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Design, Construction and Evaluation of the Eight Circle Vertical Array for Low Band Receiving©

If you have the available real estate, this steerable array of vertical antennas may offer significant advantages.

In recent years, interest in DXing on the 160 and 80 meter amateur bands has increased. This has been driven by a number of factors including ARRL's DX Challenge Award and the expanded volume of low band antenna information in various publications and on the internet.[1] The impact of *ON4UN's Low Band DXing* book is not to be underestimated.[2] In addition, the large signal handling capability of Amateur Radio equipment has improved tremendously in the last two decades. These positive influences have prompted many radio amateurs to increase their knowledge of antenna and propagation characteristics on the low bands. Many have attempted to apply that knowledge by constructing and evaluating various antenna designs in different environments, and the authors are included in that group.

W5ZN has many years of experience in designing and evaluating antenna systems for amateur microwave applications, and has presented numerous technical papers at conferences of the Central States VHF Society, Southeast VHF Society and the Microwave Update Conference, as well as co-authoring the chapter on multi-band feeds in the *W1GHZ Microwave Antenna Book*.[3, 4, 5, 6] Using these designs at W5ZN resulted in first place finishes and new records in numerous contests. In 1987, after moving from a city lot to a 30 acre field he became interested in expanding his knowledge and experience with receiving antennas for the Amateur Radio 160 and 80 meter bands.

N4HY has actively designed and modeled numerous antenna systems for multi-station amateur installations. He was AMSAT VP of Engineering for 3 years. Bob is the author of numerous papers about Amateur Radio for ARRL/TAPR Digital Communications Conferences, AMSAT Symposia and *QST*. He was previously an active member of the Frankfurt Radio Club but has been inactive in HF contesting for 15 years. He is active in VHF+ contesting. Bob is a proud member of the "Amateur Radio Geek Squad," and is a co-developer of the SDR code for Flex Radio's PowerSDR™.

The authors teamed up to refine the design, document the construction and evaluate the performance of the "W8JI Eight Circle Vertical Array" at Joel's station in north central Arkansas.

1.0 Design of the Eight Circle Array

The primary objective of any low band receiving array is to obtain a directivity pattern that will reduce the impact of various noise sources from multiple directions and locations. Antenna gain is not of specific importance in these designs since the sky noise is sufficiently high that not all of the gain in full size antennas and modern receivers can be used on the low bands. It is better to optimize directivity and ambient noise suppression in the antenna, and to optimize the receivers for large signal handling and dynamic range. It is not the intent of this paper to discuss all of these topics. We suggest that a thorough study and understanding of *ON4UN's Low Band DXing*, Fourth Edition, by John Devoldere, ON4UN, is a requirement prior to proceeding with any low band operation. (See Note 2.) Chapter 7 is prerequisite for any receiving antenna project. In addition, the specific theory related to end-fire and broad-side arrays in the same chapter must be read and understood as well. The Eight Circle Vertical Array system is based on this theory and cannot be used to its full potential without this knowledge. If you don't fully and completely understand this material, read it as many times as necessary to adequately comprehend it, along with the wave characteristics and mathematics that encompasses the design.

1.1 Element and Array Design

The 160 meter Eight Circle Vertical Array was designed by Tom Rauch, W8JI, and previewed in the Fourth Edition of *ON4UN's Low Band DXing*, Chapter 7, Section 1.30. The array is centered on a shortened top loaded vertical and described in the above reference in section 1.21.1. Additional information on small vertical arrays can be found on Tom Rauch's Web site.[7]

[After reading the "In the Next Issue of QEX" item in the Jan/Feb issue, Robert Zavrel, W7SX, sent me a note to tell me that he holds a patent on an eight-circle vertical

[1]Notes appear on page 17.

array from work he did in 1994. Bob's patent is number 5,479,176: "Multiple-element driven array antenna and phasing method." Details are available on the US Patent Office Web site; **patft.uspto.gov/**. The details are also available from several other patent search Web sites, including **www.google.com/patents**. — Ed.]

We wished to further evaluate the design of the array and also evaluate an 80 meter version that did not exist (at least at the time of the original analysis that was done before the Devoldere publication of details of the 160 m array in *Low Band DXing* and later presented to N2NT, W2GD, and K3LR). The most crucial missing piece of all is a step by step *how-to* in building, tuning, and using the antenna. None chose to build it at the time of the original analysis, so it was dropped until W5ZN declared an intention to do so. It is important to understand first and foremost that this is a receiving antenna. Like most receive antennas, it is designed only for this purpose and is wholly unsuitable for transmitting.

One of the ways we make sure it is unsuitable for transmit applications is to use impedance matching with a low-wattage-rated resistor. This resistor will do great things in this application; most prominently it will lower the *Q* and broaden the response of the antenna at good SWR and match it to widely available and inexpensive coaxial cable. This comes at the expense of gain, but in the overall communications system, coupled with analysis of the noise temperature of the bands (160 meters as well as 80 meters), gain is not the primary objective with a low band receiving antenna design, and its insertion loss is not harmful. At 160 meters, the array using the elements proposed will have plenty of gain at –8 dBi. This loss actually helps increase the IP^3 of the system — a very important thing on the low bands! As such, we believe you should not even need a preamp unless you are installing an incredibly long feed line run from the array center to the shack, or feel the need to have one just as a buffer between the antenna and the rigs. That will be for you to determine based on your specific installation. Numerous methods for determining this need have been previously published. (See Notes 2 and 7.) With the theoretical gain given above, this will equate to an MDS in, say, an FT-1000MP, that will be –120 dBm on this antenna. That is very low for both 160 and 80 meters.

This antenna array will exhibit nearly the same gain and directivity over the entire 160 meter band and even better results should be achieved on 80/75 meters from 3.5 to 3.8 MHz with the 80 meter version. The results of the 160 m construction and testing, presented later, do attest to the validity of the analysis. Our recommendation is that the design be skewed toward the bottom of each band.

Of primary importance in the design of low band receiving antennas is the Directivity Merit Factor (DMF, referred to by ON4UN) or a better measure, Receiving Directivity Factor (RDF, the W8JI measure) which is the ratio in dB of the forward gain at a desired direction and take off angle to the average gain over the rest of the entire sphere around the antenna. (See Notes 2 and 7.) These two "Factors" are described in detail in Sections 1.8 through 1.10 of Devoldere's book. While this antenna array has some small side lobes (see Figure 9), they are really nothing to be concerned about and are better than most four squares and Yagi antennas. You can trade off some side lobes for better directivity, and this was done in the original analysis discussed above. A nine element circle array, design by John Brosnahan, WØUN, makes these side lobes smaller but it does not increase the directivity factor significantly and has a larger lobe upward, which is prone to sky noise.[8] One benefit of the WØUN design is that it can also be used for transmitting, but this comes at the expense of a more complicated switching and phasing network than needed for the eight circle antenna. John's system phases a three element parasitic array with a broadside/end-fire cell.

The Eight Circle Vertical Array is inexpensive, easy to build and easy to feed, as the utilization of a broadside/end-fire array reduces the complexity of the switching system. An analysis of vertical elements shows why the short vertical element is ideal for low band receive applications.

First, the ground is much less important. There is little ground effect cancellation of radiation. These small vertical elements with a top hat are still quite sensitive and have a low feed point impedance after you cancel their capacitive reactance with a small inductor at the base. Since the antenna needs to be broadband, the feed is swamped with a resistor and we should make it as large as practical, consistent with the coaxial feed line impedance. This allows us to use the least expensive coax that will permit reliable, robust operation. In this case 75 Ω cable is perfect, plentiful, and cheap. Therefore, a short element with a capacitive top and an inductive loading coil at the base with enough resistance to bring the mostly resistive impedance up to 75 Ω is nearly ideal. The resistive swamping lowers the *Q* and increases the operating bandwidth with 75 Ω cable.

1.2 Modeling the Individual Elements

The best approach is to use the W8JI element. There isn't a great deal of information published about this design, so Bob did our own modeling with *EZNEC/4 Professional*.

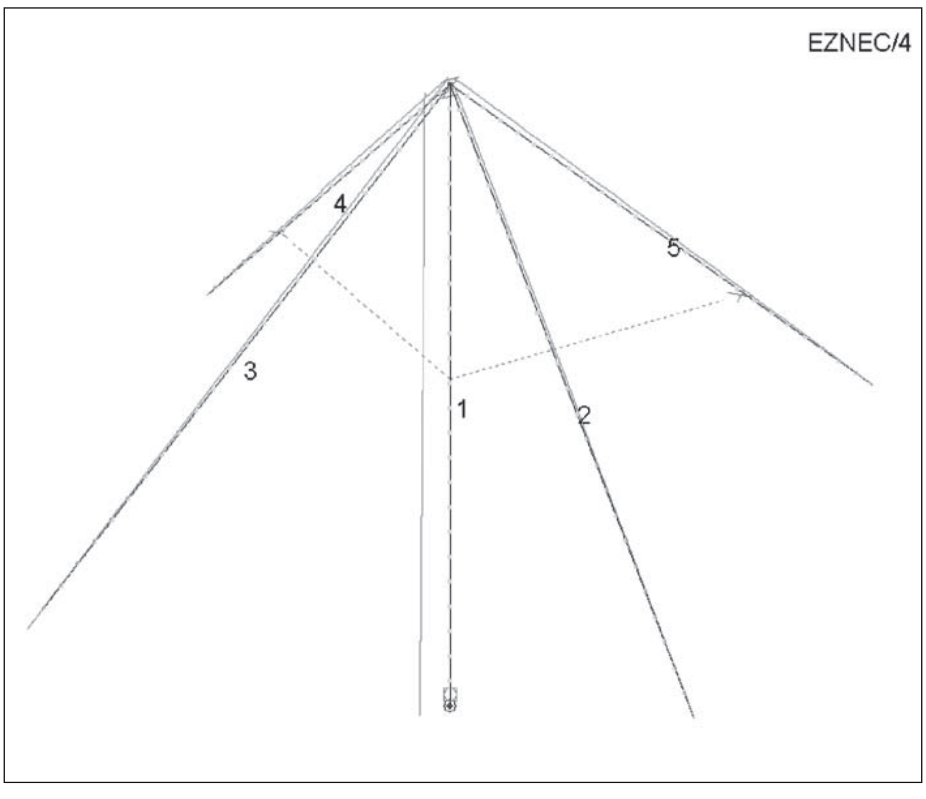


Figure 1 — This antenna drawing from *EZNec/4 Pro* shows the analysis segments and bottom load as well as top-hat details of one element of the Eight Circle Vertical Array (no radials shown here).

Figure 1 shows the segment layout of the shortened vertical. This vertical contains some minor modifications from the W8JI design, based on Bob's studies.

The model shown in Figure 1 is from the W8JI site but has been slightly modified based on our analysis. The EZNEC/4 model files we used for our analysis are available for download from the ARRL *QEX* files Web site.[9] Our model contains the correct number of segments and a better analysis of the loading of both the top-hat and base, and does an adequate job of modeling with the radial system. This determination was made because using *EZNEC/4 Pro* allows for good theoretical ground models. It is here we learned of the importance of the construction details over various quality grounds and how to achieve robust and predictable operation over all sorts of climates and soil conductivities. The160 meter and 80 meter models are approached as lump resistance in the feed with lumped inductance, and no attempt is made to account for the resistance of the small inductors except when choosing the appropriate resistor. This is taken care of when we get to setup and tuning.

For 160 and 80 meters, the dimensions of the vertical and top hat wires are all 25 feet in length, with the top-hat wires also acting as guys, 25 feet from the base of the vertical. This allows the top-hat to serve as both capacitive top-loading and provide very good high angle rejection as well. Because the structure is ground mounted and four of the elements are active in each of the eight directions in a broadside/end-fire cell, the rejection above 45° is at least 9 dB down from the main lobe maximum. The suppression goes up with increasing angle and is a key feature of the top-hat because it acts as a shield against a large expanse of the sky and reduces sky noise above the antenna from reaching the receiver. The short, ground-mounted structure provides immunity from man-made noise in all but the immediate vicinity. So performance will be good so long as you minimize line of sight noise sources for the array.

The individual vertical structure is self resonant at 75 meters so we will need to bring the resonant frequency down with a small inductor. On 160 meters, our design indicated the load inductor to be 30 µH with enough resistance to give a low SWR at 1.85 MHz. This will provide less than 1.5:1 SWR from 1.8 to 1.9 MHz to 75 Ω coax. On 80 meters, the design indicates a 2 µH inductor will be required with the addition of enough resistance to give a low SWR from 3.5 to 3.8 MHz.

The 75 Ω feed point impedance was chosen because of the availability of inexpensive, readily available coax (cable TV installation)

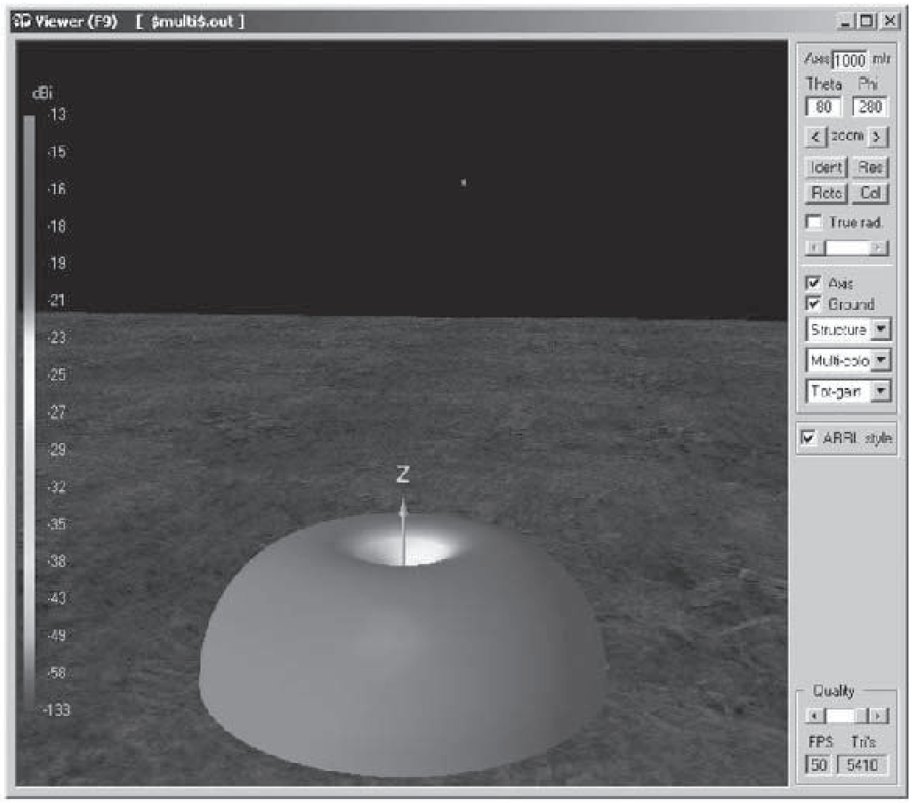


Figure 2 — This 3D radiation pattern for a single element from the array is captured from *4nec2.*

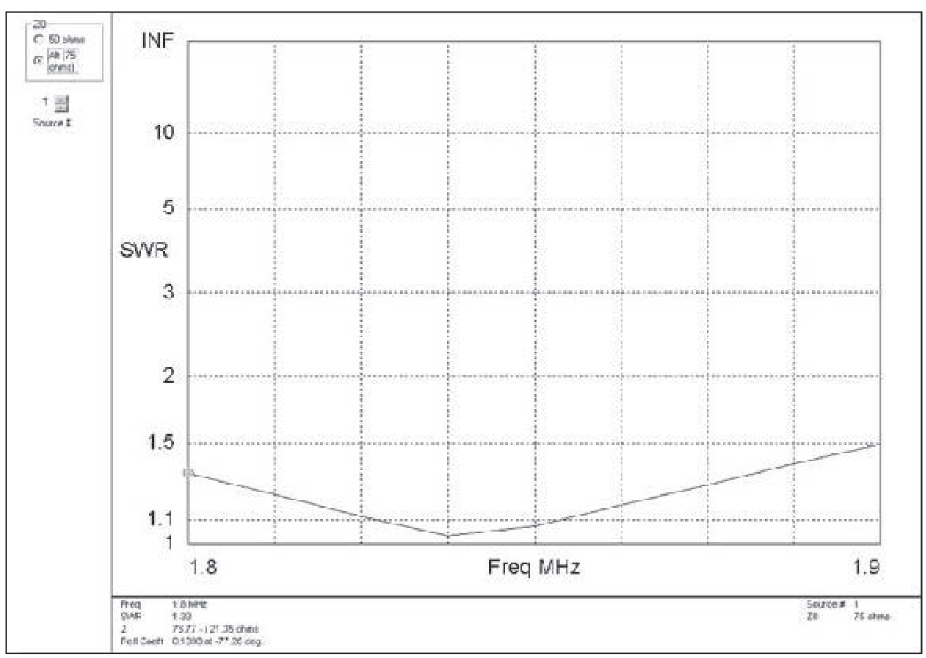


Figure 3 — This SWR profile is for one 160 meter vertical.

plus the higher resistance is used to broaden the SWR, since it is accomplished by lowering the *Q*. This helps guarantee the front end of your receiver sees the kinds of loads it needs to see to perform correctly.

The mounting is not critical and no special fixtures are needed to insulate the vertical element and top hat wires. You will not be able to tell the difference between an insulated bottom from one held off the ground by a fence post (non-conductive of course!).

The design uses a top-hat made from AWG no. 16 wire with the vertical element assumed to be a 1.25 to 1.5 inch diameter vertical pipe.

Even though ground resistance is not particularly important for radiation resistance, as mentioned earlier, you will need at least four ⅛ to ¼ λ radials on each element in order to stabilize the feed point resistance over changing ground conditions year round. The exact number and length can be determined with some very easy tests after initial construction. That process will be covered later. Again, the ground system only needs to be good enough to provide a stable feed point resistance, since the object is not super efficiency and gain, but directivity and stability of the impedances in all seasons. This will permit the system to be close enough to "perfect" that the modeling applies consistently. Four radials are likely sufficient and that is what you should start with, but testing can easily be performed after construction to determine the exact number required. One each of these initial radials should be buried beneath each one of the top-hat wires. Depending on your location, just remember that if the radials are under more than just a few inches of water, they are effectively shielded from the antenna, and ineffective. Figure 2 shows the 3D pattern of one of the vertical elements at resonance using *4nec2dx*.

Figure 3 displays the SWR profile for Bob's 160 meter design, computed by *EZNEC/4 Professional*, assuming perfect ground, 30 μH base inductor, resistor and 75 Ω coax.

The 80 meter design SWR profile, as computed by *EZNEC/4 Professional* assuming perfect ground, 2 μH base inductor, resistor and 75 Ω coax is shown in Figure 4.

1.3 Array Geometrics

The Eight Circle Vertical Array is comprised of broadside/end-fire cells. The circle's dimension is determined by the broadside spacing and the end-fire spacing. Much analysis has been performed on the optimum broadside and end-fire spacing so rather than spend time in an effort to determine the same conclusions we will use those results. For those wishing to dig into the theory behind the spacing you can review Chapter 7 Section 1.11 and 1.12 of *ON4UN's*

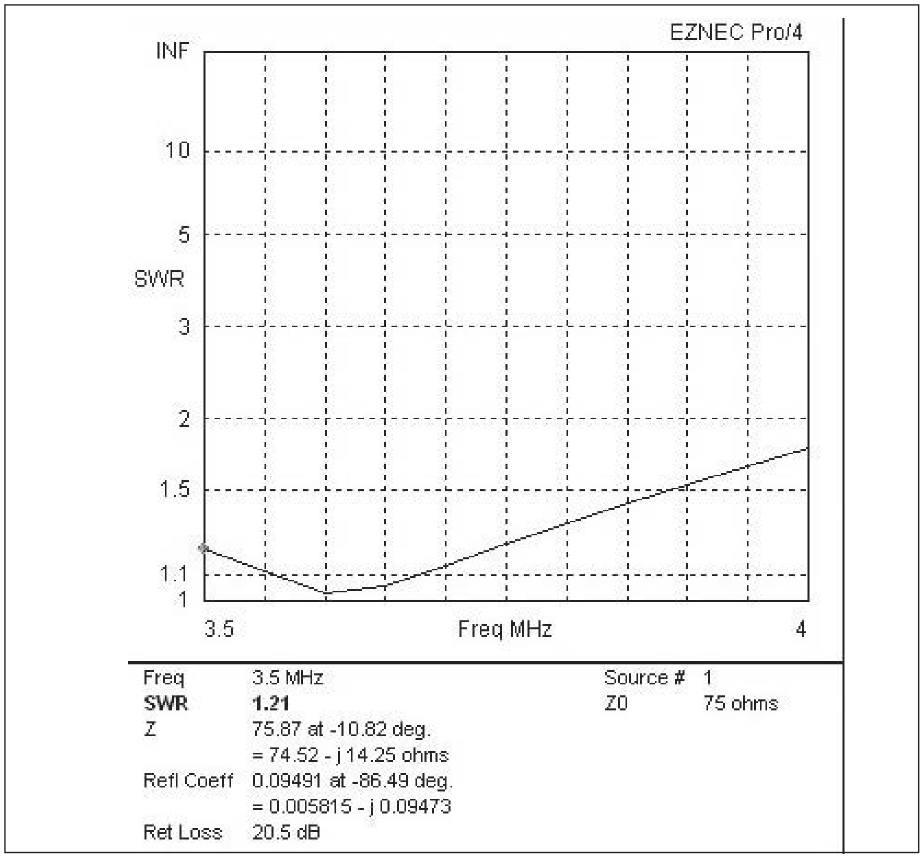


Figure 4 — Here is an SWR Profile for one 80 meter vertical.

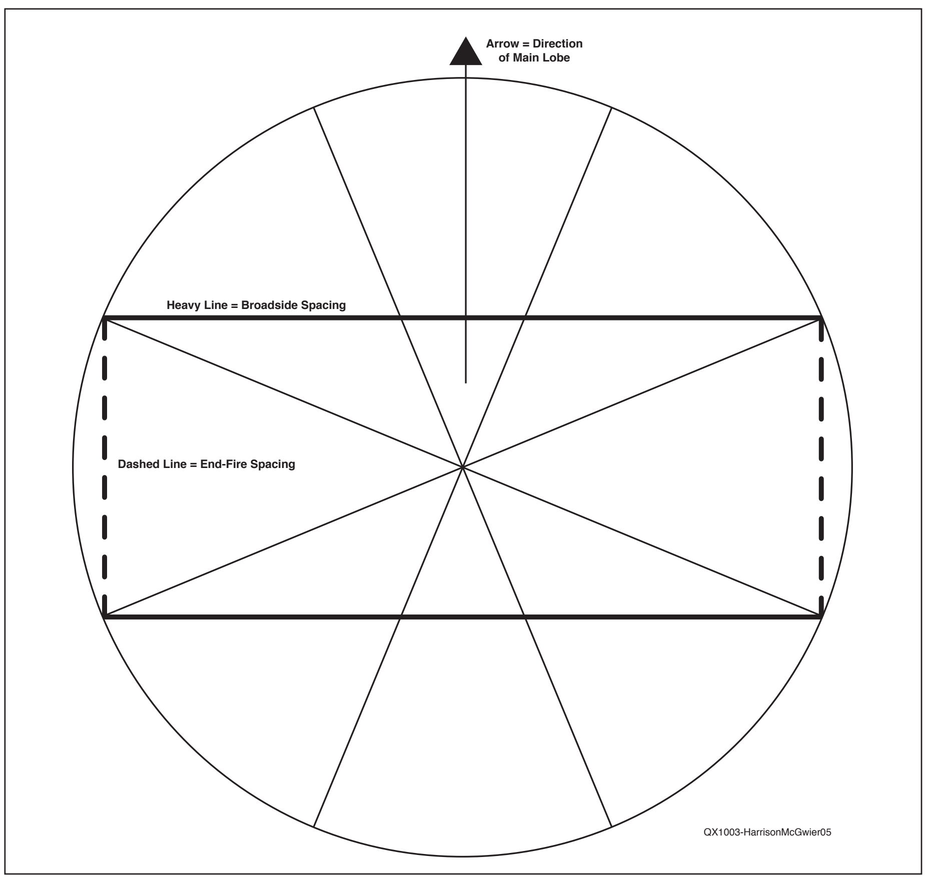


Figure 5 — This drawing shows the geometry of the Eight Circle Vertical Array of broadside/end-fire cells.

Low Band DXing.

The optimum broadside spacing for a takeoff angle of 24°, which yields the best attenuation off the sides, is 0.55 λ and yields an RDF of 13 dB. W8JI has suggested the possibility of using a slightly wider spacing of 0.65 λ. With this spacing, you will increase the number and/or size of the side lobes but in return you get a narrower 3 dB beamwidth. Bob calculated the RDF for this spacing to be 12.5 dB. For those in quiet areas, there is no doubt you should use 0.65 λ broadside spacing. If you live near a variety of noise sources you could use 0.55 λ broadside spacing to increase the rejection on as many of those sources as possible.

As depicted in Figure 5, once you decide on the broadside spacing and understand that the elements are going to land on a circle, the entire array geometry is determined.

The broadside dimension determines the entire circle as soon as it is specified. The end-fire spacing is determined by the broadside spacing and the circular array. The broadside spacing is the *only* degree of freedom in the entire design.

The crossing diameter lines represent the individual feed lines to each vertical antenna. These may be any equal electrical length pieces of 75 Ω coax. If you make them odd multiples of ¼ λ in length (¼ λ lengths of feed line will not reach the center feed point of the array) such as ¾ λ, then some nice opportunities are available for measuring antenna currents and voltages at the feed points. This is not necessary! They just have to all be equal lengths.

If the forward two elements are combined in phase and the back two elements are combined in phase then run through a phasing line and inverted in a 1:1 inverter transformer, then the antenna is beaming in the direction of the arrow.

The layout for this specific design is given in Table 1.

Table 1
Eight-Circle Array Configuration

Band (Meters)	*Broadside Spacing (λ)*	*(Meters)*	*(Feet)*	*Circle Diameter (ft)*
160	0.55	90.1	296	320
160	0.65	106.5	350	378
80	0.55	46.5	152.5	165
80	0.65	55	180	194

1.4 Feeding the Array

Feeding this array is relatively easy. The materials required are:

One — 4:1 UNUN transformer.

One — 1:1 Inverter transformer.

Nine — DPDT relays.

Two — 75 Ω coaxial phasing lines.

• These two pieces of 75 Ω coax are connected in parallel to form a 37.5 Ω phasing line. The final length will be discussed later, as there are trade-offs to consider.

Figure 6 shows the feed arrangement for the broadside/end-fire cell. Upon careful review, it becomes clear why this is so easy. The "front two antennas" consist of the two elements in the "front" of the four element cell coming to a Tee. The "back two antennas" are the back elements in the four element cell coming to a Tee. Two pieces of

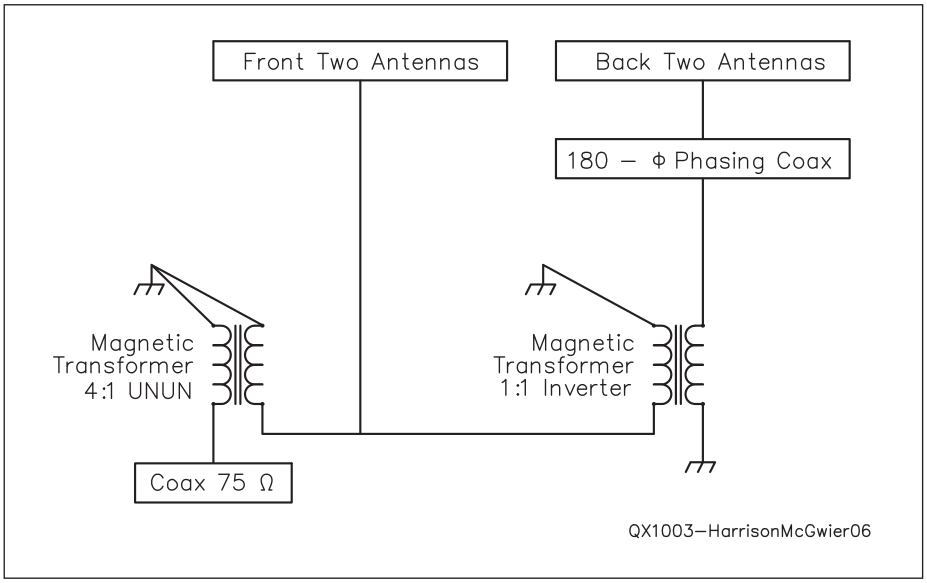


Figure 6 — Here is the feed arrangement for one cell.

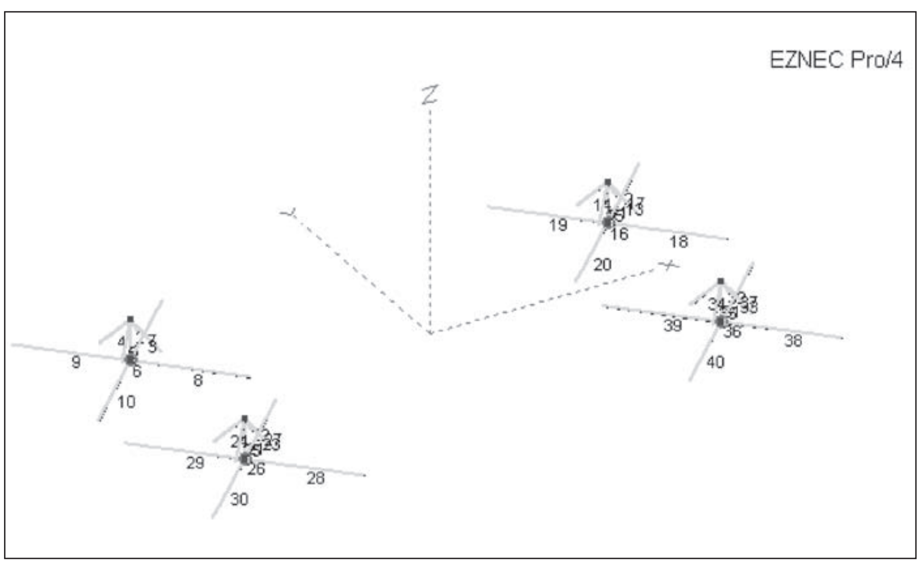


Figure 7 — The *EZNEC/4 Pro* model of an array of one 4-cell.

equal length 75 Ω coax are feeding the front two elements, which form a combined impedance of 37.5 Ω. The back two elements are the same and again form a combined impedance of 37.5 Ω, but with a phasing line (180° minus the desired phase angle) consisting of 75 Ω coax. The back two elements are then fed through an inverter, which allows us to feed them not with our phase angle, but with 180° minus the phase angle, which, among other things, allows for a shorter length of phasing line coax.

This phasing line consists of two equal length pieces of 75 Ω coax connected in parallel to produce a 37.5 Ω impedance to match the element feed line impedance (two 75 Ω feed lines in parallel to the back two elements), which should be 180° – 125°, or 55° in length. If you assume a 0.66 λ velocity factor, this would be a length of 54.2 ft (16.5 meters) for the 160 meter band and 28 ft (8.5 meters) for 80 meters. But remember, always measure your velocity factor or the delay, *do not assume*!

A simple collection of nine DPDT relays or four 4PDT relays with one DPDT can switch the array in eight directions. One of the nine, or the lone DPDT in the second example, does nothing but swap which side, front or back, sees the 180° minus phasing line coax.

1.5 Modeling the Complete Array Design

With the design assumptions now completed and understood, let us look at the results as an array. Figure 7 shows the *EZNEC/4 Professional* antenna model of a four cell broadside/end-fire array. Figures 8, 9 and 10 display the azimuth, elevation and 3D pattern for the 160 meter array and Figures 11, 12 and 13 show the azimuth, elevation and 3D pattern for the 80 meter array. The calculated RDF for the 160 meter array is at least 13 dB, as shown in the modeling figures that follow. Although the main sidelobe is >15 dB down from the highest gain point, RDF is about total contribution of power from behind the main lobe. The 80 meter model patterns show similar results.

2.0 Construction of the Eight Circle Vertical Array

Once the decision was made to erect a 160 meter Eight Circle Vertical Array at W5ZN, the construction phase began and involved numerous steps to ensure the design parameters were met.

2.1 Location and Physical Layout of the Array

The first step was to select an appropriate location and lay out the circle. Fortunately W5ZN has an area that seemed ideal for the array out in a field approximately 700 ft from the shack to the proposed center of the array. See Figure 14.

The location of the 160 meter transmit antenna, a shunt fed tower with HF Yagis seen in Figure 15, had to be taken into consideration. An existing barbed wire fence to the south of the proposed location

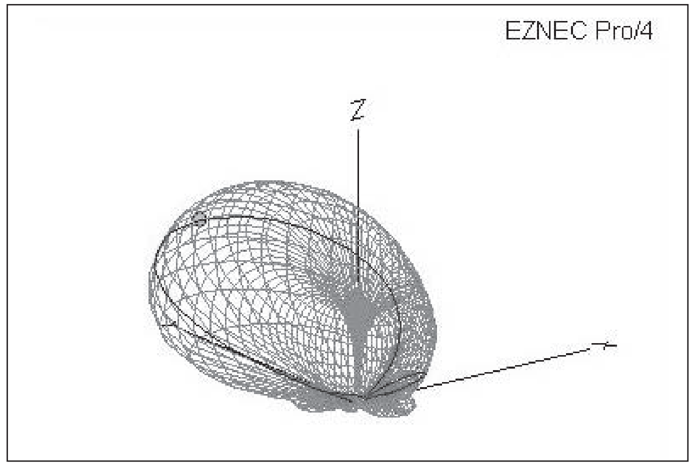


Figure 10 — This 3D plot shows the 160 meter radiation pattern.

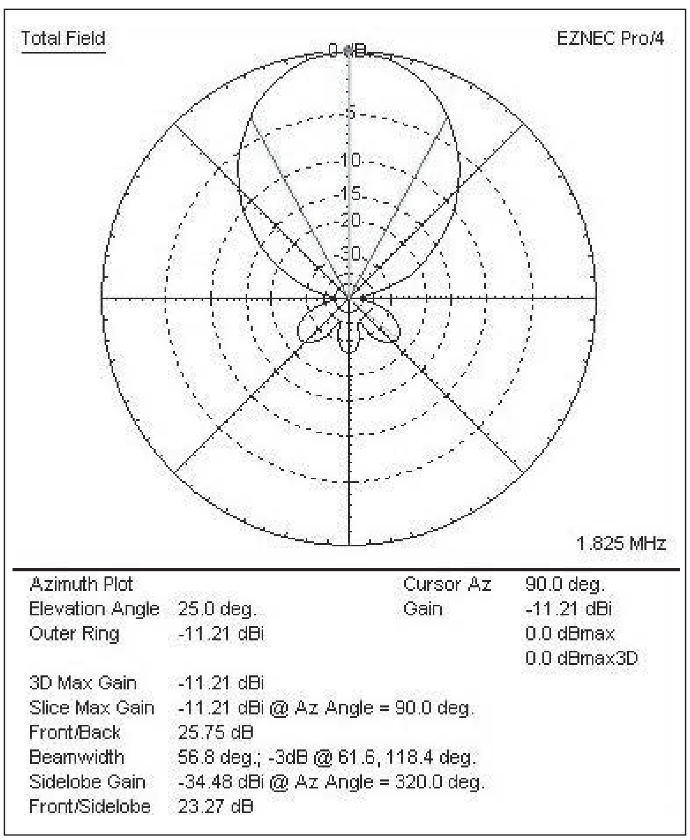


Figure 8 — The azimuth pattern for the 160 meter array.

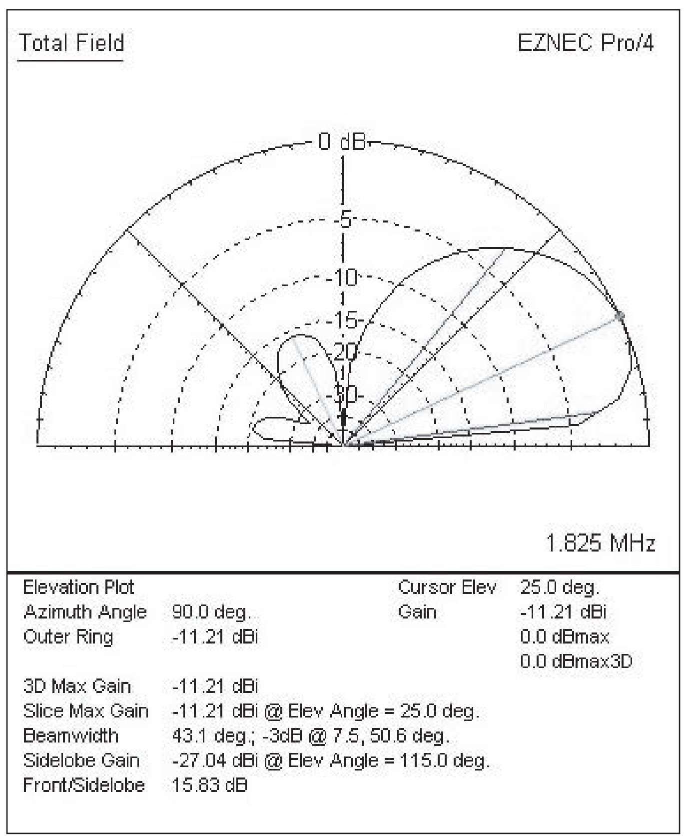


Figure 9 — Here is the elevation pattern for the 160 meter array.

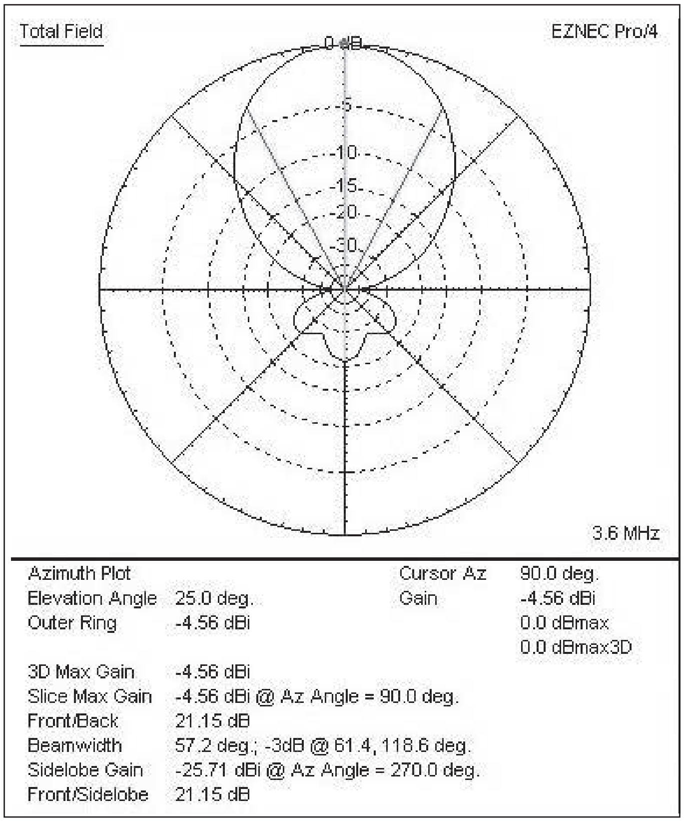


Figure 11 — Here is the azimuth pattern for the 80 meter antenna.

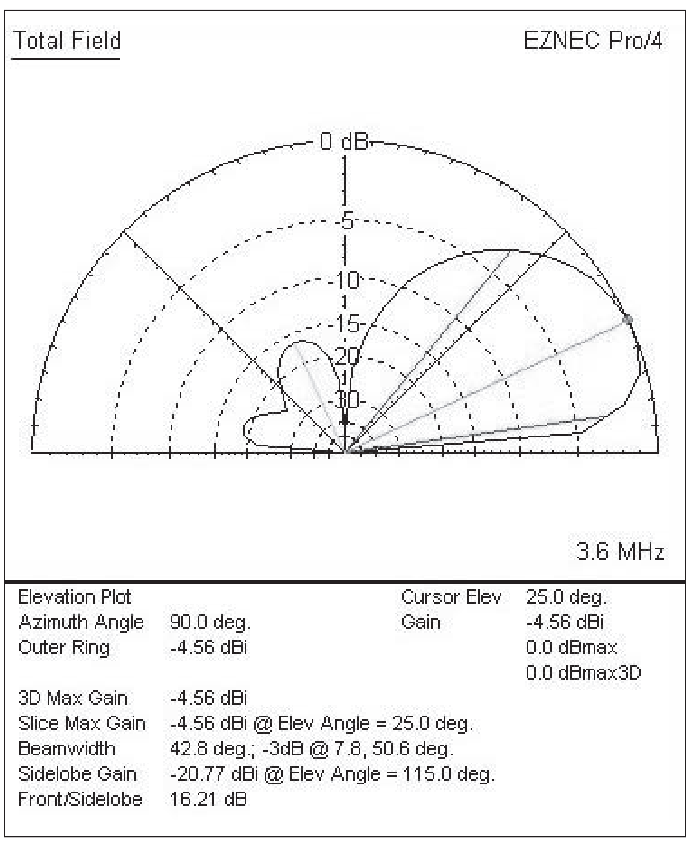


Figure 12 — This elevation pattern is for the 80 meter antenna.

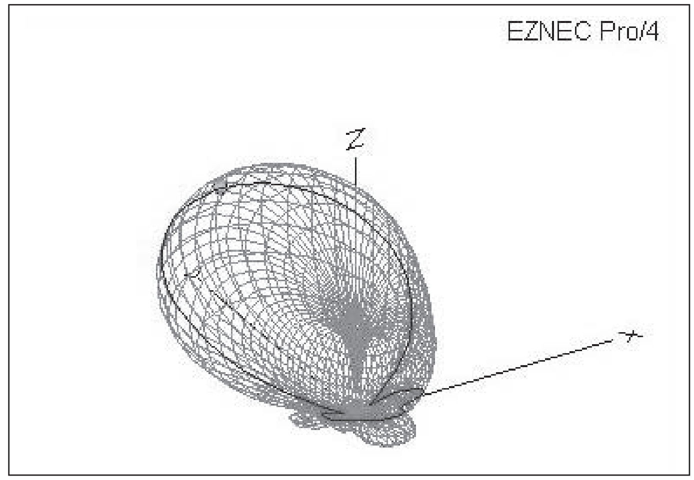


Figure 13 — Here is a 3D plot of the 80 meter radiation pattern.

Figure 14 — This photo shows the area selected for the Eight Circle Vertical Array.

Figure 15 — You can see the 160 meter transmit antenna (left tower) in this photo.

Figure 16 — Each vertical element is installed on 2×4 base.

Figure 17 — A close-up view of a vertical element sitting inside bottom support enclosure.

also had to be evaluated. The western edge of the circle was measured to be 280 ft from the shunt fed transmitting tower, greater than ½ λ, and the southern edge was 75 feet from the barbed wire fence running east-west.

After consultation we concluded these distances should be adequate to prevent interaction with the array. Another concern we had was sloping ground, as can be seen in Figure 14. We concluded that, if the slope was less than approximately 10°, there should be no major deviation from the model. Prior to laying out the circle we needed to verify the slope angle of the ground. The most accurate way to accomplish this would be to use a transit, however a less expensive method that is somewhat less accurate but well within acceptable tolerances may be employed. A 4 ft level was placed on the ground at the western edge of the proposed circle pointing in the direction of the slope, assuring it was "level". At the far eastern end of the proposed circle at the maximum point of the slope we vertically supported a 10 ft piece of white PVC pipe. While staring down the level to project a "level" straight line to the PVC pipe we marked this point on the pipe. We could then measure this distance down to the ground and use simple trigonometry to calculate the slope angle. We calculated that the sloping ground was no more than 2°, which is very acceptable.

Now that we verified that we had an acceptable location for the array, it was time to lay out the circle. Having identified the western edge of the circle by measuring its distance from the transmitting antenna, as well as the southern edge of the circle by measuring its distance from the barbed wire fence, we began the layout. We had previously concluded we would use a broadside spacing of 0.55 λ (296 ft), which results in a 320 ft diameter circle. We simply measured 160 ft (the radius of a 320 ft diameter circle) from each of the two previously identified edge points to a center point. From this now-identified center point we began measuring out 160 ft in 20 ft spacing segments, marking each edge point with an orange survey flag. In just a short time there was a 320 ft diameter orange flag circle in the field.

From this "circle" we could lay out the location of each vertical with a broadside spacing of 296 feet, physically spacing them equally around the circle so that a broadside array would project a main lobe in each of the eight directions of interest. The result is an end-fire spacing of 123 ft. Remember, the broadside spacing is the only degree of adjustment you have and the end-fire spacing is simply the result of the selection of the broadside spacing.

2.2 Element Supports

As noted earlier in the section on modeling, the material and method for supporting and insulating the vertical elements from the ground is insignificant. We used four 12 ft treated 2×4s and sawed them in half to produce eight 6 ft posts. Following this we dug a post hole about 18 inches deep, inserted the 2×4 and packed it in with Quickcrete to form a solid base. There's no need to mix the Quickcrete with water, just use it as a filling and packing material in the hole. It will absorb the moisture in the ground or during the next rainfall and the moisture will solidify the mix.

2.3 Element Material and Construction

The material used for the vertical elements and the construction technique is not critical as long as you stay within the dimensions of the model in order to replicate it. A variety of acceptable possibilities exist. In this section we will describe the procedure we followed. W8JI has very successfully used other materials (steel conduit and chain link fence top rails) and techniques that provide very strong elements mechanically, and excellent results as detailed on his Web site. (See Note 7.)

We chose to use aluminum tubing for the elements. There was no particular reason for this other than personal preference. We used 12 ft lengths of 1¼ inch diameter aluminum tubing and a supply of 1⅛ inch diameter tubing that has a 0.058 inch wall thickness. As such, the 1⅛ inch diameter tubing fits right inside the 1¼ inch tubing. Then the smaller diameter tubing was cut into 2 ft lengths and inserted 1 ft into one end of eight of the 12 ft lengths of the 1¼ inch tubing. We secured the joint with no. 10 stainless steel screws and nuts. This provides 24 ft long elements. Next, we cut 18 inch lengths of 1⅛ inch diameter tubing, inserting it 6 inches into what would be the top end of each 24 ft long element and secured it with stainless steel screws and nuts. We now had very nice 25 ft elements. Four holes are drilled at the top, 90° apart in order to attach the top hat wires.

For top hat wires we used some AWG no. 16 speaker wire (16-2 stranded). Separating the two wires is very easy and this wire worked great. Again, there is flexibility with the material but stay with no. 16 gauge in

Table 2 Vertical Element Self Resonance Measurement Results			
Vertical	*Self Resonance*	*Feed Point Impedance*	*160 Meter Feed Point Resistance (no matching)*
1	3.90 MHz	20 *j*0 Ω	18 *j*321 Ω
2	3.85 MHz	19 *j*0 Ω	16 *j*321 Ω
3	3.90 MHz	22 *j*0 Ω	16 *j*321 Ω
4	3.92 MHz	21 *j*0 Ω	18 *j*328 Ω
5	3.92 MHz	18 *j*0 Ω	18 *j*328 Ω
6	3.90 MHz	18 *j*0 Ω	18 *j*328 Ω
7	3.90 MHz	18 *j*0 Ω	18 *j*321 Ω
8	3.90 MHz	22 *j*0 Ω	16 *j*315 Ω

Figure 18 — One completed vertical.

Figure 19 — You can see the ground rod and radial attachment for a vertical in this photo.

Figure 20 — W5ZN measuring the self-resonance of the vertical elements.

order to replicate the design model. For guy lines we first used 50 pound fishing line. This worked well for a short period, however the lines began to break (they weren't stretched *that* tight), possibly from deer or other wild animals hitting them, so the fishing line was replaced with ⅛ inch Kevlar® rope. It does not stretch, it is perfect for guying vertical antennas and the Kevlar® rope has held nicely for several months now. We used tent stakes for the guy anchors.

After assembling the elements and top hat wires it was now time to mount the vertical elements to the 2x4 base supports. This can be accomplished in a variety of ways. At a local hardware store we located some plastic conduit clamps and some plastic housings with an opening at the top, ideal for mounting the elements and also a means to weatherproof the feed line connections.

Figures 16, 17 and 18 show a 2x4 support, element attachment and completed element.

2.4 Ground Radial System

As described in the modeling section, some ground radials are required to stabilize the feed point impedance over changing ground conditions throughout the year.

At first we chose to bury four radial wires that were 65 ft long (⅛ λ on 160 meters) a few inches in the ground. These were laid out with one under each of the top hat wires. These wires aren't critical and they don't necessarily have to be buried, but they do need to be lying on the ground as a minimum. A large supply of 16 gauge wire was acquired and used for radial wire.

For ground rods, all antenna and shack grounds are using ¾ inch copper pipes. We purchased 10 ft lengths and then cut them in half. We placed an end cap over one end and then drove it into the ground. That is relatively easy to do in Arkansas, especially during the wet winter and spring months. Your specific area may prove difficult or prevent using this method entirely, and that is understood. Just get a good ground rod in the ground. The ground radials and outer shield of the coax connector are all connected to the ground rod. A solder connection is made to the copper pipe ground rod. Figure 19 shows the W5ZN ground radial system installation. It is important to note that the ground rod does nothing to improve the pattern or efficiency of the antenna. It is simply to provide a good dc ground.

2.5 Tuning the Individual Elements

Now that each vertical element was erected and the ground radial system installed, it was time to test and tune each element. Bob and Al Ward, W5LUA, traveled to Arkansas to assist with this process, and evaluate actual results with the designed/modeled results. Our first step was to check the self-resonance of each vertical. This is a simple process if you have an antenna analyzer similar to the MFJ-259B. Simply connect the analyzer directly to the vertical element and record the readings. Table 2 shows the results from each element while Figure 20 shows the measurements being taken. Needless to say, we were all quite happy with the results, which clearly prove the design dimensions!

Now it was time to tune each element. The design indicated an inductor of 30 μH would be required to tune the element down to 160 meters and our resistor should be somewhere around 70 Ω. Our target was to center the zero reactance component between 1.8 and 1.9 MHz.

We had some small molded 27 μH and 31 μH inductors on hand, and some 75 Ω non-inductive resistors, so the first attempt was to try a 27 μH / 75 Ω combination. This produced a 160 meter feed point resistance of 100 j0 Ω, clearly a sufficient amount of inductance but way too much resistance since 75 Ω was our target.

We then went to the resistor box and pulled out some 47 Ω resistors to try. These were not "non-inductive" but only measured about 1 μH, so we decided to give them a try. This combination worked pretty well. The feed point resistance came down to about 68 Ω but the zero reactance point didn't really move as we had expected, since we were using an "inductive" resistor. After scratching our heads for a bit we decided to check our "non-inductive" resistors and discovered they were anything but "non-inductive"! A case in point here: we did a search on the internet for "non-inductive" resistors and found just about all of our hits for "non-inductive" resistors came back to numerous ads that stated "non-inductive wire wound resistors." Huh? Obviously a wire wound resistor will not be "non-inductive" so beware! The resistors W5ZN had on hand, which were purchased from a popular surplus dealer, were very clearly marked and identified as "non-inductive resistor," but they weren't. The good news is this is not really necessary for this application as long as you take the inductance of the resistor into account for the overall inductance/resistance combination. You should also be aware that the inductor will have some small amount of resistance as well but again just make sure you account for all of this in your inductor/resistor network. This is easily done when we calculate the overall reactance and SWR at the desired frequency.

Before you begin the tuning process it is a good idea to have a supply of 0.5 and 1.0 μH small molded inductors as well as some 1 to 3 Ω resistors on hand for fine tuning, especially if you're a perfectionist!

Once you have the element tuned to a reasonable point, it is now time to check the effectiveness of the ground radial system. This is easily done with an antenna analyzer similar to the MFJ unit. When the shell of the coax connector from the analyzer is attached to the radial system then the analyzer believes this is a perfect ground since there is zero ohms resistance (close enough). If, during the following test the value of the feed point impedance changes by more than 5%, the ground radial system is insufficient.

First, disconnect all of the ground radials, leaving only the ground rod connected to the cable shield and record the feed point impedance. Next, connect one ground radial and then the remaining three, recording the feed point resistance change at each step. If the change is less than 5%, then you have a very good ground radial system that should be stable under changing conditions throughout the year.

Table 3
Feed Point Resistance Change with Added Ground Radials. Readings Taken in October with Dry Ground.

Frequency	*Ground Rod Only*	*1 Radial*	*2 Radials*	*4 radials*	*8 Radials*
Self Resonance No RL Matching 80 Meters	38 *j*30 Ω	32 *j*0 Ω	30 *j*0 Ω	30 *j*0 Ω	20 *j*0 Ω
No RL Matching 160 Meters	42 *j*360 Ω	6 *j*300 Ω	7 *j*300 Ω	8 *j*300 Ω	0 *j*310 Ω
RL Matching For 160 Meter Resonance	110 *j*0 Ω	80 *j*15 Ω	81 *j*12 Ω	80 *j*10 Ω	78 *j*0 Ω

Table 4
Feed Point Resistance Change with Added Ground Radials. Readings Taken in January with wet ground.

Frequency	*Ground Rod Only*	*1 Radial*	*2 Radials*	*4 radials*	*8 Radials*
Self Resonance No RL Matching 80 Meters	42 *j*30 Ω	31 *j*10 Ω	30 *j*0 Ω	28 *j*0 Ω	18 *j*0 Ω
No RL Matching 160 Meters	40 *j*363 Ω	5 *j*306 Ω	5 *j*306 Ω	5 *j*307 Ω	0 *j*323 Ω
RL Matching For 160 Meter Resonance	120 *j*0 Ω	80 *j*20 Ω	80 *j*20 Ω	78 *j*20 Ω	75 *j*0 Ω

We did not. The change we experienced was greater, so we chose to add four more radials, bringing our total to 8 for each element. We continued the test by adding two, then the additional two and the change was now within 5% so we were satisfied we had a stable ground radial system. Table 3 shows the typical change in feed point resistance recorded for each of the verticals when adding radials in October with dry ground and Table 4 shows the typical change from readings taking in January with wet ground.

After completing the ground radial test we then performed some fine tuning and tweaking of the inductor/resistor values to bring the feed point resistance into our design range. Table 5 shows the final results along with the required individual inductance and resistance used as well as the total inductance and resistance of the network.

2.6 Feed lines and Phasing Lines

We are using 75 Ω coaxial cable feed line in this array. We chose to acquire "flooded" cable so it could be buried without the worry of moisture influx and deterioration. Good quality RG-6 flooded coax, along with very good F-connectors that work great in low band receiving applications are available from a few select Amateur Radio dealers. We recommend you bury the feed lines. If you choose not to, however, we recommend you use the flooded cable anyway just in case a wild animal wants to chomp on the coax. They most definitely will not enjoy the taste of the flooding compound and will look for another treat!

In order to accurately prepare our phasing lines we decided to measure the velocity factor of our RG-6 cable. Our test setup included an MFJ-259 Antenna Analyzer used as our signal generator and a dual trace oscilloscope to measure the signal time delay in a length of cable. We concluded the velocity factor of our cable to be about 80%. From this, we determined our 55° phasing lines should be 66 ft in length. Two of these were prepared, per the design.

We then prepared nine 75 Ω RG-6 coaxial lines of equal length (one each to feed each of the eight verticals and one spare), sufficient to run from the center point to each vertical element with about 5% extra to have some spare.

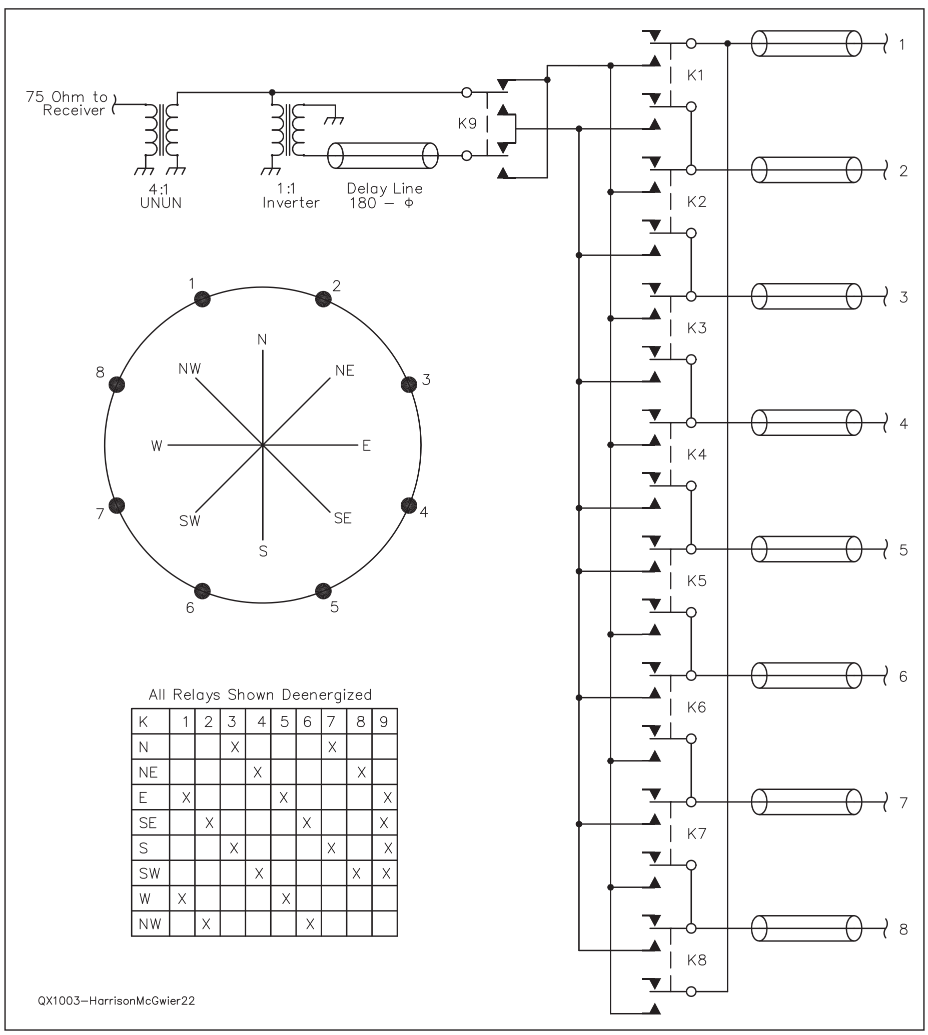
2.7 Switching Unit

The switching unit schematic is shown in Figure 22.

Rather than go through the time and expense of designing and manufacturing a circuit board, we chose to assemble a switching unit using point to point wiring. Figures 23 and 24 show the W5ZN unit.

The components for the switching unit aren't critical. Some chassis mount F connec-

Figure 21 — N4HY is very pleased with the design as compared to the actual results!



K	1	2	3	4	5	6	7	8	9
N			X				X		
NE				X				X	
E	X				X				X
SE		X				X			X
S			X				X		X
SW				X				X	X
W	X				X				
NW		X				X			

Figure 22 — This is a schematic drawing of the switching unit.

tors and simple (but good) enclosed 12 V dc relays will work just fine, and we used some small gauge enameled wire to connect everything. Don't use wire that is too small, which can become brittle and break, but don't use wire so large that it is too rigid and does not provide some flexibility. If you use point to point wiring, just remember the small pins on the relays are strong, but they won't stand up to a lot of stress. Even though is it not what we used, we recommend the use of small gauge stranded wire.

The relay unit was laid out on a piece of paper, and then a sheet of aluminum was used to mount the relays. We drilled the holes to mount the connectors. Epoxy glue was used to mount the relays upside down on the aluminum sheet, and some small, flexible enameled wire was used to connect everything.

After you have the switching unit assembled you can perform some simple tests to ensure everything is working fine. First, make sure all of the relays are working individually and then as a group in the proper sequence by using a simple continuity test with an ohm meter. Now you can inject a signal into the unit using an antenna analyzer or other weak signal source to verify that all of the other components are working. Figures 25, 26 and 27 show some of our test results.

The switching unit is really simple and straightforward, however there are a couple of points that need to be highlighted. First, make sure you note the wiring sequence "swap" when you go from relay 4 to relay 5. Again, this is a simple process, just make sure you are aware of it and wire it correctly, otherwise the unit will not switch the elements properly.

The second point is the 1:1 inverter and the 4:1 UNUN, which are very simple to construct. Binocular cores seem particularly useful for low band receive antenna applications. The Fair-Rite 2873000202 core that W8JI has popularized is easy to locate and purchase, easy to wind and works great. We used small gauge enameled wire, but this is not necessary and any small gauge wire

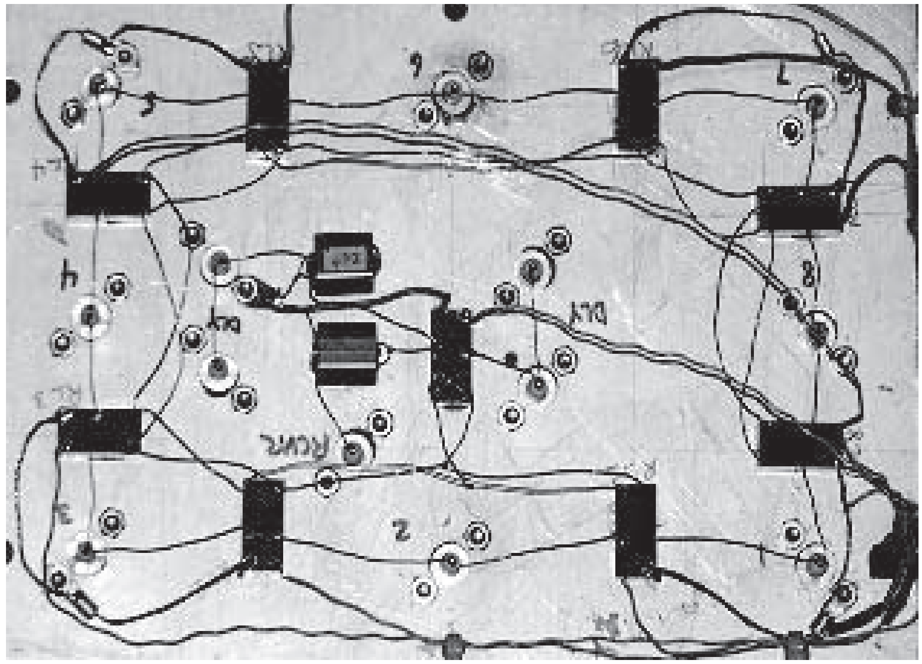


Figure 23 — This is a view of the component side of the switching unit.

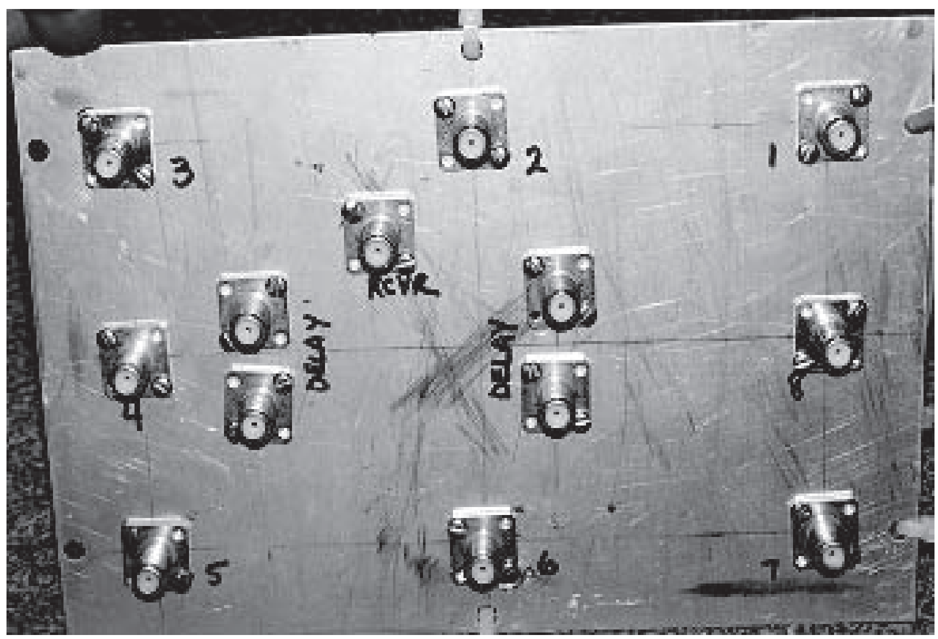


Figure 24 — This view shows the connector side of the switching unit.

Table 5
160 Meter Results After Tuning

Vert	*1.800*	*1.830*	*1.860*	*1.890*	*j0 Bandwidth*	*Ind*	*Res*	*Total Ind and Res*	
1	74 *j*13 Ω	75 *j*0 Ω	75 *j*0 Ω	76 *j*16 Ω	1.815 - 1.862	28 µH	56 Ω	28.4 µH	56.5 Ω
2	75 *j*10 Ω	75 *j*0 Ω	76 *j*0 Ω	77 *j*19 Ω	1.815 - 1.860	27.5 µH	55 Ω	28.6 µH	54 Ω
3	76 *j*15 Ω	76 *j*0 Ω	76 *j*0 Ω	76 *j*9 Ω	1.817 - 1.868	28 µH	54 Ω	28.6 µH	54.5 Ω
4	76 *j*15 Ω	75 *j*0 Ω	75 *j*0 Ω	76 *j*15 Ω	1.820 - 1.874	28 µH	53 Ω	28.3 µH	54 Ω
5	76 *j*17 Ω	75 *j*0 Ω	75 *j*0 Ω	76 *j*12 Ω	1.824 - 1.878	27.5 µH	53 Ω	28.0 µH	54 Ω
6	74 *j*11 Ω	74 *j*0 Ω	75 *j*0 Ω	76 *j*20 Ω	1.814 - 1.863	28 µH	55 Ω	28.5 µH	56 Ω
7	75 *j*15 Ω	74 *j*0 Ω	75 *j*0 Ω	75 *j*17 Ω	1.818 - 1.868	28 µH	53 Ω	28.5 µH	54 Ω
8	73 *j*16 Ω	73 *j*0 Ω	74 *j*0 Ω	74 *j*16 Ω	1.815 - 1.862	27.2 µH	56 Ω	27.7 µH	56.5 Ω

will work as long as it is insulated. For the 1:1 inverter just twist two wires together and make three passes through each hole in the core, to produce a 3 turn winding. Connect it as shown in Figure 22, making sure the ends of the two windings are reverse connected. For the 4:1 UNUN, just use four turns on the primary and two turns on the secondary. That is four passes through each hole for the primary winding and two passes through each hole for the secondary winding. This will give you a 2:1 voltage ratio, which equates to a 4:1 impedance ratio, and you're in business! You can check it on an oscilloscope and it will show a perfect 2:1 voltage ratio (the equivalent of a 4:1 impedance ratio).

Once the switching unit was installed, a ground rod is installed and connected to the aluminum sheet. Figure 28 shows the finished installation. A rubber trash can be used for weather proofing to protect the switching unit from the elements.

2.8 Switching Control

The control for the switching unit can be built in a number of different ways. Figure 29 shows the W5ZN method. Joel uses a diode matrix with an eight position pushbutton antenna relay control box. He prefers the pushbutton variety rather than rotary switches to eliminate a lot of "cranking" and switching through unwanted directions to prevent unnecessary relay activation. For control cable, we used 5 conductors of a CAT5 cable. Any 5 conductor cable will work fine to provide the proper dc relay voltage to the external unit. Joel's run is approximately 600 ft from the shack.

3.0 Evaluation of the Eight Circle Vertical Array

Evaluation of any antenna system requires that you have a realistic understanding of what to expect! In the case of low band receiving antennas, some radio amateurs have erroneously assumed that after installing a Beverage or similar receiving antenna you will automatically begin to miraculously hear stations that never existed at your location before. The most important factor in being able to hear stations on the low bands is propagation characteristics. Joel listened for two 160 meter seasons as east coast stations boasted about how strong VQ9LA was without a peep of a signal into Arkansas. No receive antenna would have changed this. Finally one night the propagation came to W5 land and thanks to low noise receiving antennas VQ9LA is in the log at W5ZN. So don't expect to begin to magically hear

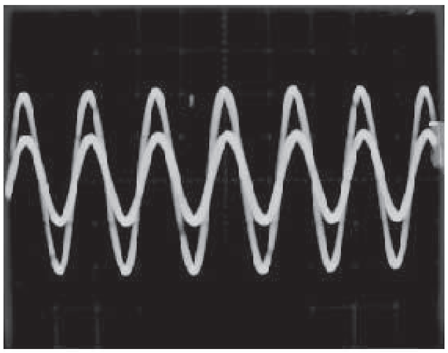


Figure 25 — This oscilloscope plot shows a 1.83 MHz signal through the 4:1 UNUN, showing a 2:1 voltage ratio (4:1 impedance ratio).

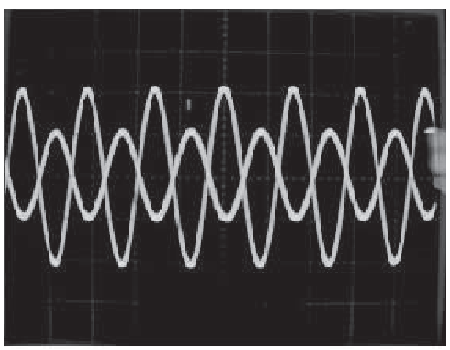


Figure 26 — Here is an oscilloscope plot of a 1.83 MHz signal through the 4:1 UNUN and 1:1 inverter (180°).

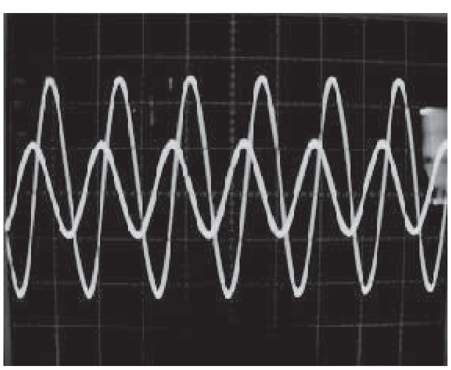


Figure 27 — The oscilloscope plot of a 1.83 MHz signal through 4:1 UNUN, 1:1 inverter and phase lines.

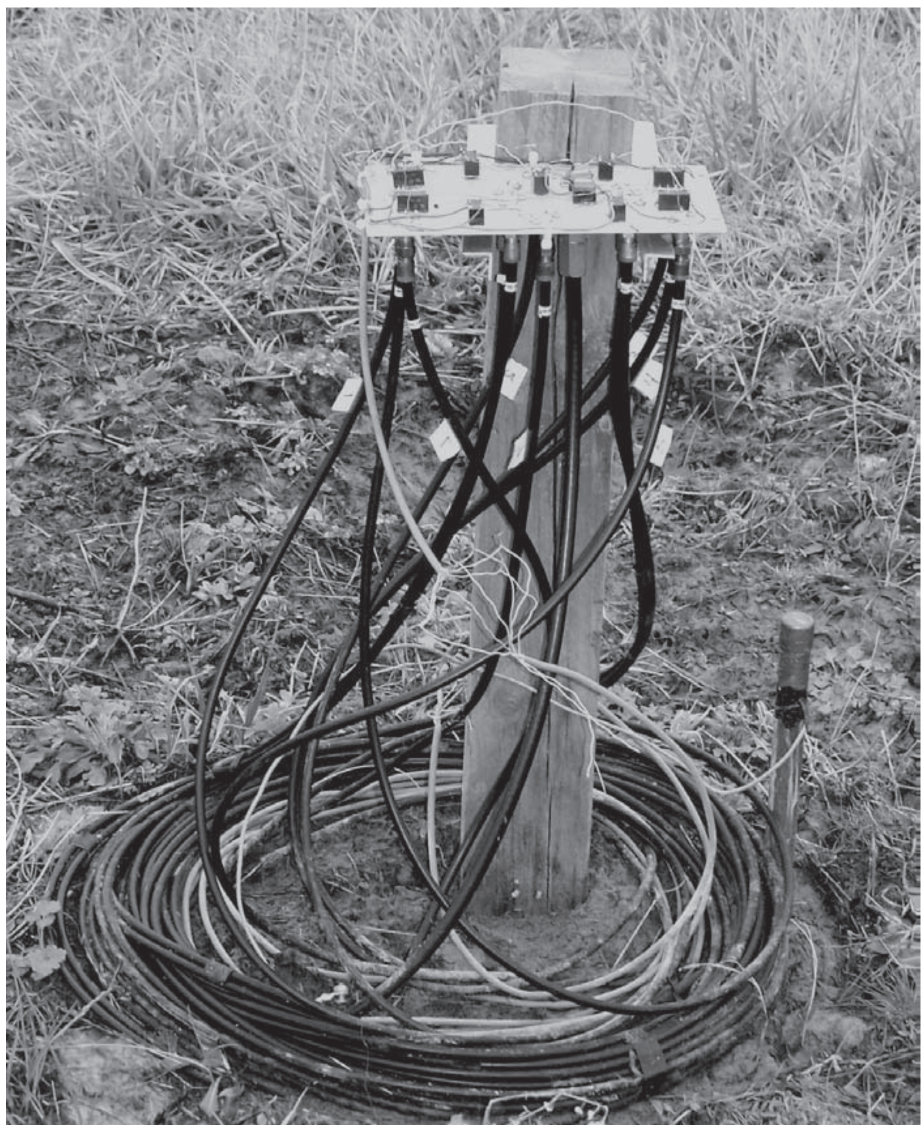


Figure 28 — This photo shows the switching unit installed at the center of the array.

stations that just never existed before. What should immediately become apparent is that your noise floor will decrease. Since DX signals on the low bands are weak signals, this component alone should allow you to hear stations that previously were buried in the noise.

Remember, your goal is to improve your DMF or RDF which will in turn reduce the amount of noise (both man-made and natural) and QRM collected by the receive antenna system in a particular direction and allow you to hear weak stations when propagation permits.

3.1 Noise Evaluation

Joel's first step in the evaluation was to record noise floor levels on the various 160 meter antennas installed at W5ZN. He has some significant noise sources in two directions, so a combination of low noise receiving antennas benefits him greatly. Table 6 shows a comparison of the noise floor for the W5ZN 160 meter antennas.

3.2 Signal Comparison, F/B Ratios, F/S Ratios

A comparison of on-the-air F/B and F/S measurements from various stations was performed over several months and the results indicate the array is comparable to the modeling parameters produced.

The charts of Figures 30, 31, 32 and 33 depict signal comparisons between the Eight Circle Vertical Array and Joel's 880 ft Beverage antennas taken at different times of the day to different parts of the world. Obviously, the signal arrival angle will play an important part in signal strength and readability. The charts are typical for each DX station, however, and represent the ability to hear a station earlier than with the Beverages

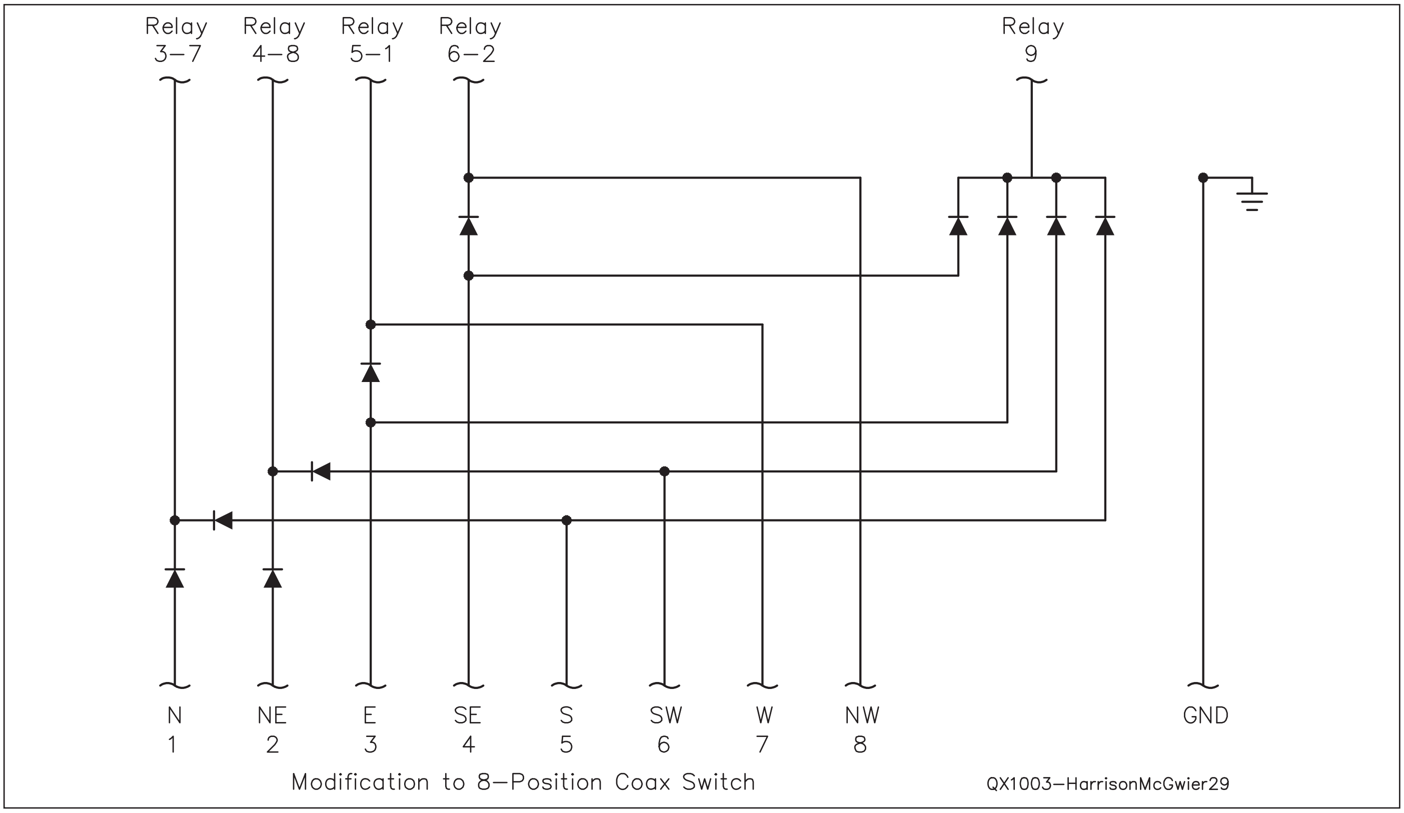


Figure 29 — Here is a switching control unit modification. Diodes are standard silicon diodes, 1N4004 or equivalent.

Table 6
Noise Floor Measurement Comparisons

Direction	*Eight Circle Vertical Array Noise Floor*	*Beverage Noise Floor*	*K9AY Loop*[1]	*Shunt Fed 135 ft HF Tower 160 Meter Xmit*[2]	*½ λ Inverted Vee*[2]
N	–129 dBm	–125 dBm	N/A	–100 dBm	–105 dBm
NE	–125 dBm	–120 dBm	–132 dBm	–100 dBm	–105 dBm
E	–125 dBm	–124 dBm	N/A	–100 dBm	–105 dBm
SE	–126 dBm	–123 dBm	–130 dBm	–100 dBm	–105 dBm
S	–126 dBm	–120 dBm	N/A	–100 dBm	–105 dBm
SW	–125 dBm	–120 dBm	–132 dBm	–100 dBm	–105 dBm
W	–126 dBm	–125 dBm	N/A	–100 dBm	–105 dBm
NW	–130 dBm	–128 dBm	–132 dBm	–100 dBm	–105 dBm

Noise Floor Measurements Comparing the Eight Circle Vertical Array, Beverages, Loop, Shunt-fed Tower and Inverted Vee at W5ZN. Measurements were taken with a 250 Hz bandwidth at a Sampling Rate of 48 kHz.
[1]Loop has considerably less gain than the Beverage or Vertical Array which equates to not only a lower noise floor but much lower signal levels as well and traditionally requires a preamp.
[2]Omni-directional.

and to also hear the station for a period of time after they can no longer be copied on the Beverages. At the peak propagation period, however, there is no noticeable or recordable differences between the two receive antenna systems.

4.0 Summary

The Eight Circle Vertical Array is a significant addition to the low band receive antennas at W5ZN. It is now the primary system used for receiving on 160 meters. It will not replace the other receive antennas because as unpredictable as 160 meters is, you never know when a propagation anomaly may occur that will present itself better to one of the other antennas, however that situation has not yet been seen.

An 80 meter version has now been constructed at W5ZN and is being evaluated during the Winter 2009/2010 low band season.

The amount of time and effort invested in this project was considerable. That was because only a very small amount of general information was available on this antenna array. Our hope is that this article will provide encouragement for others to try such an array, and that the time required to build one will be reduced significantly. For 160 meters, this array takes up a circle diameter of less than 350 ft, with an additional 65 feet for radials. That is less than a 1 λ Beverage on 160 meters, and eight directions can be obtained. So, if you're space limited for a Beverage array but can afford the real estate for an Eight Circle Vertical Array, give it a try. You will *not* be disappointed!

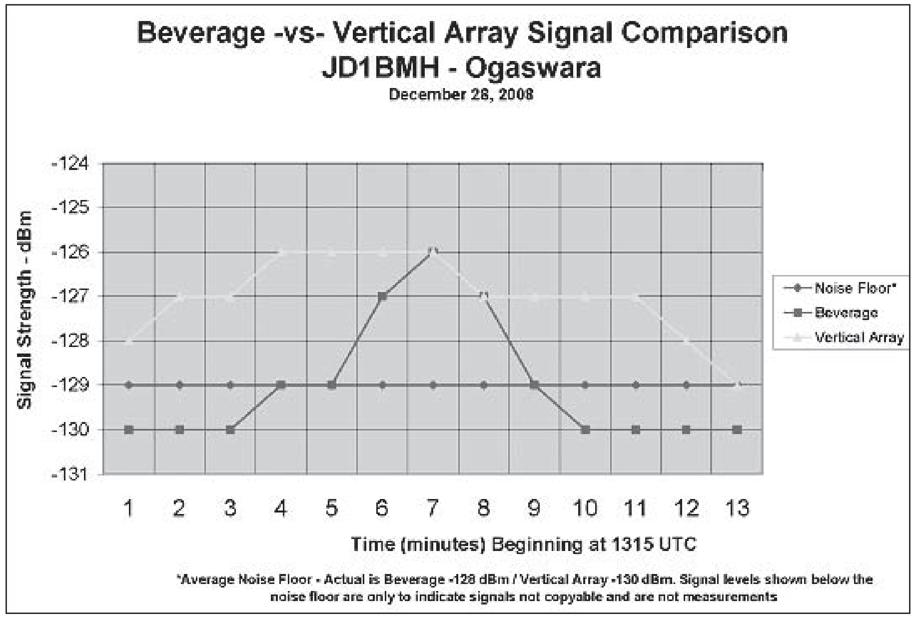


Figure 30 — This chart compares signal levels between the Eight Circle Vertical Array and a Beverage antenna for signals from JD1BMH, Ogaswara.

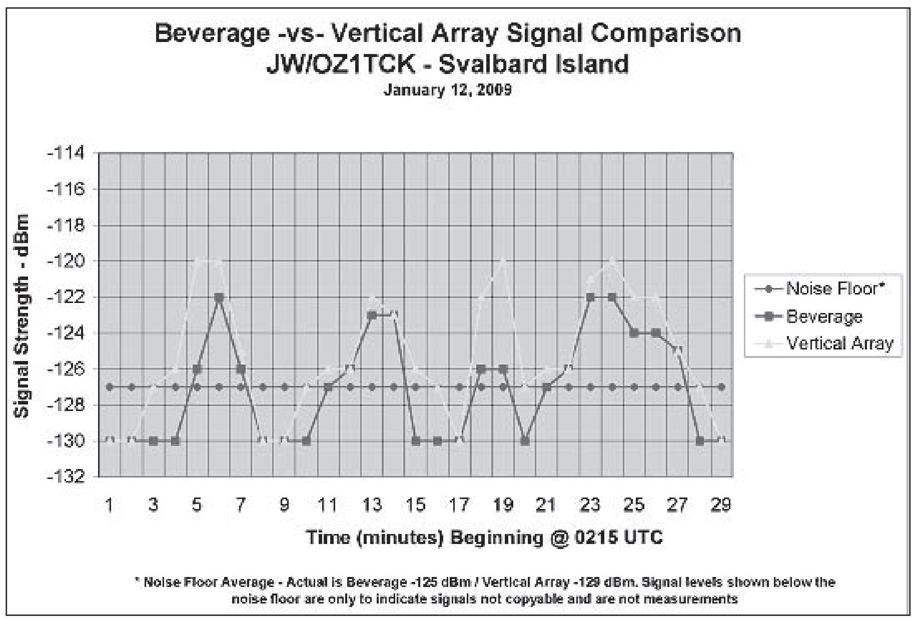


Figure 31 — This chart compares signal levels between the Eight Circle Vertical Array and a Beverage antenna for signals from JW/OZ1TCK, Svalbard Island.

Notes

[1]ARRL DX Challenge Award: www.arrl.org/news/stories/2001/05/08/3/.

[2]John Devoldere, ON4UN, "*ON4UN's Low Band DXing*," Fourth Edition, ARRL — The National Association for Amateur Radio™, 2005. ARRL publications are available from your local ARRL dealer, or from the ARRL Bookstore. Telephone toll free in the US 888-277-5289 or call 860-594-0355, fax 860-594-0303; www.arrl.org/shop; pubsales@arrl.org.

[3]JoelHarrison, W5ZN, "Horns for the Holidays," *Proceedings of Microwave Update '97*, ARRL, 1997, pp 147-149.

[4]Joel Harrison, W5ZN, "W5ZN Dual Band 10 GHz / 24 GHz Feedhorn," *Proceedings of Microwave Update '98*, ARRL, 1998, pp 189-190.

[5]Joel Harrison, W5ZN, "Further Evaluation of the W5LUA and W5ZN Dual Band Feeds," *Proceedings of Microwave Update '99*, ARRL, 1999, pp 66-84.

[6]Paul Wade, W1GHZ and Joel Harrison, W5ZN, "Multi-band Feeds for Parabolic Dish Antennas," *W1GHZ Microwave Antenna Book*, Chapter 6, W1GHZ, 2000, www.w1ghz.org/antbook/chap6_9p1.pdf.

[7]Tom Rauch, W8JI, www.w8ji.com, www.w8ji.com/small_vertical_arrays.htm, W8JI, 2008.

[8]John Devoldere, ON4UN, "*ON4UN's Low Band DXing*," Third Edition, ARRL — The National Association for Amateur Radio™, 1999, pp 11-68 to 11-71.

[9]The authors' *EZNEX 4* model files are available for download from the ARRL *QEX* web site. Go to www.arrl.org/qexfiles and look for 3x10_Harrison_McGwier.zip.

Joel Harrison, W5ZN, was first licensed as WN5IGF in 1972. He went on to acquire his General, Advanced and Amateur Extra licenses as WB5IGF. He's had his current call sign since 1996.

Joel has many interests in Amateur Radio including VHF/UHF/Microwave weak signal communication, EME, low band DXing and contesting. His Amateur Radio operating awards include DXCC Honor Roll, DXCC Challenge, 9 Band DXCC, 11 Band VUCC (50 MHz through 24 GHz), 6 meter WAS and WAC, 2 meter WAS and WAC and Satellite WAS and WAC. He held the ARRL June VHF Contest Single Operator World Record from 1996 to 2006 and held the 80 meter record for the W5 call area in the ARRL International DX Contest, CW, from 2006-2009. In 2001, the Central States VHF Society awarded him the

Mel S. Wilson Award for continuous service and dedication toward promoting VHF and UHF activity, in 2008 La Federacion Mexicana de Radioexperimenatdores awarded him the prestigious Azteca Diploma for 25 years of service to Amateur Radio and in 2010 the ARRL Board of Directors awarded him the ARRL Outstanding Service Award for over 25 years of volunteer service to ARRL, including two terms as ARRL President. He is a member of the Collierville Millimeter Wave Society, a life member of the Central States VHF Society, a Life Member of ARRL and just retired as President of ARRL, The National Association for Amateur Radio™.

Joel began his formal education studying industrial electronics at Arkansas State University and then traveled overseas to further his education in Germany, Norway and Denmark, completing his curriculum at the Electric Power Research Institute. In 1983 he became the first person in the world to qualify an automated ultrasound imaging system for use in the nuclear power industry, and in 1995 received Special Recognition for Contributions from the American Society for Nondestructive Testing.

In 2008 he was appointed by Arkansas Governor Mike Beebe to serve on the Board of Directors of the Arkansas Science and Technology Authority. Joel is Manager, NDE Technology for URS (United Research Services) Corporation in Princeton, NJ, which serves the nuclear power, government, space and infrastructure markets. More information about Joel can be found at ***www.w5zn.org****.*

Dr. Robert McGwier, N4HY, has been licensed since the early 1960s when he was WN4HJN. He received N4HY in 1976 when he decided he did not want to be N4BM (with apologies to the current owner of that call).

Bob holds a BSEE and BS in Mathematics from Auburn and Ph.D. in Applied Mathematics from Brown University. He serves as Chairman of the ARRL Software Defined Radio Working Group. Bob is the immediate past Vice President of Engineering for AMSAT. Bob's early work included writing the Quiktrak satellite tracking software package for the Commodore, RadioShack, and then PC computers. He has worked on several satellite projects and was a co-designer of the Microsat satellites and on the early design teams for AO-40. With Tom Clark, K3IO, he started the AMSAT/TAPR digital signal processing project. Bob received the 1990 Dayton Hamvention® Award for Technical Achievement for his work with AMSAT, TAPR, and the ARRL. Recent DSP and software-defined radio activities include authoring the DSP software (DttSP: in PowerSDR) along with Frank Bickle, AB2KT.

Bob is employed with the Center for Communications Research in Princeton, New Jersey.

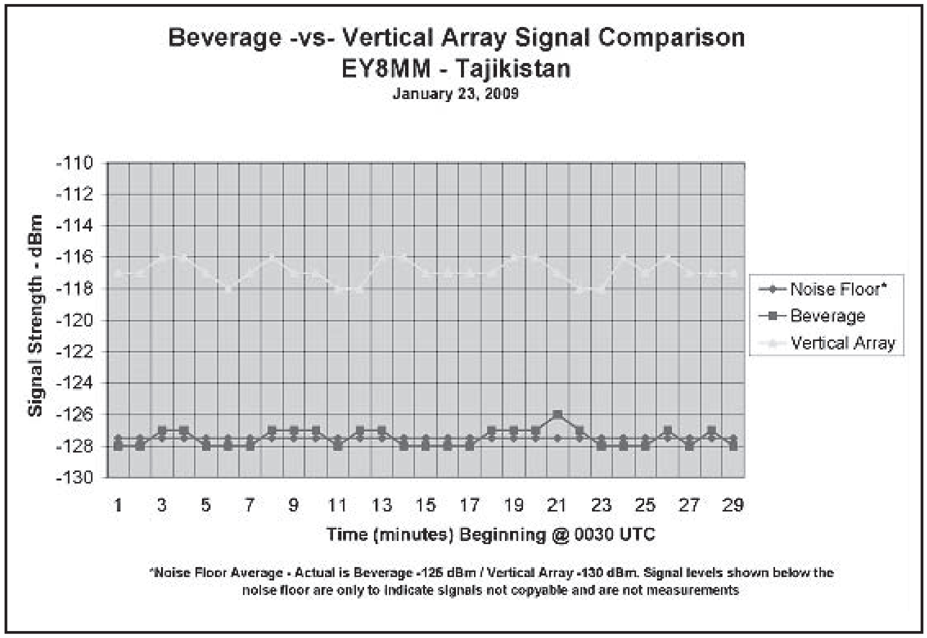


Figure 32 — This chart compares signal levels between the Eight Circle Vertical Array and a Beverage antenna for signals from EY8MM, Tajikistan.

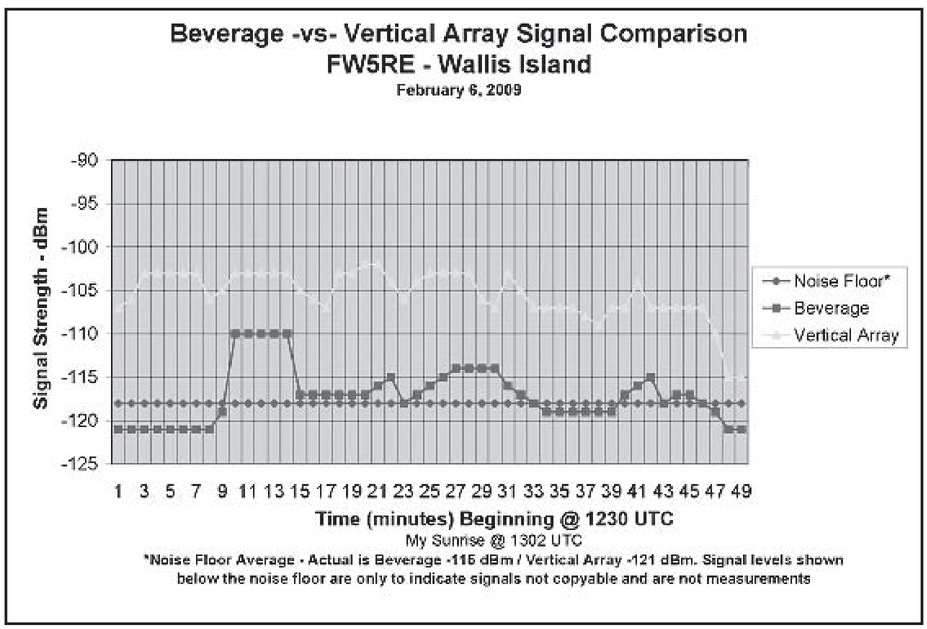


Figure 33 — This chart compares signal levels between the Eight Circle Vertical Array and a Beverage antenna for signals from FW5RE, Wallis Island.

QEX