Comparison of Vertical Arrays For Low Band Receiving

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Abstract

Accurately assessing the real-world performance of an antenna, especially phased vertical arrays designed for weak signal reception in the 160-meter band, is quite challenging. The large area footprint required to erect these types of arrays is beyond what most radio amateurs have available, and installing multiple designs of vertical arrays in one location is, for the most part, prohibitive. Geographical differences in propagation also prohibits antenna comparison unless the antennas are erected at the same location.

Modeling software is now a common tool at many amateur radio stations. It is relatively easy to acquire a working knowledge of the software that will allow an individual to make improvements to a particular design and immediately view the simulated result. Creating a model and running a performance simulation will do only that; provide a simulation of expected results. Verification of a simulation from an antenna model requires evaluation against empirical data that is often beyond the capability of most radio amateurs.

The conclusions in this paper are the result of evaluating ten years of empirical data against modeling simulations that will aid in the development of a technical foundation to assist radio amateurs in assessing their low band receive options.

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1.0 Introduction

For over 25 years I have been passionately driven to improve my 160-meter receive capability. I continually strive to gain whatever advantage I can to increase the desired signal and reduce extraneous noise in order to hear DX stations.

I have acquired considerable experience with short vertical arrays over the past 17 years while also working to a lesser extent with receiving loops, Beverages, and Beverage arrays. In March, 2008 Bob McGuire, N4HY, told me about a vertical array system he had conducted extensive design evaluation and modeling on and was anxious to see it put into service. Prior to this time no information was available or could be found in a public forum about short verticals for low band receiving. At Bob's urging I constructed, and placed into service, a broad side-end fire (BSEF) 8 vertical array for 160 meters in the fall of 2008 based on this design. The details of that project were thoroughly documented in a paper published on my website in July 2009[1] and later published in QEX[2]. A revised Second Edition of the paper was published in March 2017[3] following input from Frank Donovan, W3LPL, based on his construction and experience with the design. The array provided stellar performance over anything I had previously used, including Beverage arrays, and inspired me to make significant improvements to my Beverage system but the vertical array continually outperformed all of my receive antennas.

Shortly after this time a design by Lee Strahan, K7TJR, of HiZ antenna systems was becoming popular with a few low band enthusiasts and excellent performance results were received. Could this suggest a system superior to the BSEF-8 array was now available? My passion for continuous improvement of my low band receive capability drove me to purchase a HiZ-8 system in the fall of 2014 with the objective of comparing it to the BSEF-8 array.

When I began evaluating the HiZ-8 system a unique 9 element design by John Kaufmann, W1FV (SK), was published in a 2-part series in NCJ, the National Contest Journal[4]. The Yankee Clipper Contest Club (YCCC) produced kits for this array consisting of circuit boards and components for the amplifiers and phasing/switching unit and the array became affectionately known as the "YCCC-9". I purchased and constructed a YCCC-9 kit in 2016 to expand my vertical array arsenal and include it in my comparative tests.

The objective in pursuing this research is to have the three vertical array systems erected at my location, in addition to Beverage's, to achieve an as near perfect "A-B" test possible and not rely on comparative readings from another station some distance away. This also presents an opportunity to compare actual results to the modeling data for each array.

This paper highlights the difference in theoretical design of the arrays and provides a performance comparison based on empirical results recorded over a ten-year period, effectively covering one solar cycle. While the focus of this research is on the 160-meter band, each of the arrays evaluated can also be configured for operation in the 80- and 40-meter bands.

2.0 Geographical Differences Related to Antenna Comparisons

Low band receive antennas cannot be properly evaluated without taking into consideration geographical differences. It is imperative that this point be understood! The propagation

[1] References appear on page 20

for a station located on the east or west coast to areas such as Europe/Africa or Japan/southeast Asia will be much different than those for a station located in the middle-United States.

Comparing one antenna in a location 1,000 miles away on the east coast with a similar antenna located in rural Arkansas will not give an accurate comparison. The exact same antenna may actually perform differently in these two locations for a variety of reasons.

I have used three stations for propagation comparison to my location over several years. W0FLS in Iowa is 425 miles north at 344°, W5UN in northeast Texas is 200 miles SW at 235°, and K5RK in south Texas is 450 miles S/SW at 205°. The propagation differences of what we each can and cannot hear is at times significant! Even close to home K5UR is 25 miles southwest, WD5R is 20 miles north/northwest, and K5EJ is 25 miles north. We compare notes frequently and the difference between signal-to-noise ratios for the four of us this close is sometimes eye opening.

160-meter propagation is beyond the scope of this paper although I encourage you to read the excellent work by Carl Luetzelschwab, K9LA[5], and Frank Donovan, W3LPL, on this topic. You must understand an effective low band receive antenna will NOT change propagation for you to magically hear stations that never existed before! What it will do is provide a very low noise input to your receiver so when propagation supports a specific path you will be able to hear weak DX stations that were previously buried under the noise.

3.0 <u>Design Differences in Vertical Arrays</u>

Even though the BSEF-8 and HiZ-8 arrays utilize 8 verticals arranged in a circle they are not the same. Even the YCCC-9, although similar, is very different. The differences are very often misunderstood by radio amateurs. Each array uses specific element spacing, different phasing/delay schemes, and a different impedance at the element feed point to achieve optimum results for the selected frequency band. A radio amateur advised me at Dayton one year he was in the process of constructing an 8 vertical circle array. When I asked him which one he replied "the one with 9 elements"! Thus, the need to explain the difference in vertical arrays.

3.1 Broad Side/End Fire 8 Element Array (BSEF-8)

The original BSEF-8 array is a passive array designed to have a low input impedance of 75Ω that results from intentional radial system losses and a resistive matching network.

This array is comprised of 8 vertical elements placed in a 350 ft diameter circle with only four of the 8 verticals used for each direction to phase a broad side pair of end fire verticals. The elements are 25 ft long made with 1.25" aluminum tubing with four 25 ft top hat wires that extend out to approximately 25 ft from the base of the element. The element is self-resonant around 3.9 MHz and requires some inductance at the base to bring the resonant frequency down to 1.825 MHz. A resistor is used at the feedpoint to adjust the impedance to 75Ω. Since the feed point impedance is low, ground variations will impact the feed point impedance. Approximately eight radials ~65 ft in length are required to stabilize the impedance at each vertical. No active components are used. This array exhibits excellent gain so a preamplifier should not be required, even with a very long feedline.

Figure 1 depicts the physical layout of the array and Figure 2 reveals N4HY's modeling results.

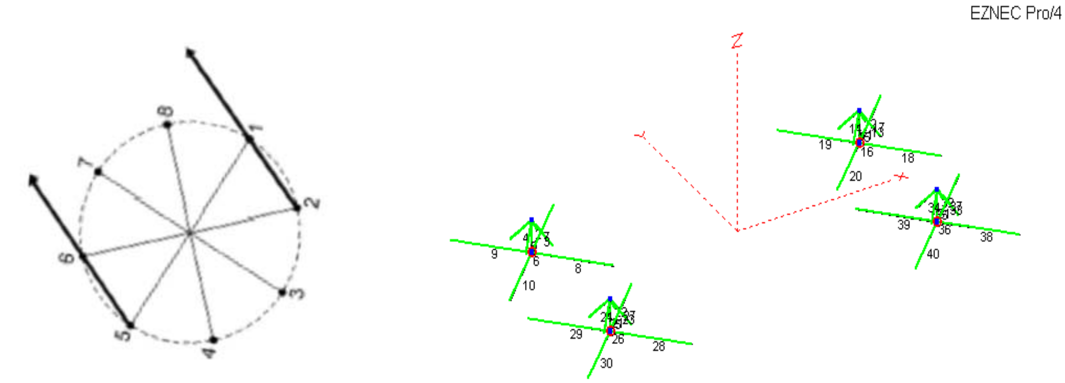


Figure 1 – Physical layout of the BSEF-8 Array

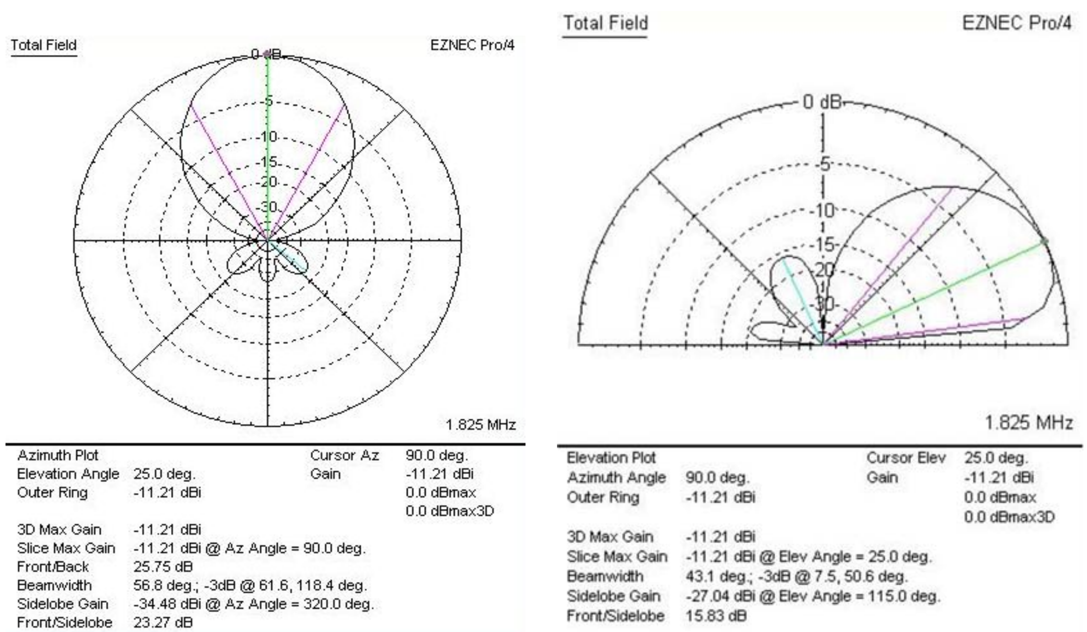


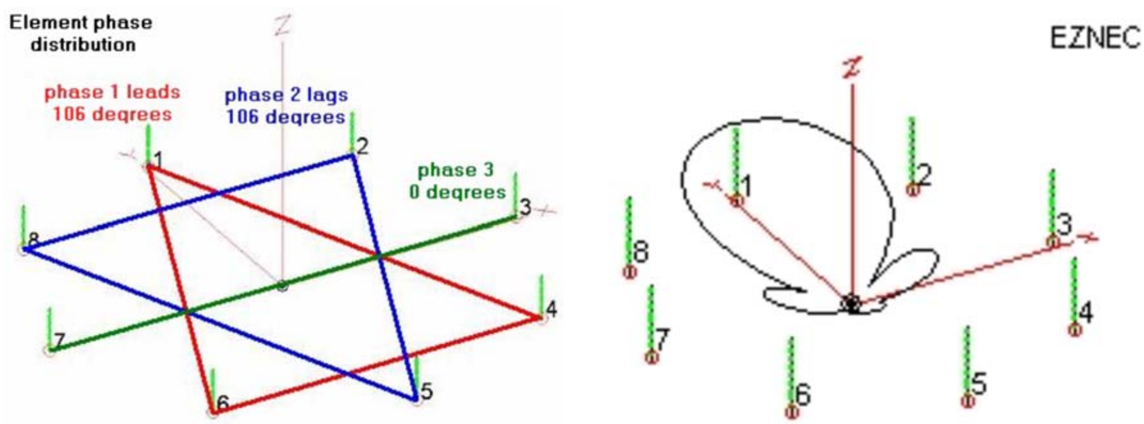
Figure 2 - N4HY Modeling Data for the BSEF-8 Array

An active high impedance version of the BSEF-8 array is also available commercially[6]. This review and comparison will only address the passive array originally built at W5ZN although both versions should have equivalent performance results. A phasing/switch package is also commercially available for this array[7].

N4HY's modeling indicates the BSEF-8 array will have an RDF of 13.0 dB, a front to back ratio (F/B) of 26 dB, and a 52-degree beamwidth.

3.2 The HiZ-8 Vertical Array

The HiZ-8 array is an active array designed by Lee Strahan, K7TJR. It consists of 8 vertical elements in a 200 ft diameter circle. The elements are 24 ft long based on a HiZ specification. Each element is assembled with four 6 ft lengths of aluminum tubing of one each 0.875", 0.750", 0,625", and 0.500" outside diameter. Each smaller diameter is inserted into the larger diameter slit end by four inches and secured with a stainless-steel hose clamp. No top hat or radial wires are required for this design. A high impedance amplifier is placed at the base of each element and connected via 75Ω RG-6 coaxial cable to the phasing unit in the center of the array. All 8 verticals are active for any one direction with three elements in phase 1 leading by 106 degrees, three elements in phase 2 lagging by 106 degrees, and 2 elements at 0 degrees as shown below in Figure 3:



Courtesy HiZ Antennas (hizantennas.com)

Figure 3 – Physical Layout and Phasing Scheme of the HiZ-8 Array

Modeling data indicates the HiZ-8 array produces an excellent pattern with an RDF of 13.45 dB and an F/B greater than 30 dB in a 52-degree beamwidth as shown in Figure 4.

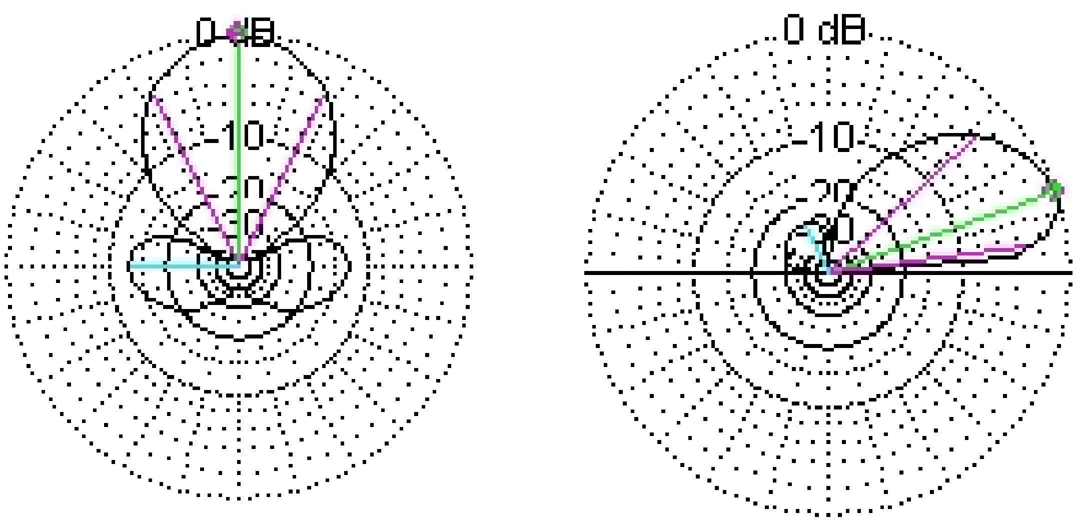


Figure 4 – Modeling Results from HiZ Antennas for the HiZ-8 160 Array

3.3 The YCCC-9 Nine Element Vertical Array

The YCCC-9 is an active array designed by John Kaufmann, W1FV (SK). Eight elements are arranged around the perimeter of a circle and a ninth element is placed at the center to produce a 3 element in-line configuration. The system uses a phase delay beginning at the forward element of 0°, -200°, and -40° so only three of the 9 elements are active for any one direction. A high impedance amplifier is placed at the base of each element and connected to the combiner via 75Ω RG-6 coaxial cable. I use 20 ft vertical elements with a spacing of 60 ft, making the entire circle 120 ft. diameter.

The kits for this array were commercially available until the original supply was depleted. The array remained popular and Steve Babcock, VE6WZ, produced an excellent series of YouTube videos[8] detailing his experience redesigning the amplifier and combiner circuit boards along with his construction experiences. Steve has made his most excellent work publicly available, free of charge, for anyone desiring to obtain circuit boards and components to construct a YCCC-9 array. The VE6WZ series of YouTube videos are very informative and practical, providing instruction worthy of viewing by not only new radio amateurs, but seasoned operators as well. I have gained a good bit of practical knowledge from Steve's videos.

The physical layout of the YCCC-9 is shown in Figure 5. Modeling data indicates an RDF of 12.1 dB, an F/B greater than 20 dB in a 75-degree beamwidth shown in Figure 6.

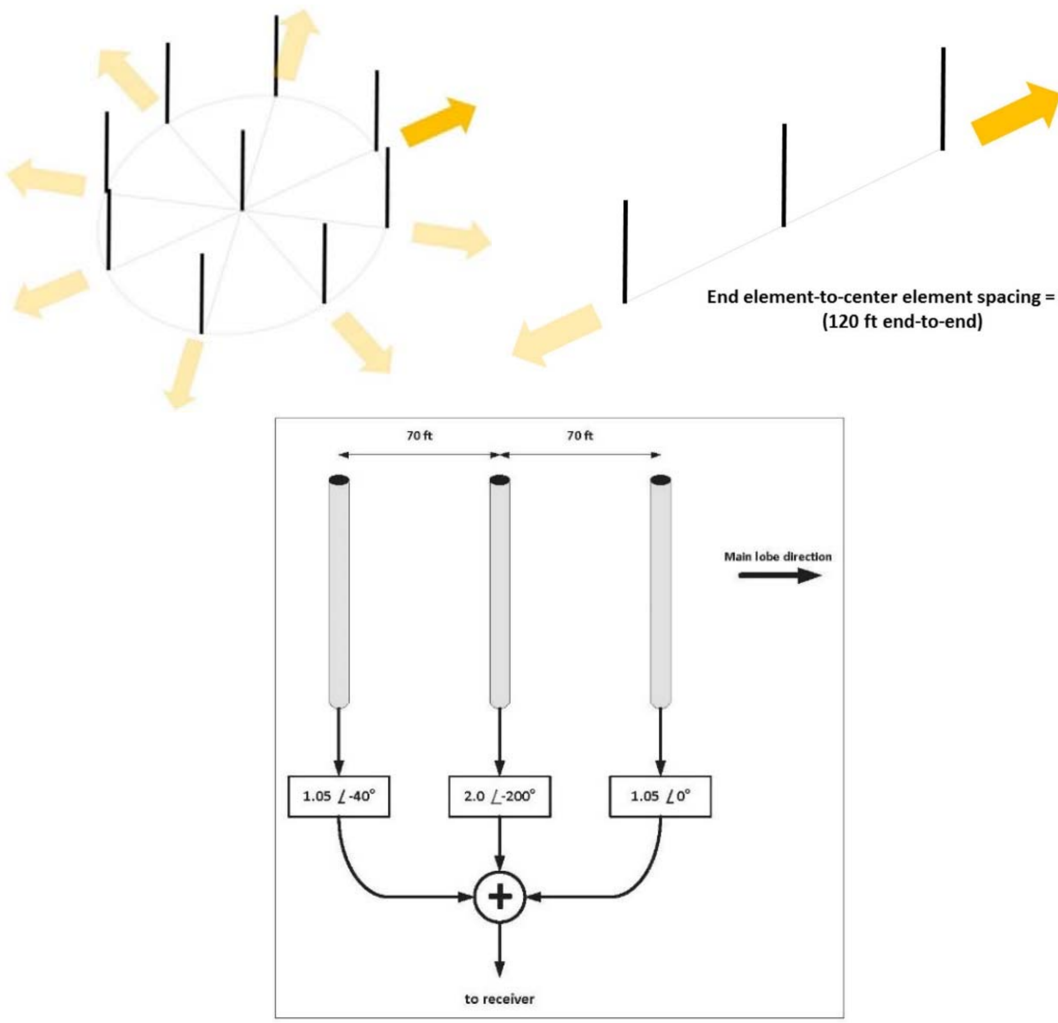


Figure 5 – YCCC-9 Physical Layout and Delay Scheme

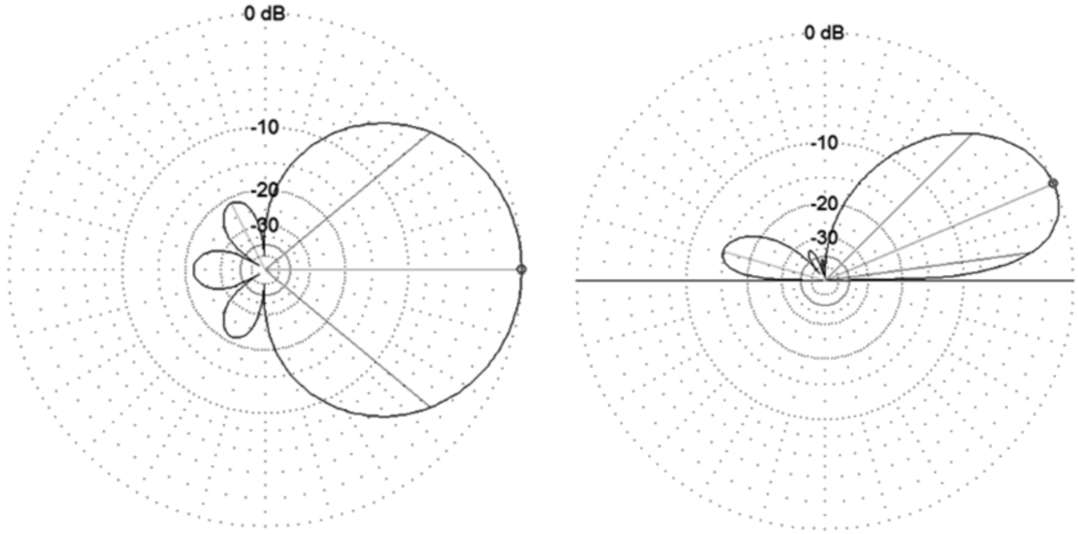


Figure 6 - W1FV YCCC-9 Modeling Results

3.4 Other Designs

Several different vertical array designs have been offered commercially, including short 4-square arrays, those with 3-elements in a triangle configuration, and many others. The time and effort required to construct every conceivable option in addition to the short low band season available each year to acquire empirical data for each design exceeds the authors available resources. The results presented in this paper focuses on the most popular designs and the empirical results compared to the modeling data could be used to extrapolate modeling data to what is achievable with different configurations.

The pros and cons of each array described in this paper are contained in Table 1 on Page 21. When constructing vertical arrays and elements, it is important to fabricate the components exactly to the design or the results may be different. Some construction notes are included in Appendix A of this paper.

4.0 <u>The Benchmark Beverage Antenna</u>

Since its introduction in 1921, the Beverage[9] antenna has rightfully become the standard by which all low band receive antenna performance is evaluated against. A plethora of papers, articles, and online content has been published about the Beverage. "The Beverage Antenna Handbook"[10] by Victor Misek, W1WCR, first published in 1977, provided informed guidance to radio amateurs for many years before "Low Band DX'ing"[11] by John Devoldere, ON4UN was published and now regarded as the go to source for Beverage antenna instruction. Greg Ordy, W8WWV, provided extensive details on Beverage antennas of different lengths in his paper "The Benchmark Beverage"[12]. In the document, Ordy states "For me, the Beverage represents a yardstick which can be used to compare the performance of other receive antennas". For decades new or revised receive antenna designs, including new versions of the Beverage in phased configurations, were all compared to the original single wire Beverage and vertical arrays are no different. To establish a performance base, a single wire 580 ft Beverage is included in my comparative analysis results.

5.0 Locating the Arrays

The performance of active vertical arrays can be affected when installed close to metallic objects such as fences, buildings, or other resonant antennas. The HiZ documentation recommends a minimum clear zone of 10 ft from any element and the YCCC-9 design recommendation is 50 to 75 ft from each side. To avoid any performance degradation from nearby objects, all of the vertical arrays in this study are located in an open field.

The BSEF-8 array is still in the original location where it was constructed in 2008, approximately 800 ft south of the shack. To ensure adequate separation between the arrays, the HiZ-8 array is in an open field 750 ft east of the shack, approximately 700 ft northeast from the BSEF-8 array. The YCCC-9 array is 500 ft E-NE of the shack and 250 ft from the HiZ-8 array. The 160-meter transmit antenna is 300 ft northwest of the BSEF-8 array and over 1000 ft from the HiZ-8 and YCCC-9 arrays. While the separation is sufficient to eliminate any interaction between the arrays, there could be a very slight spatial affect when comparing receive signals however, it was determined to not be a factor in the documented results.

I am fortunate to be able to locate my arrays in an open field although it would be informative to compare performance between arrays where one is located in a compromised location. Stan Stockton, K5GO, has a YCCC-9 installed at his ZF9CW Cayman Brac contest station. He does not have enough area to support a Beverage or large vertical array so the YCCC-9 is a logical choice. It is however, located in an area with heavy brush with a pool of water inside the circle perimeter. Stan has spent a considerable amount of time optimizing the array in this environment and seems to obtain acceptable results although no baseline is available to compare the performance to an array located in an open area.

The layout of the receive antennas at W5ZN is shown in Figure 7.

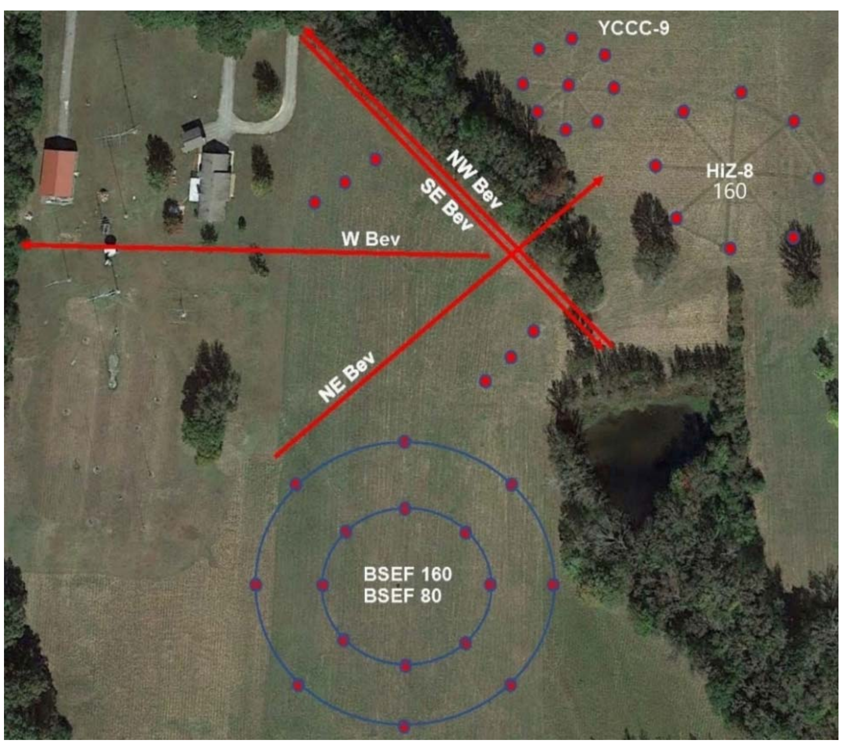


Figure 7 - W5ZN Receive Antenna Layout

6.0 Test Parameter Design

The objective for collecting empirical test data, after evaluating the similarities and differences in the modeling data, is to determine if those differences would present a real-world variation that could be identified in day-to-day operation on 160 meters. A limited amount of initial data had already proven the BSEF-8 array to be superior to any Beverage or loop antenna at my location. Based on modeling data the HiZ-8 and YCCC-9 should also outperform a Beverage however, no empirical data was available to support a conclusion or how these two designs would compare to the BSEF-8.

6.1 Test Equipment

Test equipment is comprised of two each of the following:

- Elecraft K3 Transceiver
- LP-PAN 2 Software Defined IQ Panadapter
- NaP3 Panadapter display software
- K9AY RAS-8 Receive Antenna Switch

The system test components and layout are shown in Figure 8. The IF output from each K3 is connected to an LP-PAN 2 SDIQ panadapter unit. The LP-PAN 2 output is connected to a computer via a USB port that drives the NaP3 panadapter display software.

The receive antennas are routed to each receiver through a K9AY RAS-8 receive antenna switch that provides for two receivers to be connected to the same, or different, antenna when activated by a push button control for each of the two receiver output ports. The RAS-8 is shown in Figure 9.

The signal level data is recorded manually then entered into an Excel spreadsheet to produce simple graphs for comparative purposes.

6.2 Calibration

The test equipment must be calibrated. An Elecraft XG-3 Signal Source[13] is used to establish and maintain a calibrated display on the NaP3 panadapter. Prior to the start of each series of measurements, a -73 dBm signal (S9) is injected into the signal cable at the array end to verify calibration. Given the approximate distance of 800 ft from each array to the equipment, RG-11 75Ω coax is used for the signal cable. The measured loss is 2.0 dB and verified daily prior to measurements. Having two outputs from the RAS-8 adds an additional 2.5 dB of loss, so the -73 dBm signal injected at the combiner output of the array is now -77.5 dBm on the panadapter screen. This is verified during the calibration procedure and before data collection.

The objective is to collect actual on-the-air data of signal to noise levels and determine if any difference in antenna performance could be detected, eliminating any known variables in the measurement procedure.

Figure 8 – Test System Components

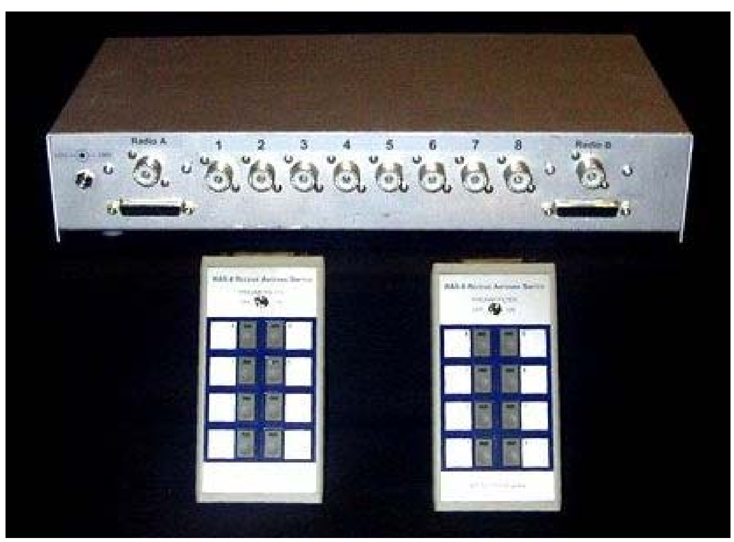


Figure 9 – K9AY RAS-8 Receive Antenna Switch

7.0 Signal Measurement & Comparisons

Comparing arrays requires documenting several different types of data. These include the level of the noise floor as well as the forward peak, front to back (F/B), and front to side (F/S) signal levels in each of the 8 directions. For these measurements the panadapter display must be capable of 1 dB resolution for measurement accuracy. This cannot be performed with a radio's S meter!

During data recording you must also consider the physical separation of the antenna arrays and any spatial effect on signals that may briefly occur. Observing signal differences over time will permit accurate data to be acquired.

The empirical data for this research was collected over a period of ten years. The forward peak signal data was recorded from over 100 DX stations outside the USA. A few of these were the same station but acquired during a different time of day, time of year, or time during the solar cycle. Since most all of the DX signals were too weak to document signal amplitude in antenna directions other than a direct path, data from approximately 30 stations in the USA was collected for pattern comparison to the model. This was conducted with the understanding that the USA stations will present a variety of different signal arrival angles originating from different transmit antenna configurations however, the results are accurate and valid.

All of the signal levels were recorded in CW mode with a 400 Hz bandwidth during or near dark time hours without noise blanking or noise reduction activated.

An example of the recorded data from each station is shown in Table 2 on page 22.

7.1 Noise Floor Measurements

Comparing the measurement of each array's noise floor must take into consideration whether it is an active or passive system. Additionally, any preamplifiers placed in the system will affect the noise floor of the array. For the two 8 vertical arrays no preamp is used on the output of the phasing unit. The design of the BSEF-8 and HiZ-8 arrays have sufficient gain and the noise floor in the shack, through 800 ft of coaxial feedline and the RAS-8 switch, averages -120 dBm. This is 12 dB higher than the receiver's noise floor measured with a 50Ω termination connected to the antenna input, and indicates plenty of array gain. The output of the YCCC-9 is low so I do have a preamp at the output of the phasing unit as recommended in the YCCC documentation. Through 500 ft of coaxial feedline and the RAS-8 switch the noise floor is -125 dBm, 5 dB less than the two 8 vertical arrays but very adequate for comparative measurements. My four Beverage antennas have a -125 dBm noise floor.

The noise floor was measured and documented in each of 8 directions in 45-degree steps from north, rotating clockwise to northwest. I've spent many days and weeks working with my local electric utility to eliminate power line noise and at least for now my location is as quiet as possible and consistent in all directions. What is out of my control are noise sources from consumer products originating from neighboring houses. While these are annoying at times, if not overly restrictive they can be used as comparison signals! My only noise source at the time of this writing is a weak electric fence "popping" at approximately 900 millisecond intervals at ~20° azimuth. It is very tolerable and nice to use as a directional test for the arrays. If needed, the noise blanker completely removes it with no adverse effect.

7.2 Forward Peak Signal Amplitude

The forward peak signal amplitude is simply the strength of the received signal in the forward (direct) path to the originating station. There were a couple of exceptions to this, when a station presented a maximum signal from a skewed or longer path along the gray line. The level is recorded in dBm and also referenced to the noise floor. For example, if I record a peak signal at -120 dBm with a -125 dBm noise floor, The signal is 5 dB above the noise floor. This is a very nice DX signal on 160 meters in Arkansas!

Some of the DX stations recorded in the data include 3B7A, 3B9HA, 3C0W, 3DA0IJ, 3V8SF, 3XY1T, 3X5A, 4W8X, 5U5R, 5V7D, 5W0UU, 5X3C, 7X7X, 7O2WX, 7Z1SJ, 9J2LA, 9K2HN, 9L5A, 9M0W, A35T, BD4WN, BU2AQ, C31CT, CB0ZA, CY9C, DU7ET, E51DWC, E77DX, ET7L, FT4JA, HL5IVL, JD1BMH, K5P, KH6AT, KL7J, OD5NJ, RA0FF, ST2AR, TF3SG, TL8TT, TU7C, V63DX, VE9AA, VK2WF, VK6HD, VP8SGI, VP8STI, XV1X, ZD8W, ZF9CW, and ZL1AZ.

The following results are peak signal levels above the noise floor for each array. As noted in Section 7.1 the noise floor for the BSEF-8 and HiZ-8 array is the same but the YCCC array's noise floor is 5 dB lower, the same for the Beverages. When a peak signal is identified as being lower on one array versus another it is based on the level above the noise floor. For example, even though the YCCC-9 noise floor is 5 dB lower than the BSEF-8 and HiZ-8, a signal 2 dB above the noise floor is considered the same as a 2 dB signal above the noise floor on the others. I did experiment, to a limited extent, with adding some external preamplification gain to bring the noise floor of the YCCC-9 and Beverage antennas up to the same -120 dBm level of the BSEF-8 and HiZ-8. This did not, in any of the situations investigated, increase the peak signal to a greater level above the noise floor than originally documented.

The forward peak results reveal the HiZ-8 array provided a 1 to 2 dB increase over the BSEF-8 array on some signals while at other times the BSEF-8 would outperform the HiZ-8 by the same difference. Often while monitoring the same station over a period of time this result would be reversed. There was no consistent difference between the two arrays in forward peak signal. If I were only using one of the arrays for receive, I would not have been prevented from hearing, and working, the DX station.

The forward peak signal received with the YCCC-9 was consistently 2 to 3 dB lower than either of the 8 vertical arrays. Remember from Section 3.3 the spacing between my YCCC-9 elements is 60 ft, not 70 ft as originally specified in the NCJ published design for 160-meters however, W1FV (SK) notes in the YCCC-9 User's Manual that the difference provides improved performance on 80 meters with virtually no degradation on 160 meters. My results assume this to be a true statement and therefore the lower forward signal levels are accurate.

The forward peak signal on the 580 ft Beverage antennas was consistently 3 dB lower than the BSEF-8 and HiZ-8 arrays and a minimum of 1 dB lower than the YCCC-9. Also, there were times when the vertical arrays recovered more quickly from deep fades than the Beverage. This was not due to the increased gain or signal level of the vertical arrays over the Beverage because at times the vertical array signal would reappear out of the noise at a high enough amplitude that the Beverage should have revealed the signal.

The results from 36 different station's peak signal measurement are displayed in a simple line graph in Figure 10. While this is not an exhaustive list containing data points from all 130 stations, it accurately represents the forward gain results.

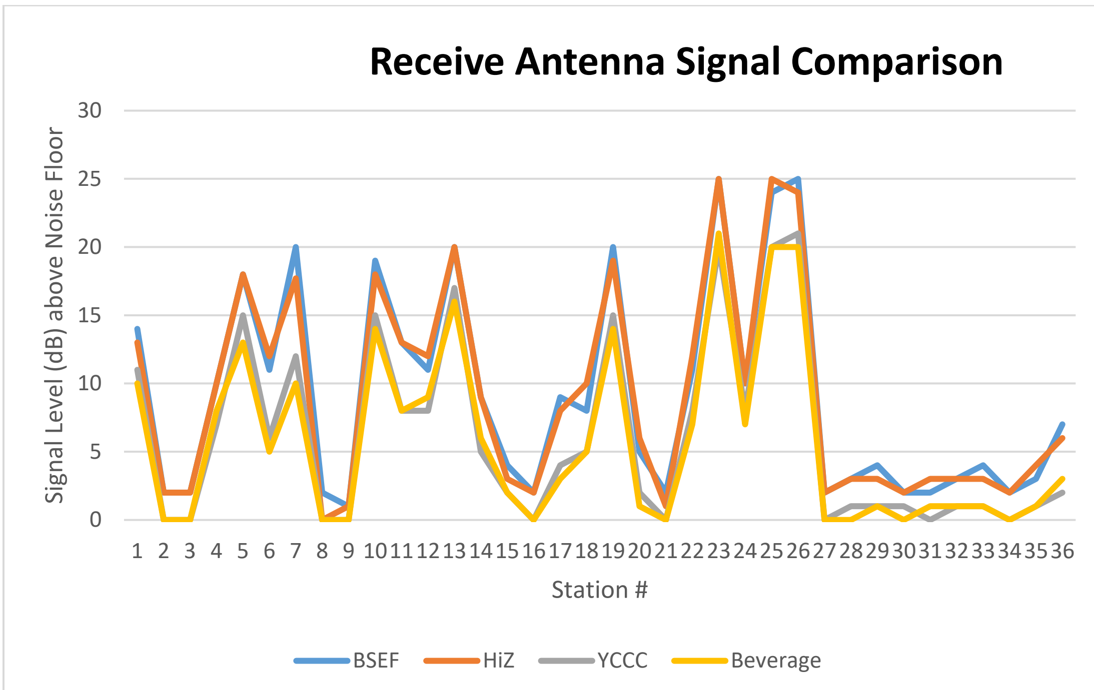


Figure 10 – Forward Peak Signal Levels from 36 Stations in this Study

7.3 Front to Back & Front to Side Comparisons

The HiZ-8 exhibited a solid 25 to 30 dB F/B repeatedly when comparing multiple signals. If a signal could be placed exactly in a side or rear null, reductions greater than 30 dB were easily achieved.

The BSEF-8 array exhibited an F/B of between 20 to 25 dB. Some of the side nulls were 2 to 3 dB better than the HiZ-8 however, when rotating away from the main lobe beginning 45° from the peak clockwise to the point 45° just prior to returning to the forward direction the HiZ-8 provided a much sharper pattern and better overall rejection. Even though the BSEF-8 had a few instances of better side lobe performance, I was unable to obtain a reduction more than 25 dB at any point.

The YCCC-9 F/B is exceptional and in line with the HiZ-8 at 25 to 30 dB. Given the design uses three in line verticals that should afford a significant F/B, this was expected.

It does not however, provide the F/S rejection seen with either the HiZ-8 or the BSEF-8. This is also expected given the broad forward pattern isn't as sharp as the other two vertical arrays.

The 580 ft Beverage averaged ~18 dB F/B and an F/S equivalent to that of the YCCC-9.

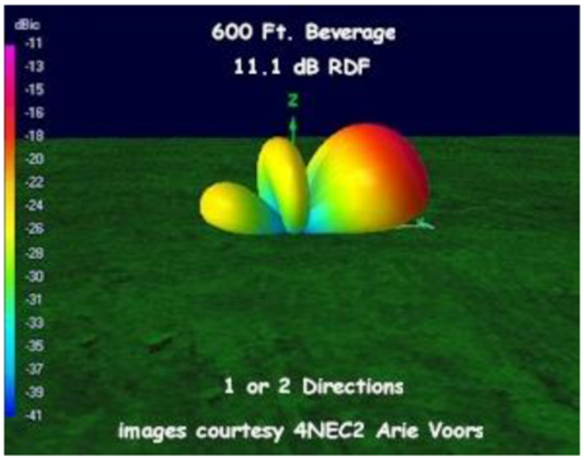
When considering F/B and F/S levels, it is important to note that 20 dB represents a significant reduction in undesired signals. I receive questions occasionally about array performance from radio amateurs confused that their receive antenna isn't performing up to expectation. Many times, people will look at the huge forward lobe of a model result and the significantly reduced rear or side lobe and wonder why a station can still be heard off the back or side of the array. The confusion is usually relieved with a discussion about signal levels. Appendix B of this paper has a brief explanation for those interested.

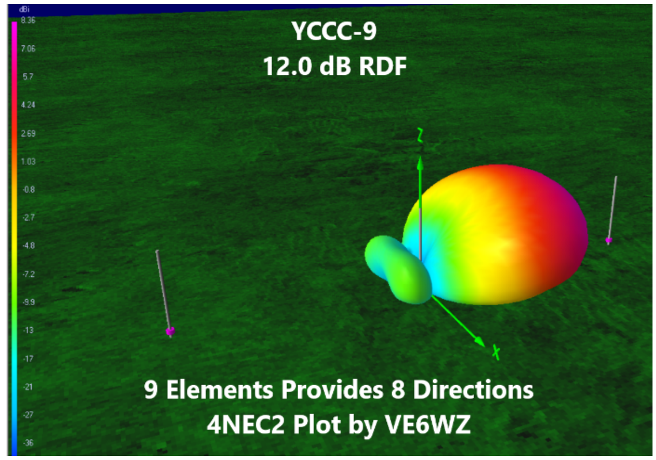
8.0 Modeling Versus Actual Field Measurements

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 one of the standards for evaluating low band receive antennas. This is described in detail in Ref. 11, page 5-11 section 2.10.2, and page 7-10, section 1.10. Some of the early work in defining RDF is documented by Bill Hohnstein, K0HA. Bill had initiated several threads on the Top Band Reflector that became the groundwork for RDF. An in-depth discussion of RDF is not germane to this paper however, I encourage you to review this early work contained in the top band reflector archives. The links have been included in the reference section[14].

Equating F/B and F/S to modeling data can be difficult in a simple test environment due to multiple factors that include arrival angle of the desired signal, arrival angle of undesired signals, the characteristics of noise generated conditions, as well as construction of the array components in relation to the design.

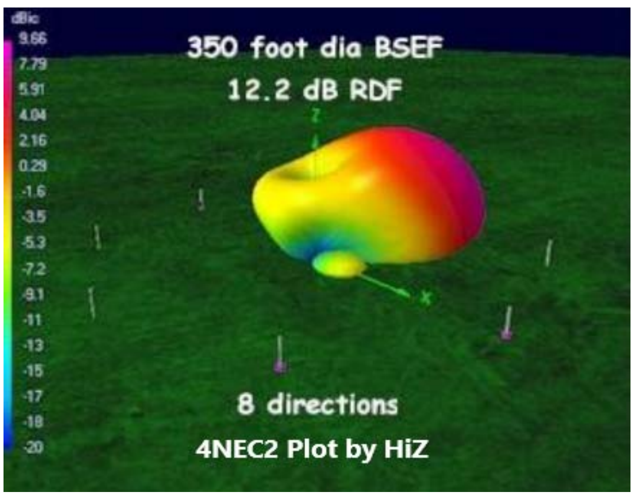
All of the documented data was compared to the 3-dimensional 4NEC2 plots shown in Figure 11. Maximum rejection off the back and side of an array will only be achieved if the arrival angle of an undesired signal appears in the deepest position of the null. Most noise sources will have a direct azimuth location but may also be present over a wide range of areas surrounding the antenna's pattern in both azimuth and elevation, thus the importance of considering RDF.

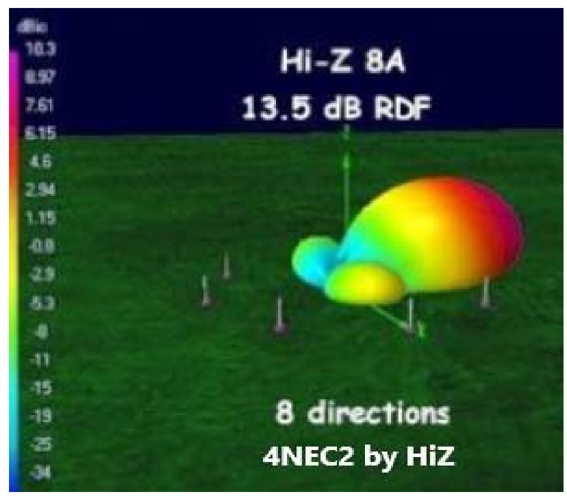




F/B = 20 dB
RDF ~10 dB See Note 1
3 dB BW = 75°

F/B = 20 dB
RDF 12.1 dB confirmed See Note 1
3 dB BW = 75°





F/B = 21 dB
RDF 12.2 dB confirmed See Note 1
3 dB BW = 50°

F/B = >30 dB
RDF 13.45 dB confirmed See Note 1
3 dB BW = 50°

Note 1 – RDF confirmation is based on comparative signal analysis from eight azimuth directions for each array per station documented

Figure 11 – 3 Dimensional plots for Each Array

The HiZ-8's 4NEC2 pattern clearly indicates the sharpest overall pattern of all the antennas and the empirical data confirms this.

The BSEF-8 pattern is interesting. At first glance I didn't believe the rear pattern as it didn't seem to agree with N4HY's EZNEC plot shown in Figure 2. I spent some time assessing this and concluded the 3-D pattern represents the total area of the rear and side lobes seen at approximately 55° elevation in the EZNEC plot that is only 15 dB below the forward lobe. This is further supported by a review of the 3-D rear pattern showing the amplitude reducing as it approaches 0° from the ~55° major lobe and then a second, lower amplitude rear lobe is present around 12° in the EZNEC pattern. The 4NEC2 result still indicates an RDF of 12.2 dB so the empirical data must be evaluated to determine any impact on signal reception. Based on the data, the high rear lobe of the BSEF-8 array is not a factor in identifying signals in the forward direction, and did not reveal an impact on F/B signal rejection. However, with this major rear lobe at ~55° the documented signals arriving at the rear of the array should have had a lower arrival angle and fall into the more reduced area of the pattern. The affect that will be realized is noise or other extraneous sources off the back of the array from the desired direction that will have a broad pattern in relation to arrival angle and fall within the major rear lobe with the least F/B reduction.

The empirical data for the YCCC-9 and Beverages correlate well with the 4NEC2 patterns. In Section 7.2 I noted the spacing between YCCC-9 elements is 60 ft, not 70 ft as originally specified in the NCJ published design for 160-meters. A note in the YCCC-9 User's Manual stated the difference provides improved performance on 80 meters with virtually no degradation on 160 meters. K5GO conducted an extensive modeling evaluation of the YCCC-9 with different spacing and determined 70 ft spacing only has a 0.07 dB improvement in RDF over 60 ft spacing on 160 meters. The specific result is 12.20 dB RDF versus 12.13 dB. You would never be able to detect this difference in reality!

Over the ten-year data collection period, various noise sources would appear from time to time. These included the ever-troublesome power line noise and minor sources from neighboring houses, but a particularly annoying noise appeared one year directly to the east. At first, I thought it was originating from power lines as the east direction is perpendicular to the power lines that run north and south along the highway ¼ mile away. The noise was only present on 160 meters and was a continuous, unmodulated white noise 20 dB above the noise floor eliminating any weak signal reception toward Africa. Following extensive tracking, the source was identified to be originating from one of two houses just over ¼ mile away and emitted from an errant consumer device or a grow light! I resisted the urge to knock on doors, hoping it would disappear but it persisted for two years. Then, one day it was gone and hasn't returned!

The purpose in mentioning this is to offer further empirical data related to the 3-D pattern of the arrays. The array closest to this noise source was the HiZ-8, ~850 ft away. With the array to the east, directly toward the source, the noise was 20 dB above the normal noise floor. When switching 45° to either northeast or southeast the noise was just barely detectable at the noise floor and not a factor in signal reception. DX stations from Europe were easily received without any negative impact from the noise source. The BSEF-8 array was further away, ~1100 ft from the source. When the array was to the east, the forward signal was equivalent to the HiZ-8 level however, when switching 45° to the northeast or southeast the source was still ~2 dB above the noise floor. The YCCC-9 forward signal level was equivalent to the HiZ-8 and BSEF-8 but only reduced the noise 16 dB in each of the adjacent 45° positions. This confirms the HiZ-8 has a sharper forward lobe that reduces earlier in the pattern when moving toward the maximum side null. The higher noise source signal on the YCCC-9 at the off axis 45° angles is simply due to the wider 3 dB points of the main lobe for this array.

I do not have a Beverage antenna oriented to the east, so a comparison to the direct forward signal level is not possible however, the noise source was detectable on the NE and SE Beverage approximately 3 dB above the noise floor.

9.0 DX Contest Performance

Detailed data was not collected during contest activity although the arrays have been evaluated in the major DX contests. Each array provided outstanding performance with a significant reduction in undesired signals and noise off the back and sides from areas other than the desired direction.

This has been noted by W3LPL near the east coast using the BSEF-8 array. Frank contends with a large geographical area full of signals off the back and sides while focusing on Europe. It is important to emphasize that, given the excellent pattern of these arrays, you will most likely not be able to hear Caribbean or South America stations calling you when focused on Europe during times when all of these areas are in darkness. This has been experienced at W3LPL and W5ZN.

10.0 Summary

Phased receiving arrays of short verticals provide superior performance over other low noise receiving antennas for 160 meters, including Beverages and loops. The low band receiving antenna appropriate for a specific location will depend on several factors, most importantly the available area for installation.

If this paper had been developed in a professional environment, we would engage a team of statistical analysts to process the data and develop multiple comparative charts based on an exploratory data analysis. These resources are not available for this work and the objective was to collect accurate data and provide simple but accurate results to permit radio amateurs to evaluate receiving arrays appropriate for their specific location.

The results are summarized below, ranked by performance at W5ZN in Arkansas.

10.1 HiZ-8 160

The empirical results for the HiZ-8 160 array constructed in a 200 ft diameter circle confirms the modeling data and it has consistently been the top performing array at W5ZN. The design produces the best overall pattern that is sharp and clean.

10.2 BSEF-8 160

The BSEF-8 160-meter array, configured in a 350 ft diameter circle, is a close second to the HiZ-8. The forward signal levels received were equivalent to the HiZ-8 however, the rear lobes do not provide an equivalent F/B or F/S as the HiZ-8 and as such does not produce the higher RDF seen with the HiZ-8. Regardless, this array is a top performer and ranked second in this evaluation.

10.3 YCCC-9

The YCCC-9 in a 120 ft diameter circle provides amazing results in forward signal level and F/B. The deeper real null, shown on the 4NEC2 plot, produced an improvement in F/B over the HiZ-8 and BSEF-8 with several of the documented signals. It does not, however, provide improved results in forward signal and F/S data compared to the previous two arrays. For the amount of space required, though, this array cannot be summarily dismissed and is a top performer. Additionally, in this spacing configuration and with the correct delay lines described in the construction details this array can also be used on the 80- and 40-meter band with outstanding performance. I have a BSEF-8 array for 80-meters and the YCCC-9 on most occasions is equivalent, or exceeds, the BSEF-8 80 performance. You only need three of the elements for any one direction so if you have 120 ft available in a desired direction say, toward Europe, then installing three of these elements will give you the same or better performance as a 580 ft Beverage in 20% of the required space! This array is also very easy to construct with full details available via the link in Ref. 8.

The array best suited for your location must be assessed and the criteria includes not only the area required but evaluation of the benefits and challenges that exist with each. These include, but are not necessarily limited to, those identified in Table 1.

On 160 meters, the HiZ-8 is the receive antenna used at W5ZN however, when conditions are marginal and extreme the HiZ-8 is used together with the BSEF-8 array in a diversity receive configuration with an Elecraft K4D (and previously with an Elecraft K3). This performance is nothing short of amazing and brings a signal just at the noise to a copyable level.

11.0 Future Evaluation Opportunities

The test described and performed for this work is simple, yet accurate. Technological advances in software and hardware components in recent years is currently being evaluated and used by industry professionals and radio amateurs who could build on the work conducted here. It is the authors desire that this can aid future confirmatory research efforts and possibly serve as a baseline for applying empirical data to modeled results.

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About the Author:

Joel Harrison, W5ZN was first licensed in 1972 as WN5IGF. He holds an Amateur Extra Class license and has acquired several operating awards. A passionate weak signal enthusiast, his work in this area on the bands from 1.8 MHz through 24 GHz has been documented in many publications, articles, and on-line content, some of which can be found on his website at https://www.w5zn.org. From 1988 to 2006 he served as a Director, Vice President, and First Vice President for ARRL, and as President from 2006 to 2010. He is currently Secretary for the International Amateur Radio Union. Professionally he worked for 38 years in the nuclear power industry and is regarded as a subject matter expert in ultrasound examination. Joel is currently a Research Analyst for the Pacific Northwest National Lab in the Nuclear Engineering and Analysis, National Security Directorate. He holds certification from the American Society for Nondestructive Testing as an NDE Level III and ASME qualifications from the Electric Power Research Institute for nuclear power plant inspections.

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https://ethw.org/Oral-History:Harold_H._Beverage

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11 - J. Devoldere, ON4UN, "Low Band DX'ing", Fifth Edition, ARRL 2010, ARRL – The National Association for Amateur Radio http://www.arrl.org

12 - W8WWV-The Benchmark Beverage, http://seed-solutions.com/gregordy/Amateur%20Radio/Experimentation/Beverage.htm

13 – Elecraft XG-3 https://elecraft.com/collections/test-equipment/products/xg3

14 - K0HA receive antenna figure of merit discussion links in Top Band Reflector archives:
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

Table 1

BSEF-8		HiZ-8A		YCCC-9	
Pro	Con	Pro	Con	Pro	Con
No expensive Electronics	Requires short radials to stabilize feedpoint impedance	No element tuning required	Requires 12 Vdc at phasing unit and at all ele amplifiers	No element tuning required No radials required	Requires 12 Vdc at phasing unit and at all amplifiers
Elements are easily tuned	Requires a large land area (~350' dia.)	No radials required	Requires expensive electronics	Requires smaller area than BSEF, HiZ or Beverage	Requires active electronic components
Can verify elements & switching unit is working with simple antenna analyzer	Elements require "top hat" wires	Requires smaller area than BSEF or Beverage	Components not repairable at home	Only need 3 elements for 2 direction	
Only need 4 elements for 2 directions	Requires additional posts for top hat wire support	Exceptional RDF and F/B pattern	Must utilize all 8 elements for any one direction	Performance equal to 580' Beverage	

Table 2

Typical Data Recorded for Each Station
(The results in this paper were expanded to include 8 data points around the azimuth)

Date	Call	Noise Floor dBM	Front dBm	Back dBm	F/B Ratio dBm	Side dBm	F/S Ratio dBm
SR 1245z	HL3IUA	-121.1	101.7	NIL	N/A	NIL	N/A
	W0FLS	120.4	-79.6	-97.2	-17.6		0.0
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
20-Nov-08	K8FC	-126.0	-90.6	-108.6	-18.0	-110.2	-19.6
0100z	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
	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	-12.4	NIL	N/A
	SV3RF	-117.4	-91.2	-115.7	-24.5	NIL	N/A
	G3PQA	-117.7	-93.9	-109.1	-15.2	NIL	N/A
	F6ELN	-119.0	-114.0	NIL	N/A	NIL	N/A
	K1LZ	-119.0	-81.5	-96.1	-14.6	-100.8	-19.3

Appendix A

Notes on Constructing Vertical Arrays

1. To obtain optimum results from any RX array it is mandatory that your focus be to assemble each vertical element the same, using the same element material and same size/diameter. Following a. through d. below and the photos in Steps 1 through 7 will provide for a clean, solid, and waterproof element joint:
   a. Use an anti-seize compound on aluminum tube joints. I prefer Jet-Lube SS-30
   b. Waterproof the joint. Water can cause long-term issue in tubing joints
   c. Tightly wrap the joint with Scotch 2228 rubber tape. Stretch it tight beginning on the larger diameter tube, progressing up and overlapping ½ the tape width per turn.
   d. Cover this with Scoth Super 33+ or Super 88 tape. Stretch it tight but don't wrinkle the turn. Overlap each turn by ½ of the tape width.
2. Amplifiers or matching networks must all be connected in the same manner
3. For low impedance verticals, tune each vertical to 1.825 MHz +/- 5 KHz
4. Signal cable to each vertical in the array must be the same. Do not use different types of RG-6 for feedline.
5. Waterproof all connections and electronic components. Moisture is your enemy! It will create noise in the system.
6. If possible, avoid using signal cables to provide 12Vdc to amplifiers
7. Once your array is in operation, measure and record the noise floor and F/B readings in each direction that the array is designed for. Any future change in these readings is a sign of possible component change or failure, or introduction of a new local noise source

Step 1

Step 2

Step 3

Step 4

Step 5

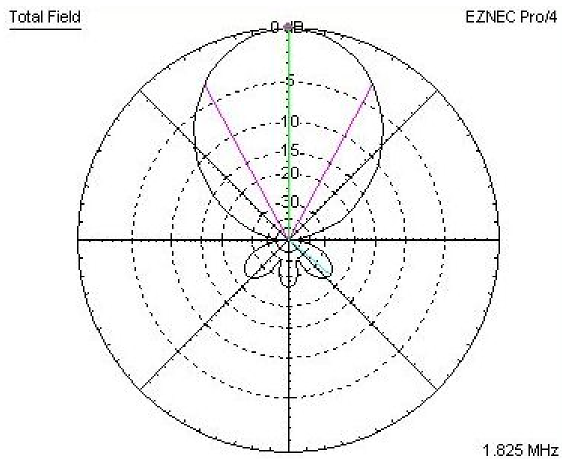
Step 6

Step 7

Appendix B

A Primer for Understanding Modeling & Signal Levels

Sometimes the correlation between objective reality and subjective expectation is clouded, especially when viewing antenna modeling plots. The appearance of a huge forward lobe and a virtually nonexistent rear lobe can produce a false belief that there will be no signals detectable off the back of an antenna. The modeling plot below is a good example.



It is imperative to pay attention to the signal level reduction of the rear lobe and understand how it will be presented by your receiver. Comparing the modeling data above to Table B1, assume you have a forward signal level of S9, which is -73 dBm. If the rear lobe produces a 30 dB reduction from the forward lobe, the -103 dBm result will be equivalent to S4 and very detectable. Even an almost unrealistic 40 dB rear lobe would provide a signal just slightly above S2.

Table B1
Signal Levels Related to S-Meter Readings

S-Meter	dBM	V	dBuV
S9 + 10 dB	-63 dBm	0.16 mV	44 dBµV
S9	-73 dBm	50 µV	34 dBµV
S8	-79 dBm	25 µV	28 dBµV
S7	-85 dBm	12.6 µV	22 dBµV
S6	-91 dBm	6.3 µV	16 dBµV
S5	-97 dBm	3.2 µV	10 dBµV
S4	-103 dBm	1.6 µV	4 dBµV
S3	-109 dBm	800 nV	-2 dBµV
S2	-115 dBm	400 nV	-8 dBµV
S1	-121 dBm	200 nV	-14 dBµ

Remembering these levels will provide a clear and objective understanding for you to evaluate antenna performance related to modeling data and what you may actually hear.

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