Design, Construction & Evaluation
of the
8 Vertical Circle Array for Low Band Receiving©

Second Edition – March 2017

Joel Harrison, W5ZN, Bob McGwier, N4HY, Frank Donovan, W3LPL

In 2008 W5ZN and N4HY embarked on a mission to construct a broad side – end fire (BSEF) 8 vertical receive array for 160 meters. At that time literally no information about the array existed in the public domain so our effort was an educational endeavor for its construction and evaluation. The result of that mission was the publication of the first edition of this paper[1].

Now, some 9 years later, considerable experience has been acquired with the array from actual on-the-air use, construction revisions and maintenance. In addition, Frank Donovan, W3LPL, built and installed the array at his Maryland location and his gracious effort to publicize his experience has been extremely valuable.

All of this experience is being detailed in a Second Edition of this publication. We believe it is important to retain the original paper, rather than to revise it, in order to provide a historical record of the evolution of this array throughout time.

1.0 Design of the 8 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 receiver for large signal handling and dynamic range. It is not the intent of this paper to discuss all of these topics. We suggest a thorough study and understanding of *Low Band DX'ing,* Fifth Edition[2], by John Devoldere, ON4UN, is a requirement prior to proceeding with any low band operation. Chapter 7 is prerequisite for any low band receiving antenna project. In addition, the specific theory related to broad side-end-fire arrays in this chapter must also be read and understood. The BSEF 8 Vertical Array system is based on this theory and cannot be utilized 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 encompass the design.

1.1 Vertical Element & Array Design

The 160 meter BSEF 8 Vertical Array was previewed in the Fifh Edition of *Low Band*

[1] References appear on page 24

DX'ing, 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, W8JI's website[3].

Our original desire was to further evaluate the design of the array and also evaluate an 80 meter version that did not exist at the time of our original analysis. We also wanted to address the most crucial missing piece of all, a step by step "How To" in building, tuning, and using the antenna.

It is important to understand first and foremost 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 design characteristics of the vertical elements in this array is to utilize impedance matching with a low wattage resistor. This resistor will do great things in this application; most prominently it will lower the Q and broaden the response of the antenna with a good SWR and match it to widely available and inexpensive coaxial cable. This comes at the expense of gain, but in the overall low band receiving system design coupled with analysis of the noise temperature of the intended 160 & 80 meter bands gain is not the primary objective 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 important parameter for the low bands! As such, we believe you should not even need a preamp unless you are installing an incredibly long feedline 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 is for you to determine based on your specific installation. The signal cable run at W5ZN is 800 feet long and a preamp has never been required or proven to add any benefit whatsoever.

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 meter construction and testing over the past 9 years attest to the validity of the analysis.

The Receiving Directivity Factor (RDF), the ratio of the forward gain at a desired direction and take off angle to the average gain over the rest of the entire hemisphere around the antenna, has become the standard for evaluating low band receive antennas. This is described in detail in Ref. 2, Section 1.08 through 1.10. Following publication of the First Edition of this paper Bill Hohnstein, K0HA, contacted W5ZN with information pertaining to prior discussions regarding a figure of merit for receive antennas he had initiated on the Top Band Reflector that became the groundwork for RDF. While not the topic of this paper, the links to those discussions is contained below[6].

While this antenna array has some small side lobes (see Fig. 9), they are really nothing to be concerned about and are better than most four squares and Yagi's. You can trade off some side lobes for better directivity and this was done in the original analysis discussed above.

The BSEF 8 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 feedline impedance. This allows us to use the least expensive coax that will permit reliable, robust operation. In this case 75Ω 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 75Ω is nearly ideal. The resistive swamping lowers the Q and increases the operating bandwidth with 75Ω cable.

1.2 Modeling the Individual Elements

The best approach is to use the W8JI element. Up until our original work in 2008 there wasn't a great deal of information published about this design, so N4HY conducted our own modeling with EZNEC/4 Professional. Figure 1 shows the segment layout of the shortened vertical.

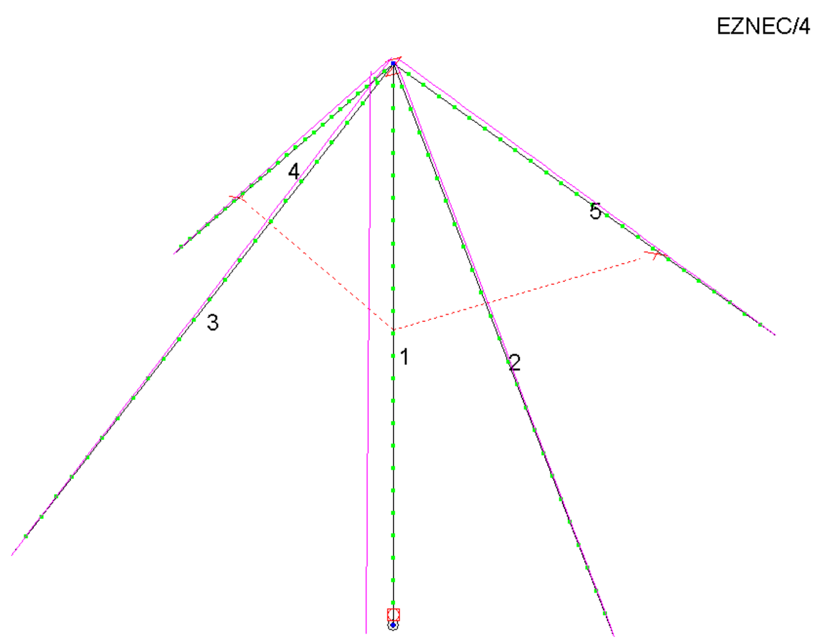


Figure 1: Antenna drawing from EZNec/4 Pro showing analysis segments and bottom load as well as top-hat details (no radials shown here).

The model shown in Figure 1 is available from the W8JI site but has been slightly modified based on our analysis. 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 capacitive top-loading and also provide very good high angle rejection. Because the structure is ground mounted and 4 of the elements are active in each of the 8 directions in a broadside/end-fire cell, the rejection above 45° is at least 9 dB down from the main lobe maximum and 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 for 160 meters we will need to bring the resonant frequency down with a small inductor. 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 VSWR from 1.8 to 1.9 MHz to 75Ω coax. On 80 meters, the design indicates a 2 µH inductor will be required with the addition of enough resistance to give a low VSWR from 3.5-3.8 MHz.

The 75Ω feed point impedance was chosen because of the availability of inexpensive readily available coax (cable TV installation) plus the higher resistance is used to broaden the VSWR 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 fixture is required 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 non-conductive fence post. The distance from the ground to the bottom of the base is not critical. 6" to 2' is acceptable.

The design utilizes a top-hat made from #16 wire with the vertical element assumed to be a 1.25 – 1.5 inch diameter vertical pipe.

Even though ground resistance is not particularly important for radiation resistance you will need a few short 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 was detailed in the First Edition of this paper. Again, the ground radial system only needs to be good enough to provide a stable feed point resistance since the objective 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.

Figure 2 shows the 3D pattern of one of the vertical elements at resonance using 4nec2dx.

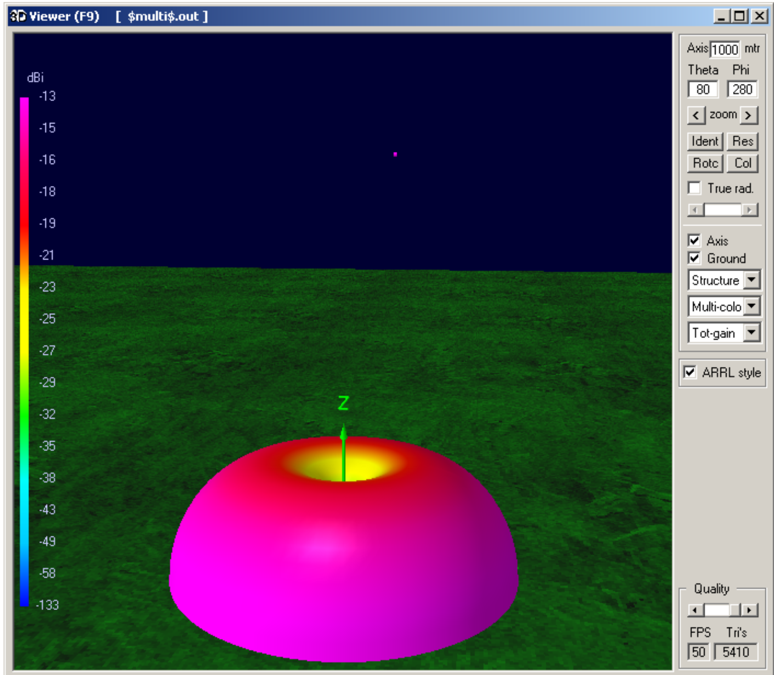


Figure 2: 3D from 4nec2

Figure 3 displays the VSWR profile for the 160 meter design computed by EZNEC/4 Professional with a 30 µH base inductor, resistor and 75Ω coax:

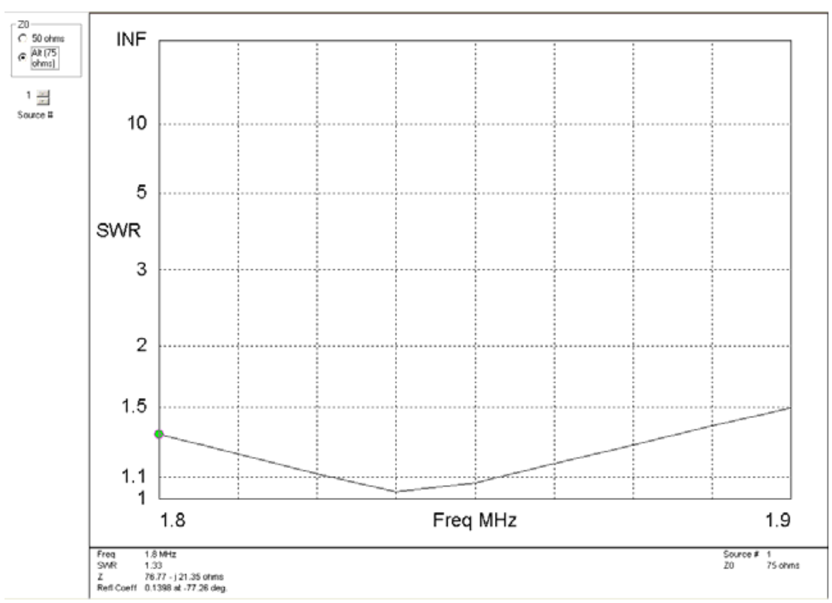


Figure 3: VSWR Profile for the 160 meter Vertical

The 80 meter design VSWR profile computed by EZNEC/4 Professional with a 2 μH base inductor, resistor and 75Ω coax is shown in Figure 4:

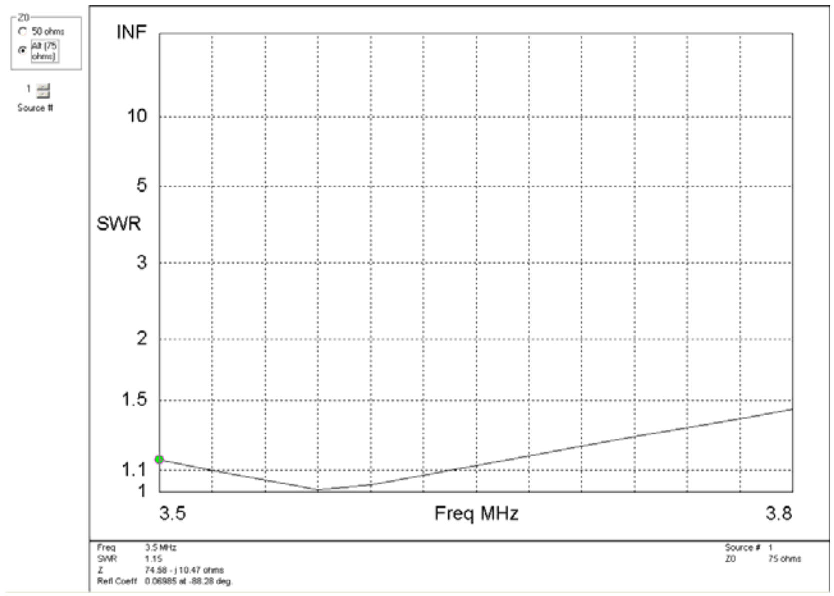


Figure 4: VSWR Profile for an 80 meter Vertical

1.3 Array Geometrics

This 8 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 for this array. For those wishing to dig into the theory behind the spacing you can review Ref. 2, Chapter 7 Section 1.11 and 1.12.

W5ZN has experimented with different broad side spacing ranging from one that yields the best attenuation off the sides of 0.55λ with a claimed RDF of 13 dB to a spacing recommended by W8JI of 0.65λ. A wider spacing will increase the number and/or size of the side lobes but in return you get a narrower 3 dB beamwidth. N4HY calculated the RDF for this spacing to be 12.5 dB. The real world results indicate, with different spacing's between 0.55λ and 0.65λ, that you really won't be able to detect any difference, except possibly in very extreme situations. The current broad side spacing at W5ZN for the past three years is 0.65λ.

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.

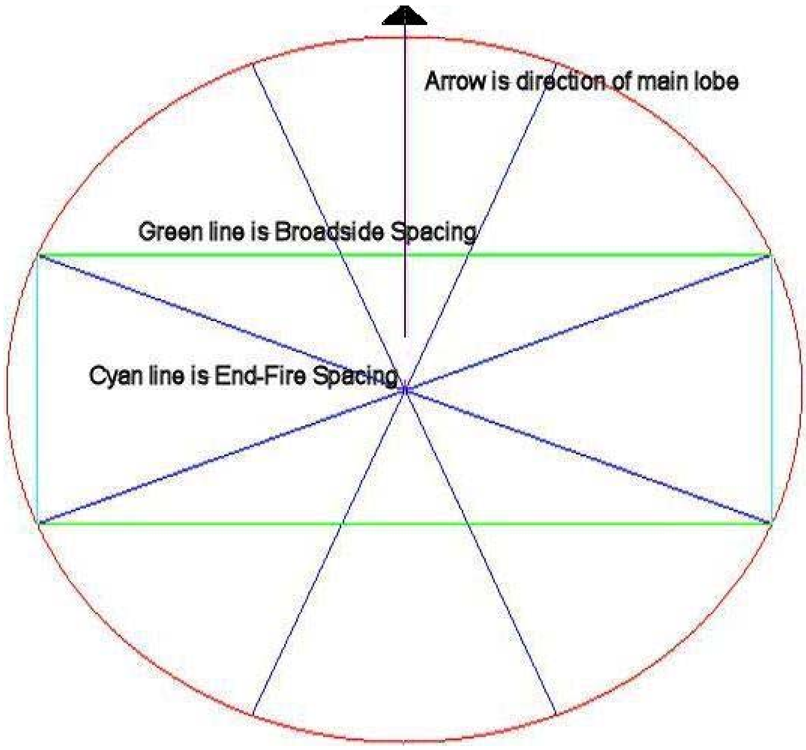


Figure 5: Geometry of 8-circle of broadside/end-fire cells.

The green lines specify the broadside dimension which determines the entire circle as soon as it is specified. The cyan lines are the end-fire spacing which is determined by the circular diameter around the broadside distance. The broadside spacing is the ***only*** degree of freedom in the entire design.

The blue lines represent the individual feedlines to each vertical. These may be any equal electrical length pieces of 75Ω coax. There is no requirement for them to be odd multiples of ¼λ in length.

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

So, the layout for this specific design is as follows:

Band – Meters	Broadside Spacing - λ	End Fire Distance
160 (1.825 MHz)	0.55 λ (296 ft.)	113.3 ft.
160 (1.825 MHz)	0.65 λ (350 ft.)	134.5 ft.
80 (3.525 MHz)	0.55 λ (153 ft.)	55.0 ft.
80 (3.525 MHz)	0.65 λ (180 ft.)	64.75 ft.

1.4 Feeding the Array

The feed system described in the original paper used a very basic design to achieve proper phasing of the array. Those basic materials were:

One - 4:1 UNUN transformer
One - 1:1 Inverter transformer
Nine - DPDT relays & and four diodes.
Two – 75Ω Coaxial Phasing Line

- Two pieces of 75Ω coax connected in parallel to form a 37.5Ω phase line. The length will be discussed later as there are tradeoffs to consider.

Figure 6 depicts the original feed arrangement for the broadside/end-fire cell. The "Front Two" consist of the two elements in the "front" of the 4 element cell coming to a Tee. The "Back Two" are the back elements in the 4 element cell coming to a Tee. Two pieces of equal length 75Ω coax are feeding the front two elements which form a combined impedance of 37.5Ω. The back two elements are the same and again form a combined impedance of 37.5Ω but with a phasing line (180° minus the desired phase angle) consisting of 75Ω 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 75Ω coax connected in parallel to produce a 37.5Ω impedance to match the element feedline impedance (two 75Ω feedlines in parallel to the back two elements) which should be 180° – 125°, or 55° in length

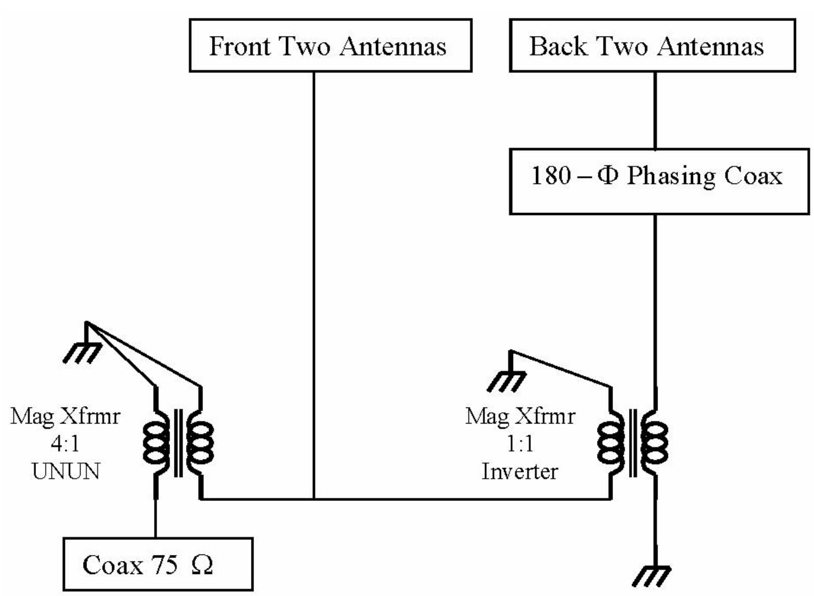


Figure 6: Feed for One Cell

The original switching unit combined a simple collection of nine DPDT relays or four 4PDT relays with one DPDT can switch the array in 8 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.

A further review and study of phasing angles and delay lines appear in Ref. 2 with detailed data contained in Table 7-16.

Following publication of our original paper in QEX, W5ZN had a very information dialogue with Robye Lahlum, W1MK. Robye noted that our gain numbers are actually 6 dB lower than reported due to the combining method used as it does not provide isolation between the antenna elements. Signals arriving on any one antenna element are dissipated not only in the 75Ω build out resistor of the element in question but also in the 75Ω build out resistor of the other three antennas. Robye explained that this 6 dB of loss can be avoided by using 0° hybrid combiners, sometimes referred to as "magic tees". Utilizing three hybrid combiners to combine the 4 antenna elements in this application provides approximately 25 dB of isolation between the antennas and also provides a 75Ω termination to both ends of the 56° delay line and as a result only one delay line is required rather than two. Robye noted this will also improve the broadband performance of the system by providing a good return loss over a much wider bandwidth for the delay line.

The current switching arrangement used at W5ZN and W3LPL utilizes magic tee combiners.

Another interesting point Robye made worth mentioning here is that in our original article we believed, even with the 6 dB loss he identified, we had adequate system gain for our application. With that in mind, if 0° hybrid combiners are used, the addition of 6 dB of gain could be used up by building out the impedance of each antenna to 300Ω. This approach lowers the Q by a factor of 4 and further improves the bandwidth by the same factor. The receive system gain is reduced by 6 dB but the hybrid combiners improved the gain by 6 dB so the net system gain change is 0 dB. This does require the addition of a 4 to 1 transformer at each antenna element to match the impedance to 75Ω transmission lines. Not only does this improve the bandwidth but it reduces the possible degradation of the antenna elements not tracking each other with time and environmental changes. This feed impedance arrangement has not yet been tried on any of the arrays we are aware of.

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 4 cell broadside/end-fire array. Figure 8, 9 and 10 display the azimuth, elevation and 3D pattern for the 160 meter array and Figures 11, 12 and 13 shows 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 below. Although the main side lobe is >15 dB down from the highest gain point, RDF is about total contribution of power from behind the main lobe. 80 meter model patterns produce similar results.

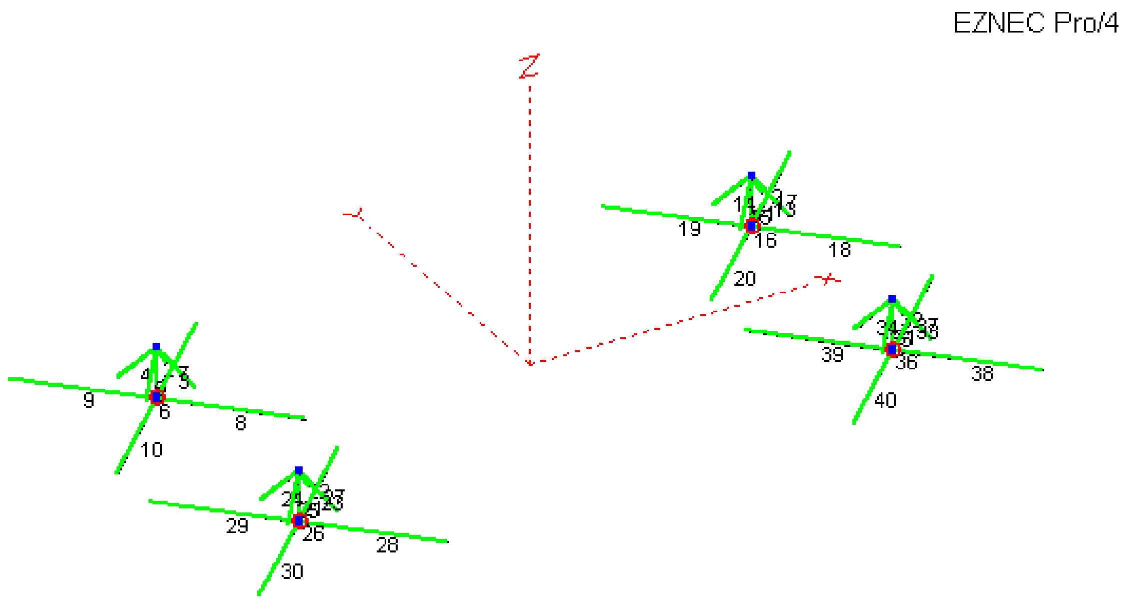


Figure 7: Array of One 4 Cell

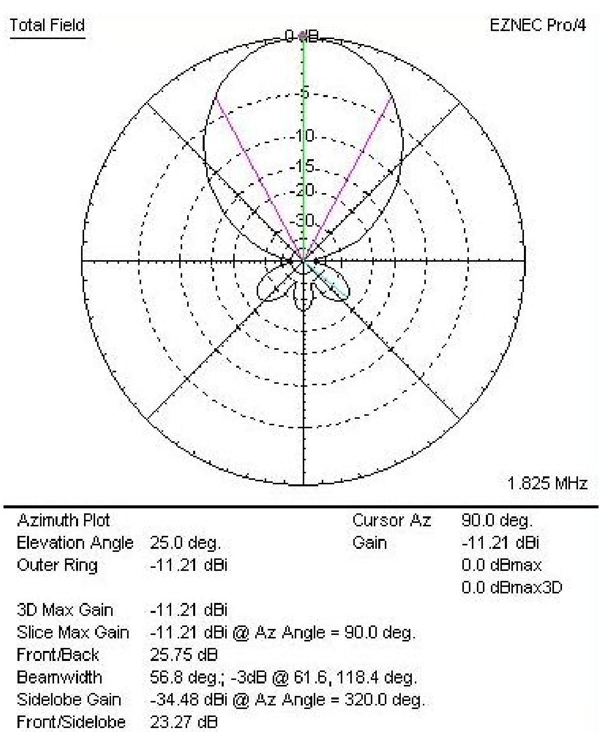


Figure 8: Azimuth Pattern for 160 meter Array

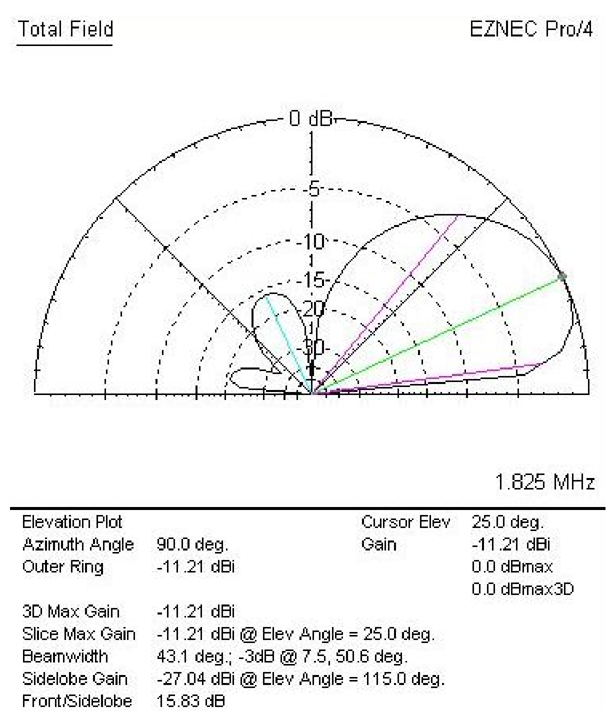


Figure 9: Elevation Pattern for 160 meter Array

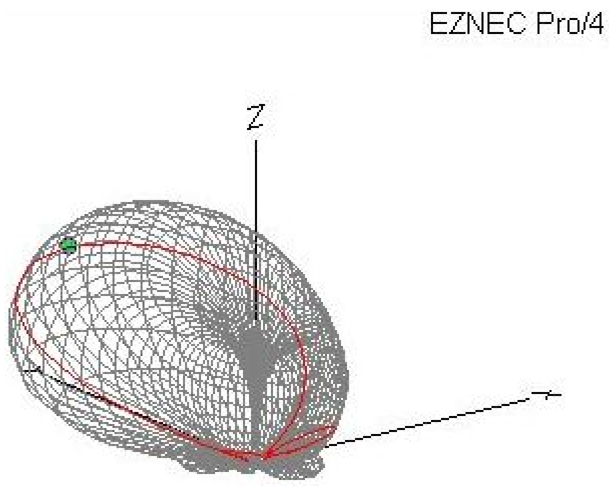


Figure 10: 3D 160 meter Pattern

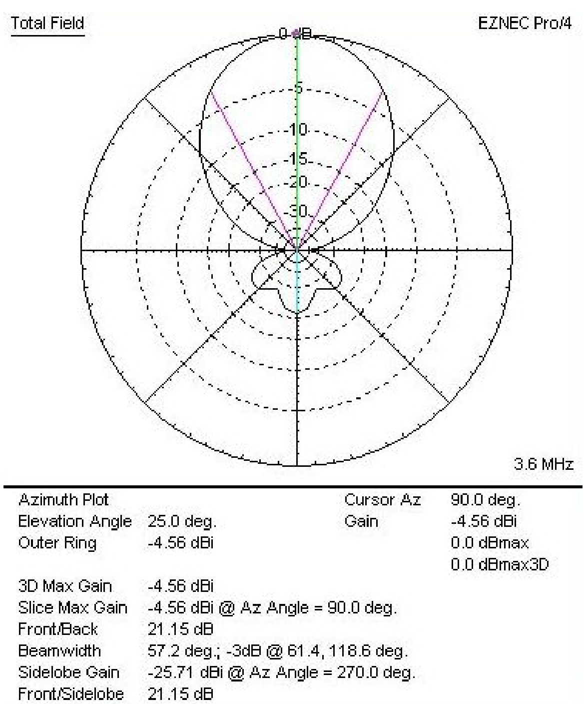


Figure 11: Azimuth Pattern for 80 meters

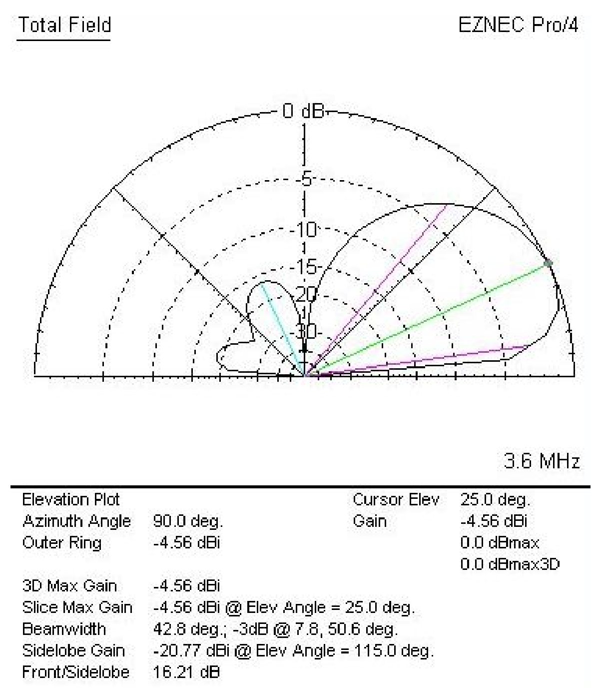


Figure 12: Elevation Pattern for 80 meters

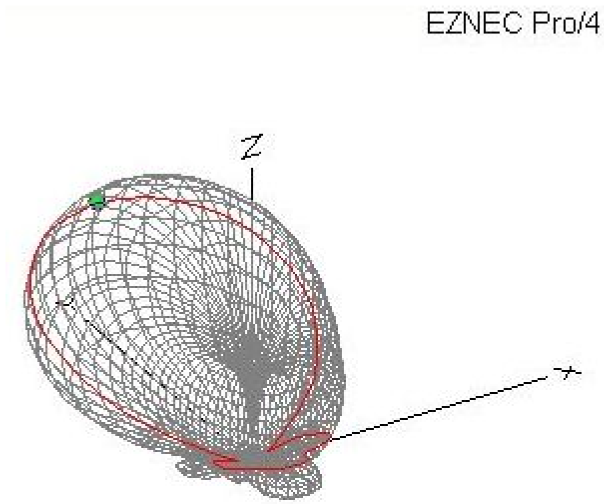


Figure 13: 3D 80 meter Pattern

2.0 Construction of the BSEF 8 Vertical Array

Once the decision was made to erect a 160 meter BSEF 8 Circle Vertical Array at W5ZN, the construction phase began and involved numerous steps to ensure the design parameters were met.

2.1 Location & Physical Layout of the Array

The first step was to select an appropriate location and lay out the circle. It was fortunate that W5ZN had an area that seemed ideal for the array out in a field approximately 750 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 Yagi's seen in Figure 15, had to be taken into consideration. An existing barb wire fence to the south of the proposed location 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 ½λ, and the southern edge was 75 feet from the barb 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 angle of slope. It was calculated that the sloping ground was no more than 2° which is very acceptable.

Figure 14 – **Area Selected for Circle Array**

Figure 15 – 160 Meter Transmit Antenna (Left Tower)

Ever since this array was first erected at W5ZN, the question of the impact of a Beverage or other antenna in close proximity to or running through the array has been posed. During a conversation between W5ZN and W8JI, Tom opined he did not believe there would be an impact on the BSEF array however due to ground radials being laid on or in the ground from the BSEF verticals the Beverage could see a shift in "ground conditions" underneath the Beverage and impact its performance. He did stress, though, that additional modeling, testing and experience is required to validate any assumption.

W3LPL does in fact have a Beverage that bisects his BSEF array. Frank reports he has not been able to detect any performance reduction on either antenna.

When W5ZN installed the first 80 meter version of this array it was installed by itself some 300 feet away from the 160 meter version in order to collect performance data solely on the 80 meter array. After two years using the 80 meter array located away from other antenna systems it was laid out and moved inside the 160 meter array. No performance impact has been recorded. W5ZN and W3LPL now regularly install their 80 meter array inside the 160 meter array.

Now that all of these parameters have been verified to be acceptable it was time to lay out the circle, having identified the western edge by measuring its distance from the transmitting antenna as well as the southern edge by measuring its distance from the barb wire fence.

2.2 Circle Layout

Layout of the circle and vertical element location can be accomplished by simply placing a post or rod at the center point of the array and then measuring the radius distance out to one of the vertical elements. Another rod or orange surveyor's flag can be placed at this point and then the same procedure used to identify the location of each additional vertical, ensuring the end fire distance between each vertical element is accurate.

2.3Element 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. Initially W5ZN used 6ft treated 2x4's inserted in a posthole about 18" deep packed in with *Quickcrete* to form a solid base. This is not necessary and in reality a bit of "over engineering" as there is really no lateral stress or tension on the vertical elements, especially once the top hat wires are secured.

W3LPL's approach, and the current method W5ZN has adopted, is to use a piece of rebar or round metal stake inserted about 6 to 12 inches in the ground with a piece of PVC, fiberglass rod or other insulating material placed over the rod to attach to the element.


Rebar Rod


PVC over Rebar Rod


Complete Mounting Assembly


Installed Ground Mounting Assembly

This allows for easy removal in late spring/summer to allow for hay cutting, summer activities, etc. and then reinstallation in the fall just prior to the start of the low band season.

2.4 Element Material & Construction

The material used for the vertical elements and the construction technique is not critical as long as you stay reasonably 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 steel conduit and chain link fence top rails and techniques that provide a vertical element that is mechanically strong with excellent results as detailed on his website. The array currently under construction at W2GD's 160 meter site is being designed around chain link fence railing for a robust element to survive the harsh winter weather on the New Jersey coast.

We chose to use aluminum tubing for our elements. There was no particular reason for this other than personal preference. W5ZN used 12 ft. lengths of 1¼" diameter aluminum tubing and a supply 1⅛" diameter tubing that has a 0.058" wall thickness. As such the 1⅛" diameter tubing fits right inside the 1¼" tubing. Then the 1⅛" diameter tubing was cut into 2 ft. lengths and inserted 1 ft. into one each of the 12 ft. lengths of the 1¼" tubing and secured the joint with #10 stainless steel screws & nuts. This provided for a 24 ft. long element so an 18" length of 1⅛" diameter tubing, inserted it 6" into what would be the top end of the 24 ft. long element was added and secured it with screws. We now had a very nice 25 ft. element. Four holes are drilled at the top 90° apart in order to attach the top hat wires.

Six foot pieces of aluminum tubing are readily available today and can ship via UPS. The joint sections can be secured with hose clamps.

For top hat wires we used #16 gauge stranded wire. Again, there is flexibility with the material although it is recommended to stay close to #16 gauge in order to replicate the design model and also provide adequate mechanical strength for the wires. Several techniques can be employed to attach the top hat wire to the vertical. W5ZN simply connects each top hat wire to a terminal lug and a stainless steel screw through the top of the vertical. Mike Wetzel, W9RE, has employed a strain relief using a piece of Plexiglas. Just ensure you have a good electrical and mechanical connection for the top hat wire. The additional length required for guy lines to reach the point you have chosen to secure the top hats may be any type of non-conductive rope, fishing line, etc.

W5ZN initially brought his top hat tie points down to the ground with fishing line, secured with a tent stake. This proved challenging with deer and other wild animals roaming around so 4 ft. metal "U" posts were subsequently installed at W5ZN to resolve this issue. The posts are approximately 3 ft. above ground and placed 22 ft. from the vertical element. The height of the post is not critical except to provide adequate clearance for the animals roaming your area. W3LPL uses 7 ft. posts to contend with the large deer population at his QTH..

Top Hat Wire Tie Point

Tie Point Posts used at W5ZN
Available from Lowe's, etc.

2.5 Ground Radial System

AAAAAAGH!!!!!!! RUN FOR YOUR LIFE, THE VERTICAL HAS RADIALS!!! This is the typical response from some radio amateurs when discussing vertical antennas and quite honestly is over exaggerated and misunderstood.

As described in the modeling section when using a low impedance feed system, in the case 75Ω, some ground radials are required to stabilize the feed point impedance over changing wet and dry ground conditions throughout the year.

During the initial construction in 2008 W5ZN chose to bury four radial wires that were 65 ft. long (⅛λ on 160 meters) a few inches in the ground. These were laid out one each under each of the top hat wires. In addition, ground rods were also installed at each vertical. After initial testing we determined 8 radials would be optimum. There is no need to bury the radials and use a ground rod. Neither approach adds any performance enhancement whatsoever. All that is required is for the ground radials and outer shield of the coax connector to be connected together as again, the only purpose of the radial system is to stabilize the feed point impedance. Following evaluation and several years of experience we have concluded eight radials 65 feet long at each vertical for 160 meters and for 80 meters eight radials 35 feet long are adequate to stabilize the feed point impedance. Expanding beyond this will not improve performance. These can simply be laid on top of the ground. Even if deer or other encroachment rearranges the radial layout from a symmetrical pattern no performance degradation has been detected at either W5ZN or W3LPL. Although we have no experience with shorter radials, it is conceivable that the same objective result could be achieved by using more, say 12 or so shorter radials if you are unable to use the recommended length. A chicken wire screen may also be adequate. The procedure described in the First Edition of this paper can be used to determine what options may provide acceptable results.

Simply connect all radials together at the shield of the feedline connector. W5ZN uses one short length of wire to connect them to the outer shell of the coax connector

Figure 18: One Completed Vertical

2.6 Tuning the Individual Elements

Once each vertical element is erected and the ground radial system installed, it is time to test and tune each element. The first step is to check the self-resonant frequency of each vertical. Using an antenna analyzer similar to the MFJ-259B, connect it directly to the vertical element and look for a dip at resonance. The self-resonant frequency of each element should be somewhere around 3.9 to 4.0 MHz. The difference is not important as long as it is around this range as the materials used for the elements and your method of construction will vary this.

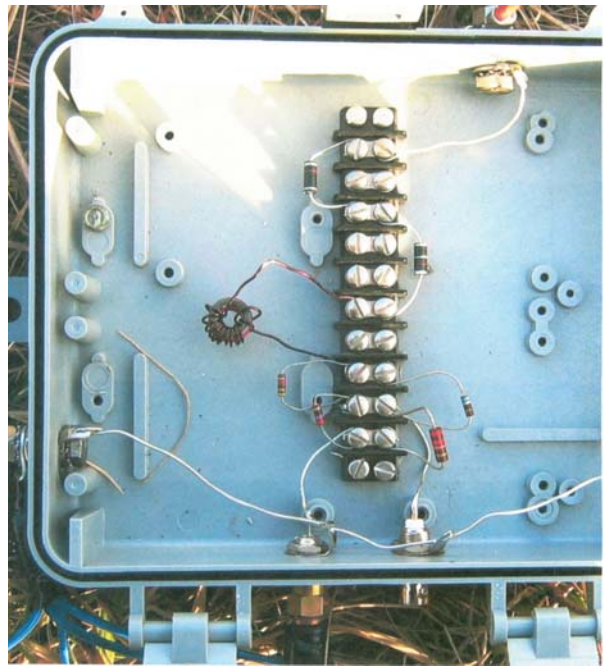
After confirming the resonant frequency of each element it is time to tune each one to the desired frequency. The tuning process in the original paper was quite detailed and laborious in identifying the specific combination of inductance required to resonate each vertical. W3LPL developed a very simple method that W5ZN incorporated. For 160 meters, insert approximately 28 uH of inductance in series with approximately a 56Ω resistor between the feed point and connection point of the vertical. Check the resonant frequency and if tweaking is required to bring the element to the desired frequency on 160 meters then adjust the length of each top hat wire by simply folding it back over and wrapping it around itself as shown below.

W5ZN's top hat wires were initially 25 feet long then approximately 18 inches of each top hat wire was folded back to achieve a proper match at 1825 KHz. There is no need to use non-inductive resistors or to be concerned with the resistance of the inductor as these simply add to the total inductance and resistance of the feed point matching circuit. Once you have your resonant frequency set, check the feed point resistance and then simply vary the value of the swamping resistor to set this at 75Ω. For example if the feed point resistance at your desired resonant frequency is 65Ω you need to add an additional 10Ω resistor at the feed point for a 75Ω match. Once this is complete on the first vertical use the same top hat length and resistance value for each of the remaining seven verticals. Each should be at resonance, or require only very minor tweaking.

The original work in 2008 was performed with an MFJ 259 antenna analyzer. The intent was to prove the array could be set up and effectively tuned with a simple piece of test equipment. We were successful in our effort, however it is important to note we were tuning an antenna with a 75Ω impedance with a test instrument designed for a 50Ω impedance. There will be some slight differences in readings utilizing this arrangement. To ensure accurate measurements W3LPL installed an additional BNC port with a 50Ω impedance at each vertical in order to use an MFJ 259 or similar antenna analyzer with a 50Ω input. A 50Ω impedance port is established by simply adding a lower value resistor, around 25Ω, in parallel across the resistor used for the 75Ω port matching to the BNC port at each vertical. When making a 50Ω measurement from this port make sure the 75Ω port is open by removing any coax connected to it so as to "float" the 75Ω port.

Today, many antenna analyzers allow the user to select a variety of antenna impedances to match the system under test, including 75Ω. I currently use a Rig Expert AA-170 and set the impedance to 75Ω prior to performing my measurements.


W5ZN Feed Point Box


W3LPL Feed Point Box

2.7 Feedlines & Phasing Lines

At W5ZN, CommScope F660BEF is used for the feedline to each vertical. This is a "flooded" 75Ω cable with an excellent published and verified velocity factor of 85%. This has been verified on multiple spools of cable and is reliable. The flooding compound is adequate to protect the cable from moisture ingress. For the original construction in 2008, the feedlines to each element were buried. In later years this was abandoned to allow summer removal so the cables are simply laid on top of the ground. There have been a few minor occurrences of raccoons and coyotes biting into the cable but nothing severe enough to cause any damage or degradation.

2.8 Switching Unit

When this array was originally constructed at W5ZN no commercially available switching unit was available or any real guidance on how to accomplish this task other than a simple schematic. As a result the original switching unit followed a very simple arrangement of relays and point-to-point wiring. This worked well and provided adequate service for four years. Since this time, a couple of different switching units have become available. W9RE designed and provided circuit boards for a switching unit and today a self-contained unit is available from DX Engineering[4]. W5ZN purchased two of the

W9RE boards and had them successfully in use for a couple of years but now uses the DX Engineering unit exclusively. It is well constructed and comes with documentation for assembling a BSEF 8 vertical receiving array. Should you desire to construct your own, the information in the First Edition of this paper and utilizing the recommendations of Robye, W1MK regarding the use of hybrid combiners detailed, or information contained in Ref. 2 will provide an excellent switching device for this array.

3.0 Evaluation of the 8 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 erroneously assume 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. As an example, W5ZN listened for two 160 meter seasons in 2005 & 2006 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 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 were previously buried under your noise.

Remember, your goal is to improve your 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

W5ZN's first step in the evaluation was to record noise floor levels on the various 160 meter antennas installed at his location. He has some significant noise sources in two directions so a combination of low noise receiving antennas benefits him greatly. Table 5 shows a comparison of the noise floor for some of the W5ZN 160 meter antennas.

It is important that you conduct a noise evaluation of your station after initial installation of a new antenna and annually thereafter and record your results in order to identify changes over time.

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

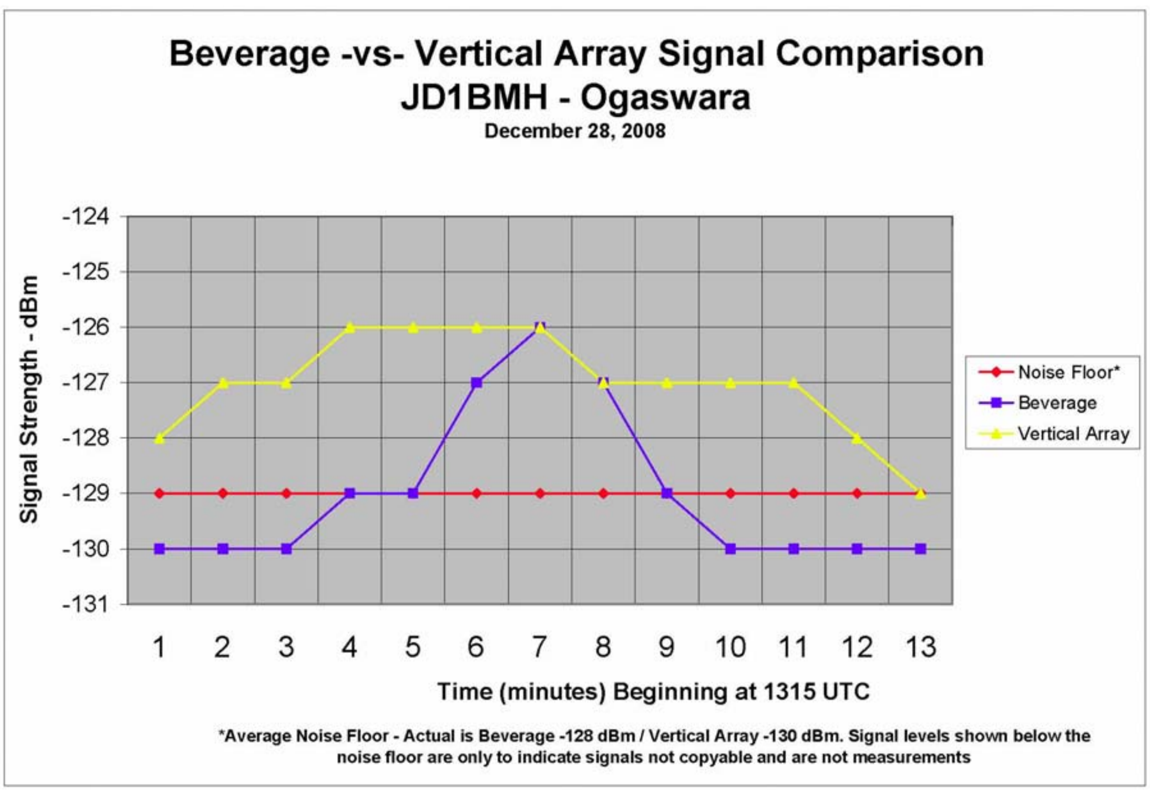
A comparison of on-the-air F/B and F/S measurements from various stations was performed over several months and the results indicate the array is comparable to the modeling parameters produced. Some of this data is contained in Appendix A.

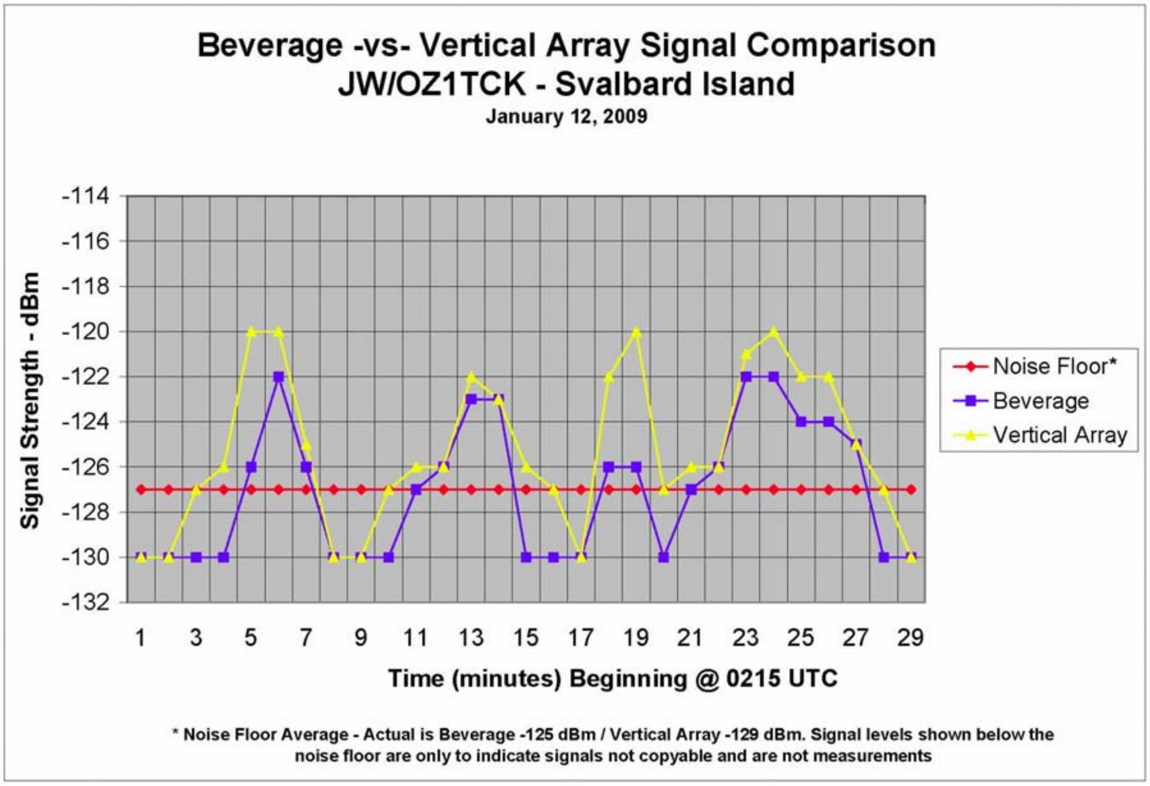
The charts below depict signal comparisons between the BSEF 8 Vertical Array and 880 ft. Beverage antennas at W5ZN taken at different times of the day to different parts of the world. Obviously, the signal arrival angle will play an important part in signal strength and readability, however the charts below are typical for each DX station data was recorded from and represent the ability to hear a station earlier than with the Beverages

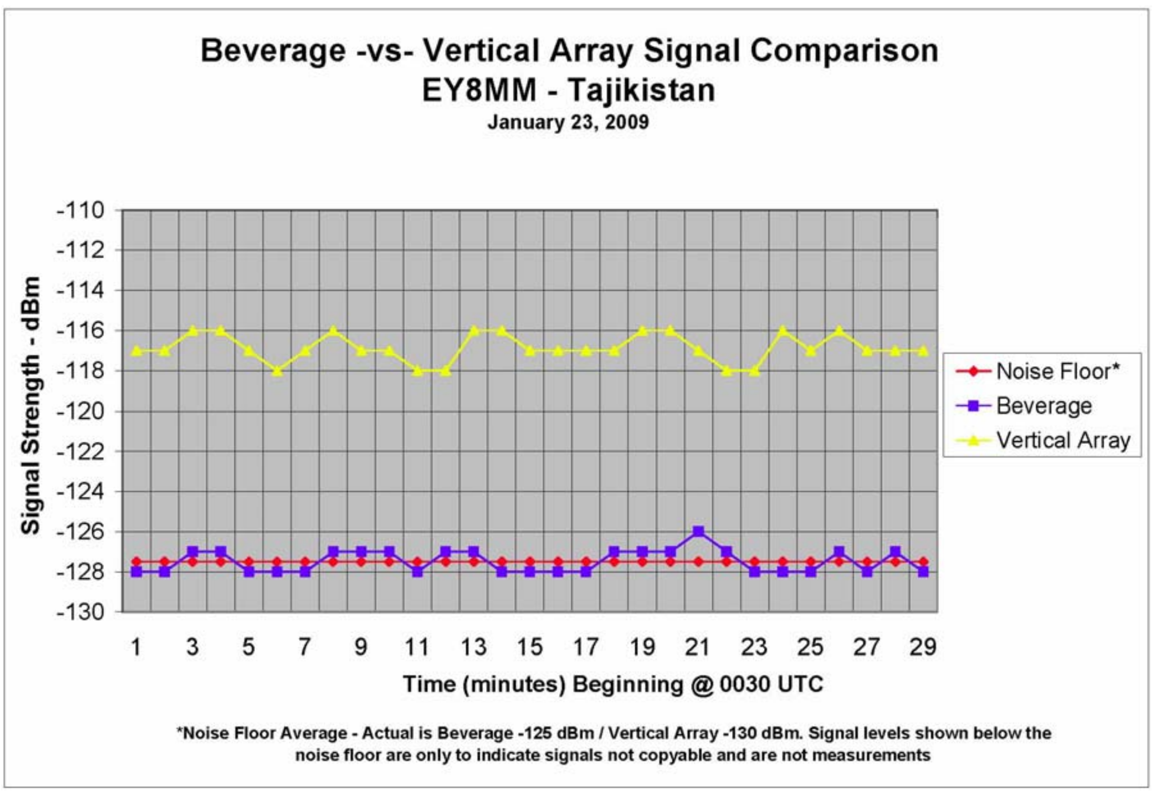
and to also hear the station for a period of time after they can no longer be copied on the Beverages. At the peak propagation period, however, there is no noticeable or recordable differences between the two receive antenna systems.
80 meter array results, while not published here, are comparable to the 160 meter results.

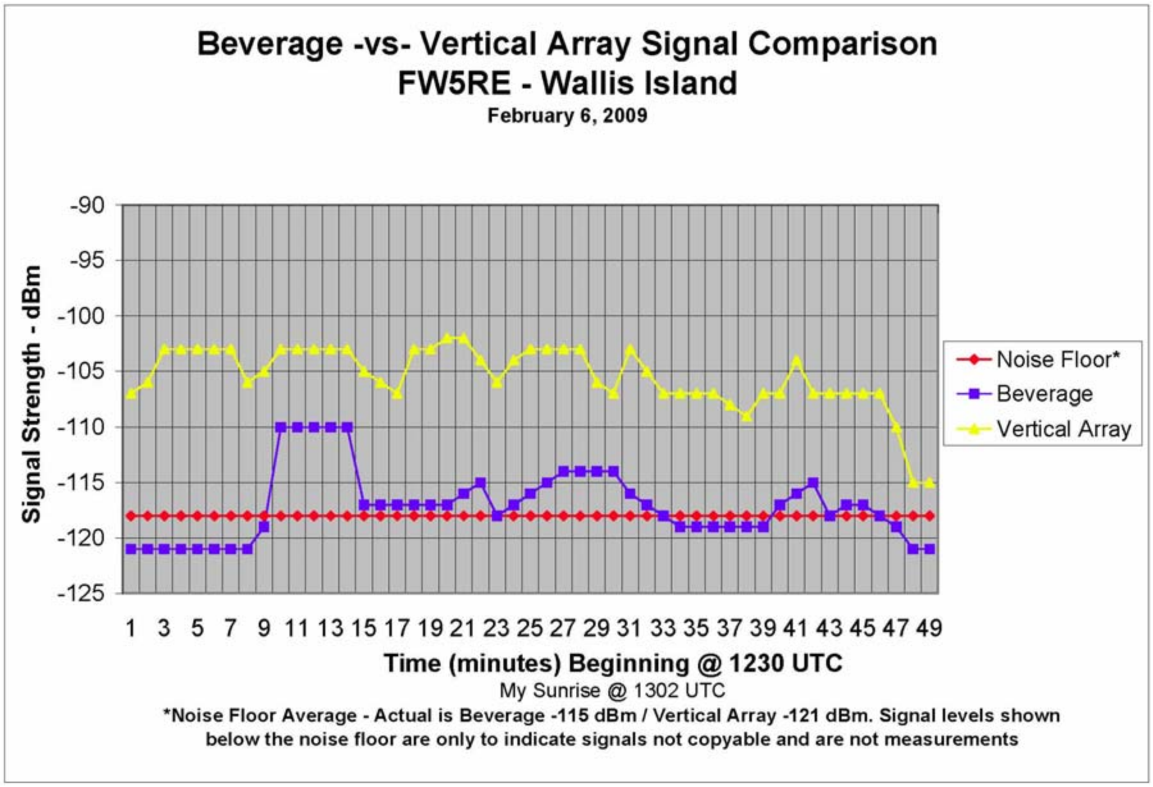
Direction	8 Circle Vertical Array Noise Floor	Beverage Noise Floor	Shunt Fed 135' HF Tower 160 Meter Xmit	½ λ Inverted Vee
N	-129 dBm	-125 dBm	-100 dBm[1]	-105 dBm[1]
NE	-125 dBm	-120 dBm	-100 dBm[1]	-105 dBm[1]
E	-125 dBm	-124 dBm	-100 dBm[1]	-105 dBm[1]
SE	-126 dBm	-123 dBm	-100 dBm[1]	-105 dBm[1]
S	-126 dBm	-120 dBm	-100 dBm[1]	-105 dBm[1]
SW	-125 dBm	-120 dBm	-100 dBm[1]	-105 dBm[1]
W	-126 dBm	-125 dBm	-100 dBm[1]	-105 dBm[1]
NW	-130 dBm	-128 dBm	-100 dBm[1]	-105 dBm[1]

Table 5 – Noise floor measurements comparing the 8 Circle Vertical Array, Beverages, Shunt-fed Tower and Inverted Vee at W5ZN. Measurements were taken with a 250 Hz bandwidth at a Sampling Rate of 48 KHz. [1] Omni- directional.




Beverage -vs- Vertical Array Signal Comparison
JW/OZ1TCK - Svalbard Island
January 12, 2009
Signal Strength - dBm
-114
-116
-118
-120
-122
-124
-126
-128
-130
-132
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29
Time (minutes) Beginning @ 0215 UTC
Noise Floor*
Beverage
Vertical Array
* Noise Floor Average - Actual is Beverage -125 dBm / Vertical Array -129 dBm. Signal levels shown below the noise floor are only to indicate signals not copyable and are not measurements


Beverage -vs- Vertical Array Signal Comparison
EY8MM - Tajikistan
January 23, 2009
Signal Strength - dBm
-110
-112
-114
-116
-118
-120
-122
-124
-126
-128
-130
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29
Time (minutes) Beginning @ 0030 UTC
Noise Floor*
Beverage
Vertical Array
*Noise Floor Average - Actual is Beverage -125 dBm / Vertical Array -130 dBm. Signal levels shown below the noise floor are only to indicate signals not copyable and are not measurements



4.0 Summary

The BSEF 8 Vertical Array is a significant addition to the low band receive antennas at W5ZN and W3LPL and is now the primary system used for receiving on 160 meters and 80 meters. W3LPL has also installed a 40 meter BSEF array and reports comparable results. This array uses vertical elements and top hat wires that are half the length of the 160 and 80 meter versions. No inductor is required at the feed point, simply adjust the length of the top hat wires for resonance at 7100 KHz and a resistor sufficient for a 75Ω impedance.

This array has now been in use for 9 years at W5ZN and 4 years at W3LPL. The performance has continued to be optimum and over the past three years W5ZN has performed comparisons with other vertical receiving arrays and has published a paper with those results[5].

During the original construction and evaluation of this array literally no information existed in the public forum to aid in its construction. A considerable amount of time and effort was invested in gaining a working knowledge of this system. Since the original publication much more information has been made available enabling other radio amateurs to construct this array and improve their low band receive capability. This accomplished our original objective in publishing our work.

GL es DX on the low bands!

Joel, W5ZN   Bob, N4HY   Frank, W3LPL

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1. J. Harrison, W5ZN & R. McGwier, N4HY,"Design, Construction & Evaluation of the 8 Circle Vertical Array for Low Band Receiving" First Edition, Rev. 3 Nov 2009; QEX March-April 2010; http://www.w5zn.org
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5. J. Harrison, W5ZN, "Comparison of HiZ-8 & BSEF 8 Vertical Arrays for Low Band Receiving" March 2017. http://www.w5zn.org
6. K0HA receive antenna figure of merit discussion links:
http://lists.contesting.com/archives/html/Topband/2000-10/msg00108.html
http://lists.contesting.com/archives/html/Topband/1999-09/msg00123.html
http://lists.contesting.com/archives/html/Topband/1999-09/msg00149.html
http://lists.contesting.com/archives/html/Topband/2000-10/msg00117.html
http://lists.contesting.com/archives/html/Topband/2000-10/msg00134.html
http://lists.contesting.com/archives/html/Topband/2000-10/msg00137.html

Appendix A

Date	Call	Noise Floor dBm	Front dBm	Back dBm	F/B Ratio dBm	Side dBm	F/S Ratio dBm
19-Nov-08	NS8S	-112.7	-78.5	-92.8	-14.3	-98.1	-19.6
Poor Condx	K9MMS	-112.7	-79.0	-93.9	-14.9	-94.9	-15.9
Band noisey	W4ZV	-112.7	-75.7	-91.2	-15.5	-98.7	-23.0
	W5UN	-112.7	-60.8	-68.5	-7.7	-73.5	-12.7
	W1AW	-112.7	-79.0	-93.9	-14.9	-100.0	-21.0
	KA9S	-112.7	-90.6	NIL	N/A	NIL	N/A
	ER4ER	-112.7	@ Noise	NIL	N/A	NIL	N/A
	UX1UA	-16.0	@ Noise	NIL	N/A	NIL	N/A
20-Nov-08	VE3CUI	-114.4	-80.7	-101.1	-20.4	-104.1	-23.4
Moderate Condx	PJ2/K8ND	-117.7	-91.2	-107.2	-16.0	NIL	N/A
Band quite	K4PI	-112.7	-62.4	-79.0	-16.6	-84.5	-22.1
	AA1K	-112.7	-85.1	-100.0	-14.9	-103.0	-17.9
	K1GUN	-112.7	-86.2	-98.3	-12.1	-106.1	-19.9
	N4IS	-118.2	-72.9	-93.4	-20.5	-96.2	-23.3
	RZ0AF	-117.7	@ Noise Q5	NIL	N/A	NIL	N/A
	K6ND	-117.1	-92.3	-103.9	-11.6		0.0
	RZ0AF	-118.2	-113.4	NIL	N/A	NIL	N/A
	W8JI	-117.7	-61.3	-79.0	-17.7		61.3
	JA8BNP	-118.8	-106.1	NIL	N/A	NIL	N/A
	JA4DHN	-118.8	-106.1	NIL	N/A	NIL	N/A
	JA Pileup	-118.8	-107.0	NIL	N/A	NIL	N/A
SR 1245z	HL3IUA	-121.1	101.7	NIL	N/A	NIL	N/A
	W0FLS	120.4	-79.6	-97.2	-17.6		0.0
	W8TE	-123.2	-90.6	-105.5	-14.9	-109.4	-18.8
1302Z	JA9LJS	-124.9	-108.8	NIL	N/A	NIL	N/A
	JA5BIN	-124.9	-108.8	NIL	N/A	NIL	N/A
	K5NZ	-124.9	-69.1	-85.6	-16.5	-93.9	-24.8
1310Z	JA2BDR	-124.9	-112.2	NIL	N/A	NIL	N/A
	UA0LCZ	-124.9	-112.2	NIL	N/A	NIL	N/A
	JA1BLY	-126.0	-117.1	NIL	N/A	NIL	N/A
	JA1SYY	-126.0	-117.1	NIL	N/A	NIL	N/A
1318Z	JA3SDJ	-126.0	-117.1	NIL	N/A	NIL	N/A

Date	Call	Noise Floor dBM	Front dBm	Back dBm	F/B Ratio dBm	Side dBm	F/S Ratio dBm
20-Nov-08	K8FC	-126.0	-90.6	-108.6	-18.0	-110.2	-19.6
2300z	K1LZ	-124.3	-83.4	-95.6	-12.2	-99.4	-16.0
	KA1J	-124.3	-80.7	-91.2	-10.5	-97.8	-17.1
	K9DX	-118.2	-74.6	-89.2	-14.6	-91.2	-16.6
	N9NJ	-118.2	-77.5	-89.5	-12.0	-92.8	-15.3
	FM5BH	-118.2	-92.8	-107.7	-14.9	NIL	N/A
	E77DX	-114.6	-99.7	NIL	N/A	NIL	N/A
21-Nov-08	UA6LV	-115.7	@ Noise Q5	NIL	N/A	NIL	N/A
Good Condx	PJ2/K8ND	-118.0	-88.7	-101.1	-120.0	NIL	N/A
	W1AW	-118.0	-84	-97.8	-13.8	-100.8	-16.8
	N1LN	-117.1	-82.3	-93.9	-11.6	-97.5	-15.2
	F6ELN	-119.0	-114.0	NIL	N/A	NIL	N/A
	K1LZ	-119.0	-81.5	-96.1	-14.6	-100.8	-19.3
	W3GH	-119.0	-66.5	-82.3	-15.8	-90.1	-23.6
0130Z	ER4ER	-116.3	@ Noise Q5	NIL	N/A	NIL	N/A
	IV3RPK	-118.0	@ Noise Q5	NIL	N/A	NIL	N/A
	VP5/W7VV	-118.0	-96.7	-110.0	-13.3	NIL	N/A
	EL2DX	-118.0	-108.3	NIL	N/A	NIL	N/A
	ZP6CW	-126.2	-107.2	NIL	N/A	NIL	N/A
	CX3CE	-126.0	-103.5	NIL	N/A	NIL	N/A
	OZ8ABE	-118.2	-100.3	NIL	N/A	NIL	N/A
0345Z	SV3RF	-117.4	-91.2	-115.7	-24.5	NIL	N/A
	G3PQA	-117.7	-93.9	-109.1	-15.2	NIL	N/A
	W1AW	-115.1	-71.8	-89.0	-17.2	-91.2	-19.4
	W8FJ	-115.1	-72.5	-90.8	-18.3	-98.0	-25.5
	S59A	-117.0	-95.0	NIL	N/A	NIL	N/A
0430z	CT1JLZ	-117.4	-85.5	-101.8	-16.3	NIL	N/A
	ES5QX	-118.0	-106.9	NIL	N/A	NIL	N/A
	G3SED	-116.5	-88.5	-98.6	-10.1	-112.4	-23.9
	SM6CLU	-121.6	-105.5	NIL	N/A	NIL	N/A
1100z	HK1X	-121.6	-117	NIL	N/A	NIL	N/A
	HC5WW	-121.6	-114.7	NIL	N/A	NIL	N/A
	JA8ISU	-126.1	-100.2	-111.6	-11.4	NIL	N/A
1240z	UA0ZL	126.6	-112.4	NIL	N/A	NIL	N/A