

A Four-Square with Eight Directions of Fire

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Introduction

The four-square phased-vertical array¹ is widely used by DXers and contesters for operation on the low bands from 40 through 160 meters. It can also serve as an effective low-profile directional antenna on the upper HF bands in locations where restrictive covenants prohibit towers and beams, or on DXpeditions where compactness and low weight are important.

This article shows how to modify a conventional four-square to provide eight directions of fire instead of the normal four. The extra directions are located at points which are mid-way between the existing four, yielding a total of eight selectable beam-headings spaced 45° apart.

Antenna Description

A computer-generated drawing of an elevated four-square array for the 80 meter DX phone band is shown in Figure 1. For simplicity, all elements are composed of #12 copper wire. In the EZNEC² simulation, the array is placed at a height of 15 feet above good ground, which has a conductivity of 5 millisiemens per meter and a dielectric constant of 13.

The elements are positioned so that the four directions of fire (through the diagonals of the square) are northeast, southeast, southwest, and northwest. When beaming northeast, the gain directly to the north (or east) is 2.80 dBi at the same take-off angle. After the four extra directions of fire are incorporated, the array can also beam north, east, south, and west. In these four "new" directions, the maximum gain is now 4.54 dBi at 21° take-off angle. Compared to the conventional array, this amounts to an improvement of 1.74 dB when beaming directly to the north, south, east, or west. Figures 2 and 3 compare the elevation and azimuthal plane radiation patterns for both configurations. A simulation was also performed over perfectly conducting earth. Here, the gain improvement achieved with the 8-direction array was 1.31 dB when firing north, south, east, or west.

Element Phasing

The conventional antenna fires out-

ward through the corners of the square formed by the four elements, while the modified array can also fire through each of the four sides. In either case, all the elements are driven by equal amplitude base currents, but the phase angles are different resulting in beams heading in

various directions.

In typical phased array fashion, the rear-most element has the leading current phase angle, with the phase lag increasing progressively as one proceeds from the rear to the front of the array. When beaming through a corner (as in

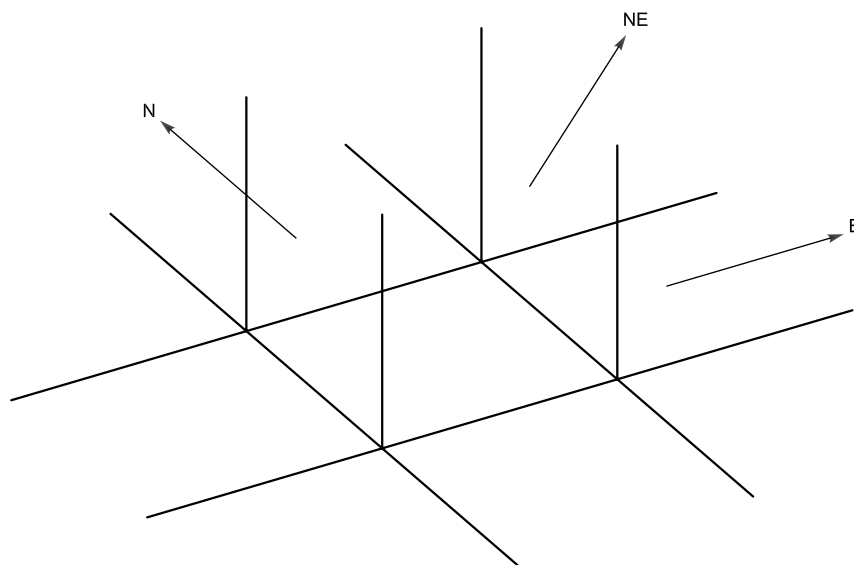


Figure 1—A computer generated drawing of the four-square array for 80 meters. Four quarter-wave elements and 12 quarter-wave radials are utilized. All conductors are #12 AWG copper wire, and the elevated feed-points are located at a height of 15 feet above the ground.

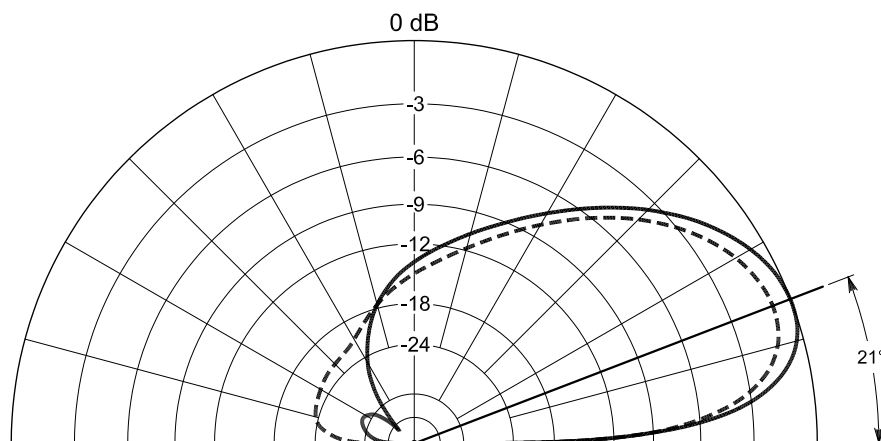


Figure 2—Elevation-plane radiation patterns for the four-square array when firing NE-SE-SW-NW through the corners of the square (solid trace), and when firing N-E-S-W through the sides of the square (dashed trace). Peak gain when firing through the corners is 5.42 dBi at a take-off angle of 21°, while maximum gain when firing through the sides is 4.54 dBi at 21° take-off angle.

¹Notes appear at end of article.

a conventional four-square) the current in the two middle elements lags that of the rear element by 90°, while the current in the front element lags that of the rear element by 180°. When firing through the sides of the square, there are two front elements and two rear elements; now the currents in the front elements lag those of the rear elements by 90°.

A variety of strategies can be used to create the networks that are required to generate the desired base currents. One method that works well, and is widely used in Amateur Radio applications, relies upon the “current forcing”³ concept described by Roy Lewallen, W7EL. If all of the elements in the array are fed by lossless transmission lines whose electrical length is 0.25 λ, then the output

current flowing into the base of the corresponding element will have a magnitude equal to the voltage at the input end of the line divided by the characteristic impedance of the line. Further, the phase angle of the output current will lag that of the input voltage by 90°, which is the electrical length of the feeder itself. Notice that the input impedances of the various elements are not a factor; in other words, the driving point currents are not dependent upon the driving point impedances.

When applying the current-forcing technique to drive a four-square, an RF network is needed that can generate two voltages that are equal in amplitude but 90° apart in phase. One strategy, adopted by Comtek Systems⁴, employs a 90° hybrid to provide the two requisite output voltages. Another method, described by W7EL, makes use of a capacitor and an inductor configured as a low-pass L-network⁵.

In a typical application, the network output terminal with the lagging voltage is used to drive the two middle elements of the four-square, which will have a lagging current phase angle of 90°. At the same time, the terminal with the lead-

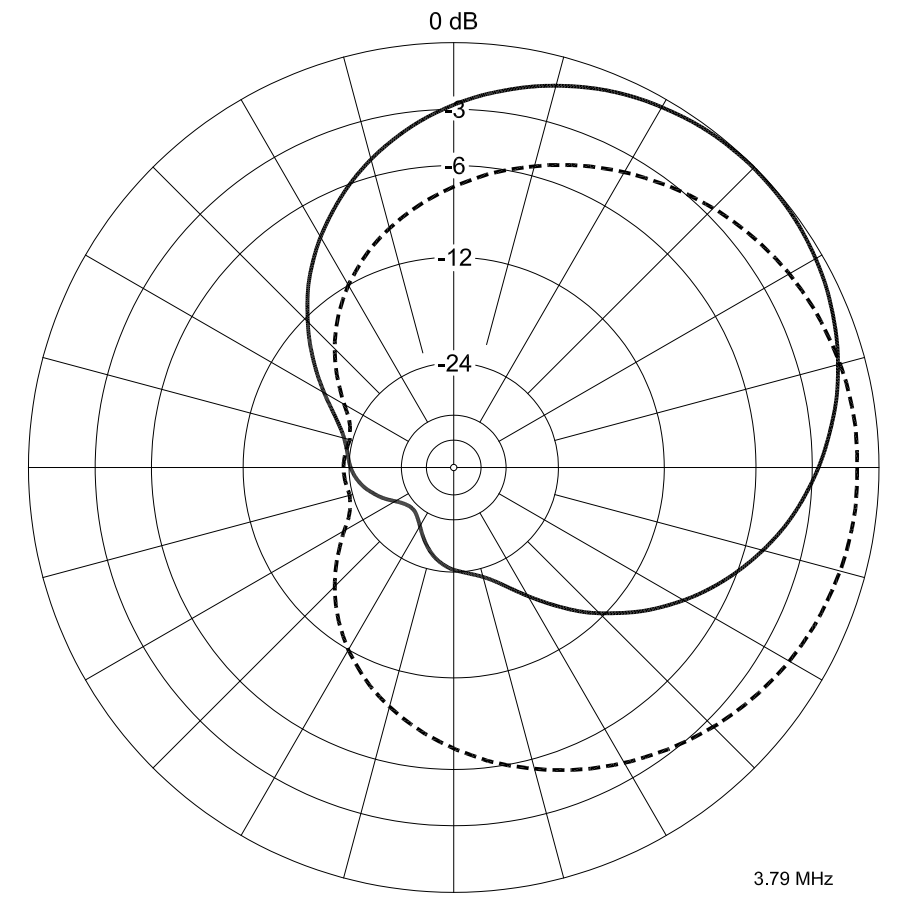


Figure 3—Azimuthal-plane radiation patterns for the four-square array when firing NE-SE-SW-NW through the corners of the square (solid trace), and when firing N-E-S-W through the sides of the square (dashed trace). Peak gain when firing through the corners is 5.42 dBi at a take-off angle of 21°, while maximum gain when firing through the sides is 4.54 dBi at 21° take-off angle.

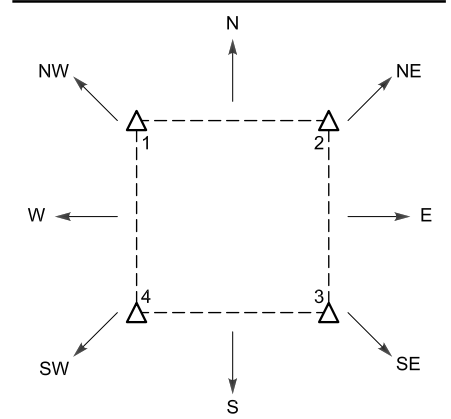


Figure 4—Plan view of the four-square vertical array. Each element is numbered, and the eight possible directions of fire are shown.

Table I

This table lists the relay control logic and the number of energized relays for each direction of fire, along with the corresponding current phase angle for each element. For the status of the six relays, “1” = on and “0” = off.

Direction of Fire	Relay States						Number of Energized Relays	Phase Angle of Current in Element			
	K1	K2	K3	K4	K5	K6		1	2	3	4
N	1	0	0	1	0	0	2	-90	-90	0	0
NE	0	0	0	0	0	0	0	0	-90	0	+90
E	0	0	1	1	0	1	3	0	-90	-90	0
SE	1	1	1	1	1	1	6	+90	0	-90	0
S	0	1	1	0	0	1	3	0	0	-90	-90
SW	0	0	0	0	1	1	2	0	+90	0	-90
W	1	1	0	0	0	1	3	-90	0	0	-90
NW	1	1	1	1	0	0	4	-90	0	+90	0

ing voltage drives both the front (current phase angle of -180°) and rear (current phase angle of 0°) elements. Since the current in the front element actually lags that of the rear element by 180° , an additional 180° phase lag must be introduced in some manner. Comtek relies upon a 1:1 toroidal transformer configured as a broadband phase inverter, while W7EL uses an electrical half-wavelength of transmission line to accomplish the same purpose. Thus, each of the two output voltages from the RF network actually furnishes current to two of the four elements of the array.

Control Circuitry

Figure 4 is a plan view of the four array elements, showing the eight directions of fire. Figure 5 is a schematic diagram that illustrates the RF wiring for the six relays that perform all of the direction switching. Four SPDT relays (K1 through K4) and two DPDT relays (K5 and K6) are used, but eight SPDT units could be substituted. In this figure, I have chosen to use 0° as the reference phase angle for the *middle* elements of the array, when firing through the corners of the square. The front element is then at -90° and the rear at $+90^\circ$. This way, the corresponding phase angles when firing through the sides of the square are 0 and -90° for the rear and front elements, respectively. Note: the terminals labeled 0° , -90° , and $+90^\circ$ on the RF network in Figure 5 correspond to the terminals labeled -90° , 180° , and 0° on the Comtek ACB-4 phased-array switch.

Table I gives complete information for all six relays, listing which are on and which are off for each of the eight directions of fire. In the northeastern USA, it is customary to make "NE" the default beam heading, and the relays have been wired accordingly. Even if control power is lost, the array will still beam to the northeast. The table also shows the relative phase angle of the current delivered to each of the array elements.

A method for distributing control power to the relays is given in Figure 6. If the RF relays have dc coils, then a single-pole eight-position rotary switch can be used in combination with 23 steering diodes as shown. These diodes can be common 1N4001 or similar rectifier devices. Figure 7 uses a similar switch, along with a diode matrix, to accomplish the same task. As before, 23 diodes are needed. The design of these direction control circuits utilizes a single deck switch and diode logic, instead of a more complex and expensive six-pole eight-position multi-section switch.

Conclusion

This article has discussed a technique for obtaining eight directions of fire from

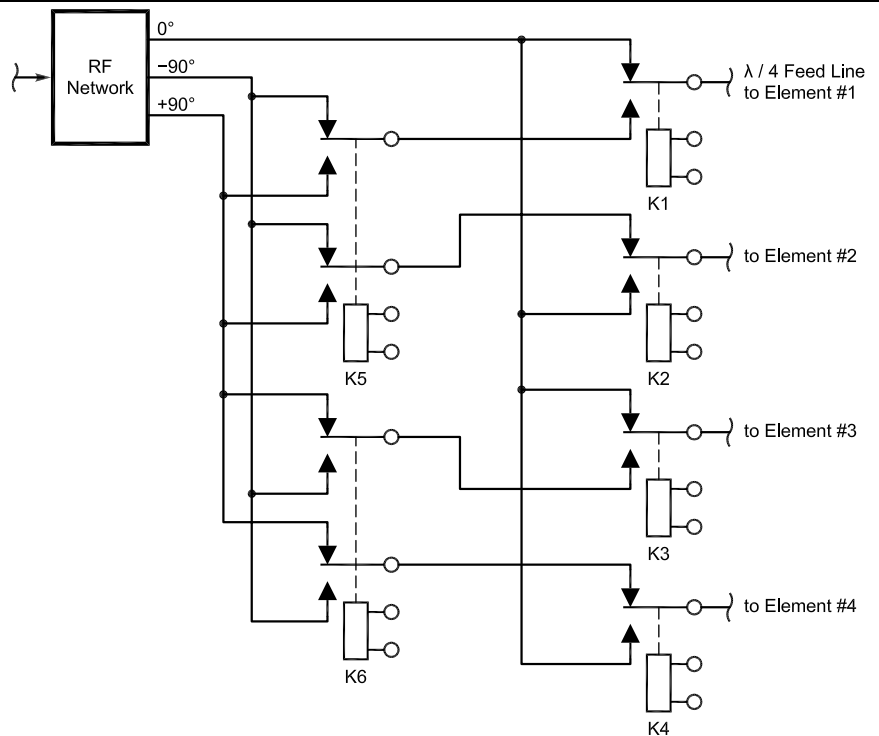


Figure 5—RF wiring for the relays that is used for direction switching. The diagram shows two DPDT relays and four SPDT relays, but eight SPDT relays could also be utilized. All relays are shown de-energized (off).

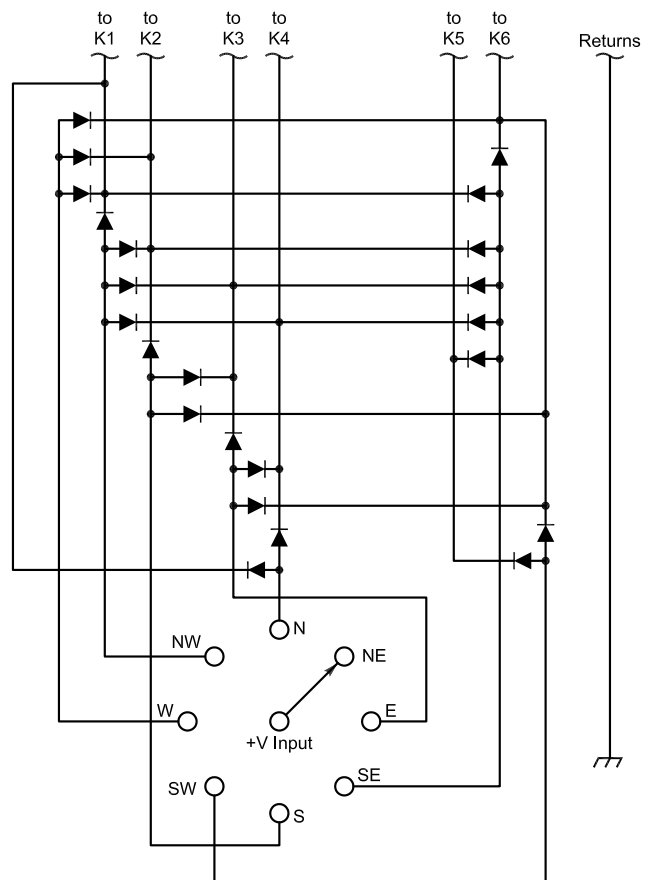


Figure 6—A direction-control switching circuit for the RF relays shown in Figure 5, assuming they have dc coils.

the well-known four-square phased vertical array. Whether these extra four azimuthal selections are important or not will depend upon the needs and desires of the operator.

For the elevated sparse-radial antenna described here, the gain improvement when firing through the sides of the square is nearly 1.75 dB, which could make a difference in a contest situation.

Notes

¹D. Atchley, W1CF, H. Stinehelfer, ex-W2ZRS, and J. White, PhD, "360°-Steerable Vertical Phased Arrays," *QST*, Apr 1976, pp 27-30.

²*EZNEC* is available from Roy Lewallen, W7EL, PO Box 6658, Beaverton, OR 97007.

³R. Lewallen, W7EL, "A Preferred Feed Method," *The ARRL Antenna Book*, 20th Edition, American Radio Relay League, 2003, pp 8-15 and 8-16.

⁴Comtek Systems, PO Box 470565, Charlotte, NC 28247-0565.

⁵R. Lewallen, W7EL, "Feeding Elements in Quadrature," *The ARRL Antenna Book*, 20th Edition, American Radio Relay League, 2003, pp 8-16.

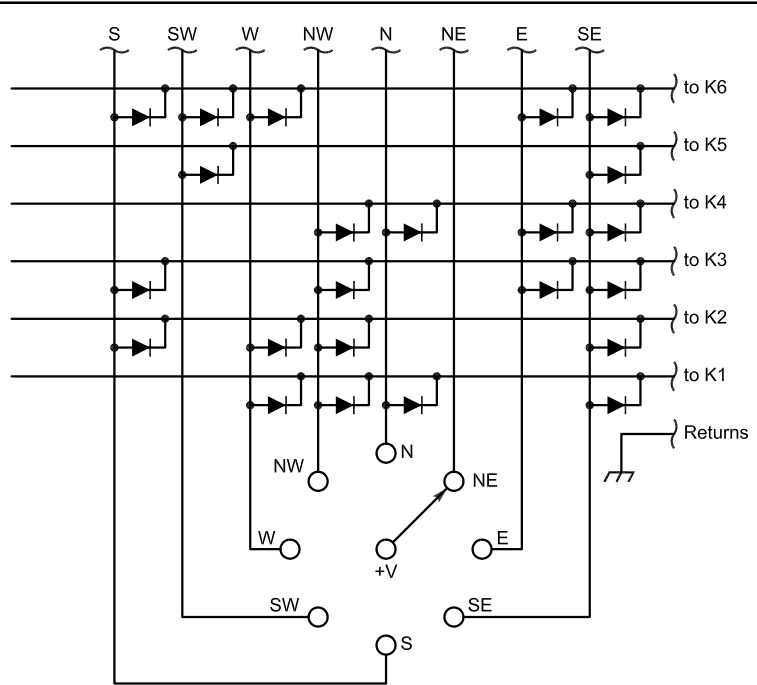


Figure 7—Another direction-control circuit for powering the RF relays shown in Figure 5. Here a diode matrix is used to feed dc to the proper relays. NCJ