COCOA—A COllinear COaxial Array

Make COCOA your cup of tea.

by James E. Taylor W2OZH

Since 1970, I have used a straightforward, phased array for 75m. This array is composed of two parallel dipoles a quarter-wavelength apart, with a ganged switch to control directivity by changing the lengths of the coaxial feedlines to the separate dipoles.[1,2]

A Few Improvement Ideas

Although I've had great results from this system, old-fashioned ham curiosity led to several improvement attempts. I first looked at two-phased verticals.[3] These vertical radiators were a quarter-wavelength high and apart, and ultimately, each included 73 quarter-wave radials. Although electrically excellent, they never showed a consistent advantage over the horizontal system over several years of use, in spite of published material to the contrary. It's likely the far-field ground losses at my location cancelled the vaunted low-angle advantages.

I then looked at using three half-wavelengths of coaxial cable, with inner and outer conductors interchanged, to provide a collinear in-phase array. Balsley and Ecklund used such a scheme for a radar system at 49.8 MHz.[4] However, space and height limitations made this system impractical on 75 meters. What to do?

Build On the Original

Challenged by the above experiences, and by an ignorance of limiting factors such as ground losses, I went back to my 2-element array to try to build on that.

Recall that this system comprises two parallel half-wave elements positioned one quarter-wavelength apart. The center feedpoint of each element is supported a quarter-wavelength above the ground. One way to improve this system would be to add a half-wavelength element, collinearly, to each end of the two radiators, yielding a total of six half-wave elements! Such prospects led to a summer of exciting experimentation. This article describes the results of my summer fun!

This article is in two parts. First, I describe the 3-element in-phase radiator (COCOA-3) and its extension to a 6-element phased array (COCOA-6). I then cover the shortened, more limited configuration I used for experimentation.

The Collinear-Coaxial Concept

Antenna handbooks commonly show a collinear antenna comprising three half-waves in phase. They usually show a centerfed flat-top, three half-waves long. In the standard configuration (Figure 1), phase reversing stubs, added at the ends of a centerfed dipole, put the instantaneous RF current in the end elements in phase with that in the center element. You can make these phase reversing stubs from open wire line or coaxial cable. Normally, a shorted quarter-wave stub is used, but an open-ended half-wave stub would work just as well. The problem here, though, is that the dangling stubs are unwieldy at the lower frequencies.

COCOA-3

We can replace the dangling stubs with something sturdier and more compact. See the basic shorted quarter-wavelength of coaxial cable, shown in Figure 2. When you apply an RF voltage of phase angle *P'* to the center conductor *A* at the open end, the stub causes a voltage phase lag of *P' − 180°* at the adjacent coax shield. Why this happens is easy to see.

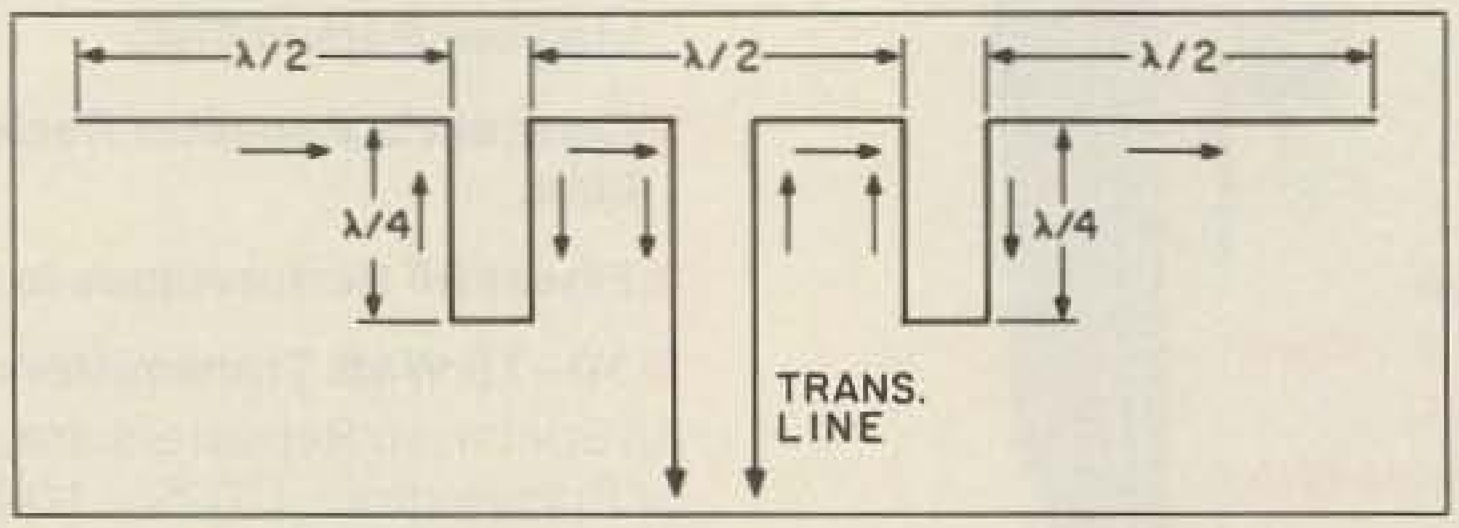

Figure 1. Three half-wave sections phased using "dangling stubs."

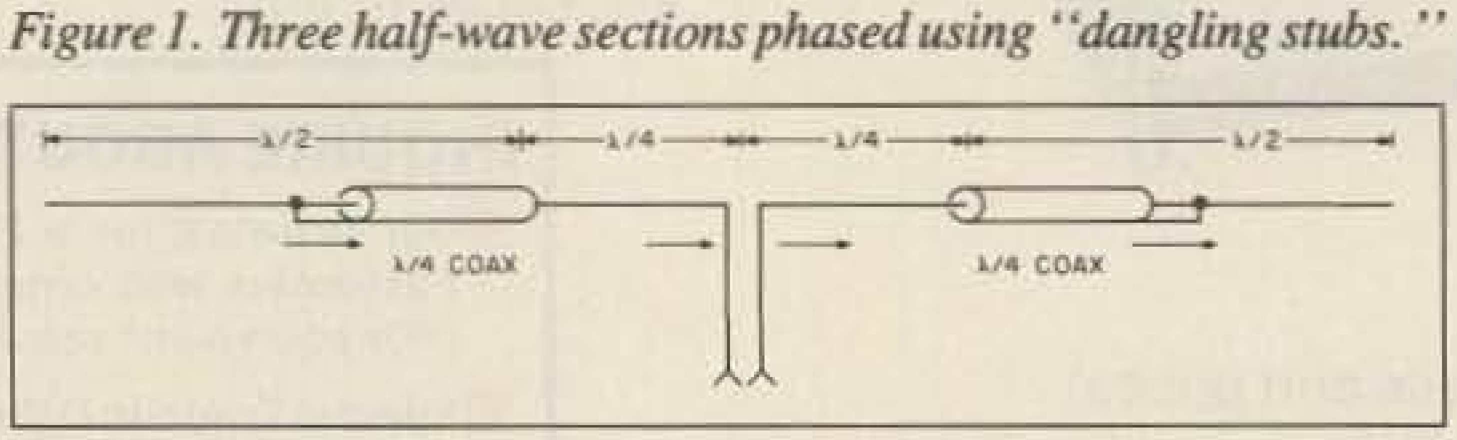

Figure 2. Horizontal quarter-wave stub. It replaces the dangling stub and is less unwieldy and sturdier.

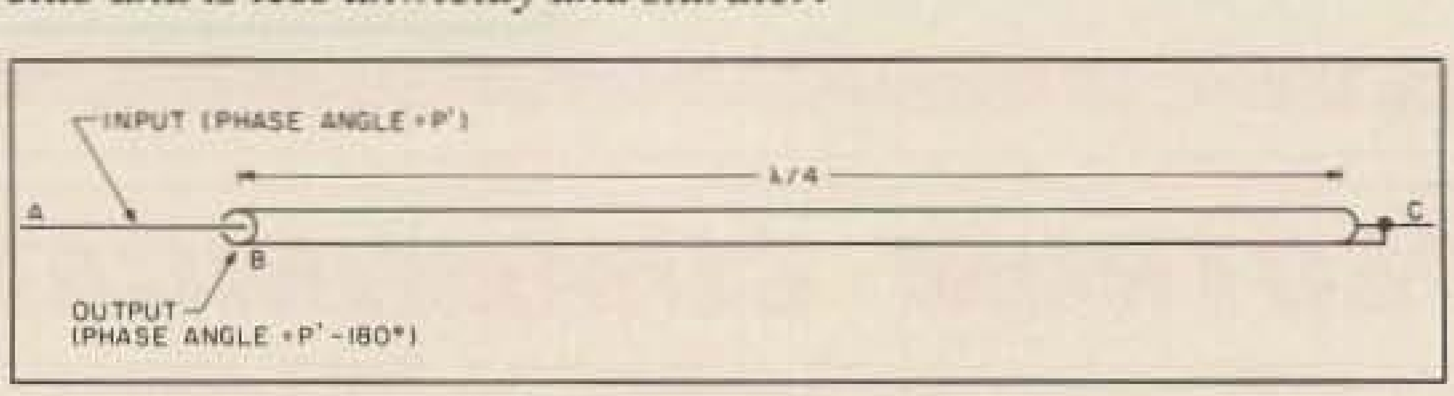

Figure 3. COCOA-3, a 3-element in-phase radiator.

The RF is delayed by one quarter-cycle as it passes from left to right, from *A*, inside the coax, to the shorted end. There's another quarter-cycle delay as the wave passes back from right to left inside the coax and emerges on the shield at *B*. Add up the delays and you get a total time delay of one-half cycle, or 180°.

RF energy can also readily turn corners if a lower impedance beckons. Thus, we further expect the RF wave to continue travelling to the right, along the outside of the coaxial shield, arriving at *C*. The setup shown in Figure 3 replaces that in Figure 1. In Figure 3, the stubs are horizontal. They perform the desired phase reversal while providing part of the added half-wave radiators with the outsides of their shields. You need only add enough wire at the ends to complete the COCOA-3 radiators. (See construction details below.)

Six-Element Phased Array (COCOA-6)

For a given power level, the current at the feedpoint of the COCOA-3 radiator is lower than that for the simple dipole radiator, so the input resistance in this case is higher. Add a toroidal transformer at the COCOA-3 input to decrease this value to 50Ω. If possible, put the matching transformer at the top of the mast that supports the radiator center.

Once the impedance is matched to 50Ω, you can excite the two COCOA-3 radiators. The phasing can be controlled by a switching network, as in the 2-element phased array. Figure 4 shows the COCOA-6 arrangement with nominal lengths for 3.955 MHz. I measured these lengths electrically, using a noise bridge to assure precise matching.

Keep'em High

Each COCOA-3 radiator is approximately 354 feet long (noise-bridge measurements determine the exact dimensions). For lower frequency bands, it's very important to place all radiating elements as high as possible above ground, since ground penetration greatly reduces radiation efficiency. If possible, support all three COCOA-3 elements no less than 40

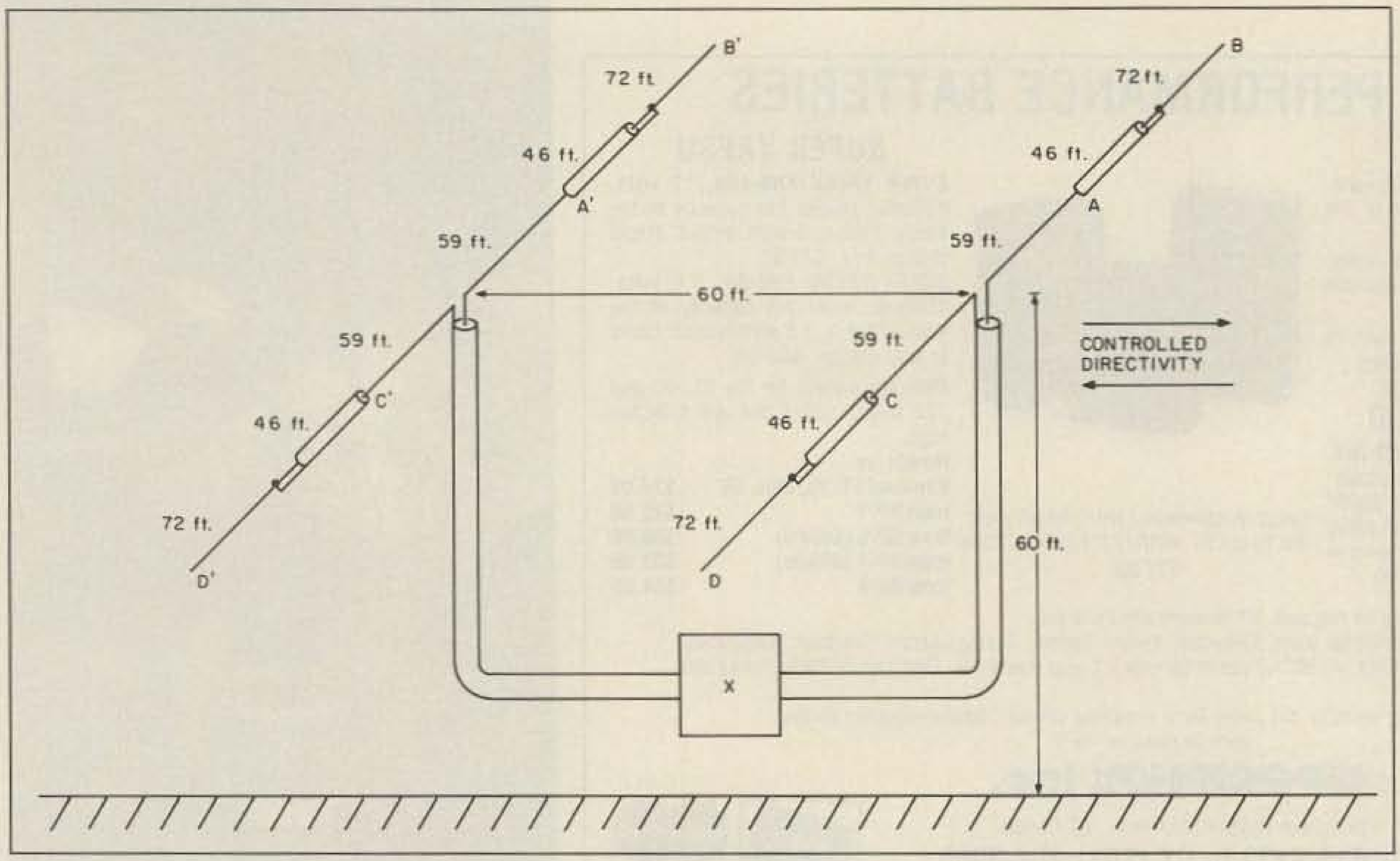

Figure 4. The COCOA-6, a 6-element phased array. "X" is the direction-switching manifold. Lengths shown are nominal values for 3.955 MHz.

both COCOA-3s) at *A*, *A'*, *C*, and *C'*, and pull the antennas up to their final positions. To allow for the mutual impedance effect between the two antennas, terminate the feedpoint of the non-adjusted "antenna" with a 50Ω, 1 Watt carbon resistor. The noise bridge null now measures the input resistance as approximately 50Ω at the resonant frequency of this dipole antenna. Adjust the lengths of the wires equally, at points *A* and *C* until you reach the desired frequency. Then shift the resistor to the newly-adjusted antenna and trim the second dipole to resonance in the same manner. These two dipoles now make up a 2-element phased array. The gain, compared to a dipole, is approximately 4 dB. The front-to-back ratio varies, typically from 3 dB to **as much as 30 dB**, depending upon propagation conditions.

feet above ground. They work best at one quarter-wavelength (about 60 feet) above ground.

The center masts at W2OZH proved practical over the years. I briefly describe their arrangement here. (See Reference 1 for more details.) Each mast is made from three 20-foot lengths of 2-inch outer diameter (o.d.) aluminum irrigation pipe, spliced end-to-end. Place the bottom half of each mast coaxially inside a 30-foot length of 3-inch o.d. pipe for added strength. Use quarter-inch crossed bolts to complete the mast assembly. Pivot the assembly on a 1-foot high, 2-inch diameter post, anchored in concrete in the ground.

The aluminum's light weight and the stiffening effect of the double pipe make for easy erection. After erection, bolt the masts to the roof structure at about 18 feet above the ground, and guy wire them in four directions at about 40 feet, as well as at the top. The center radiator wires guy the mast at the top in two of the four directions.

Pass the coaxial feedline (RG-213/U) up through the masts to the top insulator assembly. This assembly is a 6-inch length of capped PVC pipe, 2-inch i.d., that contains a balun transformer. Firmly anchor the feedline here, and pot the assembly in automotive grade epoxy.

Phase Reversing Stubs

The center radiators extend about 59 feet to either side of the center masts. Use seven strands of #22 copper-clad wire. After final measurements, paint them with polyurethane varnish to resist rust. Type RG-8 Mini-Foam coax works well here because it's light and convenient to handle. Make sure the coax terminals are mechanically secure, and that you've put a good moisture seal on them. Figure 5 shows this in detail. Seal both ends of the coax **after** trimming it to precisely one quarter-wavelength. The spade lugs are convenient for disconnecting the end sections of the COCOA-3 during resonance measurements.

Measurements and Adjustments—COCOA-6

You need to adjust the electrical length of each phase reversing stub on the ground, before assembly, using a noise bridge. The impedance-transforming properties of a quarter-wavelength of coax are such that, if the far end is an open circuit, the impedance at the near end is essentially zero. Connect the noise bridge with short leads to one end of a 47-foot length of RG-8 Mini-Foam coax, and trim the other end until the null corresponds precisely to the desired frequency. In this article, I use 3.955 MHz. Then assemble and seal both ends, as Figure 5 shows.

Let's assume we are adjusting the full 6-element array (The procedure for adjusting a single, 3-element array is identical, except you don't have to consider the second fed radiator.) You adjust the three elements of the COCOA-3 sequentially by noise bridge measurement, beginning with the center element. Before measuring the antennas, trim the two feedlines so that the electrical length of each is an integral multiple of one half-wavelength (in the coax) for the frequency used. This assures that the impedance of the antenna feedpoint is measured accurately by the noise bridge. In my case, each feedline is two half-wavelengths long at 3.955 MHz, measured and trimmed in a like way as for the phase reversing stubs.

Again refer to Figure 4. To adjust the antennas, open the spade lugs (which connect the end elements to the center elements of both COCOA-3s) at *A*, *A'*, *C*, and *C'*, and pull the antennas up to their final positions.

End Element Radiator Adjustment

You can still terminate the feedline of the antenna you are not adjusting with a 50Ω resistor, even though the feedpoint resistance is now somewhat higher. Connect the spade lug at *A* on the side which goes to the feedline's *center conductor*. Point *C*, on the side going to the shield, remains open during the resonating of the opposite end element. Connect the noise bridge at the input end of the feedline to see the resonance of the 2-element (COCOA-2) antenna—two half-waves in phase. Trim the element at *B* until you get the desired resonant frequency. The measured input resistance will be somewhat higher than for the dipole, about 60–70Ω. Next, shift the resistive termination to the feedline of the COCOA-2 just adjusted, and adjust the resonance of the other antenna in a similar manner by trimming at *B'*. Check and readjust, if necessary, the first antenna.

The two antennas just adjusted make up a 4-element phased array, the COCOA-4. There's a slight mismatch because the input resistances are no longer 50Ω. This results in a small phasing error, but you can compensate for this by using two toroidal matching transformers (see below and Figure 9).

Adjust the remaining two elements, *C-D* and *C'-D'*, in the same fashion. The spade lugs at *A* and *A'* remain connected, and those at *C* and *C'* will now be connected. Trim the ends at *D* and *D'* to resonate the two COCOA-3 radiators, just as the COCOA-2 antennas were adjusted. Here, the input resistance will be from 100–120Ω, so the

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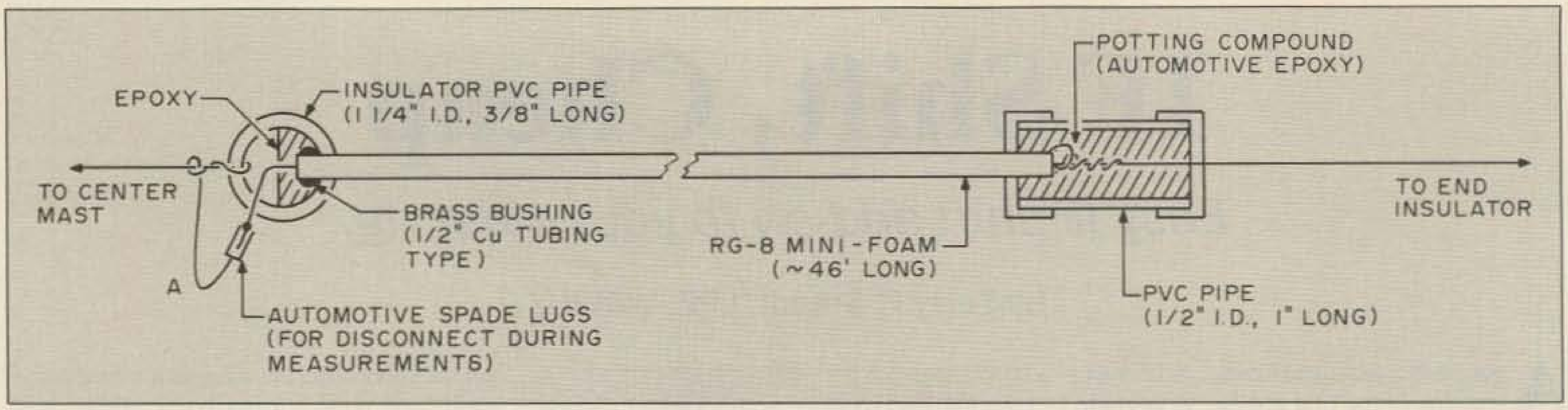

Figure 5. Quarter-wave phasing stub construction details.

continued from p. 26

terminating resistor should be changed from 50Ω to about 100Ω.

Because of the higher input resistance, wind a a toroidal matching transformer to match the 50Ω value at the transceiver. If possible, place these transformers at the tops of the masts at the feedpoints. If this is impractical, place the transformers at the feedline inputs with tolerable standing waves in the lines. Again, losses are low at these frequencies.

Physical Layout

Suburban plot limitations (about two-thirds of an acre) demand dimensional compromises. Figure 6 shows the original 2-element phased array for each dipole. The mast is assembled from aluminum irrigation tubing as described above, and the support posts are 2½" (i.d.) galvanized steam pipe.

The radiation capture area may greatly increase if the halyards, which are almost a quarter-wavelength long, could support radiator extensions. For example, if each halyard supported a half-wave element fed inphase from the end of the corresponding radiator, we would have three half-waves in phase, instead of a half-wave basic radiator. Two of these makes up the 6-element phased array.

For this, I put together the quarter-wave phase reversing stubs, and connected them as shown in Figure 4. Since I had limited space, however, I couldn't extend the end sections the full 72 feet. I foreshortened these sections by adding inductive loading coils beyond the ends of the quarter-wave stubs. To reduce inductive loading and decrease ground losses due to penetration by the high E-fields at the ends of the radiators, I turned these extensions upwards to form vertical terminations above the support posts. I achieved this by clamping 10-foot lengths of 2"-PVC (i.d.) pipe against the support posts.

The coils were commercial units, 2½" in diameter. They slipped over and were supported by these pipes above the support post tops. 8½-foot long CB whips mounted on caps at the tops of the pipes terminated these extensions. See Figures 7 and 8 for details.

Again, the four quarter-wave phase reversing stubs were made from RG/8M Mini-Foam coaxial cable. I adjusted the lengths to resonance with a noise bridge. Due to the slight variations in dielectric constant, these

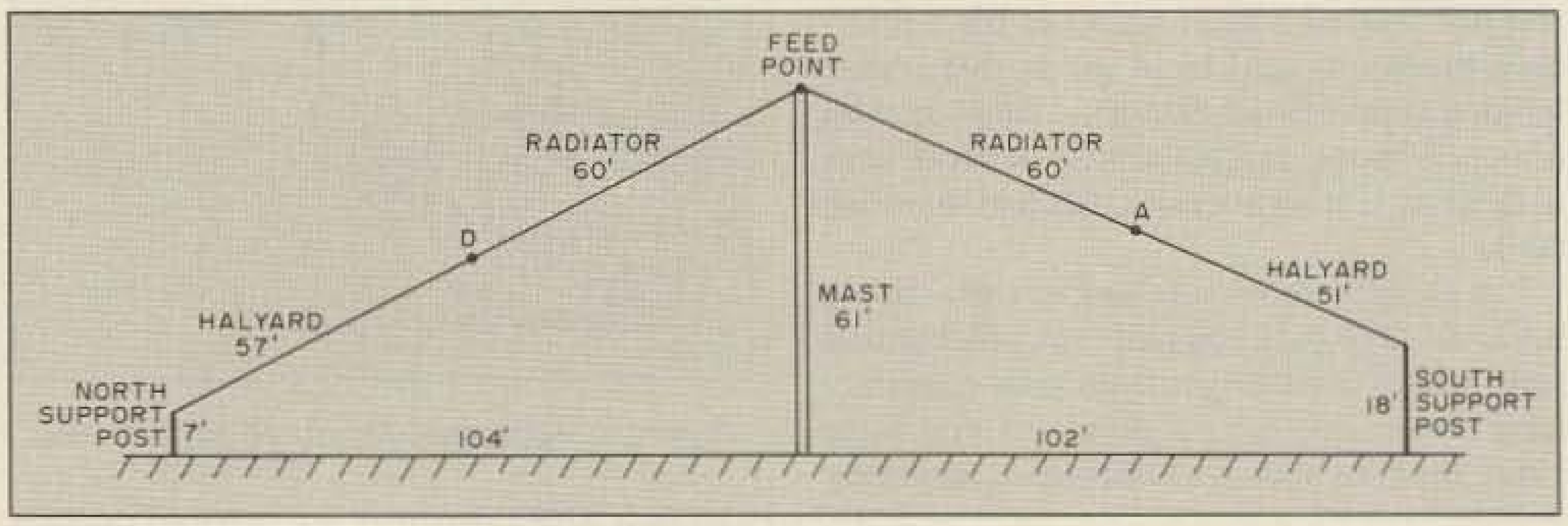

Figure 6. Original two-element phased array.

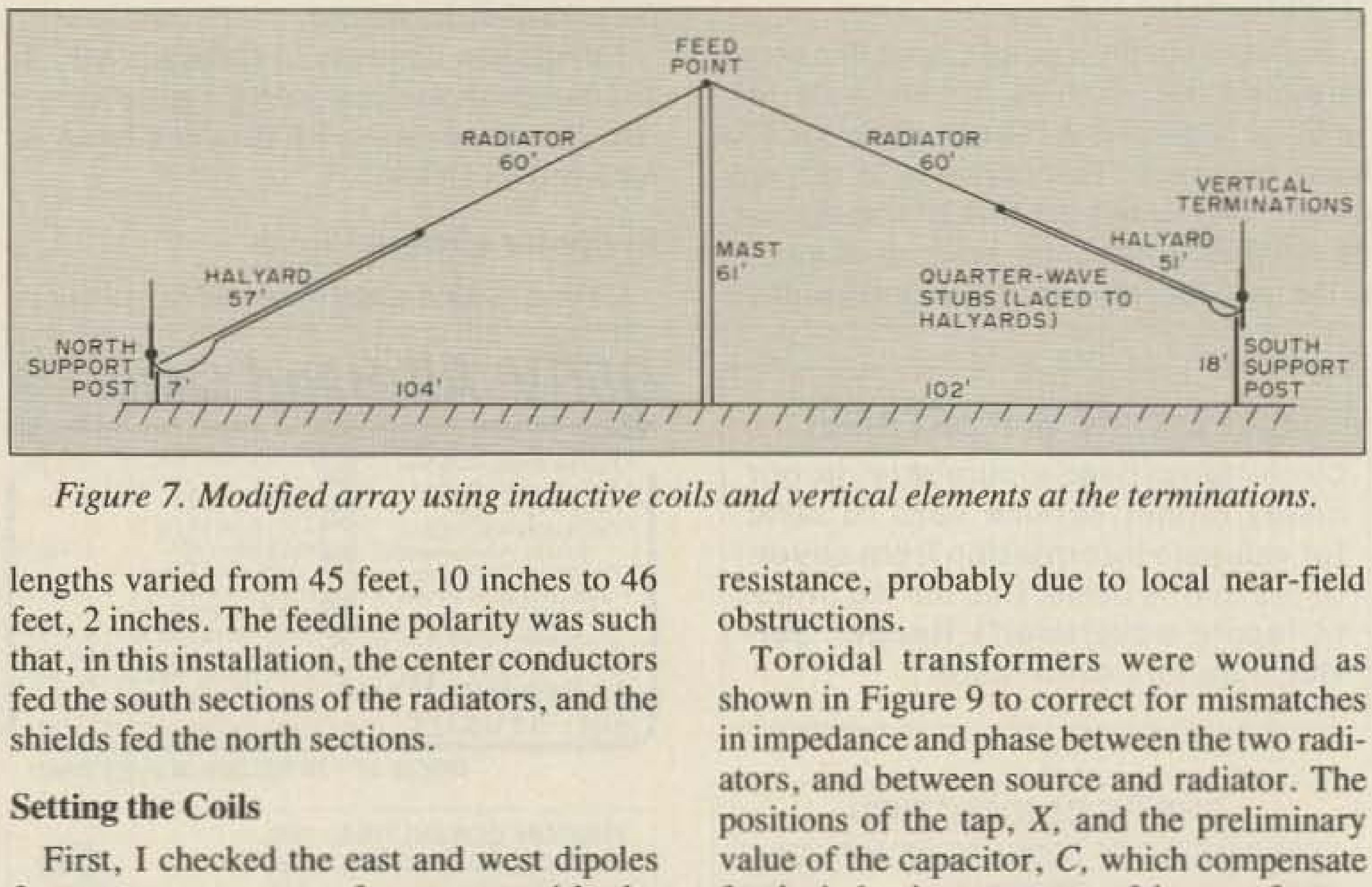

Figure 7. Modified array using inductive coils and vertical elements at the terminations.

lengths varied from 45 feet, 10 inches to 46 feet, 2 inches. The feedline polarity was such that, in this installation, the center conductors fed the south sections of the radiators, and the shields fed the north sections.

Setting the Coils

First, I checked the east and west dipoles for proper resonant frequency with the stubs and terminations in place, but with all of the spade lugs open. Then I connected the southeast stub and termination, and adjusted the southeast coil using clip leads until the resonant frequency was as desired (3.955 MHz in this case). For these measurements, I used a noise bridge at the input end of the feedline. Resonance occurred with 27 ¼-turns on the coil. The corresponding input resistance measured about 60Ω.

Next, I connected the northeast stub and termination and adjusted the northeast coil until I again reached the desired resonant frequency. This occurred with a northeast coil of 22 ¼-turns. The input resistance measured 110Ω.

I adjusted the west radiator system in the same way to yield the COCOA-3 arrangement. The measured resonance values were similar, with slight variation in coil turns and resistance, probably due to local near-field obstructions.

Toroidal transformers were wound as shown in Figure 9 to correct for mismatches in impedance and phase between the two radiators, and between source and radiator. The positions of the tap, *X*, and the preliminary value of the capacitor, *C*, which compensate for the inductive reactance of the transformer windings, were determined by noise bridge measurement using a load resistor of 110Ω. I completed the final trimming adjustment of *C* using the antennas as loads.

Results

After completing the resonating adjustments, I measured the SWR for each of the combinations corresponding to the seven positions of the phase controlling switch. The reflected indication was less than five percent of full scale for each of the combinations. This is far below 1.5:1 SWR for all settings. For the two separate COCOA-3 radiators, the indication was less than two percent of full scale.

The performance of the array with foreshortened radiators was evaluated in some detail using a receiver equipped with an accu-

continued on p. 78

continued from p. 54

can assume identical results for the transmitted signal.

Symmetry Comparisons

With a symmetrical, dual-radiator antenna system, you can compare the two individual radiators. You can run listening tests by switching from one radiator to the other and often detect any defects from the outset. I compared each of the three radiator types—the dipole, COCOA-2, and COCOA-3—with its counterpart before progressing to the next, more complex configuration. In each case, listening tests showed the two radiators identical, within the 1-2 dB accuracy of the measurement method.

Front-to-Back Measurements

After finishing the tests above, I ran extensive listening tests, using the foreshortened model, to determine the overall feasibility of these configurations. Front-to-back ratios for each of the radiator combinations averaged 10-15 dB. Principal directivities in this installation are in the east-west direction (elements run north and south). However, with the two radiators connected *in-phase*, both the COCOA-6 arrangements gave an F-to-B of up to 30 dB and signal strengths approximately 4 dB stronger for stations to the south, compared to the single radiator of the same type. Repeating this comparison for the dipole radiators yielded only a 2 dB change.

Gain Considerations

I found a loss of 10 dB for a dipole at a height of 12 feet, compared to an identical dipole at a height of 61 feet. This is about equivalent to the gain of a typical linear amplifier! Keep this in mind when evaluating data for the foreshortened COCOA-3 radiators.

Figure 7 shows that the two foreshortened radiators, with the high induction fields of their loading coils on either end of the high dipoles, are close enough to the ground to have appreciable comparative ground losses, perhaps in excess of 10 dB. See Figures 10a and 10b. Using the high dipole mentioned above for comparison, we see that, for a level COCOA-3 radiator, the effective radiation from the three dipoles located collinearly is *3 x P/3*, or *P*. That is, nearly all of the power is effectively radiated. However, referring to Figure 10b, if we assume that the two low dipoles are each down by 10 dB in effective radiated power (equivalent to the 12-foot-high case), the resulting effective power from the three dipoles is only *0.4P*. In other words, expect the output to be down approximately 4 dB from the high dipole.

Signal Strength Comparisons

I made extensive dB comparisons, using the receiver mentioned above. The east and the west COCOA-2 and COCOA-3 were compared with the opposite standard dipole using signals at various distances and times of day.

The signal strengths from both of the compound radiators showed losses compared to the reference dipole. Specifically, the COCOA-2 measured about 3 dB down and the COCOA-3 measured about 6 dB down, compared to the dipole. Recall though, that for the uncompromised antenna shown in Figure 4, if all four terminations are located at the highest practical height (60 ft.), the gain would be 8 dB over a dipole—the kind of gain one would expect in a 4-element rotary beam!

Conclusion

This article described a practical design of a 6-element, direction-switching phased array antenna system for 75 meters. This system features two coaxial, collinear radiators, each comprising three half-waves in phase. You can control directivity and angle of radiation by switching delay lines in the coaxial feed system. A version of this system, using inductively foreshortened elements close to the ground, has been constructed and used to evaluate gain and front-to-back ratios. Height above ground is all-important! ■

References

[1]"A Balanced Dipole Antenna," by J.E. Taylor, *73 Magazine*, October 1973, page 57.

[2]"A Low Frequency Phased Array," by J.E. Taylor, *73 Magazine*, July 1974, page 49. Also, "An 80 Meter Phased Array," by J.E. Taylor, *73 Magazine*, March 1975, page 52.

[3]"The 80 Meter Pile Crusher," by J.E. Taylor, *73 Magazine*, June 1978, page 76.

[4]"A Portable Coaxial Collinear Antenna," by B.B. Balsley and Warner Ecklund, *IEEE Transactions* on Antennas and Propagation, July 1972, pages 513-16. See also *Radio Communication*, September 1972, page 597.

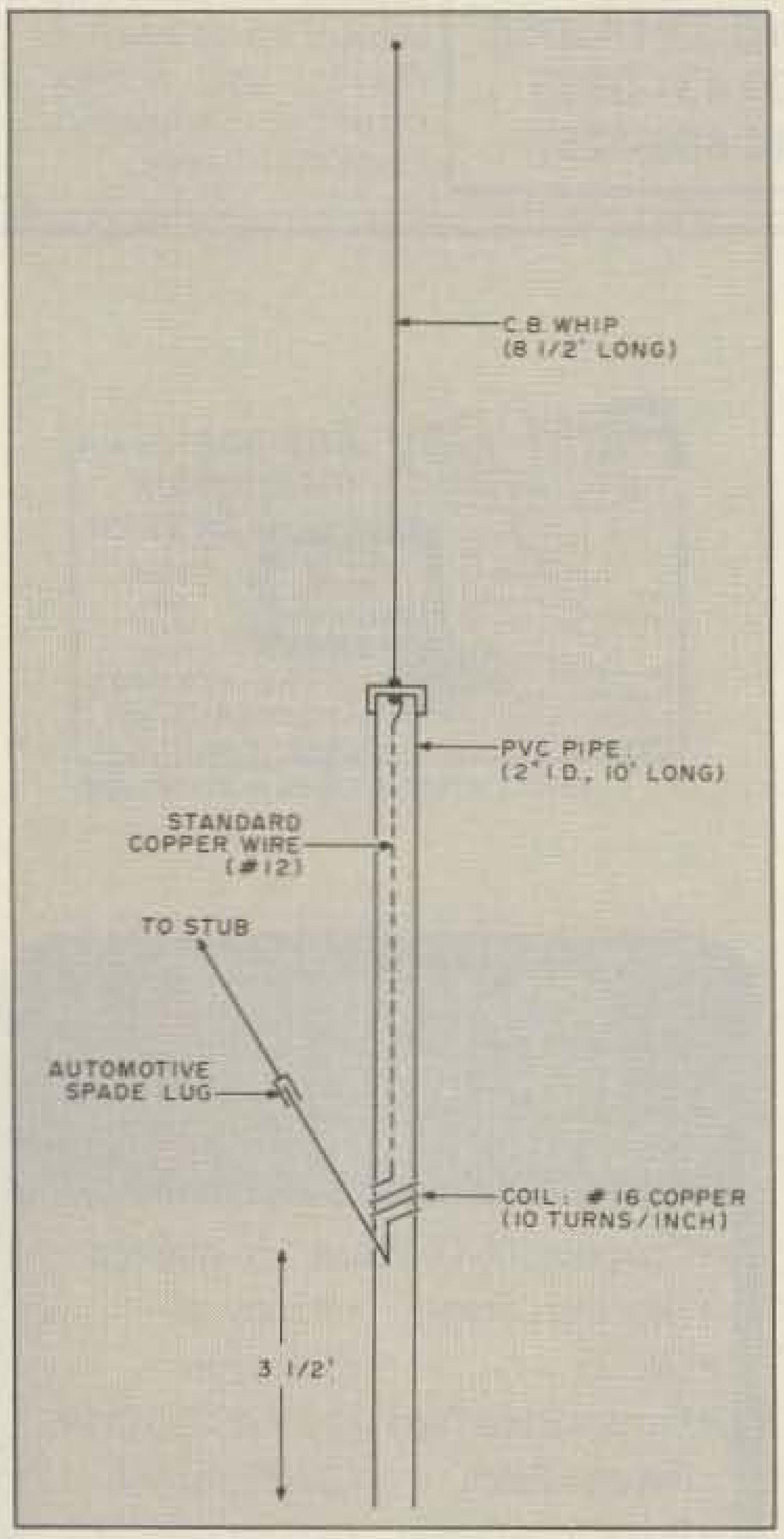

Figure 8. Detail of vertical terminations.

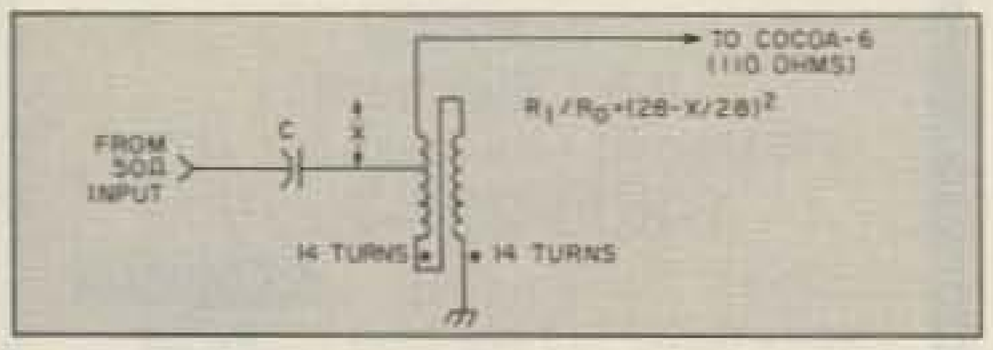

Figure 9. Diagram of toroidal matching transformer.

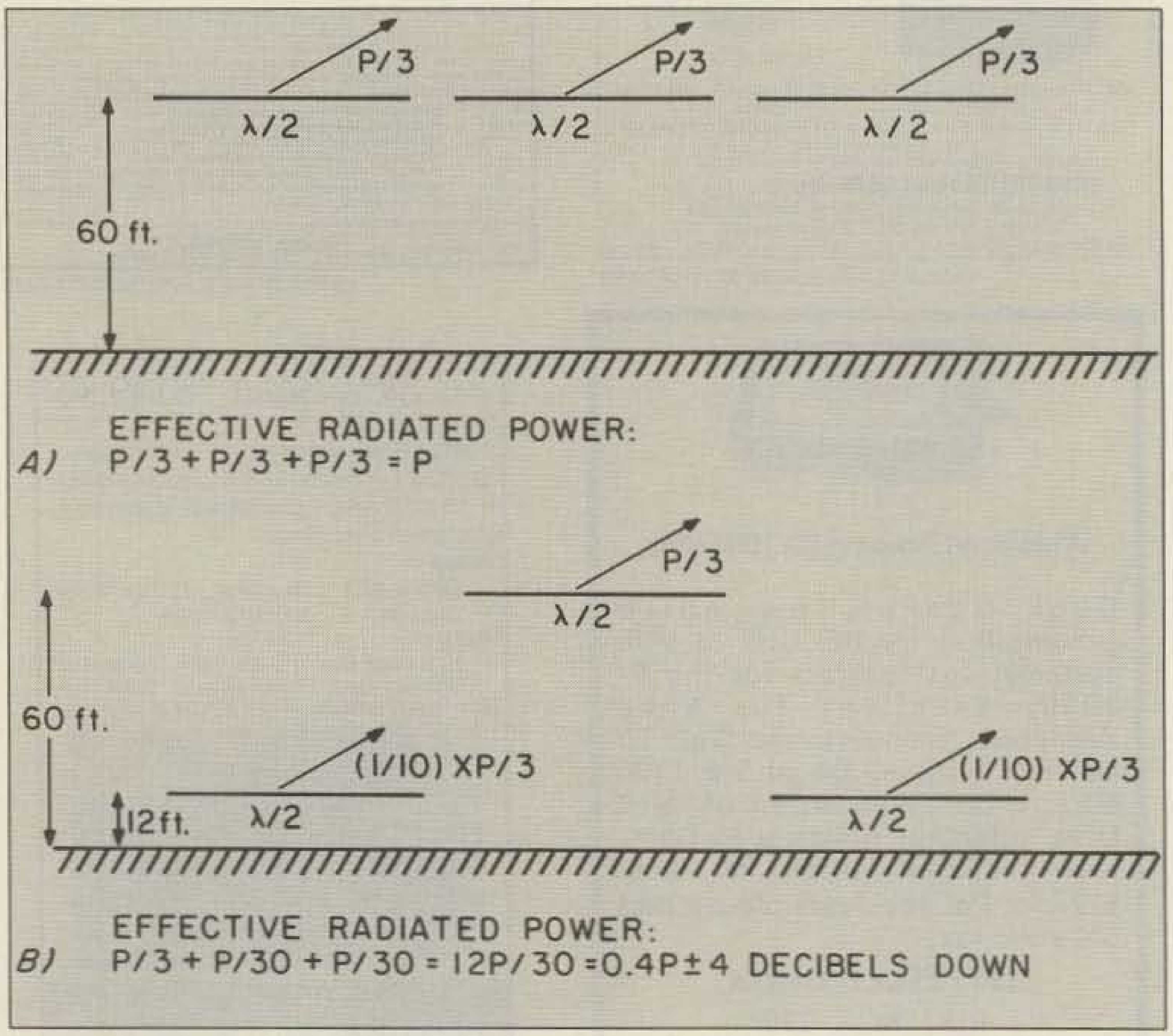

Figure 10. Calculated gain difference between a) an antenna whose three half-wave elements are all up at 60 ft, and b) an antenna whose two outside half-wave elements terminate at only 12 feet above the ground. Ground absorption at low frequencies greatly reduces antenna gain.