A New Spin on the Big Wheel

A popular 2 meter antenna returns in an improved, easier to reproduce form.

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In his "Antenna Options" column in the Jan/Feb 2008 issue of *QEX*, L.B. Cebik discusses some different options for omnidirectional horizontally polarized antennas. Here he and Bob Cerreto provide the details on how to build and use two versions of an update to the Big Wheel antenna from the '60s.

Most attempts to develop a horizontally polarized omnidirectional (HPOD) 2 meter antenna have sought to minimize the antenna's size. Shapes such as circles (halos), squares and rectangles usually result in the need for either hypercritical dimensions or difficult matching conditions — or both. By turning to more conventional full size structures using three dipoles, we can reduce the number of critical parameters and ease the process of replicating the antennas in a home workshop. In fact, we shall describe two versions of the same basic antenna. One is a triangle of three dipoles that folds into a flat package, suitable for easy transport to a hilltop. The other is a circle of three dipoles that requires somewhat less space but needs greater precision in construction. Both antennas share a common feed system and display broadband characteristics that ease the builder's task.

The Basic Three Dipole Design

A 1961 *QST* article described a horizontally polarized 2 meter antenna called the big wheel.[1] The authors described it as three full wavelength (λ) loops with a parallel connection at the central hub and feed point. Unfortunately, their description proved to be off target. In fact, the antenna is a continuous loop with three high-impedance feed points, as shown by the current curves on the left in Figure 1. (All wire models of the same antenna show the same results, but are less clear to read when converted to graphics showing the current distribution.) The legs constituted transmission lines (with variable spacing in the original) that transformed the high impedance at the rim to a low impedance at the hub. By judicious sizing of the circle and the legs, the authors managed a very good omnidirectional antenna.

Unfortunately, many amateurs had difficulty replicating the design because the antenna's dimensions are critical at every point. Small changes in the leg (transmission line) spacing or even differences in the tubing curvature at the rim could throw off the impedance values at the hub.

The big wheel is difficult to model because numerical electromagnetic code (NEC) based antenna modeling tools implementation of transmission line models are not fully accurate when applied to a low current position along the antenna's geometry. The antenna proved equally difficult to build due to the sensitivity of the structure to small dimensional changes. Therefore, we decided to re-explore a territory that the big-wheel authors had set aside: the use of three dipoles to form the same HPOD patterns. The center and right outlines in Figure 1 show the triangular and circular forms that emerged. Note that the current magnitude curves place the feed points of the dipoles at high current, relatively low impedance positions, removing the big wheel's matching challenge.

Both forms are very broadband in virtually every operating parameter once the builder gets the dimensions correct. The triangle, with a wider separation between the dipole end tips, is less critical with respect to dimensions, but requires more space. The circular version, with tighter coupling between dipole tips, requires more careful construction, but results in a more compact structure. In fact, for the same performance, the circular three dipole antenna is smaller than the original big wheel.

The far-field performance of the three dipole HPODs and the big wheel are virtually identical. Therefore, the data in Figure 2 applies equally to all three designs. At a height of 20 feet above average ground, the three elements in all of the designs provide

[1]Notes appear on page 34.

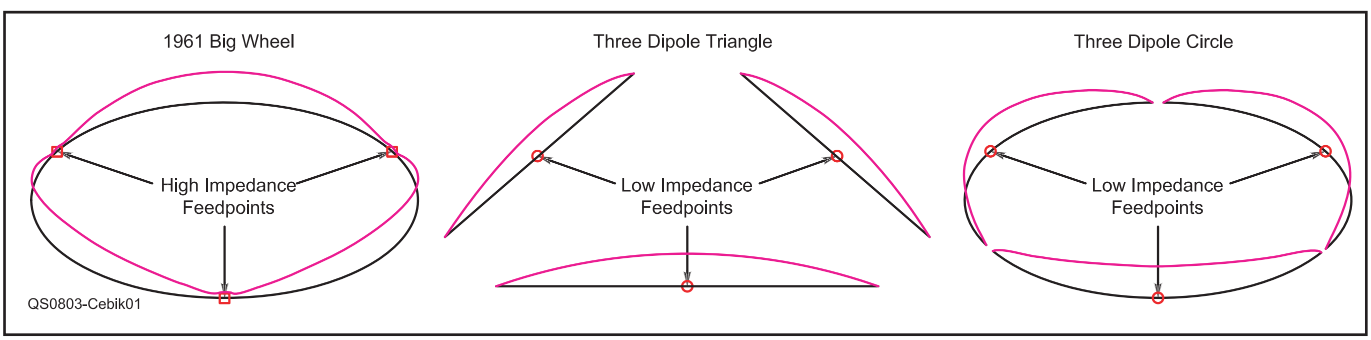

Figure 1 — Relative current magnitudes on three different three element HPOD antennas.

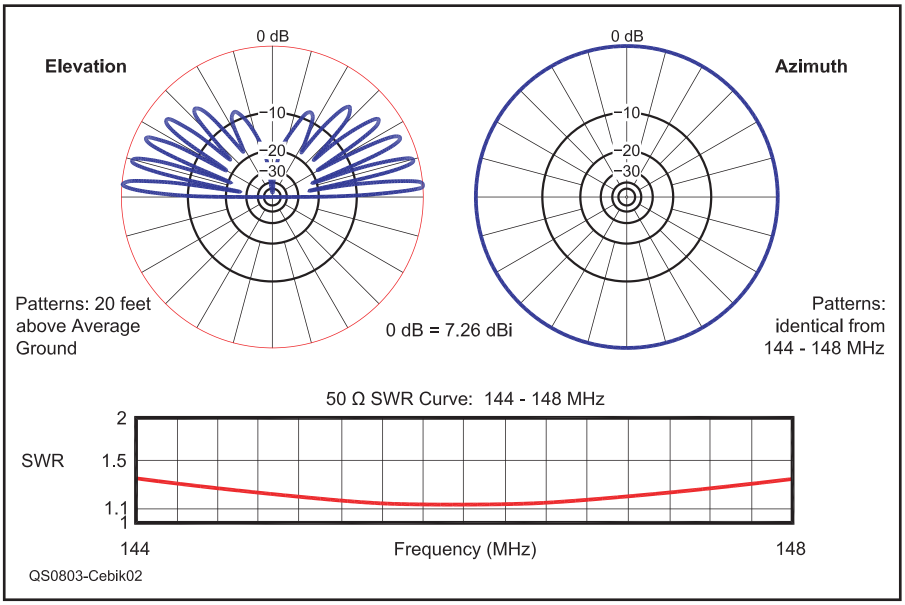

Figure 2 — Representative elevation and azimuth patterns and 50 Ω SWR curve for a three dipole HPOD antenna using either a triangular or a circular shape at 20 feet above average ground. The patterns of the conventional big wheel are virtually identical in shape and strength.

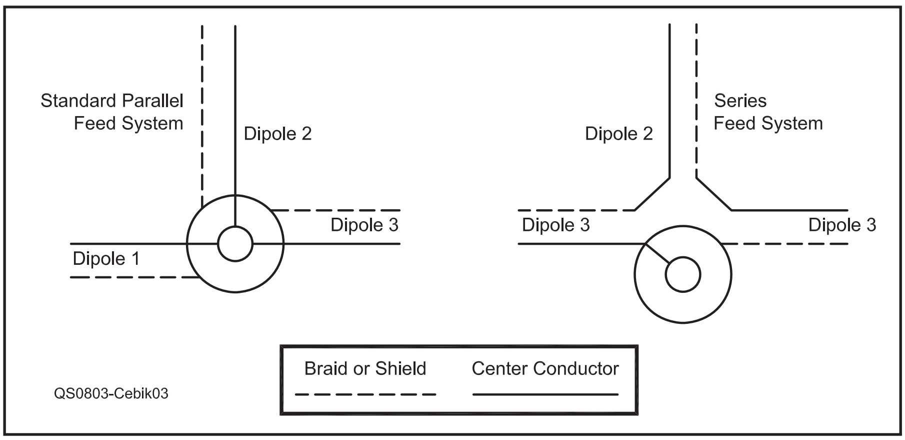

Figure 3 — Alternative methods of feeding the three dipole arrays: the prototypes employ the series feeding system for ease of matching to a 50 Ω main feed line.

an average gain in the lowest lobe of about 7.2 dBi. The azimuth pattern is as close to circular as is possible with fewer than four elements. The gain variation for the worst case was less than 0.3 dB. Although a physical antenna is unlikely to obtain the perfection of a model, the differences in gain around the horizontal will still fall below the level that an operator can detect.

The modeled SWR curve applies to both of the three dipole models.[2] Because the dipoles of the final designs present feed point impedance close to 50 Ω, we may use standard coaxial cable of virtually any length to reach the hub without changing the impedance significantly. Matched to a 50 Ω main feed point at the hub junction, the SWR curve is very flat and in the model shown in the graph, the SWR is acceptable (well under 2:1) for at least 8 MHz in the 2 meter range. Moreover, the circularity of the pattern and the gain are virtually constant across the entire 2 meter band. Even though the antenna is likely to see service only in the first MHz of the band, the broadband characteristics ease the difficulty of successfully building a version at home.

To obtain a 50 Ω main feed point impedance, the three dipole arrays use a somewhat nonstandard arrangement at the hub. As shown on the left in Figure 3, most builders would try to connect the three connecting cables in a parallel arrangement. The resulting impedance would be less than 17 Ω, a somewhat difficult value to handle. As well, any remnant reactance at the hub would constitute a significant portion of the impedance magnitude, creating a matching challenge. However, both of our three dipole designs use the scheme on the right, a series connection of the lines with the source. The resulting hub impedance is close to 150 Ω, and any stray reactances become very small portions of the impedance magnitude. Therefore, a simple λ/4 matching section can handle the impedance transformation to the 50 Ω region.

150 Ω is a borderline value. If the actual impedance of a physical antenna is below this value, then a 75 Ω line (such as RG-59) provides the best match. If the value is a bit higher than 150 Ω, then a 93 Ω cable (such as RG-62) is the better choice. For the lower half of the 2 meter band, λ/4 is about 20 inches. Multiply this length times the velocity factor of the line actually used to obtain the physical length of the matching line. If you are not satisfied with the frequency of the SWR minimum value, you can lower it by lengthening or shortening the matching line.

Based on the basic design information, W4RNL built a triangular version of the array, suitable for both home and hilltop service. WA1FXT took on the task of bending aluminum to form a circular prototype that is both smaller and perhaps more aesthetically pleasing. The differences give the builder options that may fit one or another set of shop skills and tools. Therefore, let's examine both antennas.

A Three Dipole Triangle

A very capable horizontally polarized omnidirectional antenna consists of three dipoles fed in phase. Each dipole is broadside to a direction 120° from the adjacent dipoles. The goal is to find dimensions that will achieve this goal plus provide a workable feed point impedance at each dipole. The prototype constructed to test the basic model of this arrangement used ½ inch diameter aluminum tubing as a light but sturdy material. Each dipole used a 2 inch length of 0.375 inch diameter fiberglass rod as a center insulator. The dipole halves are held in place with #6 stainless steel sheet metal screws. The gap should be as small as is feasible, ⅛ to ¼ inch. These same screws will fasten the ends of the coax cable to the element, with a stainless steel washer to prevent electrolysis between the aluminum element and the copper wires. For ease of disassembly in portable operation, the prototype used lugs under the screws.

The key is to find the correct dimensions so that each dipole presents a 50 Ω impedance at its feed point to match the connecting cable impedance. Table 1 lists some dimensions for both 0.5 and 0.375 inch aluminum tubing, perhaps the two most likely materials for this project. For the triangle, we used

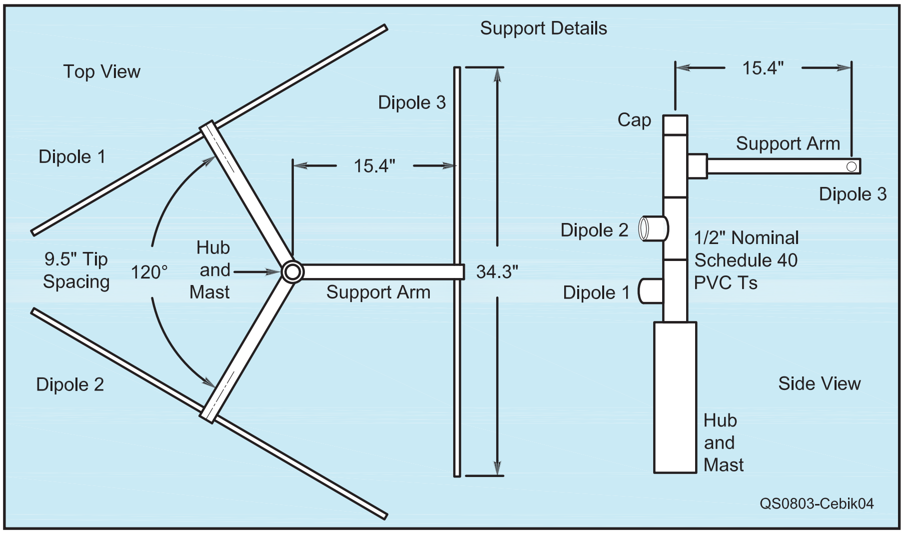

Figure 4 — Some details of the support structure used for the three dipole 2 meter triangle.

Table 1

Dimensions for a Three Dipole 2 Meter Triangle (inches)

Design Frequency (MHz)	*Element Diameter*	*Radius to Feed Point*	*Dipole Length*	*Tip-to-tip Spacing*
146	0.5	15.4	34.3	9.5
146	0.375	15.3	34.7	9.15
144.5	0.5	15.6	34.7	9.6
144.5	0.375	15.5	35.1	9.25

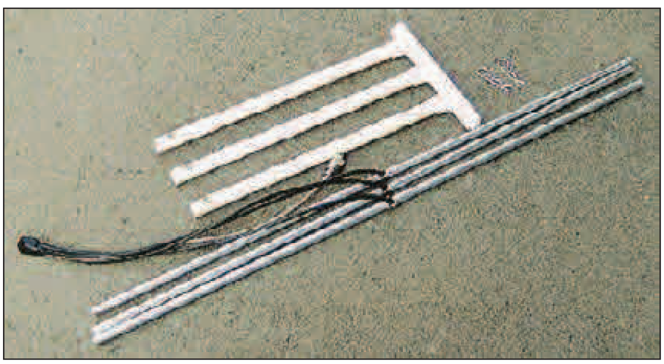

Figure 5 — The triangle HPOD disassembled for transport.

146 MHz as the design frequency because the performance and the SWR do not significantly change across the band. This center-design frequency also provided a good view of the antenna's broadband properties. However, the table also lists dimensions that are usable if the builder wishes to place the performance center of the antenna at 144.5 MHz. The prototype used the half-inch-diameter material and the 146 MHz dimensions for that material.

Note the length of the dipole. It is about 3.3 inches shorter than an independent dipole composed of the same material. The resonant impedance (50 Ω) is lower than the usual value for a standard dipole of about 70 Ω. The three dipoles in the triangle do interact by virtue of both the proximity of their feed points and the closeness of their tips. The dimensions of the triangle are therefore quite critical to successful operation of the array as designed. However, in the triangular form, they are not finicky, and cutting errors of ⅛ to ¼ inch will not materially affect performance.

In fact, the relatively relaxed conditions for the triangle prompted the particular design that emerged. The prototype may be useful for field or hilltop service, since the support structure and the elements and their cable come apart and store in a flat package for transport. Figure 4 provides a few of the support structure details. The arms are ½ inch nominal Schedule 40 PVC, with T fittings at the hub. Each fitting has a cemented stub pointing upward. For field service, do not cement the upper part of the stub to the next T. Instead, let it twist. Once you have aligned the elements as specified below, drill holes through the T fitting and the stub and install 2.5 inch hitch-pin clips to hold the antenna in alignment during use. A convenient way to accomplish this without a protractor is to predrill only the T fitting of each movable arm. Then, assemble the hub and install the elements and align the arms so that each of the three spaces between dipole ends is as equal as possible. Finally, drill through the outer T fitting holes through the stub. Install the hitch-pin clips.

To fold the structure for transport, first remove the clips, and then twist the arms into parallel alignment. Remove the elements and cables as a unit. Figure 5 shows the two piece transport package for the antenna. Assembly is simply the reverse of disassembly. In field service, each assembly will require a new set of cable ties, while disassembly will require a small knife or cutter. (Please carry away cut cable ties from the operating site.)

For field use, the elements pass through tight ½ inch diameter holes in the outer ends of the arms (carefully measured to establish the feed-point radius). Each element slides into the armhole until the cable connections touch the edge of the hole. Under most conditions, the element will not need further pinioning to remain in place. However, a small cable tie on the other side of the arm will increase holding power. For a more permanent installation, the builder can cement the hubs in final alignment and install any desired kind of brace at the armhole to position the elements more permanently. Caution — each element should be marked to ensure that the connecting cable center conductor is in the same position on each arm. Either all three center conductor screws should be touching the armhole or all three should be away from the armhole. Reversing one of the dipoles relative to the other two will produce a highly directional pattern and a feed-point impedance that is well off the target value.

The construction style vertically spaces the element at 2.5 inch intervals. Modeling tests showed that the displacement increased the distortion of the circular azimuth pattern from about 0.1 dB up to about 0.3 dB, a variation that we have not been able to detect in operation.

Figure 6 shows the cabling details of the triangle, beginning with the dipole connection at the end of the support arm. For field use, small cable ties hold the connecting cables neatly on their way to the junction. Since the connecting cable impedance matches the dipole impedance, the cable length is not at all critical. As well, the cable

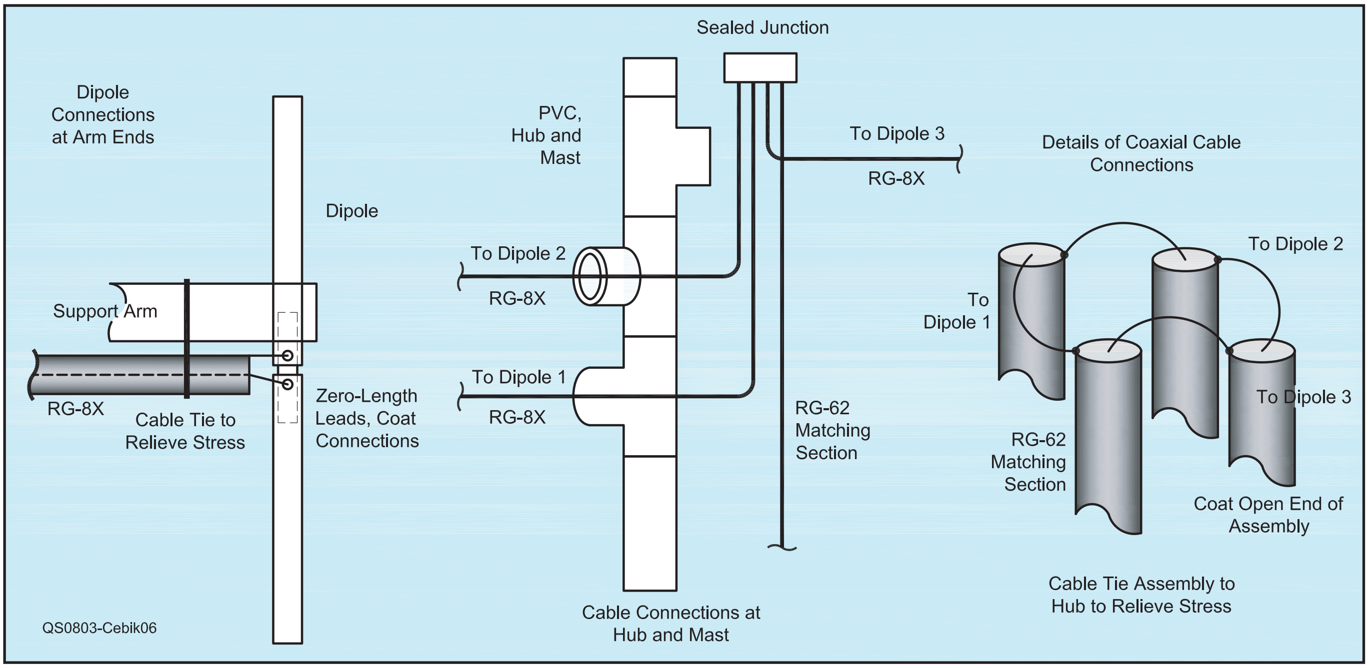

Figure 6 — Some details of the cable runs and connections used on the three dipole triangle; a similar system is used with the three dipole circle.

type also makes no significant difference to performance. Calculations show that cables ranging from RG-58 on the lossy end of the scale to lossless hypothetical cables change the array gain by about 0.1 dB for reasonable cable runs. The prototype used 20 inch connecting cable lengths to ensure that there are no stresses at the main junction of the cables. Figure 7 shows the entire assembled antenna on its test mast, including the cable ties that keep the coaxial cables neatly arranged and free of stresses. Figure 8 shows the simple connections at the dipole centers, uncoated for portable use and easy disassembly.

Since the antenna uses a series connection to arrive at a junction impedance above 50 Ω, as shown on the right in Figure 6, the antenna requires a λ/4 cable section to transform the impedance to a value that matches the main feed line. The design data showed a net junction impedance of about 150 Ω. Although a section of 75 Ω cable can be pressed into service, it will transform the impedance to a value in the 30 Ω range. A better choice is RG-62 (A or B) with an impedance of 93 Ω and a measured velocity factor of 0.84. Ideally, a 50 Ω impedance at the source end of the matching section calls for close to 170 Ω at the load end. At the design frequency, the impedance will be about 57 Ω, a very usable figure. With about 17 inches of RG-62 93 Ω cable having a velocity factor of about 0.82, the antenna provided a 50 Ω SWR of 1.3:1 or better from 144 to 145 MHz.

The SWR check is one of two tests for the assembled antenna. The other check requires a second person stationed about 10 λ (about 65 to 70 feet) or more away. One person provides a signal source and the other provides reception with a signal strength reading. It does not matter which person is at the antenna. For the test, simply hand rotate the antenna and test mast, checking for any changes in the signal strength. If the assembly has gone well, the S-meter should not budge.

Although the triangle assembly leans toward potential hilltop uses for the array, permanent installation requires only a few extra steps. Instead of using hitch-pin clips at the hub, cement the rotatable hubs. As well, cement or otherwise fasten the dipole elements into place at the armholes. For both types of use, seal the cable junction. Several thin coats of *Plasti-Dip* or liquid electrical tape work well and durably. Finally, use a brush to coat the arm ends of the connecting coaxial cables with the same material.

Figure 7 — An overall view of the HPOD triangle in use, showing the general construction and cable routing.

Figure 8 — A close-up of the junction of the support arm, the dipole element, and the connecting cable termination for portable operation. For a permanent installation, insert a stainless steel washer between the hook connector and the element and seal the junction.

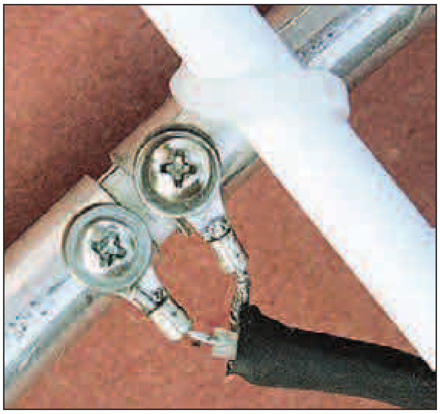

Figure 9 — A close-up of the method used to connect the element to the support arm with cable ties in the circular antenna.

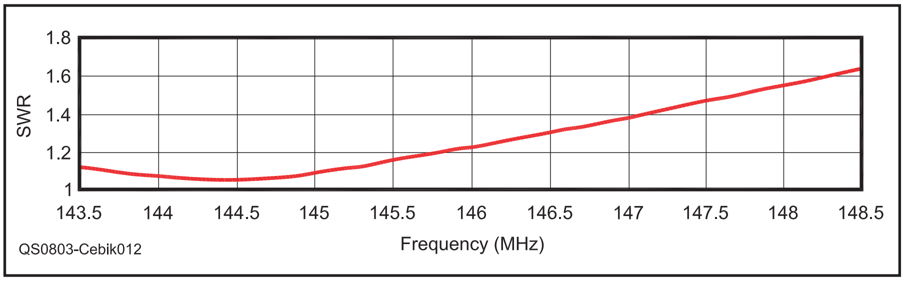

Figure 11 — Measured SWR of the circular three dipole horizontally polarized omnidirectional antenna.

Table 2

Modeled and Final Dimensions for a Three Dipole 2 Meter Circle (inches)

Design Frequency (MHz)	*Element Diameter*	*Radius to Feed Point*	*Circumference*	*Dipole Length*	*Tip-to-Tip Gap*
Modeled					
146	0.5	15.5	97.4	31.4	1.0625 (1 1/16)
146	0.375	16.0	100.5	32.4	1.125 (1⅛)
144.5	0.5	15.7	98.4	31.75	1.0625 (1 1/16)
144.5	0.375	16.2	101.6	32.75	1.125 (1⅛)
Final					
144.5	0.5	15.8	99.375	32.0	1.0625 (1 1/16)

Figure 10 — The hub, support rods and the main junction of connecting cables and the λ/4 matching section before final sealing.

Table 3

List of Materials and Local Sources for Circular Wheel

Material	*Suggested Source*
Two pieces 36 × 36 × ¾ inch plywood	Old pallets or Home Center
144 inches ⅜ inch aluminum tubing	Texas Towers or **online metals.com**
12 inches ⅜ inch aluminum tubing	Texas Towers or **online metals.com**
6 feet ⅜ inch fiberglass rod	Home Center, farm and garden supply, Max Gain Systems
1¼ inch PVC coupler, pipe, end cap	Home Center, hardware stores
No. 6 stainless steel hardware	Home Center, hardware stores
1¾ inch ¼-20 bolts	Home Center, hardware stores

A Three Dipole Circle

For a permanent installation or for mobile use, you may prefer a circle of three dipoles. The circle has no loose dipole ends and is more compact than the triangle. Indeed, it is aesthetically more pleasing. However, such pleasure comes at a cost. The construction and adjustment of the elements are somewhat more critical, although completely manageable.

The element connection arrangements for the circular version are shown in Figure 9 with the required materials in Table 3. The hub connections are shown in Figure 10. Figure 11 shows the resulting SWR — well below 2:1 across the entire band. Detailed fabrication instructions, including a fabrication jig are described in a Web version of this article found at **www.arrl.org/files/qst-binaries/.** The Web version also describes the methodology of stacking either version for additional omnidirectional gain towards the horizon.

Conclusion

Over the years, the use of three dipoles to form an omnidirectional horizontally polarized radiation pattern for 2 meters has experienced unwarranted neglect. The designs and prototypes described in these notes should restore these arrays to their rightful places as viable alternatives to many of the other possible HPOD designs. Except for using reasonable care both in cutting and adjusting the elements, the three dipole array — in either triangular or circular form — provides both a high performance antenna of its type and the potential for a satisfying antenna building experience.

Notes

[1]R. Mellen, W1IJD, and C. Milner, W1FVY, "The Big Wheel on Two," *QST*, Sep 1961, pp 42-45.

[2]*EZNEC* models of a big wheel simulation and of various versions of the three dipole triangle and circle are available at **www.arrl.org/files/qst-binaries/**.

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