24 feet of 1-inch ladder line (the black, 450-Ω plastic kind widely available) for the dipole length. He hung the system from a tree using nylon fishing line, about 4 feet from the tree at the top, and about 8 feet from the ground on the bottom end. It was slanted at about a 60° angle to the ground. This antenna resonated at 12.8 MHz and had a measured resistance of about 35 Ω. After the resonance measurements, he fed it with 1-inch ladder open-wire line (a total of about 100 feet to the shack).

For brevity, this is called a vertical *LLSD* (linear-loaded short dipole). A tuner resonated the system nicely on 20 and 30 meters. On these bands the performance of the vertical LLSD seemed comparable to his 120-foot long, horizontal center-fed Zepp, 30 feet above ground. In some directions where the horizontal, all-band Zepp has nulls, such as toward Siberia, the vertical LLSD was definitely superior. This system also resonates on 17 and 40 meters. However, from listening to various signals, NNØF had the impression that this length LLSD is not as good on 17 and 40 meters as the horizontal 120-foot antenna.

Using Capacitance End Hats

He also experimented with an even shorter resonant length by trying an LLSD with capacitance end-hats. The hats, as expected, increased the radiation resistance and lowered the resonant frequency. Six-foot long, single-wire hats were used on each end of the previous 24-foot LLSD, as shown in **Fig 61**. The antenna was supported in the same way as the previous vertical dipole, but the bottom-end hat wire was only inches from the grass. This system resonated at 10.6 MHz with a measured resistance of 50 Ω.

If the dipole section were lengthened slightly, by a foot or so, to about 25 feet, it should hit the 10.1-MHz band and be a good match for 50-Ω coax. It would be suitable for a restricted space, shortened 30-meter antenna. Note that this antenna is only about half the length of a conventional 30-meter dipole, needs no tuner, and has no losses due to traps. It does have the loss of the extra wire, but this is essentially negligible.

Any of the linear-loaded dipole antennas can be mounted either horizontally or vertically. The vertical version can be used for longer skip contacts—beyond 600 miles or so—unless you have rather tall supports for horizontal antennas to give a low elevation angle. Using different diameter conductors in linear-loaded antenna configurations yields different results, depending on whether the larger or small diameter conductor is fed. NNØF experimented with a vertical ground-plane antenna using a 10-foot piece of electrical conduit pipe (⅝ inch OD) and #12 copper house wire.

Fig 62 shows the configuration. The radial ground system was buried a couple of inches under the soil and is not shown. Note that this is not a folded monopole, which would have either A or B grounded.

The two conductors were separated by 2 inches, using plastic spreaders held onto the pipe by stainless-steel hose clamps obtained from the local hardware store. Hose clamps intertwined at right angles were also used to clamp the pipe on electric fence stand-off insulators on a short 2×4 post set vertically in the ground.

The two different diameter conductors make the antenna characteristics change, depending on how they are configured. With the antenna bridge connected to the larger diameter conductor (point A in Fig 62), and point B unconnected, the system resonated at 16.8 MHz and had R = 35 Ω. With the bridge at B (the smaller conductor), and point A left unconnected, the resonance lowered to 12.4 MHz and R was found to be about 24 Ω.

The resonant frequency of the system in Fig 62 can be adjusted by changing the overall height, or for increasing the frequency, by reducing the length of the wire. Note that a 3.8-MHz resonant ground plane can be made with height only about half that of the usual 67 feet required, if the smaller conductor is fed (point B in Fig 62). In this case, the pipe would be left unconnected electrically. The lengths given above can be scaled to determine a first-try attempt for your favorite band. Resonant lengths will, however, depend on the conductor diameters and spacing.

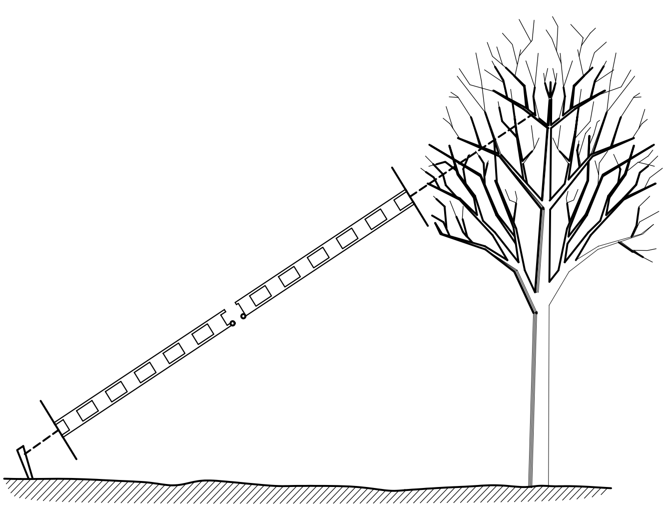

Fig 61—Two-wire linear-loaded dipole with capacitance end hats. Main dipole length was constructed from 24 feet of "windowed" ladder line. The end-hat elements were stiff wires 6 feet long. The antenna was strung at about a 60° angle from a tree limb using monofilament fishing line. Measured resonant frequency and radiation resistance were 10.6 MHz and 50 Ω.

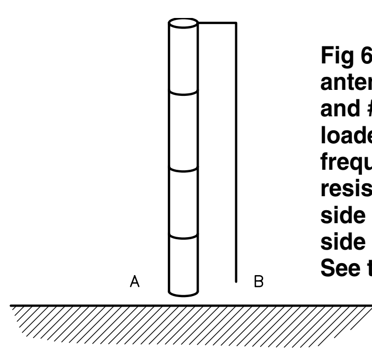

Fig 62—Vertical ground-plane antenna with a 10-foot pipe and #12 wire as the linear-loaded element. Resonant frequency and radiation resistance depend on which side (A or B) is fed. The other side (B or A) is *not* grounded. See text for details.

The same ideas hold for a dipole, except that the lengths should be doubled from those of the ground plane in Fig 62. The resistance will be twice that of the ground plane. Say, how about a shortened 40-meter horizontal beam to enhance your signal?!

COMBINED LOADING

As an antenna is shortened further the size of the top loading device will become larger and at some point will be impractical. In this situation inductive loading, usually placed directly between the capacitance “hat” and the top of the antenna, can be added to resonate the antenna. An alternative would be to use linear loading in place of inductive loading. The previous section contained an example of end loading combined with linear loading.

SHORTENING THE RADIALS

Very often the space required by full-length radials is simply not available. Like the vertical portion of the antenna, the radials can also be shortened and loaded in very much the same way. An example of end loaded radials is given in **Fig 63A**. Radials half the usual length can be used with little reduction in efficiency but, as in the case of top loading, the antenna Q will be higher and the bandwidth reduced. As shown in Fig 63B**,** inductive loading can also be used. As long as they are not made too short (down to 0.1λ) loaded radials can be efficient—with careful design.

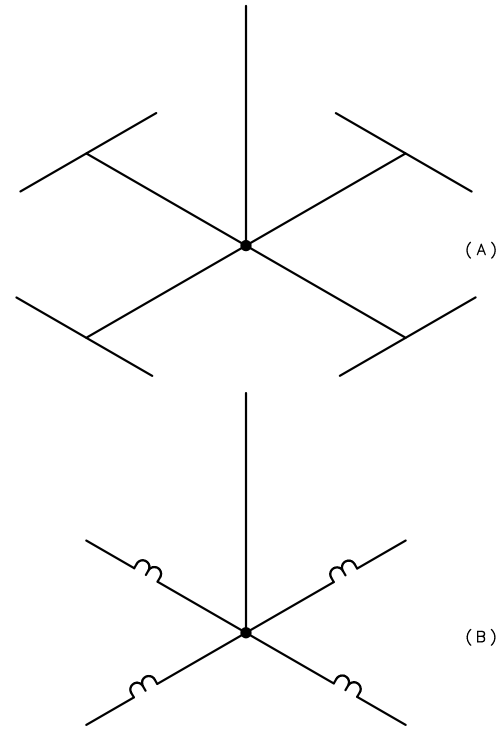

Fig 63—Radials may be shortened by using either capacitive (A) or inductive (B) loading. In extreme cases both may be used but the operating bandwidth will be limited.

GENERAL RULES

The steps in designing an efficient short vertical antenna system are:

- Make the vertical section as long as possible.
- Make the diameter of the vertical section as large as possible. Tubing or a cage of smaller wires will work well.
- Provide as much top and/or bottom loading as possible.
- If the top/bottom loading is insufficient, resonate the antenna with a high-Q inductor placed between the hat and the top of the antenna.
- For buried-ground systems, use as many radials (> 0.2 λ) as possible. 40 or more is best.
- If an elevated ground plane is used, use 4 to 8 radials, 5 or more feet above ground.
- If shortened radials must be used then capacitive loading is preferable to inductive loading.

EXAMPLES OF SHORT VERTICALS

A 6-Foot-High 7-MHz Vertical Antenna

Figs 64 through 67 give details for building short, effective vertical quarter-wavelength radiators. This information was originally presented by Jerry Sevick, W2FMI.

A short vertical antenna, properly designed and installed, approaches the efficiency of a full-size resonant quarter-wave antenna. Even a 6-foot vertical on 7 MHz can produce an exceptional signal. Theory tells us that this should be possible, but the practical achievement of such a result requires an understanding of the problems of ground losses, loading, and impedance matching.

The key to success with shortened vertical antennas lies in the efficiency of the ground system with which the antenna is used. A system of at least 60 radial wires is rec-

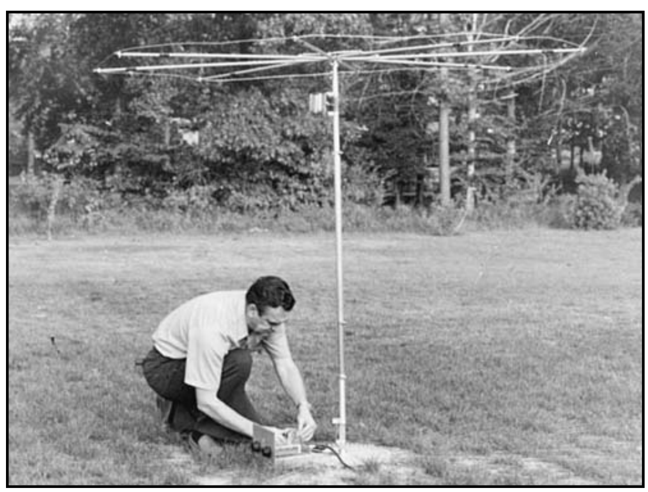

Fig 64—Jerry Sevick, W2FMI, adjusts the 6-foot high, 40-meter vertical.

ommended for best results, although the builder may elect to reduce the number at the expense of some performance. The radials can be tensioned and pinned at the far ends to permit on-the-ground installation, which will enable the amateur to mow the lawn without the wires becoming entangled in the mower blades. Alternatively, the wires can be buried in the ground, where they will not be visible. There is nothing critical about the wire size for the radials. Radials made of 28, 22, or even 16-gauge wire, will provide the same results. The radials should be at least 0.2 λ long (27 feet or greater on 7 MHz).

A top hat is formed as illustrated in **Fig 65**. The diameter is 7 feet, and a continuous length of wire is connected to the spokes around the outer circumference of the wheel. A loading coil consisting of 14 turns of B&W 3029 Miniductor stock (2½-inch dia, 6 TPI, #12 wire) is installed 6 inches below the top hat (see Fig 65). This antenna exhibits a feed-point impedance of 3.5 Ω at 7.21 MHz. For operation above or below this frequency, the number of coil turns must be decreased or increased, respectively. Matching is accomplished by increasing the feed-point impedance to 14 Ω through addition of a 4:1-transformer, then matching 14 Ω to 50 Ω (feeder impedance) by means of a pi network. The 2:1 SWR bandwidth for this antenna is approximately 100 kHz.

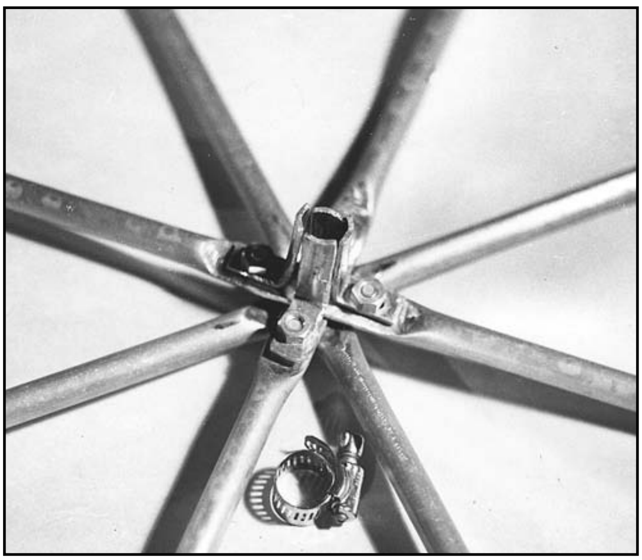

Fig 65—Construction details for the top hat. For a diameter of 7 feet, ½-in. aluminum tubing is used. The hose clamp is made of stainless steel and is available at Sears. The rest of the hardware is aluminum.

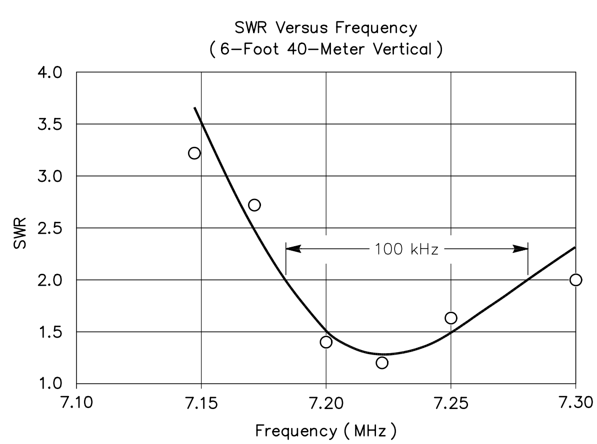

Fig 66—Standing-wave ratio of the 6-foot vertical using a 7-foot top hat and 14 turns of loading 6 inches below the top hat.

More than 200 contacts with the 6-foot antenna have indicated the efficiency and capability of a short vertical. Invariably at distances greater than 500 or 600 miles, the short vertical yields excellent signals. Similar antennas can be scaled and constructed for bands other than 7 MHz. The 7-foot-diameter-top hat was tried on a 3.5-MHz vertical, with an antenna height of 22 feet. The loading coil had 24 turns and was placed 2 feet below the top hat. On-the-air results duplicated those on 40-meters. The bandwidth was 65 kHz.

Short verticals such as these have the ability to radiate and receive almost as well as a full-size quarter-wave. Trade-offs are in lowered input impedances and bandwidths. However, with a good radial system and a proper design, these trade-offs can be made entirely acceptable.

Short Continuously Loaded Verticals

While there is the option of using lumped inductance to achieve resonance in a short antenna, the antenna can also be helically wound to provide the required inductance. This is shown in **Fig 68**. Shortened quarter-wavelength vertical antennas can be made by forming a helix on a long cylindrical insulator. The diameter of the helix must be small in terms of λ to prevent the antenna from radiating in the axial mode.

Acceptable form diameters for HF-band operation are from 1 inch to 10 inches when the practical aspects of antenna construction are considered. Insulating poles of fiberglass, PVC tubing, treated bamboo or wood, or phenolic are suitable for use in building helically wound radiators. If wood or bamboo is used the builder should treat the material with at least two coats of exterior spar varnish prior to winding the antenna element. The completed structure should be given two more coats of varnish, regardless of the material used for the coil form. Application of the varnish will help weatherproof the antenna and prevent the coil turns from changing position.

No strict rule has been established concerning how short a helically wound vertical can be before a significant drop in performance is experienced. Generally, one should use the greatest amount of length consistent with available space. A guideline might be to maintain an element length of 0.05 wavelength or more for antennas which are electrically a quarter wavelength long. Thus, use 13 feet or more of stock for an 80-meter antenna, 7 feet for 40 meters, and so on.

A quarter-wavelength helically wound vertical can be used in the same manner as a full-size vertical. That is, it can be worked against an above-ground wire radial system (four or more radials), or it can be ground-mounted with

Fig 67—Base of the vertical antenna showing the 60 radial wires. The aluminum disc is 15 inches in diameter and ¼ inches thick. Sixty tapped holes for ¼-20 aluminum hex-head bolts form the outer ring and 20 form the inner ring. The inner bolts were used for performance comparisons with more than 60 radials. The insulator is polystyrene material (phenolic or Plexiglas suitable) with a 1-inch diameter. Also shown is the impedance bridge used for measuring input resistance.

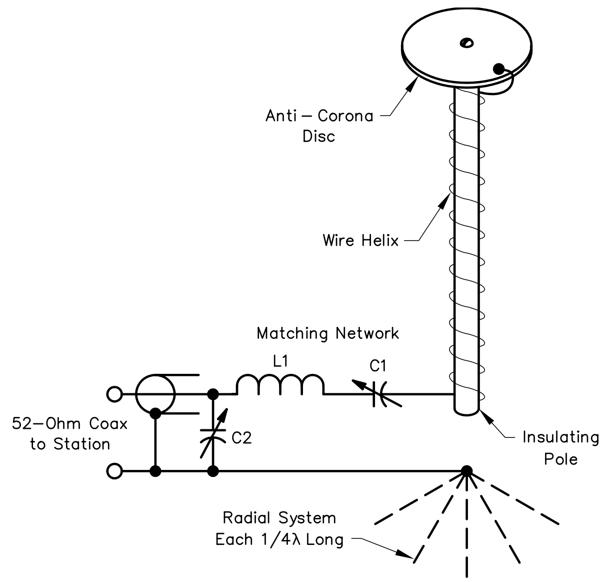

Fig 68—Helically wound ground-plane vertical. Performance from this type of antenna is comparable to that of many full-size λ/4 vertical antennas. The major design trade-off is usable bandwidth. All shortened antennas of this variety are narrow-band devices. At 7 MHz, in the example illustrated here, the bandwidth between the 2:1 SWR points will be on the order of 50 kHz, half that amount on 80 meters, and twice that amount on 20 meters. Therefore, the antenna should be adjusted for operation in the center of the frequency band of interest.

radials buried or lying on the ground. Some operators have reported good results when using antennas of this kind with four helically wound radials cut for resonance at the operating frequency. The latter technique should capture the attention of those persons who must use indoor antennas.

Winding Information

There is no hard-and-fast formula for determining the amount of wire needed to establish resonance in a helical antenna. The relationship between the length of wire needed for resonance and a full quarter wave at the desired frequency depends on several factors. Some of these are wire size, diameter of the turns, and the dielectric properties of the form material, to name a few. Experience has indicated that a section of wire approximately one half wavelength long, wound on an insulating form with a linear pitch (equal spacing between turns) will come close to yielding a resonant quarter wavelength. Therefore, an antenna for use on 160 meters would require approximately 260 feet of wire, spirally wound on the support.

No specific rule exists concerning the size or type of wire one should use in making a helix. Larger wire sizes are, of course, preferable in the interest of minimizing I^2R losses in the system. For power levels up to 1000 W it is wise to use a wire size of #16 or larger. Aluminum clothesline wire is suitable for use in systems where the spacing between turns is greater than the wire diameter. Antennas requiring close-spaced turns can be made from enameled magnet wire or #14 vinyl jacketed, single-conductor house wiring stock. Every effort should be made to keep the turn spacing as large as is practical to maximize efficiency.

A short rod or metal disc should be made for the top or high-impedance end of the vertical. This is a necessary part of the installation to assure reduction in antenna Q. This broadens the bandwidth of the system and helps prevent extremely high amounts of RF voltage from being developed at the top of the radiator. (Some helical antennas act like Tesla coils when used with high-power transmitters, and can actually catch fire at the high-impedance end when a stub or disc is not used.) Since the Q-lowering device exhibits some additional capacitance in the system, it must be in place before the antenna is tuned.

Tuning and Matching

Once the element is wound it should be mounted where it will be used, with the ground system installed. The feed end of the radiator can be connected temporarily to the ground system. Use a dip meter to check the antenna for resonance by coupling the dipper to the last few turns near the ground end of the radiator. Add or remove turns until the vertical is resonant at the desired operating frequency.

It is impossible to predict the absolute value of feed impedance for a helically wound vertical. The value will depend upon the length and diameter of the element, the ground system used with the antenna, and the size of the disc or stub atop the radiator. Generally speaking, the radiation resistance will be very low—approximately 3 to 10 Ω. An L network of the kind shown in Fig 68 can be used to increase the impedance to 50 Ω. The Q_L (loaded Q) of the network inductors is low to provide reasonable bandwidth, consistent with the bandwidth of the antenna. Network values for other operating bands and frequencies can be determined by using the reactance values listed below. The design center for the network is based on a radiation resistance of 5 Ω. If the exact feed impedance is known, the following equations can be used to determine precise component values for the matching network. (See Chapter 25, Coupling the Transmitter to the Line, for additional information on L-network matching.)

XA QRL (Eq 7)

$$X_{C2} = 50\sqrt{\frac{R_L}{50 - R_L}} \qquad \text{(Eq 8)}$$

$$X_{L1} = X_{C1} + \frac{R_L 50}{X_{C2}} \qquad \text{(Eq 9)}$$

where

X_{C1} = capacitive reactance of C1
X_{C2} = capacitive reactance of C2
X_{L1} = inductive reactance of L1
Q = loaded Q of network
R_L = radiation resistance of antenna

Example: Find the network constants for a helical antenna with a feed impedance of 5 Ω at 7 MHz, Q = 3:

$$X_{C1} = 3 \times 5 = 15$$

$$X_{C2} = \sqrt{\frac{5}{50 - 5}} = 16.666$$

$$X_{L1} = 15 + \frac{250}{16.666} = 30$$

Therefore, C1 = 1500 pF, C2 = 1350 pF, and L1 = 0.7 µH. The capacitors can be made from parallel or series combinations of transmitting micas. L_1 can be a few turns of large Miniductor stock. At RF power levels of 100 W or less, large compression trimmers can be used at C1 and C2 because the maximum RMS voltage at 100 W (across 50 Ω) will be 50 V. At, say, 800 W there will be approximately 220 V RMS developed across 50 Ω. This suggests the use of small transmitting variables at C1 and C2, possibly connected in parallel with fixed values of capacitance to constitute the required amount of capacitance for the network.

By making some part of the network variable, it will be possible to adjust the circuit for an SWR of 1:1 without knowing precisely what the antenna feed impedance is. Actually, C1 is not required as part of the matching network. It is included here to bring the necessary value for L1 into a practical range.

Fig 68 illustrates the practical form a typical helically wound ground-plane vertical might take. Performance from this type antenna is comparable to that of many full-size quarter-wavelength vertical antennas. The major design trade-off is in usable bandwidth. All shortened antennas of this variety are narrow-band devices. At 7 MHz, in the example illustrated here, the bandwidth between the 2:1 SWR points will be on the order of 50 kHz, half that amount on 80 meters, and twice that amount on 20 meters. Therefore, the antenna should be adjusted for operation in the center of the frequency spread of interest.

SHORTENED DIPOLES

As shown in preceding sections, there are a number of ways to load antennas so they may be reduced in size without severe reductions in effectiveness. Loading is always a compromise; the best method is determined by the amount of space available and the band(s) to be worked.

The simplest way to shorten a dipole is shown in **Fig 69**. If you do not have sufficient length between the supports, simply hang as much of the center of the antenna as possible between the supports and let the ends hang down. The ends can be straight down or may be at an angle as indicated but in either case should be secured so that they do not move in the wind. As long as the center portion between the supports is at least ¼, the radiation pattern will be very nearly the same

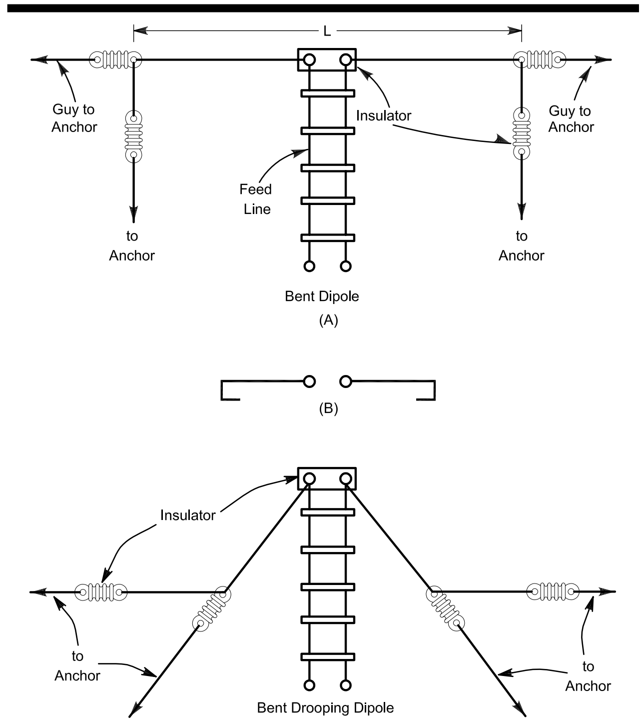

Fig 69—When space is limited, the ends may be bent downward as shown at A, or back on the radiator as shown at B. The bent dipole ends may come straight down or be led off at an angle away from the center of the antenna. An inverted V at C can be erected with the ends bent parallel to the ground when the support structure is not high enough.

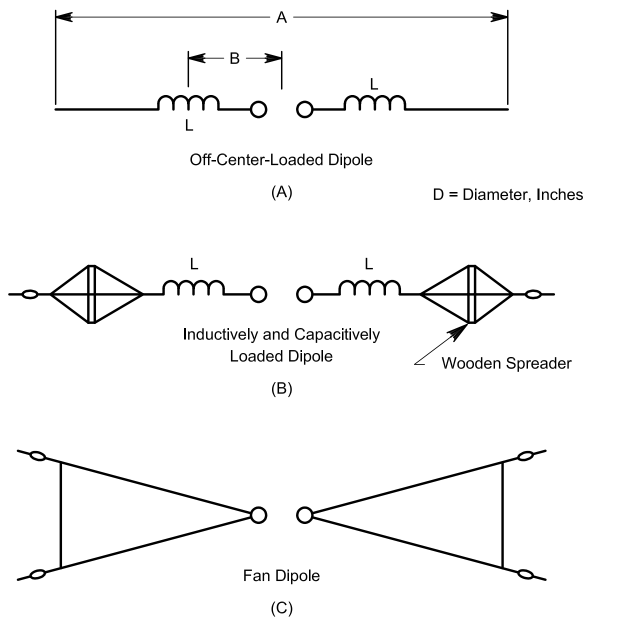

Fig 70—At A is a dipole antenna lengthened electrically with off-center loading coils. For a fixed dimension A, greater efficiency will be realized with greater distance B, but as B is increased, L must be larger in value to maintain resonance. If the two coils are placed at the ends of the antenna, in theory they must be infinite in size to maintain resonance. At B, capacitive loading of the ends, either through proximity of the antenna to other objects or through the addition of capacitance hats, will reduce the required value of the coils. At C, a fan dipole provides some electrical lengthening as well as broadbanding.

as a full-length dipole.

The resonant length of the wire will be somewhat shorter than a full-length dipole and can best be determined by experimentally adjusting the length of ends, which may be conveniently near ground. Keep in mind that there can be very high potentials at the ends of the wires and for safety the ends should be kept out of reach. Letting the ends hang down as shown is a form of capacitive end loading. While it is efficient, it will also reduce the matching bandwidth—as does any form of loading.

The most serious drawback associated with inductive loading is high loss in the coils themselves. It is important that you use inductors made from reasonably large wire or tubing to minimize this problem. Close winding of turns should also be avoided if possible. A good compromise is to use some off-center inductive loading in combination with capacitive end loading, keeping the inductor losses small and the efficiency as high as possible.

Some examples of off-center coil loading and capacitive-end loading are shown in **Fig 70**. This technique was described by Jerry Hall, K1TD in Sep 1974 *QST*. In the equation below, the diameter D is that of the wire used for the antenna, in inches. The frequency f is expressed in MHz.

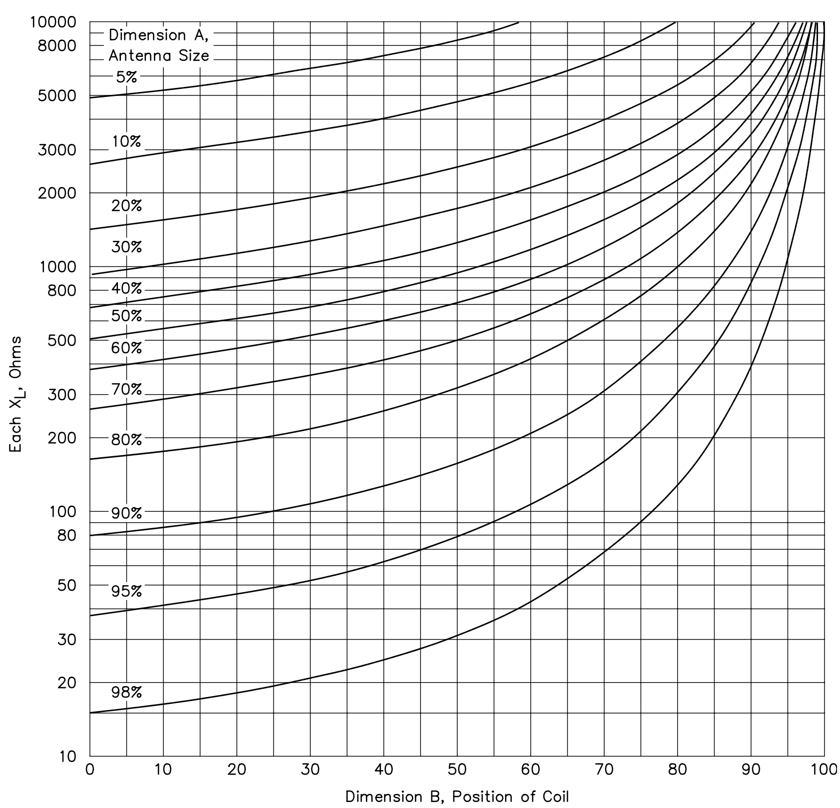

Fig 71—Chart for determining approximate inductance values for off-center-loaded dipoles. See Fig 70A. At the intersection of the appropriate curve from the body of the chart for dimension A and proper value for the coil position from the horizontal scale at the bottom of the chart, read the required inductive reactance for resonance from the scale at the left. Dimension A is expressed as percent length of the shortened antenna with respect to the length of a half-wave dipole of the same conductor material. Dimension B is expressed as the percentage of coil distance from the feed point to the end of the antenna. For example, a shortened antenna, which is 50% or half the size of a half-wave dipole (one-quarter wavelength overall) with loading coils positioned midway between the feed point and each end (50% out), would require coils having an inductive reactance of approximately 950 Ω at the operating frequency for antenna resonance.

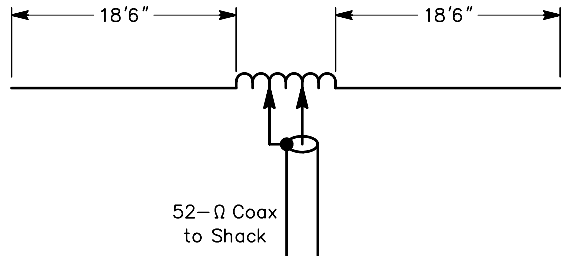

Fig 72—The WØSVM "Shorty Forty" center-loaded antenna. Dimensions given are for 7.0 MHz. The loading coil is 5 inches long and 2½ inches diameter. It has a total of 30 turns of #12 wire wound at 6 turns per inch (Miniductor 3029 stock).

For the antennas shown, the longer the overall length (dimension A, Fig 70A, in feet) and the farther the loading coils are from the center of the antenna (dimension B, also in feet), the greater the efficiency of the antenna. As dimension B is increased, however, the inductance required to resonate the antenna at the desired frequency increases.

Approximate inductive reactances for single-band resonance (for the antenna in Fig 70A only) may be determined with the aid of **Fig 71** or from Eq 10 below. The final values will depend on the proximity of surrounding objects in individual installations and must be determined experimentally. The use of high-Q low-loss coils is important for maximum efficiency.

A dip meter or SWR indicator is recommended for use during adjustment of the system. Note that the minimum inductance required is for a center-loaded dipole. If the inductive reactance is read from Fig 66 for a dimension B of zero, one coil having approximately twice this reactance can be used near the center of the dipole. **Fig 72** illustrates this idea. This antenna was conceived by Jack Sobel, WØSVM, who dubbed the 7-MHz version the "Shorty Forty."

$$X_L = \frac{10^6}{34\pi f}\left(\frac{\left(\ln\frac{24\left(\frac{234}{f}\right)-B}{D}-1\right)\left(\left(1-\frac{fB}{234}\right)^2-1\right)}{\frac{234}{f}-B} - \frac{\left(\ln\frac{24\left(\frac{A}{2}-B\right)}{D}-1\right)\left(\left(\frac{\frac{fA}{2}-fB}{234}\right)^2-1\right)}{\frac{A}{2}-B} \right) \quad \text{(Eq 10)}$$

Inverted-L Antennas

The antenna shown in **Fig 73** is called an *inverted-L* antenna. It is simple and easy to construct and is a good antenna for the beginner or the experienced 1.8-MHz DXer. Because the overall electrical length is made somewhat greater than λ/4, the feed-point resistance is on the order of 50 Ω, with an inductive reactance. That reactance is canceled by a series capacitor as indicated in the figure. For a vertical section length of 60 feet and a horizontal section length of 115 feet, the input impedance is ≈ 40 + *j* 300 Ω. Longer vertical or horizontal sections would increase the input impedance. The azimuthal radiation pattern is slightly asymmetrical with ≈1 to 2-dB increase in the direction opposite to the horizontal wire. This antenna requires a good buried ground system or elevated radials and will have a 2:1 SWR bandwidth of about 50 kHz.

This antenna is a form of top-loaded vertical, where the top loading is asymmetrical. This results in both vertical and horizontal polarization because the currents in the top wire do not cancel like they would in a symmetrical-T vertical. This is not necessarily a bad thing because it eliminates the zenith null present in a true vertical. This allows for good communication at short ranges as well as for DX.

A yardarm attached to a tower or a tree limb can be used to support the vertical section. As with any vertical, for best results the vertical section should be as long as possible. A good ground system is necessary for good results—the better the ground, the better the results.

If you don't have the space for the inverted L shown in Fig 73 (with its 115-foot horizontal section) and if you don't have a second tall supporting structure to make the top

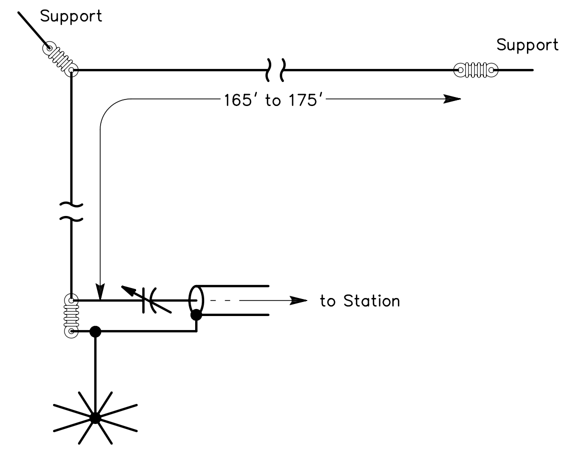

Fig 73—The 1.8-MHz inverted L. Overall wire length is 165 to 175 feet. The variable capacitor has a capacitance range from 100 to 800 pF, at 3 kV or more. Adjust antenna length and variable capacitor for lowest SWR.

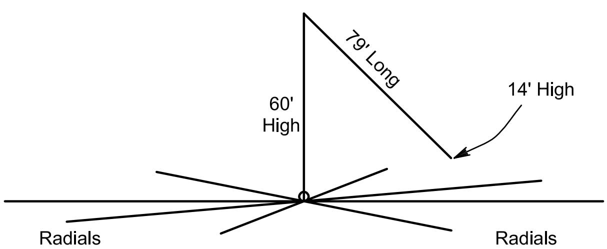

Fig 74—Sketch showing a modified 160-meter inverted L, with a single supporting 60-foot high tower and a 79-foot long slanted top-loading wire. The feed-point impedance is about 12 Ω in this system, requiring a quarter-wave matching transformer made of paralleled 50-Ω coaxes.

wire horizontal, consider sloping the top wire down towards ground. **Fig 74** illustrates such a setup, with a 60-foot high vertical section and a 79-foot sloping wire. As always, you will have to adjust the length of the sloping wire to fine-tune the resonant frequency. For a good ground radial system, the feed-point impedance is about 12 Ω, which may be transformed to 50 Ω with a 25-Ω quarter-wave transformer consisting of two paralleled 50-Ω quarter-wave coaxes. The peak gain will decrease about 1 dB compared to the inverted L shown in Fig 73. **Fig 75** overlays the elevation responses for average ground conditions. The 2:1 SWR bandwidth will be about 30 kHz, narrower than the larger system in Fig 73.

If the ground system suggested for Figs 73 and 74 is not practical, you can use a single elevated radial as shown in **Fig 76**. For the dimensions shown in the figure $Z_i = 50 + j\,498\ \Omega$, requiring a 175-pF series resonating capacitor. The azimuthal radiation pattern is shown in **Fig 77** compared to

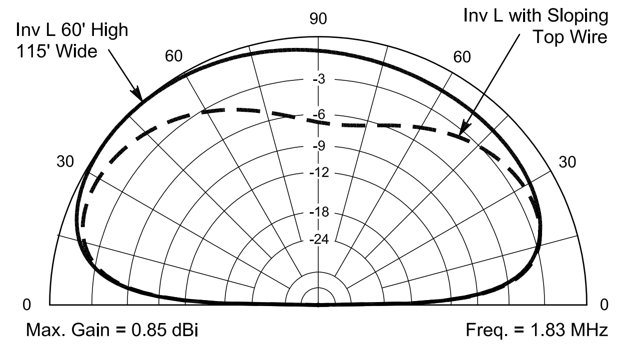

Fig 75—Overlay of the elevation responses for the inverted-L antennas in Fig 73 (solid line) and Fig 74 (dashed line). The gains are very close for these two setups, provided that the ground radial system for the antenna in Fig 74 is extensive enough to keep ground losses low.

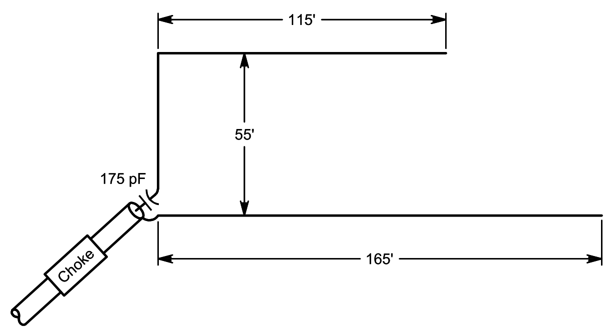

Fig 76—A single elevated radial can be used for the inverted-L. This changes the directivity slightly. The series tuning capacitor is approximately 175 pF for this system.

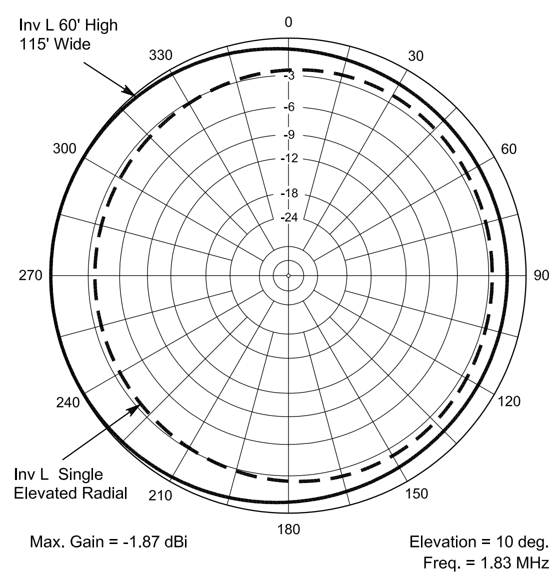

Fig 77—Azimuthal pattern comparison for inverted-L antennas shown in Fig 73 (solid line) and the compromise, single-radial system in Fig 76 (dashed line). This is for a takeoff angle of 10°.

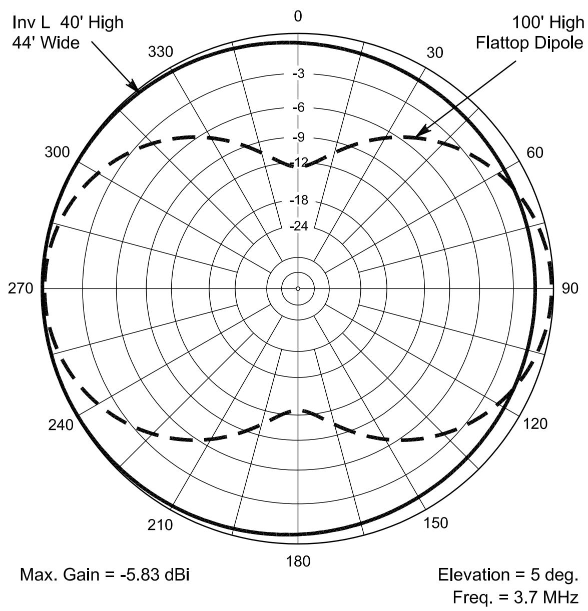

Fig 78—Azimuthal pattern at a takeoff angle of 5° for an 80-meter version of the inverted L (solid line) in Fig 73, compared to the response for a 100-foot high flattop dipole (dashed line).

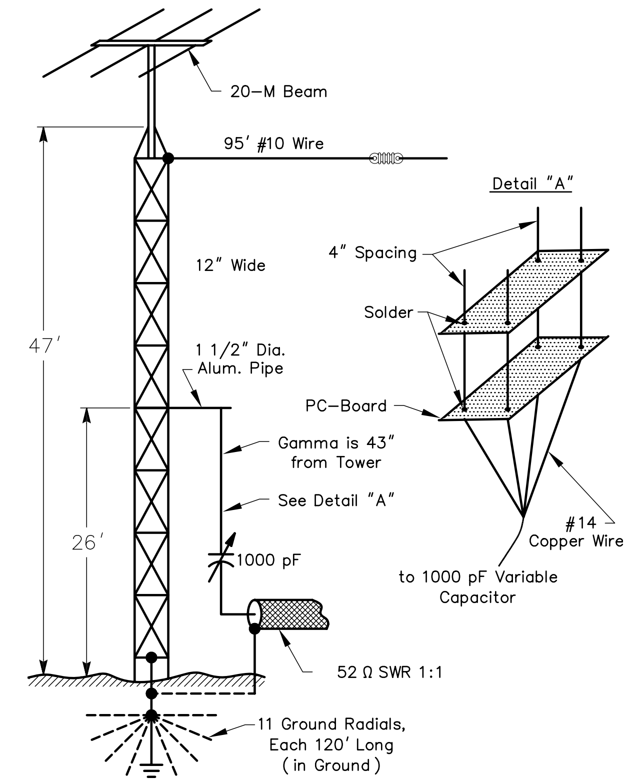

Fig 79—Details and dimensions for gamma-match feeding a 50-foot tower as a 1.8-MHz vertical antenna. The rotator cable and coaxial feed line for the 14-MHz beam is taped to the tower legs and run into the shack from ground level. No decoupling networks are necessary.

the inverted L in Fig 68. Note that the 1 to 2-dB asymmetry is now in the direction of the horizontal wires, just the opposite of that for a symmetrical ground system. The 2:1 SWR bandwidth is about 40 kHz, assuming that the series capacitor is adjusted at 1.83 MHz for minimum SWR.

Fig 78 shows the azimuthal response at a 5° elevation angle for an 80-meter version of the inverted L in Fig 73. The peak response occurs at an azimuth directly behind the direction in which the horizontal portion of the inverted L points. For comparison, the response for a 100-foot high flattop dipole is also shown. The top wire of this antenna is only 40 feet high and the 2:1 SWR bandwidth is about 150 kHz wide with a good, low-loss ground-radial system.

Fig 78 illustrates that the azimuth response of an inverted L is nearly omnidirectional. This gives such an antenna an advantage in certain directions compared to a flattop dipole, which is constrained by its supporting mounts (such as trees or towers) to favor fixed directions. For example, the flattop dipole in Fig 78 is at its weakest at azimuths of 90° and 270°, where it is down about 12 dB compared to the inverted L. Hams who are fortunate enough to have high rotary dipoles or rotatable low-band Yagis have found them to be very effective antennas indeed.

A DIFFERENT APPROACH

Fig 79 shows the method used by Doug DeMaw, W1FB, to gamma match his self-supporting 50-foot tower operating as an inverted L. A wire cage simulates a gamma rod of the proper diameter. The tuning capacitor is fashioned from telescoping sections of 1½ and 1½-inch aluminum tubing with polyethylene tubing serving as the dielectric. This capacitor is more than adequate for power levels of 100 W. The horizontal wire connected to the top of the tower provides the additional top loading.

Sloper Antennas

Sloping dipoles and λ/2 dipoles can be very useful antennas on the low bands. These antennas can have one end attached to a tower, tree or other structure and the other end near ground level, elevated high enough so that passersby can't contact them, of course. The following section gives a number of examples of these types of antennas.

THE HALF-WAVE SLOPING DIPOLE

If you have a sufficiently high support, you can install a halfwave dipole sloping downwards toward ground to provide vertical as well as horizontal polarization. This antenna is popularly known as a *sloper* or a *halfwave sloper*. The amount of slope from horizontal can vary from 0°, where the dipole is in a flattop configuration, all the way to 90°, where the dipole becomes fully vertical. The latter configuration is sometimes called a *Halfwave Vertical Dipole* (HVD).

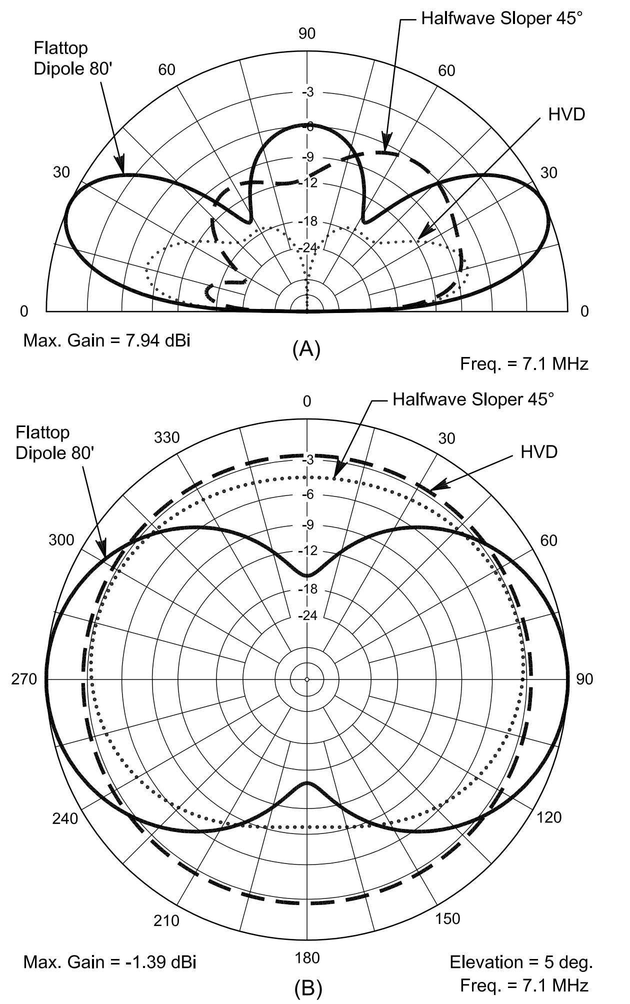

Fig 80—At A, the azimuthal responses for a flattop dipole (solid line), a dipole whose end has been tilted down 45° (dashed line), and a HVD (halfwave vertical dipole, dotted line). All these were modeled over average ground, with a conductivity of 5 mS/m and a dielectric constant of 13. Note that the tilted dipole exhibits about 5 dB front-to-back ratio, although its maximum gain is less than either the HVD or flattop dipole. At B, the elevation-plane patterns for the same antennas. Note that the tilted halfwave dipole (dashed line) has more energy at higher elevation angles than either the flattop dipole or HVD.

The question arises when contemplating a vertical half-wave dipole or a halfwave sloping dipole about how to treat the feed line to make sure it doesn't accidentally become part of the radiating system. The ideal situation would be to bring the feed line out perpendicular to the vertical or sloping wire for an infinite distance. Obviously, that isn't very practical because the feed line eventually has to be connected to a transmitter located near the ground. An intensive modeling study on feeding an HVD was done for the book *Simple and Fun Antennas for Hams*. This study indicated that a slant angle down to the ground of as little as 30° from a vertical radiator can work with only minor interaction, provided that common-mode decoupling chokes were employed at the feed point and a quarter-wavelength down the line from the feed point. These common-mode chokes can consist of either discrete ferrite beads placed over the outer jacket of the coaxial line or multiple turns of the coax itself to form a choke.

Fig 80A compares the 40-meter azimuthal patterns at a DX takeoff angle of 5° for three configurations: a flattop dipole, a dipole tilted down 45° and an HVD (halfwave vertical dipole). These are computed for ground with average conductivity and dielectric constant, and for a maximum height of 80 feet in each configuration. The sloping halfwave dipole exhibits about 5 dB of front-to-back ratio, although even at its most favored direction it doesn't quite have the same maximum gain as the HVD or the flattop dipole.

The reason why the maximum gain for the sloper is less than the other two configurations, even while still exhibiting some front-to-back pattern, is shown in Fig 80A, which shows the elevation-plane patterns for the same antennas, each at the azimuth of maximum gain. The halfwave sloper distributes much of its energy higher in elevation than the HVD, lowering the peak-gain potential of the sloper.

You can also see from Fig 80B that the 80-foot high horizontal dipole would perform much better than either the HVD or halfwave sloper for close-in local contacts, which occur at high elevation angles. On the other hand, except for the greater gain exhibited in the flattop dipole's most favored directions, the HVD has more gain than the other antennas at low elevation angles. While the HVD's omnidirectional pattern is a plus for transmitting, it may be a problem for receiving, where local noise may be coming from specific directions (such as power lines) and may also be predominantly vertically polarized. In such cases, a horizontally polarized flattop dipole may be a considerably better receiving antenna than a vertically polarized antenna of any sort. We've already mentioned the fact that a rotary flattop dipole high in the air can be a very effective antenna on the low bands.

THE QUARTER-WAVELENGTH "HALF SLOPER"

Perhaps one of the easiest antennas to install is the λ/4 sloper shown in **Fig 81**. As pointed out above, a sloping λ/2 dipole is known among radio amateurs as a *sloper* or sometimes as a *full sloper*. If only one half of it is used, it becomes a *half sloper*. The performance of the two types of sloping antennas is similar—They exhibit some directivity in the direction of the slope and radiate vertically polarized energy at low angles respective to the horizon. The amount of directivity will range from 3 to 6 dB, depending upon the individual installation, and will be observed in the slope direction.

The main advantage of the half sloper over the full half-wave-long sloping dipole is that its supporting tower needn't be as high. Both the half sloper and the full sloper place the feed point (the point of maximum current) high above lossy ground. But the half-sloper only needs half as much wire to build the antenna for a given amateur band. The disadvantage of the half sloper is that it is sometimes difficult or even impossible to obtain a low SWR when using coaxial-cable feed, especially without a good isolating choke balun. (See the section above on isolating ground-plane antennas.)

Other factors that affect the feed impedance are tower height, height of the attachment point, enclosed angle between the sloper and the tower, and what is mounted atop the tower (HF or VHF beams). Further, the quality of the ground under the tower (ground conductivity, radials, etc) has a marked effect on the antenna performance. The final SWR can vary (after optimization) from 1:1 to as high as 6:1. Generally speaking, the closer the low end of the slope wire is to ground, the more difficult it will be to obtain a good match.

Basic Recommendations for a Half Sloper

The half sloper can be an excellent DX type of antenna. Hams usually install theirs on a metal supporting structure such as a mast or tower. The support needs to be grounded at the lower end, preferably to a buried or on-ground radial system. If a nonconductive support is used, the outside of the coax braid becomes the return circuit and should be grounded at the base of the support. As a starting point you can attach the sloper so the feed point is approximately λ/4 above ground. If the tower is not high enough to permit this, the antenna should be fastened as high on the supporting structure as possible. Start with an enclosed angle of approximately 45°, as indicated in Fig 81. Cut the wire to the length determined from

$$\ell = \frac{260}{f_{MHz}} \qquad \text{(Eq 11)}$$

This will allow sufficient extra length for pruning the wire for the lowest SWR. A metal tower or mast becomes an operating part of the half sloper system. In effect, it and the slope wire function somewhat like an inverted-V dipole antenna. In other words, the tower operates as the missing half of the dipole. Hence its height and the top loading (beams) play a significant role.

Detailed modeling indicates that a sufficiently large

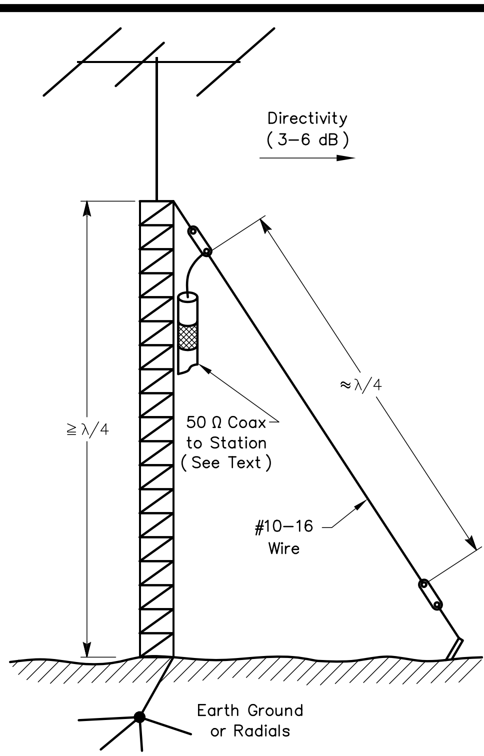

Fig 81—The λ/4 "half sloper" antenna.

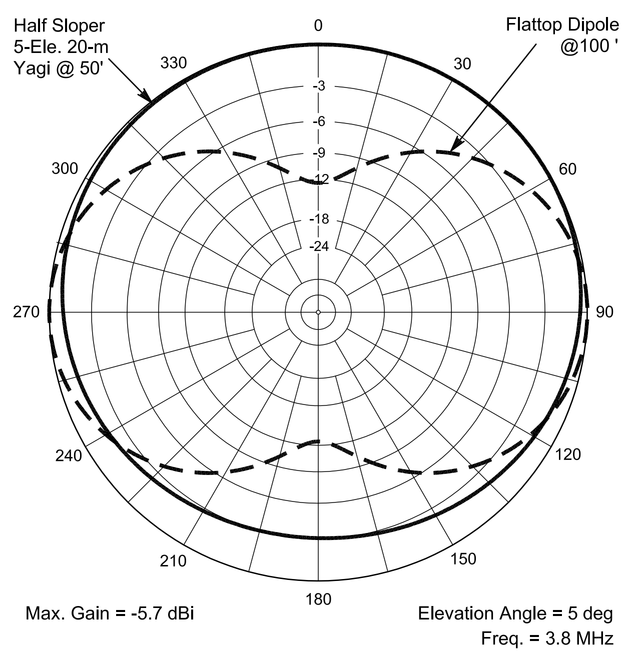

Fig 82—Radiation pattern for a typical half sloper (solid line) mounted on a 50-foot high tower with a large 5-element 20-meter beam on the top compared to that for a flattop dipole (dashed line) at 100 feet. At a 5° takeoff angle typical for DX work on 80 meters, the two antennas are pretty comparable in the directions favored by the high dipole. In other directions, the half sloper has an advantage of more than 10 dB.

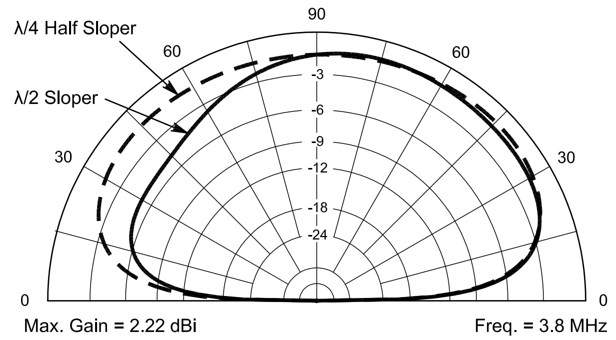

Fig 83—Comparison of elevation patterns for a full-sized halfwave sloper (solid line) on a 100-foot tower and a half sloper (dashed line) on a 50-foot tower with a 5-element 20-meter Yagi acting as a top counterpoise. The performance is quite comparable for these two systems.

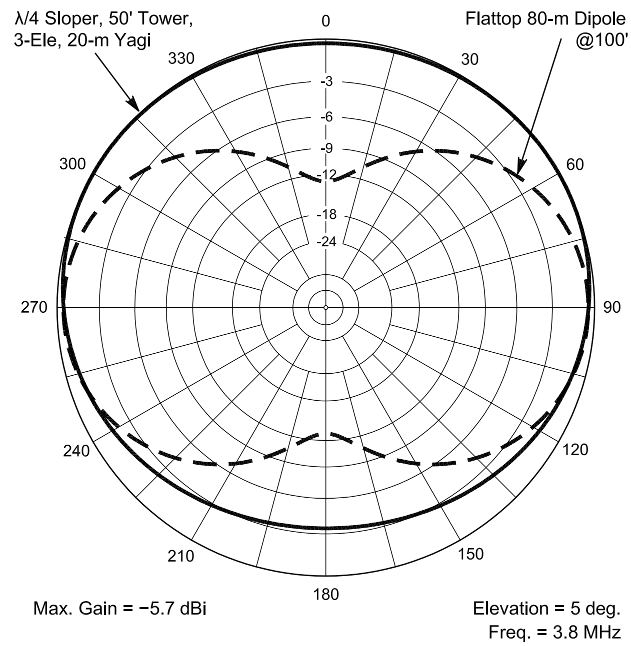

Fig 84—Comparing the azimuthal response of a half sloper (solid line) on a 50-foot tower with a 3-element 20-meter Yagi on top to that of a flattop dipole (dashed line) at 100 feet. The two are again quite comparable at a 5° takeoff angle.

mass of metal (that is, a large, "Plumber's Delight" Yagi) connected to the top of the tower acts like enough of a "top counterpoise" that the tower may be removed from the model with little change in the essential characteristics of the half-sloper system. Consider an installation using a freestanding 50-foot tower with a large 5-element 20-meter Yagi on top. This Yagi is assumed to have a 40-foot boom oriented 90° to the direction of the slanted 80-meter half-sloper wire. The best SWR that could be reached by changing the length and slant angle for this sloper is 1.67:1, representing a feed-point impedance of 30.1 – *j* 2.7 Ω. The peak gain at 3.8 MHz is 0.97 dBi at an elevation angle of 70°. **Fig 82** shows the azimuth-plane pattern for this half sloper, compared to a 100-foot high flattop dipole for reference, at an elevation angle of 5°.

Removing the tower from the model resulted in a feed-point impedance of 30.1 – *j* 1.5 Ω and a peak gain of 1.17 dBi. The tower is obviously not contributing much in this setup, since the mass of the large 20-meter Yagi is acting like an elevated counterpoise all by itself. It's interesting to rotate the boom of the model Yagi and observe the change in SWR that occurs on the half-sloper antenna. With the boom turned 90°, the SWR falls to 1.38:1. This level of SWR change could be measured with amateur-type instrumentation.

On the other hand, substituting a smaller 3-element 20-meter Yagi with an 18-foot boom in the model does result in significant change in feed-point impedance and gain when the tower is removed from the model, indicating that the "counterpoise effect" of the smaller beam is insufficient by itself. Interestingly enough, the best SWR for the half sloper/tower and the 3-element Yagi (with its boom inline with the half sloper is 1.33:1), changing to 1.27:1 with the boom turned 90°. Such a small change in SWR would be difficult to measure using typical amateur instrumentation.

In any case, the 50-Ω transmission line feeding a half sloper should be taped to the tower leg at frequent intervals to make it secure. The best method is to bring it to earth level, then route it to the operating position along the surface of the ground if it can't be buried. This will ensure adequate RF decoupling, which will help prevent RF energy from affecting the equipment in the station. Rotator cable and other feed lines on the tower or mast should be treated in a similar manner.

Adjustment of the half sloper is done with an SWR indicator in the 50-Ω transmission line. A compromise can usually be found between the enclosed angle and wire length, providing the lowest SWR attainable in the center of the chosen part of an amateur band. If the SWR "bottoms out" at 2:1 or lower, the system will work fine without using an antenna tuner, provided the transmitter can work into the load. Typical optimum values of SWR for 3.5 or 7-MHz half slopers are between 1.3:1 and 2:1. A 100-kHz bandwidth is normal on 3.5 MHz, with 200 kHz being typical at 7 MHz.

If the lowest SWR possible is greater than 2:1, the attachment point can be raised or lowered to improve the match. Readjustment of the wire length and enclosed angle may be necessary when the feed-point height is changed. If the tower is guyed, the guy wires will need to be insulated from the tower and broken up with additional insulators to prevent resonance.

At this point you may be curious about which antenna is better—a full sloper or a half sloper. The peak gain for each antenna is very nearly identical. **Fig 83** overlays the elevation-plane pattern for the full-sized halfwave sloper on a 100-foot tower and for the half sloper shown in Fig 81 on a 50-foot tower with a 5-element 20-meter Yagi on top. The

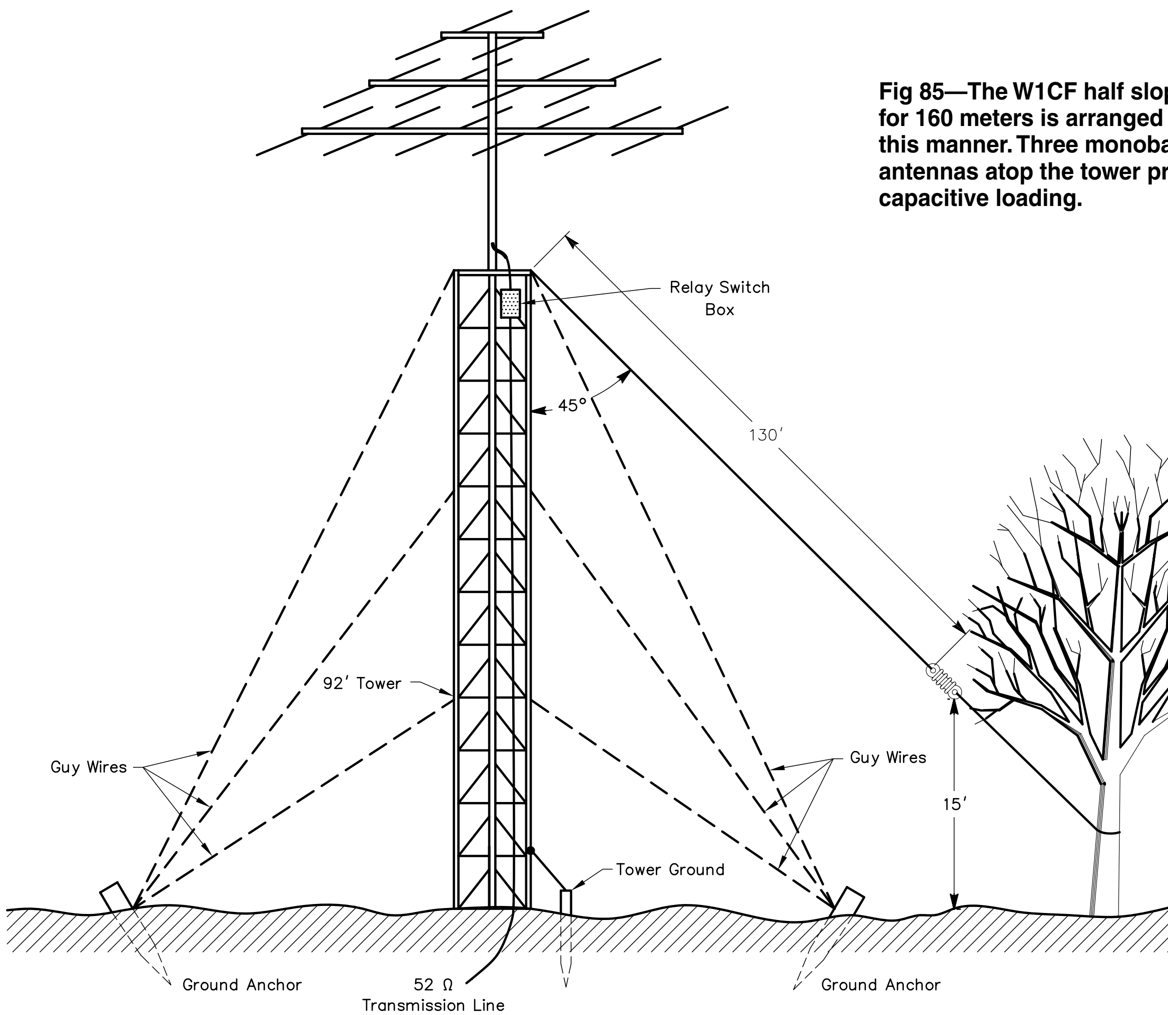

Fig 85—The W1CF half sloper for 160 meters is arranged in this manner. Three monoband antennas atop the tower provide capacitive loading.

full-sized halfwave sloper has more front-to-back ratio, but it is only a few dB more than the half sloper. **Fig 84** compares the azimuthal patterns at a 5° takeoff angle for a 100-foot high flattop dipole and a half-sloper system on a 50-foot tower with a 3-element 20-meter Yagi on top.

Despite the frustration some have experienced trying to achieve a low SWR with some half-sloper installations, many operators have found the half sloper to be an effective and low-cost antenna for DX work.

1.8-MHz ANTENNA SYSTEMS USING TOWERS

The half sloper discussed above for 80 or 40-meter operation will also perform well on 1.8 MHz where vertically polarized radiators can achieve the low takeoff angles needed on Topband. Prominent 1.8-MHz operators who have had success with the half sloper antenna suggest a minimum tower height of 50 feet. Dana Atchley, W1CF (SK), used the configuration sketched in **Fig 85**. He reported that the uninsulated guy wires act as an effective counterpoise for the sloping wire. In **Fig 86** is the feed system used by Doug

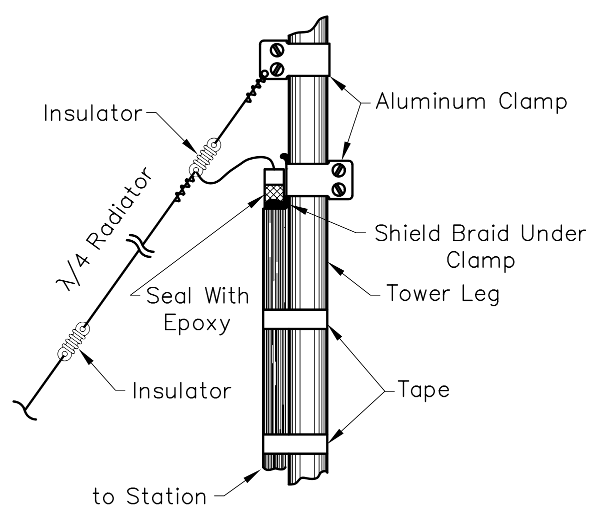

Fig 86—Feed system used by W1FB for 1.8 MHz half sloper on a 50-foot self-supporting tower.

DeMaw, W1FB (SK), on a 50-foot self-supporting tower. The ground for the W1FB system is provided by buried radials connected to the tower base.

As described previously, a tower can also be used as a true vertical antenna, provided a good ground system is used. The shunt-fed tower is at its best on 1.8 MHz, where a full λ/4 vertical antenna is rarely possible. Almost any tower height can be used. An HF beam at the top provides some top loading.

THE K1WA 7-MHz "SLOPER SYSTEM"

One of the more popular antennas for 3.5 and 7 MHz is the half-wave long sloping dipole described previously. David Pietraszewski, K1WA, made an extensive study of sloping dipoles at different heights with reflectors at the 3-GHz frequency range. From his experiments, he developed the novel 7-MHz antenna system described here. With several sloping dipoles supported by a single mast and a switching network, an antenna with directional characteristics and forward gain can be simply constructed. This 7-MHz system uses several "slopers" equally spaced around a common center support. Each dipole is cut to λ/2 and fed at the center with 50-Ω coax. The length of each feed line is 36 feet.

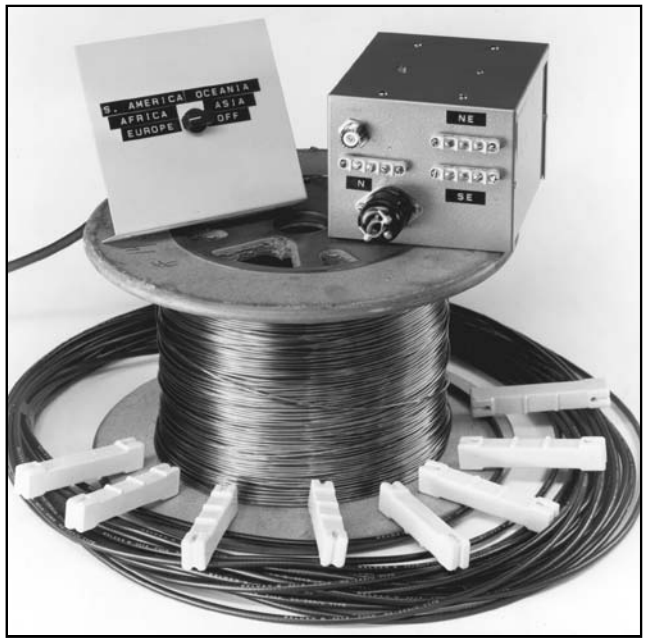

Fig 88—The basic materials required for the sloper system. The control box appears at the left, and the relay box at the right.

All of the feed lines go to a common point on the support (tower) where the switching takes place. The line length of 36 feet is just over 3λ/8, which provides a useful quality. At 7 MHz, the coax looks inductive to the antenna when the end at the switching box is open circuited. This has the effect of adding inductance at the center of the sloping dipole element, which electrically lengthens the element. The 36-foot length of feed line serves to increase the length of the element about 5%. This makes any unused element appear to be a reflector.

The array is simple and effective. By selecting one of the slopers through a relay box located at the tower, the system becomes a parasitic array that can be electrically rotated. All but the driven element of the array become reflectors.

The physical layout is shown in **Fig 87**, and the basic materials required for the sloper system are shown in **Fig 88**. The height of the support point should be about 70 feet, but can be less and still give reasonable results. The upper portion of the sloper is 5 feet from the tower, suspended by rope. The wire makes an angle of 60° with the ground.

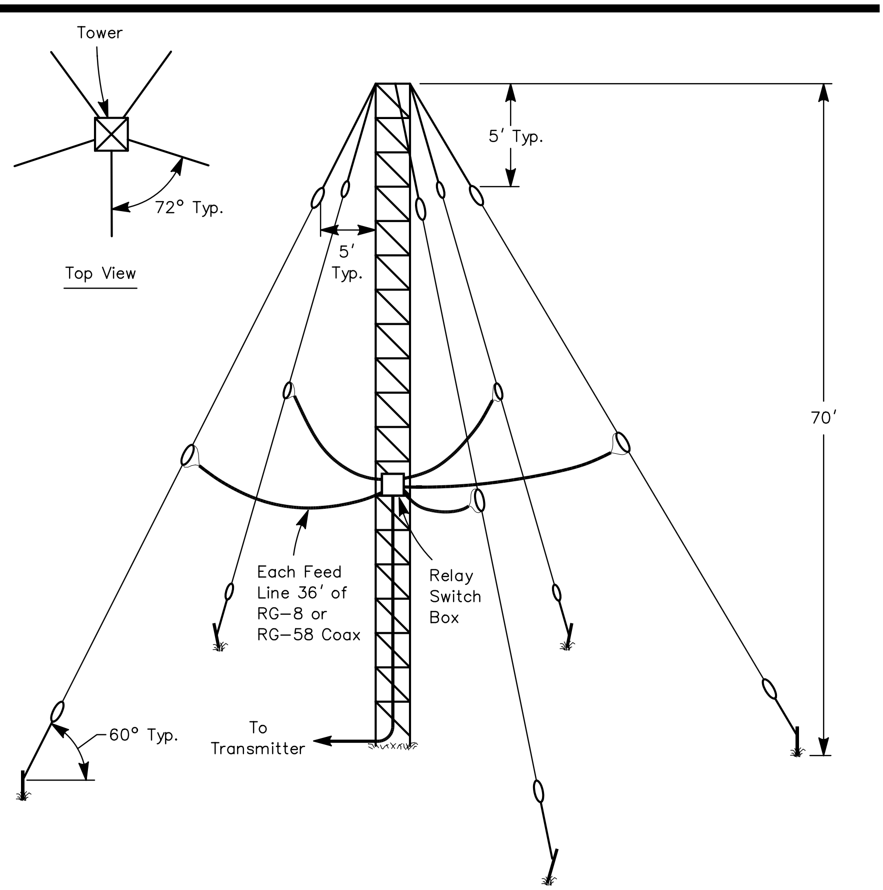

Fig 87—Five sloping dipoles suspended from one support. Directivity and forward gain can be obtained from this simple array. The top view shows how the elements should be spaced around the support.

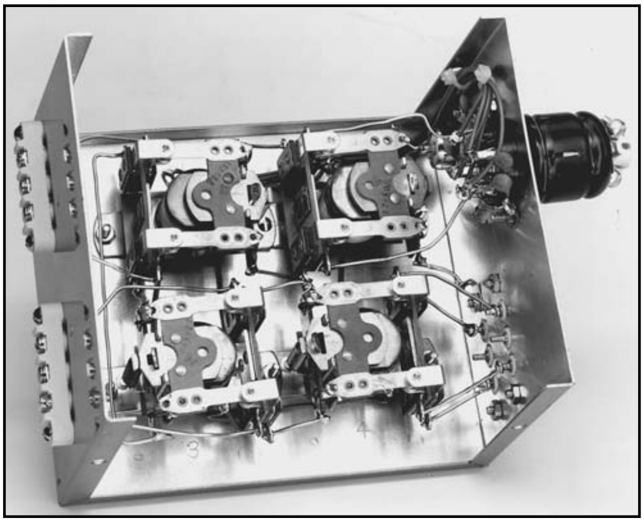

Fig 89—Inside view of relay box. Four relays provide control over five antennas. See text. The relays pictured here are Potter and Brumfeld type MR11D.

In **Fig 89**, the switch box is shown containing all the necessary relays to select the proper feed line for the desired direction. One feed line is selected at a time and the feed lines of those remaining are opened, **Fig 90**. In this way the array is electrically rotated. These relays are controlled from inside the shack with an appropriate power supply and rotary switch. For safety reasons and simplicity, 12-volt dc relays are used. The control line consists of a five conductor cable, one wire used as a common connection; the others go to the four relays. By using diodes in series with the relays and a dual-polarity power supply, the number of control wires can be reduced, as shown in Fig 90B.

Measurements indicate that this sloper array provides up to 20 dB front-to-back ratio and forward gain of about 4 dB over a single half-wave sloper. **Fig 91** shows the azimuthal pattern (at a 5° takeoff angle) for the K1WA array, compared to a 100-foot high flattop dipole and a full sloper suspended from a 50-foot tower. These patterns were calculated for average ground conditions. Just for fun, look at

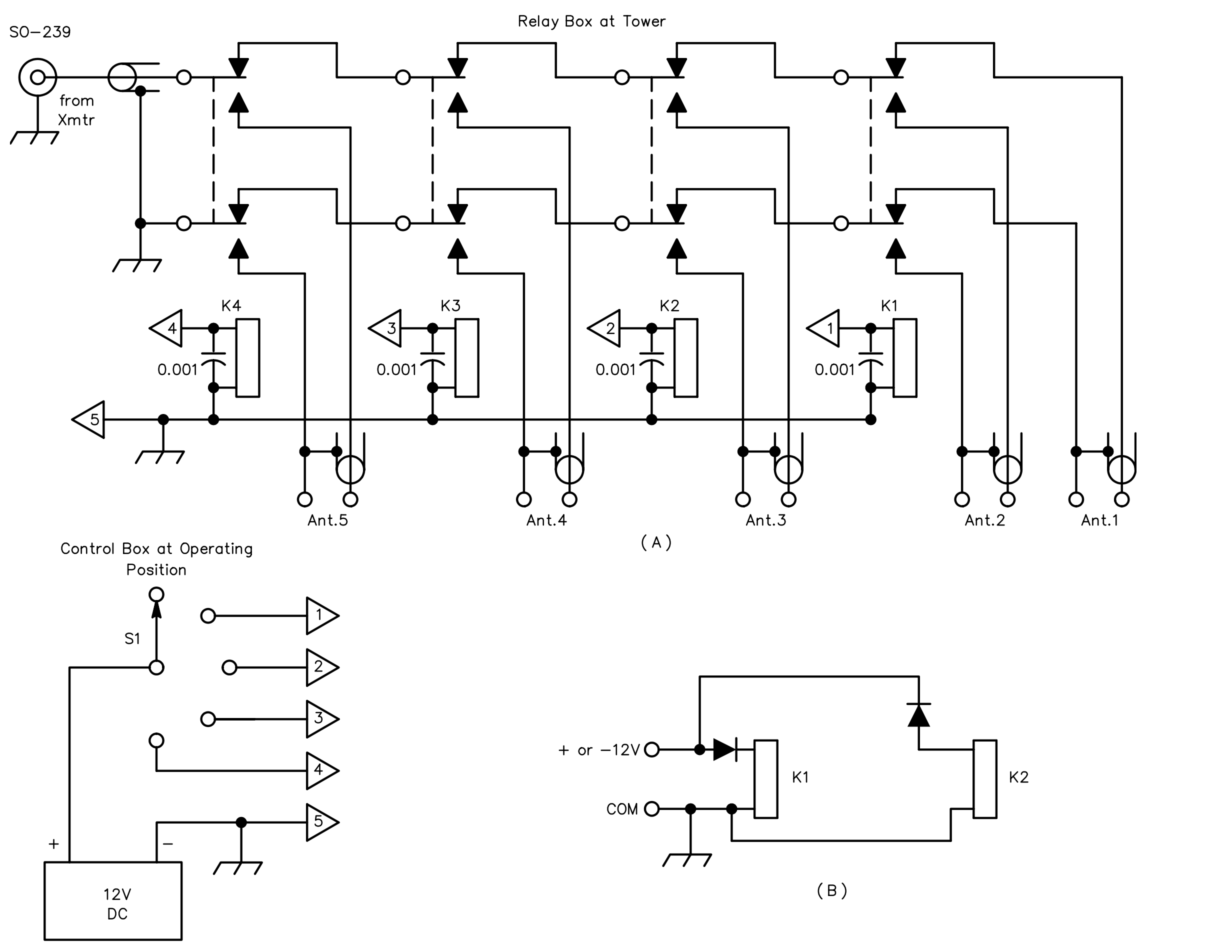

Fig 90—Schematic diagram for sloper control system. All relays are 12-volt dc, DPDT, with 8-A contact ratings. At A, the basic layout, excluding control cable and antennas. Note that the braid of the coax is also open-circuited when not in use. Each relay is bypassed with 0.001-µF capacitors. The power supply is a low current type. At B, diodes are used to reduce the number of control wires when using dc relays. See text.

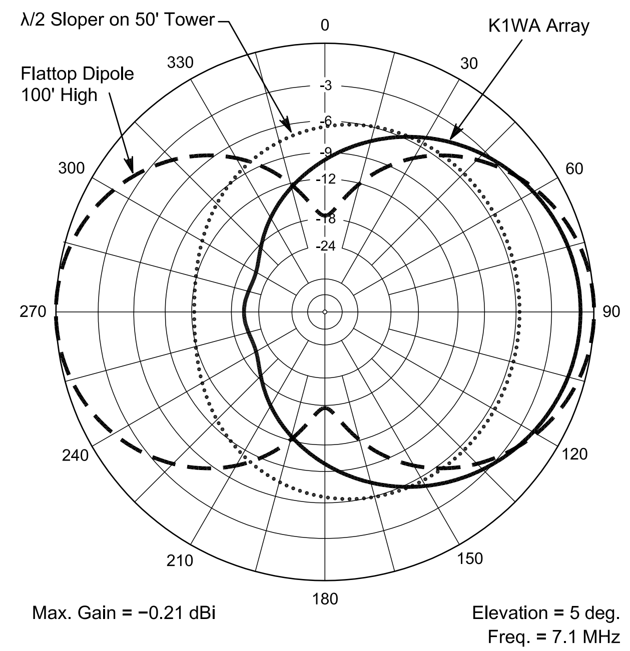

Fig 91—Azimuth pattern for K1WA 40-meter sloper array (solid line), compared to a flattop dipole (dashed line) at 100 feet and a halfwave full sloper on a 50-foot tower (dotted line). The K1WA array has an excellent front-to-back ratio and almost as much gain as the high flattop dipole. These patterns are for average ground.

Fig 92, which shows a comparison between a 100-foot high flattop dipole and a K1WA array placed over saltwater. Now that's a real barnburner at low takeoff angles! Such a seaside system would be very competitive with a rotatable 2-element "shorty-40" type of Yagi.

If one direction is the only concern, the switching system can be eliminated and the reflectors should be cut 5% longer than the resonant frequency. The feature worth noting is the good F/B ratio. By arranging the system properly, a null can be placed in an unwanted direction, thus making it an effective receiving antenna. In the tests conducted with this antenna, the number of reflectors used were as few as one and as many as five. The optimum combination appeared to occur with four reflectors and one driven element. No tests were conducted with more than five reflectors. This same array can be scaled to 3.5 MHz for similar results.

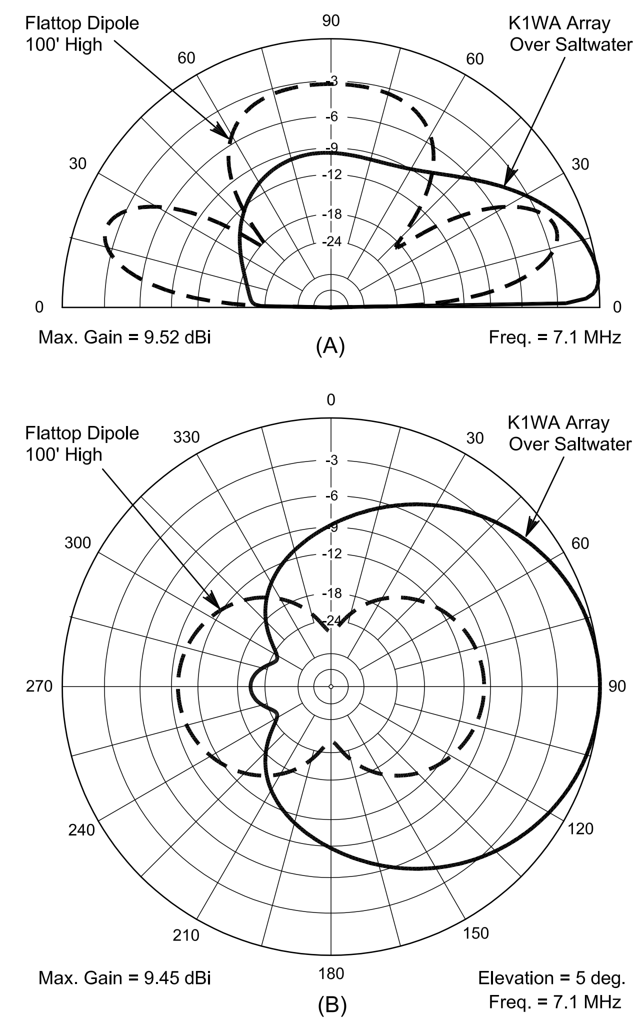

Fig 92—The K1WA 40-meter sloper array over saltwater, compared to a 100-foot high flattop dipole. At A, azimuth patterns. At B, elevation patterns. Now the sloper array really comes into its own!

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