

four-element collinear antenna for 440 MHz

Complete
construction details
for a
high-performance,
omnidirectional
antenna for 440 MHz
that is built from
easy-to-find materials
and provides
up to 6-dB gain
over a dipole

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Regardless of its design, a vertical omnidirectional gain antenna achieves its gain by the same process. It simply compresses the energy down on to the horizon where it is useful, and as a result, it wastes less radiating into the ground and up into the sky. Uhf antennas usually accomplish this by feeding several vertically mounted elements in phase so that the energy will combine itself into a pattern similar to that shown in fig. 1. These elements can all be fed in series, as Franklin, the originator of the collinear, did. This is the same system used by many commercial models (fig. 2). The elements can also be fed in parallel as I have done.

At first the series method seems much easier. A few inverted pieces of coax or a wire with some bends here and there and you're done. However, this approach has several big disadvantages. First of all, all the construction errors are cumulative. If you're slightly out of resonance at the

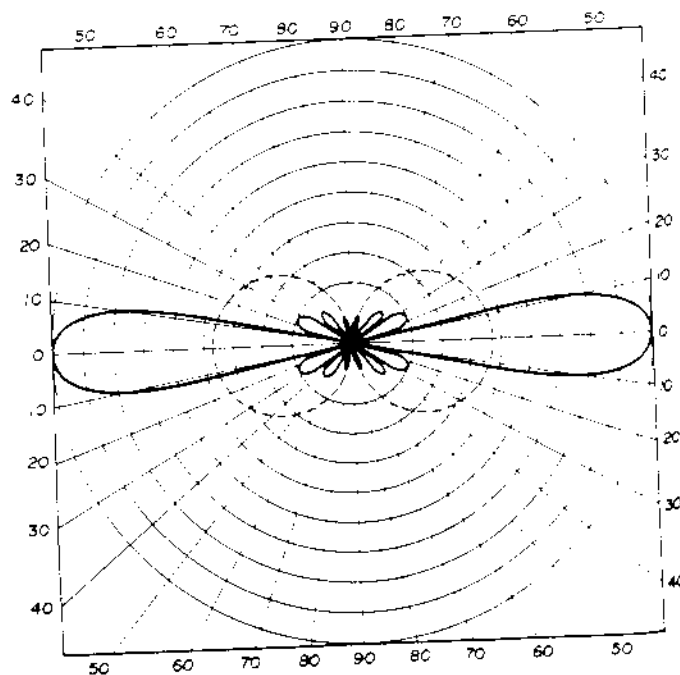


fig. 1. Vertical field strength of the four-element collinear (solid line) vs the dipole (dashed line). Collinear elements are positioned for omnidirectional pattern.

bottom, you can be sure that you're way out at the top. By its nature the series-fed collinear is a very touchy thing to get working properly and has very narrow band-width. Also, it must be supported by a low-loss pole or suspended from above. If it doesn't work when it's built, you have your hands full trying to find out why.

On the other hand, the parallel approach offers several advantages. First, all the elements exhibit 50-ohm input impedance and can be individually adjusted with a wattmeter. Secondly, the design is very rugged and the metal support pole can be grounded for lightning protection. In addition, the bandwidth of the antenna is at least 30 MHz and the elements can be positioned for either an omnidirectional or an offset pattern. Finally, it *will* work the first time you try it!

the dipole

Since the theory of the dipole is well known and covered in great detail in most antenna discussions, I won't dwell on it. The reason I selected the dipole over a folded dipole or a J-pole configuration is because of its simplicity and very wide bandwidth. It is constructed from 1/2-

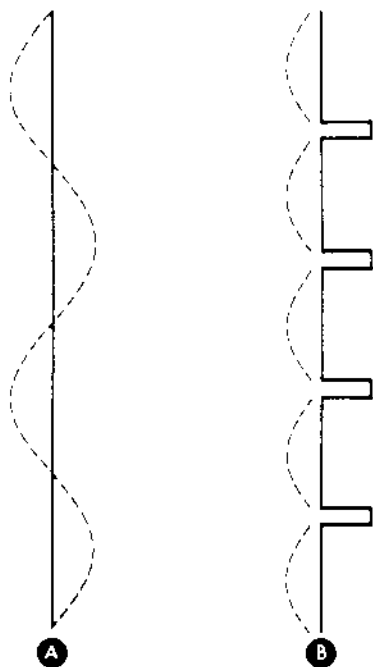


fig. 2. Franklin antennas. Natural standing-wave current distribution is shown in (A). Co-phased standing-wave current distribution is shown in (B).

inch copper water pipe and 1/4-inch soft-drawn copper tubing. Both are excellent conductors and are readily available from most hardware stores.

As shown in fig. 3, the impedance of the dipole increases from the center to a maximum of about 70 ohms at the ends. The exact impedance depends on the length-to-diameter ratio of the element as well as the distance from other objects.

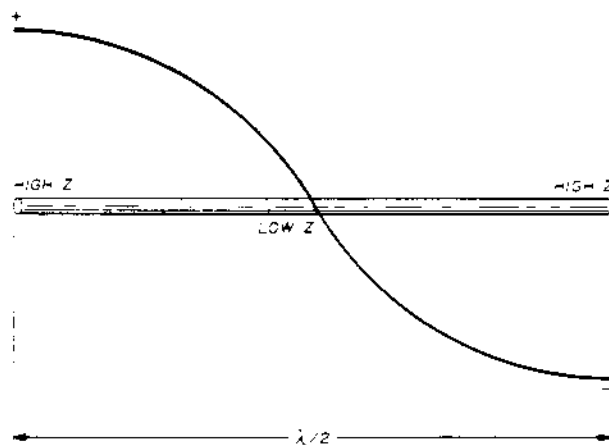


fig. 3. Half-wave dipole. Since there is no voltage to ground at the center, the element may be grounded to the support mast at this point.

At one point along either side a place will be found that will match perfectly into a 50-ohm transmission line. This is where the gamma rod is attached. Because of all the unknown variables, this point must be found by trial and error. With the antenna described here the gamma rod is attached 3-inches from the center.

To compensate for the inductive reactance of the gamma rod and to achieve a perfect impedance match, a series gamma capacitor is required. This consists of a length of number-12 Teflon-insulated wire fitted inside the end of the gamma rod (fig. 9). A variable capacitor could be used but it would be hard to find one as inexpensive and weatherproof as the Teflon-insulated wire. Teflon was picked for its excellent electrical properties as well as for its resistance to the weather.

If Teflon is not available the center conductor of some RG-58/U coax will do, but the length will not be quite the same. If you use number-12 Teflon-insulated wire and follow the dimensions,

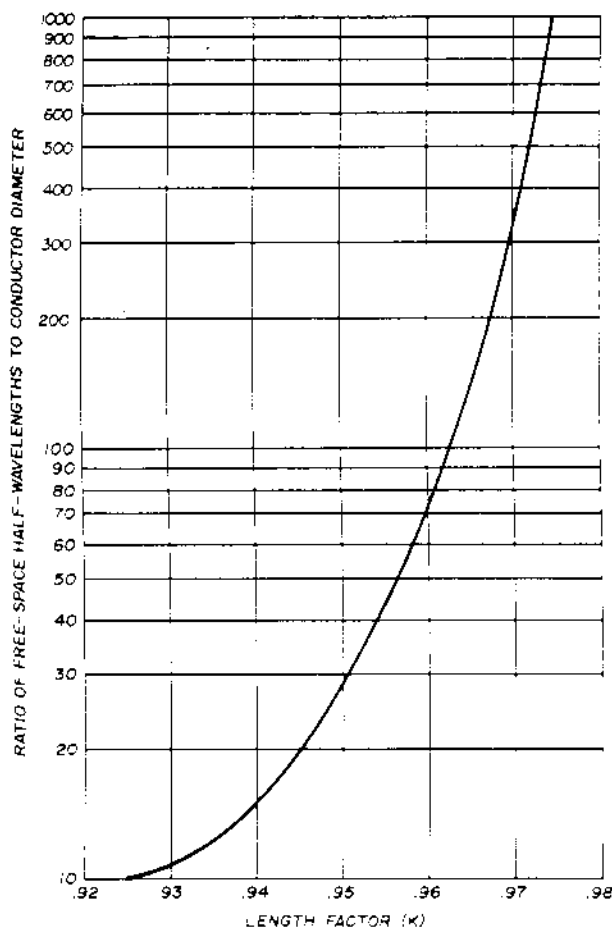


fig. 4. Effect of element diameter on the length of a half-wave dipole.

chances are that no tuning will be required.

As with the input impedance, dipole length is also affected by several variables. The approximate length is given by the formula

$$\text{length (inches)} = \frac{5905k}{\text{freq (MHz)}}$$

The k factor compensates for the shortening effect that increasing element diameter has on the length. This is plotted in fig. 4. With a length-to-diameter ratio of 24:1, k is equal to 0.9475. Therefore,

$$\begin{aligned} \text{length (inches)} &= \frac{(5905) (0.9475)}{\text{freq (MHz)}} = \\ &= \frac{5595}{\text{MHz}} \end{aligned}$$

or a length of 12.7 inches at 440 MHz. Again, unfortunately, the graph of fig. 4 doesn't take into account the additional shortening effect of the support mast. The increased capacitance of the mast causes the actual resonant length to decrease by an additional 3½% (12¼ inch-

es). This is mentioned mainly for those of you who wish to scale this basic design to another band. This information will get you close enough so that only a little trimming will be necessary.

matching harness

The function of the matching harness is to split the power evenly and deliver it to the elements in phase and at the proper impedance. Fig. 5 shows that, in a transmission line of even half wavelengths, the voltage and current are exactly the same at the load as at the input. This is true regardless of the vswr, assuming a lossless line. Therefore, it follows that the impedance is also the same at both ends.

The graph of fig. 5 also shows that for an odd 1/4-wavelength section the input and the load impedance are inverted. In other words, if at the input the voltage peaks and the current nulls, at the load the current would be at a peak and the voltage would null. This relationship is given by

$$\text{input impedance} = \frac{Z_0^2}{Z_r}$$

Where Z_0 is the characteristic impedance of the line and Z_r is the load impedance (must be resistive).

Now, look at the harness schematic in fig. 6. Since each 50-ohm dipole is fed with a one-wavelength section the impedance at the input end is also 50 ohms. The four 50-ohm sections pair into two tees. Therefore, the impedance at the tees becomes 25 ohms. The tees are then

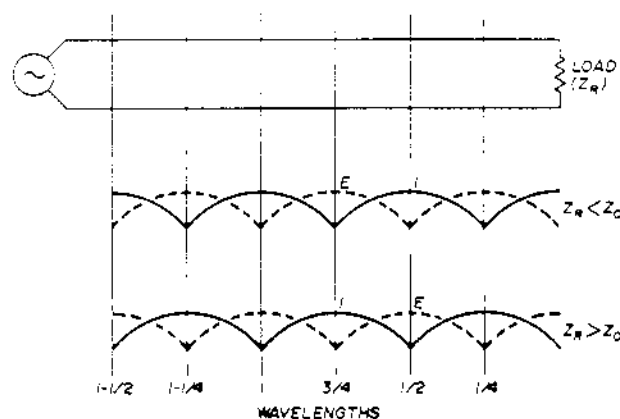


fig. 5. Standing waves on a transmission line terminated in a resistive load.

connected to a 1-1/4 wavelength section of transmission line. Therefore, from the above equation

$$\begin{aligned} \text{input impedance} &= \frac{50 \text{ ohms}^2}{25 \text{ ohms}} \\ &= \frac{2500}{25} = 100 \text{ ohms} \end{aligned}$$

The two 5/4-wavelength lines are then connected through a tee, providing an input impedance of 50 ohms.

antenna spacing

With the dipoles and the harness out of the way only two things remain. The dipole to mounting pole spacing and the dipole to dipole spacing.

The horizontal field-strength patterns in fig. 7 were plotted using one of the dipoles mounted with a clamp to a pole on the roof of my house. The skewing of the patterns is due to the large relative

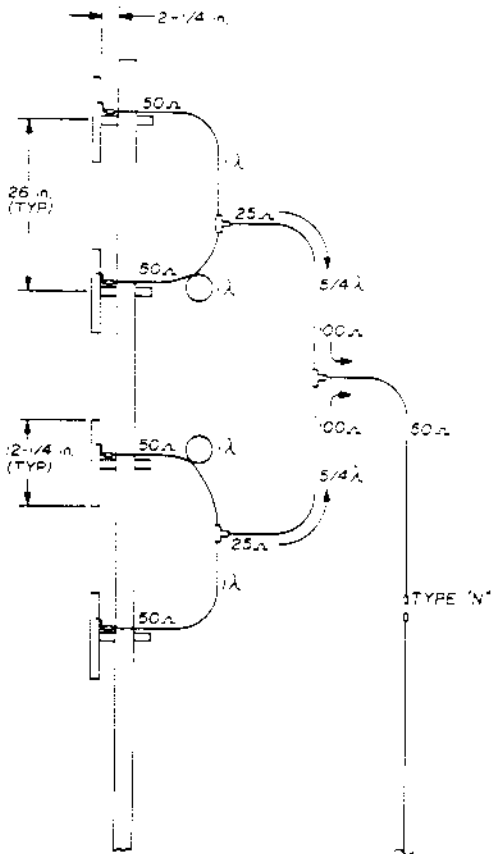


fig. 6. Layout of the matching harness for the four-element collinear. All sections are made from foam-filled Belden 8219 coaxial cable. The 1-wavelength sections are 20-15/16" long from the center of the tee to the solder terminal of the jack. The 5/4-wavelength sections are 26-11/64" long, measured between the centers of the tee connectors. All connectors are weatherproof BNC units (see parts list).

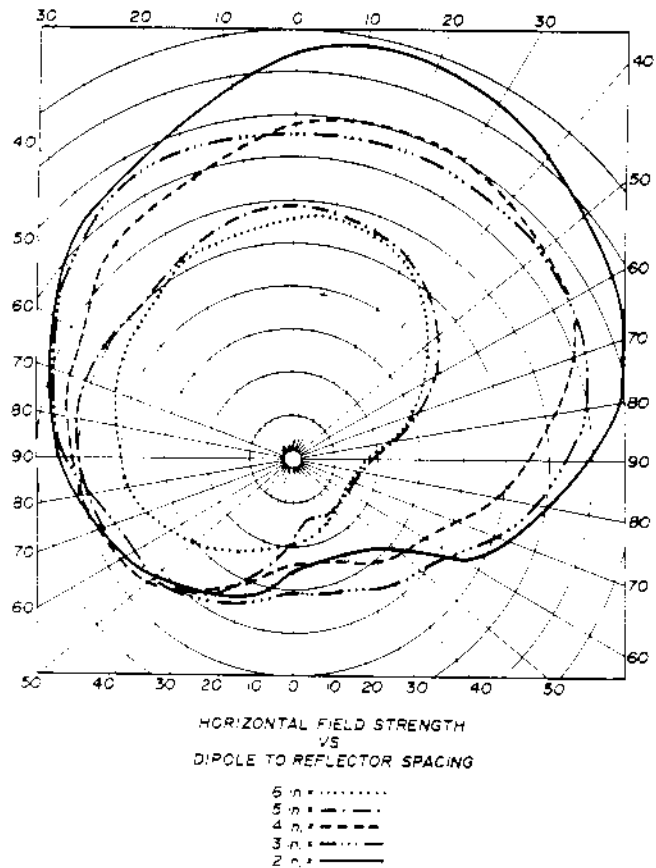


fig. 7. Field strength of single dipole element versus various dipole-to-reflector spacings.

size and close proximity of the clamp. I found that a spacing of 2- to 2 1/4-inches produced the best match and the highest gain. This corresponds to a spacing of about 0.11 to 0.12 wavelengths.

I didn't run any tests on vertical spacing, but research by others on similar antennas has shown that the maximum gain for a four-element array is achieved with a spacing of 0.97 wavelengths (26 inches at 440 MHz). This, incidentally, is the main reason for using the foam-filled coax. Belden 8219 coaxial cable has a velocity factor of 0.78 as opposed to only .659 for RG-58/U. Therefore, the length of harness made of 8219 cable will be correspondingly longer, thus allowing the elements to be spaced for maximum gain. If RG-58/U is used, the harness will not quite reach, and the spacing has to be reduced slightly. Since the difference is only a few inches, only a few tenths of a dB are lost, so don't worry if you can't find Belden 8219 coaxial cable.

construction

I would suggest that all the copper and

brass be polished before it is cut up, as this is much easier than doing it afterwards and will help to insure good solder joints. If you are going to use a gas stove or a torch be sure to do the actual soldering away from the flame. Otherwise, the rosin will burn and won't do its job.

Remember, at these frequencies the rf is concentrated in the outer few thousandths of an inch of conductor and a good solder joint is more important than ever. After soldering, cooling can be speeded up a bit by dripping a small amount of water on the end of the pipe *farthest* from the solder joint.

However, don't overdo it. Also, be very careful not to move the solder joint while it is cooling. A good solder joint will have a smooth appearance and a nice even fillet. If it's dull and grainy looking it was either moved before it solidified or was cooled too fast.

Dipole construction is simple and straightforward. A tubing cutter is a big time saver and does a very neat job. Other than that, no special tools are required. First, take the 1/2-inch pipe and cut it into eight pieces, each 5-3/4-inches long. In four of these pieces drill a 1/4-inch hole 3-inches from one end (fig. 9). From the remaining piece of pipe cut four pieces, each 4-1/2-inches long.

Next comes the 1/4-inch tubing for the gamma match. Make a 3/8-inch radius bend of 90-degrees and cut to size as shown in fig. 9. Be careful to leave at least 1/4-inch extra where the gamma rod

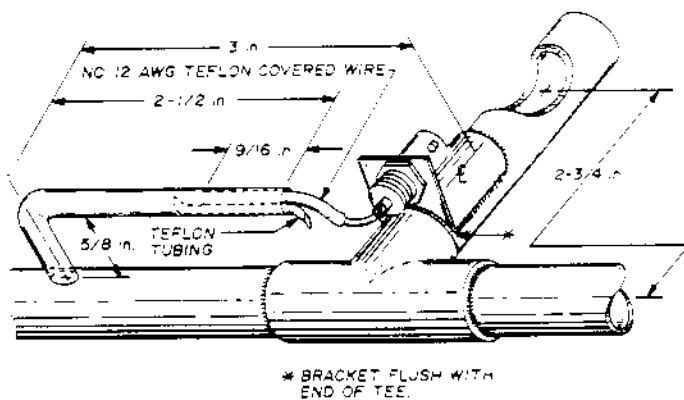
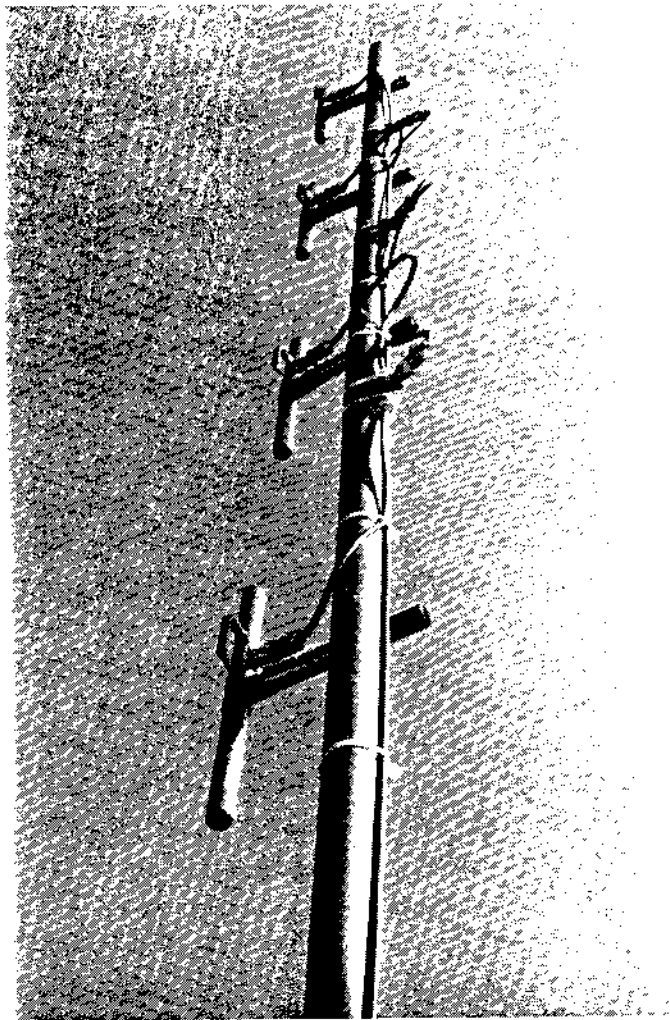


fig. 9. Construction of the gamma match. The Teflon tubing is used only to hold the wire firmly in place.



Collinear antenna with elements placed for skewed pattern. Gain in this configuration is approximately 9 dB. Note placement of harness away from elements.

mounts into the 1/2-inch element. The important thing here is to avoid kinks. After the 1/4-inch gamma rods have been bent, deburr the end that the wire will go into, using a small round file or a drill.

To make the support brackets cut a piece of copper or brass sheet 5/8-inch wide by 6-inches long and drill four 3/8-inch holes as shown in fig. 10. Cut and bend the brackets as shown, and then, using a vise or pliers, bend the side that is to be soldered to the pipe to conform to it.

Now, you are ready to begin soldering. First, solder the gamma rod to the pipe element. Pinch the end of the gamma rod a bit so you have a tight fit; then line it up. Hold the gamma rod and the element steady with a damp rag and start soldering. When it cools off, if it's a little out of line, it can easily be bent into shape. Next, assemble the element, temporarily

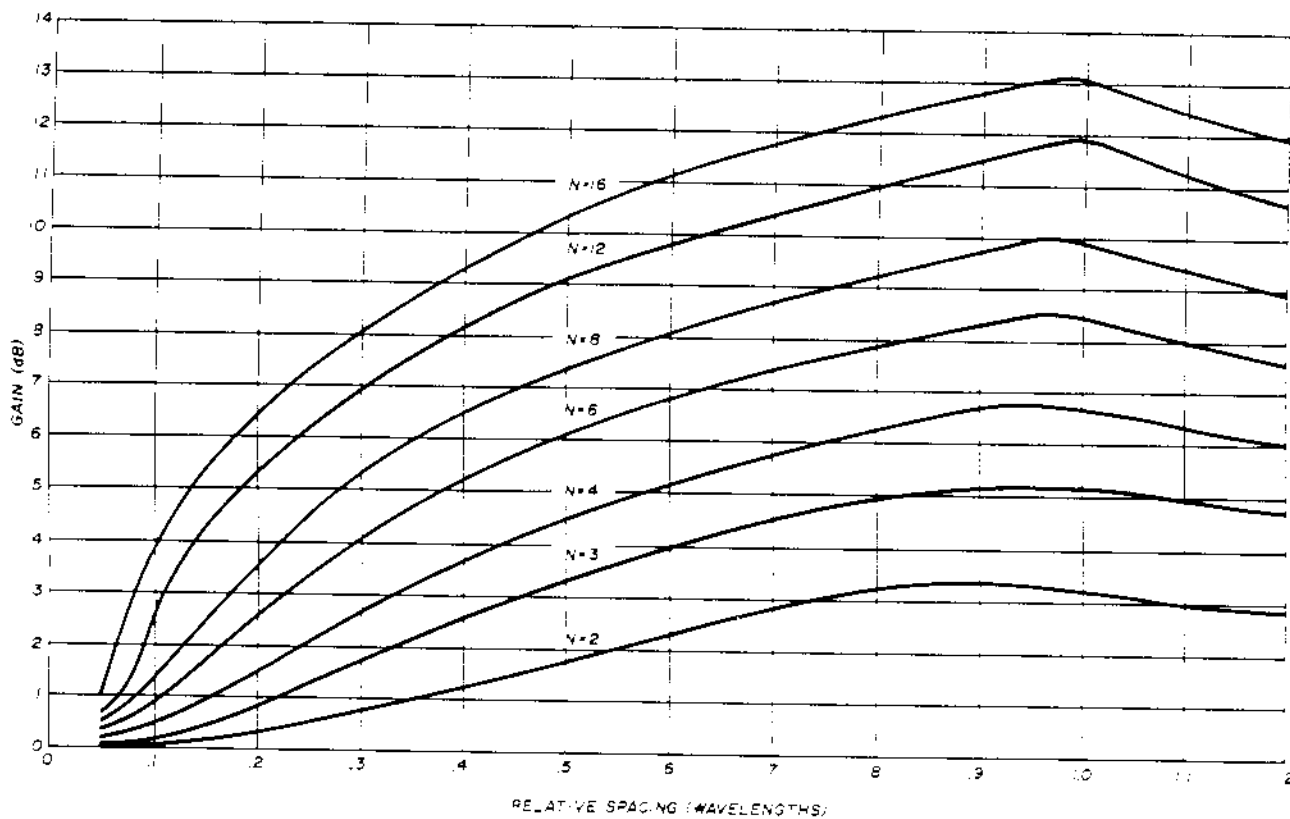


fig. 8. Gain to be expected from an omnidirectional collinear array of dipole elements relative to the gain of a single element. N = number of elements.

leaving off the connector and the wire.

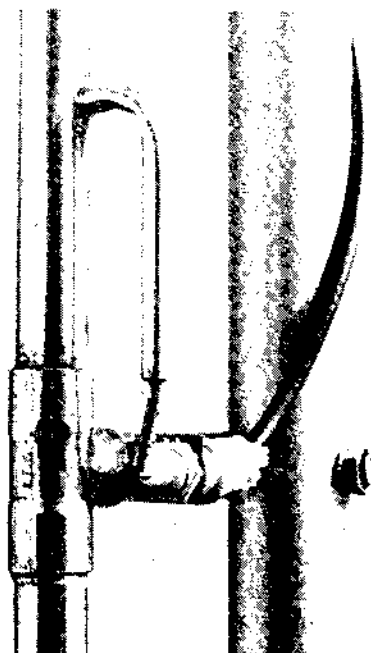
With the dipole laying on your bench the bracket and the gamma rod should point straight up with the bracket flush with the tee. Drill a small hole through both the bracket and the pipe, and run a screw through them to hold everything steady while you're soldering (the screw can then be removed).

To keep the gamma rod from coming loose while you're soldering the bracket, hold the dipole with a damp rag at the gamma-rod end. Now, solder all the parts together.

When it cools you are ready to cut the mounting hole in the support arm (fig. 11). First, cut a V-shaped hole with a hack saw, being careful to keep the saw blade parallel with the element. Then file the hole to the same radius as the mounting pole. Check your progress often by fitting it to the mast. It's important for the spacing to be an even 2¼-inches the whole length and for the dipole to be parallel with the mast.

You might think that a simple clamp would be much easier, but a glance at fig. 7 shows what that does to the pattern. Now, give the whole thing a quick going

over with the polish and install the connector and the wire. Make sure no strands are sticking out beyond the insulation that could short to the copper tubing. Leave a slight bend in the wire so that it can be adjusted a little each way from the 9/16-inch depth. Jam a piece of Teflon tubing in to hold the wire securely in place.



Construction of the dipole elements, showing the layout of the gamma match.

If you have access to a wattmeter you can now temporarily mount each element on the mast and tune for minimum reflected power. Keep everything, including your body, at least ten feet away when taking a reading. Tape the coax out of the way behind the pole and run it down to the ground. Only a slight adjust-

$$\text{wavelength (inches)} = \frac{11800 (\text{velocity factor})}{\text{freq (MHz)}}$$

Remember that the connectors are considered to be part of the coax cable and must be included in your measurements (fig. 6). I found it easiest to stick a length of masking tape down on my work bench and mark the length out on it. Install a BNC connector on one end of the coax, connect it to a tee and then measure from the center of the tee. I intentionally made my cables a little long and then figured out how much shortening was necessary to make them the right length.

When you have finished all the matching sections assemble the harness and check for continuity between all the center pins. Now, liberally coat all the places that water could ever conceivably enter with silicon sealant.

final assembly

After everything is dry all that is necessary is to mount everything on the mast. If you use the Belden 8219 coax you can use the maximum gain spacing of 0.97-wavelength. If you use RG-58/U you will have to mount the elements slightly closer together. Leave a foot between the top of the mast and the top of the first dipole. Line it up and drill a hole through the pole and the pipe (fig. 11).

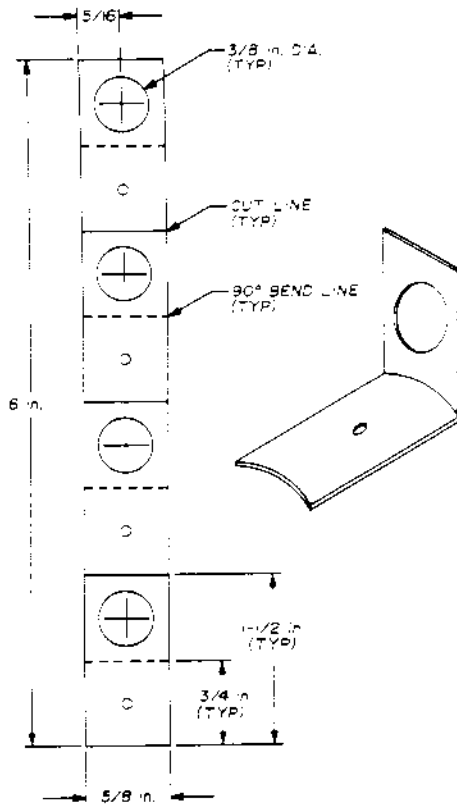


fig. 10. Construction of the mounting bracket. Material is thin brass sheet.

ment of the wire depth, if any, should be required (with 50-watts input the reflected power should be much less than a watt).

When each element has been tuned remove the rosin and polish with a solvent such as undiluted alcohol, tape over the mating end of the BNC connector and you're ready to put on a coat of epoxy. I sprayed the epoxy on using an aerosol power pack but it can also be brushed on. Cover everything thoroughly. If it's not covered it will corrode, and corrosion is a lousy conductor! When you are done hang the elements up to dry.

harness construction

The construction of the harness is very simple. The lengths are found from

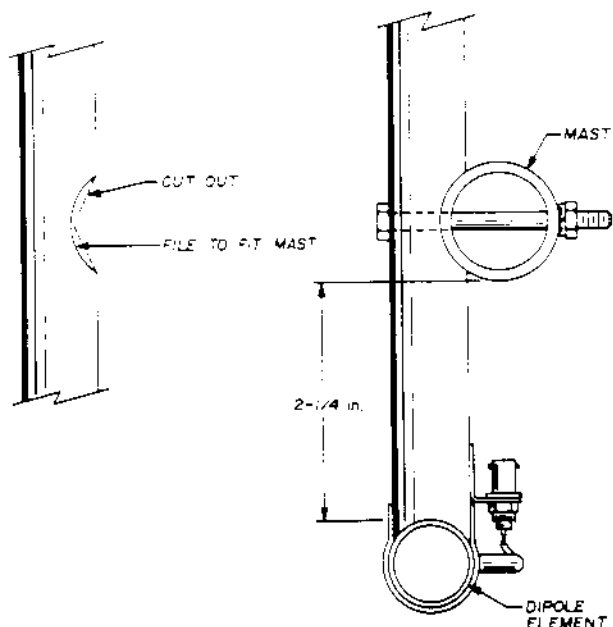


fig. 11. To mount each individual dipole on the mast a small circular section must be cut out of the support pipe.

When you tighten the mounting bolt don't get carried away. The copper pipe deforms quite easily. Be sure to use a lock washer or a self-locking nut. Then run the cable around to the back, away from the element, and secure it with a plastic cable tie or tape.

Next, decide what kind of a pattern you want. The omnidirectional pattern has about 6 dB gain over a dipole and the offset pattern, about 9 dB toward the front (fig. 12). If you want the offset pattern all you have to do is mount all the elements facing the same way. If you want the omni pattern point them 90-degrees apart. Mount the bottom element as far down the mast as it will easily go if you use RG-58/U or 78-inches if you use Belden 8219 coax. Don't cheat and use a BNC right-angle connector as that would change the length of the line and mess it up. Next, mount the remaining two elements evenly between the others and secure the harness in place behind the dipoles.

conclusion

If some of the materials listed are not

table 1. Parts list for the four-element 450-MHz collinear antenna.

8 feet	1/2" hard-drawn copper pipe
2 feet	1/4" soft-drawn copper tubing
20 feet	Belden 8219 foam-filled coaxial cable
1 foot	1/16" Teflon tubing
1 foot	number-12 Teflon-insulated wire
1 pint	clear epoxy paint
1 tube	silicon sealant
1 can	Brasso metal polish
4 sets	stainless-steel hardware (2" x 1/4" bolts, nuts and washers)
4	1/2" copper tees
1	brass sheet, 6" long, 5/8" wide
1	12- or 17-foot single-section aluminum swimming pool skimmer pole (or equivalent for mast)
13	UG-88E/U BNC cable-mounted male connectors
3	UG-274B/U BNC tee connector
4	UG-1094A/U BNC female bulk-head mount connectors
1	UG-556B/U type-N female cable connector

available, don't be put off. Improvise. The BNC connectors were selected because they are *improved* and weather-proof. However, if they are all sealed with silicon sealant, as I have suggested, the older type BNC connectors should work just fine. In fact, if a low-loss weather-proof connection can be devised, no

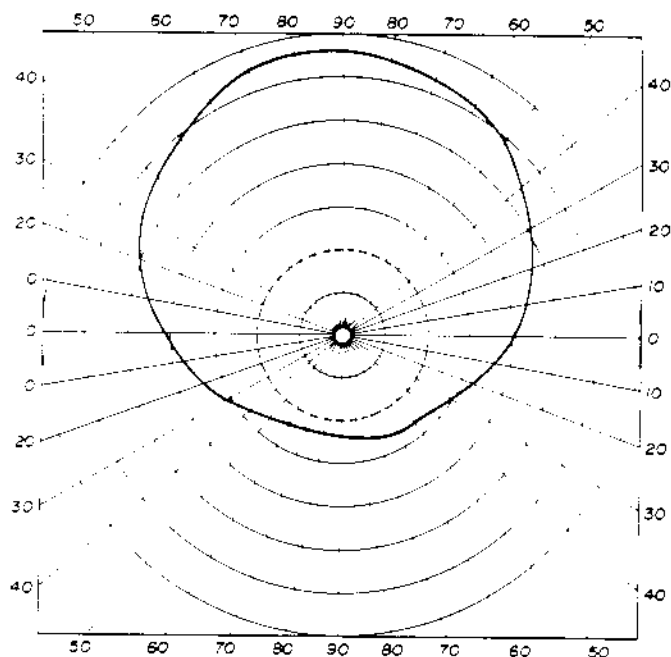


fig. 12. Horizontal field strength of the four-element collinear with all elements facing front. Gain in this configuration is approximately 9 dB. Single dipole is shown for reference (dashed line).

connectors would be needed at all. This would save considerable money and might allow the harness to fit inside the mast out of the weather.

The pool skimmer pole I used for the mast was selected only because of its low cost and availability in California. It can be replaced by almost anything. I hope that you have as much fun building this antenna as I had — you will be pleased with the results.

references

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2. E. Tilton, W1HDQ, *The Radio Amateur's VHF Manual*, A.R.R.L., Newington, Connecticut, 1972.
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