The 160-Meter Sloper System at K3LR

Sure, doesn't everyone have a 190-foot tower in his backyard? With help from his friends, K3LR made his 160-meter dream come true.

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During the spring of 1992, we began the development work on a 160-meter antenna system using half-wave slopers. This antenna was to be installed on the 190-foot tower belonging to Tim Duffy, K3LR. Our goal was to build an array that would provide forward gain in any one of several switch-selectable compass directions. Good rejection of high-angle signals was an important requirement, as was overall efficiency. We describe in this article a quick review of the theoretical design process, and then discuss the construction, testing and operation of the actual array.

Background

Perhaps the best-known directional antenna using sloping dipoles is that of Dave Pietraszewski, K1WA.[1] His design utilizes five identical λ/2 slopers spaced uniformly around a mast tall enough so the dipoles descend toward the ground at an angle of 60° below horizontal. All five radiators are fed with equal lengths (slightly over 135°) of coax. Only one element is driven at a time, and the other four open-circuited transmission lines function as loading inductors so that all of the passive elements act as reflectors.

A second type of directional array using slopers was described by Dennis Mitchell, K8UR.[2] This antenna system requires only four dipoles, and the lower half of each radiator is "pulled in" (see Figure 1) so that it slopes back toward the base of the tower. Changing the geometry this way produces a signal whose polarization is almost entirely vertical, depending on the exact disposition of the wires. All of the elements in the K8UR antenna are driven with equal-amplitude currents phase-shifted by either 0°, 90°, or 180°, just like the classic "4-Square" phased-vertical array. As with all such phased arrays, the challenge is to get the feed currents into each element exactly right, so the full potential of the array can be realized, particularly for front-to-back ratio.

Design

The initial design of the K3LR antenna combines some of the best features from both the K1WA and K8UR arrays—the mechanical simplicity of the K8UR design, with the straightforward feed system of the parasitic K1WA array. The physical appearance of the K3LR system is close to

[1]Notes appear on page 38.

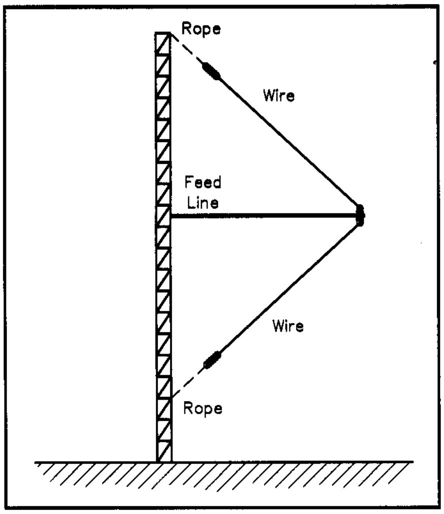

Figure 1—The K8UR Sloper System uses four identical half-wave sloping dipoles spaced uniformly around a tall mast. The lower half of each dipole is pulled in toward the tower.

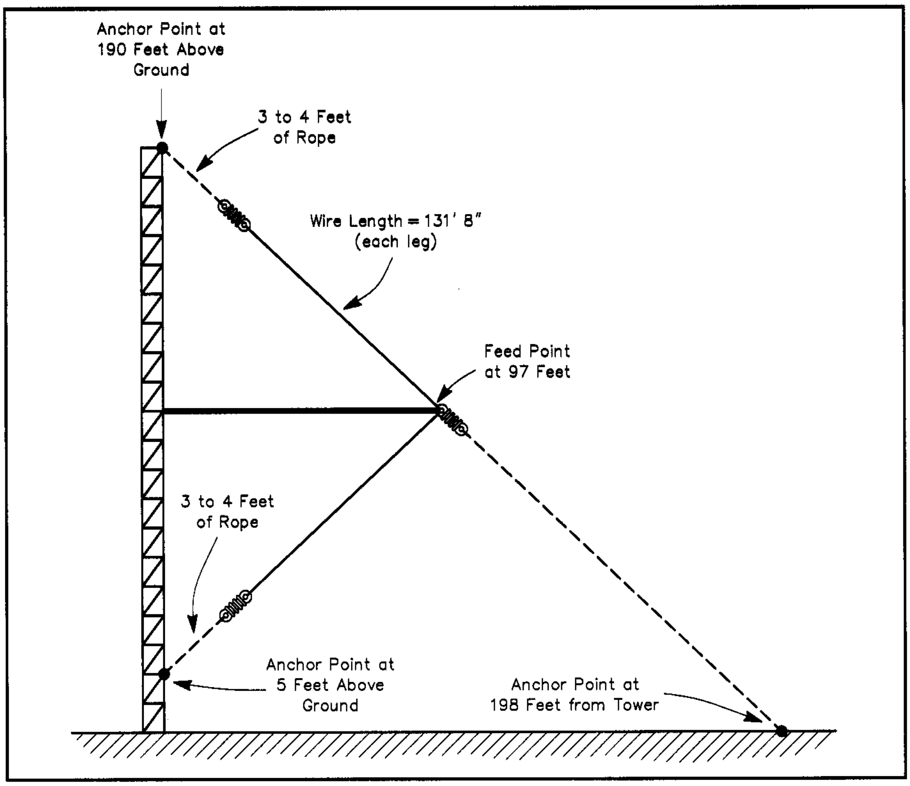

Figure 2—Detail of one element (of four) of the K3LR Sloper System, after tuning adjustments to compensate for insulation on element wires.

that of K8UR's, consisting of four identical bent dipoles spaced at 90° intervals around a tall mast. Figure 2 shows the layout of a single element, including all of the final dimensions. This array is electrically similar to that of K1WA, because only one element at a time is driven. The remaining three dipoles are inductively loaded by open-circuiting the far end of each individual feeder, so that all three act as parasitic reflectors. Only four elements are used (rather than five as described by K1WA) because modeling with *ELNEC*[3] indicated that there were no performance advantages to be gained by using the extra dipole. Figure 3 illustrates the principal-plane radiation patterns of this early-stage K3LR antenna system.

For the 160-meter array, experimentation with *ELNEC* indicated that the best combination of gain and front-to-back ratio would occur when the parasitic elements were loaded with about 100 Ω of inductive reactance. To produce this amount of loading, an electrical length of 153.45° of open-circuited *lossless* 50-Ω line was needed at the center of each element. Because of the long cable lengths, we chose to use RG-8X (instead of RG-213) for the feeders in order to reduce the suspended weight. With a velocity factor of 78%, the calculated physical length of each transmission line is 177.74 feet at the design frequency of 1.840 MHz.

Since the four RG-8X feeders actually have a small amount of loss, even at 160 meters, the impedance at the center of each reflector due to the open-circuited lines was not purely inductive but had become complex, with a value of 25.76 + j93.45 Ω. When this corrected loading impedance was substituted into *ELNEC*, the radiation patterns that resulted were rather surprising. Figure 4 shows that there is a small reduction in forward gain—but a dramatic improvement in front-to-back ratio!

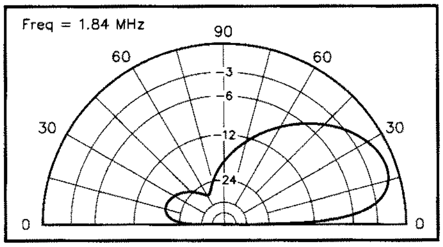

Figure 3—K3LR Sloper System, early stage modeling (elevation plot). The outer ring is 6.0 dBi, maximum gain of array is 5.06 dBi.

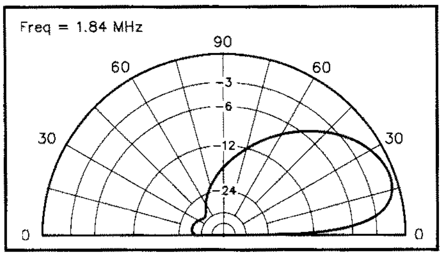

Figure 4—K3LR Sloper System, including feed-line losses in computations (elevation plot). The outer ring is 5.0 dBi, maximum gain of array is 4.57 dBi.

Table 1

***NEC*-Predicted Performance of the 160-Meter Sloper System in Various Configurations**

Description	*Forward Gain (dBi)*	*Front-to-Back Ratio (dB)*
No HF beams, no radials	2.88	18.59
No HF beams, 4 radials	3.85	15.59
4 HF beams, no radials	3.27	14.42
4 HF beams, 4 radials	3.74	19.10

We wanted even more gain, so a decision was made to add four elevated quarter-wave radials to the antenna system. These radials would be horizontal, mounted about 10 to 15 feet above the ground, and all four were to have their inner ends connected directly to the tower. Since the radials were close to the ground in terms of wavelength, we decided to use *NEC*[4] with its Sommerfeld/Norton ground model (rather than *ELNEC*, with its simplified Fresnel reflection coefficient ground model) for the remainder of our computer analysis. In order to be really precise, we felt that it would also be necessary to include all of the small antennas (relatively speaking, of course) which were already mounted on the K3LR 190-foot tower. So, two full-size 3-element 40-meter beams (at 100 and 190 feet), a 6-element 10-meter beam (at 198 feet), and a 3-element 20-meter beam (at 60 feet) were added to the *NEC* computer model, along with the tower, the four slopers and the four elevated radials.

Figure 5 is a drawing of the *NEC* model for the complete tower, including the entire top-band sloper system and the four HF beams. The principal elevation and azimuthal-plane radiation patterns for the 160-meter array are shown in Figure 6. *NEC* indicates a maximum gain of 3.74 dBi at a take-off angle of 20°, and a front-to-back ratio of 19.10 dB. The driving-point impedance predicted by the computer (for any one of the four elements) is 80.4 + j 65.2 Ω at a frequency of 1.84 MHz.

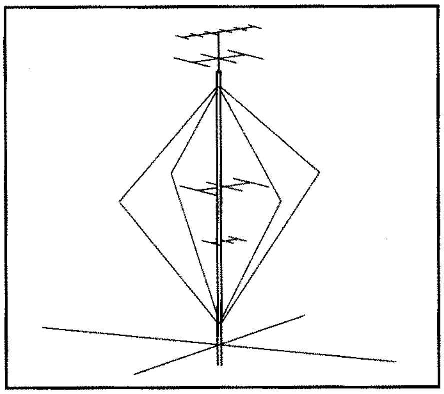

Figure 5—*NEC* model of the 160-meter array as mounted on K3LR's 190-foot tower.

Table 1 shows the *NEC*-generated values for the forward gain and front-to-back ratio when the top-band antenna is mounted on the 190-foot tower, both with or without the HF beams, and with or without the four elevated horizontal radials.

Construction

The four bent dipoles were made from standard #14 insulated electrical wire. The insulation necessitated an increase in the final element lengths in order to achieve resonance at the desired frequency. All of the elements were fed with home-brew ferrite-bead current baluns, with the length of the balun taken into account when

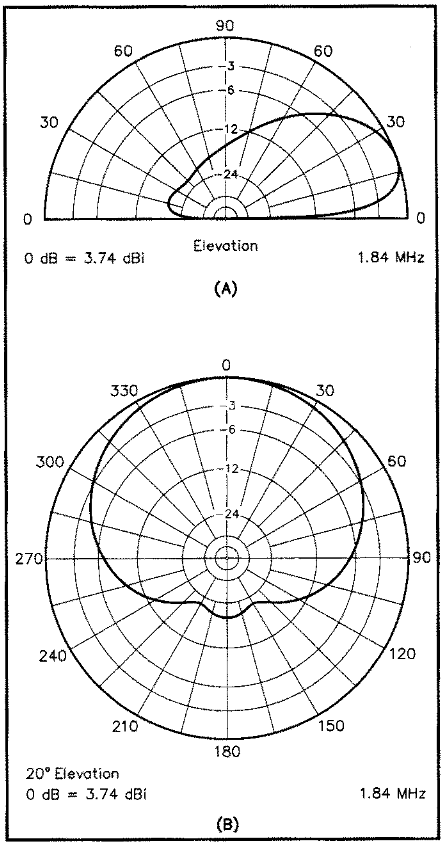

Figure 6—At A, elevation-plane radiation pattern for the K3LR 160-meter array. At B, azimuthal-plane radiation pattern. Maximum gain is 3.74 dBi. *NEC* models ground losses more accurately than *MININEC*-based programs when wires are located close to ground. The elevated radials are 13 feet high. The four antennas have their maximum radiation in the NE, SE, SW and NW directions.

determining the electrical length for each of the Belden RG-8X feed lines. These slopers are oriented at 45°, 135°, 225°, and 315°.

We used a fiberglass box to house the antenna-switching circuitry, so that the coax connectors would be insu-lated from each other without having to use special hardware. Four double-pole double-throw Deltrol relays (from Surplus Sales of Nebraska[5]) were used for driven-element selection. Five UHF chassis-type female coax connectors were installed on the outside of the fiberglass enclosure, with the 12-V relays mounted inside the box immediately adjacent to the SO-239 fittings. A conventional antenna switch will not work for this project, because both the center conductor and the shield must float, to allow the coaxial feeders to act as loads.

Four 15-foot pressure-treated 4×4-inch wooden poles were installed at azimuth angles of 0°, 90°, 180° and 270° to support the 133-foot elevated radials attached to the tower at a height of 13 feet. These horizontal radials are also made of #14 insulated wire.

Testing

When initially constructed in accordance with the original design dimensions, the radiators were a little bit short, since minimum SWR occurred at about 1.86 MHz. Each element was then lengthened by 1.3 feet (for a total of 131 feet, 8 inches) to bring the resonant frequency to 1.84 MHz. At that point, the SWR in the directional mode was so low that no impedance-matching was required.

The array seemed to perform somewhat erratically at first, but it became much more stable after the "common point" was grounded. This was done by running a short, heavy wire from the chassis-mounted SO-239 coax connector for the main feed line (at the Hoffman enclosure) to the base of the tower, which is set in cement and grounded via three 8-foot rods. In this manner, the outer shield of the main coaxial feeder is tied directly to a good earth ground immediately adjacent to the relay switch-box.

The antenna system was tested both with and without the four elevated radials, and the front-to-back ratio appeared to be at least 20 dB in either case. The difference in front-to-back ratio, which had been predicted by *NEC* was not noticed, either because it was too small to be discerned, or because other environmental factors in the real world were involved. The array seemed to play slightly better with the radials (perhaps because of some extra forward gain), so they were left in place.

Since the wire elements and the support ropes are very long, there is a fair amount of sag in the system. As a result, the lower ends of the slopers actually overlap at the base of the tower, and the wires extend rather close to the ground. Thus, all four ends are spaced well apart, in order to avoid arcing, which can occur if the wire elements should accidentally touch each other (or the tower itself). This problem could be avoided completely if the anchor-points for the support ropes could be raised off the ground, or moved farther away from the tower base. In addition, the array would fit somewhat better if the tower itself were slightly taller.

Table 2

Approximate Dimensions for the Sloper System on Various Amateur Bands

Freq (MHz)	*Tower Attach (Feet)*	*Element Length (Feet)*	*Anchor Distance (Feet)*	*Feed Line Length* (Feet)*	*Radial Length (Feet)*	*Radial Height (Feet)*
1.8	200	131	208	176.2	133	13
3.7	100	65.5	104	87.8	66.5	10
7.1	60	34	62	44.9	34.5	6

* These lengths assume that Belden RG-8X is used, and that a 14-inch length of RG-142 is added at the feedpoint for construction of a ferrite-bead current balun.

Operation

The sloper system was used for the first time during the CQ World-Wide SSB DX Contest in October 1992. K3LR was operated in multi-multi class, and the new 160-meter antenna worked very well. The operators (Alan, N3BJ, and Scott, WR3G) felt that the array was "loud" and that there were no problems hearing or working any station. The transmitting setup was a bit compromised by the use of an old amplifier that put out only 800 W. Even at that power level they completed 124 QSOs, working 13 zones and 32 countries. In the 1993 SSB Contest, the score was 102 QSOs, 12 zones, and 36 countries. All of these numbers stack up very well against other top multi-multi entries.

The sloper system was again put on the air during the ARRL 160-Meter Contest in early December 1992. This time K3LR was entered in the multi-single category with WR3G, W3YQ and K3LR as operators. The final total was 1333 QSOs and 99 multipliers, a new all-time record for this category. During the contest, the big antenna was compared to an inverted **V** (apex at 150 feet) located 750 feet away from the 190-foot tower. The parasitic array was always one S-unit better than the inverted **V** in a desired direction, as long as the station was at least 500 miles away. However, there were times when close-in stations were better on the inverted **V**.

During the 1993 CQWW CW Contest, the top-band sloper system really shined. With nearly 200 QSOs in 72 countries, the array kept Tim's station close to the top on 160 meters. K3LR worked 104 Europeans, compared with the 111 European stations worked by K1AR. Since K3LR is in Western Pennsylvania (only half a mile from Ohio), the new antenna is the "secret weapon" that enables Tim to be competitive with the East Coast stations.

Interactions

K3LR has noticed some *minor* fluctuations in the SWR readings taken while rotating the lower 40-meter beam (which is mounted at 100 ft), and he attributes these variations to the presence of the 160-meter sloper system. Otherwise, there have been no discernible effects on the remaining HF beams due to the array.

Using the Array on a Different Band

The design can be scaled easily to other frequencies, and suggested *initial* dimensions are given in Table 2. We are looking forward to receiving comments from others who build or modify this antenna system.

Acknowledgments

We'd like to thank Scott Jones, WR3G, and Tim Jellison, W3YQ, for their assistance in building the antenna, and for their operational observations.

Notes

[1]D. Pietraszewski, K1WA, "7-MHz Sloper System," *The ARRL Antenna Book*, 1991, pp 4-12 to 4-14.
[2]D. C. Mitchell, K8UR, "The K8UR Low-Band Vertical Array," *CQ*, Dec 1989, pp 42 to 46.
[3]*ELNEC* is available from Roy Lewallen, W7EL, P. O. Box 6658, Beaverton, OR 97007.
[4]G. J. Burke and A. J. Poggio, *Numerical Electromagnetics Code (NEC)—Method of Moments*, Naval Ocean Systems Center, San Diego, CA, Jan 1981.
[5]Surplus Sales of Nebraska, 1502 Jones St, Omaha, NE 68102. Tel 402-346-4750.

Al Christman was first licensed in 1974 as WA3WZD. He received his Doctorate in Electrical and Computer Engineering from Ohio University, and is Professor of Electrical Engineering at Grove City College in Western Pennsylvania. When not modeling antennas by computer for fun, Al chases SSB DX on 20 and 80 meters, or enjoys ragchewing and contesting.

Tim Duffy was first licensed as WN3SZX at the age of 12, receiving his Extra Class two years later. He graduated from Penn State University and is Director of Engineering for a communications company. Tim has a long and distinguished string of contest awards to his credit, and is a member of the ARRL Contest Advisory Committee.

Jim Breakall was first licensed in 1965 as WN3FET. Dr Breakall is a professor of Electrical Engineering at Penn State University, specializing in antenna theory and design. Like Al Christman, Jim has been very involved with the development and validation of the NEC computer modeling program. Jim is very familiar to Dayton attendees because of his well-received lectures in the Antenna Forum. He is now building a "large station in central Pennsylvania." Watch out, K3LR!