THREE-ELEMENT VERTICAL DRIVEN ARRAY FOR 10 METERS

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Ten meters is wide open to Europe and Africa in the mornings, and to Japan and Australia in the evenings. But you just can't seem to break through the pileups — all the guys with their kilowatts and six-element monobanders at 70 feet grab the DX before you can even hit the microphone switch. Your barefoot transceiver and trap dipole just don't cut the mustard. Sure, you make a few contacts overseas — but your signal reports are always low, and no one wants to ragchew the way they do with those who are putting in better signals. Even if you had the money, your neighborhood's deed restrictions make a tower and rotatable beam out of the question, and an amplifier would only cause more TVI.

Sounds familiar? Well, why not try a vertical driven array? A three-element array for 10 meters is only 8 feet tall by 17 feet long, and should fit in the smallest backyard. The antenna in **Figure 1** is an end-fire array with elements 2 and 3 fed 90 and 180 degrees out of phase, respectively, relative to element 1. The array provides about 4.5-dB gain over a single quarter-wavelength vertical, has a front-to-back ratio of 15 to 20 dB, costs less than $30 to build (even if you buy everything new), and can be erected in a single weekend. Separate gamma matching for each element simplifies adjustment and provides a low VSWR. Its low height makes this array unobtrusive, and if you mount the elements in your backyard the neighbors won't even know it exists. The major lobe is fairly broad, and the beam heading can be switched 180 degrees by swapping the phasing lines to elements 1 and 3.

Construction

The elements are made of 3/4-inch diameter EMT conduit, which sells in hardware stores for under $3 a 10-foot section. The gamma-matching rods are made from 1/2-inch diameter EMT conduit, which runs about $2 per 10-foot section. The shorting bar, clamps, and coax-connector support are made from the U-shaped two-hole straps commonly sold as wall fasteners for 3/4-inch conduit (see **Figure 2**). These usually sell for about $1.25 per dozen. Radials for each element are quarter-wavelength sections of whatever size wire you happen to have on hand. It doesn't matter whether the radial wires are solid or stranded, and insulation on the radials makes no difference in performance.

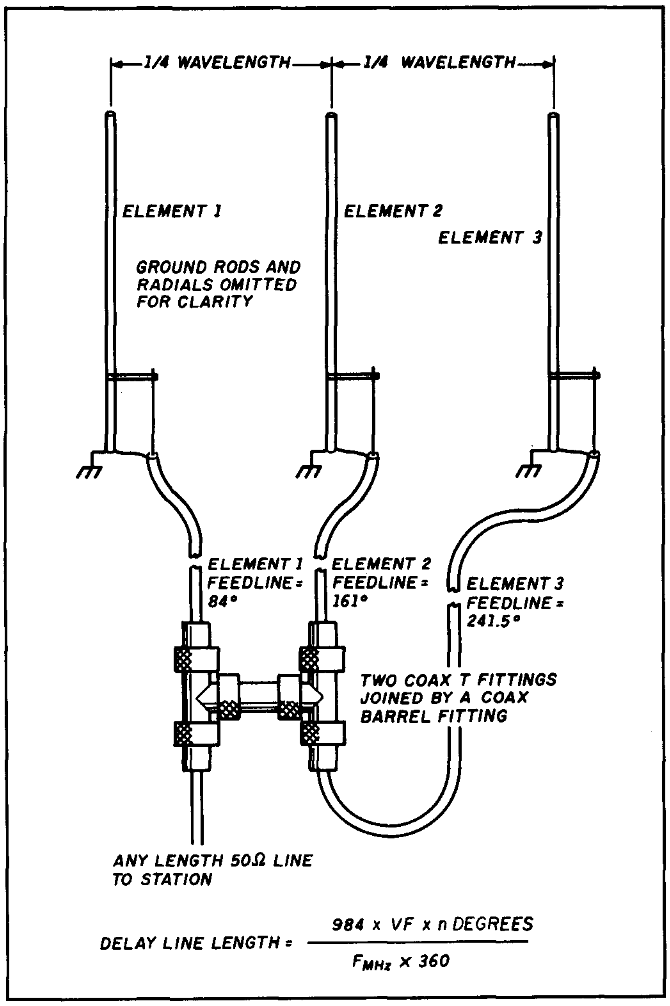
Element lengths

Antenna elements constructed of tubing should be slightly shorter than quarter-wavelength elements made of wire. The formula $230/F_{MHz}$ results in element lengths of 8 feet at 28.5 MHz, which will provide a reasonably low VSWR over the entire 10-meter band. After the elements have been cut, deburr the cut ends with a file and drill four evenly spaced 3/32-inch holes around the circumference and 1/4 to 1/2 inch from one end of each element. You'll attach the radials and coax connectors at these points later with no. 6 self-tapping sheet metal screws.

Gamma rods

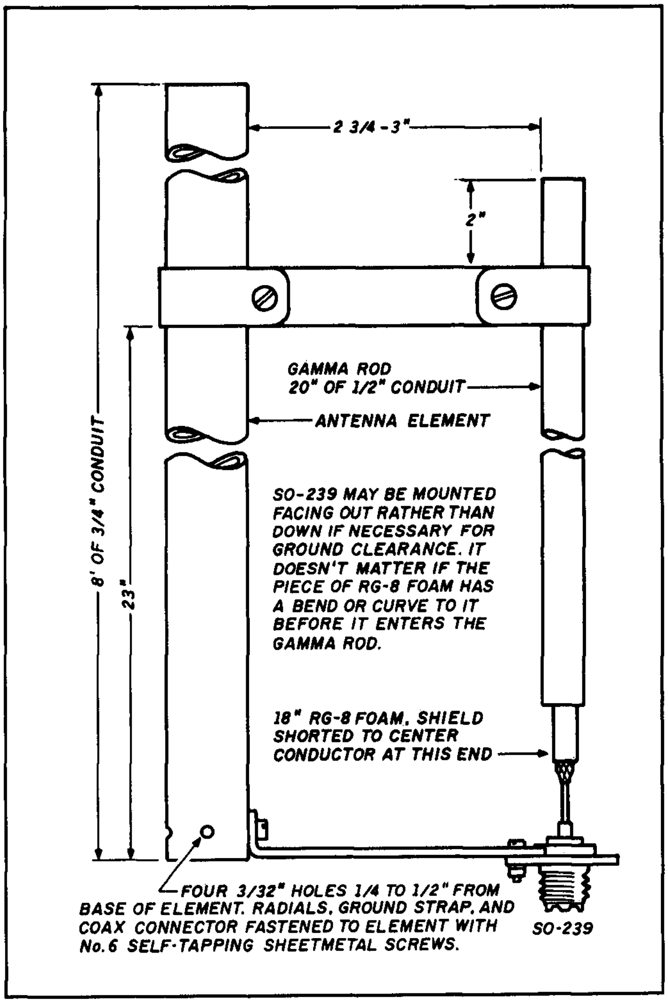
The gamma rod and variable gamma capacitor for each element consists of a 20-inch piece of 1/2-inch conduit, an 18-inch piece of RG-8 foam dielectric coaxial cable, four conduit straps, and an SO-239 female coaxial cable connector. Cut and deburr the piece of conduit, then strip 1.5 inches of insulation from one end of the piece of RG-8 foam coax. Fold back the braid and remove 1 inch of the center dielectric; then solder the braid to the center conductor. Tape and seal the other end of the cable to prevent moisture contamination. Next, flatten two of the conduit

FIGURE 1



Three-element driven array for 28 MHz. Phasing lines are cut according to formula in text.

FIGURE 2



Assembling gamma rod and antenna element.

straps (a hammer works fine for this). File a notch in the end of one strap so the hole in the strap will mate with one of the holes on the SO-239's mounting flange. Fasten the strap to the connector with a 4-40 screw, lockwasher, and nut as shown in **Figure 3**. Bend the other end of this strap as indicated, and fasten it to the bottom of one element with a no. 6 self-tapping sheet metal screw.

Gamma assembly

Make the shorting bar clamps by straightening the "ears" on the two remaining straps. Slip one modified strap onto the element, slide the other onto the gamma rod, place the remaining previously flattened strap between them (see **Figure 3**), and fasten tightly with machine screws, lockwashers, and nuts. Tighten the screws to form the clamps; they can be loosened for adjustment. Slip the already prepared section of coaxial cable into the gamma rod (don't worry about the sloppy fit — it won't make any difference in performance) and solder the shorted end of the cable to the center conductor of the SO-239.

The gamma rod with the cable inside makes an adjustable tubular capacitor of about 100 pF, which eliminates the expense of finding a suitable transmitting-type variable capacitor and the hassle of building some sort of weatherproof enclosure for each element. Loosen the clamps on the shorting bar and set the top edge of the gamma rod clamp 2 inches from the top of the rod and the bottom edge of the element clamp 23 inches from the base of the element. These dimensions will be your starting points during adjustment and tuneup. Tighten the clamps, set the element aside, and prepare identical matching sections for elements 2 and 3. It should take only a couple of hours to build all three elements.

Element mounting

The elements should be spaced a quarter wavelength apart using the formula $246/F_{MHz}$ (8 feet, 7 inches at 28.5 MHz), and mounted so they are in line with the compass bearing you wish to favor. I put mine on a wooden picket fence running due east and west; this gives me good coverage of Europe and Africa in one direction, and Australia and Japan in the other. As the main lobe is fairly broad, precise aiming isn't necessary with this array. The elements are fastened to the fence with conduit straps and wood screws. If you don't have a handy wooden fence running in the right direction, you can fasten the elements to wooden posts set deep enough to ensure that they won't topple over if disturbed.

The importance of a good ground system

I can't overemphasize the importance of a good ground system for this or any other type of ground-mounted vertical array. Remember, the efficiency of a grounded vertical antenna is directly related to the quality of its ground system. This array *will* radiate with no ground system at all (although it will be difficult to tune) and will still provide about 4.5 dB of gain, but that gain is referenced to a single *similar* element. The efficiency of a quarter-wavelength vertical over poor ground may be 25 percent or less, which means that a poorly grounded array of this type would barely achieve the efficiency of a single horizontal dipole.

Ground losses

The ARRL Antenna Book lists the loss resistance for a quarter-wavelength vertical with only four radials as 29 ohms! Because loss resistance is added in series to radiation resistance, four radials on a vertical is equivalent to putting a 30-ohm resistor in series with your feedline. Eight radials drops the loss resistance to 18 ohms, while 16 radials lowers it to only 9 ohms. While this isn't ideal, it's a figure most of us can live with.

An ideal ground system would consist of 120 or more quarter-wavelength radials fanned out equally around the base of each element, but a reasonable compromise can be achieved using a ground rod and 16 quarter-wavelength radials for each element. Obviously, the more radials the better, with 16 per element as a minimum starting figure. However, if you decide to install more than 16 radials, remember that you'll need to double the number of radials *per element* to achieve any appreciable reduction in ground loss. The next step up from 16 would be 32 radials, and the step after that would be 64 — that's a total of 192 radials!

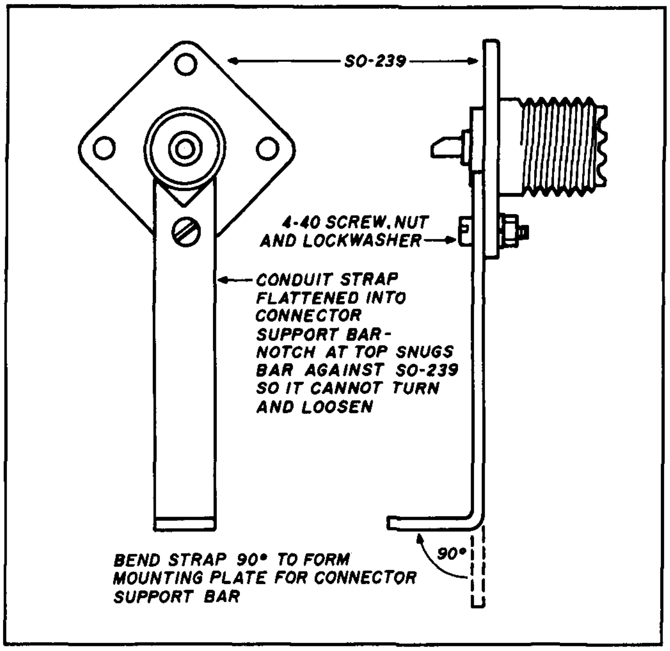
The ground screen

An alternative to installing a radial system is to use metal screening or hardware cloth. As long as all the joints are bonded together electrically, you can lay the metal mesh directly on the ground, secure it, and let the grass grow up through it. Eventually you won't even be able to tell it's there. Such a ground screen should cover the area immediately under the array and extend a quarter wavelength from the sides and ends. Individual strips of screening material must be soldered or welded to adjoining strips every few inches. That much hardware cloth (nearly 700 square feet) would be pretty expensive, which is why I used radials. But if you happen to have enough screen on hand, give it a try. It will make a nearly perfect ground for your array, and cut ground losses to nearly zero.

Ground rod and radial construction

Each element in my array has its own ground rod made from 4-foot pieces of steel reinforcing rod (rebar), hammered into the ground at the base of the element until only the top 2 inches stick out. Perhaps copper ground rods would be better, but rebar is cheap, durable, and readily available in my area. You could also use 4-foot sections of conduit in place of the rebar. Longer ground rods might be better, but 4-foot rods are difficult enough to drive into the soil. Bond the ground rod to the base of the element with a short piece of heavy wire or braid.

FIGURE 3



Connector support bar is fashioned from conduit strap.

The quarter-wavelength radials are cut to the formula $234/F_{MHz}$, which makes them 8 feet, 2-1/2 inches long at 28.5 MHz. I used inexpensive four-conductor telephone hookup wire because I had it on hand, cut four sections for each element to the proper length, separated the four wires in each section from their outer covering, and fastened them to the bottoms of the elements with ring connectors and sheet metal screws. Any wire of any size will do, as long as the radials are close to the right length. Ideally, the radials should be fanned out around the base of each element evenly; however, if you don't have the space, don't worry too much about it. There will be some pattern skewing in the direction of the greatest number of radials, but the array will still function just fine. Some people like to bury their radials; I use U-shaped pieces of stiff wire (ordinary bobby pins work well) to peg the radials to the ground at approximately 1-foot intervals, so people won't trip over them.

Phasing lines

As shown in **Figure 1**, the phasing or delay lines for this array are brought to a common point and connected together by a "plumber's delight" arrangement of two coaxial T fittings joined by a coaxial barrel connector. One feedline of any length of 50-ohm coax goes to the station. I recommend Belden 9913, RG-8 Foam, RG-8, or RG-8X for long runs. Stay away from RG-58 unless the transmission line going to your shack is shorter than about 50 feet. Cut the remaining three feedlines to the elements so that element 2 is 90 degrees out of phase with element 1, and element 3 is 180 degrees out of phase with element 1. Cut the phasing lines according to the formula:

$$\frac{984 \times VF \times n\ degrees}{F_{MHz} \times 360} \tag{1}$$

where VF = the velocity factor of the coaxial cable used.

This gives you the *electrical* length of a piece of coaxial cable n degrees long. Thus, element 1 is fed with a 90-degree (quarter wavelength) section of coaxial cable; element 2, if it is to be 90 degrees out of phase with element 1, requires a 180-degree section (half wavelength); and element 3, which you want to be 180 degrees out of phase with element 1, takes a 270-degree section (three-quarter wavelength). However, since there's mutual coupling among the elements in the array, the line lengths must be adjusted from these values somewhat to provide a proper feed. The line to element 1 should be 84 degrees long, the line to element 2 should be 161 degrees, and the line to element 3 should be 241.5 degrees long. I used RG-8X coaxial cable, which has a velocity factor of 0.75, to construct my delay lines. The feedline for element 1 is 6 feet, for element 2 it's 11.5 feet, and for element 3 it's 17 feet 4 inches. These lengths include the coaxial connectors at the ends of each feedline. If you use a different type of coaxial cable, with a different velocity factor, you'll have to refigure the feedline lengths. Chapter 24 of *The ARRL Antenna Book* lists the velocity factors of popular coaxial cables.

Adjustment

Before you connect the phasing lines to the elements, you must first tune each element to resonance. Without a feedline attached to either element 2 or 3, but with all three elements mounted in place, connect a VSWR bridge to the base of element 1 directly through a short piece of 50-ohm coax, and connect the meter to your transceiver through the feedline you'll use to drive the array. Adjust the position of the clamps on the element and gamma rod for lowest VSWR (making sure the transmitter is off while you work on the antenna, of course).

Obtaining lowest VSWR

First move the shorting bar up and down both the element and the gamma rod in small increments, until you reach the point of lowest VSWR. Then move the gamma rod only up and down in its clamp (this adjusts the variable capacitor) to bring the VSWR down further. By alternating these adjustments — first the shorting bar, and then the gamma capacitor, you should be able to find a point where the VSWR is nearly 1:1. Once you've found this point, tighten the clamps securely, and repeat the procedure for each of the other two elements. Go back and check that element 1 is still in tune. (Remember, there's mutual coupling among the elements and all adjustments are somewhat interdependent.) Repeat these adjustments until each element's VSWR is as close to 1 as possible.

Now connect the three delay lines to the elements, and their opposite ends to the main feedline, as shown in **Figure 1**. Apply power to the array. The VSWR at the station should be around 1.5:1. If it isn't, and all the elements are close to 1:1 at their feedpoints when tuned individually, you can feed the array through a matching network located at the transmitter end of the feedline to make your transistorized finals happy. Tuning will differ from one installation to another, depending upon ground losses, proximity to nearby conducting objects, and the number of radials attached to each element.

That's all there is to it. The direction of maximum radiation or reception will be in line with the array from element 1 to element 3. To switch the direction of the array, simply connect the feedline of element 1 to element 3, and the feedline of element 3 to element 1.

Performance

I don't have an antenna range, but on-the-air tests comparing the array with a 10-meter dipole at 35 feet indicate that the array beats the dipole by a minimum of 1 to 2 S-units — and sometimes (especially if the other station is using vertical polarization) by as much as 4 to 5 S-units. The low angle of radiation presented by vertical antennas helps on those long DX contacts, and the vertical array seems less susceptible to atmospheric noise than the dipole — although it is more susceptible to manmade noise. Stations off the back of the array are typically 4 to 6 S-units weaker than with the dipole, which helps when you're trying to pull a weak one through QRM.

Adding more elements

I like a three-element design for this array because of its broad main lobe, and because it simplifies beam pattern switching. I just have to swap the feedlines to elements 1 and 3 to "turn" the beam 180 degrees. However, if you wish to work in one direction only, or if you don't mind changing several different feedlines, there's no reason why you can't add more elements to this array. The theoretical gain of an array of this type is 10 log(N), where N equals the number of elements. Thus, maintaining quarter-wavelength spacing between elements, an array with four elements would have a gain of 6 dB, five elements would give you 7 dB, and six elements would give 7.8 dB over a single similar element. Actual gain figures will, of course, be slightly lower, depending upon ground losses, feedline losses, and proximity to nearby objects. Remember that adding elements will narrow the beamwidth, which will make aiming the beam more critical.

The effects of mutual impedance among the elements become more critical as the number of elements increases; so do delay line losses. You'll want to use only high quality, low loss coax for your delay lines, and you'll probably want to use the current-forcing method of feeding multi-element arrays described in Chapter 8 of *The ARRL Antenna Book*. However, the math and measurements involved in using the current-forcing method are quite cumbersome. If you're in the mood to experiment, you might try delay line lengths of 322 degrees for element 4, 402.5 degrees for element 5, and 483 degrees for element 6.

I'd be interested in hearing from others who build this array — especially from those who adapt it to other bands, or add additional elements. **hr**