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An 8-Element, All-Driven Vertical Beam

—super array for DX

Good news from New Hampshire.

The most popular 20 meter beam antenna in use today is the yagi mounted horizontally on top of a tall tower. A "package" price on such an antenna, a three-element triband beam, a rotator, a 51-foot crank-up tower, and 100 feet of coax and rotator cable was recently advertised in ham magazines at $1,095. In addition, you will have to pay for shipping and cost of erection (including concrete, guy wires, anchors, etc.), to say nothing of the legal fees to defend yourself against the local zoning board because you erected a 51-foot structure on your property without a building permit. To avoid the above expenses, I designed and built a vertical array over a ground plane with a maximum height of only 16.4 feet and a total erected cost of only $60, plus a few bucks for the extra RG-58/U needed, thus saving well over $1000. well over $1000.

A general view of the array in relation to the shack which is in the upper rear room of the old farmhouse.

Vertical beams described in the literature are generally either two- or four-element ground-mounted phased arrays for 3.5 or 7 MHz.[1] The directivity of these beams can be changed by various switching arrangements. The usual method is to switch in coils of coax cable cut to the required length for the number of degrees lag required. This is relatively simple for two elements. However, the gain from such a two-element beam is also relatively low. To increase the gain, it is necessary to increase the number of elements in the beam. Four is usually the

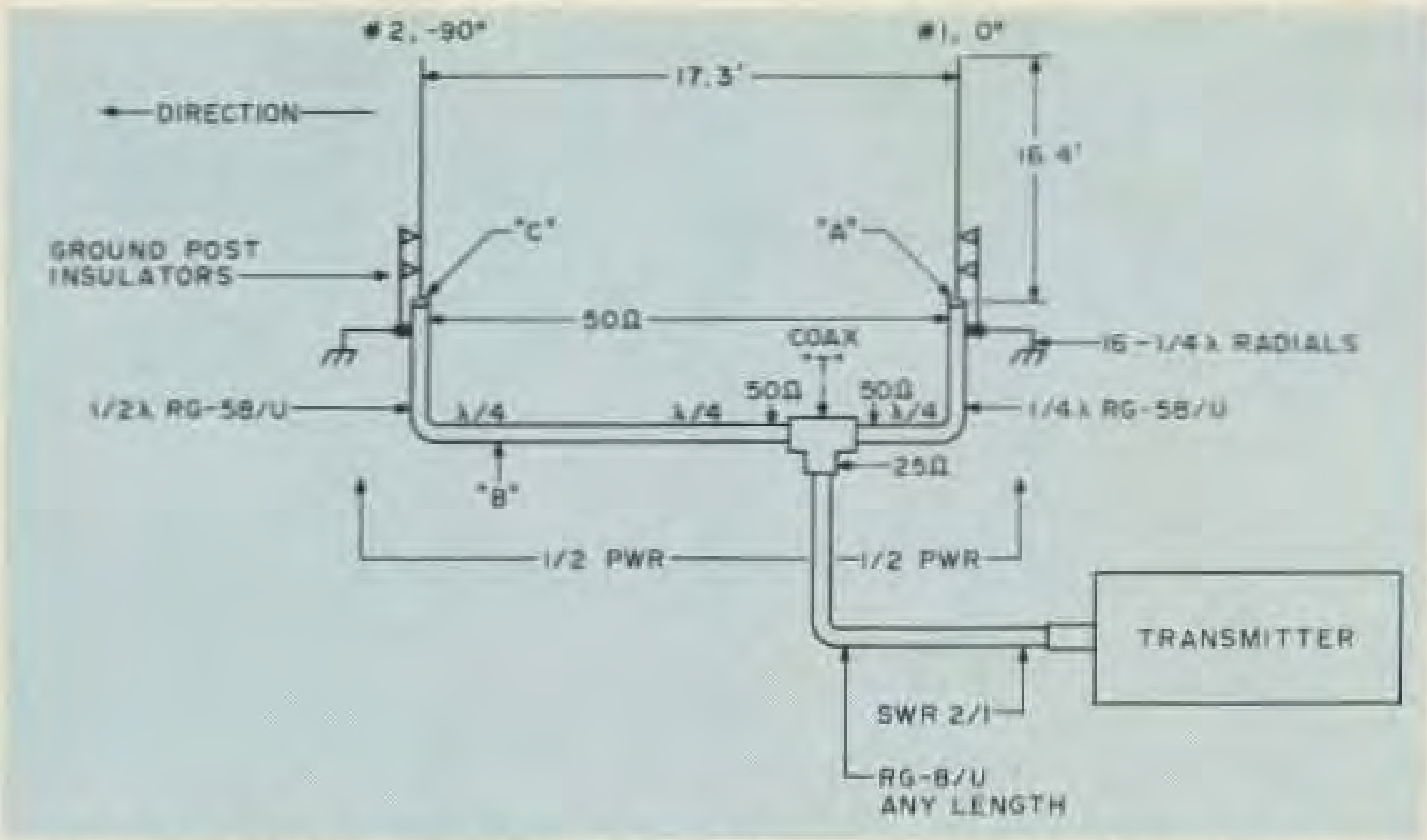


Fig. 1. Method of feed for the 2-element phased array.

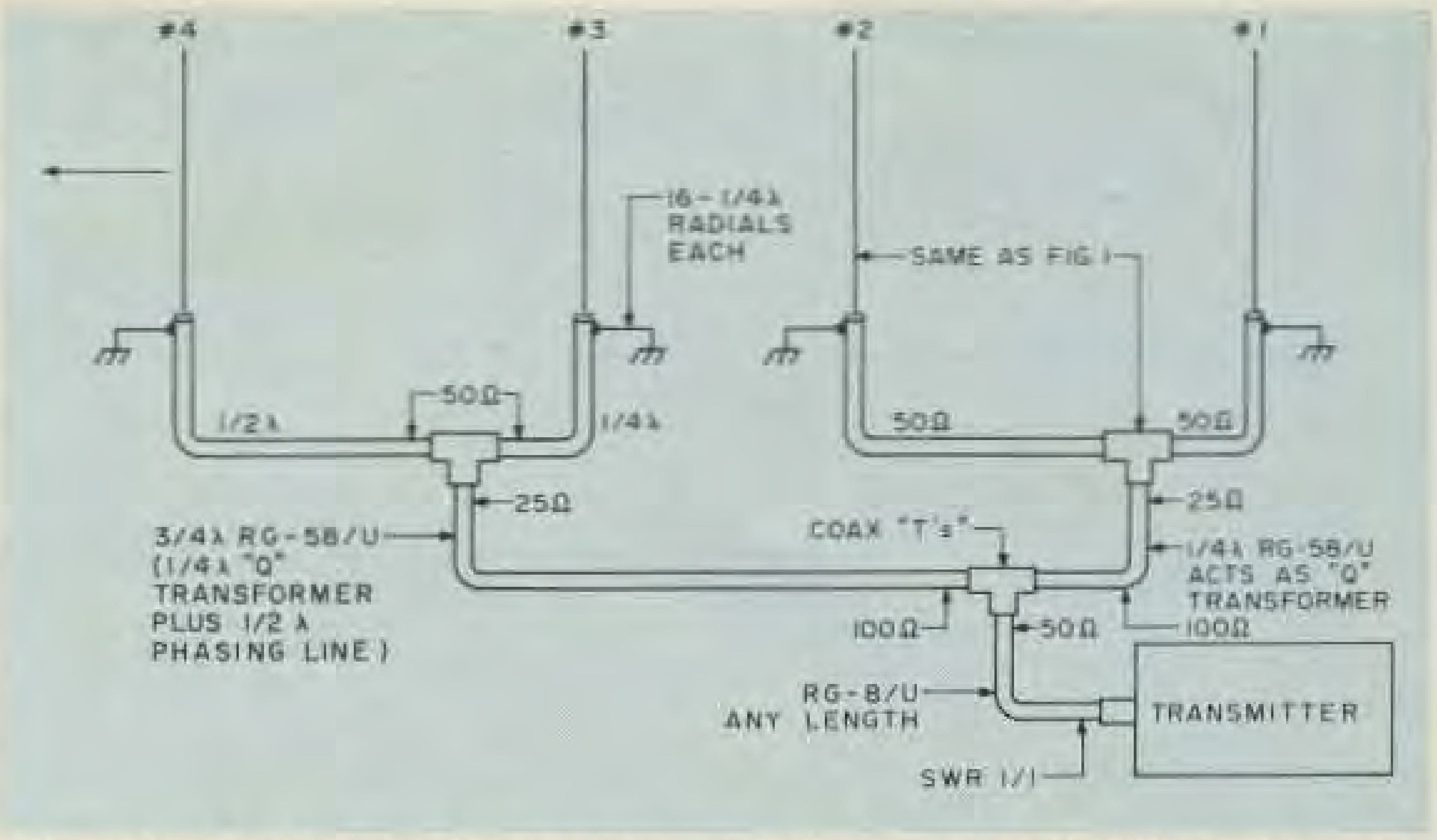


Fig. 2. Method of phasing and power division for the 4-element array.

maximum number of elements used. These may be arranged in a straight line, a square, or a triangle, with the fourth element in the center.[2] The complexity of the switching and phasing increases at a faster rate than the gain from such an array. Although the gain is low from such an array, it is more than adequate on 3.5 and 7 MHz, where rotatable beams are very expensive and difficult to construct.

To get enough gain on 14 MHz from such an array to be competitive with yagis and quads on towers, at least eight elements are necessary. Therefore, I sketched up an eight-element phased array with switchable directivity, but gave up the idea after calculating the number of relays and the feet of coax cable that would be needed.

Parasitic Array

One-half of an eight-element yagi (split down the middle) mounted vertically over a ground plane looked really interesting[3] since it only required a single length of RG-8/U for a feeder and could possibly be made into a tribander for 20/15/10. An eight-element parasitic beam could not have its directivity switched, but since I had already given up that idea, I decided to go ahead with a large high-gain unidirectional beam fixed on Oceania. It was decided to start with four elements, a reflector, a driven element, and two directors, later expanding it to eight or more elements by adding more directors. With this in mind, I reviewed the literature on yagi antennas. A 20 meter beam is generally limited to three elements only because of the difficulty in supporting a long boom 50 to 60 feet up in the air. Imagine the wind and ice load of an eight-element beam with an 80- to 100-foot boom! This is no problem on VHF where high-gain 10- to 16-element yagis are common. Neither is it a problem on HF when the beam is vertical with each element mounted on its own ground post.

Since I wanted my beam to point to Australia, which is 270 degrees true from central New Hampshire, I drove a 5-foot ground stake of 1-inch diameter pipe into the ground and attached the driven element to it. At precisely noon sun time, a stake was driven at the end of the shadow of the driven element.[4] This established true north. Next, I measured off 90 degrees and drove another stake, marking the true east/west axis of my new beam. The three ground posts for the reflector and two directors were installed next, together with their elements, along this east/west line. A length of RG-8/U was hurriedly run from the shack to the driven element just before dark. There was no time to install radials, but I did have a good (?) ground, four pipes driven into the moist soil to a depth of 3 feet.

At 6:00 am the next morning, I called CQ and was elated that VK3AKK answered and gave a report of strength 5 on a rather poor band. I was delighted that the first QSO on my new Australian beam was with a VK station. Anxious to see how much better it was than my other antennas, I switched in turn to a Hustler 4BTV, a dipole, and an eight-wavelength longwire. Ken came back saying: "Don't slash your wrists or cut your throat with this report, but although your new beam is a good S-5, the 4BTV ground plane is an S-7 and the dipole is an S-9. The longwire (pointing at South America) is an S-6."

So, back to the drawing board! It seems I have read somewhere that a pipe driven into the ground makes a good lightning arrester but not an rf ground! An swr check showed an extremely high swr ratio, so a 50-Ohm dummy load was placed at the far end of the coax. The swr came down to 1 to 1, showing the cable to be OK. Realizing that the trouble was probably due to the lack of a ground plane, four radials, each ¼ of a wavelength long, were installed at the base of each element. The swr immediately came down to 3 to 1.

A field-strength meter was set up about 60 feet in front of the beam, and the lengths of each element were varied in steps of 2 to 3 percent both ways with no very conclusive results. The elements did not want to tune. It appeared that I was trying to adjust the length of an element an inch or so at a time against some unknown random length of a ground system. Four more radials were added, making a total of eight radials per element. I reset the lengths of each element to 5 and 10 percent shorter for the directors and 5 percent longer for the reflector and ran another swr check. The swr was now down to 2 to 1, a worthwhile improvement.

The next morning, another CQ raised VK4AGL. The new beam was beginning to work. Joe gave me the following comparative report: new beam S-9, dipole S-8, 4BTV S-7, longwire S-5. It appeared I was now in business, so I started adding more elements, more radials, and a 4-to-1 step-down transformer. After each change, I would collect comparison reports for about a week. The greatest improvement in reports resulted from increasing the radials to 16 per element. The final 8-element

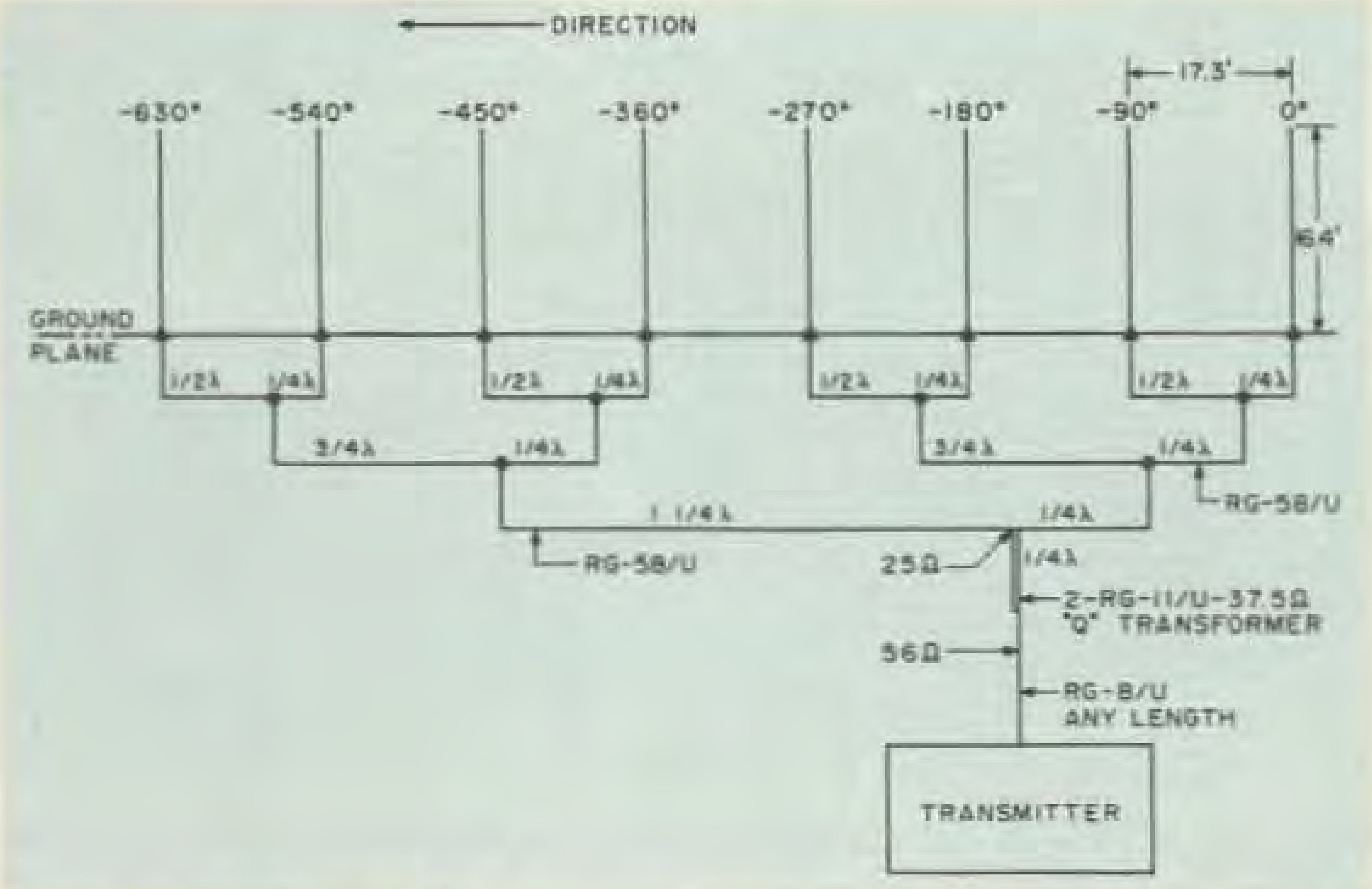


Fig. 3. Feeding and phasing an 8-element array. Note the 37.5-Ohm Q transformer. Refer to Fig. 5.

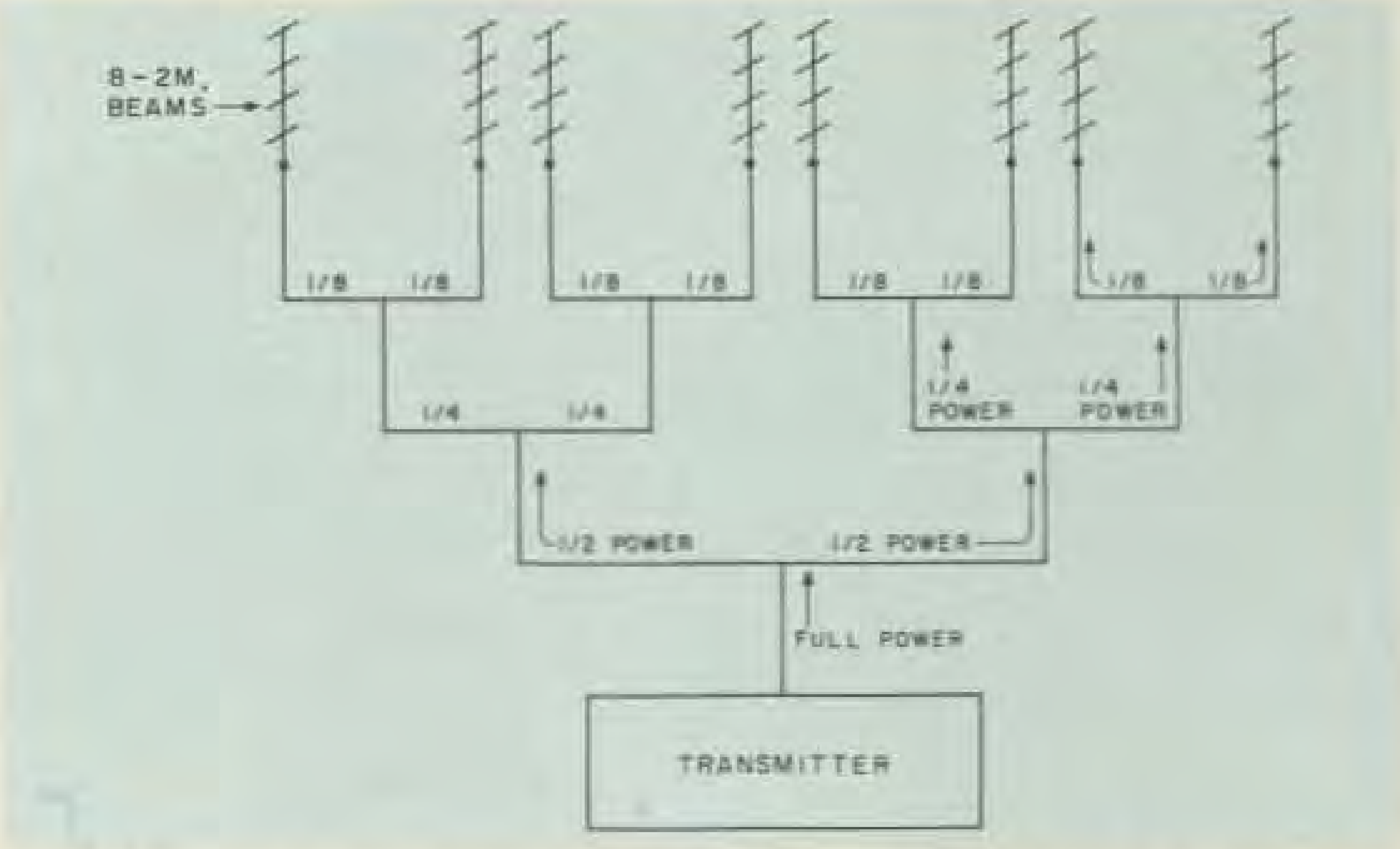


Fig. 4. Feeding eight 2 meter beams in phase with equal power. Feedlines to all beams are of equal length for in-phase operation. This is the type of phasing harness to use for broadside directivity of the 8-element array.

yagi beam gave a consistent two S-unit increase in signal strength (about 12 dB) over the best of my reference antennas. I still was not happy with the beam because I could not see any definite results from trying to tune it. Adjusting the lengths of each of the eight elements became very tedious and time-consuming. It was decided, therefore, to try an all-driven 8-element phased array, starting with two elements, then going to four, and then to all eight.

Phased Array

In a phased array, there are two things to watch out for: First, if ¼-wavelength spacing between elements is used for end fire, then there must be a 90-degree lag between elements, and second, the power must be divided equally among all elements.[5] The first problem is solved by feeding the first element directly from the coax from the transmitter and then feeding the second element through an extra ¼ wavelength of coax. Now, obviously, an electrical ¼ wave of coax, 11.4 feet, will not reach between two ¼-wave spaced elements, 17.3 feet; therefore, we must lengthen the coax to each element by an equal amount. For ease in grid-dipping each length of coax, I chose to lengthen each coax by ¼ of a wave. Refer to Fig. 1 for the power division and phasing of the first two elements. The formula for the electrical length of a quarter wavelength of coax is: L in feet $= 246 \times V/f = 11.39$ feet when f (frequency in MHz) $= 14.25$ MHz and V (velocity factor) $= .66$.

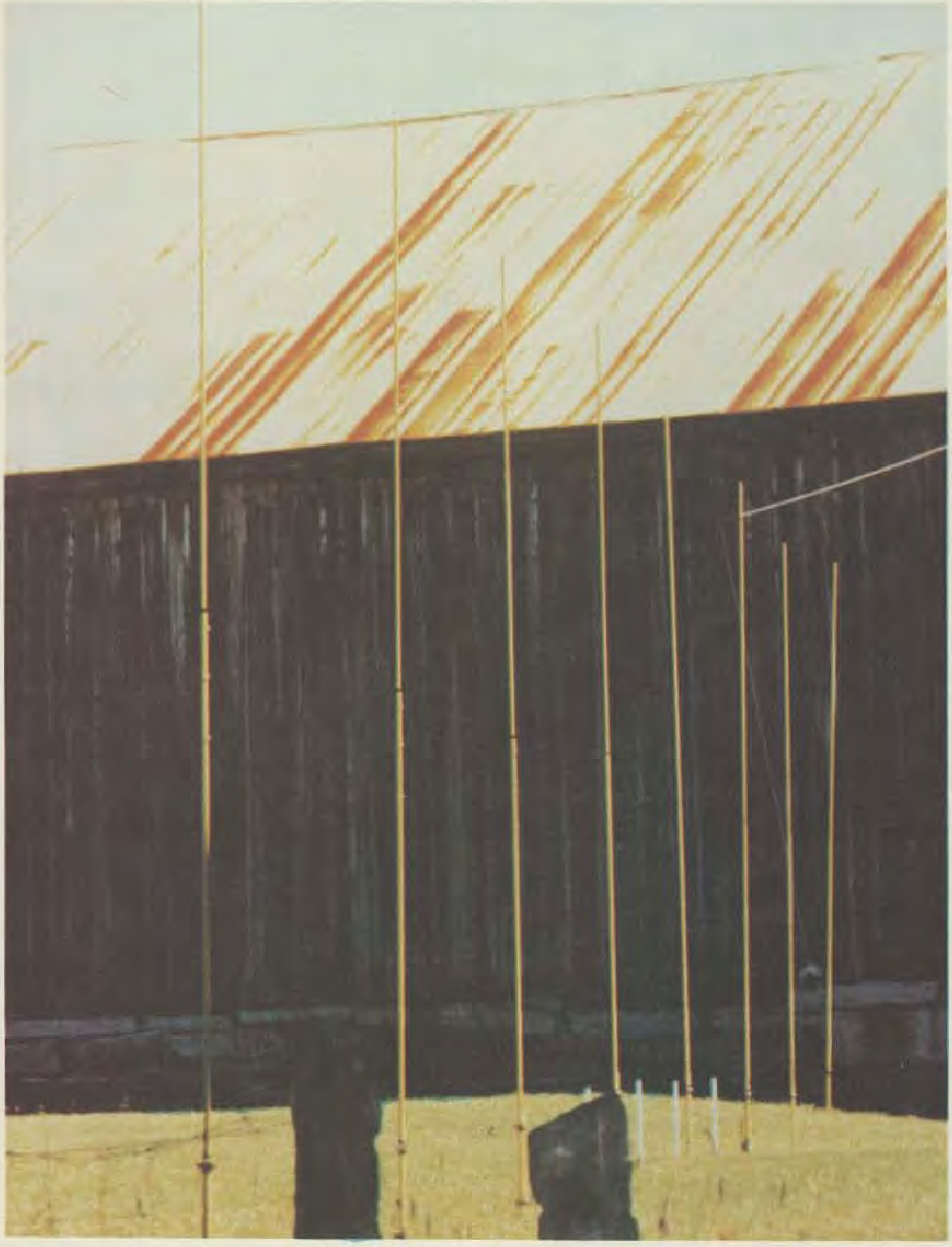
Handbooks say that V equals .8 for foam dielectric RG-8/U and .66 for solid dielectric. This makes a good starting point. Be sure to grid-dip your particular coax to 14.250 MHz, each time checking the grid-dip frequency on your receiver. Solder a 1-inch diameter loop onto a coax chassis fitting and then screw on the length of coax to be checked. If it is solid dielectric cable, then it should be cut to a few inches longer than .66 times ¼, ½, ¾, or 1¼ wavelengths and then pruned to length with the grid-dipper. When dipping the ½-wave coax, set the dipper at 7.125 MHz and read its second harmonic at 14.250 MHz. For all odd quarter wavelengths of coax, set the dipper at 14.250 MHz. The end of the cable you are pruning must be open-circuited. It was interesting to note that none of my coax had a velocity factor, V, of .66; it varied from .59 to .62.

Referring again to Fig. 1, you will note that the power from the transmitter is hopefully divided in half by the coax "T", one half going to element #1 and the other half going to element #2. Also note that points A and B are equidistant from the coax "T"; therefore, there is no phase difference between them. There is, however, an additional ¼ wavelength of coax between points B and C; therefore, it takes the signal that much longer to reach point C. Since there are 360 degrees in a wavelength, ¼ of a wave equals 90 degrees, and the signal in element #2 is said to "lag" that in element #1 by 90 degrees. This same method of feed will be used for each pair of elements.

This 2-element phased array was used for a week working VKs and ZLs, with results equal to the 4-element parasitic beam. Of course, by now I had a better ground plane than earlier. Next, two more driven elements with ¼-wave spacing were added. In each case, the division of power was hopefully accomplished by simply installing a coaxial "T" in the line as shown in Fig. 2. Phasing was accomplished by feeding the two pairs of elements through a ¼-wave and a ¾-wave section of coax as shown. The reason for doing this was to avail myself of a pair of ¼-wave matching transformers. If each of the driven elements had feedpoint resistances of 50 Ohms, they would be in parallel at the first "T", producing 25 Ohms of output. Now, if we connect in a 50-Ohm coaxial transformer an odd number of quarter waves in length, we can raise this 25 Ohms to 100 Ohms. $Zo = \sqrt{Zr \times Zs}$, where Zo is the line impedance (in our case, for RG-8/U, 50 Ohms), Zr is the impedance at one end, and Zs is the impedance at the other end, 25 Ohms. $Zr = Zo^2/Zs = 50 \times 50/25 = 100$ Ohms.

Now, at the next "T", we have two 100-Ohm resistances in parallel, giving us the desired 50 Ohms for the RG-8/U. An swr check bears this out. The swr with two elements was a little over 1.5 to 1. With the four elements and the transformers, it dropped to almost 1 to 1. The element lengths and the spacing had been calculated from the following formulas: All ¼-wave elements, length in feet $= 246 \times .95/14.250 = 16.4$ feet. All element spacing, in feet $= 246/14.250 = 17.26$ feet.

A week of operation proved that the four phased elements equaled the 8-element parasitic beam. Many VKs and ZLs were worked, as well as some long-path contacts to



A view of the array from the highway with our old cattle barn in the background. This view is looking to the east off the back of the array and causes considerable comment among passing CBers. I often notice truck drivers looking out their windows with mike in hand . . . "Got your ears on, good buddy?"

the Indian Ocean, South Africa, and the South Atlantic. Another set of four elements was installed, one at a time, in line and phased, the same as shown in Fig. 3. The second group of four elements was delayed the proper number of degrees each by feeding them off another "T" with a 1¼-wavelength coax line.

The method of power division into eight equal parts is patterned after the way you would divide the power to eight two meter beams. I used this method very successfully in the 1950s on a 32-element beam for 144 MHz. Fig. 4 shows how it is done. No measurements have been made to find out exactly what the power division actually is between elements; however, judging by the array's performance, it must be fairly correct.

Swr measurements with various numbers of elements are as follows: 1 element, 1:1; 2 elements, 1.5:1; 3 elements, 3:1; 4 elements, 1:1; 5 elements, 2:1; 6 elements, 3:1; 7 elements, 2:1; 8 elements, 1.5:1. The addition of a ¼-wave Q transformer, Fig. 5, made up of 2 parallel lengths of 75-Ohm coax, as shown, raised the 25-Ohm output of the last "T" to 56 Ohms, close enough to 50 Ohms to give an swr of 1:1 for the transmitter to look into. Several weeks of tests on the completed 8-element phased array show that it tops the parasitic beam by a good S-unit. This is perhaps because I was never able to get all six directors and the reflector properly tuned for maximum gain. It appears that a parasitic element requires a much more perfect ground plane for tuning than does a driven element. At any rate, the all-driven array was much easier to get going than was the parasitic array. I suspect that an all-driven 4-element rotary beam would outperform a conventional yagi.

Construction

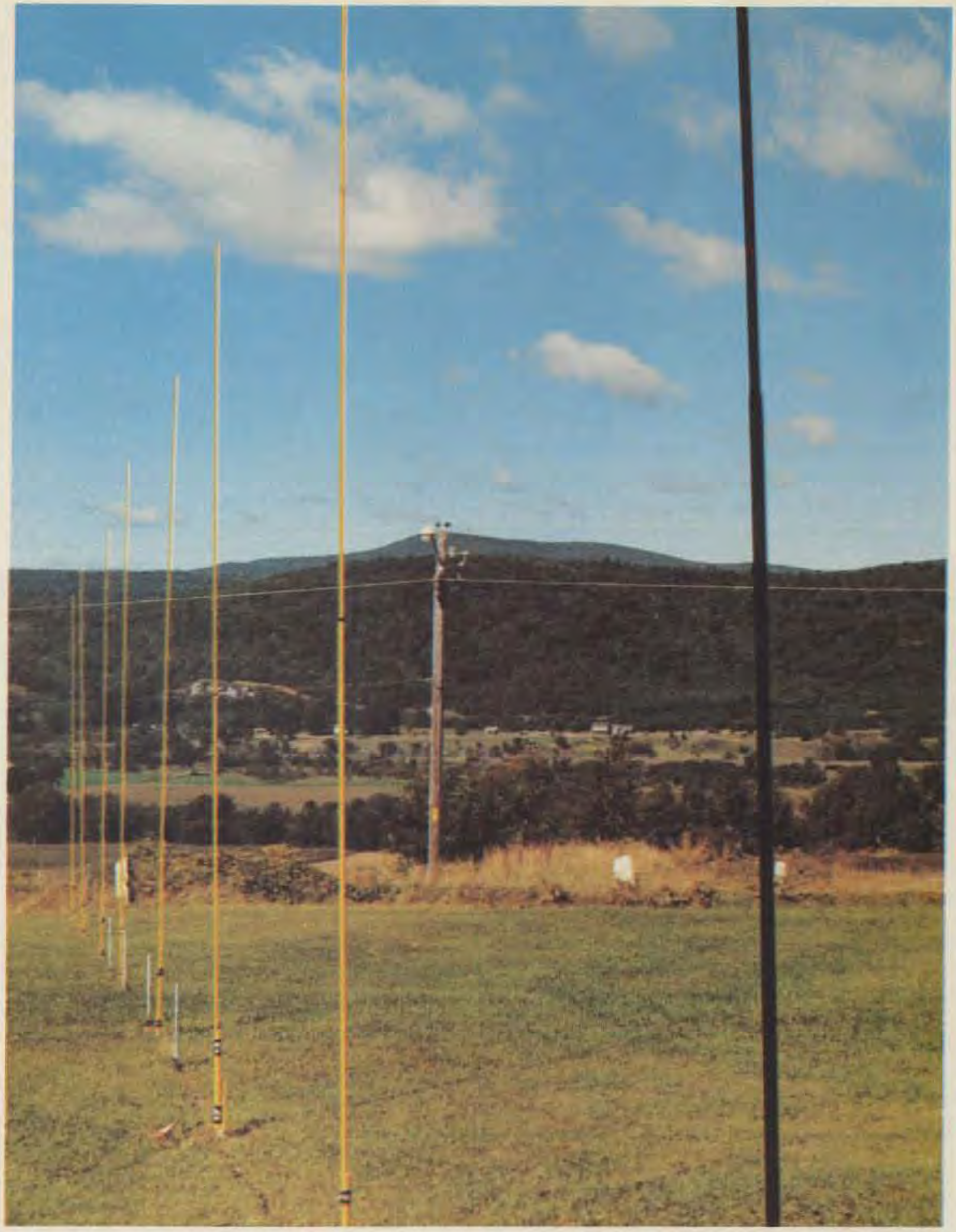
A readily available source of inexpensive tubing for this array is thin-walled galvanized steel electrical conduit, found at most electrical supply houses or discount stores. Each element is made up of a 10-foot top section of ½-inch diameter tubing telescoped into an 8-foot bottom section of ¾-inch diameter tubing. The two sections are accurately measured to 16.4 feet and then fastened together with three 10/32 machine screws tapped into the outside tube.

The ground post is a 5-foot section of 1-inch-diameter tubing driven 3 feet into the ground with a sledgehammer. Be careful to get it exactly vertical using a carpenter's level so that all your elements will line up nicely. Cut off the top 2 inches to get rid of the deformed part caused by the pounding.

The driven elements are each insulated from the ground posts with thick-walled plastic conduit or rigid plastic water pipe.

This is cut into 3-inch lengths and split lengthwise, one size to fit the ¾-inch conduit and one size to fit the 1-inch ground post. See Fig. 6. The RG-58/U is attached to the bottom of the element with a 10/32 machine screw, while the braid, after tinning, is clamped to the ground post along with 16 radials by using a stainless steel hose clamp right at ground level. The plastic insulators are squeezed into place with a C-clamp about 18 inches apart and held there with black vinyl electrical tape until the elements are secured with TV U-clamps.

Remember that the element length is from the top of the element to the point where the radials are clamped to the ground post. Fig. 7 shows the right and wrong way of attaching the radials. Keep the leads on the end of the coax as short as possible, as these add to the length of the driven element. It would be wise to give all the pieces of conduit a couple of coats of rustproof paint before erection. Also, put corks in the top of each element and ground post to keep out water which will freeze and split the tubing in the winter. Tape the joint of the ½- and ¾-inch tubes with vinyl tape for the same reason.

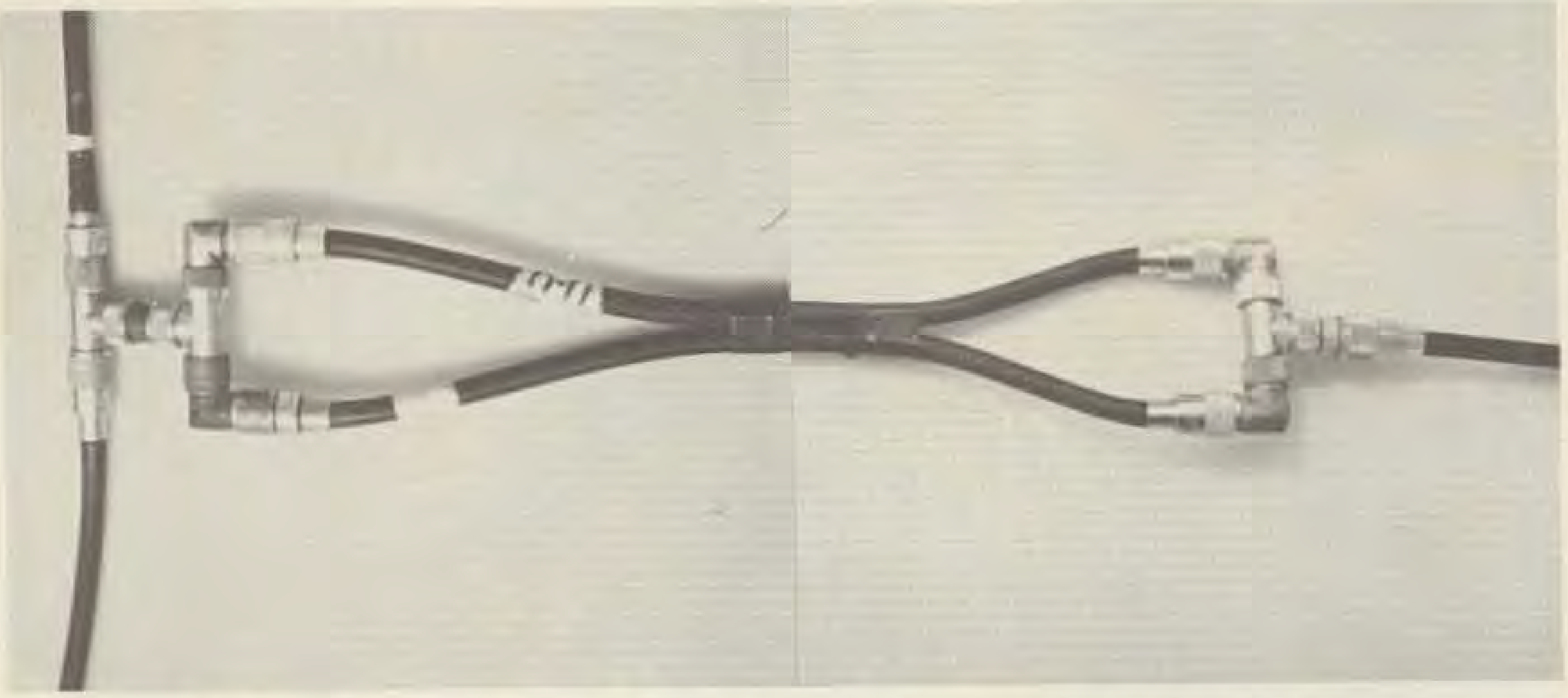


Looking west along the line of the array: The Connecticut River flows in the valley and the hills in the distance are in Vermont. Note that the top of the 7th element is just even with the horizon. A little trig with a pocket calculator tells us that our minimum angle of radiation is about 6 degrees.

Ground Plane

There have been a number of papers published recently[6] on the importance of ground radials or ground planes for vertical radiators. Most of these have been for single-element verticals or for shortened verticals. They have compared the efficiencies of several different ground planes using various numbers and various lengths of radials. A broadcast band station normally uses 120 radials, each 0.4 wavelengths long. If you plan to do this at 14 MHz for each of 8 elements, you will have to bury about 5 miles of wire in your yard, and if you do not want any TVI, you had better solder each place that the wires might touch each other or insulate them well. See Fig. 8. A poor joint will rectify your signal and generate harmonics.

Since I had found no information on the number of radials needed for an 8-element array, I decided to start with none and add them a few at a time until there was no longer any noticeable improvement. You have already read of the disastrous results with no radials and of the improvement as radials were added. If you decide to stop at 16 radials as I did, you will need 16 × 8 × 17 or about 2176 feet of wire, just under ½ of a mile. I bought two ¼-mile spools of #17 galvanized electric fence wire from the local farm supply store for $12. To solder the crossover points before burying the wire, I used acid core solder and then brushed the joint with baking soda to neutralize the acid. The radials were buried a maximum of 1 inch in the sod so that they would not get



This photo shows the use of coaxial fittings in construction of the 37.5-Ohm quarter-wave matching transformer. Refer to Fig. 5 for dimensions. RG-8/U from the transmitter connects at the bottom. The coax leaving the "T" at the top of the picture drives the right-hand and left-hand halves of the array, respectively.

tangled up in the lawn mower. The less "lossy" the dirt over the radials, the better. Fig. 8 shows the layout of the radial system. The dots indicate soldered crossover points.

Coaxial Cable

RG-8/U solid dielectric coax was used for the feedline from the transmitter to the first "T". RG-59/U, 75-Ohm, was used for the 37.5-Ohm ¼-wave transformer, and RG-58/U was used for the phasing harness. Of course, you could use the larger coax throughout if you have it available.

Results

How do you report on the merit of a new beam? The usual method is to set up a field-strength meter and rotate the beam, noting how the field strength varies with different headings. You could calculate the theoretical gain[7] or perhaps program a computer to do it for you. In this way, you could find out what the beam should do under certain conditions. What I wanted to know was what *would* the beam do under *actual* conditions. The only way to find this out is to call CQ DX and see from what direction your answers come. Then instantly switch back and forth between the beam and a fixed reference dipole and a reference ¼-wave ground plane antenna and request the DX station to give you comparative reports on the three antennas.

As a general rule of thumb, the gain of a beam increases by about 3 dB when you double its size. *The ARRL Antenna Handbook*[8] states that a 3-element phased endfire beam has an average gain of 5 dB depending on several variables, while a 6-element beam has a gain of 8 dB. In an attempt to measure the gain of our new array with a homemade field-strength meter with a remote indicating meter, we got a gain figure of 12 dB.[9] In a test with W1PFB/mobile on a hill 20 miles away in Vermont on a bearing of 270 degrees, Glen reported the array was S-9, the Hustler 4BTV was S-4, and the dipole was S-2. At six dB per S-unit, this looks like a 30 dB gain, 1,000 times in power; well, you know how S-meters are. The average VK and ZL station, however, also reports the array 3 to 5 S-units better than the two reference antennas. The proof of the pudding is in the high percentage (about 95%) of answers to CQ DX that come from VK, ZL, and other southwest Pacific Ocean areas.

A possible explanation for the reports of 20- to 30-dB gain at a distance of 10,000 miles from an antenna that should only have a gain of 9 dB is that perhaps its angle of radiation exactly matches the angle of propagation for that distance and that the angles of radiation of the 4BTV and the dipole do not. *The Handbook*[10] states in Table 1, p. 18, that at 14 MHz, signals arrive 99% of the time at between 6 degrees and 17 degrees and

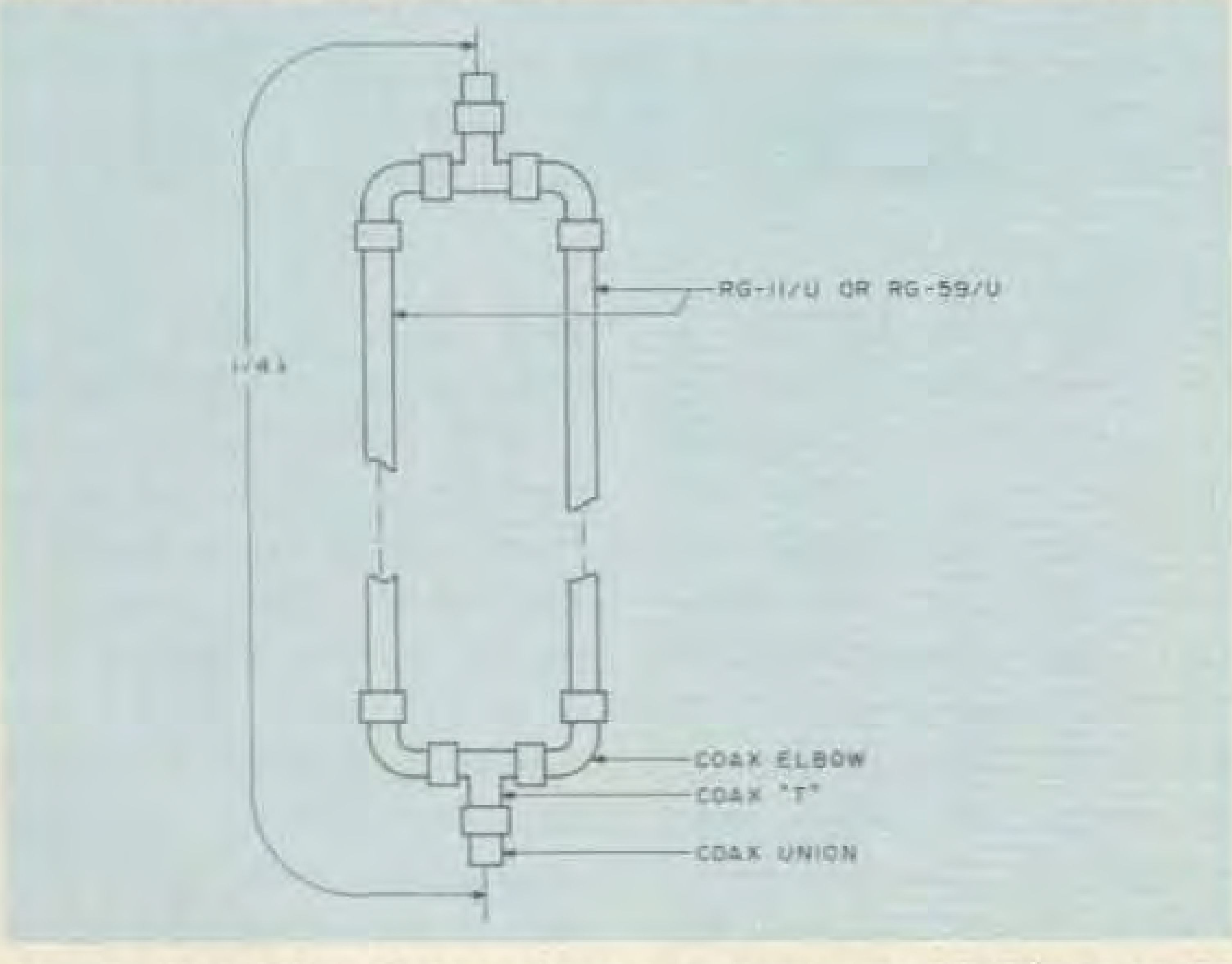


Fig. 5. 37.5-Ohm Q transformer—converts 25 Ohms to 56 Ohms.

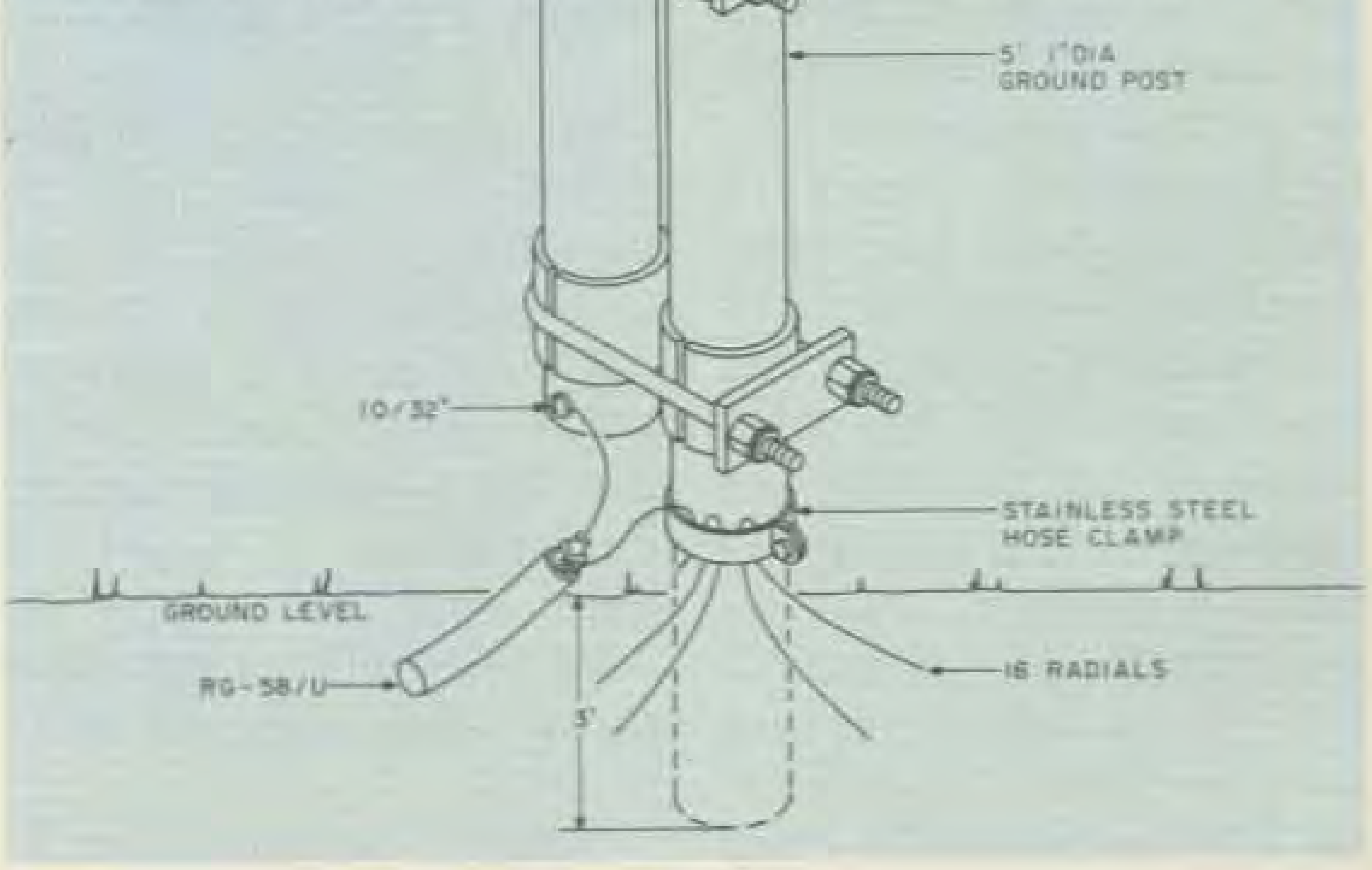


Fig. 6.

Each of the eight elements is attached to its ground post as shown, using split sections of plastic water pipe for insulators held in place with mylar™ electrical tape and clamped together with TV U-clamps. Refer to Fig. 6.

arrive 50% of the time between 6 and 11 degrees. It is also pointed out that since the maximum single hop via the F2 layer is 2500 miles,[11] a signal traveling from New Hampshire to Australia, 10,000 miles, would require a minimum of four hops. A signal radiated from a dipole ½ of a wave high would have a pattern like that in Fig. 9, with most of its power being radiated at an angle of 28 degrees. It would, therefore, require more hops to reach Australia, and since each hop attenuates the signal, it might be several S-units weaker than the array, thus accounting for the discrepancy in the gain figures between the array and the dipole.

Fig. 10 shows the vertical radiation of a vertical dipole with its center ¼ of a wave above ground. It is believed that a ¼-wave ground plane would have a similar pattern. Note that the effect of ground attenuation absorbs most of the radiation below 10 degrees. My 4BTV has 16 ¼-wave radials, more than usually used, but far less than the recommended 40 radials, each 0.4 of a wavelength long. Therefore, it may have a higher angle of radiation than the array and take one or two extra hops to reach Australia. Thus, with the ground attenuation and the extra hops, it might be even weaker than the dipole, and it appears to be. This same phenomenon, of course, also applies to rotary beams. For example, three identical beams with a gain of 8 dB will each exhibit completely different gains at a point 10,000 miles away, depending on the height at which they are mounted. The one exactly ½ of a wave above ground will be the weakest, the one 1 wave above ground will be an S-unit or so stronger, while the one 1½ waves high will be by far the strongest. At 2500 miles, however, they may be all equal.

Over a three-month period, more than 150 VKs and ZLs were worked, many of whom could not even be heard on the 4BTV or the dipole. QRM from the west is louder, of course, because the array points that way; however, most of these stations are still asleep at 6:00 am Eastern Time. The side-to-front and front-to-back ratios must be fairly good because QRM from Europe and South America is rarely a problem.

If you already have a quad at 60 to 100 feet, this array will not help you. If, on the other hand, you only have a tribander at 35 feet, you may do better in one direction with this phased array, saving the cost of a taller tower. If you are considering spending a bundle for a 60-foot tower and rotatable beam, you may do well to consider two or three of these arrays, each pointing toward needed new countries. Your ability to instantly switch direction with several of these arrays without waiting for a cumbersome rotary beam to turn is indeed a new experience in DXing.

This array, with its method of phasing and power division, may be scaled to other amateur bands. It is possible that top-hat loaded elements could be used on 80 and 40 to keep the height down to 16 feet.[12]

The directional characteristics, both horizontal

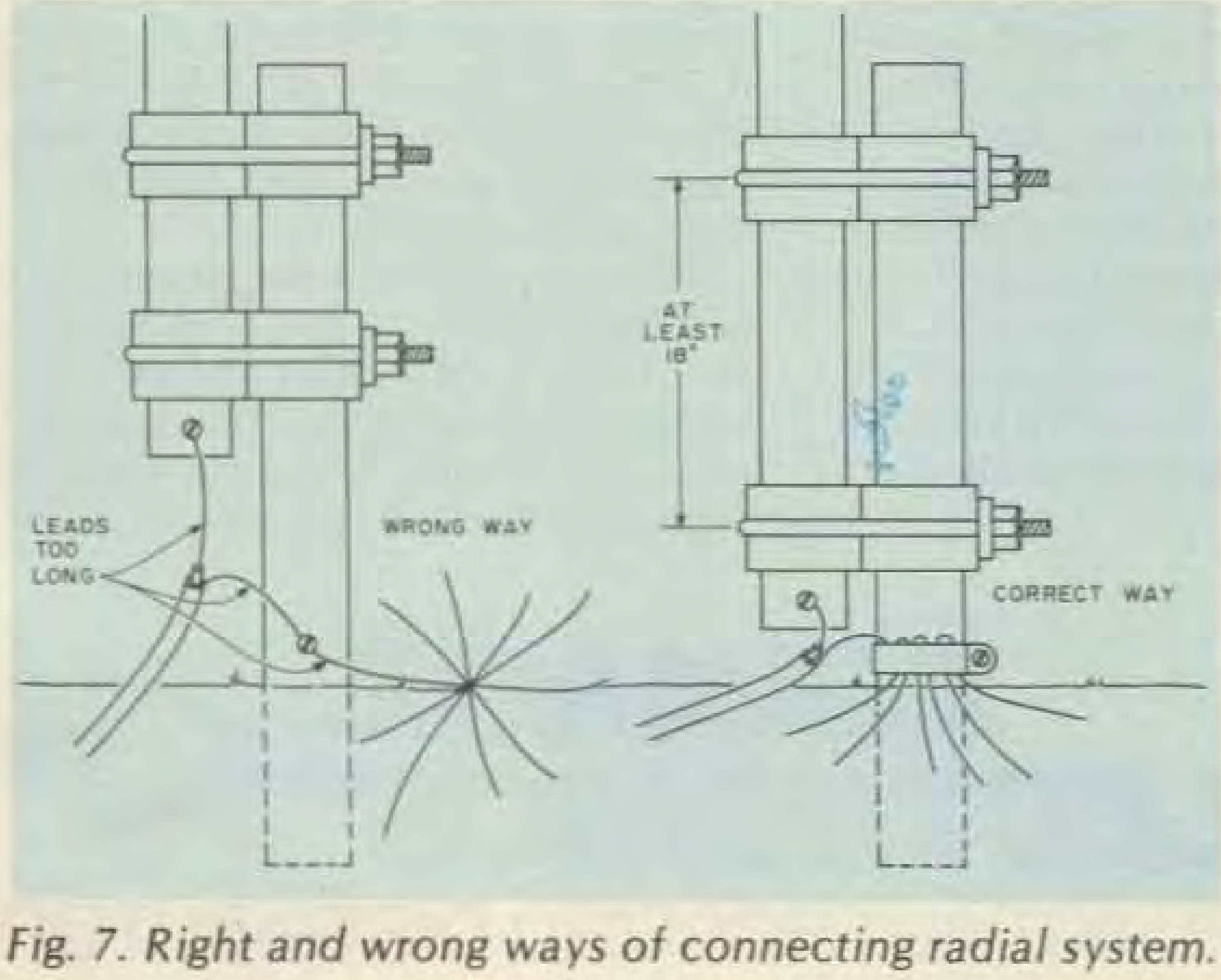


Fig. 7. Right and wrong ways of connecting radial system.

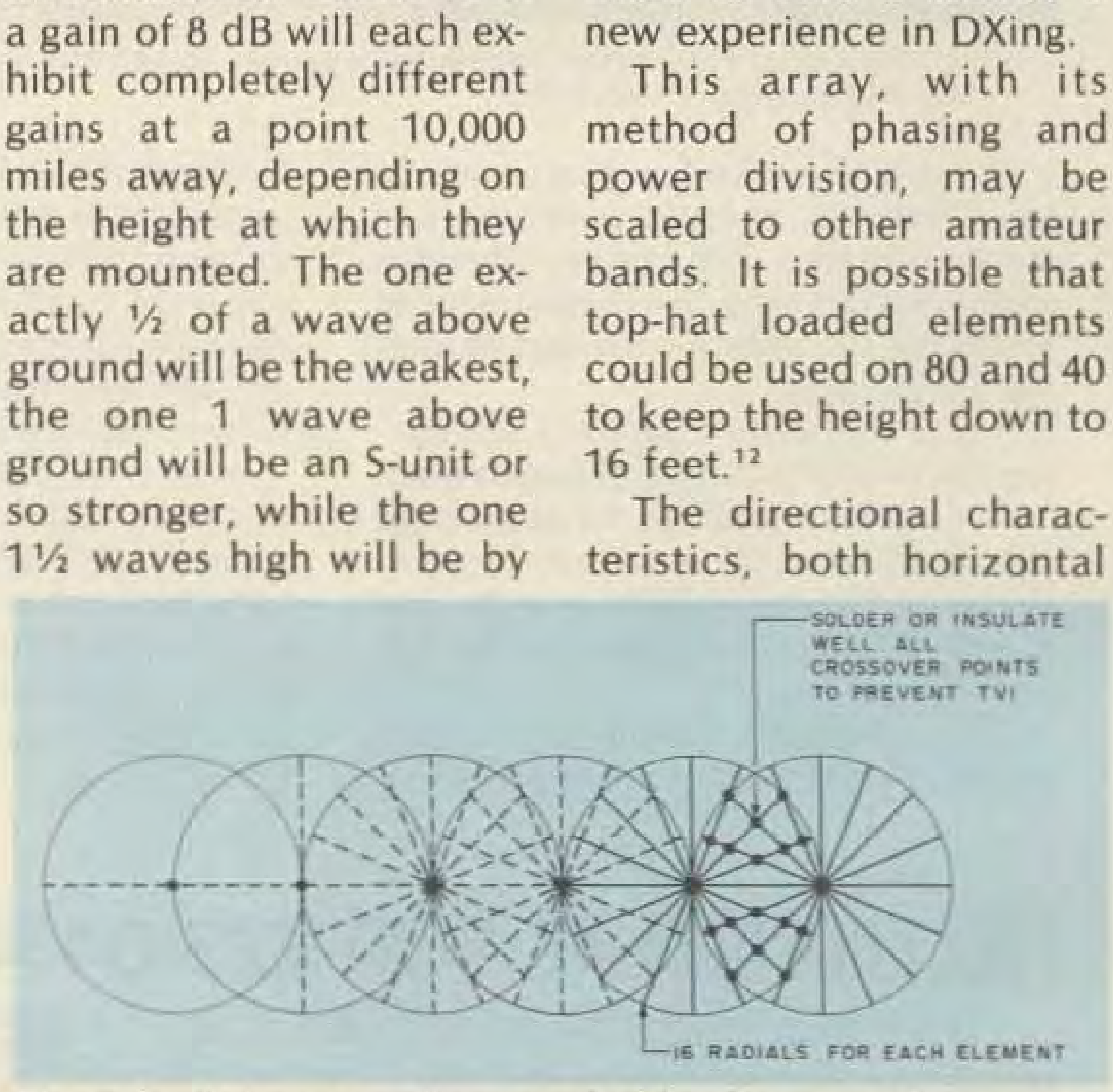


Fig. 8. Radial system shown in full for first two elements on the right. The other six are identical.

and vertical, of antenna arrays similar to the one discussed in this article may be found in various handbooks.[13]

The direction of radiation of this array may be switched end-for-end or broadside by bringing equal lengths of RG-58/U from each element into the shack to eight single-pole, three-position coaxial switches. Three different phasing harnesses would be switched into circuit.

Four more radials were added after this picture was taken, making a total of sixteen; all were from 16 to 20 feet in length. The author employed a trained mole; however, any sharp-pointed garden-weeding or cultivating tool may be used to scratch the shallow trench needed to bury the radial about 1 inch. Refer to Fig. 8.

Operation of the Array on 21 and 28 MHz

Recently, during a 10 meter band opening, I decided to check the swr of the 4BTV vertical on 28 MHz, and, to my surprise, it was 1:1. I was more surprised to find that the coaxial switch was in the 20 meter array position, not the 4BTV position. Further measurements showed the swr of the array on 10 meters to be as shown in Fig. 11. Next, the swr was measured on 21 MHz. These figures indicate that the array should work on both 10 and 15 meters, and indeed it does. On 10 meters, the swr is 1:1 around 28.5 MHz and is below 1.5:1 from 28.1 to 28.8 MHz as shown. On 15 meters, the swr is 1.3:1 at 21.150 and is below 1.7:1 from 21 to 21.450 MHz. Listening and transmitting tests confirmed that on the ten meter band the directivity was essentially the same as that on the 20 meter band. Signals from the west peaked up a couple of S-units, while signals from the south and northeast fell off a couple of S-units compared to the 4BTV and the dipole. On 21 MHz, the directivity was less pronounced, but the array proved to be effective, equal to or better than the 4BTV or dipole in the westerly direction.

Why does a 20 meter array work on 15 and 10 meters? Terman[7] states that an endfire array consists of identical antennas arranged along a line carrying equal currents excited so that there is a progressive phase difference between adjacent antennas equal in cycles to the spacing between these antennas in wavelength. He further states that the gain of the array is proportional to the length of the array, but is independent of the spacing of the elements provided that the spacing does not exceed a critical value of about 3/8 wavelength. Greater spacing is permissible under certain conditions. The array being described fulfills the above conditions on 14 MHz with a 90-degree phase lag and ¼-wave element spacing. On 21 MHz, using the same phasing harness, the phase lag becomes 135 degrees with the 3/8-wave spacing between elements. On 28 MHz, we have a 180-degree phase lag with ½-wave spacing. In other words, the phase lag between elements is correct for the element spacing on each of the three bands. The element lengths, however, are incorrect on 21 and 28 MHz. On 21 MHz, the elements are 3/8 of a wave long, as are the ¼-wave Q transformers. It is not quite clear why it works as well as it does on 15 meters. On

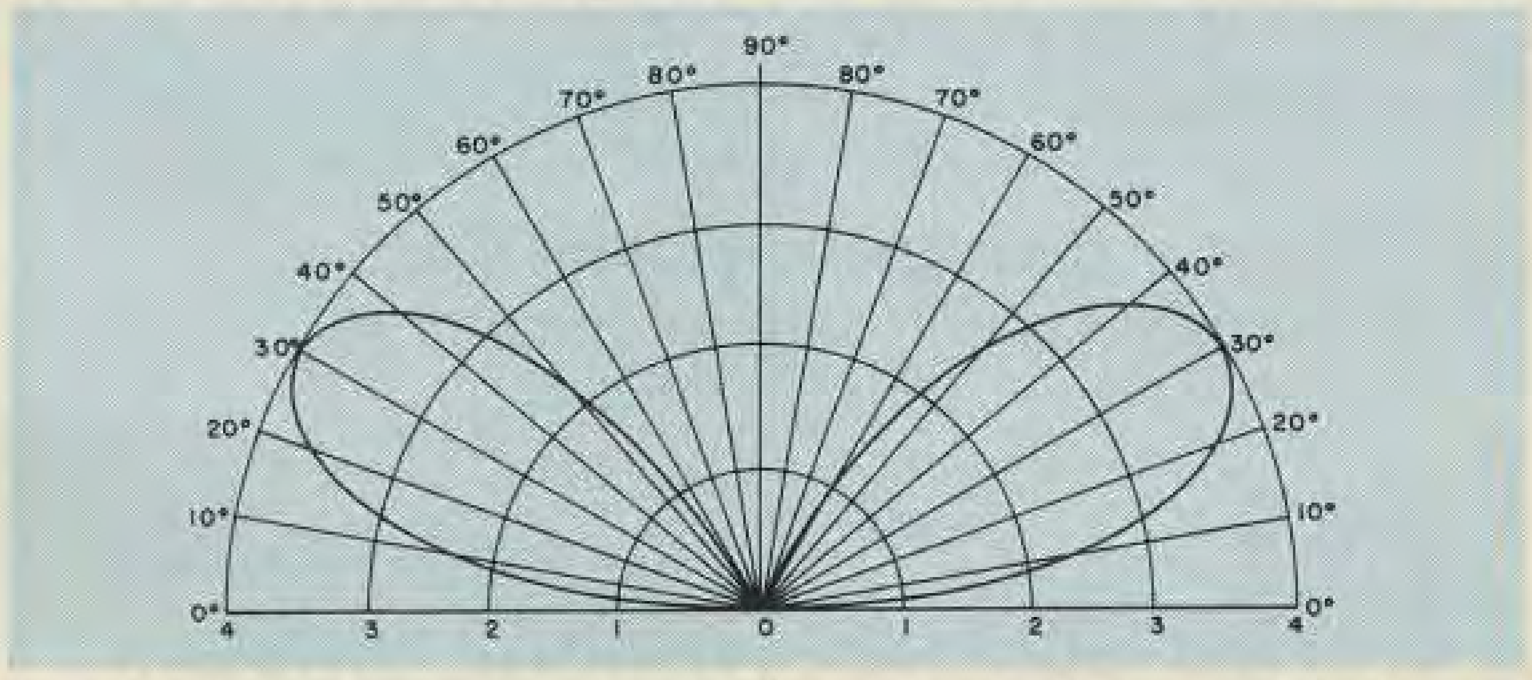


Fig. 9. Vertical angle of radiation of a half-wave dipole at a height of ½-wave above a perfectly conducting ground.

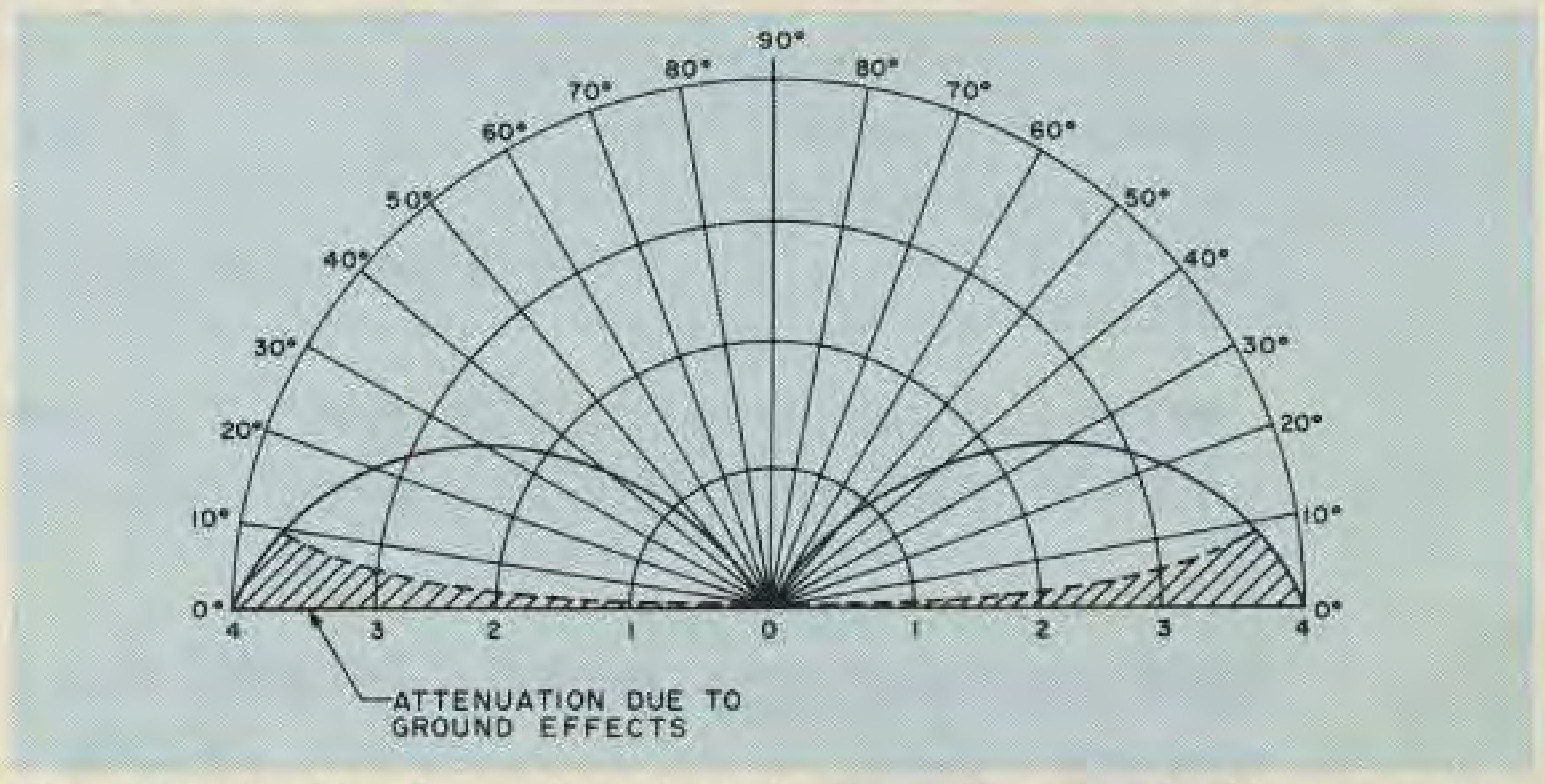


Fig. 10. Vertical angle of radiation from a half-wave vertical antenna whose center is ¼-wave above a perfectly conducting ground.

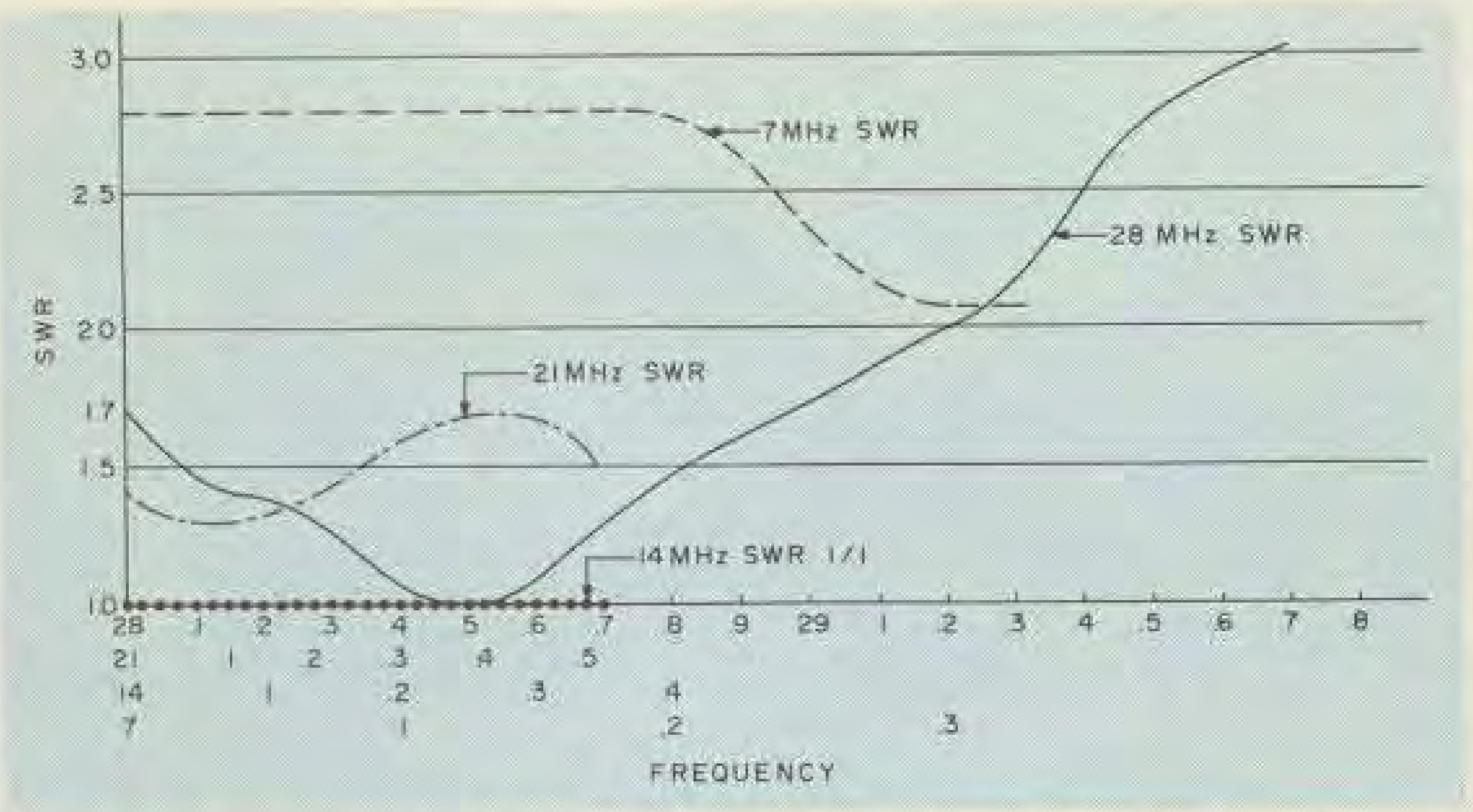


Fig. 11. Swr curves for 7 MHz through 28 MHz for the array.

28 MHz, where the elements are ½ of a wave long, it would appear that we are trying to feed a high impedance point with a low impedance feeder. There is undoubtedly a very high swr on the coax nearest to the elements. The losses will be low since the coax is short. Since our ¼-wave Q transformers are now ½ of a wave long, they no longer act as Q transformers but simply repeat the impedance from one end to the other. At each "T", we parallel these impedances and cut them in half, thus reducing the swr as we get nearer to the transmitter. Terman shows that the gain with ½-wave spacing is only about ½ that of ¼-wave spacing; however, since the array on 10 meters is twice as long as it is on 20 meters, the gain doubles and therefore is about the same as on 14 MHz.

P.S. It works like a bomb on CB. ■

References

1. Atchley, "Switchable 4-Element 80 Meter Phased Array," *QST*, March, 1965, p. 48.
Atchley, "360° Steerable Vertical Phased Array," *QST*, April, 1976, p. 27.
Atchley, "Up-dating Phased-Array Technology," *QST*, August, 1978, p. 22.
Lawson, "Simple Arrays of Vertical Antenna Elements," *QST*, May, 1971, p. 22.
Elliott, "Phased Verticals for 40," *QST*, April, 1972, p. 18.
Hall and Myers, "Phased Verticals," *QST*, August, 1972, p. 36.
Botts, "A Four-Element Vertical Beam for 40/15 Meters," *QST*, June, 1975, p. 30.
La Baume, "A Multiband Phased Vertical Array," *QST*, February, 1976, p. 28.
Fenwick and Schell, "Broadband, Steerable Phased Array," *QST*, April, 1977, p. 18.
2. Lawson, "75/80 Meter Vertical Square Array," *QST*, March, 1971, p. 18.
3. Mayo, "7 Mc Beam for the Small Yard," *QST*, September, 1952, p. 25.
Sevick, "The W2FMI 20 Meter Vertical Beam," *QST*, June, 1972, p. 14.
Jones, "7 Mc Vertical Parasitic Array," *QST*, November, 1973, p. 39.
4. *The ARRL Antenna Handbook*, 13th Edition, p. 323.
5. Terman, *Radio Engineer's Handbook*, 1st Edition, p. 800, McGraw-Hill Book Co.
6. Sevick, "Short Ground Radial Systems," *QST*, April, 1978, p. 30.
Stanley, "Optimum Ground Systems for Vertical Antennas," *QST*, December, 1976, p. 13.
7. Terman, *Radio Engineer's Handbook*, 1st Edition, p. 801, McGraw-Hill Book Co.
8. *The ARRL Antenna Handbook*, 13th Edition, p. 138.
9. *The Radio Amateur's Handbook*, ARRL, 1978 Edition, p. 531.
10. *The ARRL Antenna Handbook*, 13th Edition, p. 18.
11. *The ARRL Antenna Handbook*, 13th Edition, p. 17.
12. Sevick, "The W2FMI Ground Mounted Short Vertical," *QST*, March, 1973, p. 13.
13. Terman, *Electronic and Radio Engineering*, 4th Edition, pp. 872-880, McGraw-Hill Book Co.