Modifying the 4-Square Array for Improved Front-to-Back Ratio

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Abstract

This article explains how to improve the front-to-back (F/B) ratio of the classic 4-square phased vertical array. While this modification adds another element to the antenna, the completed array fits into the same space as the original. Computer simulation indicates that this change increases average F/B ratio by nearly 20 dB, while reducing peak forward gain by less than 0.4 dBi.

Background

For many contesters, a 4-square array represents the state of the art in antennas for 160 meters, and often for 80 meters as well. Figure 1 shows a bird's-eye view of a 4-square with an AM broadcast-style ground screen. Each quarter-wave element utilizes a ground system comprising 60 radials with a maximum length of 0.25 wavelength — just under 65 feet at 3.79 MHz. Buried three inches deep, these radials are not allowed to overlap one another where they cross. Instead, they are truncated wherever they intersect, and are bonded to four buried "bus wires" oriented north, east, south and west on the drawing. In this configuration, the radial system for each monopole consists of approximately 3300 feet of wire, but all four elements actually share the entire ground screen because of the many interconnections the bus wires provide.

This array was modeled using EZNEC ver 4.0[1] with a double-precision calculating engine. In this simulation, all conductors were assumed to be #12 AWG copper and the antenna installed over average soil with a conductivity of 5 mS (millisiemens) per meter (or 5000 micromhos) and a dielectric constant of 13. When the monopoles are driven with equal-amplitude currents using a progressive 90° phase shift, the elevation plane pattern is as expected (see Figure 2). The peak forward gain is 6.04 dBi at a take-off angle of 23° with a F/B ratio of 18.17 dB in the elevation plane. As shown in Figure 3, the principal azimuthal plane pattern has a F/B ratio of 23.82 dB and a half-power beamwidth of 100.2°.

Improving Front-to-back Ratio

One way to increase the performance of this array would be to somehow shrink the undesired lobe of radiation at the back of the beam. This can be accomplished by converting the antenna into a pair of identical 3-element arrays that are perpendicular to one another. To do this, a fifth monopole is placed in the exact center of the existing "square." This additional element then becomes the center radiator of a 3-in-line array. Figure 4 depicts a plan view of the modified system, which includes the added radials for the new (fifth) monopole. In the computer model, I first removed about three feet from each of the four bus wires at the point where they intersected in the center of the array. This opened up a spot to install the new element. Next, I added 60 quarter-wave radials at the base of the fifth monopole, buried only two inches deep so they wouldn't touch the wires already present. Four of these extra radials — the ones oriented exactly north, east, south and west of the new element — turned out to be directly above and parallel to the four existing bus wires and separated from them by a vertical distance of only one inch. So I reduced their length to about three feet, sloped them slightly downward and connected their tips to the inner ends of the bus wires, which are part of the original radial system. This served to bond together the ground screens of all five monopoles.

When the 5-element array is operational, the two inactive monopoles must be open-circuited at their bases to make them electrically invisible. A binomial (1:2:1) current distribution is used, with the center element receiving twice as much current as the front and rear monopoles. With the base current of the central radiator used as a 0° reference, the phase angles of the input currents to the two remaining elements were then continually adjusted in an effort to maximize the front-to-back ratio in the elevation plane. The best F/B ratio — 37.22 dB — was achieved with phase angles of +130° to the rear monopole and –130° to the front radiator. The forward gain did slip a bit — from 6.04 to 5.66 dBi, but the F/B ratio increased by slightly more than 19 dB. This seemed like a worthwhile trade-off. Unfortunately, the feed-point impedance of the front element was now 0.31 Ω + j77.86 Ω — a very small resistance combined with a large reactance — which is undesirable.

Eventually I realized that the front monopole could be converted into a parasitic element by adding a capacitor in series with its feed point to cancel the large positive input reactance, and then connecting its base through the series capacitor to the ground screen. This strategy also simplifies the networks needed to properly drive the modified array, since power is fed (via transmission lines) into two radiators instead of three. I altered the computer model by removing the current source from the front monopole and replacing

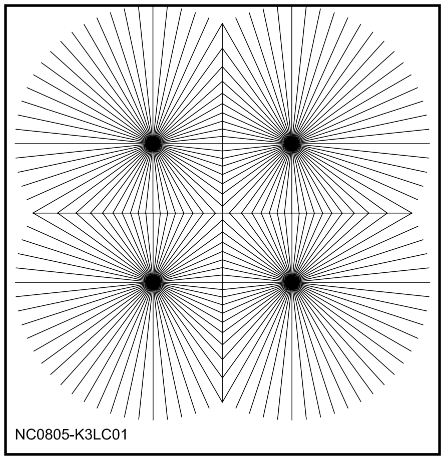

Figure 1 — A plan view of the conventional 4-square array with a broadcast-style radial ground screen. Note the four "bus wires" (oriented north, south, east and west) that are used to terminate the radials in those regions where they could overlap.

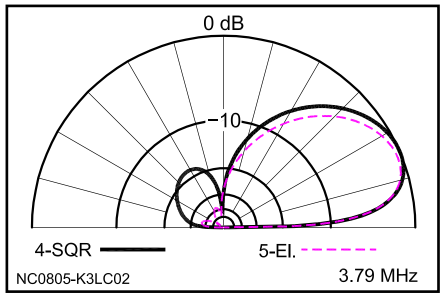

Figure 2 — Elevation plane radiation patterns for the conventional 4-square and for the modified 5-element array described in the text.

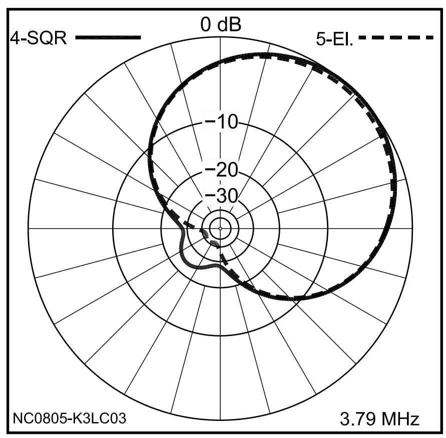

Figure 3 — Azimuthal plane radiation patterns for the conventional 4-square and for the modified 5-element array described in the text.

it with a passive reactance of –77.86 Ω, which corresponds to a capacitance of approximately 539 pF at 3790 kHz.

According to *EZNEC*, this final version of the array should perform well. The forward gain remains exactly the same as before — 5.66 dBi at a 22° take-off angle — while the F/B ratio drops just a bit to 36.65 dB. In the azimuthal plane, the F/B is now 40.49 dB while the half-power beamwidth is 103.8°, with both values taken at an elevation angle of 22°. Figures 2 and 3 show the radiation patterns of the resulting 5-element array along with those of the conventional 4-square. Table 1 compares the F/B ratio for the two antennas throughout the entire range of take-off angles. The modified array yields an average F/B improvement of more than 19 dB, providing superior performance at virtually all elevation angles.

Table 1

Front-to-back ratio for the two phased vertical arrays, as a function of take-off angle.

Take-Off Angle	*F/B Ratio 4-sq (dB)*	*F/B Ratio 5-el (dB)*	*F/B Ratio Improvement (dB)*
5°	27.28	34.17	6.89
10°	26.71	35.03	8.32
15°	25.82	36.59	10.77
20°	24.63	39.10	14.47
25°	23.25	43.20	19.95
30°	21.72	51.15	29.43
35°	20.10	60.07	39.97
40°	18.45	48.86	30.41
45°	16.80	45.46	28.66
50°	15.16	42.15	26.99
55°	13.60	37.06	23.46
60°	12.12	32.02	19.90
65°	10.79	28.03	17.24
70°	9.68	25.43	15.75
75°	9.02	25.23	16.21
80°	9.48	29.23	19.75
85°	15.18	12.89	-2.29

Networks for the New Array

Figure 5 shows the passive networks needed to drive the modified array correctly, assuming the use of lossless 75 Ω quarter-wave phasing lines. The L network on the right, designed around the W7EL "current forcing" method,[2] provides a voltage with a 130° leading phase angle for the rear monopole. It also divides the voltage magnitude by a factor of two, since the rear element requires only half as much current as the one in the center. The L network on the left matches the combined impedances to 50 Ω. No power need be supplied to the front radiator, so it's not shown in the drawing. The feed points of each of the four outer monopoles must be switched as follows: When inactive, the element's base must be open circuited. When used as a passive director, the base of that monopole must be grounded via a 539 pF series capacitor. When used as the rear radiator, that feed point must be connected to its corresponding 75 Ω phasing line. The switching needed to accomplish these tasks is not shown.

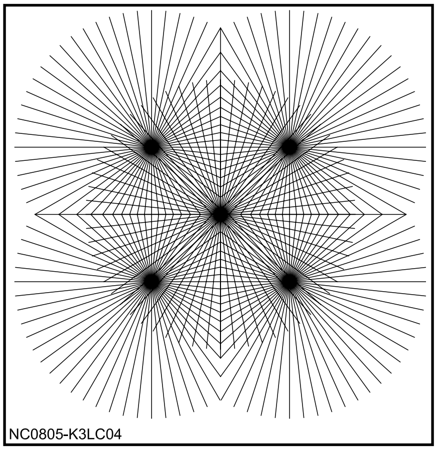

Figure 4 — A plan view of the modified 5-element array showing the additional radials laid over the pre-existing broadcast-style ground screen.

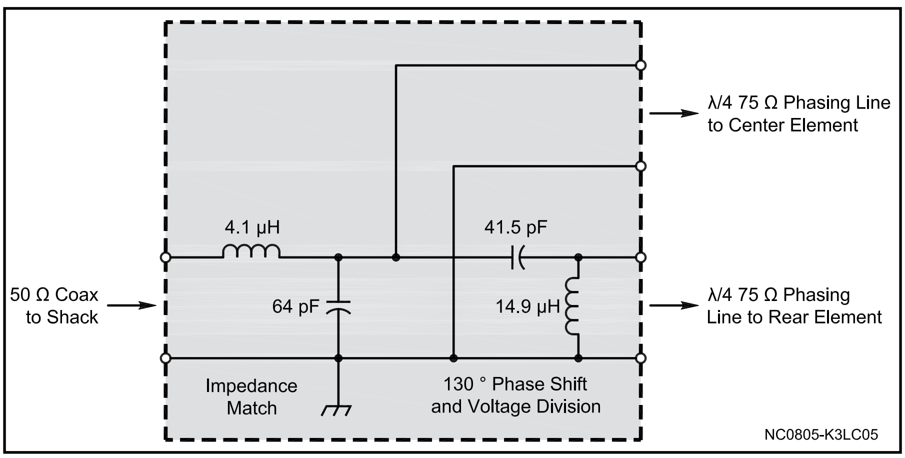

Figure 5 — A schematic of the phasing-matching networks used with the modified 5-element array described in the text.

Noise

Tom Rauch, W8JI, has done considerable research and development work on low-band "receive only" antennas and utilizes a parameter he calls "receiving directivity factor" or RDF to rank the performance of various receive antennas.[3] The classic 4-square array described at the beginning of this article has a calculated RDF of 10.42 dB, versus an RDF of 10.74 dB for the 5-element antenna. The difference in these two values is quite small, despite the modified array's markedly superior F/B ratio. On his Web site, Tom points out that RDF is meaningful when unwanted noise arrives uniformly from all elevation and azimuth angles. Carl, K9LA, discusses the topic of noise in his "Propagation" column elsewhere in this NCJ issue and shows that noise can have pronounced directional properties. In those situations, the enhanced F/B ratio provided by the 5-monopole array could be quite advantageous.

Conclusions

This article has shown how to modify an existing 4-square array to improve the rejection of signals arriving at the back of the beam. This requires considerable construction work, but the resulting 5-element antenna provides an increase in average front-to-back ratio of nearly 20 dB.

Some may wonder, "Why go to all the trouble of adding a fifth element when simpler alternatives exist?" For example, both Jim Breakall, WA3FET, and Tom, W8JI, have designed 4-squares that offer increased forward gain and improved front-to-back ratio. Either of these arrays would make a good choice if maximum forward gain is the main priority. If the goal is maximum suppression of minor lobes to the rear and sides of the main beam, however, neither 4-element antenna can match the 5-element design described here. Further, both of these modified 4-element arrays generate their increased forward gain at the expense of azimuthal plane beamwidth — roughly 86° in the case of the WA3FET design and 80° for that of W8JI. The 5-element antenna has a broad main beam, with a half-power beamwidth of nearly 104°, and provides ample signal strength at azimuth angles midway between the four principal directions of fire.

Notes

[1] Several versions of *EZNEC* antenna-modeling software are available from Roy Lewallen, W7EL. Price and ordering information is on the *EZNEC* Web site, **www.eznec.com/.**

[2] Lewallen, Roy, *The ARRL Antenna Book* (19th ed), p 8-15. American Radio Relay League, Newington, CT, 2000.

[3] Tom Rauch, W8JI, at **www.w8ji.com/receiving.htm.**

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