

# **YCCC low band receiving array kit**

## **User's manual**

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## Revision history

Revision number	Date	Description
0.2	1 July 2015	Initial version. Direction controller build instructions yet to be added.
1.0	26 August 2015	Added step-by-step build instructions for direction controller. Added miscellaneous additional information, editorial changes, and clarifications.
2.0	27 December 2015	Clarified wording and fixed typos in sections <a href="#">9.1</a> , <a href="#">10.1</a> , and <a href="#">11</a> . Added footnote in section <a href="#">12.1</a> about Clifton Laboratories.
3.0	3 September 2016	Added new Sections: <a href="#">14</a> (Troubleshooting) and <a href="#">15</a> (What to expect on the air). Added more information on combiner testing (Sections <a href="#">9.4.1</a> , <a href="#">9.4.2</a> , <a href="#">9.4.3</a> ). Fixed typos and added minor clarifications in multiple sections.
4.0	22 December 2016	Updated Section <a href="#">9.1</a> instructions for combiner (replace C1 with jumper wire). Updated Section <a href="#">9.4.2</a> for improved clarity and accuracy. Updated combiner schematic diagram in Section <a href="#">16.3</a> .

## 1 Background on the YCCC kits

The YCCC kits implement the key components of the low band receiving array described in W1FV's article, "A Compact Dual-Band, 9 Circle Receiving Array" that appeared in two parts in the September/October 2011 and November/December 2011 issues of NCJ. Builders are encouraged to read the article to understand the design, construction, and operation of this system. A few design improvements have been made since publication of the article. In cases where the information in the original article differs from what is described in this document, use what is presented here.

The implementation is based on the use of electrically short vertical antenna elements that are easy to build and erect, and electronics to implement to combining and phasing of element feeds to form a beam pattern that can be switched in multiple directions.

The array provides a highly directional beam pattern with a RDF (receiving directivity factor) of 12.1 dB on 160 meters, 11.3 dB on 80m, and 9.1 dB on 40m. See W8JI's Web site (<http://www.w8ji.com/receiving.htm>) for more information on RDF and its use as a metric for comparing different receiving antennas. Each dB increase in RDF generally translates into a one dB improvement in receiving SNR (signal-to-noise ratio) in the peak direction. In designing the array, primary emphasis was placed on 160-meter RDF performance, followed by 80 meters, and then 40 meters. On 160, the RDF of the array matches that of a terminated Beverage antenna that is 800-1000 feet long. On 80, its RDF exceeds that of a conventional 4-square array and is comparable to a 500-foot terminated Beverage. See Section [14](#) of this document for calculations of beam patterns for this array.

Note: Text in blue, [like this](#), represents a hyperlink to a Web page or another section or figure within this document. The listings in the Table of Contents at the beginning of this document are also hyperlinked to their respective sections. You can click a hyperlink to jump directly to the referenced item.

*Notes on kit building:* The Yankee Clipper Contest Club (YCCC) is cooperating with DX Engineering to provide kits to build the key electronics for the system. This includes all discrete parts, high-quality PCB's, and PCB enclosures. Kit ordering information can be found at: <http://www.dxengineering.com/search?keyword=yccc>. This manual includes assembly instructions for each of the kit units. Experience in building and working with electronics are prerequisites for building the kits. This includes soldering skills, the ability to read resistor color codes and other component markings, and some mechanical assembly skills. The kits have been designed for ease of assembly, with very little point-to-point wiring. However, if you are in doubt about your kit-building capabilities, please consider having someone with the necessary skills do it for you.

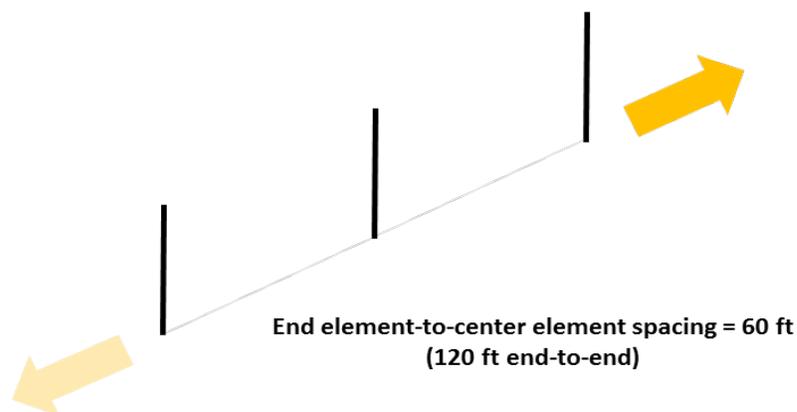
*Technical support:* Technical support for the kits is being provided solely by YCCC volunteers. Do not contact DX Engineering. Technical questions should be directed by e-mail to: [yccctechsupport@verizon.net](mailto:yccctechsupport@verizon.net).

## 2 Selecting an array configuration

### 2.1 Three different configurations

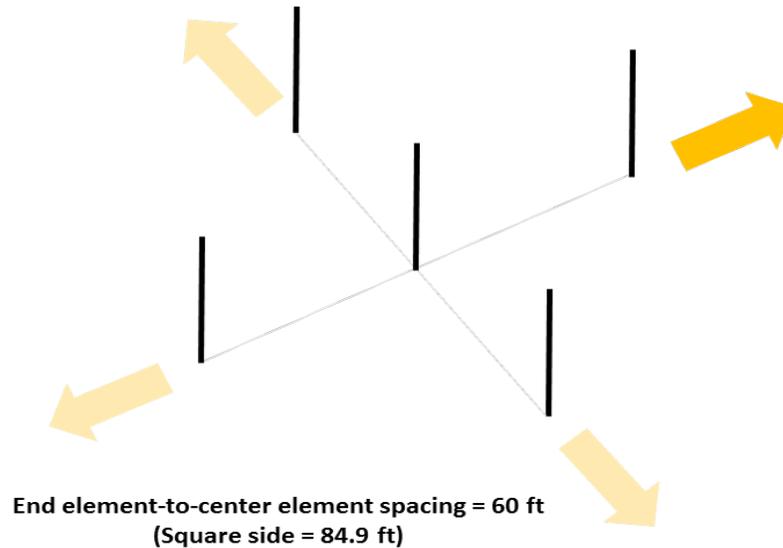
The user can select one of three possible array configurations. These employ a 3-element inline array, with 60-foot element-to-element spacing, as the basic building block. All three configurations generate the same beam pattern. The only difference is the number of switching directions. The YCCC kit supports all three options, with details to follow later.

1. 3-element inline: A single array with two directions of coverage as indicated by the arrows in [Figure 1](#). End-element to center-element spacing is 60 feet, giving an end-to-end span of 120 feet. Note that this spacing is different than the 70 feet originally specified in the NCJ article. The reason for the change is that improved performance is obtained on 80 meters with virtually no degradation on 160 meters. The closer spacing also yields a 40m beam pattern that may be useful, although not as directive as on 160 or 80.



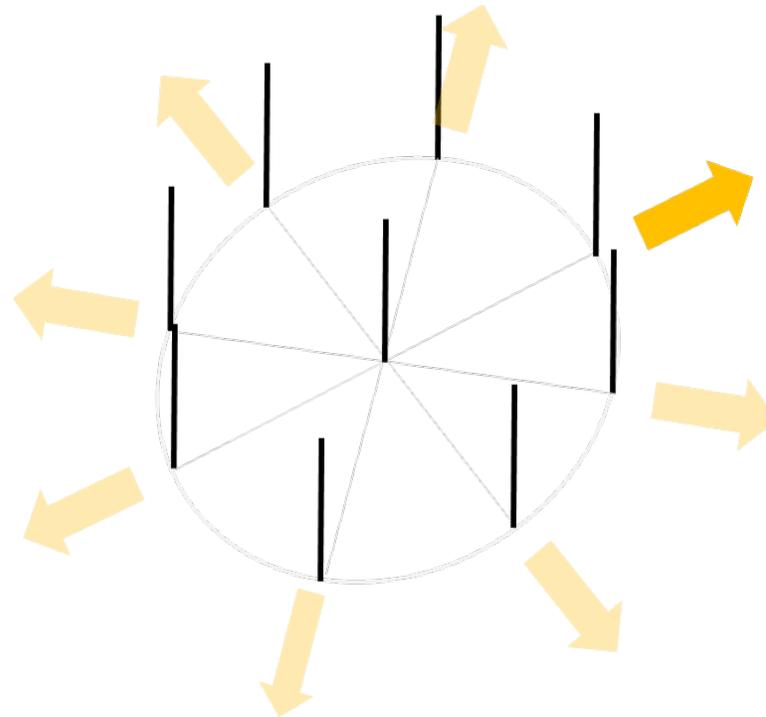
*Figure 1. 3-element inline configuration*

2. **5-element square:** Two 3-element inline arrays with a common center element. Switching circuitry selects which of the two inline arrays is activated. The elements are normally arranged to form a square, as shown in [Figure 2](#), so four directions of coverage, every 90 degrees in azimuth, are provided. End-element to center-element spacing is 60 feet, and the sides of the square are 84.9 feet. The inline arrays are independent and, if desired, can also be oriented in a non-square configuration. For example, the arrays can be aimed along the NE-SE axis and the E-W axis, forming a rectangle.



*Figure 2. 5-element square configuration*

3. **9-element circle:** Four 3-element inline arrays, with a common center element, laid out in a circular configuration as shown in [Figure 3](#). Switching circuitry selects which inline array is activated. The array provides eight directions of coverage, every 45 degrees in azimuth. The diameter of the circle is 120 feet.



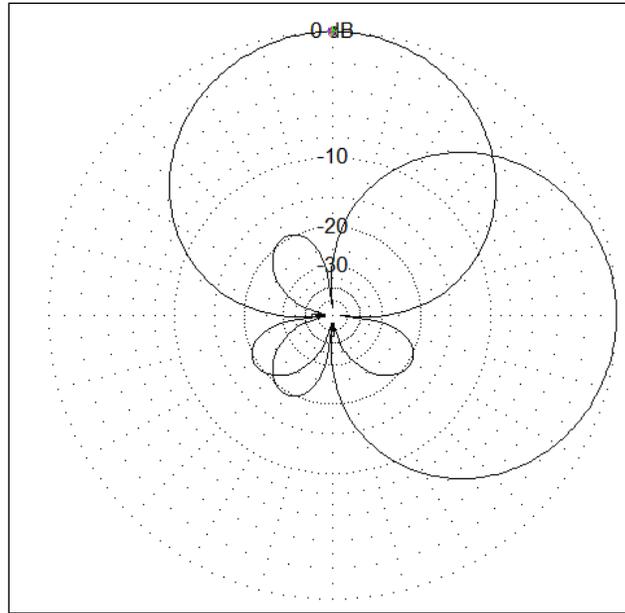
Outer element-to-center element spacing = 60 ft  
(Circle diameter = 120 ft)

*Figure 3. 9-element circular configuration*

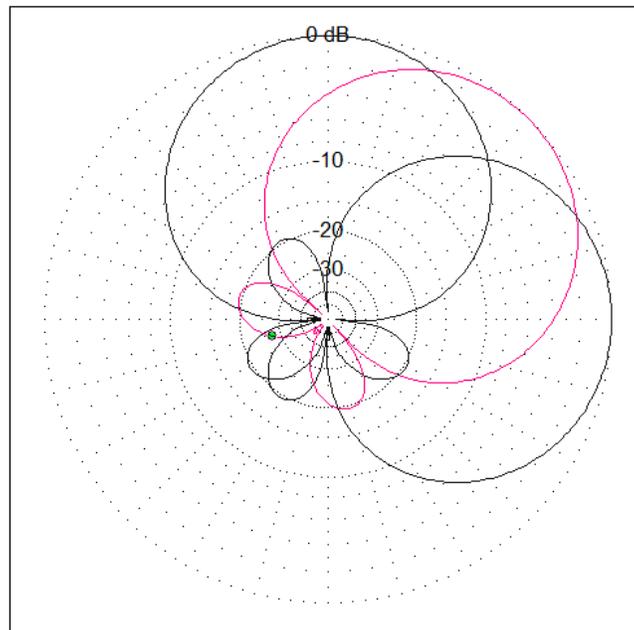
## 2.2 Choosing between the 5-element and 9-element configurations

Potential builders may question whether the additional cost and complexity of the 9-element configuration, with eight directions of coverage, can be justified relative to what the 5-element version offers with four directions of coverage. [Figure 4](#) and [Figure 5](#), calculated for 160 meters, are provided to help answer that question.

As you can see, the difference lies in the amount of overlap between adjacent switched directions. The red trace in [Figure 5](#) illustrates how the 9-element array fills in the gap between the patterns in [Figure 4](#). The individual patterns are otherwise identical in shape in all directions. The 9-element array does not provide any directivity improvement over the 5-element array other than the ability to cover additional directions. With 5 elements, the relative gain response has dipped by -4 dB relative to the peak where it crosses over to the next adjacent direction. This translates directly into a 4 dB reduction in RDF. With 9 elements, the loss is just -1 dB at the crossover point.



*Figure 4. Pattern overlap of 5-element array*



*Figure 5. Pattern overlap of 9-element array*

### **3 How a complete system is configured**

The system is based on the use of “active” receiving verticals that use amplification at the feedpoint to make up for the large amount of loss incurred with the very short element. [Figure 6](#) illustrates the concept. Each active element consists of three basic parts:

1. The vertical element (see [Section 6](#))

2. The feedpoint preamplifier that is built as part of this kit (see Section 8)
3. A ground rod

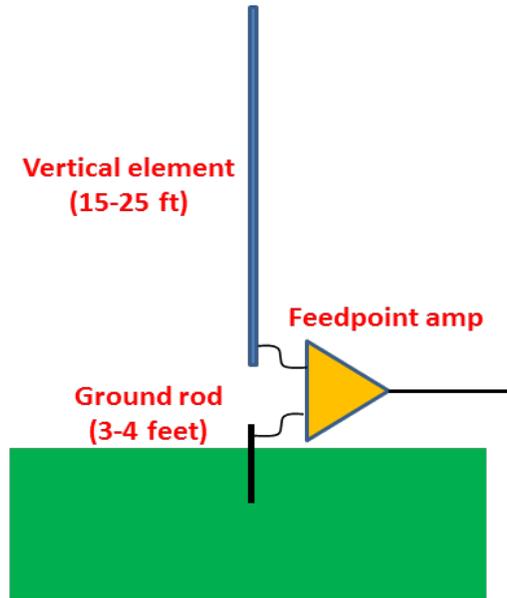


Figure 6. An “active” receiving antenna

Figure 7 shows how the various items are interconnected in a full 9-element array. The connections for the 3-element and 5-element systems are similar.

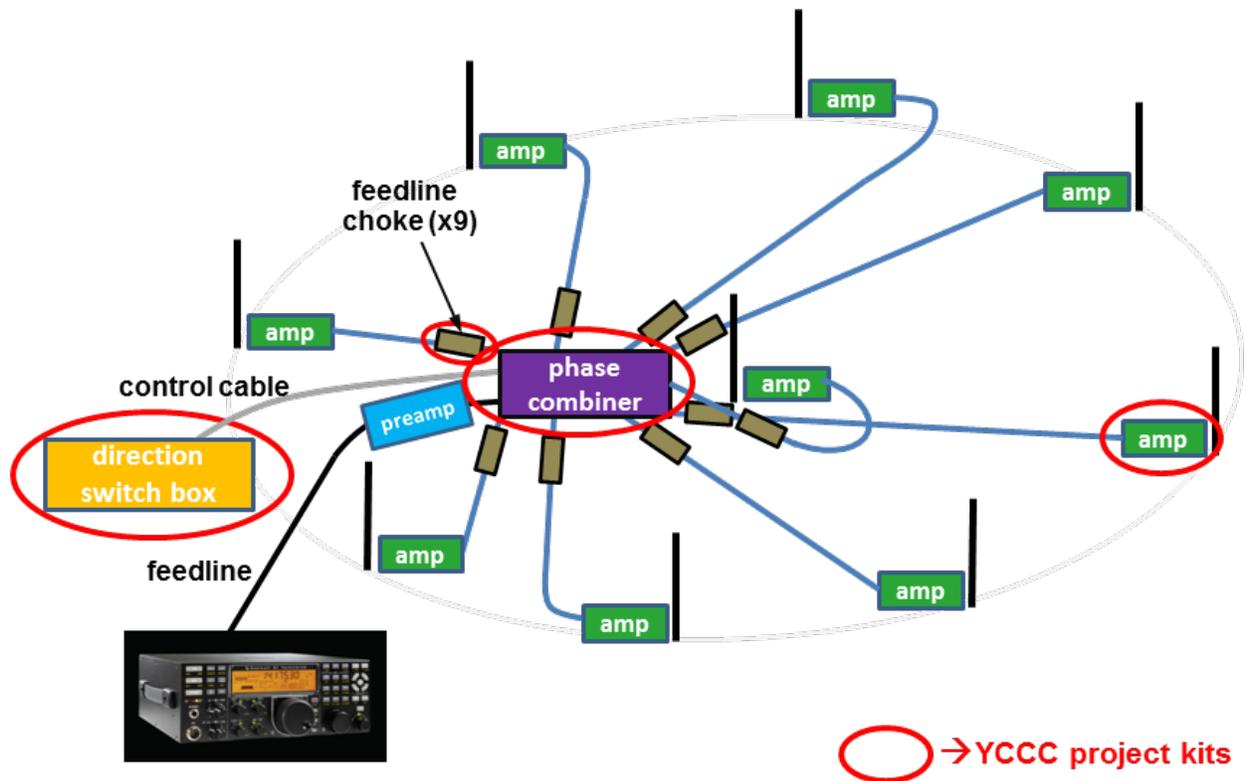


Figure 7. System diagram for a 9-element array

The YCCC kits supply the following items (circled in red in Figure 7):

1. Array combiner
2. Antenna feedpoint preamplifiers, one per element
3. Directional switch control unit
4. Feedline chokes, one per element

The builder must supply the following items:

1. RG-6 feedline (see Section 7)
2. 10-foot section of Schedule 40 PVC pipe
3. Control cable (see Section 9.5)
4. Materials to construct the vertical antenna elements (see Section 6)
5. Outboard preamplifier with 10-20 dB gain, as needed, between the phase controller/combiner and the receiver (see Section 12)
6. 12 V (or 13.8V)<sup>1</sup> regulated DC power supply (not a “wall wart”) with at least 1A current capability

#### 4 Ordering information

Kits are ordered through DX Engineering at either [DXEngineering.com](http://DXEngineering.com) or by calling 800-777-0703. The following three subsections list the quantities of kit components required to implement each of the three possible array configurations. DX Engineering has each unit available individually or in packages (see Section 17 for part numbers and pricing).

##### 4.1 Nine-element circle system

Item	Qty
Feedpoint preamp	9
Combiner/controller	1
Direction switch unit	1

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<sup>1</sup> Either 12 VDC or 13.8 VDC may be used with no difference in operation or performance. The DC voltage is used to power 12 volt switching relays and the active electronics in the preamps. The preamp circuit has voltage regulation (a Zener diode) that regulates the applied supply voltage, whether 12 or 13.8 VDC, down to 10 VDC. If you are using an outboard preamplifier (see Section 12.1) that requires 13.8 VDC, then it is recommended that you use 13.8 VDC rather than 12 VDC to power the entire system.

Chokes	9
--------	---

#### 4.2 Five-element square system

Item	Qty
Feedpoint preamp	5
Combiner/controller	1
Direction switch unit	1
Chokes	5

#### 4.3 Three-element inline system

Item	Qty
Feedpoint preamp	3
Combiner/controller	1
Chokes	3

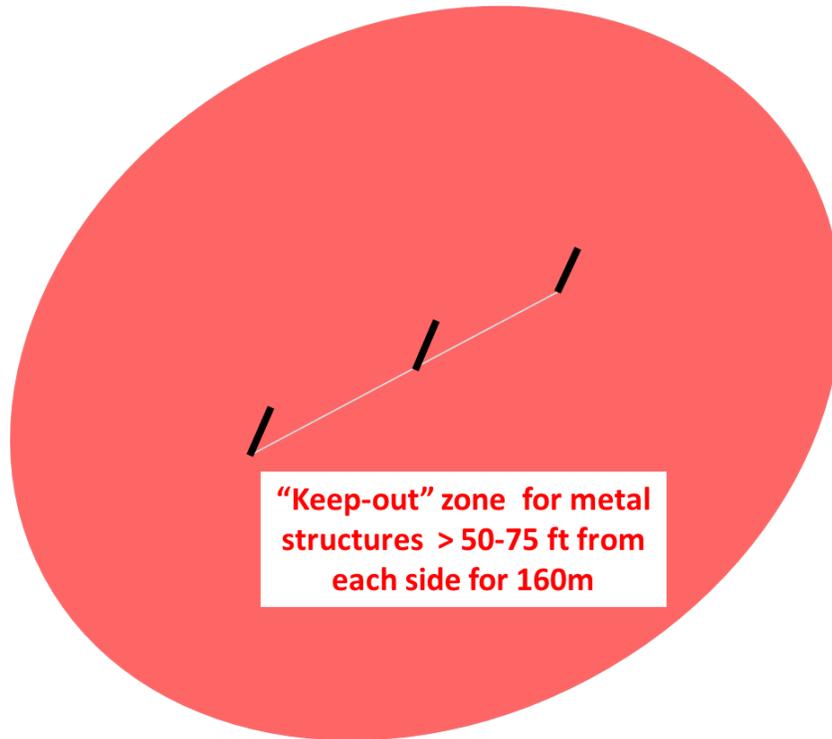
Note that a direction switch unit is not specified for the 3-element system. Although the YCCC switch unit will work with this system and could be ordered, it is a bit of overkill because only two switchable directions need to be supported. Instead it is recommended that builder construct the simple switching circuit described in Section [Figure 29](#).

## 5 Selecting and preparing a site

The verticals should be installed on level ground with little or no elevation change around the array. Clear away any foliage within 5 feet or so of each vertical. Trim away any tree branches that may come into contact with the verticals. Experience indicates that the presence of trees—even large ones—nearby has little noticeable effect on array performance, although a separation of at least a few feet between an array element and a large tree trunk is prudent.

Do not install the verticals near large metal objects (towers, other antennas, building structures, etc.). Do not allow any wires, such as Beverage antennas, or other metallic structures to pass into the interior of the array. If possible, maintain “breathing room” of at least 50 to 75 feet or more around all sides of

the array when 160m operation is intended. As an example, the “keep out” zone for metal structures around a 3-element inline system is shown below in [Figure 8](#) as the red shaded area.



*Figure 8. “Keep out” zone for 3-element inline system*

In order to realize a highly directive beam pattern in a relatively small footprint, tight tolerances in amplitude and phase must be maintained through the system. It does not take much in the way of stray coupling to nearby metal objects to upset a finely tuned system. In the special case where there is a resonant antenna nearby, such as a transmit vertical, detuning techniques should be applied to the resonant antenna. See [Section 13](#) for more information on how to minimize interactions.

## **6 Constructing the vertical elements**

All verticals must be constructed as identically as possible. The height is not critical, but they should all exactly the same. The recommended vertical height is 20 feet for operation on both 160 and 80 meters. Greater heights do not improve, or otherwise alter, the beam pattern but do yield somewhat greater signal output. The signal output scales roughly as 0.5 dB more signal for each foot increase in height in the range of 10 to 25 feet. For a system that is to be used only on 160 meters, heights up to 25 feet will provide plenty of signal output. Construction (tubing diameters, lengths) should be exactly the same for all vertical elements. All wiring from the vertical feedpoint preamplifiers to the vertical elements and to the ground rod connections should be kept as short as possible (no more than a few inches). All verticals should use exactly the same wiring lengths in the same physical arrangement. Ideally the environments around each vertical should be the same.

A 3- to 4-foot ground rod close to the base of each vertical is sufficient for a grounding system under each vertical. Do not use radials because wires of significant length in the vicinity of electrically short vertical elements will induce beam-pattern distortion.

Figure 9 shows a construction technique for a self-supporting vertical approximately 20 feet tall and completely self-supporting. The vertical is constructed from telescoping sections of aluminum tubing with diameters of 5/8", 1/2", and 3/8". Allow 6" of overlap between telescoping sections.

The bottom section inserts inside a 3-foot section of a 0.5" ID PVC tube. A 3-foot angle iron is driven into the ground, leaving approximately 9 inches extending above ground. Use two hose clamps to secure the bottom of the PVC tube to the angle iron. *Maintain some vertical separation between the bottom of the aluminum tube and the top of the angle iron to reduce stray capacitance between the element and the angle iron.*

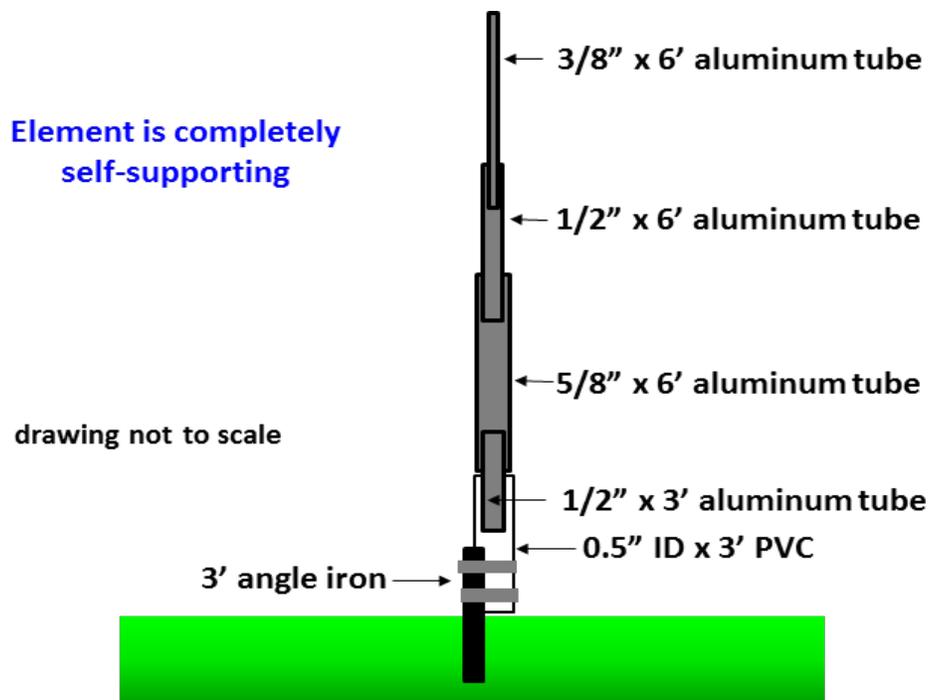


Figure 9. Construction of an aluminum tubing vertical

To make an electrical feedpoint connection to the vertical element, drill a hole through the PVC tube and into the lowest point on the bottom section of aluminum tubing. Insert a stainless sheet metal screw through this hole.

Each inline group of elements should be maintained in as straight a line as possible. Side-to-side deviations up to two or three feet can be tolerated, however, with little effect on the array pattern. However, the 60-foot spacing between center and end elements should be held very tightly.

Aluminum tubing for constructing the vertical elements may be purchased from a number of sources, including DX Engineering (<http://www.dxengineering.com/search/department/rigid-tubing/part-type/aluminum-tubing>).

Ready-to-install vertical systems are also available from DX Engineering (<http://www.dxengineering.com/parts/dxe-al24>).

## 7 Choosing feedlines

Use high quality RG-6 for the feedlines between the antennas and the controller/combiner unit. The most important parameter is the characteristic impedance of the line because a 75 ohm impedance must be maintained throughout the system to insure phasing accuracy. Although all RG-6 cables are specified nominally at 75 ohms, we have measured a number of different makes of RG-6 lines that differ significantly from 75 ohms. We recommend Commscope flooded RG-6 or equivalent, which is available from many vendors. DX Engineering sells a flooded RG-6 feedline that is equivalent:

<http://www.dxengineering.com/search/department/cable-and-connectors/product-line/dx-engineering-6uf-75-ohm-dual-shield-coaxial-cable?autoview=SKU&N=4294953052%2B4294951385&sortby=Default&sortorder=Ascending>.

The phase combiner/controller is designed to work with EQUAL LENGTH FEEDLINES between each of the elements and the controller. Referring to [Figure 7](#), the actual length of the feedlines between the vertical elements and the phase combiner/controller is not critical, but whatever the lengths, they must all be EXACTLY THE SAME. If the combiner is located at the center of the array, which will be typical for most installations, then a feedline length of 70 feet should be sufficient.

## 8 Antenna feedpoint preamplifier assembly

### 8.1 Step-by-step instructions

A small fine-tip soldering iron is recommended for all soldering work. The component numbers and outlines are silkscreened on the top of the PCB to make it easy to identify correct parts placement. Refer to [Figure 11](#) as you follow these instructions. Color codes for the various resistors are provided below for easy identification. If you are still unsure about the value of a resistor, measure its resistance with an ohmmeter.

1. Inventory the parts against the following list to be sure all parts are on hand:

Qty.	Part description
1	AD8055ANZ op amp
1	Ferrite binocular core
2	100K $\Omega$ (brown, black, yellow) resistor 1/4W
2	470 $\Omega$ (yellow, violet, brown) resistor 1/4W
1	150 $\Omega$ (brown, green, brown) resistor 1/4W
1	75 $\Omega$ (violet, green, black) resistor 1/4W

2	0.22 $\mu$ F capacitor
2	0.1 $\mu$ F capacitor
1	10 $\mu$ F capacitor
1	5 pF capacitor
2	470 $\mu$ H RF choke
1	1N4740A 10V zener diode
1	Female F connector, right angle PCB
1	PCB
2	Wing nut, 8-32
2	Nut, 8-32
2	Screw, 8-32x1"
2	Lock washer, 8-32
4	Flat Washers, 8-32
2	3/8-32 nuts for F connectors
2	Solder lugs
1	Length of red magnet wire, 28 AWG
1	Length of green magnet wire, 28 AWG
1	Length of black hookup wire
1	Length of white hookup wire

2. Looking at the top (component) side of the board, you will see for the resistors that the value and the part designator are both stenciled on the board. For the other parts, just the part designator (for example, C1, RFC1, etc.) is stenciled on the board.
3. Install and solder R1 and R2, 100K (brown, black, yellow) resistors.
4. Install and solder R4 and R5, 470 ohm (yellow, violet, brown) resistors.
5. Install and solder R3, 150 ohm (brown, green, brown) and R6, 75 ohm (violet, green, black) resistors.
6. Install and solder diode D1 - match the dark band on one end of the diode to the white bar on the silkscreen.
7. Install and solder RF chokes RFC1 and RFC 2, 470  $\mu$ H chokes (light green body color).
8. Wind T1 on the binocular ferrite core with a 5-turn primary using green magnet wire and a 5-turn secondary using red magnet wire. Please note that the insulation must be scraped off the wire with a knife or sandpaper where solder connections are made. The insulation is not solder-strippable. Refer to [Figure 10](#) as an example of a transformer winding. The primary and secondary windings should exit from opposite ends of the core.

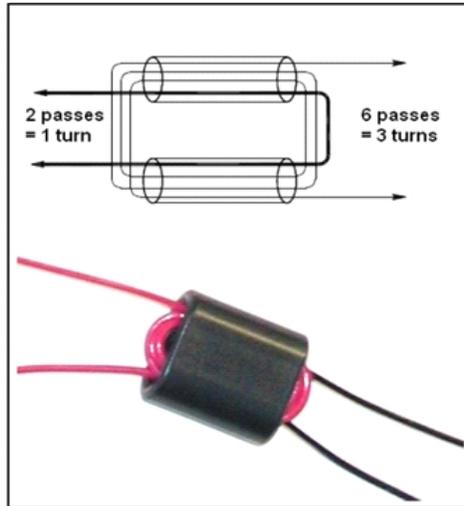
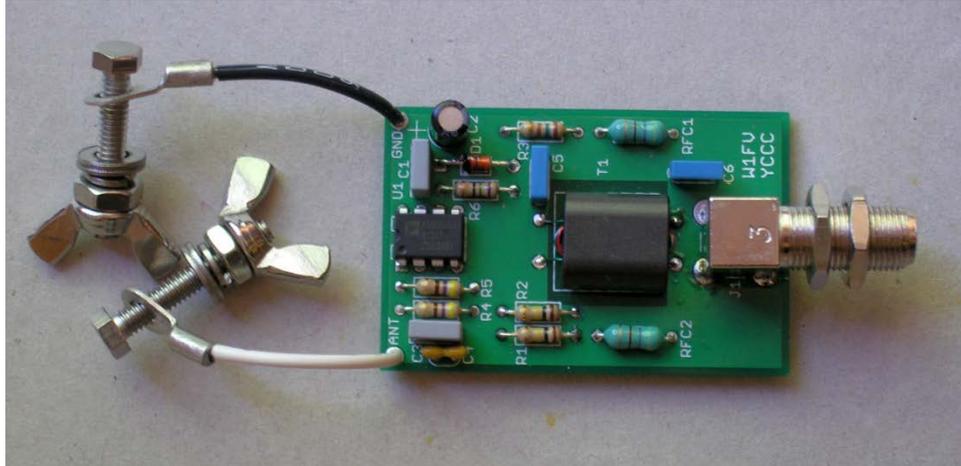


Figure 10. Transformer winding technique

9. Install and solder T1 - the red windings should go on the side facing connector F1.
10. Install and solder C5 and C6, .22  $\mu\text{F}$  capacitors ( $\mu\text{22J3}$  marking, blue body color).
11. Install and solder C1 and C3, 0.1  $\mu\text{F}$  capacitors (100n marking, gray body color).
12. Install and solder C4, 5 pF mica capacitor (5D marking, dark yellow body color).
13. Install and solder C2, 10  $\mu\text{F}$  electrolytic capacitor - observe polarity; the grey marking on the side of the body is the negative lead and goes on the side opposite the "+" marking on the PCB.
14. Install and solder integrated circuit U1 on the PCB. Make sure the IC is oriented correctly, with the small notch on the end of the IC facing the end of the PCB.
15. Solder the J1 pins to the foil side of the PCB. This will place J1 on the top of the board, the same side as the components as shown in [Figure 11](#).
16. Solder a 1 1/2" white wire through the ANT hole on the PCB. Solder a lug to the other end of the wire.
17. Solder a 1 1/2" black wire through the GND hole on the PCB. Solder a lug to the other end of the wire.
18. Thread a 3/8"-32 nut onto J1 most of the way.
19. Install the mounting screw hardware through the lugs on the ANT and GND wires and leave them loose for now. The order of hardware from inside to outside of the enclosure will be:
  - screw head
  - solder lug
  - flat washer
  - pipe wall
  - flat washer
  - lock washer
  - nut
  - wing nut

Cut off all excess component lead lengths on the bottom side of the PCB. A finished PCB is shown in [Figure 11](#).



*Figure 11. Feedpoint preamplifier PCB*

## **8.2 Building the enclosures**

To save money on the cost of nine enclosures for the feedpoint preamplifiers, we use enclosures made from 2" ID Schedule 40 PVC pipe, which is available at almost any hardware store or from home supply vendors such as Home Depot or Lowe's. PVC is also used as an enclosure for the feedline chokes (see Section 11). It is not included as part of the kit because it would cost more to ship an oversize pipe section than to have builders obtain the pipe on their own. PVC end caps are used to seal off the ends of the pipe enclosures. The builder should buy caps with flat ends rather than domed ends. The builder should also obtain PVC cement, which is available wherever PVC pipe is sold.

Cut a 4" length of PVC pipe. Drill a 3/8" hole in the center of one end cap and push the F connector through the hole as illustrated in Figure 12. Secure tightly with a nut on the outside of the cap. This cap will be the bottom of the enclosure so that the feedline drops vertically from it. Temporarily mount the cap with the attached PCB to the 4" pipe section without glue.



*Figure 12. Preparation of end cap for preamplifier enclosure*

Drill two holes with an 11/64" drill bit on the sides of the PVC pipe to align with the end of the PCB where the antenna and ground wire connections will be made to the screw connections through the PVC pipe. Remove the end cap from the pipe.

Apply a generous amount of PVC cement around the end of the PVC pipe and on the inside of the end cap. Mount the end cap on the pipe. Allow the cement to dry overnight.

After the glue is dry, install the screw terminals for antenna and ground leads through the holes that were drilled in the pipe. Then tighten down the outside nut so that the wing nut can be screwed on and off without the screw coming loose. It is suggested that the antenna and ground screw terminals be labeled on the outside of the PVC pipe as ANT and GND. The partially finished assembly should look like [Figure 13](#).



*Figure 13. Mounting of PCB inside PVC pipe*

Mount a second end cap onto the open end of the pipe. It is not necessary to cement this cap, but just push it on tightly. This will allow the cap to be removed if the enclosure ever needs to be opened in the future.

Figure 14 shows a finished feedpoint preamplifier unit.



*Figure 14. Completed feedpoint preamplifier*

Although the cemented caps are reasonably watertight, it is possible for moisture to seep in. Therefore, it is essential to provide a means for water to drain out and for the enclosure to “breathe”. Drill two

small drain holes through the bottom end cap. A 5/64 inch hole (#47 drill bit, or 2mm) allows air and water flow, while restricting insect ingress.

For reference, a schematic of the feedpoint preamplifier is provided in Section [14.2](#).

### 8.3 Connecting up the feedpoint preamplifier

The antenna and ground connections are made as shown in [Figure 6](#), with the ground terminal connected to a ground of three to four feet in length. The controller/combiner and feedpoint preamplifier circuits are designed to pass and accept DC power for the preamplifiers through the feedlines, so no separate DC power connection is needed at the preamplifier.

## 9 Phase combiner/controller assembly

### 9.1 Step-by-step instructions

1. Inventory the parts against the following list to be sure all parts are on hand:

Qty	Part description
5	Ferrite binocular core
1	75Ω (violet, green, black) resistor 1/4W
2	240Ω (red, yellow, brown) resistor 1/4W
1	12Ω (brown, red, black) resistor 1/4W
1	150Ω resistor (brown, green, brown) 1/4W
2	1.0Ω (brown, black, gold) resistor 1/4W
1	3300Ω (orange, orange, red) resistor 1/4W
9	470 μH RF choke
3	0.22 μF capacitor
1	0.047 μF capacitor
14	Female F connector
4	DPDT 12VDC relay
1	PCB
1	Enclosure, pre-drilled
1	Terminal block, 5 contacts
1	Terminal block plug, 5 contacts
1	52 inches of red magnet wire, 28 AWG
1	60 inches of green magnet wire, 28 AWG
14	3/8-32 nuts for F connectors
4	Phillips head screw

2. Looking at the top (component) side of the board, you will see for the resistors that the value and the part designator are both stenciled on the board. For the other parts, just the part

designator (for example, C1 or RFC1) is stenciled on the board. The top side of the PCB is also identified by the Yankee Clipper Contest Club logo stenciled onto the board. All components except the F connectors and terminal block mount to the top side of the PCB. Refer to [Figure 16](#) and [Figure 17](#) as you follow these instructions. Note that the labels on the transformers shown in [Figure 16](#) are for reference for identifying the transformers but the labels are not included in the kit.

3. Install and solder the four relays, K1 through K4.
4. Install and solder R1, 75 ohm (violet, green, black) resistor.
5. Install and solder R2, 240 ohm (red, yellow, brown) resistor.
6. Install and solder R3, 12 ohm (brown, red, black) resistor.
7. Install and solder R4, 240 ohm (red, yellow, brown) resistor.
8. Install and solder R5, 150 ohm (brown, green, brown) resistor.
9. Install and solder R6 1.0 ohm (brown, black, gold) resistor.
10. Install and solder R7, 3300 ohm (orange, orange, red) resistor.
11. Install and solder R8, 1.0 ohm (brown, black, gold) resistor.
12. Install and solder the nine RF chokes, RFC1 through RFC9, all 470  $\mu$ H (light green body color).
13. A jumper wire will be used in place of C1. (A change to the original design has eliminated C1, so it is no longer needed, although the part is still included in the parts kit). Cut a short (1/2 inch) piece of bare wire and solder it across the location marked for C1.
14. Install and solder C2, C3, and C4, all 0.22  $\mu$ F capacitors ( $\mu$ 22J63 marking, blue body color).
15. Refer to [Figure 41](#) for configuration of the different transformers. Please take care to wind and install the transformers exactly as described here. Mistakes here will prevent the combiner from working properly.
16. The next five steps describe the winding of the transformers using 28 AWG magnet wire. Please note that the insulation must be scraped off the wire with a knife or sandpaper where solder connections are made. The insulation is not solder-strippable.
17. Transformer T1 is 10 turns center-tapped using **9 inches of green 28 AWG** and **9 inches of red 28 AWG**. As in [Figure 10](#), two passes form one turn. First wind 5 turns of the green wire through the core and then start a second winding of 5 turns with the red wire. Solder the end of the first 5 turns to the beginning of the second 5 turns to form the tap point. Solder the three transformer connections to the PCB. The center tap goes to the middle hole on the PCB. Because of the symmetry of the tapped transformer, it does not matter which ends of the transformer go to the outer holes.
18. Transformer T5 is 7 turns, tapped at 5 turns above ground, using **9 inches of green (5 turns) 28 AWG** and **3-5/8 inches of red (2 turns) 28 AWG**. Solder the green and red wires together to form the tap connection. The mounting holes on the PCB for T5 are labelled GND, R/G, R. Solder the green wire to GND. Solder the tap (where red and green are joined) to R/G. Solder the red wire to R.
19. Transformers T2, T3, are T4 are wound as bifilar transformers. [Figure 15](#) shows the bifilar winding technique. Take two wires (shown as red and green in the figure) in parallel and wind them through the binocular core, keeping them together as though they were a single wire. As in [Figure 10](#), two passes form one turn.

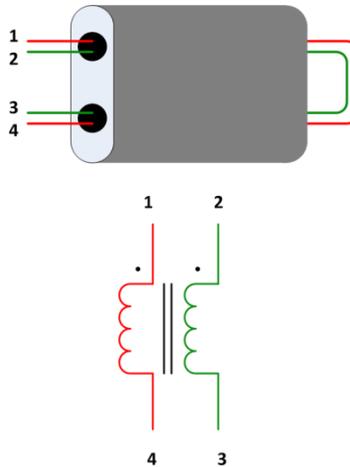


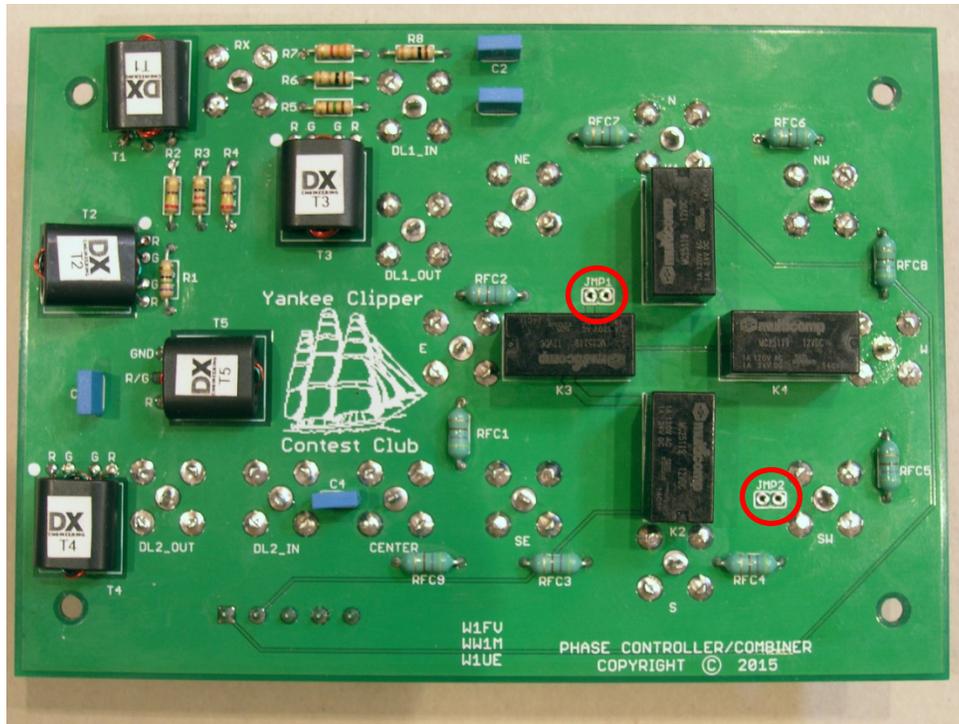
Figure 15. Bifilar winding technique

20. Transformers T2 and T3 are each 7 bifilar turns using **13 inches of green 28 AWG** and **13 inches of red AWG**. The red and green wires will each make 7 complete turns through the core. The mounting holes on the PCB for T2 and T3 are labelled R, G, G, R. Take the wires from one end of the bifilar winding and solder the red wire to R and the green wire to the adjacent G hole. Take the wires from the other end of the bifilar winding and solder the red wire to R and the green wire to the adjacent G hole. Because of the symmetry of the bifilar winding, it does not matter which end of the winding is soldered to each pair of R and G holes.
21. Transformer T4 is 6 bifilar turns using **11 inches of green 28 AWG** and **11 inches of red 28 AWG**. The red and green wires will each make 6 complete turns through the core. The mounting holes on the PCB for T4 are labelled R, G, G, R. Take the wires from one end of the bifilar winding and solder the red wire to R and the green wire to the adjacent G hole. Take the wires from the other end of the bifilar winding and solder the red wire to R and the green wire to the adjacent G hole. Because of the symmetry of the bifilar winding, it does not matter which end of the winding is soldered to each pair of R and G holes.
22. Install and solder all 14 female connectors to the bottom side of the PCB as shown in [Figure 17](#). Do not yet install the nuts.
23. Install and solder the 5-pin terminal block J1 to the bottom side of the PCB as shown in [Figure 17](#). Make note of the labelling of the connections (+12V, GND, K3/4, K2, K1) for future reference. The mapping to connector pin numbers is:
  - K1 to pin 1
  - K2 to pin 2
  - K3/K4 to pin 3
  - GND to pin 4
  - +12V to pin 5
24. If you are building the 3-element inline system, install two short wire jumpers through the holes circled in red in [Figure 16](#). The jumpers bypass the unneeded relay switching circuitry on the PCB when there are only three antenna elements to be switched. If you are building either the 5-element square or 9-element circle systems, do not install the jumpers and leave the holes as

is.

25. Cut off all excess component lead lengths on the bottom side of the PCB.

26. The two sides of the finished combiner PCB should now look like [Figure 16](#) and [Figure 17](#).



*Figure 16. Component side of combiner PCB (jumper locations circled in red—see text)*

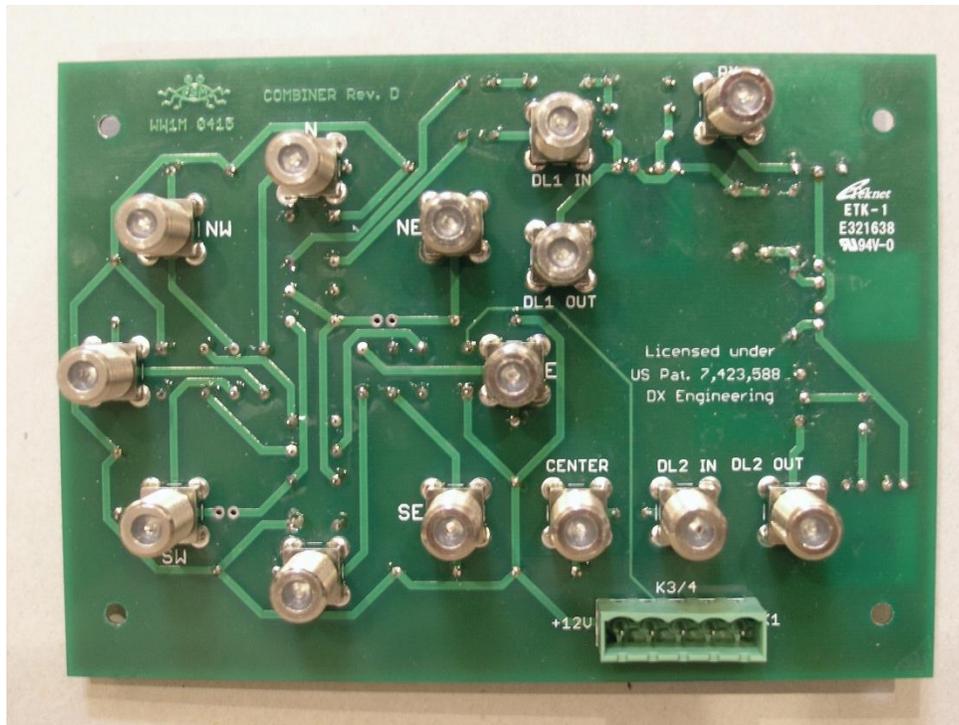
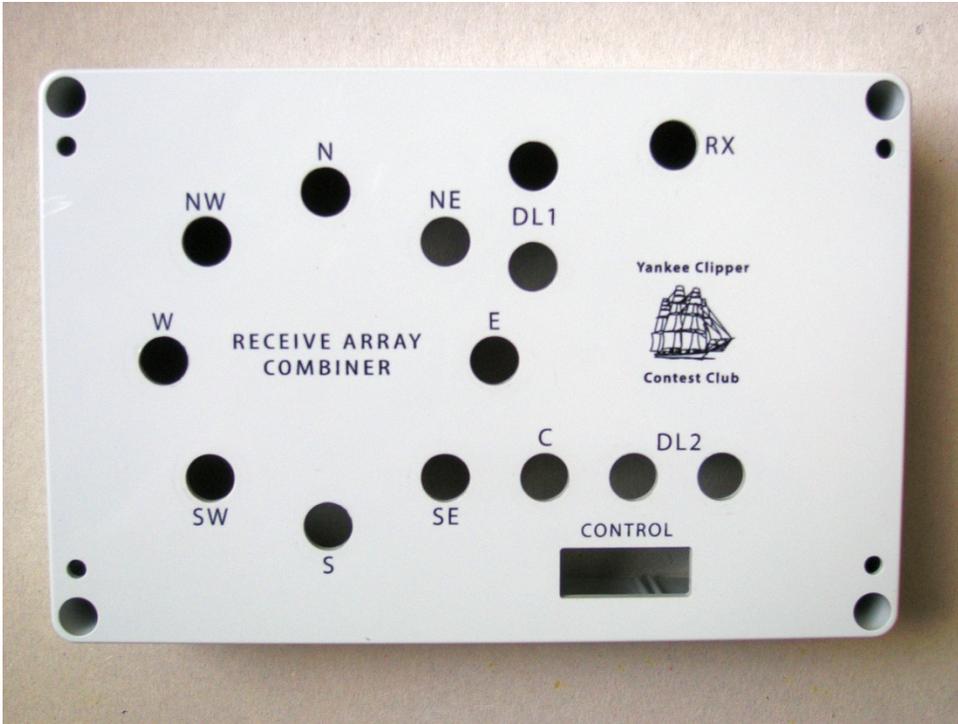


Figure 17. Bottom side of combiner PCB

27. A predrilled combiner enclosure is provided in the kit for easy installation of the PCB. See [Figure 18](#).



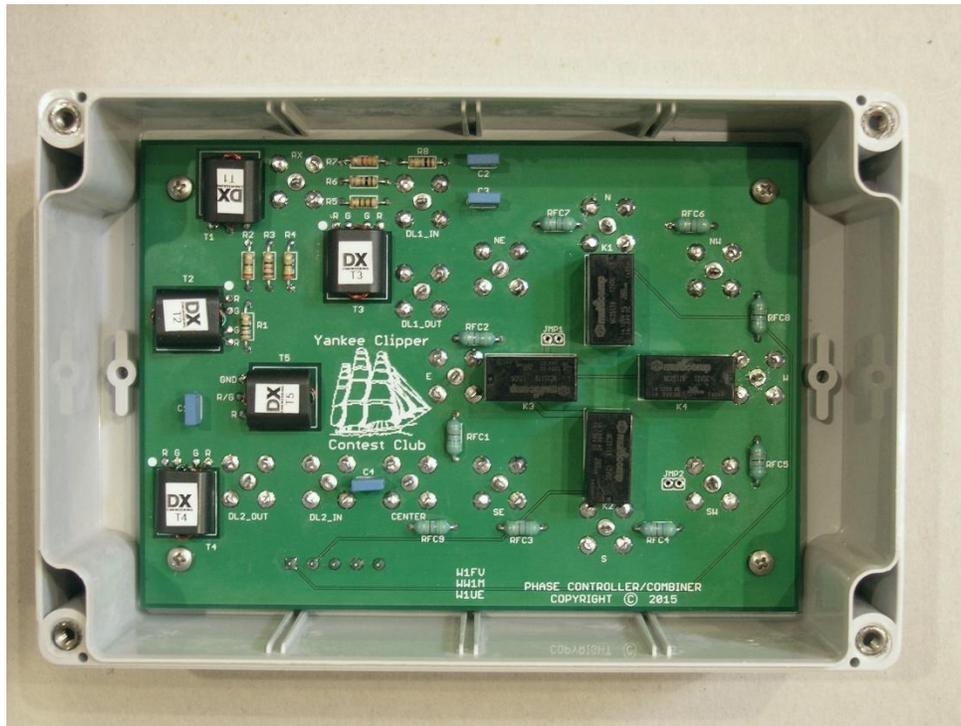
*Figure 18. Bottom view of pre-drilled combiner enclosure*

The enclosure includes a cover with a string rubber gasket that must be put in place. Push the gasket into the groove around the perimeter of the inside of the cover. Cut off any excess gasket material when done. The cover with gasket in place should look like [Figure 19](#).



*Figure 19. Combiner cover with gasket in place*

28. Mount the PCB by passing the F-connectors and the terminal block through the holes. There are four mounting holes at the corners of the PCB (refer to [Figure 20](#)). These holes line up with threaded holes inside the enclosure. Install Phillips screws at each of the corners to secure the PCB to the inside of the enclosure. Then install and tighten the nuts on all 14 F-connectors on the outside of the enclosure. The finished unit should look like [Figure 21](#).



*Figure 20. Inside view of PCB mounted in enclosure*

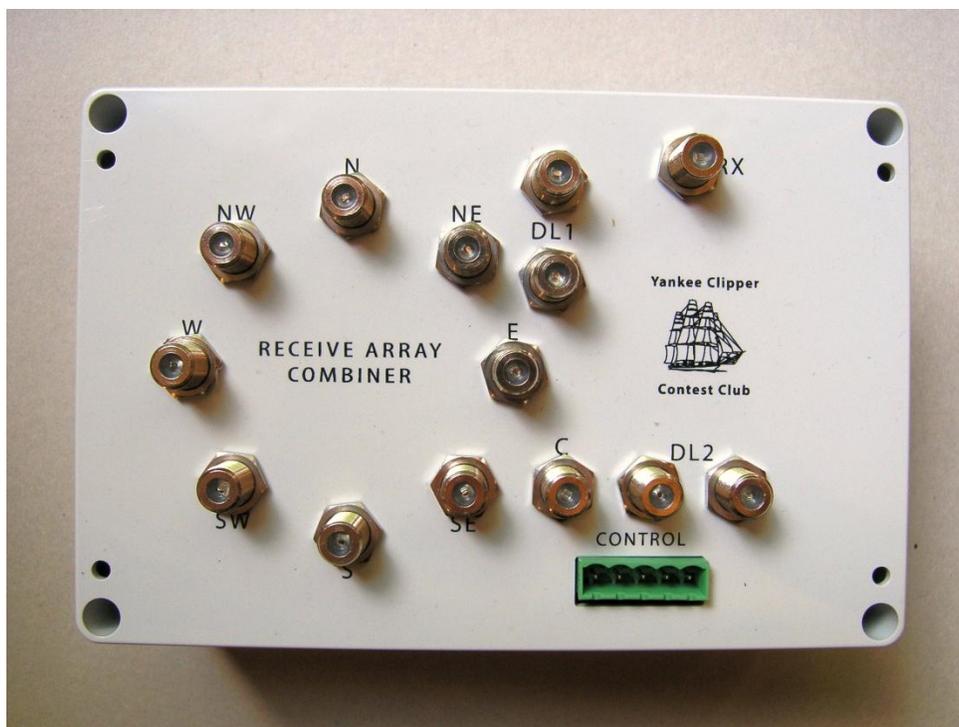


Figure 21. Bottom view of combiner enclosure with PCB mounted inside

## 9.2 Cutting the delay lines

The combiner/controller requires connection of two RG-6 delay lines (DL1 and DL2 in Section 9.5) as part of the phasing circuitry. DL1 comprises a 40 degree phase delay as measured at 1.83 MHz while DL2 is 20 degrees. When DL1 and DL2 are cut to these lengths, they will also be the correct lengths for the higher frequencies (80 and 40 meters), which allows multiband operation with a single set of delay lines and no band-switching. To minimize phase errors and maximize directivity of the array, it is very important that these lines be cut accurately. Do not rely on the published velocity factor ( $V_f$ ) for a particular coax cable because it is not always accurate or it sometimes varies with frequency.

If you are using the Commscope flooded RG-6 coax cable referenced in Section 7, then the correct delay line lengths for this cable are as follows: DL1 is 49 feet, 10 inches and DL2 is 25 feet exactly.

If you are using a RG-6 line other than the Commscope RG-6, then the lines should be cut according to the instructions that follow. An accurate antenna analyzer, such as the MFJ 259B or AEA VIA, that can measure complex impedance (Z, R, and X) is required. A VNA (vector network analyzer) may also be used if you are fortunate enough to have access to one. If you do have a VNA, it is assumed you know how to make two-port phase delay measurements on coaxial lines. Therefore, the instructions that follow apply only to the antenna analyzer method.

The trick to cutting a line with a specific phase delay at a specific frequency is to recognize that phase delay for a given line length scales directly with frequency. The easiest way to cut a 40 degree cable at 1.83 MHz is to find the frequency where that line becomes 90 degrees in electrical length. When it is 90

degrees long, the input impedance at one end will (ideally) look like a short circuit when the far end is left open-circuited. This condition is then easy to measure with the analyzer. The 40-degree line at 1.83 MHz becomes a 90 degree line at  $1.83 \times (90/40) = 4.118$  MHz by applying frequency scaling. Similarly, the 20-degree line at 1.83 MHz becomes a 90 degree line at 8.235 MHz.

To cut the 40 degree line, start with a length of RG-6 that will be slightly longer than will be required, using the specified velocity factor as a starting point for determining approximate length. As an example, let's assume the velocity factor is  $V_f = 0.85$ . If this figure is truly accurate, then the correct length would be  $.85 \times (984/1.83) \times (40/360) = 50.78$  feet. However, we will start by cutting the line to approximately 55 feet long. Install a male F-connector on one end of the cable. Leave the other end open with no connector. Connect the F-connector end of the line to the analyzer (using a connector adapter as necessary to mate to the analyzer). Then sweep the analyzer to find the frequency where either of the two conditions (preferably the first) occurs:

1. Reactance  $X=0$  (or as close to zero as possible), or
2. Total impedance  $Z=0$  (or as close to zero as possible).

This frequency should be lower than 4.118 MHz. Trim off a small amount of line from the far end of the cable and repeat the process until you obtain  $X=0$  (or  $Z=0$ ) at 4.118 MHz, at which point the line length is correct. Install a second F-connector on the open end of the cable.

The process is the same for the 20 degree line, except that the line will should be half as long. Start with a line that is about 27-28 feet long and trim until you obtain  $X=0$  (or  $Z=0$ ) at 8.235 MHz.

### **9.3 Cutting antenna feedlines**

The combiner requires the feedline lengths from every array element to the combiner to be exactly the same. The exact length is not critical at all. What is important is that the lengths be identical. If the combiner is located at the center of the array, a feedline length of about 70 feet, including the feedline from the center element, should be sufficient to reach from each element to the combiner. The feedline to the center element may simply be coiled for neatness. Note that each feedline will connect to a feedline choke first before it terminates in the combiner box, as shown in [Figure 7](#).

### **9.4 Testing the combiner circuit**

First, a note on the nine RF chokes in the combiner circuit: These are relatively fragile devices in terms of current handling and they are easily damaged by excessive DC current flow. In normal operation the current flow through the chokes is very small and this is not an issue. However, they can be damaged if any of the antenna ports are accidentally short-circuited. Take great care to avoid shorting these ports!

As a first test, measure the DC resistance across each of the nine RF chokes on the combiner board. They should all be  $6\Omega \pm 1\Omega$ . A damaged or defective choke will measure as open-circuited or close to short-circuited (zero ohms).

### 9.4.1 Optional impedance analyzer test

If you have an accurate antenna/impedance analyzer such as the MFJ 259B, AEA VIA, AIM4170, etc., a few simple measurements may be performed to check for correct assembly of the combiner circuit before installing it in the field. If you have a VNA, you may skip this test and proceed to the VNA test described in Section 9.4.2. If you do not have a VNA or an impedance analyzer, skip these sections.

The first test is to confirm that the termination impedance on all four combiner ports is  $75\Omega$ . Significant deviations (more than a few ohms) from this value indicate wiring or component errors. The most likely cause of errors is incorrectly wound transformers since the PCB virtually eliminates the possibility of other wiring errors (other than misplaced components). This test requires three non-inductive  $75\Omega$  resistors. For ease of testing, make up three 75-ohm F-connector terminations, each with a 75-ohm resistor and a male F-connector. Use the shortest leads possible between the resistor and the F-connector.

Connect the delay lines DL1 and DL2 to their respective ports. There are 4 antenna ports involved in this test: NE, SW, C, RX. When the analyzer is connected to any one of the 4 ports, the other 3 ports must be terminated in 75 ohms. When you move the analyzer from port "A" to port "B", remove the resistor from port B, move the analyzer from port A to port B, and then place the resistor on port A. In other words, every one of the 4 ports must have either an analyzer or a 75 ohm resistor in place during this test. Connect a  $75\Omega$  resistor to each of the NE, SW, and C antenna ports and the analyzer to the RX port. Do NOT connect the 12 VDC (or 13.8 VDC) source for this test. The RX port impedance, as measured by the analyzer, should be  $75\Omega$  resistive +/- a few ohms with little or no reactance on 1.8 through 4.0 MHz.

Repeat the same test with the analyzer connected to the NE port and a  $75\Omega$  resistor on the RX port. The analyzer should read  $75\Omega$  +/- a few ohms. Repeat the test for the SW and C ports.

If any of the measurements are not close to  $75\Omega$ , refer to Section 9.4.3 on transformer testing.

### 9.4.2 Optional VNA test

If you have a VNA, you can perform a comprehensive test of the functionality of the combiner by measuring the complex  $S_{21}$  (gain and phase) parameters at the antenna ports. A VNA has two ports, call them "A" and "B". Port A drives a signal into the input port of the device under test (DUT) and the output port of the DUT drives port B.

The VNA's port B connects to the combiner RX port. VNA port B typically presents a 50 ohm load to the DUT. The combiner circuit is designed to drive 75 ohm loads on its antenna ports, so VNA B port should be made to look like 75 ohms. This can be done in one of two ways (do not do both):

1. Connect a 50 ohm-to-75 ohm impedance transformer, like that in [Figure 38](#), between the combiner's RX port and VNA port B. The 50 ohm side of the transformer goes to the VNA.
2. Connect a series resistance of 25 ohms (two 50 ohm resistors in parallel can be used) to the center pin connection to port B so that a total of  $25+50=75$  ohms is seen by the DUT.

Make up two 75-ohm F-connector terminations, each with a 75-ohm resistor and a male F-connector. Use the shortest leads possible between the resistor and the F-connector.

The VNA typically requires that a “through” calibration procedure be run between ports A and B before measurements are made. All the cabling that will be used for making connections between the VNA and the combiner in the S21 measurements must be in place for the calibration process. Use 75-ohm cable (short lengths of RG-6 will do) for these connections. Perform this calibration by connecting VNA port A to the center (C) port of the combiner and VNA port B (with the transformer or series resistance, as described above, in the path to port B) to the combiner RX port. Connect the two 75-ohm terminations to the NE port and the SW port. Set the frequency span for this calibration and the subsequent measurements to 1 to 4 MHz. Remove any DC power supply connections from the combiner because DC power is not used in these tests.

The through calibration establishes the S21 parameter for the RX-to-center-port path as unity gain (0 dB) and zero phase, against which other ports will be referenced. What matters for proper functioning of the combiner is the relative, not absolute, gains and phases of the other antenna ports referenced to the center port. Once the calibration is complete, measure S21 for the center-to-RX port path to confirm the correct results. You should see 0 dB gain and 0 degrees phase (or very close to it) across the entire frequency span.

It sufficient to perform just two other S21 measurements: (1) NE to RX port and (2) SW to RX port. This is because only two perimeter elements, besides the center port, are “active” at a time. With no DC power applied, these would be the NE and SW perimeter elements. When switching directions other than NE or SW are selected, the relays will switch the same combiner circuitry to the other perimeter elements, so S21 measurements on any other antenna ports will be redundant.

Connect the 75-ohm terminations to the center (C) and SW ports. Connect VNA port B (with the transformer or series resistance, as described above, in the path to port B) to the combiner RX port. Connect VNA port A to the combiner NE port. Measure S21 for the NE-to-RX port path and save the results. Remove the 75 ohm termination from the SW port and connect it to the NE port. Connect VNA port A to the SW port. Measure S21 for the SW-to-RX port path and save the results.

The ideal S21 gains are -5.6 dB for both the NE and SW ports at all frequencies. The ideal S21 phases for 160m are +160 degrees on the SW port and -160 degrees on the NE port at 1.83 MHz. The ideal phases for 80m are +140 degrees on the SW port and -140 degrees on the NE port at 3.66 MHz. Component tolerance variations, or VNA instrument error, will usually lead to small deviations from the ideal. In practice, deviations of +/- 0.1 dB in amplitude and +/- 1 degree in phase, or possibly slight greater, are in the “normal” range. It is more critical that the measured S21 values be close to ideal on 160m than on 80m. On 80m, the array, with its larger element spacing (in terms of wavelengths), is more forgiving of amplitude and phase errors.

Large deviations in the measured S21 values from these values are mostly likely caused by incorrectly wound transformers. If this is the case, then you may troubleshoot the individual transformers by performing the tests in the next section.

### 9.4.3 Transformer tests

If either the impedance analyzer or VNA tests points to a problem, then the individual transformers may be tested to determine if the windings are correct. This will require removal of the transformers from the PCB. A number of resistors (75 ohms) will be required for these tests. All connections to the resistors should be made with leads as short as possible for the most accurate results.

1. T1: Place a 75 ohm resistor across the entire winding of T1. Measure the impedance from the center tap to either end of T1. It should be about 18.75 ohms (1/4th of 75 ohms).
2. T2: You will need five 75 ohm resistors to perform this test. Make up two 37.5 ohm resistors by putting two 75 ohm resistors in parallel. There is a red wire and a green wire exiting each side of T2. On one side of T2, we'll call the wires "green1" and "red1". On the other side of T2, we'll call the wires "green2" and "red2". Make the following connections:
  - Red2 to green1.
  - One side of one 37.5 ohm resistor to red1. We'll designate the other side of the 37.5 ohm resistor as "ground".
  - One side of the other 37.5 ohm resistor to green2 and the other side of the resistor to ground.
  - The remaining 75 ohm resistor between green2 and red 1.

Now measure the impedance between green1 and ground. It should be about 18.75 ohms.

3. T3: This measurement is the same as T2 except the resistances are one half the values you used for T2. You will need four 75 ohm resistors to perform this test. Make up a 150 ohm resistor by putting two 75 ohm resistors in series. There is a red wire and a green wire exiting each side of T3. On one side of T3, we'll call the wires "green1" and "red1". On the other side of T3, we'll call the wires "green2" and "red2". Make the following connections:
  - Red2 to green1.
  - One side of one 75 ohm resistor to red1. We'll designate the other side of the 75 ohm resistor as "ground".
  - One side of the other 75 ohm resistor to green2 and the other side of the resistor to ground.
  - The 150 ohm resistor between green2 and red 1.

Now measure the impedance between green1 and ground. It should be about 37.5 ohms.

4. T4: There is a red wire and a green wire exiting each side of T4. On one side of T4, we'll call the wires "green1" and "red1". On the other side of T4, we'll call the wires "green2" and "red2". Connect a 37.5 ohm resistor between green1 and green2. Measure the impedance across red1 and red 2. It should be about 37.5 ohms.
5. T5: Connect a 75 ohm resistor across the entire winding of T5. Measure the impedance between the tap (where the green and red wires connect together) and the green wire exiting T5. It should be about 37.5 ohms.

All impedances should be within 5% to 10% of their specified values. Any significant deviations indicate a problem with the transformer winding.

### 9.5 Connecting up the combiner/controller

There are 14 female F-connectors and a 5-pin terminal block for control cable connections on the PCB. All external cable connections to the controller are labeled on the outside of the enclosure and should be made as follows:

1. The long delay line (DL1) connects to the DL1 ports. It doesn't matter which end goes into each port. See Section 9.2 for instructions on how to cut DL1.
2. The short delay line (DL2) connects to the DL2 ports. It doesn't matter which end goes into each port. See Section 9.2 for instructions on how to cut DL2.
3. The center element feedline connects to the port labeled "C".
4. The feedline to the receiver connects to the port labeled "RX".
5. The remaining ports connect to the feedlines from the vertical antenna elements. For labeling purposes, it is assumed that the verticals are arranged around the points of a compass as N, NE, E, and so on. If you are building the 9-element system, the eight feedlines from the verticals on the perimeter of the circle connect to their respective ports on the PCB. If you are building a 5-element system, then connect the feedlines to the ports corresponding to the element positions on the compass that you intend to cover. Leave the other antenna ports unterminated. If you are building a 3-element system, connect the feedlines from the two end elements only to the NE and SW ports, regardless of which directions you intend to support. The other ports are not used and may be left unterminated.
6. Control cable connections are made to the 5-pin terminal block. Use the plug that is supplied with the kit. Viewed from the bottom of the enclosure (see Figure 21) the order of terminal block connections on the outside, from left to right is +12V, GND, K3/4, K2, K1.
7. If you are building a 9-element or 5-element system, a 5-conductor control cable is required. Connect the +12V and GND terminals on the plug to the corresponding conductors of the cable. If you have a very long control cable run (hundreds of feet or more), you should use additional control line conductors in parallel for the power connections to reduce voltage drop along the cable. Connect the K1, K2, and K3/K4 terminals on the plug to the corresponding conductors of the cable. Relays K3 and K4 are always switched together as a pair, so only one control line connection is needed for these. The direction switch controller that is part of this kit will properly switch the K3/K4 relays together through the single conductor.
8. If you are building a 3-element system, a 3-conductor control cable is required. One control line conductor is required and it goes to the K1 connection, while the remaining two are for +12V and GND. Leave the K2 and K3/K4 connections unused.

## 10 Direction switch controller assembly

### 10.1 Step-by-step instructions (5 and 9 element systems)

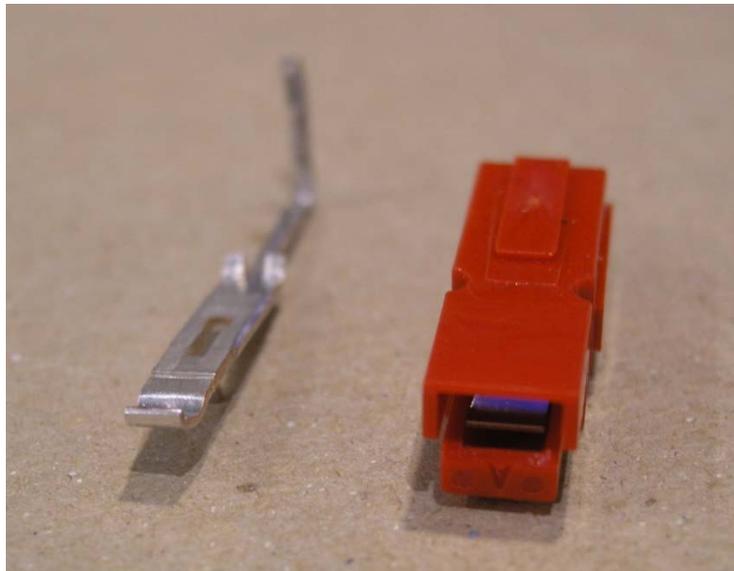
Constructing the switch controller requires soldering of pins with very close spacing. A fine-tip soldering iron is strongly recommended for this job.

1. Inventory the parts against the following list to be sure all parts are on hand:

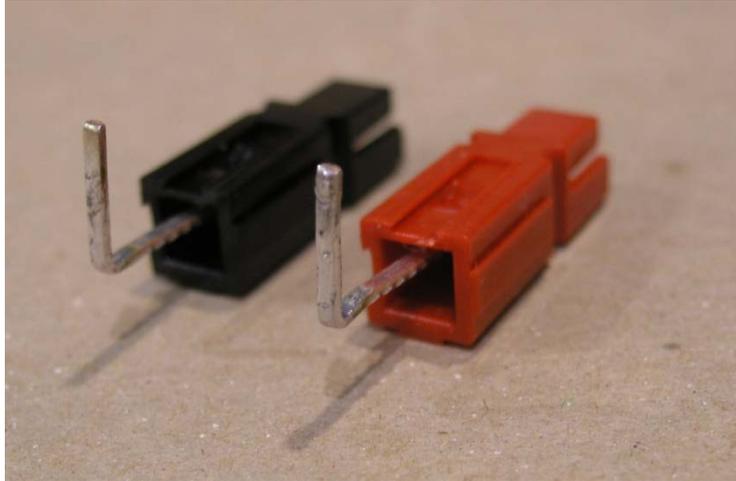
Qty	Part description
1	470 $\mu$ H RF choke
12	1N4001 rectifier diode
8	LED circuit board indicators
1	DC power connector, red housing
1	DC power connector, black housing
1	DC power connector 13.5mm staple
1	1500 $\Omega$ (brown, green, red) resistor 1/4W
1	Rotary switch
1	Pluggable terminal block header, 5 pin
1	Pluggable terminal block plug, 5 pin
5	4-40 1.25" aluminum threaded standoffs
6	.25" black oxide screw
6	4-40 black oxide internal lock washers
10	.25" zinc plated screw
1	10-32 x 1" Screw
1	10-32 lock washer
1	10-32 nut
2	10-32 flat washer
1	10-32 wing nut
1	Knob
1	PCB
1	2-piece pre-drilled steel enclosure

2. Looking at the top (component) side of the board, you will see the part designators (for example, R1, D1, etc.) are stenciled on the board. The top side of the PCB is also identified by the Yankee Clipper Contest Club logo stenciled on the board. All components except the terminal block, rotary switch, and DC power connectors mount to the top side of the PCB. Refer to [Figure 26](#) and [Figure 27](#) as you follow these instructions.
3. Install and solder RF choke RFC1 (light green body color).
4. Install and solder R1, 1500 ohm (brown, green, red) resistor.
5. Install and solder the twelve rectifier diodes, D1-D12. Orient each diode so that the white band at one end lines up with the white band on the stenciled outline on the PCB.

6. Install and solder eight LED's, (N, NE, E, SE, S, SW, W, NW). Be careful not to bridge solder across the LED leads on the bottom side of the board. Be sure the LED's are lined up straight and facing outward from the board edge as shown in [Figure 26](#).
7. Install the 5-pin terminal block header P2 on the bottom side of the board. The pins are soldered on the top side of the board.
8. Install the rotary switch on the bottom side of the board. The pins are soldered on the top side of the board. The pins are spaced very close together, so be sure not to bridge solder across the pins.
9. The DC power connectors mount to the bottom of the board and consist of two halves, one black and one red. There are several steps involved in assembling and mounting these connectors, so pay close attention to the following instructions. A right-angle metal pin is used with each connector body, as shown below in [Figure 22](#), for making an electrical connection to the PCB. The front of the connector body has a metal tab visible through the opening, as shown in [Figure 22](#). Push the wide side of the pins into the back opening of the bodies, as shown in [Figure 23](#), until they snap in place. The pins should protrude exactly 1 cm (.39 inches) beyond the rear end of the connector body when installed correctly. The bent end of the pins should face downward towards the PCB where they will install.

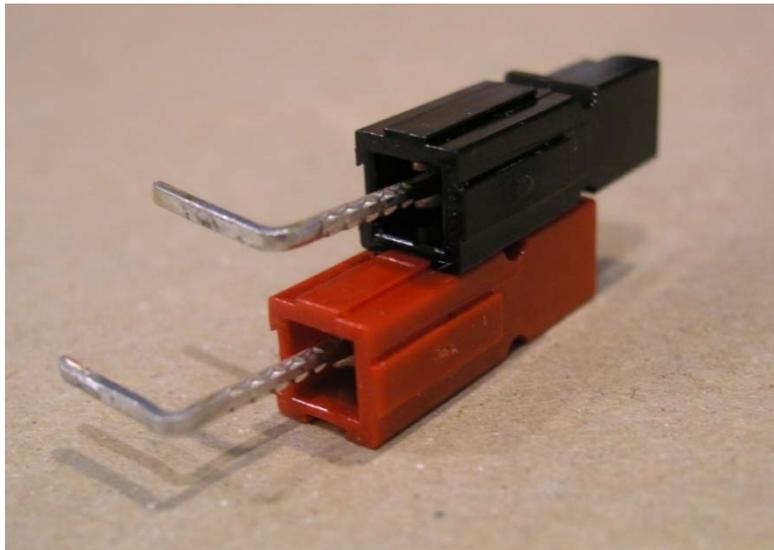


*Figure 22. DC power connector body and pin*



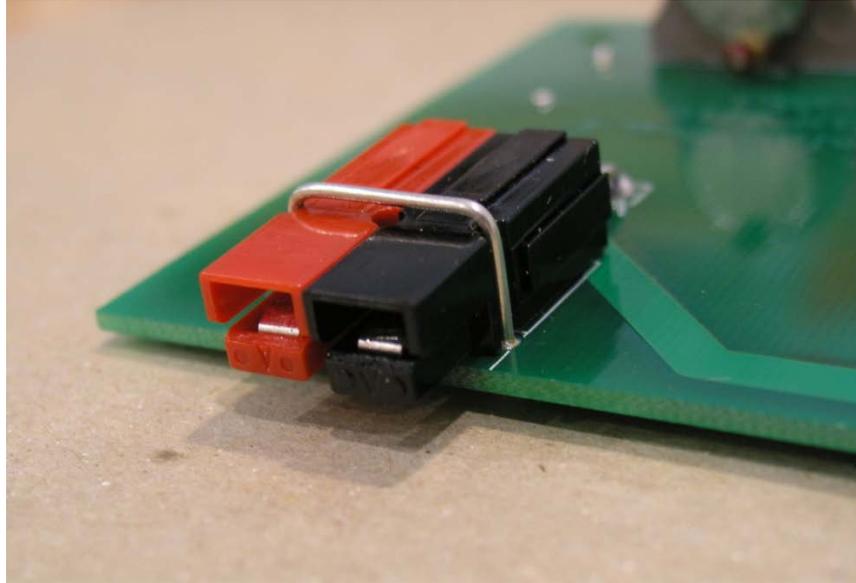
*Figure 23. Rear side of DC power connectors with pins in place*

10. The DC power connector bodies have rails and grooves on their sides that allow them to be joined together. Engage the rail of the red body with the groove of the black body and slide them together lengthwise as shown below in [Figure 24](#). The ends of the connector bodies will line up when fully joined.



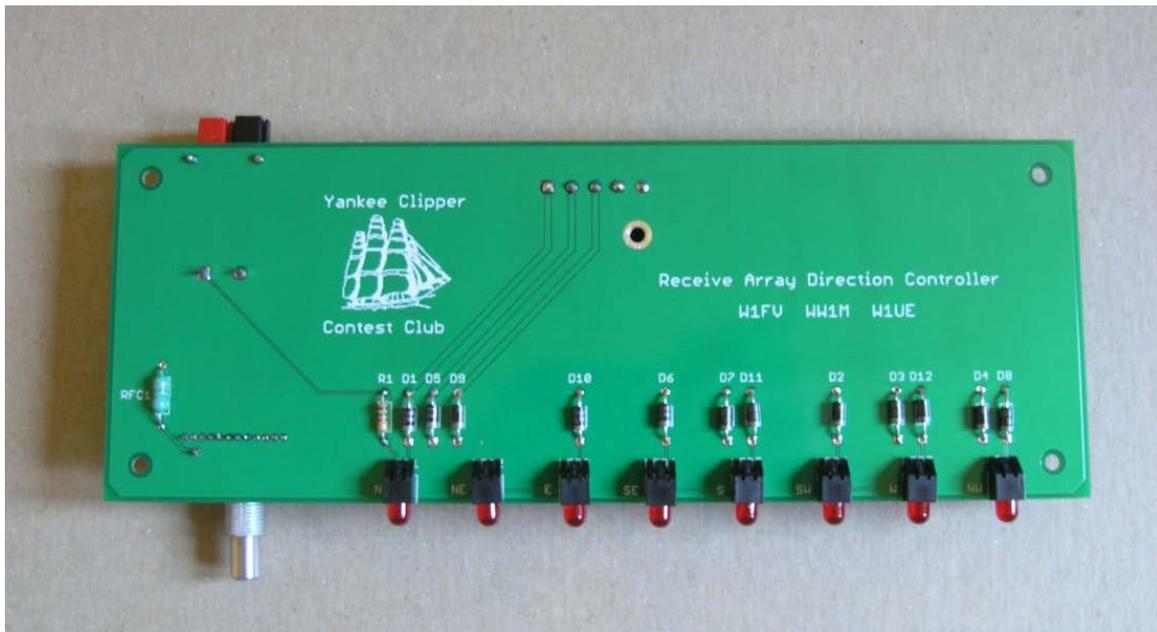
*Figure 24. DC power connector bodies being joined together*

11. Mount the connector on the bottom side of the PCB and solder the pins on the top side as shown in [Figure 27](#).
12. Insert the wire staple around the power connector as shown in [Figure 25](#). The staple should slide through grooves on the sides of the connector as shown in the figure. Solder the two ends of the staple to the top side of the PCB.

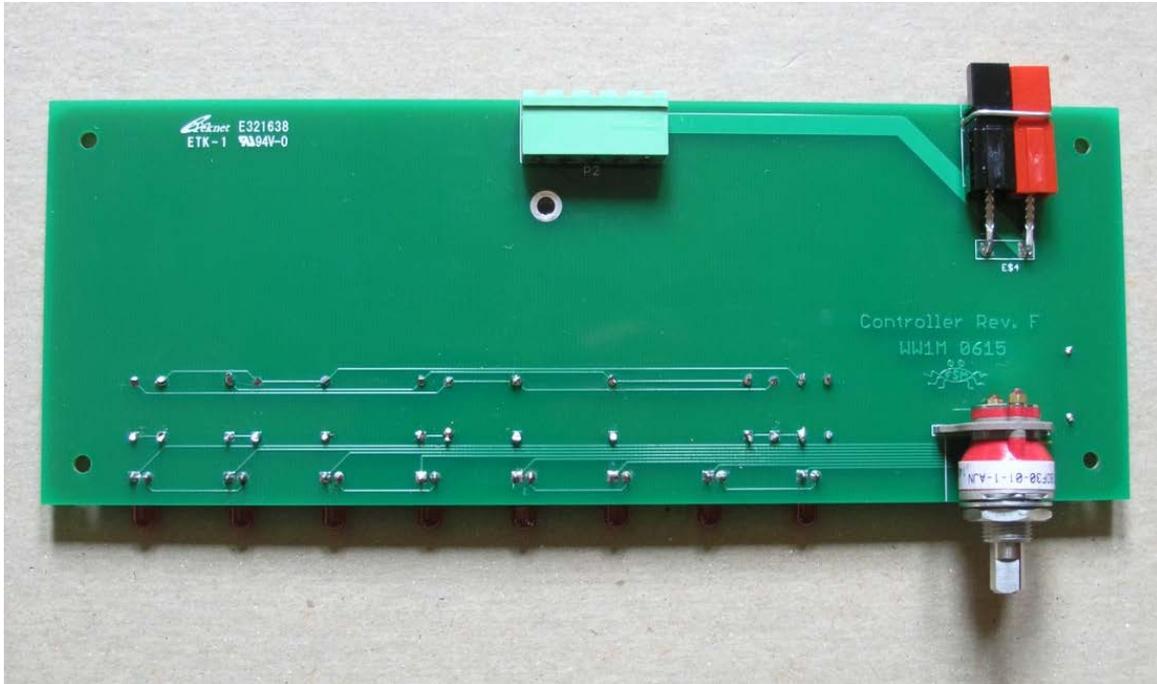


*Figure 25. Wire staple holding power connector to PCB*

13. Cut off all excess lead lengths on both sides of the PCB and check carefully for solder bridges. The finished PCB should like [Figure 26](#) from the top and [Figure 27](#) from the bottom.



*Figure 26. Top side of direction controller PCB*



*Figure 27. Bottom side of direction controller PCB*

14. The direction controller enclosure consists of two pieces. Each needs to be prepared first by scraping away paint around two of the mounting holes on the inside of the enclosure. The locations that are to be scraped are indicated in [Figure 28](#) and [Figure 29](#). Removal of the paint is necessary to insure good electrical connections are made to the metal enclosure at those locations.

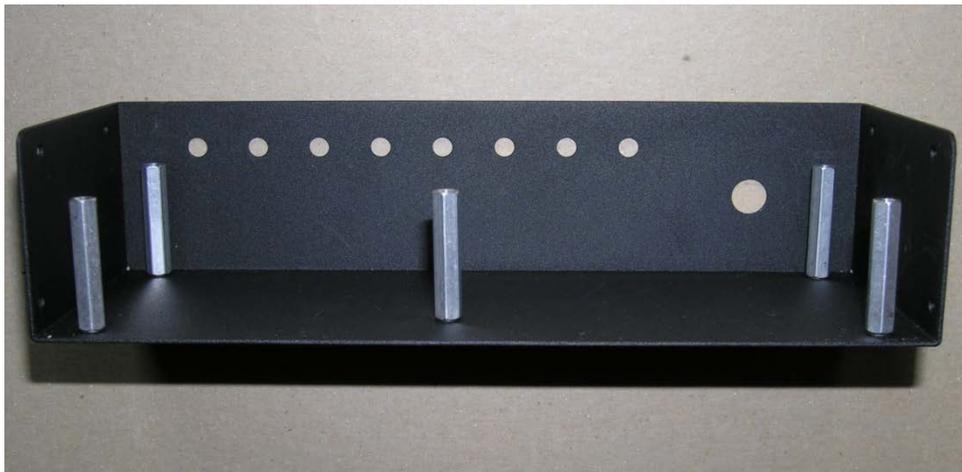


*Figure 28. Scrape away paint around hole encircled in red*



*Figure 29. Scrape away paint around hole encircled in red*

15. Mount the five aluminum standoffs as shown below in [Figure 30](#). Install a .25" zinc plated screw (silver in color) from the outside of the enclosure to secure each standoff to the enclosure.



*Figure 30. Mounting of aluminum standoffs*

16. Remove the nut and lock washer from the shaft of the rotary switch and mount the PCB on top of the aluminum standoffs as shown below in [Figure 31](#). The shaft of the rotary switch and the eight direction LED's should protrude through the holes in the front panel of the enclosure. The holes at the four corners and rear middle of the PCB should line up with the threads in the aluminum standoffs. Install a .25 inch zinc plated screw through each hole to secure the PCB to the standoffs. Install the lock washer and nut on the threaded part of the rotary switch shaft on the outside of the enclosure front panel. Install the knob on the shaft.

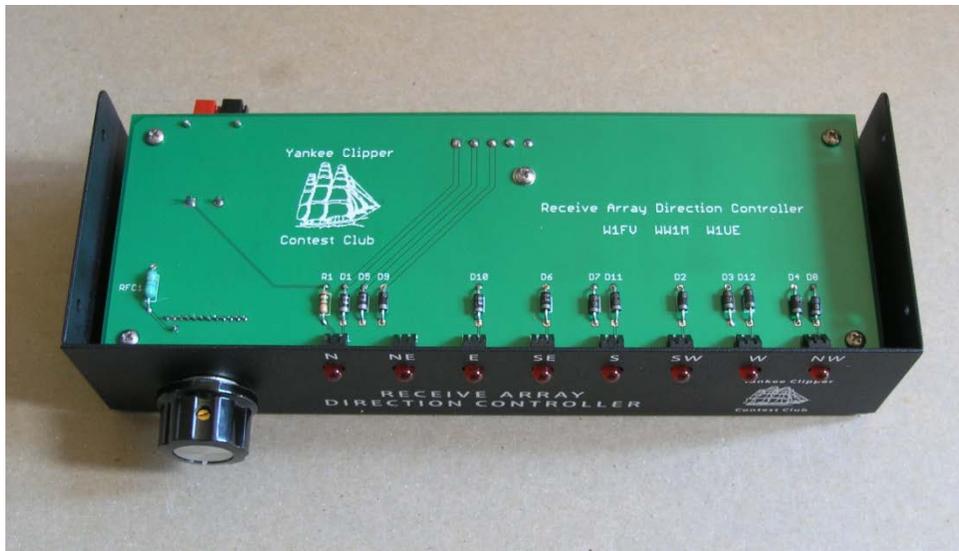


Figure 31. PCB mounted inside enclosure

17. Mount the 10-32 x 1" ground terminal screw through the hole in the rear panel of the enclosure, as shown below in Figure 32. On the outside of the enclosure, install the remaining screw hardware in the following order: lock washer, nut, two flat washers, and wing nut. Tighten the nut to secure the screw to the enclosure. The wing nut and flat washers will be used to make a ground connection to the chassis once the unit is installed in your station.



Figure 32. Ground terminal screw on rear panel

18. Attach the cover to the rest of the enclosure using three .25" black oxide screws and lock washers on each side of the enclosure. The finished enclosure should look like Figure 33 from the front and Figure 34 from the rear.



*Figure 33. Front side of finished direction controller unit*



*Figure 34. Rear side of finished direction controller unit*

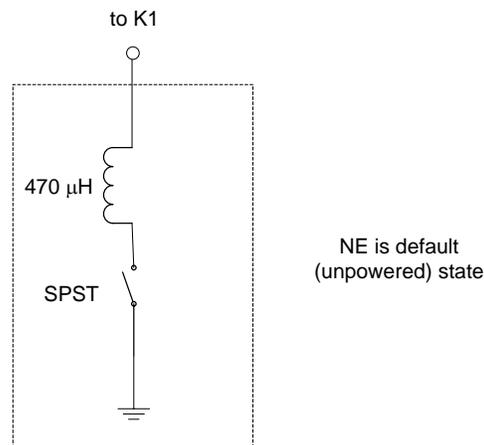
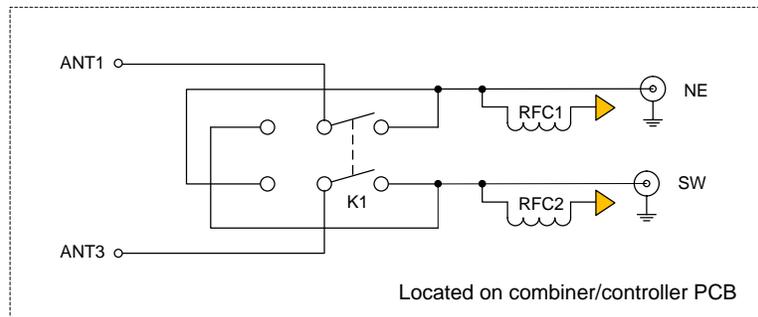
19. You may test the direction controller at this time by connecting a 12 (or 13.8) VDC power supply to the power connector. A DC power cord with a “Power Pole” connector, which can be purchased from many sources, is required to make the power connection to the connector on the rear panel of the enclosure. Be sure to observe the correct polarity. As the switch is rotated, you should see the LED’s light up one at a time. Note that the particular rotary switch that was selected for this unit has more positions than are actually used. There will be several “inactive” positions where none of the LED’s will be lit. In the inactive positions, the direction controller defaults to the NE direction, even though the NE LED will not be lit. You may also test the direction controller with the combiner by interconnecting the two units with a 5-conductor control cable. Refer to Section 10.3 for instructions on the control cable connections. As you select the various active positions of the direction switch, you should hear the relays in the combiner box clicking on and off.

## 10.2 A switching unit for the 3-element inline array

The 8-direction controller described in the previous section can be used to switch the 3-element system in two directions, but may be considered overkill for that application. The 3-element inline array in fact requires only a very simple switching circuit with one SPST switch. Let's say the user wants an array that is switchable between the NE and SW directions. In this case only one relay (K1) on the combiner/controller PCB is active (refer to [Figure 43](#)). Relays K2, K3, and K4 on the PCB are left in their unpowered states. [Figure 35](#) shows how this is done. The top half of figure represents the relay circuitry that is already on the combiner/controller PCB. The user should connect the feedlines from the NE and SW ends of the array to the NE and SW ports respectively on the combiner/controller unit, while the center element is connected to the center element port. The other antenna ports are not used and may be left unterminated. Also be sure to install the jumpers on the phase combiner PCB (see [Section 9.1](#) and [Figure 16](#)).

The direction switching unit that the user can build is the bottom half of [Figure 35](#), consisting of just an RF choke and the SPST switch. Only one control line conductor is used for switching and it connects to the K1 terminal on the controller/combiner PCB. The terminals for K2, K3, and K4 are not used.

Because the switching circuitry is so simple, the YCCC kit does not provide parts for this unit and it is left to the builder to implement it.



*Figure 35. Switching circuitry for 3-element inline array*

Should you decide to use the YCCC direction switch controller instead of the circuit in [Figure 35](#), then read [Section 10.3](#) for instructions on connections.

### **10.3 Connecting up the direction switch controller**

The switching unit is normally installed in the shack, with the control cable run from the switching unit to the combiner/controller unit at the array. Power for the entire system is provided by a 12 VDC (or 13.8 VDC) power supply, with 1A capability or greater. The kit does not include the power supply. Do not use a “wall wart” type of supply because they generally have very poor regulation. Connect the DC power source to the DC power connector on the switch box. Make the control cable connections to the 5-pin plug that is supplied with the kit. The mapping of control functions to connector pin numbers is:

- K1 to pin 1
- K2 to pin 2
- K3/K4 pin 3
- GND to pin 4
- +12V to pin 5

The 9-element system requires control line connections to the K1, K2, and K3/K4 terminals. Use the for making the control cable connections to the switching unit. Relays K3 and K4 are always switched together as a pair by the direction switch controller, so only one control line connection is needed. The 5-element system requires control line connections to the K1 and K2 terminals. The K3/K4 terminals are not used. If you are building the 3-element system and decide to use this switch controller unit rather than the circuit of [Figure 35](#), one control line connection should be made to the K1 terminal and K2 and K3/K4 left used.

## **11 Building the feedline chokes**

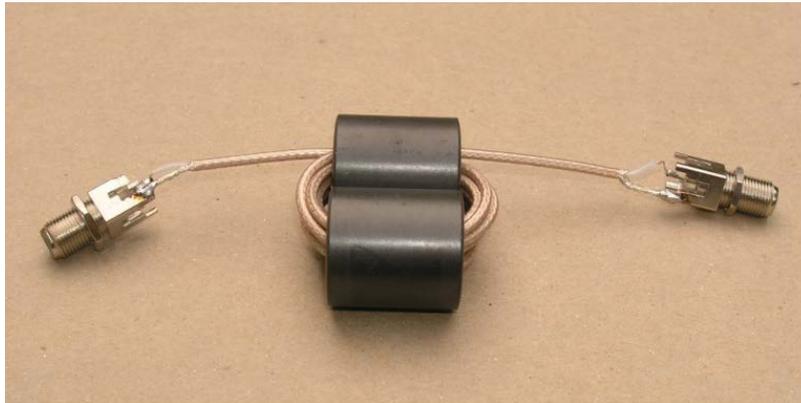
Feedline chokes are an essential part of the system. Do not be tempted to skip them! They are needed to suppress common mode signal pickup that can distort the beam pattern.

Each feedline from one of the vertical antenna elements requires a choke be installed at the point where the feedline enters the combiner/controller box, as illustrated in [Figure 7](#). One side of the choke will connect to the feedline from an antenna element while the other side will connect to the combiner/controller box. The exact insertion point is not critical but we suggest that a choke be installed at a distance of a few feet from the combiner, which will normally allow the chokes to lie flat on the ground. The lengths of RG-6 from each choke to the combiner box should all be the same, such that the feedlines from each element to the combiner are exactly the same length. Maintain some physical separation between the individual chokes to prevent coupling between them.

Each choke consists of 7-1/2 turns of RG-179 miniature 75Ω coaxial line wound through two cylindrical 31 material ferrite cores (Fair-Rite part no 2631102002) put together in the binocular arrangement

shown in [Figure 36](#). This choke is designed specifically to maximize common-mode suppression in the 160 and 80 meter bands. It provides several thousand ohms of common-mode choking impedance on those bands.

As in [Figure 10](#), two passes through the pair of cores form one turn. When constructing multiple chokes, the lengths of RG-179 used for each choke should be exactly the same. Each choke installs in a PVC enclosure, similar to that used for the antenna feedpoint preamplifiers.



*Figure 36. Feedline choke winding*

Cut a 3-1/2 foot length of RG-179 and wind the turns tightly through two side-by-side cores, which should leave a few inches of line protruding from each end of the core stack. Solder a female F-connector at each end of the RG-179. Use PCB-mount F-connectors and solder the shield to one of the ground pins on each connector as shown in [Figure 36](#). The dielectric material of the RG-179 is resistant to melting from heat, but use no more heat than necessary to solder the connections. Also, the center conductor of the RG-179 uses small conductor wire that is fairly fragile, so be careful not to nick the wire or to put it under bending stress, particularly when mounting it in the PVC enclosure.

Cut a 6" length of schedule 40 PVC pipe. Drill a 3/8" hole in each of two end caps. Mount one of the F-connectors through the hole in one end cap and secure tightly with a nut on the outside. Insert the choke assembly inside the PVC pipe. It should be a fairly tight fit. Cement the end cap with the F-connector on the end of the PVC pipe. Push the other F-connector through the hole in the remaining end cap, secure tightly with a nut on the outside, and cement that cap in place. A finished choke is shown in [Figure 37](#).



*Figure 37. Completed feedline choke*

Although the cemented caps are reasonably watertight, it is possible for moisture to collect or to seep in, especially around the F-connectors. Therefore, it is essential to provide a means for water to drain out and for the enclosure to “breathe”. Drill two small drain holes in the pipe (or end cap) at the lowest point in the enclosure, depending on orientation. A 5/64 inch hole (#47 drill bit, or 2mm) allows air and water flow, while restricting insect ingress.

## **12 Connecting the combiner/controller output to your radio**

### **12.1 Use of an outboard preamplifier**

The gain of this antenna system is very low, particularly on 160 meters, and an additional outboard preamplifier may be inserted between the RX port of the combiner/controller circuit and your radio to provide additional signal gain. However, beware that use of any broadband preamplifier, no matter how good, will degrade system dynamic range to some degree. Depending on your particular RF environment, this may or may not be a significant consideration. Degraded dynamic range can show up as spurious signals in-band, particularly on 160m. In particular, AM broadcast band spurs may be generated within the 160m band if there are very strong local AM stations around your location.

If the feedline to the receiver is long (i.e., has more than a few dB of loss), it is recommended that the preamplifier be installed right at the combiner/controller end of the feedline so as not to degrade the overall noise figure of the system. Otherwise the preamplifier may be installed right at the receiver, if it is more convenient. In most applications, 10 to 15 dB of preamplifier gain will be sufficient.

There are many possible preamps to choose from. We have tested several with good results, including the following (in no particular order):

1. DX Engineering RPA-1 (<http://www.dxengineering.com/search/product-line/dx-engineering-receive-preamplifiers>)

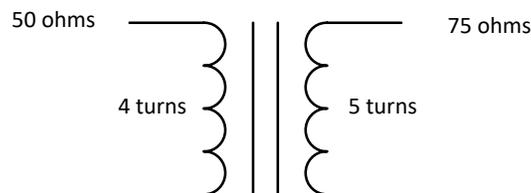
2. Clifton Laboratories Z10046A<sup>2</sup>  
([http://www.cliftonlaboratories.com/z10046a\\_high\\_gain\\_amplifier.htm](http://www.cliftonlaboratories.com/z10046a_high_gain_amplifier.htm))
3. Clifton Laboratories Z10043A<sup>3</sup>  
([http://www.cliftonlaboratories.com/z10043a\\_norton\\_amplifier.htm](http://www.cliftonlaboratories.com/z10043a_norton_amplifier.htm))
4. Hi-Z Antennas 75-ohm inline preamp (<http://www.hizantennas.com/preamp.htm>)<sup>4</sup>

There are undoubtedly other suitable units that we have not tested.

When using a preamplifier, it is important to understand that the antenna input port of the preamplifier must present a 75-ohm load to combiner/controller in order to terminate the combiner circuit properly. If the input differs significantly from 75 ohms, the combiner circuit, which depend upon a 75-ohm termination on all ports, will not function optimally and degraded array performance will be the result. Therefore the preamplifier must be operated in a way that insures that it terminates the RX port of the combiner/controller in 75 ohms. For the four preamplifier units listed above, the following subsections describe how they should be installed. If you wish to use another preamplifier type, you should still read the information below to understand the issues involved in interfacing it properly with the combiner/controller circuit.

### 12.1.1 DX Engineering RPA-1

The RPA-1 provides exceptional dynamic range performance of 110 dB or greater (IM3 at 500 Hz BW) and a +43 dBm third-order intercept. It has 16 dB gain and is nominally a 50-ohm preamp, but its input impedance varies with the load impedance on its output port. If the output is terminated in a 50-ohm load, then the input impedance is very close to 50 ohms. This 50-ohm input can be stepped up to 75 ohms by means of the broadband transformer shown in [Figure 38](#), wound on a Fair-Rite 2873000202 core.



*Figure 38. 50-to-75 ohm transformer*

Materials for making this transformer are not included in the kit. Commercial solutions for a 50-to-75 ohm broadband transformer can also be used, for example the one sold by Hi-Z Antennas ([http://www.hizantennas.com/75\\_to\\_50\\_ohm\\_transfomer.htm](http://www.hizantennas.com/75_to_50_ohm_transfomer.htm))<sup>5</sup>.

<sup>2</sup> Clifton Laboratories has been acquired by DX Engineering. Products were to be available from DX Engineering late in 2016 (<https://www.dxengineering.com/techarticles/dxepressreleases/dx-engineering-acquires-clifton-laboratories>).

<sup>3</sup> See footnote 2.

<sup>4</sup> DX Engineering has been the exclusive reseller of Hi-Z products since late 2013.

<sup>5</sup> DX Engineering has been the exclusive reseller of Hi-Z products since late 2013.

To insure that the output of the RPA-1 sees 50 ohms (and thereby insure 50 ohms on its input), you should run a 50-ohm coax line, instead of RG-6, between its output port and the input to your receiver. This assumes the receiver presents a 50-ohm load to the feedline.

### **12.1.2 Clifton Laboratories Z10046A**

The Z10046A is a high gain (23.5 dB nominal) preamplifier that presents 50 ohms on its input and output ports. The large gain would normally be needed only if you have high loss between the combiner/controller and your radio—for example, if your feedline is extremely long. The 50-ohm side of the transformer in [Figure 38](#) should be connected to the input port of the Z10046A and the 75-ohm side to the combiner/controller RX port. Run a 50-ohm coaxial line back to the receiver and connect directly to the receiver's receiving antenna input port.

### **12.1.3 Clifton Laboratories Z10043A**

The Z10043A has a nominal gain of 11 dB. Unlike the Z10046A, it mirrors the load impedance on its output port back to its input port. If the output port of the Z10043A sees 75 ohms, its input will also be close to 75 ohms and it can be connected directly to the output port of the combiner/controller. Run RG-6 from the output port of the Z10043A to the receiver. At the receiver, the 50-ohm input impedance of the receiver should be stepped up to 75 ohms, using the 50-to-75 ohm step-up transformer in [Figure 38](#), to terminate the RG-6 properly.

### **12.1.4 Hi-Z Antennas 75-ohm preamplifier**

The Hi-Z preamplifier has an advertised 15 dB gain and is designed to provide a 75-ohm input impedance when its output port is terminated in 75 ohms. Therefore its input can be connected directly to the combiner/controller output port. Run RG-6 to the receiver. At the receiver, the 50-ohm input impedance of the receiver should be stepped up to 75 ohms, using the transformer in [Figure 38](#), to terminate the RG-6 properly.

## **12.2 No preamplifier**

If you choose not to use a preamplifier, then simply run an RG-6 feedline from the RX port of the combiner/controller unit to the 75-ohm side of the transformer in [Figure 38](#). Connect the 50-ohm side to the receiver.

## **13 How to detune nearby towers and transmit verticals**

As described in [Section 5](#), it is very important to keep interactions with nearby metallic structures to a minimum. Otherwise stray coupling to those structures can introduce distortion in the array's beam pattern. If the nearby structure is a tower or resonant transmit vertical, then the special measures that are described here should be implemented.

A transmit vertical is commonly a  $\frac{1}{4}$ -wave radiator that is fed against a ground system (usually radials). Regardless of whether the vertical is actually a physical  $\frac{1}{4}$ -wave, an electrically loaded vertical that is physically shorter than  $\frac{1}{4}$ -wave, an inverted L, or some other implementation, it will couple strongly to the array if it is close to resonance at the frequency of operation of the array, even at large physical separations. One way to reduce the stray coupling is to open-circuit the connection to ground at the

base of the transmit vertical when it is not being used for transmitting. In many cases this will reduce interaction with the array to an acceptable degree.

If a serial feed system is used for the vertical, this can be accomplished by means of a SPST relay installed at the feedpoint of the vertical and keyed from transmitter. If a multi-element transmit vertical array is used, then the base connections at all of the verticals must open-circuited on receive. The transistor driver circuit shown in Figure 39 can be used for this purpose.

The relay is installed at the feedpoint of the vertical with the relay contacts opening and closing the connection between the vertical and the center conductor of the vertical's feedline. The relay is energized by grounding the base of Q1 through the radio's amplifier keying line (the same line that is used to switch on a linear amplifier, if used). Grounding that line turns on the transistor and closes the relay contacts to complete the feedline connection to the vertical when transmitting. On receive, the relay contacts open and the vertical "floats" with no path to ground.

The circuit shown allows an amplifier and the relay to be activated simultaneously. A "generic" PNP switching transistor can be used, but be sure its maximum current rating is sufficient for the current drawn by the type of relay(s) used. The value of R1 will depend on the amount of current supplied to the relay(s). Start with a value around 4.7k $\Omega$  and, if necessary, trim R1 until the voltage between the transistor's collector and emitter terminals drops to a few tenths of a volt when the amplifier keying line is grounded. CW QSK operation can be supported if the relay is a fast vacuum relay like the Gigavac GH-1. The YCCC kit does not include parts to build this driver circuit.

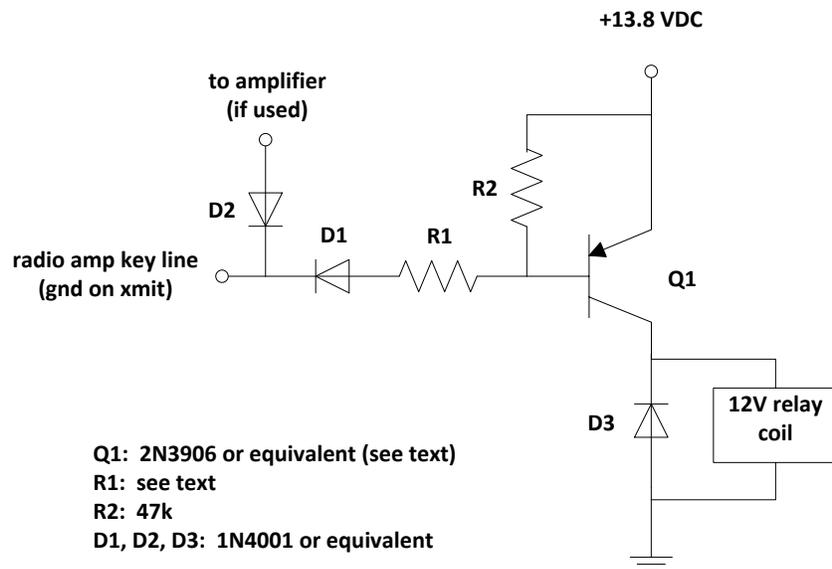


Figure 39. Relay keying circuit

If the vertical is shunt (and not serial) fed, then tower-detuning techniques, such as those described at [http://www.w8ji.com/detuning\\_towers.htm](http://www.w8ji.com/detuning_towers.htm), should be employed. In this case the relay is used to close

the connection to the detuning circuit when receiving and open it when transmitting. For verticals that are  $\frac{1}{4}$ -wave tall, or shorter, the detuning circuit should be installed close to ground. Try a vertical detuning “drop” wire about 20 feet long, tapping the tower or vertical at the far end of the wire, spaced about two to three feet out from the tower or vertical. Insert a 1000 pF air variable capacitor in series with the bottom end of the detuning wire to ground. The capacitor is tuned to resonate the detuning circuit to the transmitting frequency by doing the following: Temporarily break the connection between the capacitor to ground and insert an antenna analyzer in series with the connection. Keep the leads to the analyzer very short. Tune the capacitor to minimize the total impedance (Z). The tuning may be very sharp because the drop wire and capacitor form a high Q circuit. It should be possible to get the impedance very close to zero. Remove the analyzer and remake the connection when done. The relay contacts that are used to open the connection to the detuning circuit when transmitting should have sufficient spacing so as not to arc when transmitting and the contacts are open.

When interactions with towers and other antennas are kept reasonably small, the RDF of the array suffers virtually no degradation and the only impact is on the sidelobe and backlobe levels. RDF becomes impaired only when beam pattern distortions start to affect the forward lobe in a significant way.

## **14 Troubleshooting**

This section provides procedures for troubleshooting a variety of problems that users may encounter. If the information here does not help in diagnosing a problem, please contact YCCC Tech Support via e-mail at: [yccctechsupport@verizon.net](mailto:yccctechsupport@verizon.net).

If you experience a sudden loss of array performance, then likely causes include lightning-induced damage or feedline damage. Animals, such as deer, squirrels, or rodents, are known to chew through feedlines or control cables. The best preventive measure is to bury the lines, if possible.

If your location is subject to lightning activity during the summer season, then it is strongly recommended that you disconnect all cabling (antenna feedlines and control cables) from every unit in the system. Even nearby lightning strikes that are not direct hits can produce very large electrical surges that can damage electronic components.

### **14.1 Preamps**

Proper functioning of the array requires that the preamps are all providing exactly the same signal gain. The circuit design insures that the gains are set very accurately and are very stable in normal operation. However, even small faults can contribute to improper function. This section provides simple field tests for checking the basic functionality and gain matching of the feedpoint preamps. It assumes the entire system (vertical elements, preamps, and combiner) are in place and connected.

Disconnect all the perimeter element antenna feedlines from their respective ports on the combiner box and leave just the center element connected to the center (C) port of the combiner. Also leave the delay lines DL1 and DL2 in place. Turn on the DC power to the system. Find a local station in the high end of the AM broadcast band during the daytime and record the S-meter reading of the signal in your

receiver. If you have a panadapter or other spectrum analyzer display capability, take the reading in dBm. It is important that the signal strength be very stable and not subject to any skywave propagation that can cause fading. If the station is extremely strong, bypass any preamp you might be using between the combiner and your receiver. This S-meter (or dBm) reading provides the baseline for comparing the other preamps in the system.

Disconnect the center element feedline from the combiner box and connect the feedline from one of the perimeter elements to the center port of the combiner box. Record the S-meter (or dBm) reading. Remove the feedline from the center port.

Repeat this procedure for each of the remaining perimeter elements, recording the signal level measured for each element.

The signal level readings for all the elements should be exactly the same. If not, then the one(s) that are out of line with the rest point to a problem with that element. Possible faults include the preamp itself or any of the external connections (antenna, ground, and feedline) to it.

If a preamp appears to be “dead”, measure the DC voltage between pins 7 and 4 of the op amp on the PCB with its feedline connected and the system powered on. A 10 volt Zener diode regulates the voltage on the preamp board so the reading should be 10.0 volts or very close to it. If there is no voltage present on the op amp, measure the voltage between the center pin of the F connector on the board and the shell of the F connector. The connector voltage should be equal to the DC supply voltage (nominally 12 or 13.8 volts). If you see voltage here but not on the op amp, there is a bad connection on the PCB. If there is no voltage present on the F connector, then a feedline connection, which carries DC to the preamp from the combiner, is broken somewhere.

Other faults to look for include: a Zener diode installed backwards, the op amp installed backwards, or a blown RF choke. To check an RF choke, remove DC power from the board and measure the DC resistance across the choke. A good choke should be 6 ohms, +/- 1 ohm. Failed chokes will typically measure as near-short circuits (very close to zero ohms) or possibly open circuits.

## 14.2 Switch controller

Figure 43 in this user’s manual has a truth table for the operation of the switch controller. This test checks the switching functionality of the controller against the truth table.

First check to see that the LED’s light up in sequence as the direction switch is rotated. This verifies that the rotary switch itself is functional. If this test fails, a possible cause is a solder bridge across the pins of the switch. The pins are tiny and very close together, so look very closely at the solder connections on the PCB.

Disconnect the control cable at the back of the controller, leaving the pins of the connector exposed. Leave the DC power supply connected and turn on the supply. Connect the positive terminal of a DC voltmeter to pin 5 of the connector. At each of the eight direction switch positions (N through NW), measure the DC voltages between (1) pin 5 and pin 1, (2) between pin 5 and pin 2, and (3) pin 5 and pin

3 of the connector. Note that pin 1 connects to relay K1, pin 2 to K2, and pin 3 to K3/K4. Where the truth table reads “1” for a particular relay, you should read close to the full DC supply voltage on the corresponding pin. Where the truth table reads “0”, you should read less than one volt.

If the truth table check fails, the most likely causes are diodes installed backwards, a blown RF choke, or bad diodes. To check an RF choke, remove DC power from the board and measure the DC resistance across the choke. A good choke should be 6 ohms, +/- 1 ohm. Failed chokes will typically measure as near-short circuits (very close to zero ohms) or possibly open circuits. Diodes can be checked with an ohmmeter. Removed DC power from the box and measure the resistance across each diode with the ohmmeter leads connected both ways. One direction of a good diode will typically measure as an open circuit while the other direction will show some finite resistance, although it could be many kilohms.

### **14.3 Combiner**

The most common problems in the combiner are failed RF chokes. The chokes are very fragile devices that can be blown if a feedline is accidentally shorted, causing very high current flow through the choke. Disconnect the control cable from the combiner so that there is no DC power applied. Measure the DC resistance across each of the 9 chokes on the PCB. A good choke should be 6 ohms, +/- 1 ohm. Failed chokes will typically measure as near-short circuits (very close to zero ohms) or possibly open circuits.

The next most common problems are incorrectly wound transformers. If you own or can borrow an RF impedance analyzer, perform the checks that are described in Section 9.4 of this manual. Incorrectly wound transformers will produce impedance readings that are out of range and will result in degraded array performance.

## **15 What to expect on the air**

The best indication of a properly functioning system is its directivity. Section 16 (Reference information) shows the ideal patterns calculated by a computer model. When aiming in a specific direction, you should see a high degree of rejection of signals off the sides (F/S ratio) and back (F/B ratio) of the array. In practice the amount of rejection depends on the signal angle-of-arrival. High-angle signals will generally show less directivity than low-angle signals.

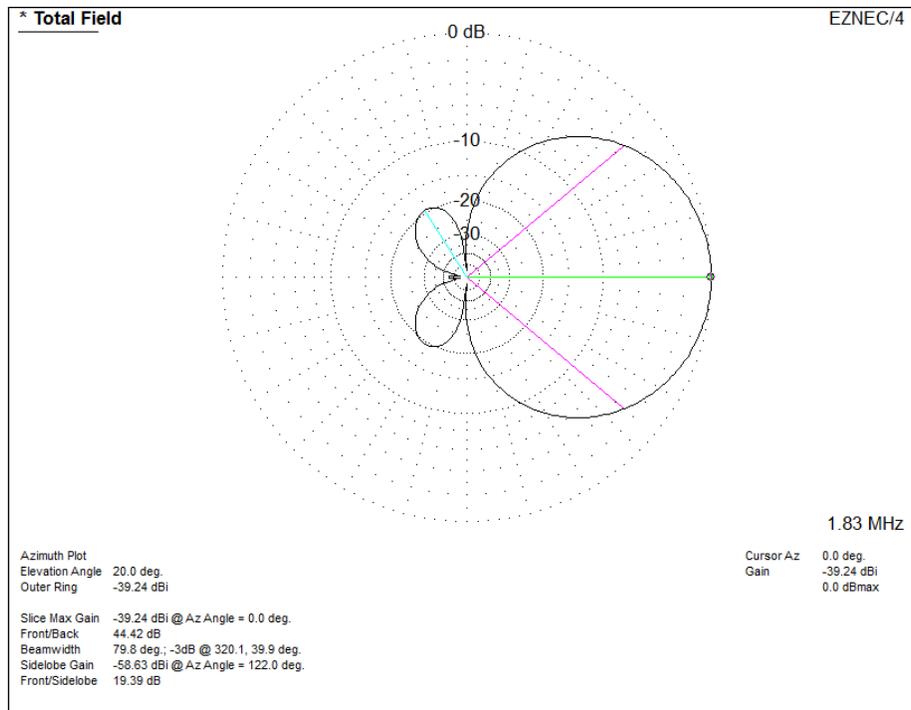
Nearby groundwave-propagated signal sources that are vertically polarized may also be used for directivity testing. By design the array is very broadband and should exhibit directivity at all frequencies between 160 and 40 meters. Signals outside the amateur bands within this range may be used for testing.

## **16 Reference information**

### **16.1 Azimuth pattern calculations (at 20 degree elevation)**

Azimuth patterns on 160, 80, and 40 meters are shown in the following subsections. These were calculated with EZNEC/4, which has the NEC-4 engine, using the “high accuracy” ground model and for an elevation angle of 20 degrees.

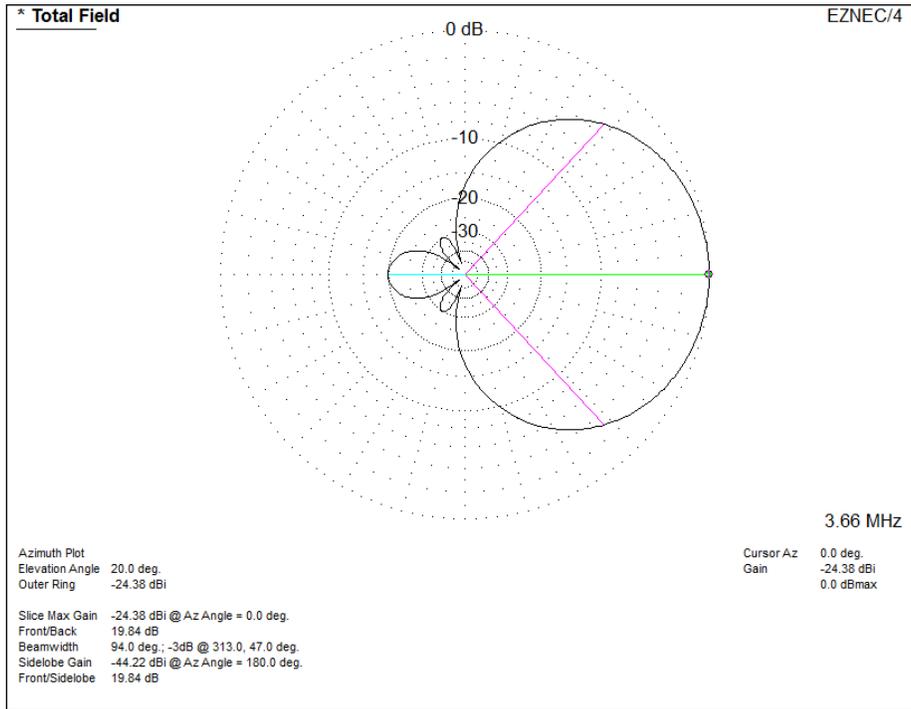
### 16.1.1 160 meters



RDF @ 20 degree elevation = 12.1 degrees

Beamwidth @ - 3 dB = 80 degrees

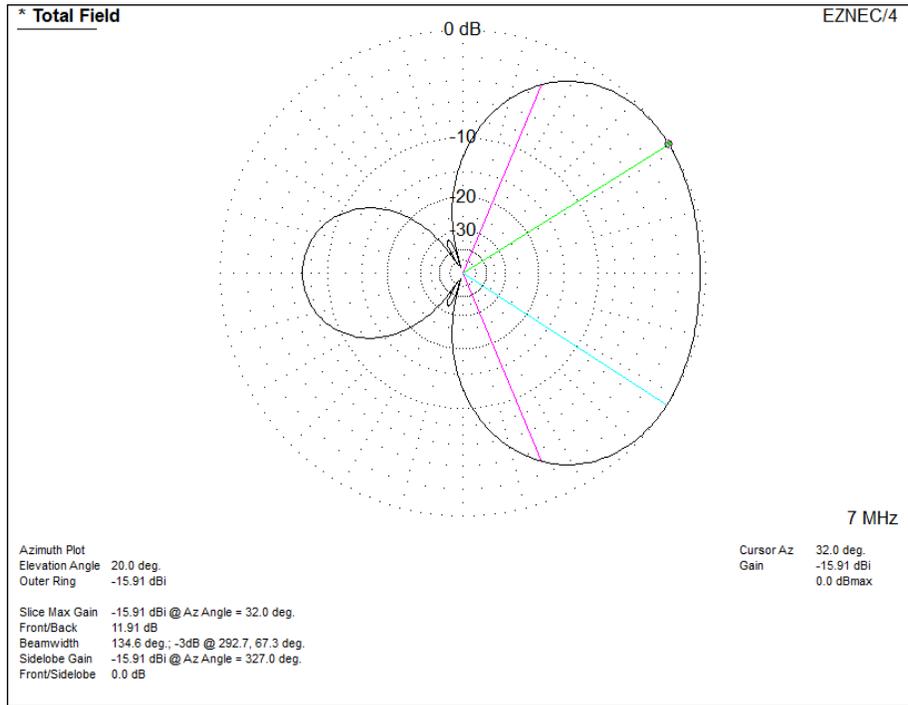
### 16.1.2 80 meters



RDF @ 20 degree elevation = 11.3 dB

Beamwidth @ -3 dB = 94 degrees

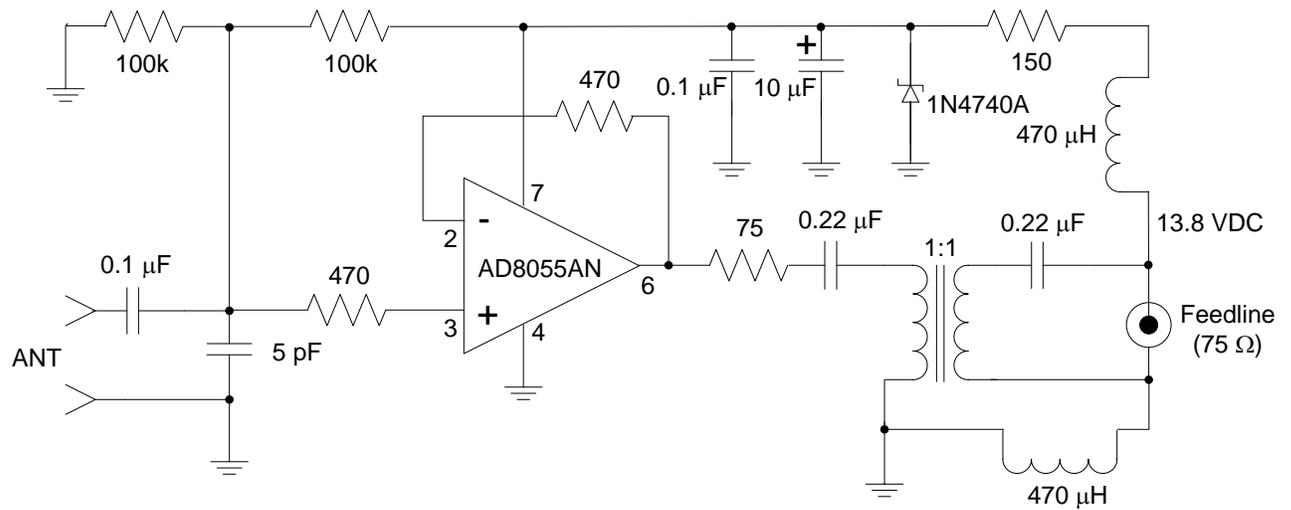
### 16.1.3 40 meters



RDF @ 20 degree elevation = 9.1 dB

Beamwidth @ -3 dB = 135 degrees

## 16.2 Feedpoint preamplifier schematic diagram



### Notes:

- Transformer core Fair-Rite 2873000202, 5 turn primary, 5 turn secondary, use #26 enamel wire
- All resistors 1/4W, 5%
- All capacitors 50V or higher

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Figure 40. Feedpoint preamplifier



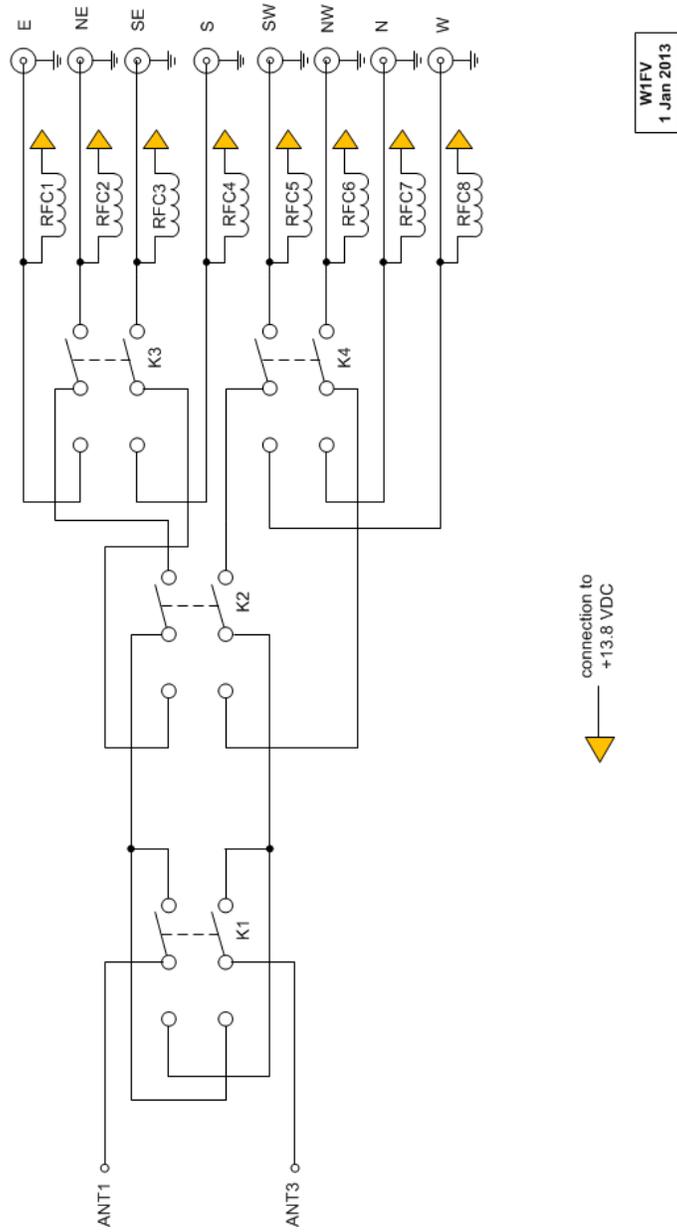
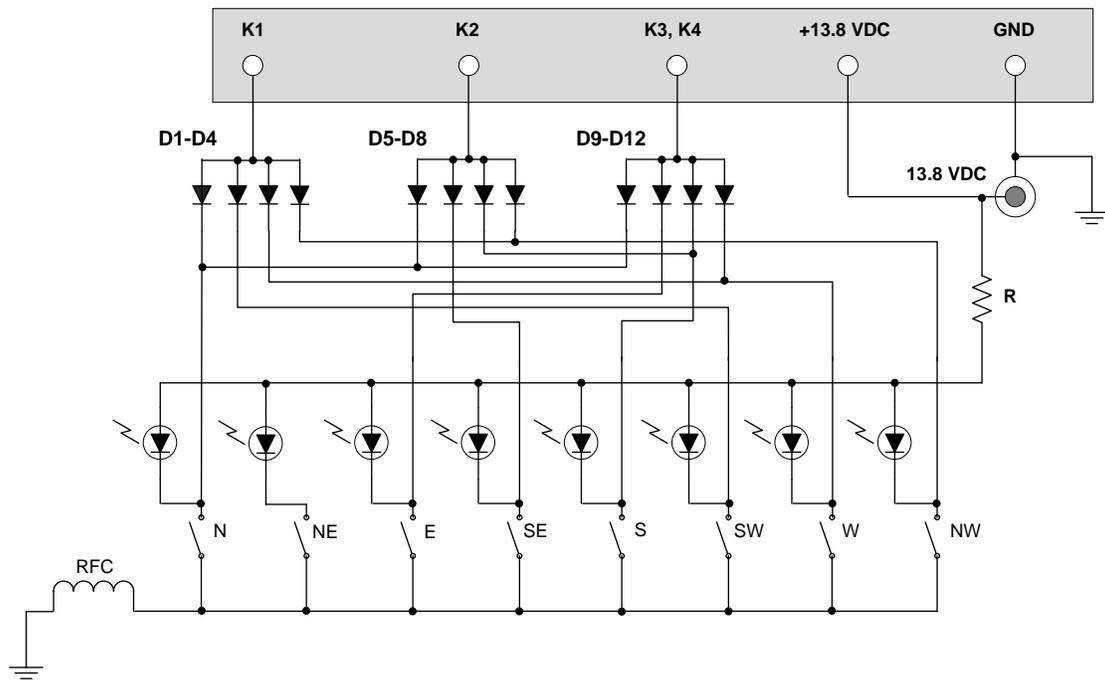


Figure 42. Direction switching relay circuitry

## 16.4 Direction switch controller schematic diagram



	K1	K2	K3	K4
N	1	1	1	1
NE	0	0	0	0
E	0	0	1	1
SE	0	1	0	0
S	0	1	1	1
SW	1	0	0	0
W	1	0	1	1
NW	1	1	0	0

- D1-D12 = 1N4001 or equivalent
- RFC = 470  $\mu$ H
- R = 1500  $\Omega$

Figure 43. Direction switch controller

## 17 Kit ordering and pricing information<sup>6</sup>

Part Number	Description	Price
DXE-YCCC-CHOKE	YCCC Feedline Choke, Unassembled Components, Kit	\$22.00
DXE-YCCC-CMBNR	YCCC Combiner, Unassembled Components, Kit	\$72.00
DXE-YCCC-PREAMPYCCC	Antenna Preamp, Unassembled Components, Kit	\$27.00
DXE-YCCC-SWITCH	YCCC Directional Switch, Unassembled Components, Kit	\$60.00
DXE-YCCC-3INLINE	YCCC 3 Element Inline Array, Kit	\$219.00
DXE-YCCC-5SQUARE	YCCC 5 Element Square Array, Kit	\$377.00
DXE-YCCC-9CIRCLE	YCCC 9 Element Circle Array, Kit	\$573.00

Additional kit information can be found at: <http://www.dxengineering.com/search?keyword=yccc>.

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<sup>6</sup> Prices as of September 2016.