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A Wire Eight-Circle Array

If you have sufficient installation space, circular phased arrays are an economical alternative to rotary beam antennas for the lower frequency bands. They have the great advantage of instantaneous direction-switching (see *Low Band DXing* by John Devoldere, ON4UN, or *The ARRL Antenna Book*) for more information on phased HF arrays). I won't repeat the basics here, just show how to construct an inexpensive eight-circle wire array which, over reasonable ground, should compare favorably with a shortened Yagi. The prototype described here was modeled with *EZNEC* and built for 7 MHz, after which Dave, G3RCQ, volunteered to build the first 3.8 MHz version following my design.

Why Eight Elements?

A convenient way to arrange arrays of vertical antenna elements is to put them in a circle and switch the direction of radiation by driving diametrically opposed phased pairs. The number of elements required to cover 360° is then dependent on the horizontal beamwidth, so four elements are usually active, regardless of the number installed. Maximum gain, with the narrowest beamwidth, occurs when the diameter of the circle is about 0.7 λ. The number of elements necessary for 1 dB gain constancy is then 18. The radiation pattern for this diameter is accompanied by very large side lobes, however. A circle of 0.54 λ diameter produces a much cleaner radiation pattern with less than 0.5 dB gain loss, and it requires only eight elements spaced 0.2 λ from each other for 360° coverage. Unfortunately, such an eight-circle array still has a diameter requiring long and possibly expensive or inefficient 270° phasing lines when employing the popular Lewallen drive system.

Design Considerations

This antenna was designed to minimize both the expense of construction and visible impact by using a single, slender support to replace the eight masts typically employed to form an eight-circle array. It also overcomes the problem of having to use 270° phasing lines by employing sloping elements that are extended and bent to minimize the high-angle radiation normally resulting with straight, sloping elements. The central support may serve as a radiator on a lower frequency band.

This wire eight-circle has several additional advantages over the popular four-square array.

- It requires a very simple phasing circuit that improves bandwidth.
- For equal efficiency, extended elements require a less-extensive ground system than necessary for quarter-wave elements.

Figure 1 — The inconspicuous 7 MHz wire eight-circle array at Marches Contest Station M8M [G3LNP photo]

• Extended elements allow six to be active in each direction.

• The eight-circle is potentially 3dB quieter, because its beamwidth is one-half that of a four-square.

• Better directivity results from closer spacing at the element ends (Moxon effect).

• The 45° azimuth increments fill in the directions between typical four-square beam headings to provide a 4.5 dB gain advantage (see Figure 2).

Dimensions are shown in terms of wavelength for one element, to enable the design to be adapted either to other bands

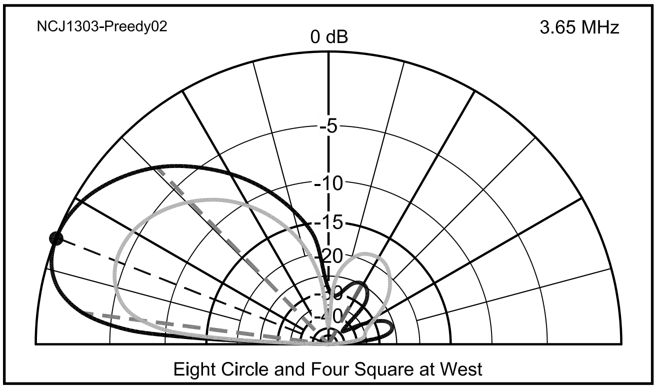

Figure 2 — Comparison of eight-circle (outer lobe) and four-square (inner lobe)

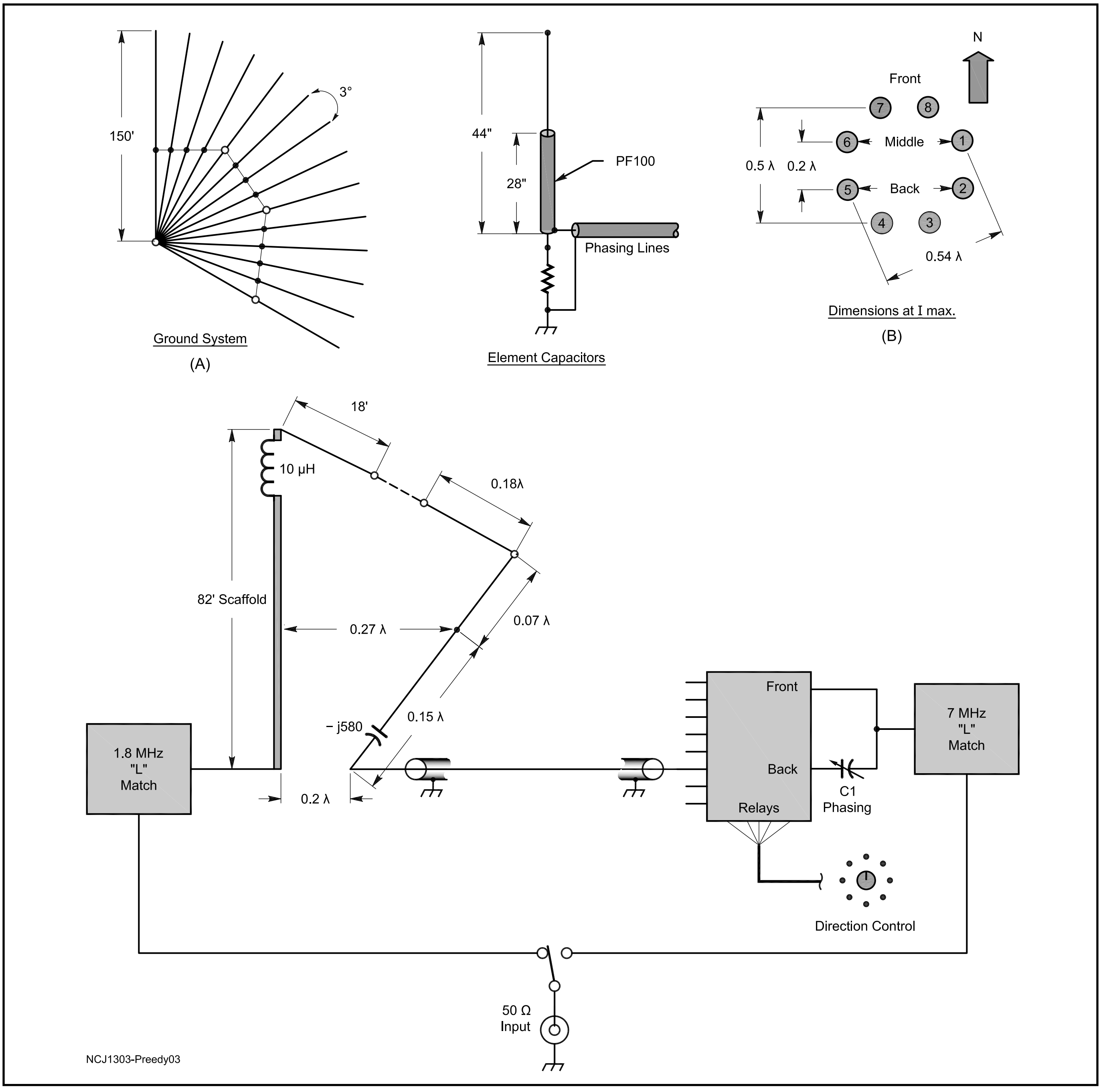

Figure 3 — The author's wire 7 MHz eight-circle, supported by a 1.8 MHz top-loaded mast radiator (a) ground system layout (b) arrangement of the individual elements

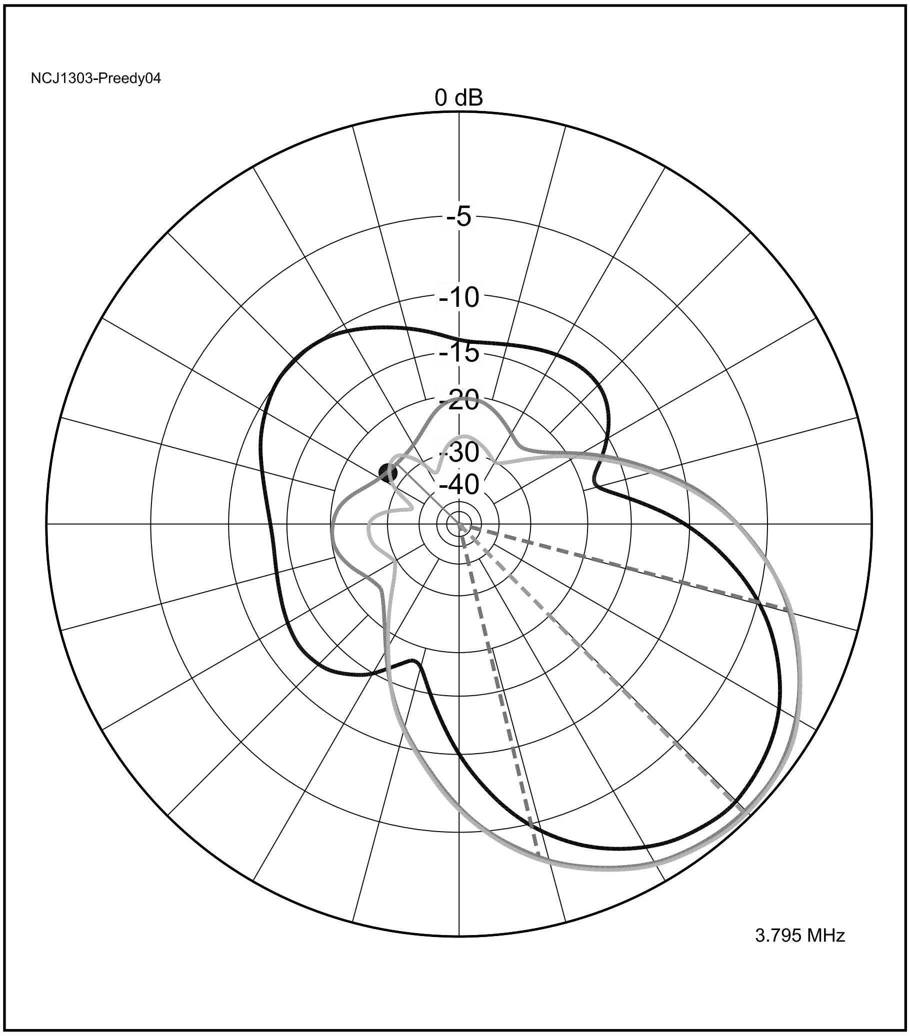

Figure 4 — Pattern with optimized mast base inductor

or to different numbers of elements, with appropriate adjustments in component values. (The same element configuration has been successful with four-square and hexagon arrays at 3.8 MHz.) A minimum height of 0.33 λ is recommended for the support, because shorter supports may require a site radius of more than a wavelength.

Unless the support is effectively non-conductive it is essential to model both antenna and support using a program like *EZNEC*. This allows choosing electrical loading and/or insulation that will minimize distortion of the eight-circle's radiation pattern. In this case the mast is loaded such that the current in the upper and lower halves cancels any re-radiation from the mast. Top loading alone may be sufficient, if, for example, it makes the mast into a grounded electrical halfwave. When the base of the mast is accessible, an inductor can be included between it and ground (see Figure 4).

This technique was applied at G3RCQ to a 3.8 MHz eight-circle on a 79 foot guyed aluminum mast that included top loading wires for 1.8 MHz. M8M uses the technique on both 3.8 MHz and 7 MHz arrays, which have survived 90 MPH winds. These arrays use 82 foot insulated masts of three steel scaffold poles, pivoted and insulated at 2 feet above ground, guyed with 4 mm pre-stretched Dacron at each joint. On top of this is a 20 foot aluminum top section, 1.5 inch diameter of 10 gauge wall, guyed by the top loading and 7 MHz elements. These were raised singlehandedly using a trailer winch and another scaffold pole as a crane. The 3.8 MHz arrays differ from the 7 MHz array in Figure 1 by not having a top inductor but 19 foot top-loading wires and an inductor,

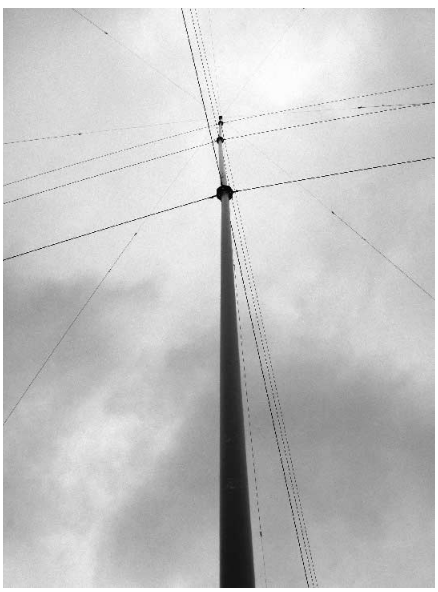

Figure 5 — Looking up the 82 foot mast to the top loading at M8M (viewed from the side it looks straight!) [G3LNP photo]

Table 1
Measurements taken on the 7 MHz array

Impedance of a single element and ground connection: 94 + j580 at 7.15 MHz

50 Ω SWR at 7.15 MHz: ≥1.1 in any direction

50 Ω SWR from 7 to 7.3 MHz: >1.7

Mid-band 75 Ω SWR on the phasing lines: 2.4

Relative back element drive current: Approximately 0.5/130° at the coaxial capacitor

Relative parasitic director current: Approximately 0.5/–130° at element center (computed)

Efficiency of phasing lines: 92.6 percent

Front/back ratio: –23dB (average of many tests, excluding local NVI)

Horizontal beam-width at ground level: 50° at –3 dB

Efficiency of elements with the ground system measuring 5 Ω: 94.7 percent

Measured at the mast:

Mast impedance: 23.5+j0 at 1.83 MHz

50 Ω SWR via L network from 1.8 to 2.0 MHz: >1.9

Efficiency at 1.83 MHz with ground system measuring 1 Ω: 95.9 percent

Power rating for either antenna: 2.5 kW PEP/1.5 kW CW typically 20 to 25 μH, between the base of the mast and ground, when the eight-circle is in use. The top-loaded masts that support the 3.8 and 7 MHz arrays at M8M are driven as a phased array on 1.8 MHz.

To achieve the required performance and particularly to minimize high-angle, horizontally polarized radiation, you must maintain the 62° slope angle and 0.22 λ of the lower part of the elements. Within reason the slope of the upper 0.18 λ section may be altered to suit support height. The upper section of the elements is #12 wire and, for flexibility and light weight, the lower rear section is RG-59 or RG-6 coax with the inner and outer conductors joined and the cable ends sealed. The cable is loosely looped through insulators at each end and held using cable ties. Tensioning lines are 2–3 mm marine type. The effective array diameter is 0.54 λ, as determined by the locations of current maxima shown in Figure 3. Elements are resonated at the design frequency by a capacitor formed from a length of coax clipped to the 4 foot wooden post where the lower ends of the elements terminate (see Figure 10).

Phasing lines are 75 Ω type PF100 cable, which has a solid copper shield and closed-cell foam insulation and is suitable for burying. Their length determines the radius of the termination posts, nominally 0.2 λ. The actual radius is 90° electrical minus the amount of cable (parameter "h" in Figure 9) required for terminations. A typical radius for 7.15 MHz is 27 feet; for 3.75 MHz it is 51.2 feet, with h = 1.2 feet, based on a measured cable velocity factor of 0.82. A weatherproof electrical junction box at the base of each post contains phasing-line and capacitor connections. These also house the 1 MΩ anti-static resistor and a test link to enable tuning and current measurements.

Construction

Figure 6 shows the RF and direction-switching circuits for the eight-circle and mast. These components are housed in a weatherproof box, such as the one in the photo at G3RCQ (see Figure 8), mounted below the mast pivot. Normally the main feed line is connected to the mast via the 1.8 MHz L network (L1/C2), but for 7 MHz operation, the feeder is transferred to the 7 MHz L network (L3/C3) via relay (K10). My mast, which is longer than a halfwave, is effectively detuned at 7 MHz by both the 1.8 MHz L network at the base and the loading inductor at the top. For both bands the phasing circuit is simply a capacitor (C1) of nominal 80 Ω reactance. C1 simultaneously advances the phase by somewhat more than 90° and sets the amplitude of the current in a pair of rear driven elements, for example 2 and 5, relative to a driven middle pair, 1 and 6.

Figure 6 also shows relays K1 to K8 that switch the beam direction and K9 that reverses it. Elements that are *not* driven have their 90° phasing lines shorted by relays K11 to K14 to present an open circuit at the element. This effectively disconnects the coaxial capacitor and allows the two elements in front of the four driven ones (7 and 8 in the example) to operate as half-wave parasitic directors. This is more to optimize the radiation pattern than to achieve extra gain. The other two elements (3 and 4) have minimal induced current and therefore make no significant contribution. Resistors R1–8 and R9, inductor L2 and the spark gap are for lightning protection.

For the 3.8 MHz arrays the 1.8 MHz network consists of the 7 MHz optimization inductor in place of R1–8 and a capacitor — chosen for best SWR bandwidth —between the inductor and relay K10.

Figure 7 shows the RF wiring of the relays, where the object is to keep the wires short to ensure the same phase delay and impedance in every direction. Connection wire is 1 mm as in PF100 cable. Relays are all DPDT, such as Schrack type RM805012. Figure 3 shows 4-pole relays, which may be substituted for K1–K8, if available. Phasing lines may use push-on blade connectors or soldered directly to the shorting relays, K11–K14. In the latter situation it is desirable to mount all components to allow for replacement without having to remove the phasing box from the mast.

Figure 7 also shows a basic direction control switch (S1) circuit. The 8-position switch may be made by modifying the click mechanism on a 360° 24-position type to skip every second and third position. G3RCQ and I operate our stations remotely with alternative software-controlled direction-switching systems.

Ground System

Figure 9 shows part of a recommended (no joints) ground radial system for the eight-circle and mast, based on that previously used successfully with a hexagon phased array. This may be buried or laid on the ground. Reasonable directivity also may be achieved when ground conductivity is good if 3 feet × ¾ to 1 inch copper ground pipes are installed at each element. The phasing lines then provide a minimal ground radial for the mast. The existing 1.8 MHz ground radials for the mast at M8M were adapted for the eight-circle by adding a transverse bus wire. That they're longer than a wavelength was expected to reduce the radiation angle. At G3RCQ the ground system of an earlier 3.8 MHz four-square array was extended for the eight-circle.

Termination Posts

Figure 10 shows the arrangement at each element termination post. The ideal way to obtain the coaxial capacitor value is to make a single element resonant against ground,

Parts List

C1 470 pF variable capacitor, 0.012 in spacing

C2 2000 pF 1000 V tubular ceramic capacitor

C3 600 pF 1000 V tubular ceramic capacitor

D1–D10 diode 1 A >100 PIV

K1–K14 DPDT relay, 415 V at 15 A, 1.5 kV insulation, 12 V dc coil (Schrack type RM805012 or similar)

L1 4 μH, 20 turns

L2 0.1 μH, 1 turn

L3 1.2 μH, 8 turns

Inductors, self-supporting, 1.5 mm wire on 1.5 inch diameter, spaced 1 mm. L1 and L3 adjusted for minimum SWR by spreading turns

R1–R8 1 MΩ 2 W resistor (or 3 × 330 kΩ 1 W)

R9 3 x 82 kΩ 1 W resistor

S1 8 position, double pole rotary switch, 125 V at 0.5 A (see text)

Gas-filled gap or non-resistor spark plug

X_p if required; experiment with 470 pF variable and parallel 4 to 10 μH

PF100 cable, 100 m (approximately 330 feet)

RG-59 or RG-6 cable, 75 m (approximately 250 feet)

Eight 4 × 4 pressure-treated wooden posts, 3 to 4 feet each

#12 copper wire, 100 m (approximately 330 feet), hard-drawn or pre-stretched, if elements also serve as guys

24 egg or dog bone insulators

16 black plastic cable ties.

Eight fabricated 5 mm (200 mil) thick laminate or Plexiglass insulators

Eight ¾ inch to 1 inch × 3 to 4 foot copper pipes or #16 or #18 enameled copper radials

Weatherproof box for phasing components.

Eight weatherproof junction boxes with terminals.

Garden hose or MDPE water pipe, 75 m (approximately 250 feet), for buried lines

CAT-5 control cable or 6 wire alarm-type cable

Main feed line (50 Ω)

Plastic cable clips, 6 mm, for coaxial capacitors

UV-stabilized, pre-stretched Dacron 2 mm rope, 60 m (approximately 200 feet). Add 2 m (approximately 6.5 feet) of steel fence wire, if lower rope ends are susceptible to vermin.)

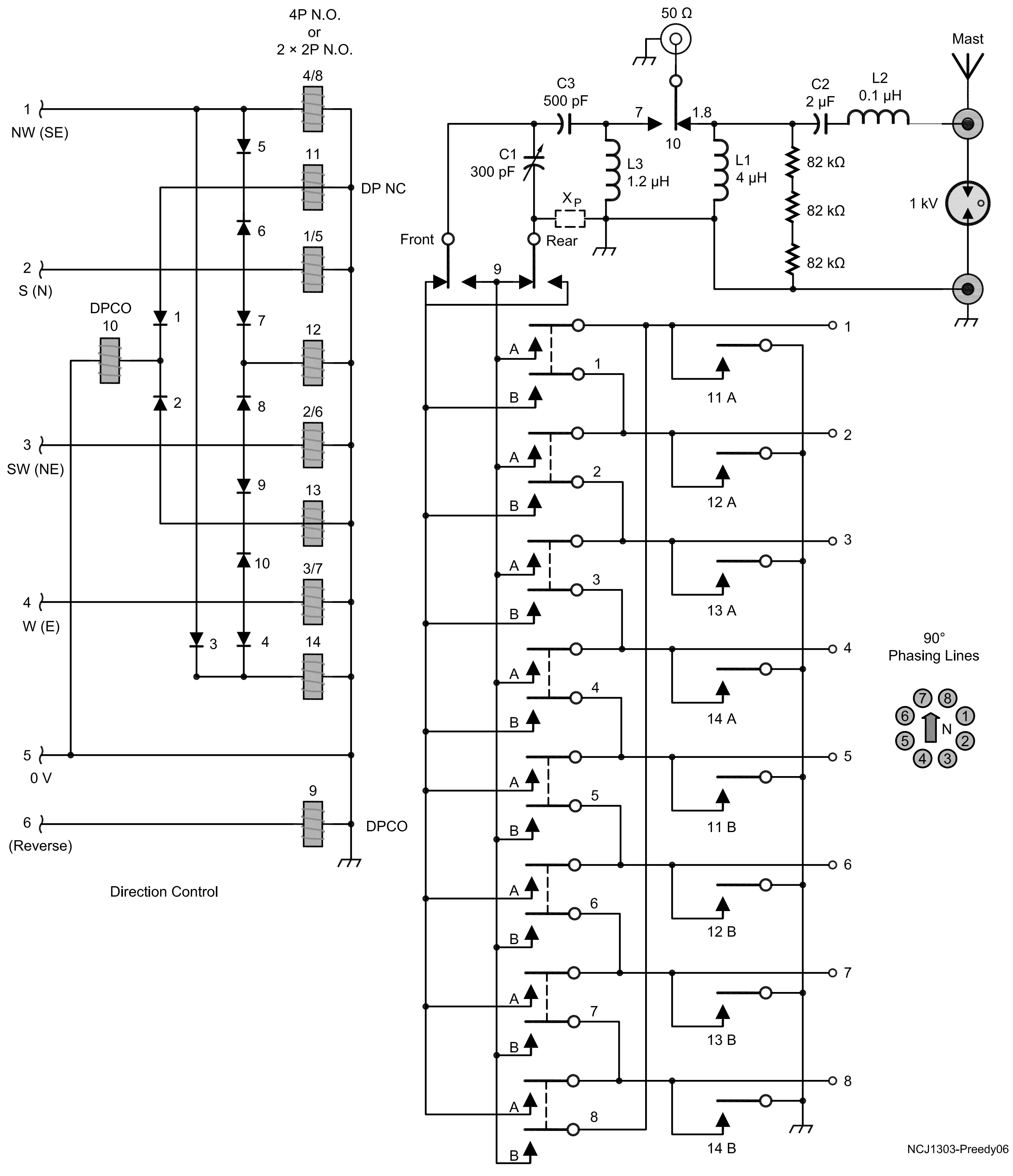

Figure 6 — The RF and direction switching circuits for the eight-circle and mast

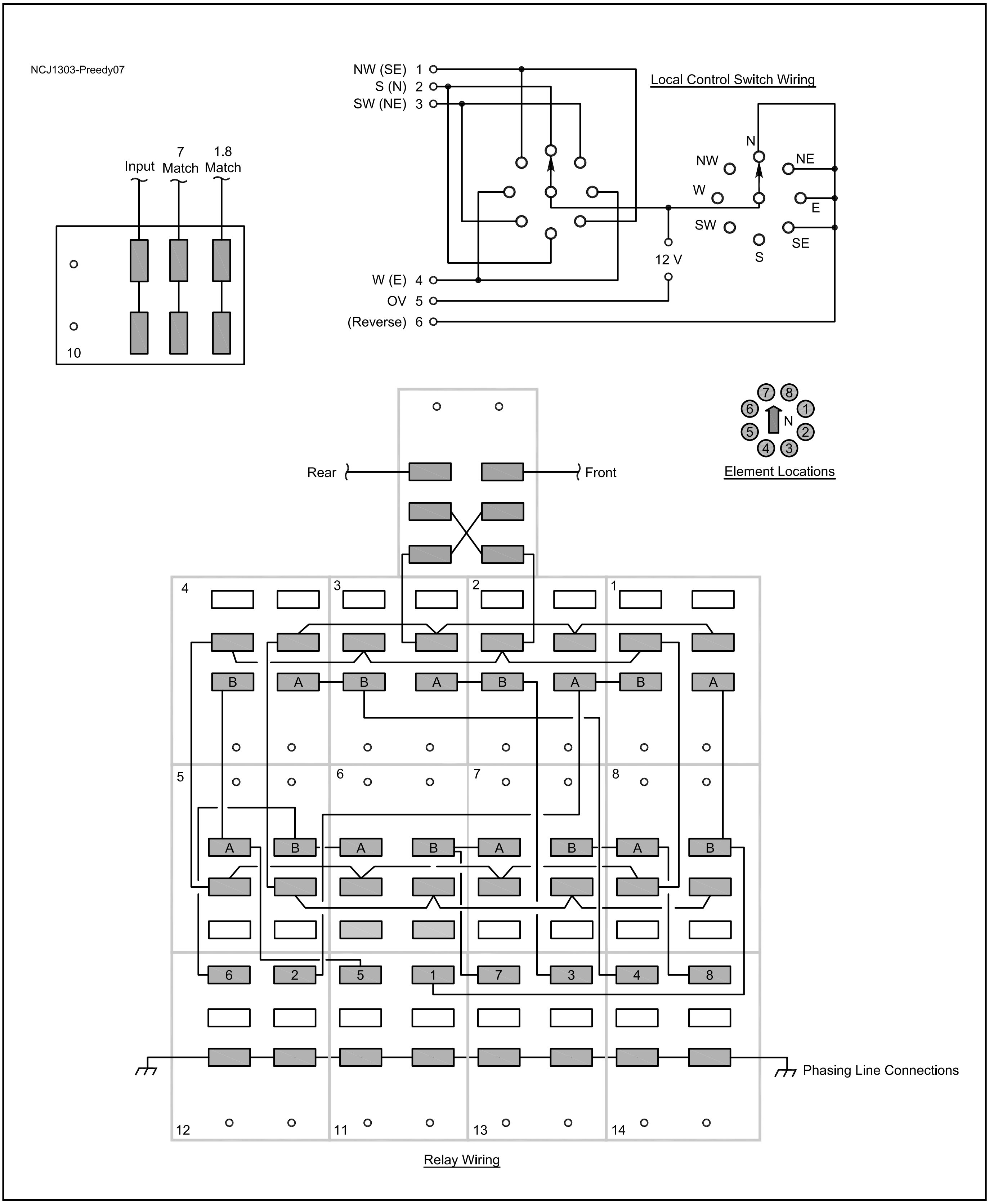

Figure 7 — RF wiring of the relays, where the object is to keep the wires short to ensure the same phase delay and impedance in every direction

with the other seven not yet rigged. This is because once all elements are installed their mutual impedance prevents measurements of self impedance. Had they been vertical quarter-wave elements it would simply require an open circuit at their base to effectively remove them. In this case, however, it is the resistance, not reactance, that changes significantly, due to the presence of the other elements. Consequently the tuning error is small, if an element is resonated with the others present but joined to ground. Tuning arrangements for the mast, such as top and/or base loading, must be in place while tuning an element, however. Remove the outer conductor from the coax until you achieve resonance (ie, zero reactance between the coax braid and ground. Eight identical capacitors, suitably sealed and protected from UV exposure by sliding some spaghetti tubing over the exposed insulation then are made and wired at the posts. For the 7 MHz array the 39 pF capacitor was formed from PF100 cable. An 80 pF capacitor of RG-213 cable was required on the 3.8 MHz arrays, but up to 100 pF may be necessary if you plan to cover down to 3.5 MHz.

Setting to Work

You may choose to set the element currents to values taken from a model, as Dave did, but I found that the only adjustment necessary, after tuning the elements, was to set C1 for minimum signal off the back from a station at least 600 miles away. Then the L networks were tuned for minimum SWR. The setting of C1 was surprisingly noncritical and, once found, a fixed value may be substituted. Other element shapes may require an additional shunt component (X_p) for best front-to-back ratio. This may be a capacitor or inductor, depending on the construction of the array. Although we provided the components for X_p, neither of us needed them. The phasing circuit may use modestly rated components, even for high power, because the power passed via this to the back driven elements is a small fraction of the total.

Results

Operating from here in the UK the most noticeable operational differences compared to a four-square are the necessity to switch the antenna from northwest to west for best results between the Central and Southern US, and the ability to "look" south for Africa, east for Asia and west for Australia (long path), rather than trying to find the best compromise between two beam headings. The wide bandwidth is a noticeable advantage over a typical Yagi (see Table 1 for the results of measurements on the 7 MHz antenna).

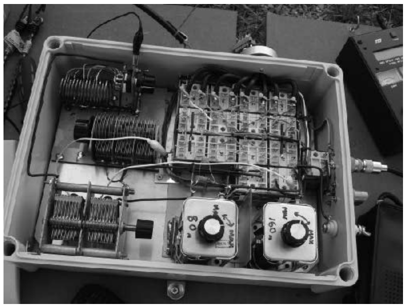

Figure 8 — G3RCQ's phasing box. C1 is at the lower left, with redundant X_p components above

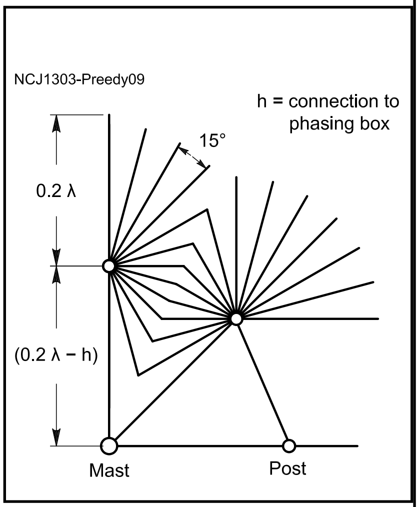

Figure 9 — Part of a recommended no-joints ground radial system for the eight-circle and mast, based on one used successfully with a hexagon phased array

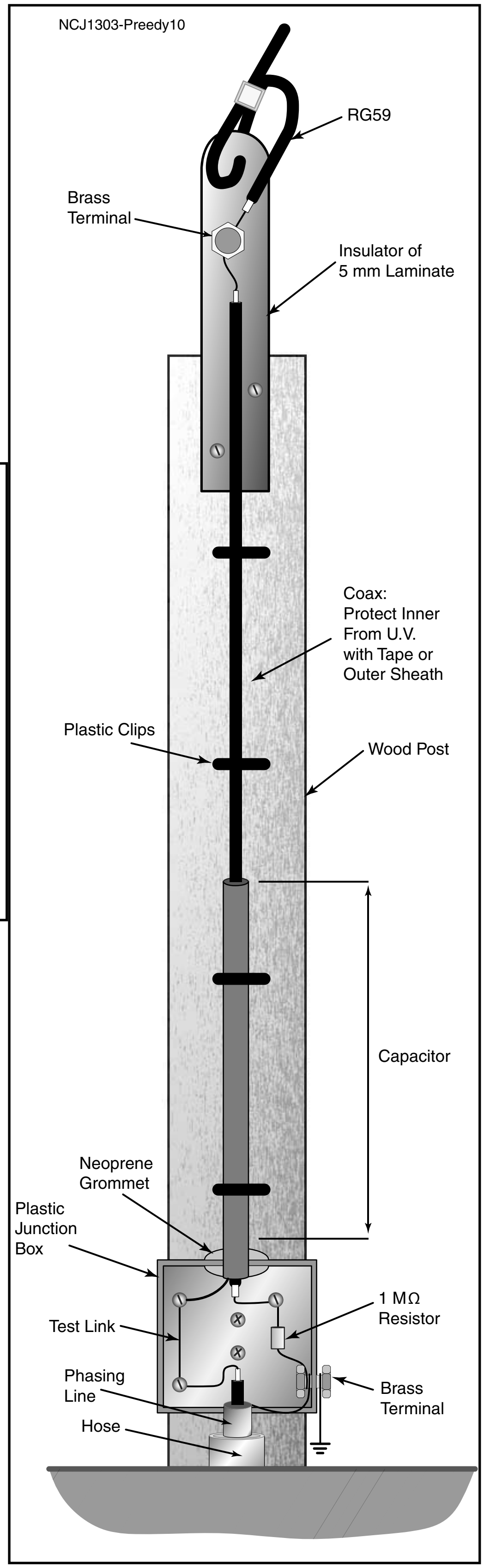

Figure 10 — The arrangement at each of the element termination posts

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