Wire and the HF Horizon
The Ys and Wherefores

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The ½-wavelength dipole and its kin (the inverted-V, the quadrant, etc.) are far more competent antennas than many folks give them credit for being. They provide good gain with a fairly wide beamwidth and are bi-directional. In fact, if we rotate a ½-wavelength dipole in 120° increments, we obtain full horizon coverage with only a small gain deficit in the pattern overlap region, as shown on the left in **Fig. 1**. With an antenna tuner and parallel feedlines, we can use the antenna at higher frequencies. Up to about 1.5 times the resonant frequency, the beamwidth is still great enough to give us less than a 3-dB gain deficit in the pattern overlap region. See the right side of **Fig. 1**. For full-horizon coverage with no more than a 3-dB gain deficit (about ½ S-unit), we need a half-power beamwidth of about 60° from each of the 3 antenna positions.

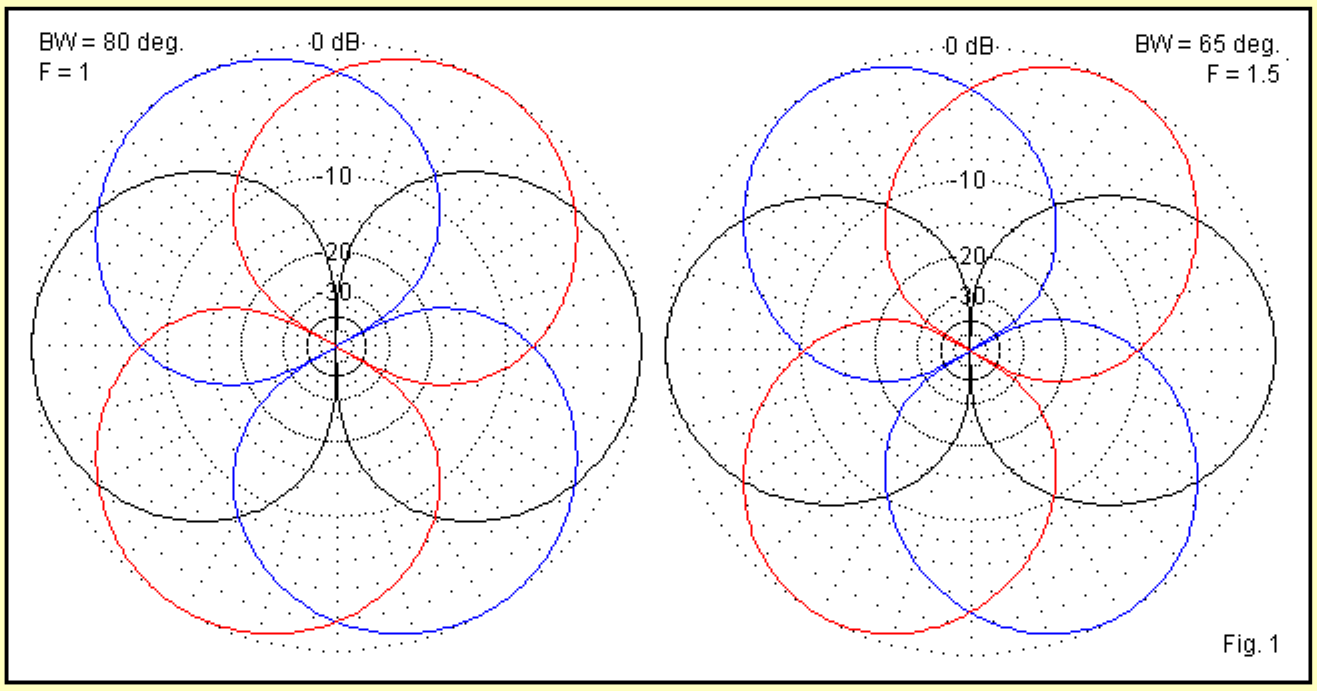


Fig. 1

Now let's give ourselves a limitation. We shall take away the rotator and use wire for the dipole. We end up with a very inexpensive but fixed antenna. For full-horizon coverage, we shall need at least 3 dipoles at approximate 120° angles. The question then becomes how to arrange the 3 dipoles. The arrangement must activate one dipole, leaving the other 2 inert or inactive. **Fig. 2** shows full-Y and triangular (or delta) arrangements. The sketches assume that each dipole has a feedline, and that all feedlines are the same length. They run from the feedpoints to a central location. That location may be at the station equipment or a remote switch at the center of the arrays.

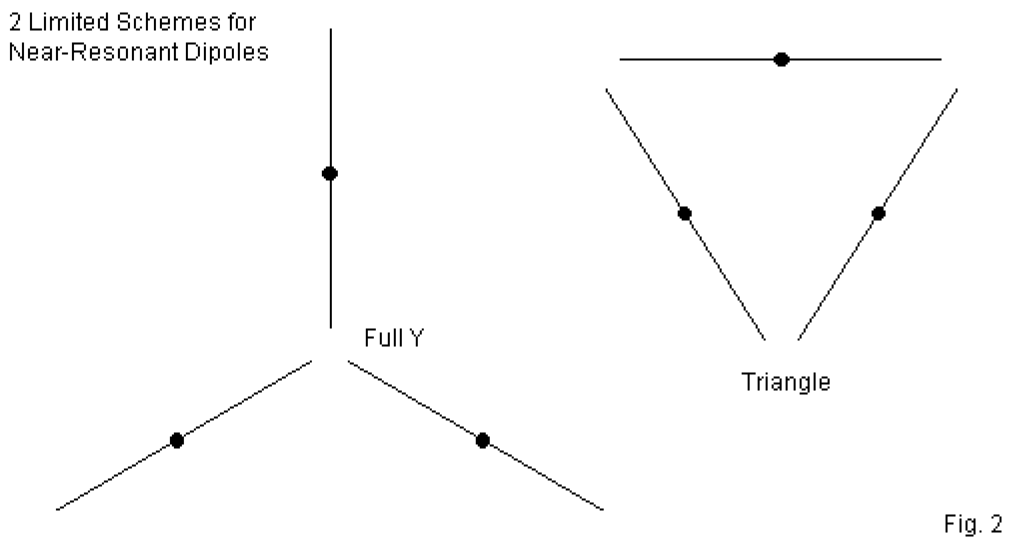
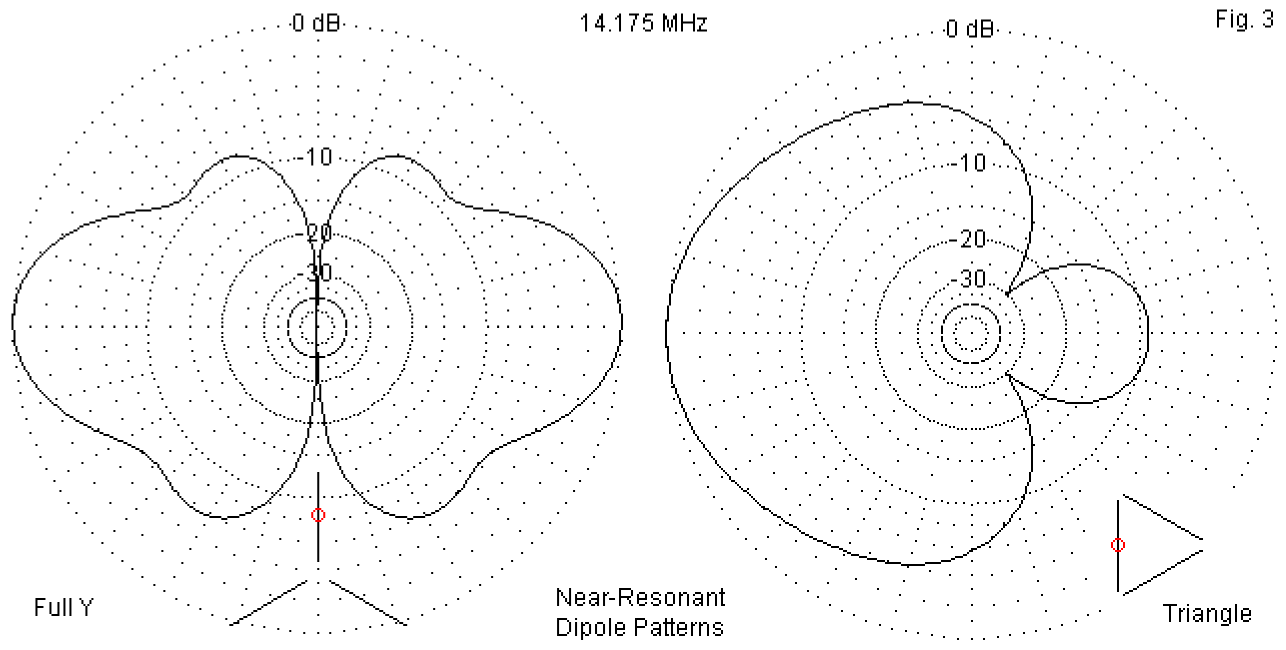


Fig. 2

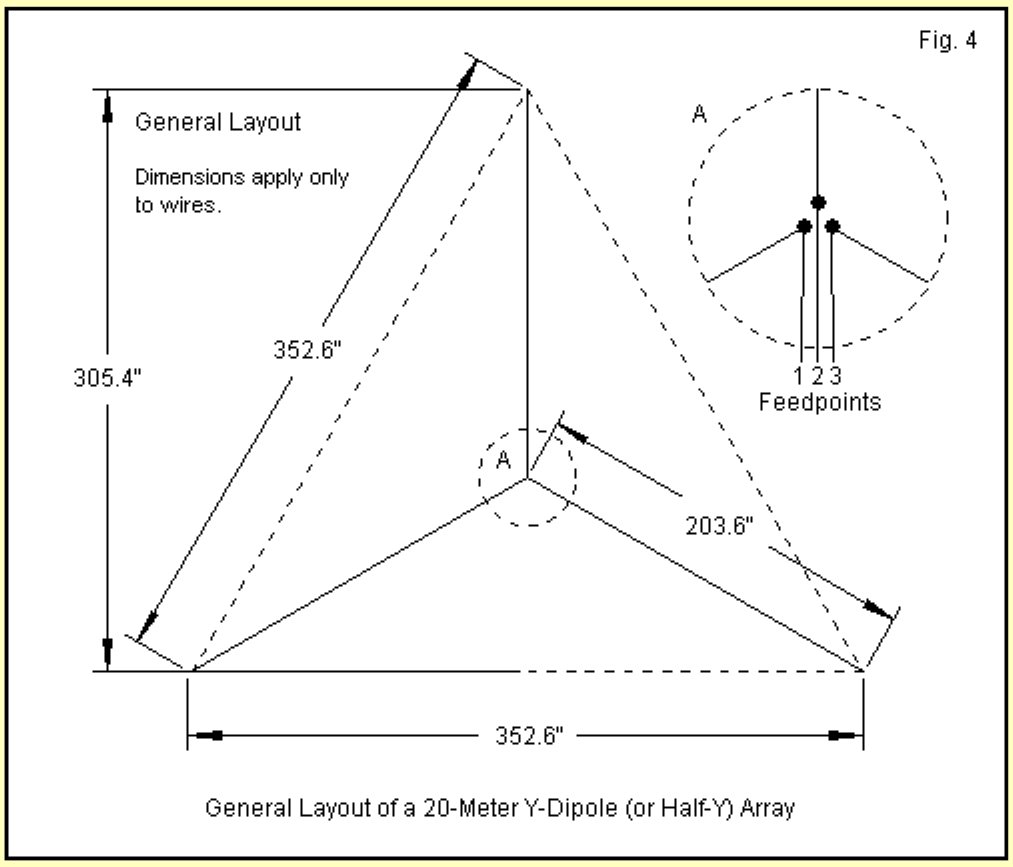
The full-Y array requires 4 supports, with one at the center and 3 for the far dipole ends. The triangle only needs 3 supports, since each support handles 2 dipole ends. However, if we wish to use the arrays at or very near to their resonant frequencies, we hit a snag in the form of very non-dipole patterns. Since the antennas are near their resonant frequencies on the lowest frequency of use, the two most obvious schemes fail us.

Fig. 3



On the left in **Fig. 3**, the full-Y array produces a bi-directional pattern with a narrow beamwidth. Interaction with the inactive dipoles produces north-south bulges and narrows the east-west pattern. In contrast, the inactive dipoles in the triangular array form reflectors to produce a spade-shaped pattern in one direction. In other applications, we might capitalize on this pattern, but for our project, it defeats the goal of covering the entire horizon. Most of the interactive effects disappear if the operating frequency is more than about 30% distant from resonance. However, that requirement would defeat our desire to have a 3-dipole array that is highly usable on several ham bands and able to cover the horizon.

There are alternative array configurations that do not result in interactions of the type we obtain from the full-Y and delta arrays. In the 1930s, some operators used a half-Y formation. The Y was full, but each element was half of a dipole. Each half-dipole leg came together at a center point and each had 1 of the feedlines already connected. Hence, the array ended up with 3 feedlines. To select a dipole, we simply used 2 of the 3 lines. Many of these early operators used the antenna on a single band. Therefore, they created twisted triplets for the feedline. The close spacing and wire insulation on the feedlines gave a reasonably constant and fairly low characteristic impedance for any wire-pair in the group. Determining the correct dipole to use simply required selecting the feedline pair that yielded the strongest signal.



General Layout of a 20-Meter Y-Dipole (or Half-Y) Array

Fig. 4 provides an outline sketch of the wire portion of the array cut for 20 meters. The dimensions are overly precise, since we shall be using the array with parallel feedline and an antenna tuner. However, the dimensions are based on first resonating the dipoles in free space and then transferring those dimensions to a model over ground. Any equal wire lengths within a few inches of the values in the figure will work as well. **Table 1** provides a recap of the critical dimensions, along with the dimensions of some other versions of the half-Y array.

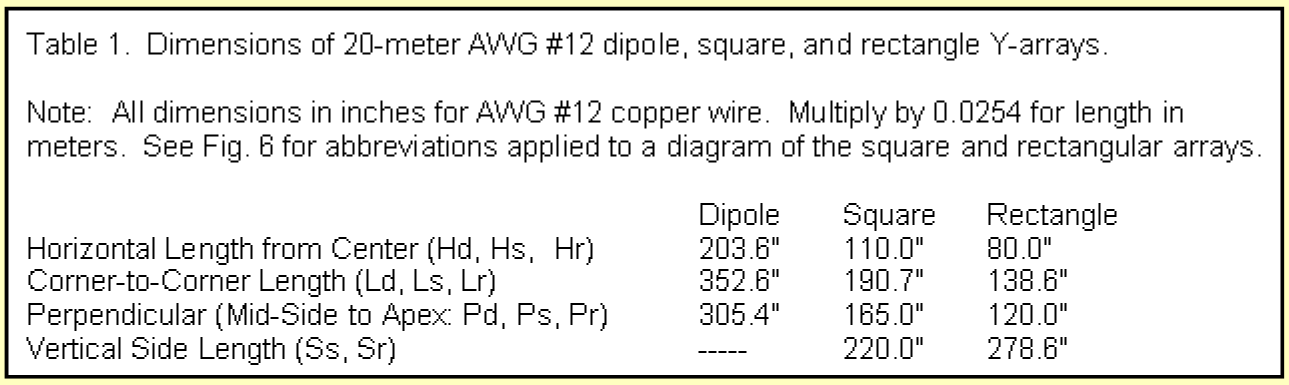


Table 1. Dimensions of 20-meter AWG #12 dipole, square, and rectangle Y-arrays.

Note: All dimensions in inches for AWG #12 copper wire. Multiply by 0.0254 for length in meters. See Fig. 6 for abbreviations applied to a diagram of the square and rectangular arrays.

	Dipole	Square	Rectangle
Horizontal Length from Center (Hd, Hs, Hr)	203.6"	110.0"	80.0"
Corner-to-Corner Length (Ld, Ls, Lr)	352.6"	190.7"	138.6"
Perpendicular (Mid-Side to Apex: Pd, Ps, Pr)	305.4"	165.0"	120.0"
Vertical Side Length (Ss, Sr)	-----	220.0"	278.6"

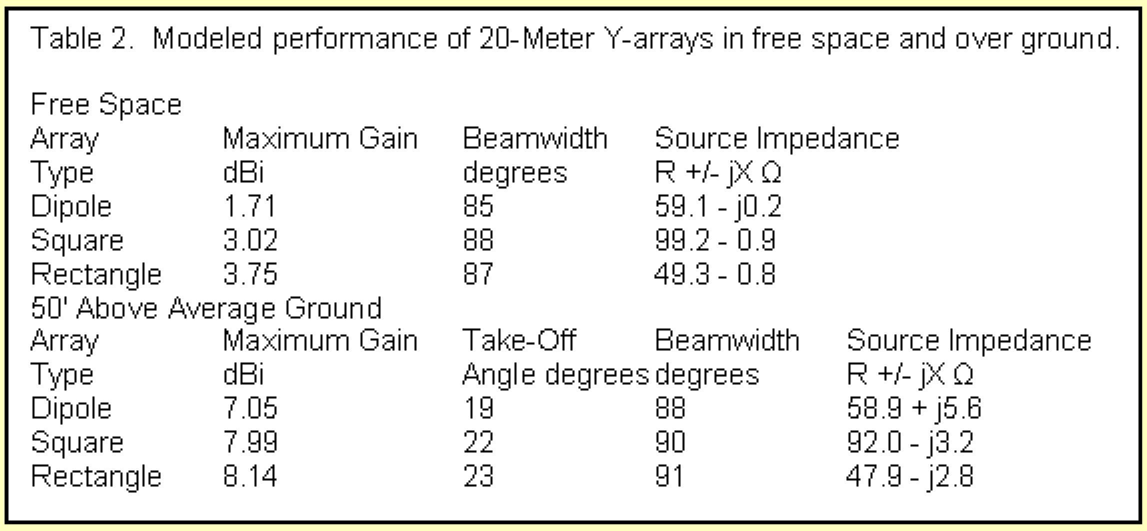


Table 2. Modeled performance of 20-Meter Y-arrays in free space and over ground.

Free Space

Array Type	Maximum Gain dBi	Beamwidth degrees	Source Impedance R +/- jX Ω
Dipole	1.71	85	59.1 - j0.2
Square	3.02	88	99.2 - 0.9
Rectangle	3.75	87	49.3 - 0.8

50' Above Average Ground

Array Type	Maximum Gain dBi	Take-Off Angle degrees	Beamwidth degrees	Source Impedance R +/- jX Ω
Dipole	7.05	19	88	58.9 + j5.6
Square	7.99	22	90	92.0 - j3.2
Rectangle	8.14	23	91	47.9 - j2.8

The pair of wires that we select forms a dipole that is bent to include a 120° angle. Like any slightly Vee'd antenna, we lose a bit of gain and some of the side null depth of a standard dipole. As shown in the top lines of **Table 2**, that gain loss relative to a standard dipole is under a half dB at 20 meters. However, in exchange for the maximum gain deficit, we obtain very workable patterns for many bands. The left portion of **Fig. 5** overlays patterns from 20 through 10 meters. The gain is remarkably consistent from one band to the next. Only on 10 meters do we find sufficient interaction between the 2 actives wires and the inactive wire to produce a 0.9-dB front-to-back ratio.

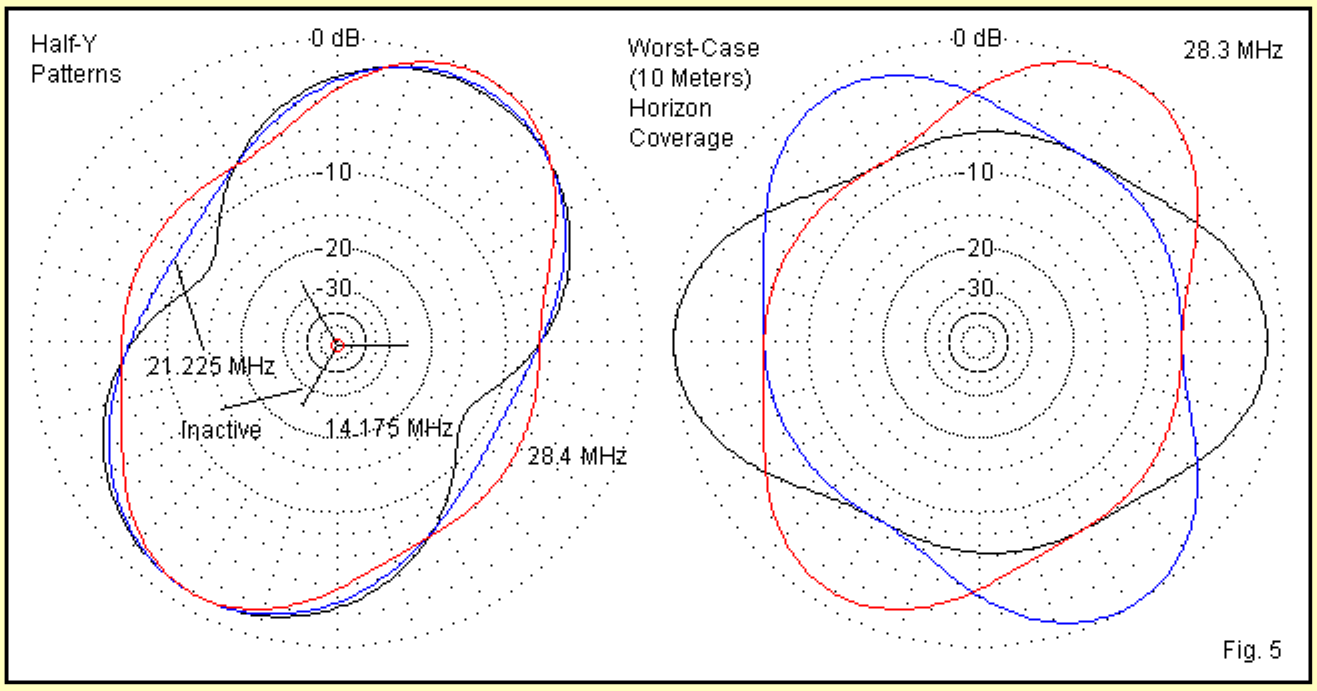


Fig. 5

10-meter operation presses the array to its limits as a means of covering the entire horizon with 3 bi-directional patterns. The right side of **Fig. 5** shows the deeper nulls in the overlap region between maximum gain points. As well, there are other cautions to observe when using the half-Y array in multiband service. **Table 4** lists some of the modeled performance figures, as well as indicating the bands most likely to yield excellent performance. Below 20 meters, we obtain an even broader beam. However, the source impedance has a low resistance and a very high reactance. With the standard high impedance lines that we tend to use for the array, this situation will likely result in a challenging matching situation for most tuners and introduce significant line losses. On 12 and 10 meters, the source impedance values reach levels that may challenge tuners in the other direction, depending upon the impedance components that exist at the terminals as a result of the line length and characteristic impedance. However, consistent operation on 20 through 15 meters--with 12 meters also a possibility--should be easy.

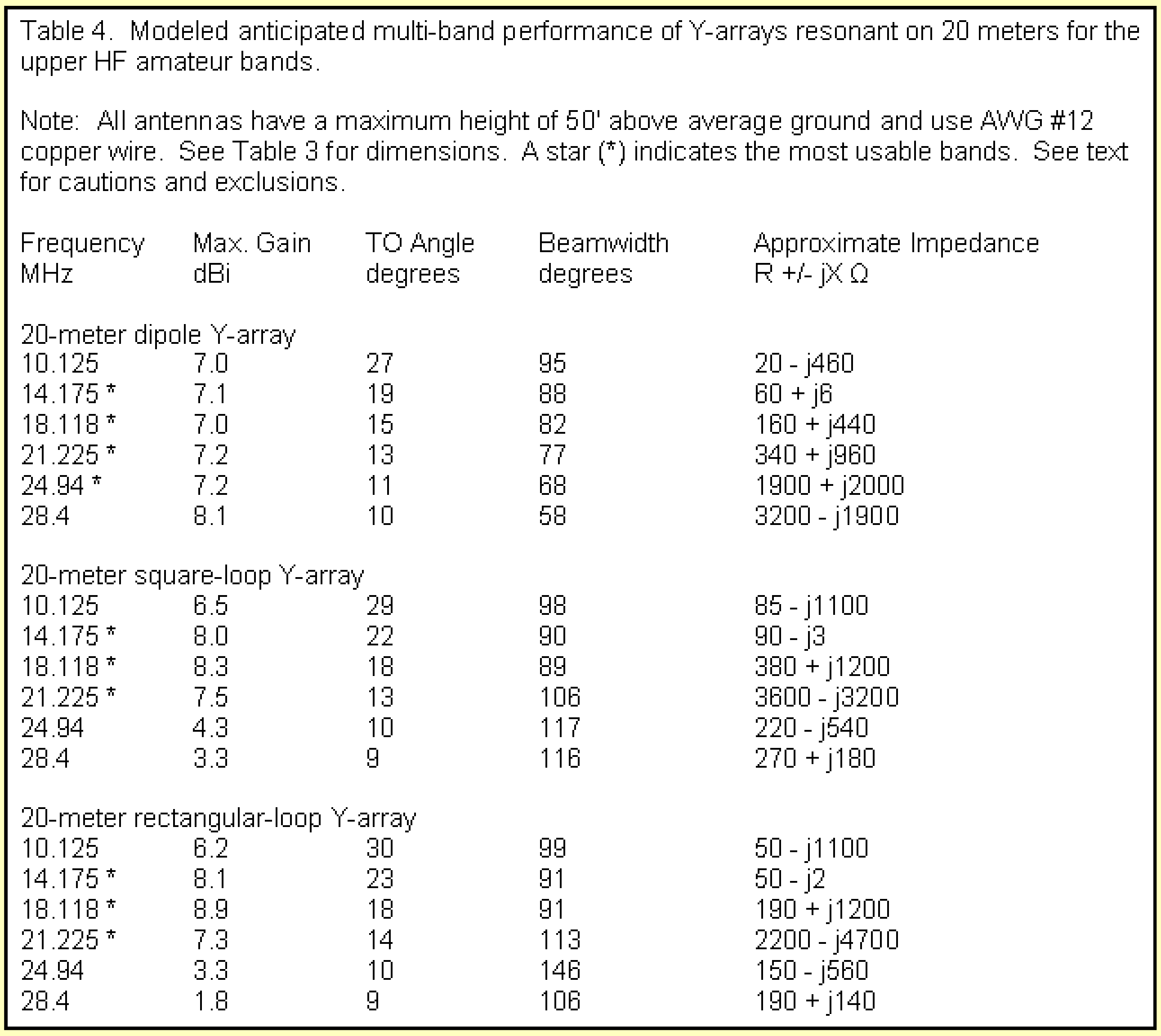


Table 4. Modeled anticipated multi-band performance of Y-arrays resonant on 20 meters for the upper HF amateur bands.

Note: All antennas have a maximum height of 50' above average ground and use AWG #12 copper wire. See Table 3 for dimensions. A star (*) indicates the most usable bands. See text for cautions and exclusions.

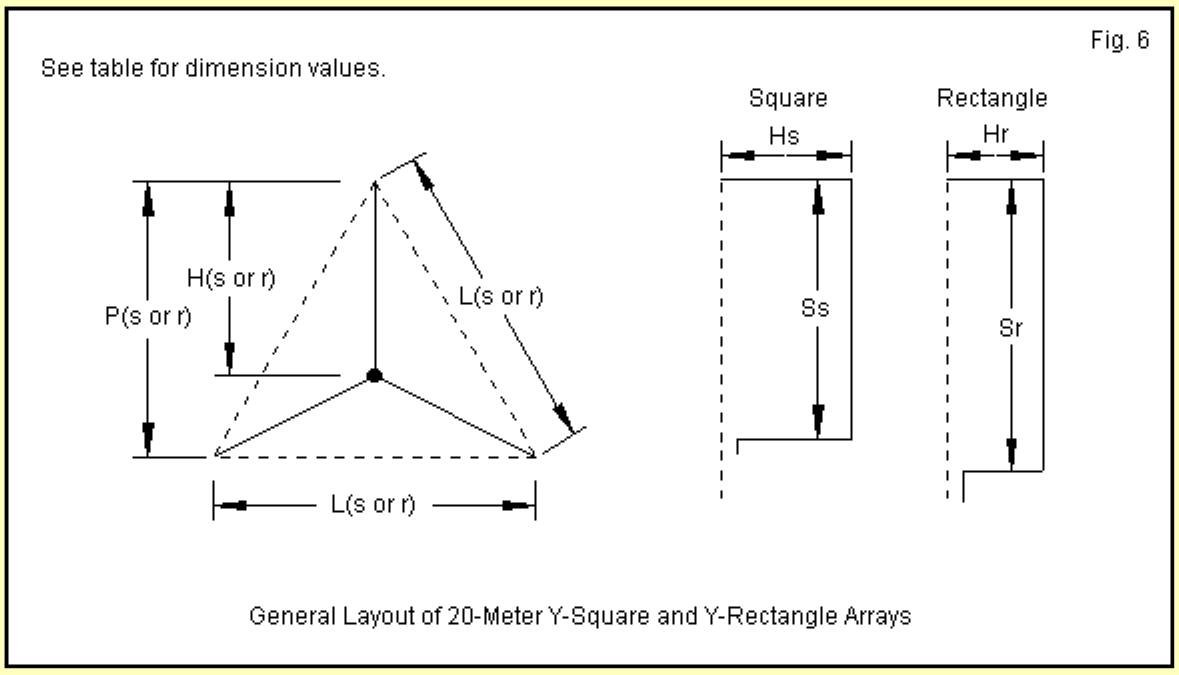
Frequency MHz	Max. Gain dBi	TO Angle degrees	Beamwidth degrees	Approximate Impedance R +/- jX Ω
20-meter dipole Y-array				
10.125	7.0	27	95	20 - j460
14.175 *	7.1	19	88	60 + j6
18.118 *	7.0	15	82	160 + j440
21.225 *	7.2	13	77	340 + j960
24.94 *	7.2	11	68	1900 + j2000
28.4	8.1	10	58	3200 - j1900
20-meter square-loop Y-array				
10.125	6.5	29	98	85 - j1100
14.175 *	8.0	22	90	90 - j3
18.118 *	8.3	18	89	380 + j1200
21.225 *	7.5	13	106	3600 - j3200
24.94	4.3	10	117	220 - j540
28.4	3.3	9	116	270 + j180
20-meter rectangular-loop Y-array				
10.125	6.2	30	99	50 - j1100
14.175 *	8.1	23	91	50 - j2
18.118 *	8.9	18	91	190 + j1200
21.225 *	7.3	14	113	2200 - j4700
24.94	3.3	10	146	150 - j560
28.4	1.8	9	106	190 + j140

For the upper HF region, installing the half-Y should require only 3 supports, one at each dipole end. The triple feedline that forms an equilateral triangle as a cross-section can simply drop from the center point. If the curve that the line forms on its way to the shack entry is shallow enough, you can maintain equal-length lines along the entire feedline run. Under these conditions, you should not need significant retuning when switching from one pair of dipole legs to the next. Hence, a simple switching scheme should give instant recognition of which dipole pair yields the strongest signal.

There will be a temptation to use a center support and to place the feedline wires symmetrically around the support. This method will work if the support does not form a conductor or semi-conductor. Trees and telephone poles notoriously change their conductive properties with the weather and the seasons. They can create losses along the line that take up much of the energy before it ever reaches the antenna. Unless the center support is certifiably non-conductive for the HF region in all weather, it may be better to offset the three feedlines from the support and to maintain sufficient distance to minimize interactions between the support and the lines.

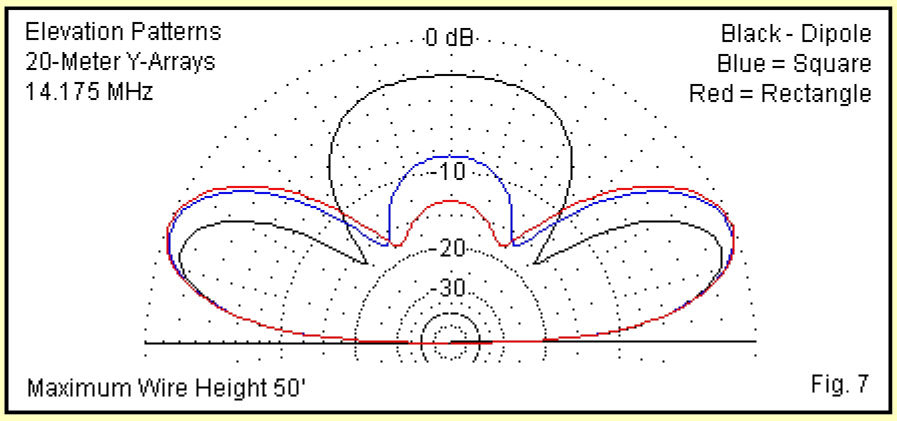
The half-dipole Y is not the only possible form for the array. Ron Wray, WB5HZE, wrote me about some interesting possible variations to suit his needs. Instead of using ¼-wavelength legs for each branch of the Y, he considered using half loops. In effect, the active pair of half loops would form a 1-wavelength quad loop with a 120° Vee. He also suggested that we need not replicate the isolation of the inactive element at the top or unfed point. The result would be a set of loops that had special advantages. First, for the same top height as the dipoles, they would yield additional gain. Second, a single top junction would simplify construction. Third, the entire array would occupy only half the lateral space required by the ¼-wavelength dipole legs. Finally, if a builder desired to use tubing or similar materials, a single center support could hold the entire array.

I modeled the revised system and ended up with the dimensions shown in the remaining lines of **Table 1** for a 20-meter version of Ron's antenna. In addition to the standard square loop, we can also form a rectangle with a 50-Ohm impedance on the fundamental band. The table also shows the dimensions for such a loop, with reduced lateral spread. The rectangle is only 40% as wide as the version using linear dipole legs. However, it is significantly longer from top to bottom. See **Fig. 6**



General Layout of 20-Meter Y-Square and Y-Rectangle Arrays

Table 2 shows the free-space and 50' modeled 20-meter performance data for the 3 versions of the half-Y array. The square and rectangular loop versions lose about a quarter dB relative to flat versions of those antennas. The loops both form in-phase fed pairs of horizontal elements and show gain over the single dipole. As well, the loops show slightly higher beamwidth values. I chose a certain maximum height (50') for the comparisons because that is likely to be the factor limiting most antenna builders. With a maximum top-wire height, the loops show slightly higher TO angles than the dipole version, since the element with the feedpoint is lower than for the linear element antenna. For any loop, the height that determines the TO angle--when referenced to a single linear element--is about 2/3 the way from the lower to the upper loop wire. (The same approximation applies also to stacks of Yagis.)



The source of the added gain for the loops on the fundamental frequency becomes apparent from **Fig. 7**. The graphic overlays the elevation patterns for the 3 versions of the loop with the 50' top-wire height. The square loop shows considerable suppression of high-angle radiation due to the use of 2 wires, one above the other. As we move toward the rectangle, the horizontal portions of the antenna come closer to a ½-wavelength spacing, at which point, radiation toward the zenith would disappear. It is not possible to reach a full ½ wavelength and still have a loop. However, the 50-Ohm rectangle has about 10 dB lower levels of zenith radiation than the linear dipole. As a result, there is more energy for the lowest lobe.

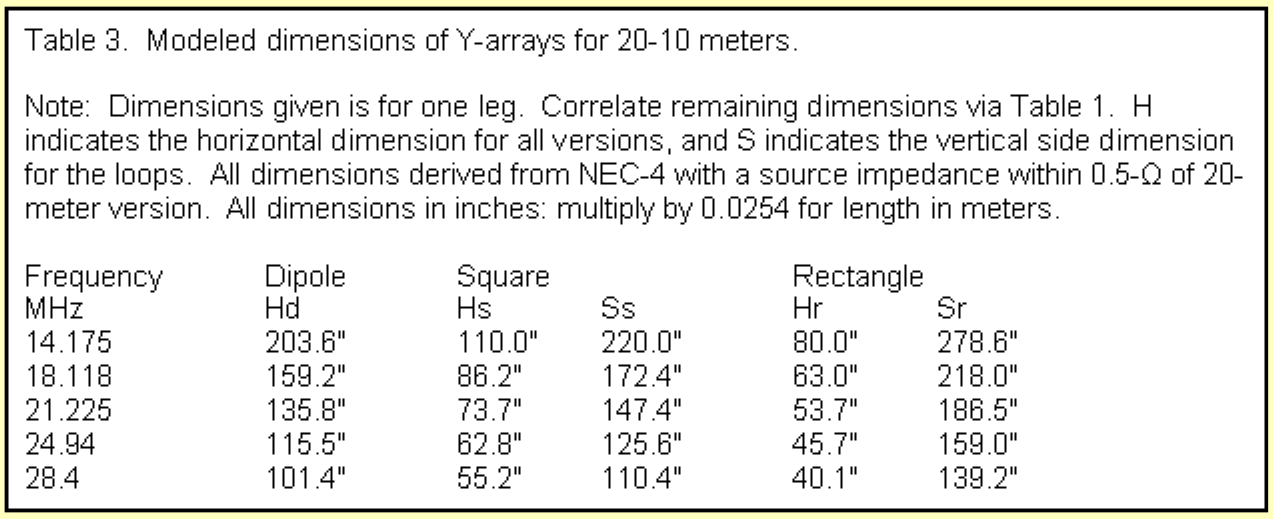


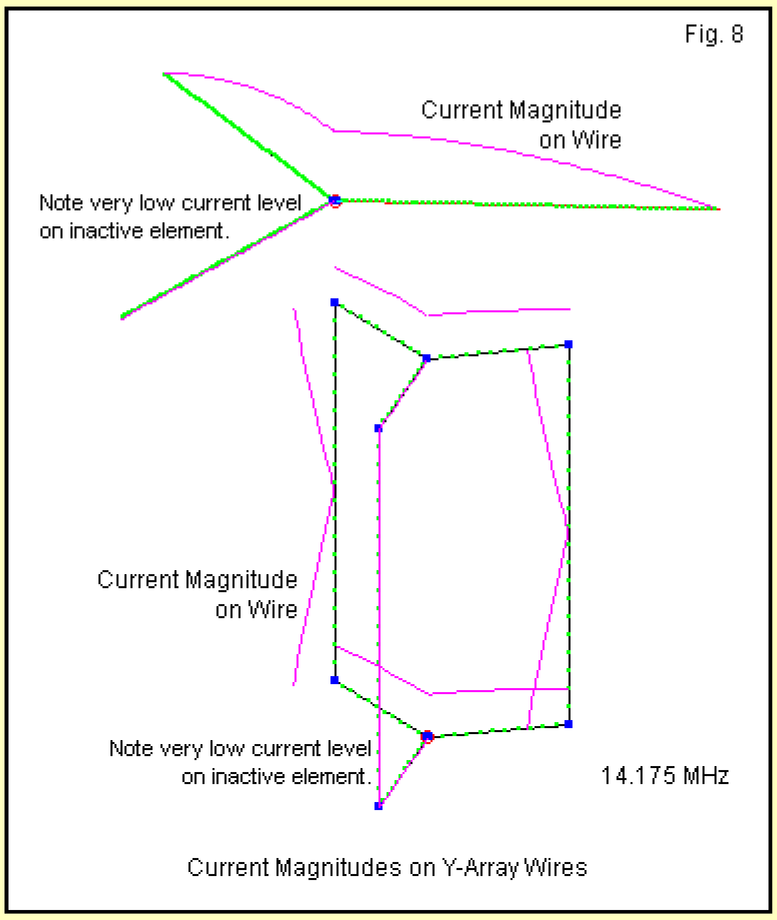
Table 3. Modeled dimensions of Y-arrays for 20-10 meters.

Note: Dimensions given is for one leg. Correlate remaining dimensions via Table 1. H indicates the horizontal dimension for all versions, and S indicates the vertical side dimension for the loops. All dimensions derived from NEC-4 with a source impedance within 0.5-Ω of 20-meter version. All dimensions in inches: multiply by 0.0254 for length in meters.

Frequency	Dipole	Square		Rectangle	
MHz	Hd	Hs	Ss	Hr	Sr
14.175	203.6"	110.0"	220.0"	80.0"	278.6"
18.118	159.2"	86.2"	172.4"	63.0"	218.0"
21.225	135.8"	73.7"	147.4"	53.7"	186.5"
24.94	115.5"	62.8"	125.6"	45.7"	159.0"
28.4	101.4"	55.2"	110.4"	40.1"	139.2"

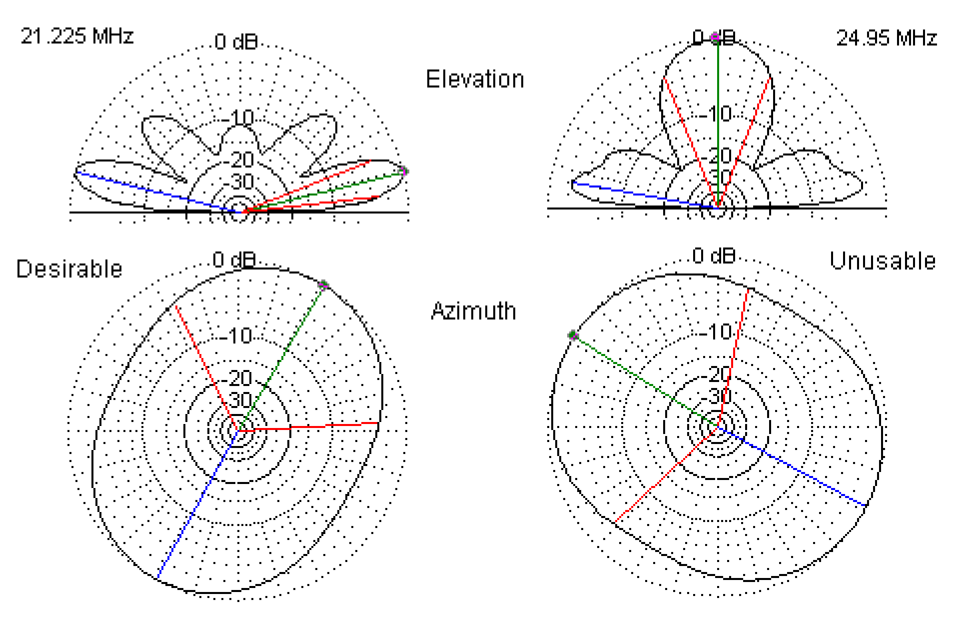
You may choose any fundamental band for a half-Y array in any of the 3 forms shown in these notes. **Table 3** provides a starting point by giving the free-space resonant dimensions for the arrays using #12 copper wire as a material. Obviously, the higher the fundamental frequency of the loop, the easier it will be to form an array that requires only a single support. With some adjustment of the loop size, you can use tubular horizontals and wire vertical elements. You may also create a 1-support structure by using a set of non-conductive horizontal supports with all-wire loops stretched between them. The variations are as unlimited as your creative adaptation of locally available materials.

Any of the 3 versions of the half-Y array will provide horizonal coverage on the primary bands because the unfed element is largely inert. The horizontal portions of the third element are at right angles to the active loop or dipole, despite the 120° Vee. Since the inactive element is also not fed, the current level remains near zero all along its length. **Fig. 8** shows an EZNEC portrayal of the relative current magnitude on the elements of both the Y-dipole and the Y-rectangle versions of the array on 20 meters, the fundamental frequency. Note that, for both versions of the antenna, the current level on the inactive element is completely insignificant, compared to the current on the active wires.



Current Magnitudes on Y-Array Wires

Table 4 provides the modeling data for all three versions of the array for a top-wire height of 50' above average ground. We have already noted the caution about operating the antennas at 30 meters, due to the low feedpoint resistance and the high ratio of source reactance to resistance in all 3 antennas. For multi-band operation, the dipole version of the half-Y array shows lower gain than the square and rectangular versions on 20 and 17 meters. However, the loop versions of the array lose any significant gain advantage on 15 meters. On 12 and 10 meters, the dipole array produces usable patterns, although the high feedpoint resistance and reactance may present some antenna tuners with a challenge.



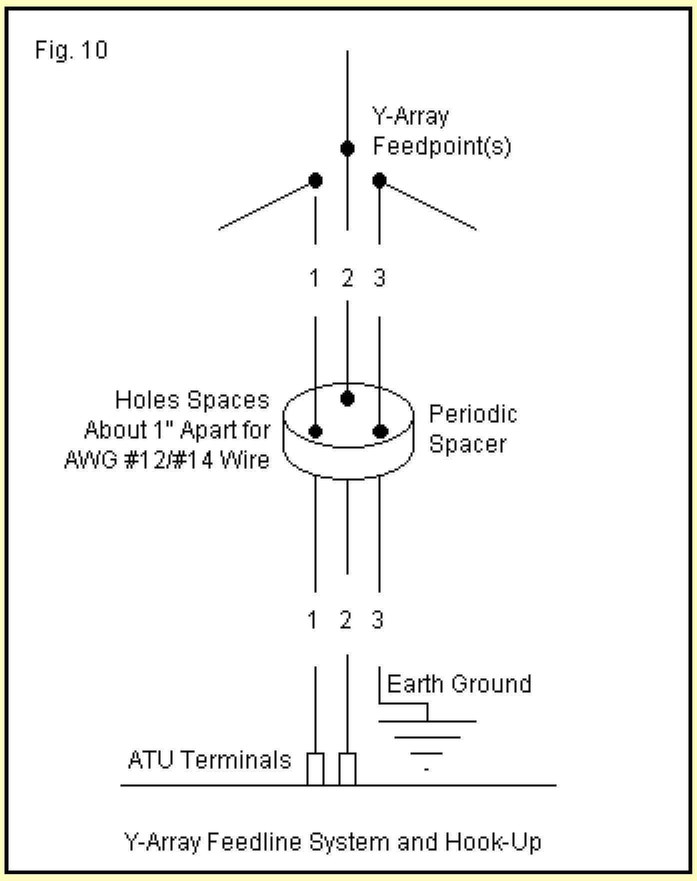
Frequency Limitations of Y-Array Loop Patterns

Fig. 9

The loop versions of the Y-array show a steep decline in gain as the frequency climbs above 21 MHz. The situation is considerably worse on 12 and 10 meters than the gain values in the performance table indicate. **Fig. 9** shows the elevation and azimuth plots for the rectangular Y-array on both 15 and 12 meters. Similar patterns emerge for the square array and for the same set of reasons. At 21 MHz, the loops still show mainly broadside radiation, which is natural to a loop with a circumference in the vicinity of 1 wavelength. However, by the time the operating frequency reaches 24.94 MHz, the array is operating like a 2-wavelength loop, with strong radiation off the edges rather than broadside to the loop face. As a result of the change in operating conditions, the loop patterns show a very strong component directed straight upward as well as strong side-to-side radiation. In terms of total coverage of the horizon, the loop-based forms of the Y-array lose their utility as the loop circumferences grow to about 1.75 wavelength or larger.

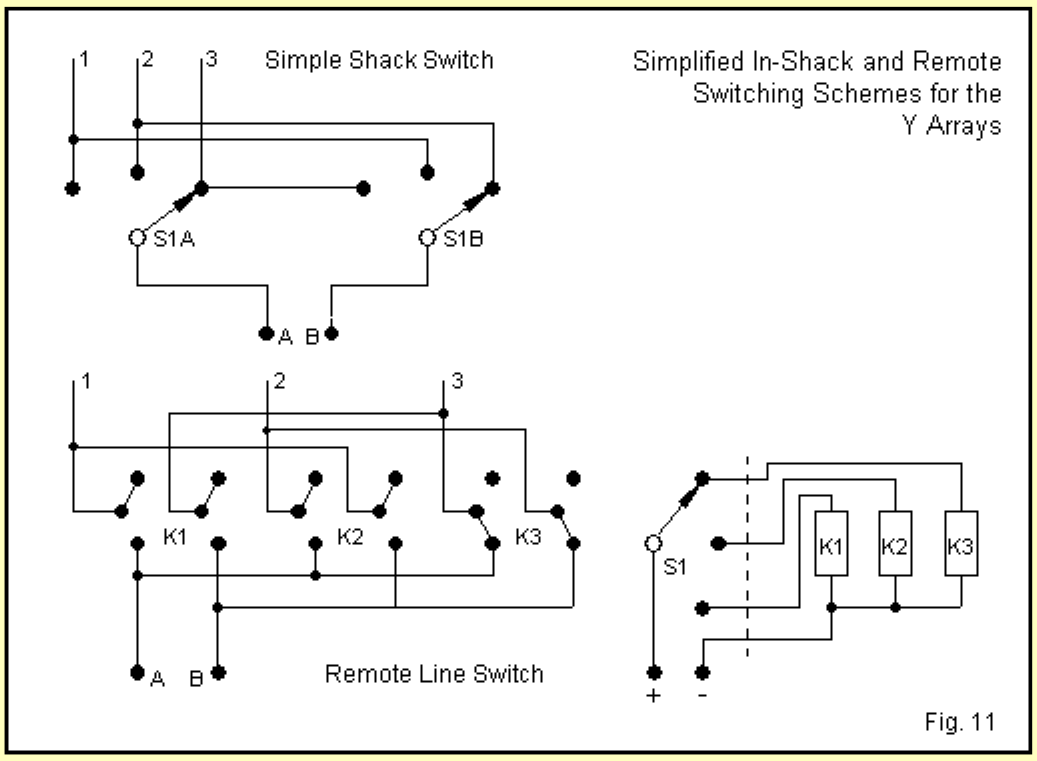
The potential Y-array builder thus has to decide whether he or she wants more gain on 20 and 17 or the possibility of extended operation to include 12 and 10 meters. Since the final decision will likely also contain strong consideration of what will fit within a given antenna space and how many supports are available, I can only suggest careful planning before attempting to construct any version of the Y-array.

The planning should also include careful attention to the method of handling the triple feedline. If you plan the system as a monoband array, you can create your own twisted triplet of wires using well-insulated AWG #12 or larger wires. If you use good quality wire with one of the modern plastics for insulation, the feedline will likely have low--or at least acceptable--losses in the HF range. Do not use computer cabling, since the wires are likely too thin for even QRP power levels. The low-impedance line may not be a match for the source impedance, so you will still need a tuner. However, tuners built into modern transceivers may be all that you need to effect an adequate match.



For multi-band use, the situation changes. **Fig. 10** shows the basic system of feeding the antenna with homemade transmission lines that have a relatively high characteristic impedance. With 1" spacing, AWG #12 or AWG #14 wire will show close to 400 Ohms as the characteristic impedance. It is possible to make periodic spacers from plastic discs. The goal is to hold all three wires in perfect alignment from the antenna source to the antenna tuner terminals or to some intervening switching system. If there is a center support, the wire-spacing disc can be the end portion of a larger piece of plastic material used to space the entire set of wires well away from the support. The plastic should have good RF properties in the upper HF region and be resistant to UV radiation. UV-protected polycarbonate is readily available from plastic supply houses and other sources.

If the run of line is fairly long and the spacers are anchored, you may also move the wire positions by one hole with each new spacer. Make each position shift in the same direction, either clockwise or counterclockwise, so that the resulting line has a stiffening twist along its total length. The ultimate goal is a set of 3 possible line combinations such that, when switching from one combination to the next, no antenna tuner changes are necessary. The result will be the ability to switch from one combination to the next to determine instantly which one produces the strongest signal. The strongest received signal normally indicates the best setting for the strongest transmitted signal.



You may switch the system manually or remotely anywhere along the line. The top portion of **Fig. 11** shows a simplified manual switching system suitable for use in the shack near the tuner output terminals. The numbered lines are the 3 wires from the loop or dipole halves. The lines marked A and B represent the 2-wire parallel feed line from the switch to the antenna tuner. Because the impedance at the switch may be either very high or very low, use as large a ceramic rotary switch (2-pole, 3-position) as you can obtain, depending on the power that you plan to use. The terminals should be well spaced and heavy to handle either high voltage or high currents. You may add a third wafer to ground the inactive line. A metal enclosure is not necessary, but the entire assembly should adhere to all safety precautions concerning unwanted contact by either the operator or shack visitors.

The lower portion of **Fig. 11** shows the bare bones of a remote relay-controlled switching system. In the sketch, the normally closed contacts are upward to simplify the drawing. The relay control switch is in the shack, while the relays might normally live very close to the array feedpoints. The schematic does not show the normal reversed diode across each relay and the extensive use of by-pass capacitors and other components needed to keep the relay control lines free of RF. Like the manual switching sections, the relays need widely spaced contacts to handle high voltage and large contact surface areas to handle high currents. The remote system allows the use of one of the commercial parallel transmission lines for the run from the switching box to the antenna tuner. The relay system requires careful weather proofing. I prefer a double-shell system, with weep holes well separated. If one shell has a hidden leak, the second shell sustains protection. Debug the relay housing(s) at least once or twice per season.

The half-Y array is not an answer to every upper-HF operating need. Its goal is to provide full horizon coverage for the general operator with limited space and a budget that does not include a rotator. Antenna and feedline switching with less expensive components substitutes for an expensive and high-maintenance rotator system. One or another version of the antenna may be suitable for potential use on any of the HF amateur bands as the fundamental frequency.

The triangular or Y-array concept is adaptable to many variations. For example, if you have a need for diverse target areas rather than whole horizon coverage, you might consider a triangle of extended lazy-H antennas. With sufficient separation, you can create a switchable triangle of Lazy-H arrays targeted by the best compromise relative to the broadside pattern of each one. The extended Lazy-H uses 1.25-wavelength elements on the highest frequency of use, with ½-wavelength to 5/8-wavelength spacing between the upper and lower elements. A perfect triangle is not necessary, so you can modify the broadside direction of each Lazy-H to accommodate the narrower beamwidth that gives you the higher gain. As well, the longer elements will be more immune to interaction with the inactive antennas. If you begin with 1.25-wavelength elements and a vertical spacing of 5/8 wavelength at 10 meters, you can cover several lower bands with good patterns and significant gain before the array approaches the size at which interactions with the inactive wires creates pattern distortions. However, the array trades beamwidth for gain, so full horizon coverage cannot be a goal. However, you can obtain good signal strength to up to 6 target communication areas.

Alternatively, especially for the lower bands, you can create triangles of vertical dipoles. By judicious switching, you can drive one dipole and let the other 2 form a set of reflectors. The leads to a central remote switch can comprise inductively reactive loads for the reflectors to create the right amount of lengthening for optimum parasitic reflector service. Vertical antenna patterns normally have a larger beamwidth than horizontal antenna patterns, and a 120° beamwidth is not difficult to obtain. Therefore, you can cover the entire horizon with just 3 vertical dipoles.

The Y-arrays and some of the possible triangles provide examples of what we can do with wire when faced with a limited budget and limited installation space. The basics for the arrays that we discussed have very old roots, but are ripe for re-use, refreshment, and contemporary adaptation to increase our antenna options. "Why" is a question, but for some operators, "Y" may be an answer.

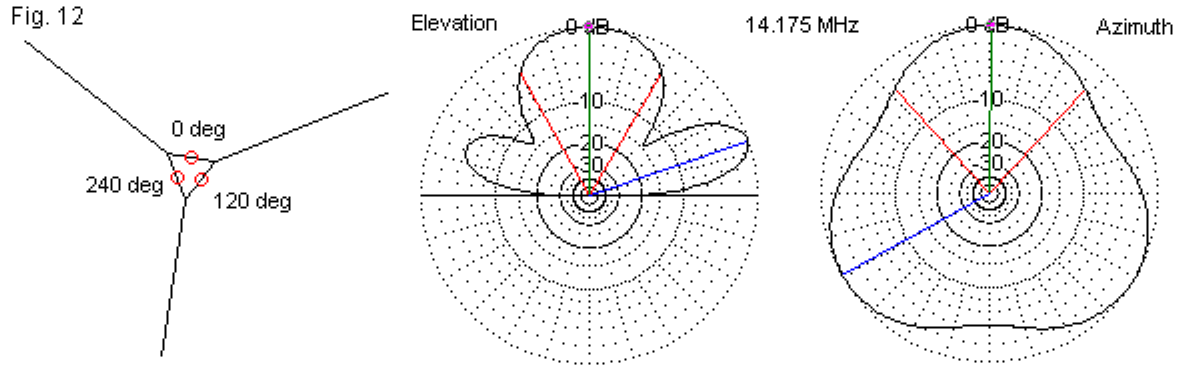
A Special Appendix

Correspondence arrived at *QEX* asking the following question. "One can make W4RNL (SK)'s Y antenna omni-directional by driving the 1, 2, 3 feedpoints with three-phase power (where the 1, 2, 3 feedpoints are driven with RF power at 0-degree, 120-degree, and 240-degree phases respectively)." "I guess I'm curious to figure out how I can take my RF signal and turn it into a 3-phase RF signal."

My reply was informal.

Although the idea is intriguing, I do not know if its is practical. I took the 20-meter Y model at 600" (50') and modified it to have 3 short feed wires, with simultaneous 0, 120, and 240 degree phased sources. The modeling plan and the elevation/azimuth plots are in **Fig. 12**.

Fig. 12



Feed System for the
Phase-Fed 20-Meter Y

Plots of a 20-meter Y with Simultaneous Feeding of All Pairs
at Phase angles of 0, 120, and 240 Degrees

The original switched Y had bi-directional gain of a little over 7 dBi at 19 degrees elevation. The phase-fed Y has a max gain of a little over 6 dB--straight upward. There is a moderately strong triangular pattern at 19 degrees elevation, with a gain only a little under the upward maximum value. (Note that the pattern is not truly omni-directional, since the individual patterns do not add smoothly.)

The impedance of each source point is about 85 Ohms. One would need 3 identical twisted pairs of about that impedance as a Zo and sufficiently separated so as not to interact. Back at the shack end of the line one could set up delay lines for 120 degrees and 240 degrees, but that is a lot of line. And it is good only for one band. One might also install delay lines at the antenna hub with a single main feedline back to the shack. However, such lines might be difficult to route to prevent undesired interactions. In the shack, double shielded coax might do the trick, with a 1:1 balun for the twisted pair runs. Coiling delay-line coax in old large metal popcorn cans would likely serve the added shielding needs, although the usual decorations on such cans might need disguising to maintain proper station dignity.

However, all is not lost. If we scale the design for 40 meters and adjust for practical height considerations, then we might have a workable combination of a NVIS and longer distance antenna. MARS and other military affiliate and related operations often look for antennas that would serve both shorter range and longer-range regional needs, and such an antenna pattern might fit their needs. But due to the need for delay lines, the antenna would be frequency or fairly narrow-band specific. I have not looked into what lower heights as measured in wavelengths will do to the pattern, but this may be a start in the design process if one has a need for such an antenna.

It is likely that the junction of the 3 lines (1 direct and 2 delay) at the TX end of the line would need a transmission-line transformer at about a 2:1 ratio to raise the parallel connection composite impedance of a little over 25 Ohms up to 50 Ohms.

Those are my off-the-shelf thoughts. At least the picture may be interesting.

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