# Array Solutions
# Four Square Array User's Guide


**Array Solutions Four Square Array Steering System shown**
**Note: Not shown is the phasing line**

**Congratulations.**

You have selected one of the finest phased array steering systems made. We have under-rated the power capability of this system to assure the user high reliability under heavy use such as in a 48 hour radio contest. Please contact us if you have any questions about the product and please send a picture and description of your station showing the control system installed and in use.

The Four Square Array system has two components: a relay box that will be mounted midway between the four verticals and a control box that is connected with a 5-wire control cable inside the operating room. With this system you will be able to beam in 4 directions and also take advantage of the OMNI mode for domestic use.

The system is available in standard quadrature feed and an optimized feed version.

**Wiring the system:**

Take the cover off the switch box and unwrap the circuit board. Wire the control cable before mounting the board to the box.

You will need a cable with 5 wires. Small gauge wires are fine and will fit inside the boxes better than large rotor cable. For runs of less than 500 feet #18 or larger gauge stranded wires will be adequate. The relays draw only 120 ma at 12V DC. Try to use a supply that has a 13.8V+ DC output.

You will also need a small two-wire 12V DC line for power. A 13.8VDC 1 amp power supply should be ample. But please use a reliable power source, since wall wart transformers have a habit of falling out of plugs and going bad in the middle of a contest.

The silk-screen on the PCB indicates where to wire the +12 V DC (+13.8V DC) supply and its RETURN or GND wire to the Power Supply.

Wire the control switch PCB to the relay box per the following Table 1.

| Control Switch PCB Terminal Strip | Relay Box Terminal strip |
|---|---|
| 1 - no wire Default position direction A | No connection and no terminal 1 in this box |
| 2 - Direction B | 2 |
| 3 - Direction C | 3 |
| 4 - Direction D | 4 |
| 5 - no wire Default position direction A | 5 no connection |
| 6 - OMNI directional | 6 |
| +12V - wire to your 13.8 V DC supply | |
| GND - Ground return to your DC supply | GND return wire back to control switch |

**Table 1**

**Please use a connector on a short piece of cable so you may disconnect the control unit form the control cable when not in use, or when a thunderstorm arrives. We also recommend the use of a surge protector at the station end for the control cable and RF cables, such as the model 348 and 303U products we sell. A little money spent now can save valuable radios later. We have MOV protection inside the relay box.**

Place the control switch PCB inside the control switch and secure the PCB in place with the rotary switch hardware. The LEDs should just protrude through the holes provided for them.

Use the tie wraps supplied as a strain relief when the control cable is fed through the grommet hole. Snug the tie wrap next to the hole in the back of the box to prevent the wire from being pulled and stressing the PCB.

Do the same with the 12V-power wires you will supply through the other grommet hole.

## Relay Box

Route the control cable through the rubber grommet hole in the relay box tray. Use a Ty-wrap™ as a strain relief. The relay box terminal strip is marked to indicate the connection to terminals. See the above **table 1** for the proper connections. There is no terminal 1 since it is the no power default position. The relays are bypassed with MOVs, capacitors, and diodes for RF and lightning suppression. See **Fig. 2** which is a picture of the inside of the phasing box.

## Figure 2 description

**Feedline** RF connector is where your 50 ohm feedline connects.

The area marked **capacitor bank** is for placement of HV RF capacitors. This is the input L network It is used to match the system to a perfect 1:1 VSWR. We have set it up using dummy loads but you will be required to adjust the network for the characteristics of your antennas by adding or removing capacitors or moving the tap on the coil, once you hook up all of the antennas and the 180 degree delay line

**Input Match L-network** – has two coil taps, one for 4-square operation and one for omni operation. Coil taps and capacitors may need slight adjustment for your antennas.

**Delay Line out and in** these are the two connectors that the 180 degree phase line is attached. It creates the 180 degree phase delay to the front element of the array.

**Antenna Ports 1-4** these are the output connectors to the 4 antennas. Each one should have a ¼ wavelength feedline connected to it. We use ¼ wavelengths to take advantage of the current forcing properties of this length of transmission line.

**90-120 degree phase shifter-** Locate on top of fig.2, is the L-network that will cause the required phase delay to the center elements Iwith respect to the rear element). It is factory set and should not require any adjustment per your requested setting but you may change it as needed by changing the coil tap and the capacitors. The capacitor bank is the in the middle of fig. 2.

**180-240 degree phase line phase shifter LC network** – located on the mid left side of fig. 2. is factory set, but may be changed by modifying the coil tap and capacitor bank following the coil. This network allows you to use a phase delay to the front element that is greater than 180 degrees, which is accomplished by the 180 degree delay (phasing) line.

**Input Match L- network** – has two coil taps, one for 4-square operation and one for omni operation. Coil taps and capacitors may need slight adjustment for your antennas.

**Control Terminals** - attach the control cable to this terminal strip.

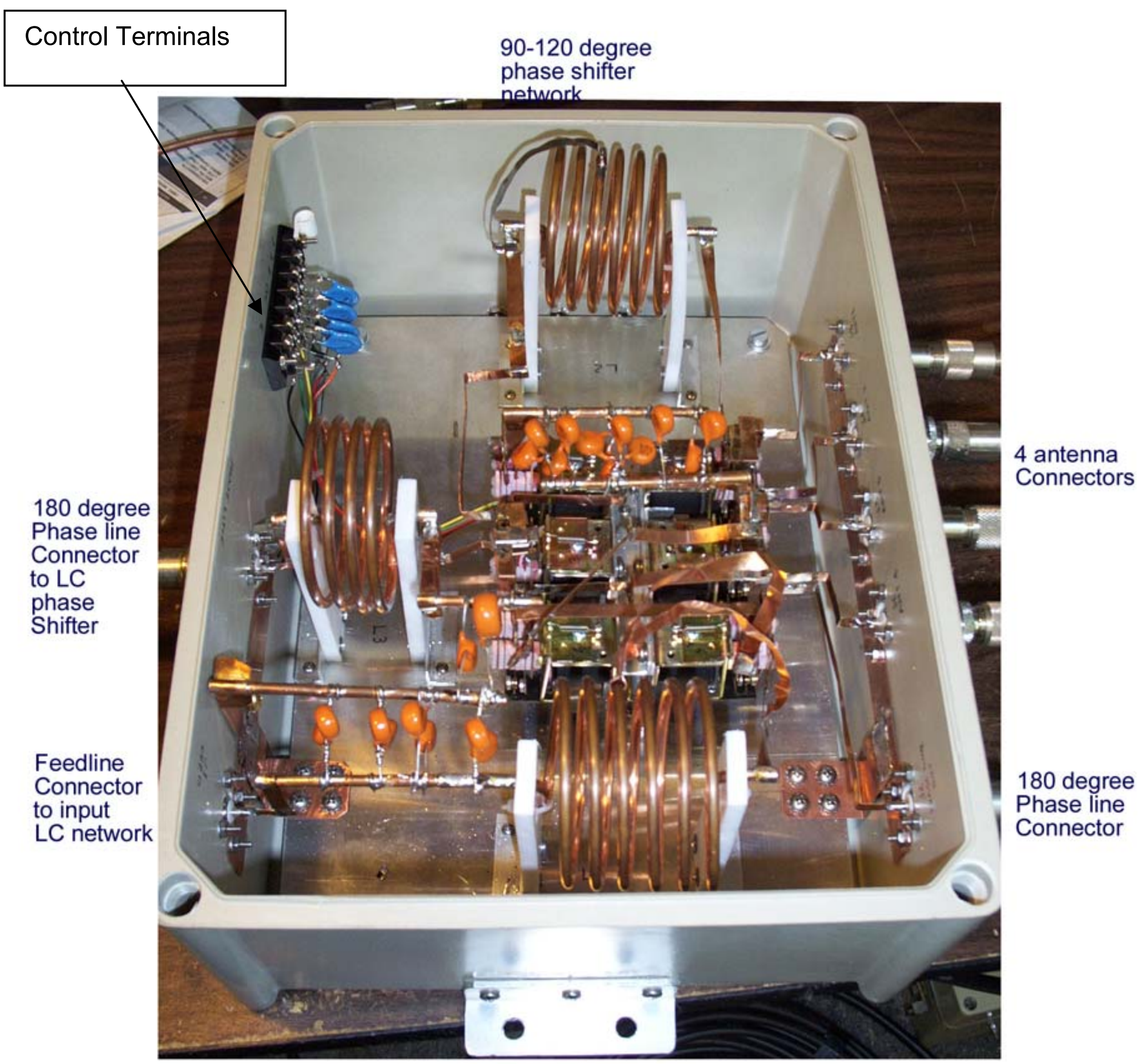

**Figure 2**

## Setting up the system

The very best book on the subject of setting up a four-square antenna array is a book by John Devoldere, ON4UN titled “Low-Band DXing”. If you do not already have this book we recommend you obtain a copy of it to learn all about these types of systems. It is available from the ARRL bookstore.

Place the controller relay box in the center of the array. Use the U-bolt provided to mount the box on a ground rod, pipe, or tower leg. Feed each vertical with ¼ wavelength of 50 or 75 ohm feedlines (75 ohm feed lines will give a little wider bandwidth). The feed lines are not matched for SWR, they are impedance transformers. Make sure you cut four feedlines to exact quarter-wave length where you want it!

Attach the 180 degree long-phasing line to the appropriate ports as well as the input feedline, and the four ¼ wavelength antenna feed lines. Make sure the delay line is exactly 180 degrees on your favorite operating portion of the band! Be sure to weather-proof the connectors. There is a ground lug on the side of the box, use it to secure a good ground connection such as a ground rod or any other ground system, like your tower ground or a radial ground plane. Do not attach this ground to a raised radial system, which must remain floating above ground.

You have set up your verticals into a square; we will define the square as follows for North America. The antennas are marked from 1 to 4

D A
**o 2 o 4**

**o 1 o 3**
C B

**The above diagram indicates verticals (o), Antenna number (1-4), and Direction (A-D)**

Drive the antennas from the antenna output ports that coincide with the above diagram.

Switching the array pattern is done with the control switch. Position one is the default position. It is not supplying any voltage to the array. Drive your antennas such that this is your most important direction. IE in North America you probably will want to have this position be your NE direction toward Europe.
Position two is SE
Position three is SW
Position four is NW
Position five is NE direction since it is not hooked to any control wire
Position six is the OMNI directional position

## VSWR and Matching

We have set the taps and capacitors for the input L network for a typical 4 square match already in your system. At most you may have to adjust them slightly for a better match. There are two taps on the INPUT L NETWORK (Fig 2 left bottom network) the tap from the relay is the tap for normal directional operation. The other tap is the omni mode adjustment tap.

**First tune the normal directional mode tap.**
Tuning the system for best VSWR is a fairly simple procedure and can be done by first adjusting this tap of the input L network coil for minimum SWR. This will require a soldering iron. If you cannot find a 1.0:1 SWR you may need to try adding a capacitor by touching it from the input connector side of the coil to ground. If the SWR goes higher you know you must remove capacitance. If the SWR goes lower, you of course will need to add capacitance. Repeat this procedure until you have a perfect match to your system. Call us if you have any SWR problems and we can help with this. We have adjusted the system for a SWR of less than 1.1:1 at the desired frequency using simulated antenna loads at the factory to give you a good starting point.

Please contact us for help in tuning your array or if you have any other questions.

**Secondly tune the Omni Mode tap.**
Select the Omni Mode with your controller, and observe the SWR. Tune the remaining tap on the L-Network if it needs tweaking. You may not be able to achieve a perfect 1.0:1 VSWR in omni mode but we usually get it under 1.5:1. This is because the capacitance has been set by the normal 4 square operation, and is slightly less then desirable. But should not be an issue.

That is all you are required to do. If you have an oscilloscope or phase meter you can observe the phasing of the controller at the antenna ports with the probes. You may adjust all the phases to be exactly perfect for your array. Doing so assures that the array is operating perfectly.

## Tuning the two Phase shift Networks

The -90 to-120 phase shift circuit (consisting of an L-network in series with the coaxial 180 degree delay line) and the -180 to -240 phase shifter (L-network) may also be adjusted by the customer. You will need a 100-300 MHz scope or better to do this. These were factory set for you but may require tweaking with the actual array or if you just want to learn how they work.

The 90-120 degree network is tuned by adjusting the tap on the coil and the capacitance on the large capacitance bank. Tune for desired magnitude and phase delay by moving the tap point and observing the results on the scope. You will find an alligator clip small jumper useful for this.

The 180-240 degree shifter can be adjusted in a similar manner. You should be able to achieve good control of the phase and magnitude at the desired frequency of operation.

# Theory of operation:

The system consists of four verticals in a square separated by .25 WL (= side of the square)

### Quadrature Feeding

The Array Solutions controller cane be used to feed all 4 of these verticals in such a way as to accomplish a quadrature feed to each antenna (quadrature means fed in 90 degree steps and with equal drive current magnitude).

The "rear" element in our diagram above is the one on the closest to us on the axis. It is fed with 1A of current at 0 degrees, the next two elements are diagonally positioned and are fed in phase with 1A of current at -90  degrees, and finally the "front" element is fed with 1A of current at -180 degrees. The direction of firing is through the diagonal of the 4-square towards the element fed with -90 degrees current. The array has a forward gain of 5.5 dB over a single vertical.

**Note the following diagrams are normalized to 5.5 dB of gain over a single same type vertical. Do not confuse 5.5 dbi with real gain, which can be more with full-size quarter-wave verticals and good ground properties. This is to display the gain over same type vertical ignore the dBi notation and consider it as dB reference over single vertical.**

The take-off angle in this system with this mediocre ground is 23 degrees. But with an excellent ground radial systems and better ground conditions it is possible to lower the angle.

The feed method using an L-network to achieve the required **90 degrees** phase shift was developed by Lewallen, and we refer to it (as in ON4UN's book) as the Lewallen feed method.

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## Optimized Feeding.

This is probably why you purchased this unit.

Using a phase shift greater than 90 degrees (back element to center elements) and greater than 180 degrees (back element to front element) makes it possible to improve the performance of the 4-square. We developed a system where the phase delay can be adjusted to achieve 90 to 120 degrees (for the center elements) or 180 to 240 degrees (to the front element).

Unlike the hybrid coupler technique where the phase shifts are required to be quadrature (in 90 degree steps and equal current magnitudes) by nature of the concept, our "optimized feed system" allows the user to optimize the drive current phase shifts and magnitudes since it is accomplished with variable networks plus (in most cases) a 180 degree phasing line.

Robye Lahlum has developed the mathematics which are published in detail in ON4UN's book Low Band DX-ing, edition 4 (an ARRL publication, available June 2005). The systems and the mathematics make it possible to have absolute control of the exact phase and magnitudes of the feed currents to each element. Networks can be designed that achieve feed current phase angles and magnitudes as desired. We are no longer bound to equal current magnitude in each element and 90 degree phase increments.

Our "optimized feed system" uses a phase shift of -111 degrees to the center elements and -224 degrees to the front element. As explained above the -111 degrees delay is achieved by a simple L network and the -224 deg. phase sift to the front element is achieved through a 180 deg line, with, in addition, an L network taking care of the remaining (224-180=) 44 degrees.

Here is what this pattern look like using the same system, same ground but with the improved phasing angles. Remember this is normalized to show gain over a single same type vertical.

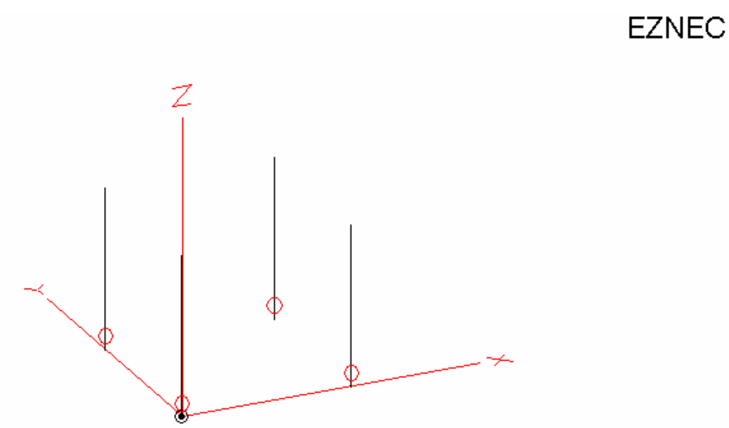
**We have increased the gain by .66 dB and the front to back radio by 6 dB or more!** This can be easily achieved with your controller by adjusting the 90 degree network for a 111 degree phase shift and the adding ~~38~~ 44 degrees to the 180 degree phase line. You can set it up yourself, or we can set it up for you when you order your phased array controller.

**Tuning the two Phase shift Networks**

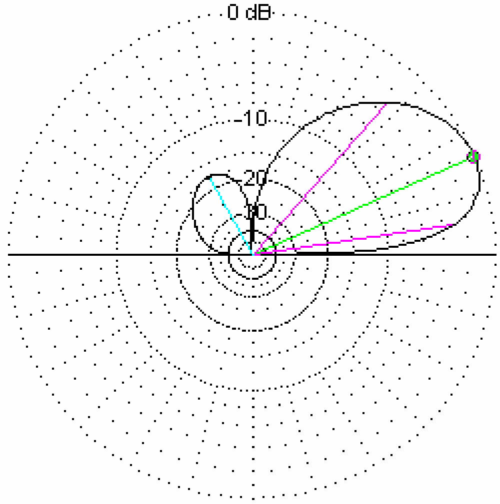
The -90 to-124 phase shift and the -180 to -224 phase shifter LC networks may also be tuned. You will need a 300 MHz scope or better to do this. These were factory set for you but may require tweaking with the actual array or if you just want to learn how they work.

1 90-124 degree network is tuned by adjusting the tap on the coil and the capacitance on the large capacitance bank. Tune for desired magnitude and phase delay by moving the tap point and seeing observing the results. You will find an alligator clip small jumper useful for this. You can achieve the desired results by working with the capacitance and the inductance together and observing the results on your scope.

The 180-224 degree shifter is similar to the above adjustment. You should be able to achieve good control of the phase and magnitude at the desired frequency of operation.

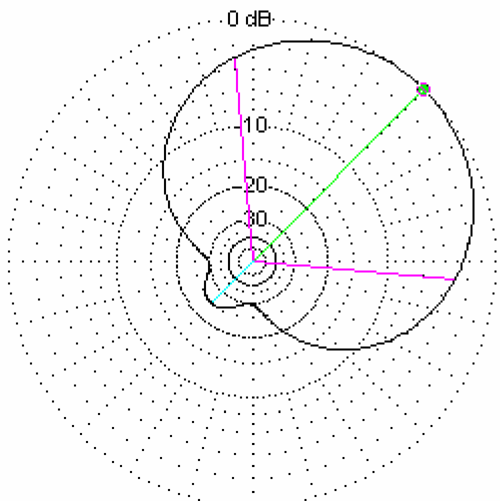


Quadrature Fed Plots




| | | | |
|---|---|---|---|
| Elevation Plot | | Cursor Elev | 24.0 deg. |
| Azimuth Angle | 45.0 deg. | Gain | 5.5 dBi |
| Outer Ring | 5.5dBi | | 0.0 dBmax |

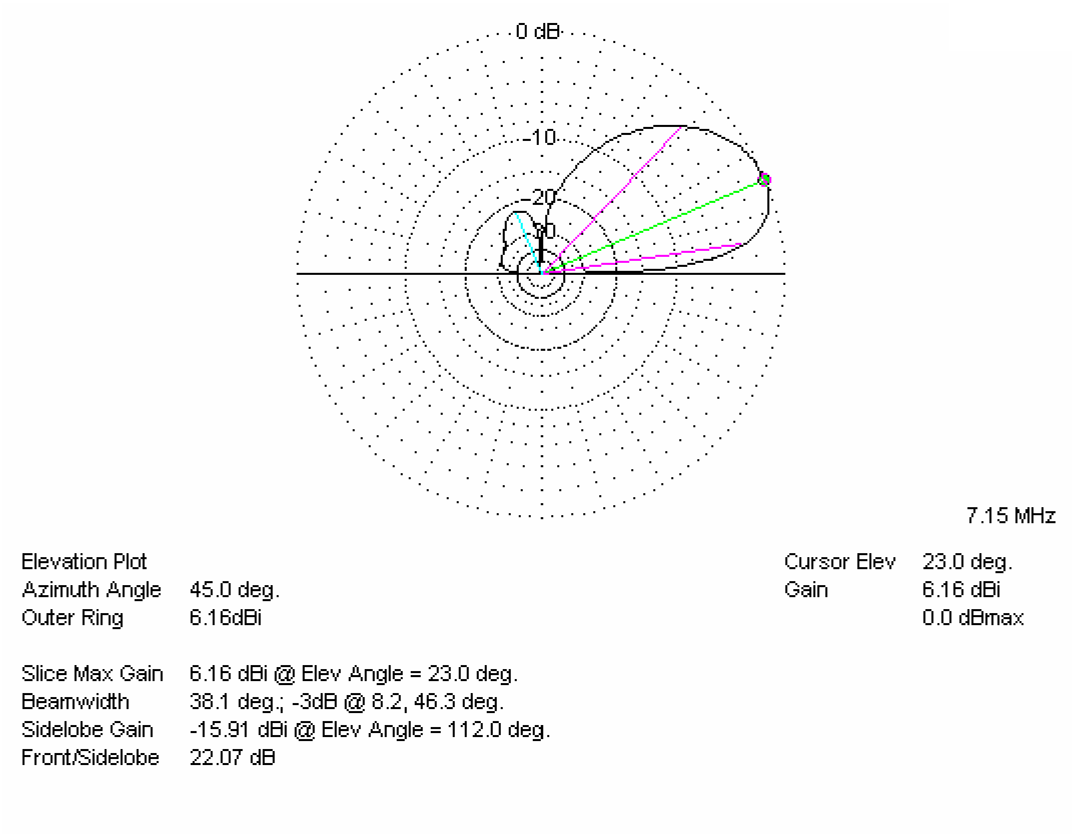
| | |
|---|---|
| Slice Max Gain | 5.5 dBi @ Elev Angle = 24.0 deg. |
| Beamwidth | 39.9 deg.; -3dB @ 8.4, 48.3 deg. |
| Sidelobe Gain | -11.68 dBi @ Elev Angle = 119.0 deg. |
| Front/Sidelobe | 17.18 dB |




| | | | |
|---|---|---|---|
| Azimuth Plot | | Cursor Az | 45.0 deg. |
| Elevation Angle | 23.0 deg. | Gain | 5.5 dBi |
| Outer Ring | 5.5dBi | | 0.0 dBmax |

| | |
|---|---|
| Slice Max Gain | 5.5 dBi @ Az Angle = 45.0 deg. |
| Front/Back | 24.45 |
| Beamwidth | 99.8 deg.; -3dB @ 355.1, 94.9 deg. |
| Sidelobe Gain | -18.96 dBi @ Az Angle = 225.0 deg. |
| Front/Sidelobe | 24.45 dB |

Optimized Fed Plots – More Gain and Front go Back




## Specifications

| | |
|---|---|
| Construction | Corrosion resistant NEMA 4X enclosure, weather seals, Amphenol Teflon SO239s |
| Power | 5 KW CW / 10 KW PEP |
| VSWR | Adjustable for 1:1 perfect match – No dump load |
| Gain | 5.5 dB over single vertical 6.16 dB optimized see theory |
| Directions | 4 directions with an additional Omni-directional feature |
| Electronic phasing | LC network and phase line |
| Phasing Options | Quadrature 90/0/-90 and Optimized 111/0/-107 |
| Capacitors in networks | Temperature stable high current RF capacitors -10 kV |
| Weight and size | 15 lbs ~14" x 11" X 8" relay box, 6"x3"x3" controller box |

**Thank you for purchasing this high quality phasing system.**

**Many thanks to John, ON4UN for his suggestions to improve this manual.**