Driving the 7-Hex Array

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Introduction and configuration #3:

The array is driven by a network located at the center of the array. 50 ohm transmission lines with an electrical length of 270° (ie ¾ wavelength) run from each of the outer 6 elements to the network. The center element is connected to the network through a 90° (ie ¼ wavelength) 50 ohm line. See figure 1. A known property of 50 ohm transmission lines that are an odd multiple of a quarter wavelength is that the antenna current is always 1/50 of the drive voltage at the network end, no matter what the antenna impedance is. Also, the phase shift is always 90° for a quarter wave line and 270° for a three-quarter wave line, again regardless of impedance. Thus if the seven lines are paralleled at the network, the elements will all be driven with equal currents. Furthermore, the center element will be 270° - 90° = 180° out of phase with the outer ones. If a 2:1 (turns ratio) step-up transformer is inserted in the line for the center element (fig. 2), then it will get twice as much current as the outer ones, resulting in the correct current distribution for configuration #3.

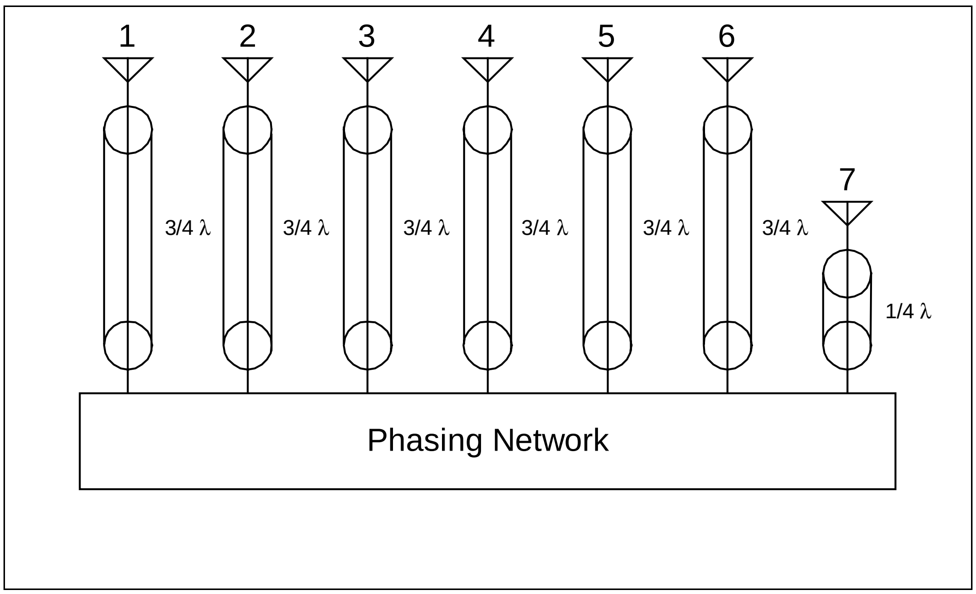

Figure 1. Transmission lines to antennas.

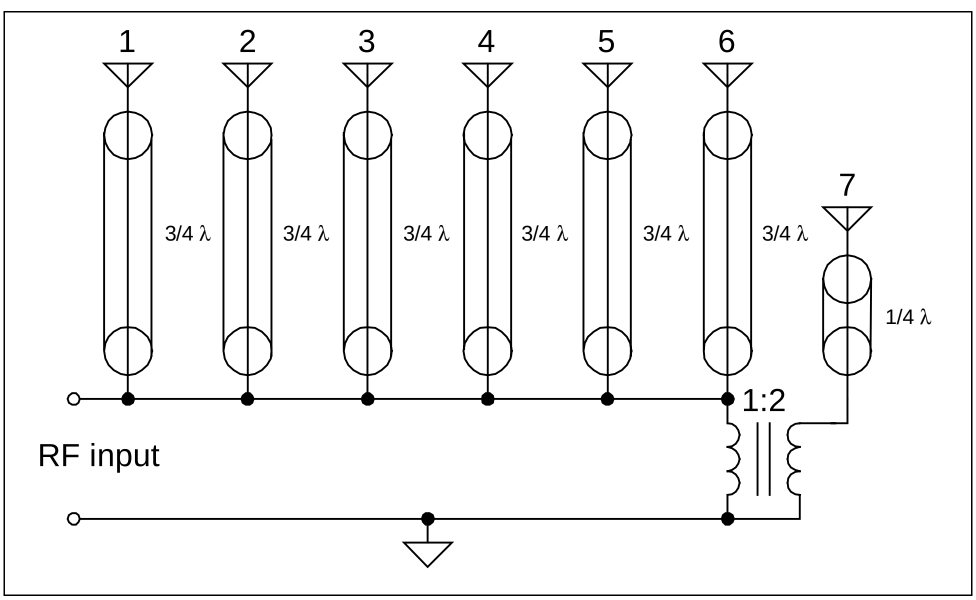

Figure 2. Configuration #3.

Configuration #1:

For configuration #1, firing in the direction of element 1, the lines are wired as in figure 3. The entire phasing network consists of one inductor, one capacitor, and one autotransformer. Nodes A and B are driven through an LC splitter, with values chosen so that voltages A and B have equal magnitudes, and the phase of B leads A by 90°. It can be shown that, for any set of load impedances, there is always a set of values for L and C that meet this condition. The lines to elements 1, 4, and 7 are driven in parallel. Similar to the reasoning for configuration #3, the outer elements (1 and 4) will be 180° degrees out of phase with the center element (7). Elements 2 and 6 are wired in parallel and elements 3 and 5 and also wired in parallel. The two pairs of elements are driven out of phase by an autotransformer. This results in the correct antenna current as shown. The transformer should be tightly coupled with low leakage inductance. The design constraints are similar to those of the autotransformer in a hybrid combiner. I constructed it, as those often are, by winding coax around a big toroid, and using the shield for one "winding", and the center conductor for the other "winding." I used special low impedance coax to get tighter coupling, but I probably could have gotten away with 50 ohm coax. This type of transformer physically looks just like a choke balun in its construction, but notice that the connections at the ends are different. The "phase" of the RF input is irrelevant since only the relative phase of the element currents matters.

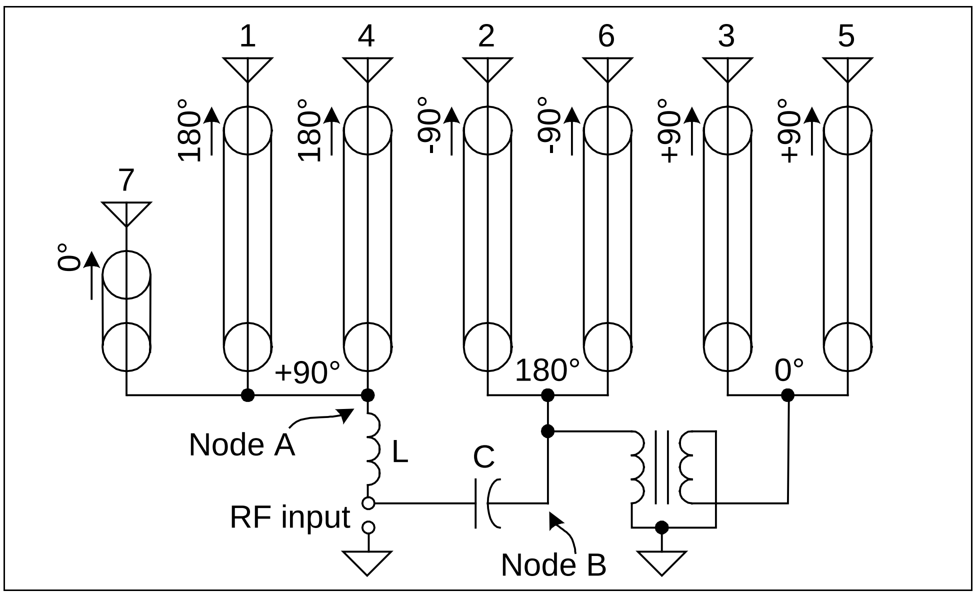

Figure 3. Configuration #1.

Configuration #2:

Before discussing the details of the phasing network for configuration #2, the choice of element currents should be explained. The element currents were deliberately chosen so that their vector sum is zero (fig. 4). By trial and error, it was determined that these values give about as good gain and pattern as any other values, whether having a zero sum or not. The zero sum property greatly simplifies the phasing network, as will become apparent below.

For configuration #2, firing between elements 1 and 2, the lines are wired as in figure 5. The phasing network consists of one inductor, one capacitor, one autotransformer, and one voltage balun. As before, nodes A and B are driven through an LC splitter adjusted for equal magnitudes, however the phase is adjusted so that B leads A by 100°. These two voltages drive elements 4 and 5 with currents of +130° and elements 1 and 2 with currents of –130°, using drive voltages advanced 270° to +40° and +140° respectively. The voltage at node A is inverted 180° by the autotransformer resulting in –140°. The primary of the voltage balun is connected across this –140° signal and the +140° signal from node B . The primary excitation can be decomposed into a differential voltage of 1.28@-90° and a common mode voltage of 1.53@0°. (fig. 6) Since the primary is floating, the common mode voltage does not excite the core and can be ignored . The voltages at the secondary of the voltage balun are then 1.28@-90° and 1.28@+90°, referenced to ground by way of the center tap. These provide the correct drive voltages for elements 3, 6, and 7.

The voltage balun is very similar to the autotransformer, except it is trifilar wound. To get tight coupling, I use triaxial cable wound around a big toroid. The center conductor is the primary and the inner and outer shields are the secondaries. This works so well, that I am surprised that I never heard of it being done before.

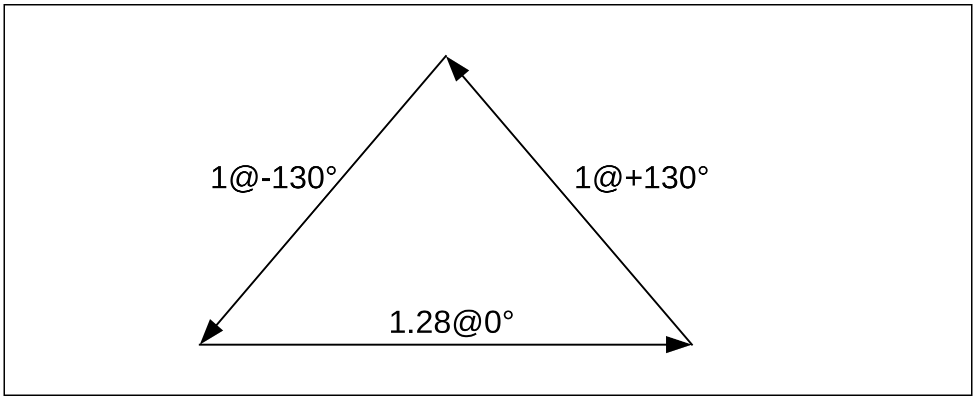

Figure 4. Vector sum of currents.

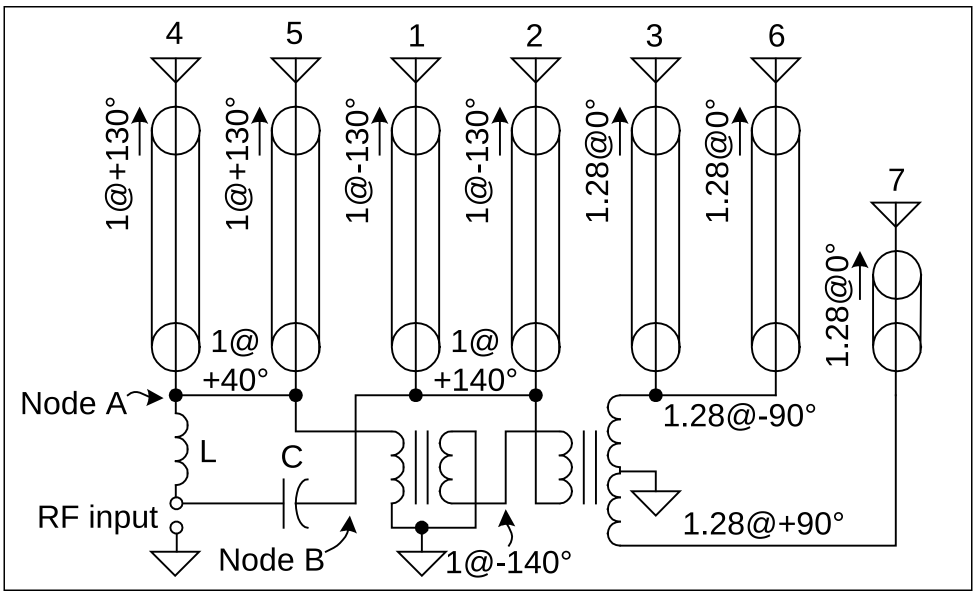

Figure 5. Configuration #2.

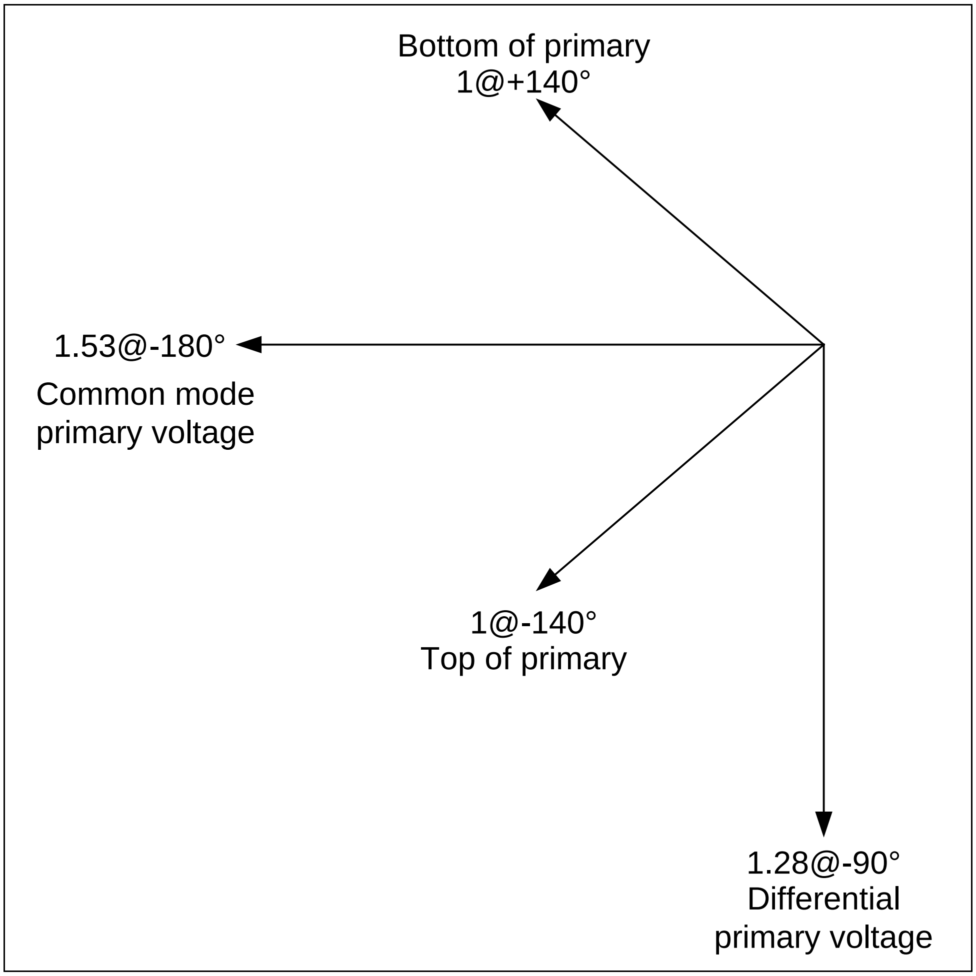

Figure 6. Voltage balun primary excitation vectors.

Adjustment techniques:

In the case of either configurations #1 or #2, a variable inductor and capacitor are used to get the drive voltages equal and at 90° or 100° respectively, using RF volt meters for the magnitudes and some sort of phase meter for the phase. The simplest way to determine the phase is to measure the differential RF voltage across the two nodes. Using the NBS "3 voltmeter" technique, the phase can be easily determined. For 90°, the voltage across the nodes should be 1.414 times the voltage from each node to ground. (Fig. 7). For 100°, the voltage should be 1.532 times the node-to-ground voltage. I've also used my scope and vector voltmeter to verify that the 3 voltmeter technique was accurate. I found that a harmonic free drive signal is essential for the 3 voltmeter technique to work accurately. Once the correct values are determined, fixed components can be substituted. On 40 meters, one set of components is good for 100 to 150 kHz, so separate LC circuits are switched in for phone vs cw. On 80 meters, I am planning to start with 3525 and 3795 settings. I may add more if it seems worth the effort. Someday, I may make a motorized auto phasing network where a control system adjusts L and C using the 3 voltmeter algorithm.

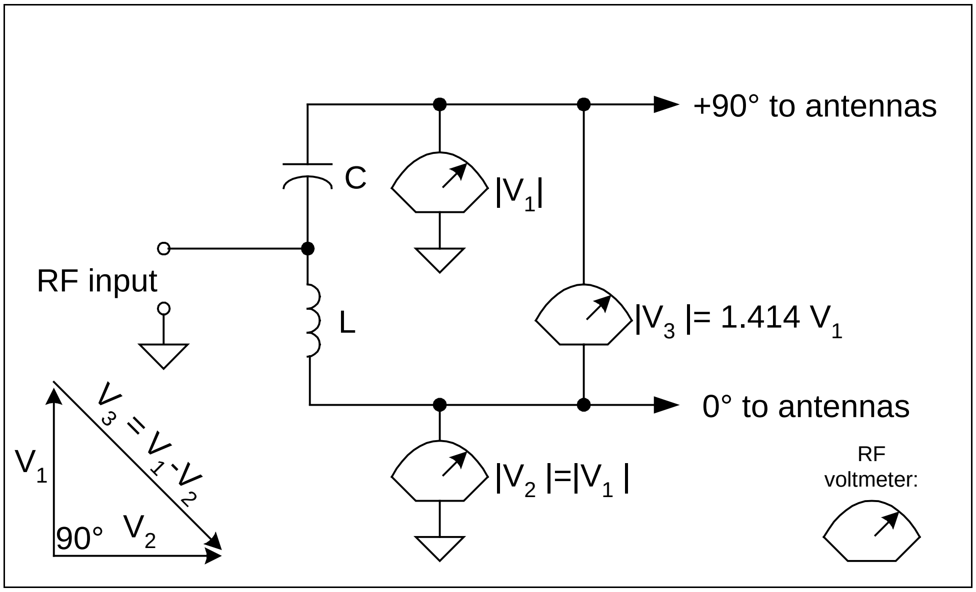

Figure 7. 3 voltmeter technique for measuring phase.

Input matching:

The input impedance of the phasing network is not any particular impedance, although it generally is a 3:1 VSWR or less in a 50 ohm system. If necessary, a tuner (transmatch) should precede the phasing network to match the line coming from the transmitter. Input mismatches have no effect on pattern or gain, they just increase feedline losses and make the transmitter unhappy. It is important to partition the matching and phasing tasks to make it easy to adjust everything.

Transmission lines to elements:

Figure 1 shows a total of 4 ¾ electrical wavelengths of coax needed for the array. It could certainly be built this way. However, what I actually do is to use just enough coax to comfortably reach from the center network to the outer elements, which requires a little over 2 ¼ physical wavelengths of coax. Since the outer elements are 50 feet out on 40 meters, I have 53 feet of coax to each one. I have 2 feet of coax to the center element, since the network is right next to that element. I then use artificial transmission lines consisting of T-networks to make the lines the right electrical length (fig. 7). An interesting feature of these T-networks is that the line length can be negative. The coax used is LMR-400 with 82% velocity factor, so 3/8 physical wavelength is less than ½ electrical wavelength. Rather than lengthen the lines to ¾ wavelength, I shorten them to ¼ wavelength. For the center element, I "shorten" the 2 foot coax to a negative ¼ wavelength. This correctly puts it 180° out of phase with the outer elements. The T-networks are made using mica capacitors and air core mini-ductors. The capacitor in series with antenna can be increased or decreased to simulate a series tuning inductor or capacitor. For example, my 40 meter verticals are 30 foot pieces of 2 inch irrigation tubing that resonate slightly above the 40 meter band. I could tune them to 7150 by putting an inductor in series with the antenna. However, this inductor would be in series with the output capacitor of the T-network. So instead, I simply increase the value of the output capacitor so that its reactance is equivalent to the net reactance of the original capacitor in series with the loading inductor.

Before discovering this technique, I used to try to cut coax cables to a particular electrical length. I found that the published velocity factor is not always accurate, so it must be measured. Then the excess coax has to be coiled up and enclosured. I think it is easier to make the coax a convenient physical length, measure its electrical length, and put in a T-network. There is also less loss this way, assuming air core inductors are used.

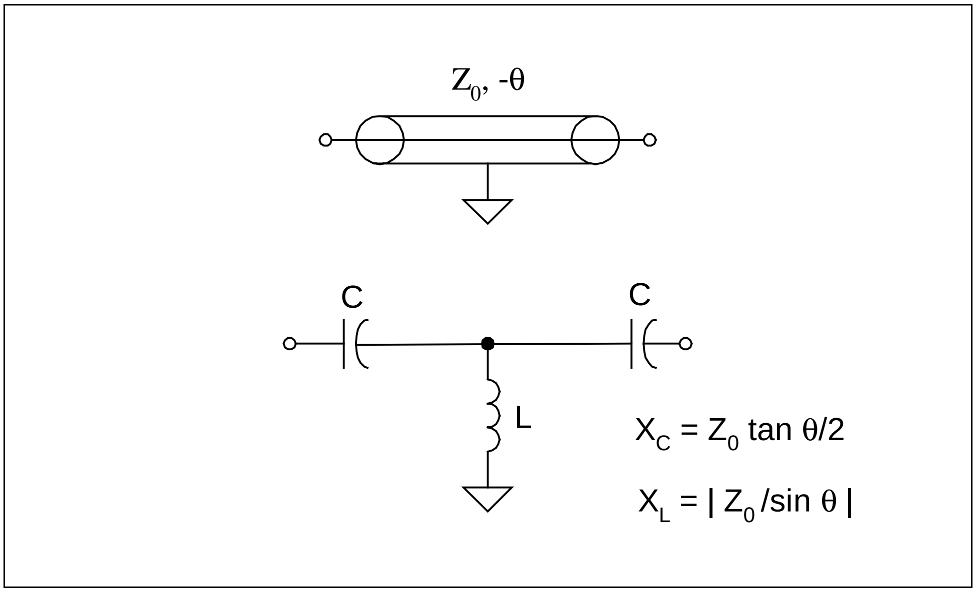

Figure 8. Artificial transmision line with negative length.

Direction switching:

Table 1 shows the 13 possible routings of the signals required to make the connections needed for 12 directions plus omnidirectional. . In the table, “+” represents either +90° or +130° and “-“ similarly represents either –90° or –130°. The switching arrangement of fig. 9 uses 9 DPDT relays and 2 SPDT relays to enable all 13 directions. A simplified switching network that covers only the 6 highest gain directions off the vertices is shown in fig. 10. It uses just 4 DPDT relays. The first system I got on the air used this scheme implemented with 4 DPDT toggle switches.

Direction	Antenna					
	1	2	3	4	5	6
1	180°	-	+	180°	+	-
2	-	180°	-	+	180°	+
3	+	-	180°	-	+	180°
4	180°	+	-	180°	-	+
5	+	180°	+	-	180°	-
6	-	+	180°	+	-	180°
1-2	-	-	180°	+	+	180°
2-3	180°	-	-	180°	+	+
3-4	+	180°	-	-	180°	+
4-5	+	+	180°	-	-	180°
5-6	180°	+	+	180°	-	-
6-1	-	180°	+	+	180°	-
Omni	180°	180°	180°	180°	180°	180°

Table 1. Signal routing vs direction.

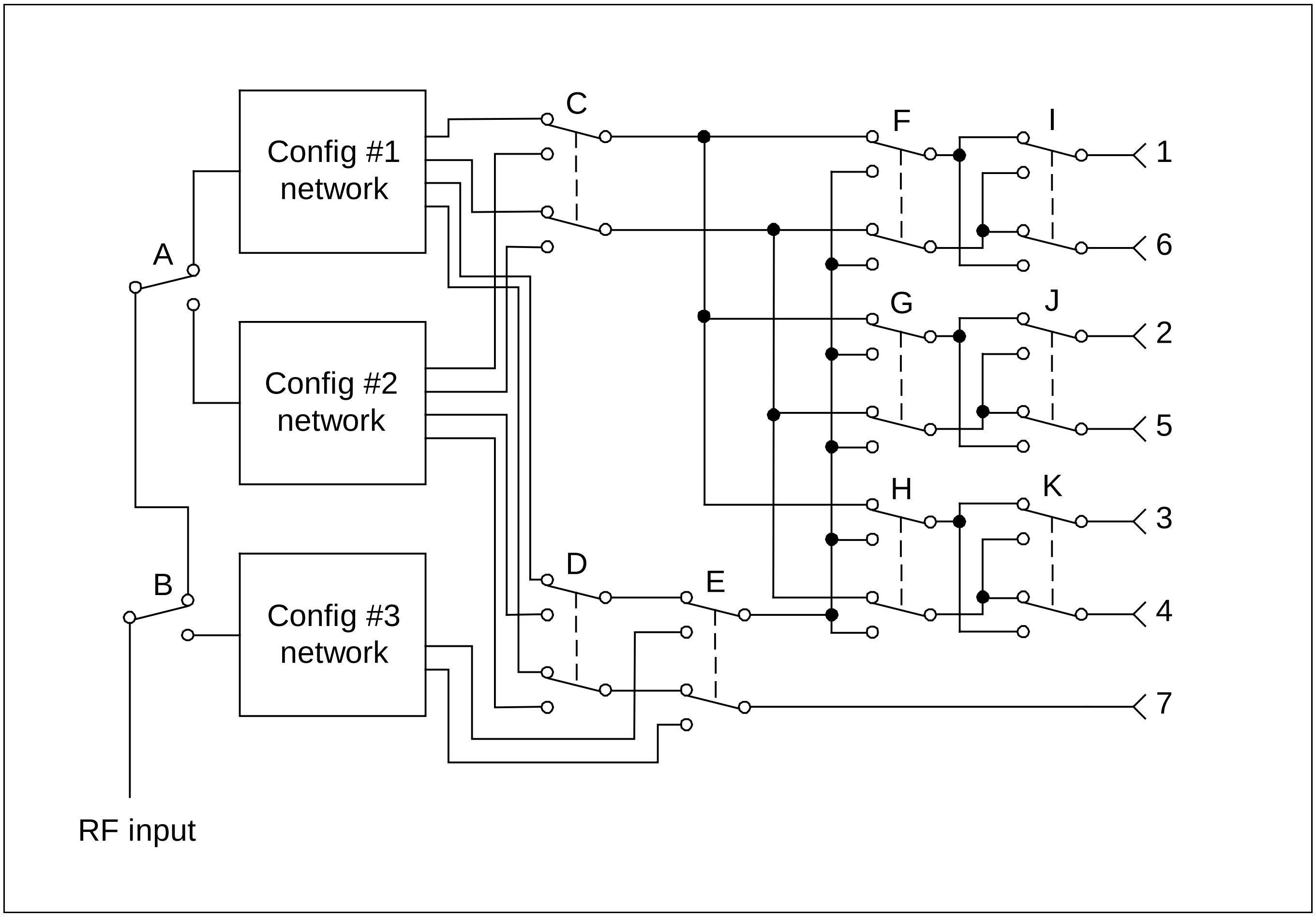

Figure 9. Direction switching relays.

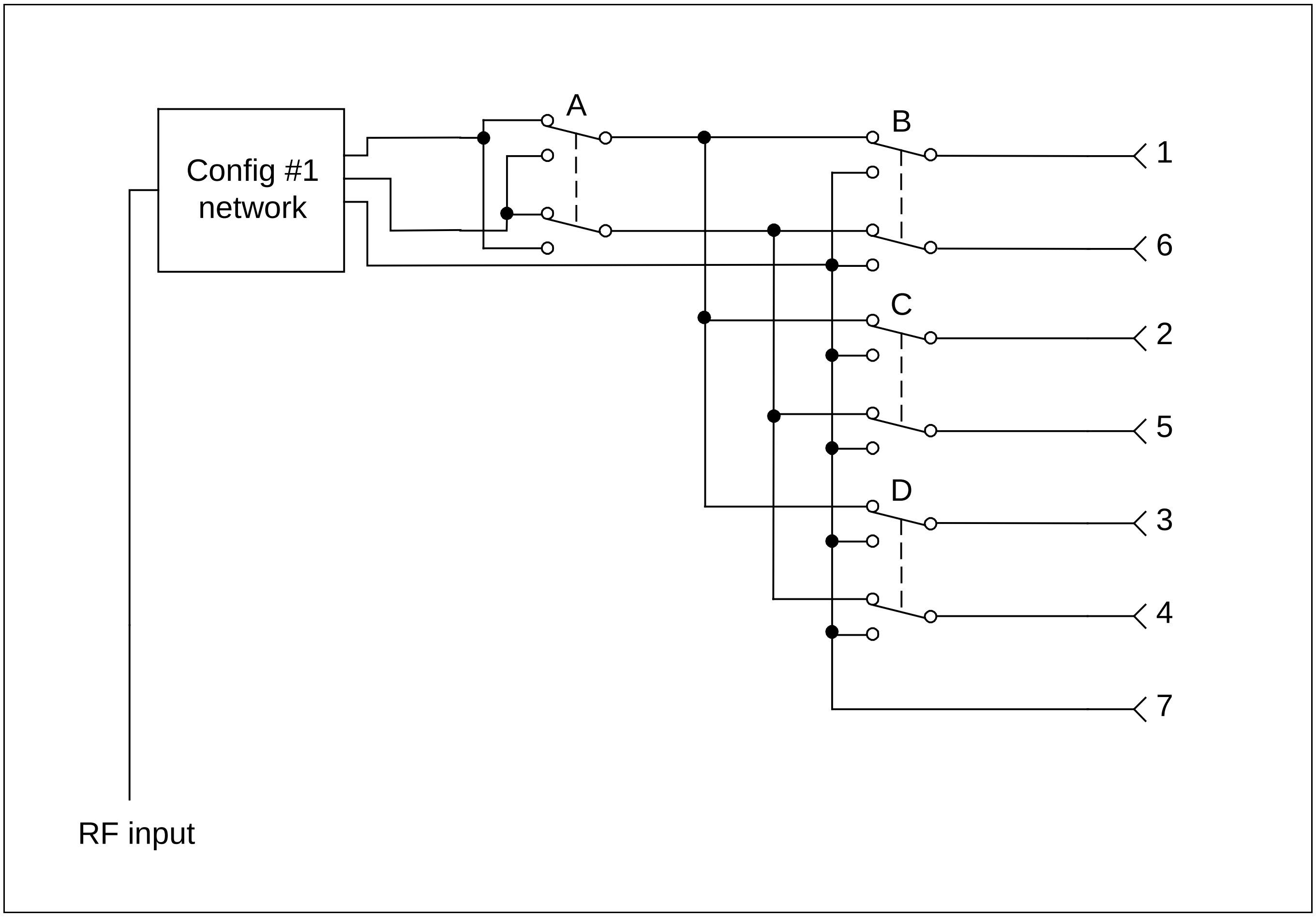

Figure 10. A simplified switching system implementing the 6 highest gain directions.

Summary:

A technique for driving the array has been shown that has about the same degree of difficulty to implement as the phasing network for a 4-square. A minimum amount of coaxial cable is necessary, and the array can be tuned up with virtually no test equipment. Everything is very non-critical. The mutual coupling between antennas does not need to be measured or controlled, nor do the individual antennas need to be tuned to any particular exact resonant frequency, although they should all be identical, so the tuning doesn’t change when directions are switched. When I built this system, I adjusted L and C, and it simply *worked*. I hadn’t even gotten around to tuning the elements to 7150 yet. It sure seems easier than the stories I have heard about trying to get 4-squares tuned up.

Frequently Asked Questions (FAQ):

1. Why not use a quadrature hybrid to get the 90° phase shift in configuration #1, like they do in 4-squares?

A quadrature hybrid only has equal output currents in quadrature if the loads are 50 ohms, or whatever Z_0 is. So, in general, it won't work. In 4-squares, some people believe that if no power is dumped to the dummy load port, the hybrid must be working into 50 ohms. Actually, as is well known, the absence of power at this port only means that the loads on the outputs are identical, not that they are matched. Don't ask me how 4-squares are supposed to work that way.

2. Why not use parasitic elements, and get rid of the coax to the outer elements?

A ground mounted vertical Yagi basically uses the ground for a "boom". Remember, that in a Yagi, you have to account for a "boom correction factor". There is no way to do this with the ground, even when you have a big ground screen like I do. Element coupling is simply too unpredictable to make this practical unless you want to hand tune the elements. Also, this is not a Yagi, since the elements are not in a line.

3. Can I make this using a tower as the center element and slopers for the outer elements?

You need to get the slopers 3/8 wl out. This may be difficult on a small lot. Anyway, I haven't tried to model this, so you are welcome to try it on your own.