By Paul Del Negro, N2PD

A Half-Square Array for 40 Meters

Tired of making do with a dipole or vertical? Don't have the bucks for a 40-meter beam and support system? This simple, low-cost directional array is what you need!

orty meters is a great band! During daylight, you can usually hear local and stateside stations, and in the evening, the band comes alive with DX. Forty does, however, have its drawbacks. Foreign broadcast stations are strong in the evening, and static levels can be high during the summer months. An antenna that attenuates signals and noise from unwanted directions can considerably improve desired-signal reception.

Directional antennas that are practical for this band range from large rotatable beams (such as Yagis and quads) to an endless variety of phased wire and vertical arrays. Constraints such as location, available lot size, antenna supports and budget can limit your choices if you want a directional antenna on 40 meters.

This antenna system evolved by eliminating antennas I could not, or did not want, to use. The process went something like this:

• A Yagi or quad is just too big

• An array of ground-mounted verticals—like the four-square or rectangular array[1]—would be perfect except that for efficient operation verticals require radials—lots of them, and I've had my share of burying wire. Elevated radials are too much hassle.

• Collinear or end-fire arrays give bidirectional or unidirectional coverage, but their direction-switching schemes are difficult.

• Phased dipoles satisfy the directional switching requirement, but in order to achieve a low angle of radiation they must be at least λ/2 high, which, on 40 meters, is about 70 feet. I don't have any trees or other supports that tall.

What evolved is an array consisting of two half-square antennas spaced λ/4 apart and phased to provide a unidirectional pattern; relay switching lets me select two directions, in my case, east or west.

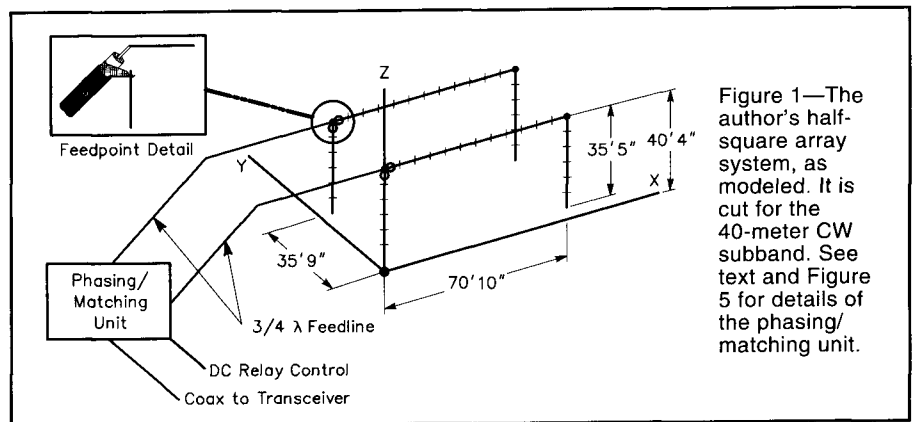The half-square antenna has been around for a number of years, but only re-

Figure 1—The author's half-square array system, as modeled. It is cut for the 40-meter CW subband. See text and Figure 5 for details of the phasing/matching unit.

cently have I seen in-depth articles about it in amateur publications.[2,3] A simple half-square antenna cut for the low end of 40 meters looks like one element of the array in Figure 1. The half square is actually a phased array all by itself, consisting of two λ/4 vertical radiators top connected via a λ/2 phasing wire. The radiation pattern is bidirectional, perpendicular to the plane in which the antenna lies. The antenna is an effective low-angle radiator, does not require radials for efficient operation and, when current-fed at a top corner, provides a good match to 50 Ω coaxial cable (see Note 2).

I have been using the half square at N2PD for several years. I find that it does, in fact, enhance distant signals and provide some attenuation of local signals. If one antenna element works so well, why not two? Using *EZNEC*,[4] I modeled the array, spacing the second element λ/4 from the first, and feeding them 90° out of phase. Figure 1 shows the configuration. I cut the second element exactly like the first. The forward gain is just over 6 dBi (see Figure 2), and the front-to-back (F/B) ratio is greater than 25 dB. The forward gain peaks at an elevation of 21°.

It is interesting that the performance of the half-square array is similar to that of a rectangular vertical array. It differs only in that its radiation pattern is slightly skewed and a bit wider than that of the rectangular array (Figure 3). As previously stated, however, the half-square array requires no radials and only two feed lines.

Low-angle radiation makes this antenna system effective for DX work. Although maximum gain is achieved at a 21° take off angle, the F/B ratio gets even better at lower angles. At an elevation of 15°, the forward gain is still more than 5 dBi, but the F/B ratio has increased to almost 30 dB (see Figure 4).

Construction

The array requires four supports. If you live on a wooded lot, you may have trees of the correct height and spacing. Once you've selected the location, construction of the first element can begin. (Although each half square is actually two elements, I will call each half square one "element" here.) Using this formula, cut the wire for the first element.

$$L = 1005/f \qquad \text{(Eq 1)}$$

where

L = element length, in feet
f = resonant frequency, in megahertz

Suspend the element between two supports

(75 feet apart, or more) using UV resistant rope. Although performance is good even when the ends are only a few feet off the ground, erect the elements as high as possible.[5] Use more rope to secure the element ends to ground stakes. (Be sure to use insulators at all wire-to-rope junctions.) I use bungee cords between the ground stakes and rope to allow flexing when the wind whistles through the trees.

Connect a $^3/_4$ λ piece of coaxial cable to the element top corner that is closest to your operating position. The length of this line—and that of the identical feed line to the other element—is critical. If you have no way to measure the coax electrical length, calculate the physical length from this formula:

$$L = 0.75 \times VF \times 984 / f \qquad (Eq\ 2)$$

where VF is the velocity factor of the coax you are using. Connect the feed line to the antenna element by any convenient method. Just make sure that the support rope places no strain on the connection.

Using a noise bridge or SWR bridge, adjust the antenna to resonance by adding or removing wire. If you start with a length calculated by 1005 / f, chances are you will be removing wire.[6] When you add or remove wire, it's best to maintain the antenna proportions. For example, if you shorten each leg by three inches, shorten the horizontal portion by six inches. Record the final length; it makes construction of the second element much easier.

Erect element 2 using the same procedure. It should be at the same height as, and spaced λ/4 from, element 1. Remember to leave the free end of the feed line coming from element 1 unshorted when tuning element 2. If you don't, mutual coupling will confuse the adjustment process of element 2. Figure 1 shows the dimensions used at N2PD.

The elements are fed 90° out of phase; that is, the element facing the desired direction of fire is fed so that the energy reaching it is electrically –90° with respect to the energy reaching the other element (0°). Using transmission lines that differ in length, electrically, by 90° will work only if the driven impedances of both elements are equal, which they are not. Source data generated by *EZNEC* illustrates this. The element fed at 0° has a feedpoint impedance of $18.43 - j\,14.22\ \Omega$, while the element fed at –90° has a feedpoint impedance of $101.2 + j\,13.53\ \Omega$. In addition, the currents delivered to each element must be equal for the array to function as designed. The current delivered to each element equals the voltage at the load divided by load impedance. Again, the load impedances are unequal, so the current amplitudes cannot be equal. *The ARRL Antenna Book* discussion of phased arrays (written by Roy Lewallen, W7EL) holds the answer.

A simple **L** network provides the required phase difference, and an interesting property of a λ/4 transmission lines helps. That is, the current at the load end of a λ/4 line equals the applied voltage divided by the characteristic impedance of the line, *regardless of the load impedance*. Additionally, the phase shift through a λ/4 line will be 90°, *regardless of the load impedance*.[7] This phenomenon holds true for odd multiples of λ/4.

Feed lines λ/4 long will not physically reach the elements, so I used $^3/_4$ λ lines. If (1) we adjust the phase and magnitude of the current fed to each element at the source end of each line and (2) the elements have the same impedance when we eliminate mutual coupling from the other element and (3) are in reasonably similar surroundings,

the current delivered to each element should be equal in magnitude with a phase difference of 90°.

Figure 5 shows the phasing/matching (PM) circuit. It is housed in a waterproof metal enclosure. The feed lines leave each element feedpoint (upper corner) horizontally, for as far as possible, then descend to the ground and along the ground to the PM unit. Coax connects the PM unit to the shack. Any handy two-conductor wire (say, #24 or larger—*Ed.*) is suitable for the dc that controls the switching relay.

Wind L1 and L2 identically on nonconductive forms. (They will hold their shapes if you want to remove the form.) A $2^1/_2$-inch length of $^1/_2$-inch ID (about $^{13}/_{16}$ OD) schedule-40 PVC pipe serves nicely as a coil form. Ten turns (bare #16 AWG wire) spaced to provide a total winding length of $1^3/_4$ inches yield a total inductance of about 1 μH. Connect a wire jumper with an alligator clip to one end of each coil to fine-tune the inductance, and install the coils with the jumper at the cold (ground) end.

These coils provide about 0.1 μH per turn. The values shown in the schematic are those at my location after the taps were adjusted. Your values (tap positions) may vary with element height, spacing and the surrounding environment.

C1 and C3 are dual-section variable capacitors (475 pF per section) with both sections parallel connected to total 950 pF each. Since the circuit nominally requires nearly that much capacitance, a 470 pF silver mica capacitor connects across each variable capacitor to increase their adjustment ranges.

Adjustment
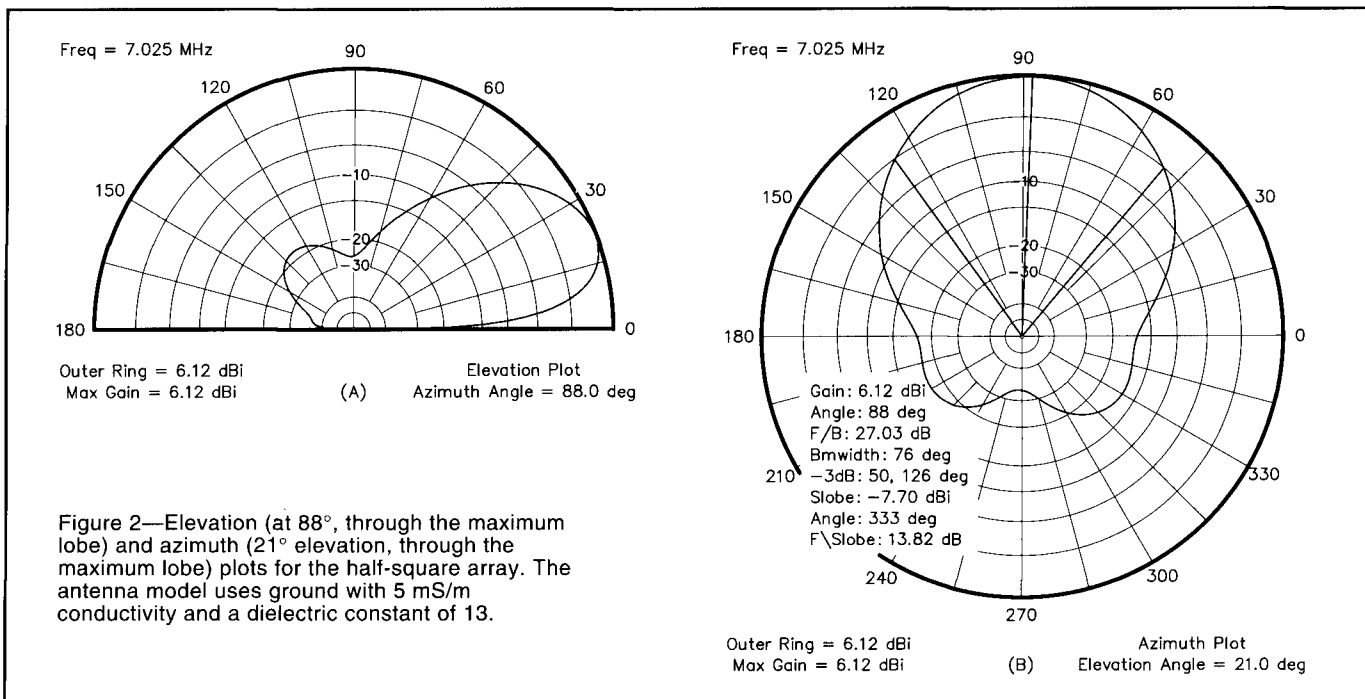
When adjusting the PM network, it's

Figure 2—Elevation (at 88°, through the maximum lobe) and azimuth (21° elevation, through the maximum lobe) plots for the half-square array. The antenna model uses ground with 5 mS/m conductivity and a dielectric constant of 13.
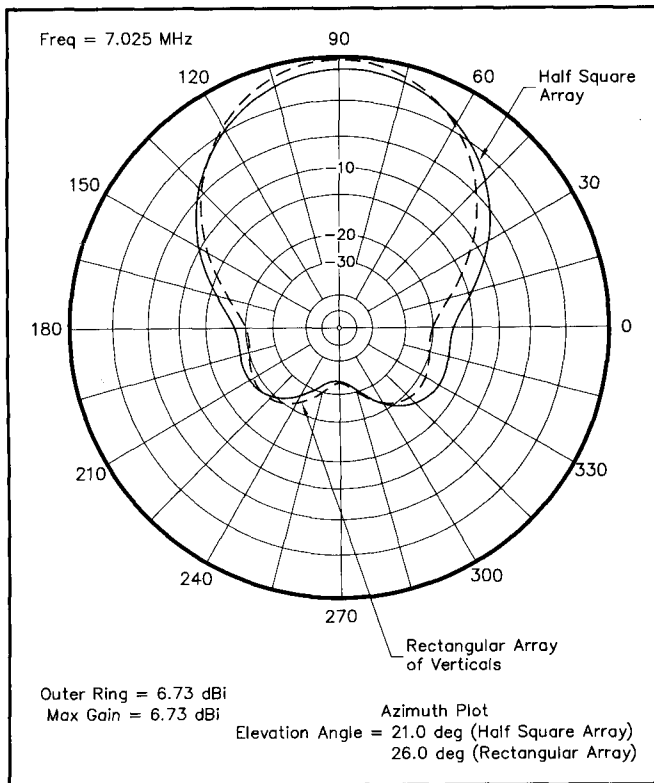
Figure 3—A comparison of half-square array (elevation 21°) to a rectangular array of vertical antennas (elevation 26°). Note the similarity in radiation pattern, gain and F/B ratio. The rectangular array is only slightly better but requires four verticals, four feed lines and many radials. The half-square array is almost the same, but it only requires two feed lines and *no radials*. These two plots are at different elevation angles to show the greatest gain for each antenna.
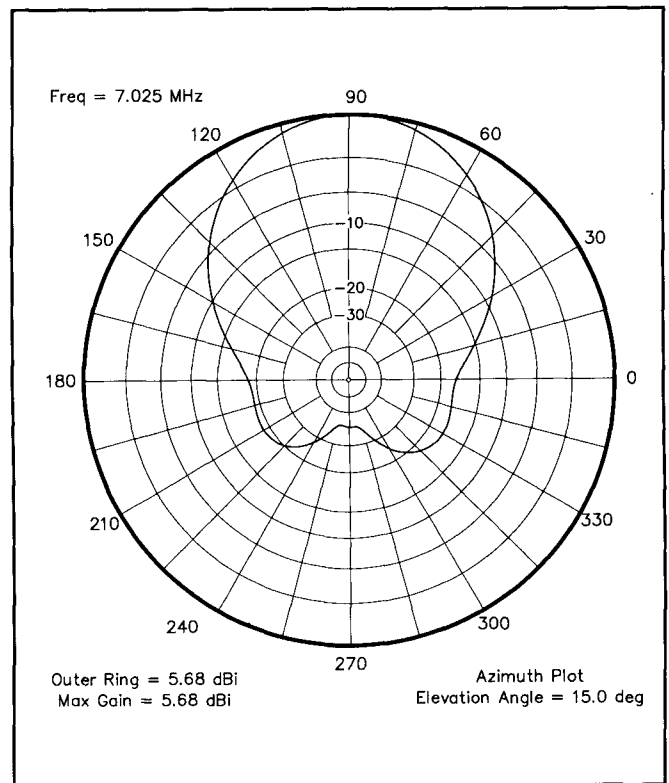

Figure 4—An azimuth plot for the half-square array for elevation of 15°. Comparison of this plot with Figure 2 shows that the F/B ratio improves at this lower take off angle.

important to set the element phasing first, then the feed-line-to-array match. This is so because the phasing adjustment affects the match, but the match adjustment does not affect the phasing.

The combination of C3, C4 and L2 comprise the phasing section. L1, C1 and C2 match the array to 50 Ω coaxial cable. (The array impedance at the junction of the $^3/_4$ λ lines is on the order of $10.95 +j10.50$ Ω, as calculated by *EZNEC* and ON4UN's software.)[10]

Adjust L2 and C3 for proper phasing. You can accomplish this by sampling the voltage at J2 and J3 and adjusting for correct phase and magnitude. You can build a sampling circuit for this purpose. One is described on page 8-27 of the *ARRL Antenna Book* (18th ed.).

A remote signal source and a receiver with an S meter can also do the job. (The remote signal source should be capable of generating a stable signal at the antenna's resonant frequency.) I tried both methods at N2PD. I built the sampling circuit and used it to adjust the array, then verified the adjustments using a remote signal source and receiver.

Here's how to adjust the antenna using a receiver and remote signal source:

Place the remote signal source (and operator) on a line perpendicular to the plane

of an array element and at least several wavelengths away from the array. My wife, Terri, KA2WZA, donated her time to the project by driving my HF equipped car to a point approximately two miles west of our house and operating the very-low-power remote signal source.

First, set the relay so that the element at −90° is nearest the signal source, and tune in the signal on the receiver connected to the array. Adjust the distance to, or level of, the signal source so that the S meter reads approximately S9. Then, set the relay so that the array is beaming away from the signal source (element at 0° phase is facing the signal source). Alternately adjust C2 and L2's tap to provide the deepest null on the S meter. (Only one combination of C2 and L2 yields the deepest null.) Switch the relay back and forth to read the difference on the S meter. When you read a difference of 25 dB or so, you are near the optimum settings. Once this adjustment is complete, the array is correctly phase tuned and you no longer need the remote signal source (tell your helper to come home!).

Now match the array to the feed line: Adjust C1 and the tap on L1 to achieve the minimum SWR. Now, switch the array direction and again read the SWR. If it is different, adjust C2 so that the SWR is the same for both directions. My array first showed a

perfect match in one direction and 1.3:1 in the other direction. I readjusted and ended with an SWR of 1.2:1 in both directions.

On-the-Air-Results

I have used the half-square array for two years now, and have found its performance impressive. Rejection of noise, QRN and such in the unwanted direction is excellent. Summer thunderstorm static west of my station is now much less bothersome when I'm working DX to the east. I've not made accurate gain measurements, but I've verified the F/B ratio using a calibrated field-strength meter. Stations more than 500 miles away are always stronger on the half-square array than on my dipole (at 40 feet, parallel to the half square). There have been times when I could not hear a station at all on the dipole, but it was readable on the half-square array.

On-the-air reports from distant stations have been favorable. Such reports are purely subjective, and their accuracy depends on the other operator's skill and equipment along with propagation variables. Nonetheless, when the other op says, "Wow, I could hardly hear you when you switched the antenna in the other direction!" you know the antenna is performing as intended.

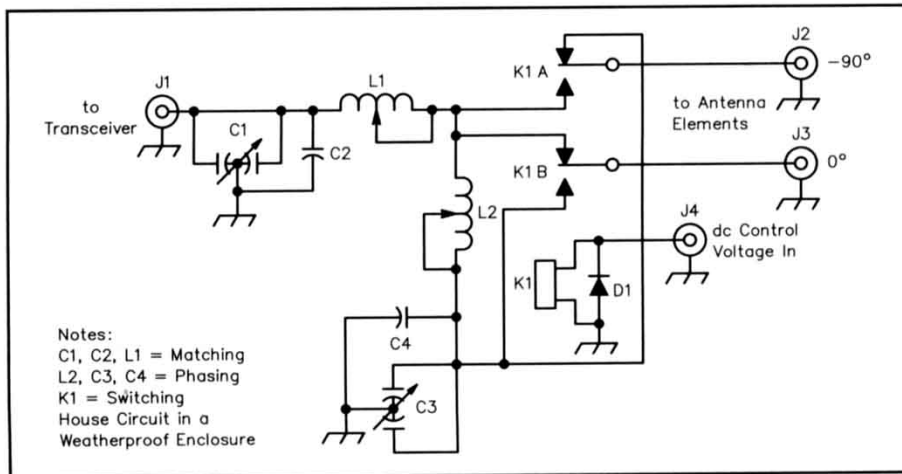If you want a 40-meter beam that is rela-

Figure 5—A schematic of the PM unit. Builders may substitute equivalent parts. RS indicates Radio Shack parts.

C1, C3—Dual-section, 475 pF per section, variable capacitors[8]
C2, C4—470 pF mica (100 V dc, minimum)[9]
D1—1N4002
J1, J2, J3—SO-239 (or builder's choice)
J4—Phono jack

K1—DPDT relay, 12 V dc coil (such as RS 275-249)
L1—0.23 µH air-core coil (tap shorts 8 turns, see text)
L2—0.6 µH air-core coil (tap shorts 4 turns, see text)

tively easy and inexpensive to construct and tune; if you can't put up a big Yagi or quad; if you hate to bury radials (like I do); the Half-Square array may be just what you're looking for!

Notes

[1]A four-element rectangular array of vertical antennas is described on pp 8-24 and 8-25 of *The ARRL Antenna Book* 18th edition (Newington: ARRL, 1997) Order No. 6133. ARRL publications are available from your local ARRL dealer or directly from ARRL. Mail orders to Pub Sales Dept, ARRL, 225 Main St, Newington, CT 06111-1494. You can call us toll-free at tel 888-277-5289; fax your order to 860-594-0303; or send e-mail to **pubsales@arrl.org**. Check out the full ARRL publications line on the World Wide Web at **http://www.arrl.org/catalog**.

[2]Rudy Severns, N6LF, "Using the Half-Square Antenna for Low-Band DXing," *The ARRL An-*

tenna Compendium, Vol 5 (Newington: ARRL, 1997), Order No. 5625. See Note 1 for ordering information. Ben Vester, K3BC, opened the topic much earlier in "The Half-Square Antenna," *QST*, Mar 1974, pp 11-14.

[3]William Van Tilburg, KG8AN, "Build a Half-Square DX Antenna," *73*, May 1997, p 48.

[4]*EZNEC* is antenna modeling software written by Roy Lewallen, W7EL, PO Box 6658, Beaverton, OR 97007; tel 503-646-2885, fax 503-671-9046; e-mail **w7el@teleport.com**.

[5]The lower ends of this antenna present significant RF voltage when it's in use. Insure that the antenna ends cannot be touched. For example, you could slide a 10 foot length of 1/2-inch PVC pipe over the antenna wire at the ground level.—Ed.

[6]You can take a short cut here. Measure the *actual* resonant frequency of the element and use it to calculate a new length factor: $k = L \times f$, where k is the length factor for *your location*. Use this new k (replace 1005 with k in Eq 1) to calculate the final element length.—Ed.

[7]*The ARRL Antenna Book*, 18th edition, p 8-13. See Note 1 for ordering information.

[8]These AM/FM receiving capacitors were used by the thousands in vacuum-tube broadcast receivers. They came with three standard plate spacings: 0.0125" (600 V maximum), 0.017" (800 V maximum) and 0.0415" (1300 V maximum). They are very common at flea markets. Dan's Small Parts & Kits (Box 3634, Missoula, MT 59806-3634; tel 406-258-2782; **http://:www.fix.net/dans.html**) sells dual-section (365 pF per section, no working voltage specified) capacitors that may be suitable substitutes. The design values for C1 + C2 and C3 + C4 are 856 and 793 pF, respectively. Higher voltage ratings are better for these capacitors. If the variable capacitors arc, replace them with high-voltage fixed capacitors.

[9]A higher voltage rating is better for these capacitors. 500 V dipped-mica capacitors are common, and Mouser Electronics (2401 Hwy 287 N, Mansfield, TX 76063; tel 800-346-6873; e-mail **sales@mouser.com**; **http://www.mouser.com**) lists 470-pF units with a 1000 V dc rating.

[10]Impedance (Z) changes along the length of a feedline. The feedpoint impedances of the elements in the half-square array are calculated by *EZNEC* at the transmission line-to-element connection point. The array uses 3/4 λ transmission lines. The Z looking into the feed end of the transmission lines at their point of connection to the PM unit are 24.36 –*j*3.2 Ω and 88.6 +*j*61.3 Ω for the lagging (–90°) and leading (0°) elements, respectively. (Do not confuse impedance with SWR, which remains fairly constant along the length of a transmission line.) Calculation of the above impedances ignores feed-line losses. Use high quality, low-loss coax.

The feed-line impedance of the lagging element is further transformed by the L-network used to cause the 90° phase shift (L2, C3, C4). The transformed Z (at the input to the L-network) is 12.39 +*j*12.4 Ω. The array feed impedance is therefore the parallel combination of the two transformed Zs, 10.95 +*j*10.5 Ω.

Paul Del Negro, N2PD, was first licensed in 1972, and upgraded to Extra class in 1977. His ham interests center on 40-meter QRP CW rag chewing using his home-built multiband transceiver. He likes to build his own gear and experiment with antennas. Paul is an IRS Enrolled Agent and a Certified Financial Planner working as a tax and financial planning consultant. You can contact him at PO Box 32, Middletown, NY 10940; e-mail pdn@warwick.net. QST

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