Title: Four-Square Phased Array for Receiving — *Date:* March 19, 2013
Reference: Low-Band DXing, Hi-Z Antennas, DX Engineering — *From:* Jeff Crawford

Background

Written and internet resources are available to provide the needed background necessary to design and build your own four-square receiving array. Several commercial systems are available, however the price tags are significant, and you do not have the satisfaction of having designed and built your own system.

Initially I had considered going with beverage antennas, but the amount of real estate needed was more than I wanted to use. Of concern too, is the fact that the wires themselves need to be near the ground, adding to the risks of unfavorable "people interaction". My most serious problems, however, were a) the NE-SW beverage would have been too close to my transmit antenna if I wanted the beverage to be sufficiently long, and b) the only area I had available for NW-SE was almost parallel to a 7.2 kV line only 50 feet away. My lot is "L" shaped with part of this being allocated for my drain field. Since this area is removed significantly from the location of my transmitting antennas, and useable for relatively little else, it is home for my four-square receive array.

Some people have designed their four-squares for a single band, using shortened antennas (low R {1 Ω} and high X_C {~ 3,000 Ω}) and accommodating the unfavorable impedance mismatch (for 75 ohm lines) by inserting a series R (around 75 ohms) with a series inductor to cancel the accompanying capacitive reactance, X_C. While such an arrangement works, it is by design, a single band system. Described here is an alternative approach, wherein a FET source follower does the impedance transformation wideband. Such an "active antenna" is capable of covering 160, 80, and 40m bands if the base length of the four-square is suitably chosen. The key to this system and those utilizing true phased lines in general is terminating the transmission lines in their characteristic impedance, Z_o, so that a one-to-one correlation exists between physical and electrical length. The greater the VSWR mismatch, the greater the difference in physical and electrical lengths, and any tracking with frequency is distorted.

Provided here are the design details of my four-square system which covers 160, 80, and 40m. My greatest interest is in good performance on 160m and 80m. The array is located approximately 500 ft from my house and 250 ft from the end of my inverted-L antenna used for 160m. In conjunction with the array I use the Time Sequencer from DX Engineering to engage/disengage SPDT relays both at the radio location and in each source follower amplifier. This switching is done within each LNA in order to a) provide protection to the LNAs from the high electric fields when in transmit mode, and b) terminate the antenna in a resistive load when not in use to ensure no charge buildup on the antenna. I also perform switching in parallel at my transceiver to ensure my RX port on my Orion II transceiver is not overloaded (a second safety measure). Two relays switched in parallel will theoretically have the same delay (less control line propagation time) as a single relay.

The Ideal Design

There are several fundamental principles which allow an active array to cover multiple amateur bands without adjustment. The first principle is that the dimensions chosen scale with frequency, directly, when the cable lengths are chosen for "true time delay" architectures. Secondly, and most importantly, the active amplifiers electronically convert a highly reactive antenna element impedance (with ~ 1 ohm real resistance; 1,000's Ω reactance) to 75 Ω across the frequency bands of interest. When this is done the electrical length is equal to the physical length since the transmission line is terminated in its characteristic impedance.

In performing the modeling with EZNEC it is not possible to directly emulate the impedance translation performed by the active amplifiers located at each element. In order to capture this effect the impedance at the base of the antenna must be determined for each of the three bands to be used; 1.8, 3.5, and 7 MHz. These impedances are "brute force" modified to be 75 Ω by a) cancelling the highly reactive component with a series inductor and b) bringing the real impedance up to 75 Ω by placing in series an additional resistance near 75 Ω. Both (a) and (b) are done by the active amplifier in the real system and are included here in the simulation only to emulate the function of the source follower amplifiers.

Shown in Figure 1 is the manner in which each antenna element is modeled in EZNEC. The radiator is a 102 inch stainless steel whip antenna available through Radio Shack. EZNEC was used to model the feedpoint impedance of this whip when connected above a perfect ground plane. The associated impedances at the antenna base as a function of frequency are shown in Table I.

Frequency, MHz	Real Impedance	Imaginary Impedance
1.8	0.126	-3,745
1.84	0.131	-3,663
3.55	0.42	-1,879
7.04	1.556	-909

Table I
Driving Point Impedances for Stainless Steel Whip Antenna Alone

When performing the EZNEC simulation, the impedances in Table I must be changed to 75 Ω "real" to emulate what, in real life, is done by the active amplifiers. In the EZNEC simulation the effect of the source follower amplifiers is handled as shown in Figure 1.

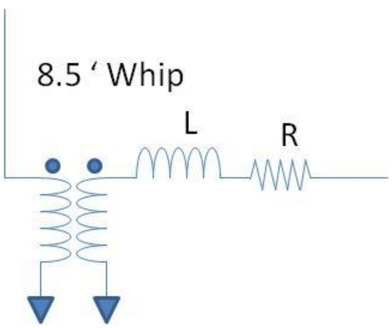
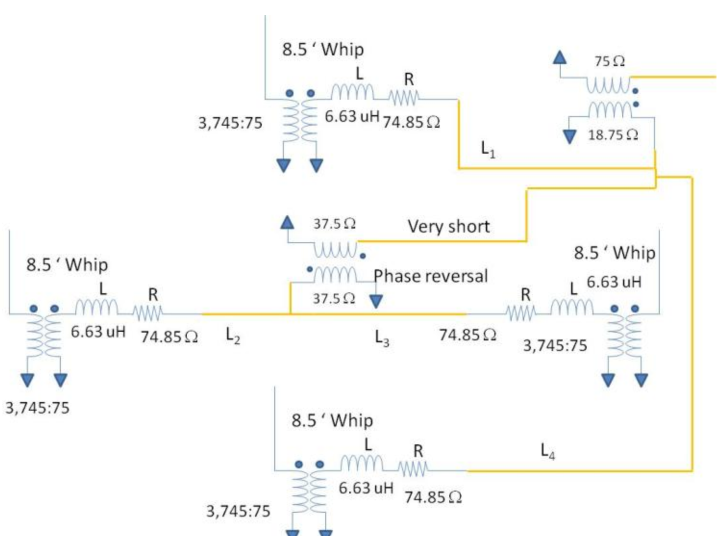


Figure 1

Consider how the model is constructed for each component at 1.8 MHz. At this frequency the reactive impedance is 3,745 Ω so an EZNEC transformer with primary 3,745 Ω and secondary 75 Ω is attached to the base of the whip. After this impedance transformation a series inductor of 6.63 uH is inserted in series to cancel the 75 ohms reactance (at 1.8 MHz) and an additional 75 Ω resistor is placed in series to give a net feedpoint impedance of approximately 75 + j0 Ω. When moving to a different simulation frequency, such as 3.55 MHz, the transformer is changed and the series L and R are also modified to give a net 75 + j0 Ω when looking into "R". These "brute force" methods are unnecessary in the hardware implementation using the source followers.

Figure 2 shows the completed model used in the EZNEC simulation for a frequency of 1.84 MHz. In this model, the main receive lobe is toward the top, or north. In the simulation the cable length from the source to the first element, L_1, is equal to essentially zero ft, the lengths to elements (2) and (3), L_2 and L_3 respectively, being 45.679 ft, and the length L_4 to element (4) equal to 91.358 ft. These lengths are for a side dimension of 80 ft.



As just stated, the cable lengths for a side dimension of 80 feet are the lengths L_1 through L_4 in the table below:

L_1	~ 0
L_2	45.679'
L_3	45.679'
L_4	91.358'

Table 2

These lengths are easily calculated.

Figure 2

$$Diagonal = \sqrt{2\times 80^2} = 113.137$$

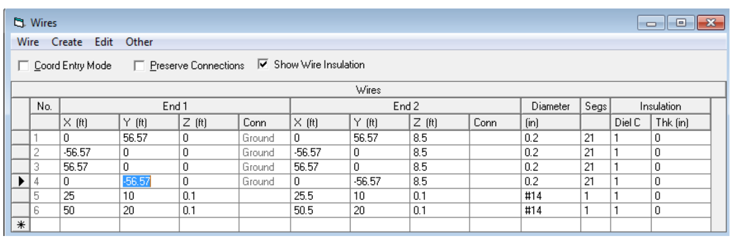
$$L_4 = 113.137\times 0.95\times V_{fac} = 113.137\times 0.95\times 0.85 = 91.358'$$

Lengths L_2 and L_3 are half the length of L_4: $L_4 = \frac{1}{2}L_4 = 0.5\times 113.137 = 45.68'$

In the actual construction of the array, each active antenna is fed from its feedpoint back to the array controller at a convenient location by equal-length 75 Ω coaxes. It is at the controller that the three different length coaxes are switched into the proper antenna feeds by relays to steer the pattern in the desired directions.

The additional cable lengths just mentioned are not included in the simulation. However, in the actual construction they must be included, otherwise the cables to elements 2 and 3 are not of sufficient length to close the distance, and certainly the ~0 length for element 1 in the simulation is nonviable.

Initially a side length of 90 feet was chosen, but after laying the array out in the drain field it became obvious that some of the antennas would be too close to nearby trees which would create asymmetry among the four elements. Therefore a side length of 80 feet was chosen. At 1.8 MHz the front-to-back ratio diminished by only 0.71 dB compared to an array with 90 foot sides.

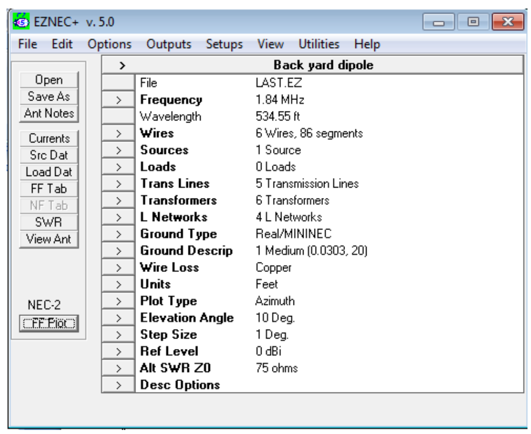


Wires

Wire Create Edit Other

Coord Entry Mode — Preserve Connections — Show Wire Insulation

No.	End 1 X (ft)	End 1 Y (ft)	End 1 Z (ft)	End 1 Conn	End 2 X (ft)	End 2 Y (ft)	End 2 Z (ft)	End 2 Conn	Diameter (in)	Segs	Insulation Diel C	Insulation Thk (in)
1	0	56.57	0	Ground	0	56.57	8.5		0.2	21	1	0
2	-56.57	0	0	Ground	-56.57	0	8.5		0.2	21	1	0
3	56.57	0	0	Ground	56.57	0	8.5		0.2	21	1	0
4	0	-56.57	0	Ground	0	-56.57	8.5		0.2	21	1	0
5	25	10	0.1		25.5	10	0.1		#14	1	1	0
6	50	20	0.1		50.5	20	0.1		#14	1	1	0

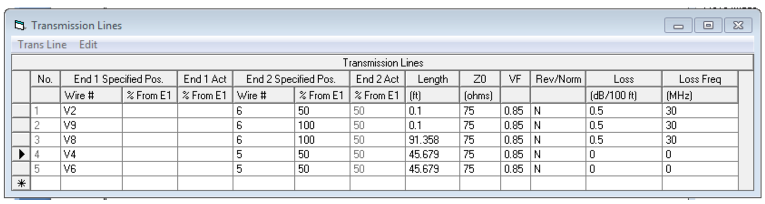


EZNEC+ v. 5.0

File Edit Options Outputs Setups View Utilities Help

Open — Save As — Ant Notes — Currents — Src Dat — Load Dat — FF Tab — NF Tab — SWR — View Ant — NEC-2 — FF Plot

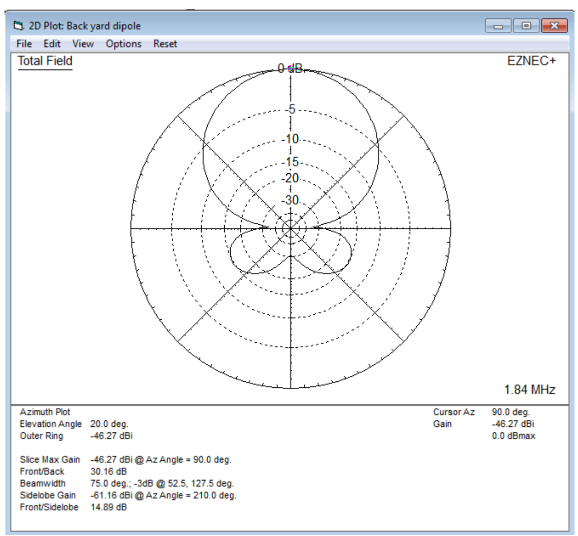
Back yard dipole	
File	LAST.EZ
Frequency	1.84 MHz
Wavelength	534.55 ft
Wires	6 Wires, 86 segments
Sources	1 Source
Loads	0 Loads
Trans Lines	5 Transmission Lines
Transformers	6 Transformers
L Networks	4 L Networks
Ground Type	Real/MININEC
Ground Descrip	1 Medium (0.0303, 20)
Wire Loss	Copper
Units	Feet
Plot Type	Azimuth
Elevation Angle	10 Deg.
Step Size	1 Deg.
Ref Level	0 dBi
Alt SWR Z0	75 ohms
Desc Options	



Transmission Lines

Trans Line Edit

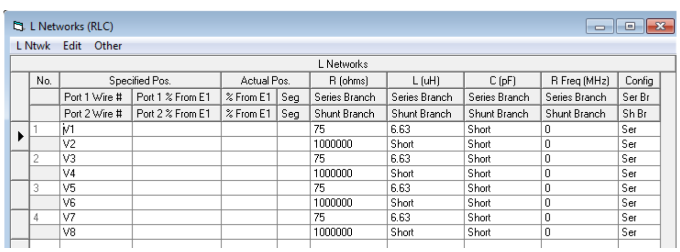
No.	End 1 Specified Pos. Wire #	End 1 Specified Pos. % From E1	End 1 Act % From E1	End 2 Specified Pos. Wire #	End 2 Specified Pos. % From E1	End 2 Act % From E1	Length (ft)	Z0 (ohms)	VF	Rev/Norm	Loss (dB/100 ft)	Loss Freq (MHz)
1	V2			6	50	50	0.1	75	0.85	N	0.5	30
2	V9			6	100	50	0.1	75	0.85	N	0.5	30
3	V8			6	100	50	91.358	75	0.85	N	0.5	30
4	V4			5	50	50	45.679	75	0.85	N	0	0
5	V6			5	50	50	45.679	75	0.85	N	0	0



2D Plot: Back yard dipole

File Edit View Options Reset

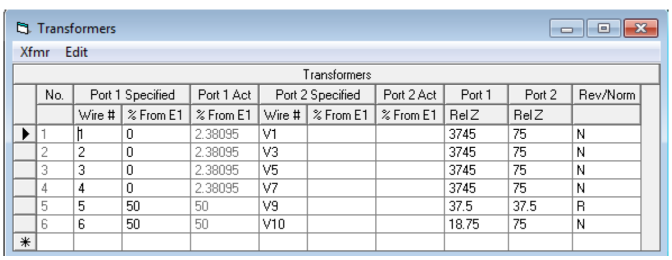
Azimuth Plot		Cursor Az	90.0 deg.
Elevation Angle	20.0 deg.	Gain	-46.27 dBi
Outer Ring	-46.27 dBi		0.0 dBmax
Slice Max Gain	-46.27 dBi @ Az Angle = 90.0 deg.		
Front/Back	30.16 dB		
Beamwidth	75.0 deg.; -3dB @ 52.5, 127.5 deg.		
Sidelobe Gain	-61.16 dBi @ Az Angle = 210.0 deg.		
Front/Sidelobe	14.89 dB		



L Networks (RLC)

L Ntwk Edit Other

No.	Specified Pos. Port 1 Wire # / Port 2 Wire #	Specified Pos. Port 1 % From E1 / Port 2 % From E1	Actual Pos. % From E1	Actual Pos. Seg	R (ohms) Series Branch / Shunt Branch	L (uH) Series Branch / Shunt Branch	C (pF) Series Branch / Shunt Branch	R Freq (MHz) Series Branch / Shunt Branch	Config Ser Br / Sh Br
1	V1				75	6.63	Short	0	Ser
	V2				1000000	Short	Short	0	Ser
2	V3				75	6.63	Short	0	Ser
	V4				1000000	Short	Short	0	Ser
3	V5				75	6.63	Short	0	Ser
	V6				1000000	Short	Short	0	Ser
4	V7				75	6.63	Short	0	Ser
	V8				1000000	Short	Short	0	Ser



Transformers

Xfmr Edit

No.	Port 1 Specified Wire #	Port 1 Specified % From E1	Port 1 Act % From E1	Port 2 Specified Wire #	Port 2 Specified % From E1	Port 2 Act % From E1	Port 1 Rel Z	Port 2 Rel Z	Rev/Norm
1	1	0	2.38095	V1			3745	75	N
2	2	0	2.38095	V3			3745	75	N
3	3	0	2.38095	V5			3745	75	N
4	4	0	2.38095	V7			3745	75	N
5	5	50	50	V9			37.5	37.5	R
6	6	50	50	V10			18.75	75	N

At 3.55 MHz

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File Edit Options Outputs Setups View Utilities Help

Open | Save As | Ant Notes | Currents | Src Dat | Load Dat | FF Tab | NF Tab | SWR | View Ant | NEC-2 | FF Plot

	Receive Four Square
File	Phased Array 3-55 MHz.EZ
Frequency	3.55 MHz
Wavelength	277.062 ft
Wires	6 Wires, 86 segments
Sources	1 Source
Loads	0 Loads
Trans Lines	5 Transmission Lines
Transformers	6 Transformers
L Networks	4 L Networks
Ground Type	Real/MININEC
Ground Descrip	1 Medium (0.0303, 20)
Wire Loss	Copper
Units	Feet
Plot Type	Azimuth
Elevation Angle	20 Deg.
Step Size	1 Deg.
Ref Level	0 dBi
Alt SWR Z0	75 ohms
Desc Options	

L Networks (RLC)

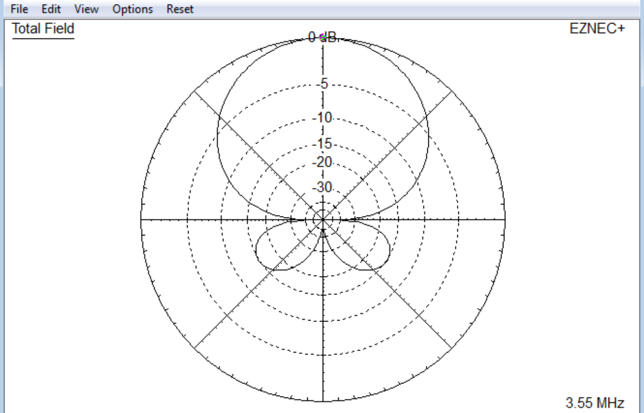
L Ntwk Edit Other

L Networks

No.	Specified Pos.		Actual Pos.		R (ohms)	L (uH)	C (pF)	R Freq (MHz)	Config
	Port 1 Wire #	Port 1 % From E1	% From E1	Seg	Series Branch	Series Branch	Series Branch	Series Branch	Ser Br
	Port 2 Wire #	Port 2 % From E1	% From E1	Seg	Shunt Branch	Shunt Branch	Shunt Branch	Shunt Branch	Sh Br
1	V1				74.85	3.36	Short	0	Ser
	V2				1000000	Short	Short	0	Ser
2	V3				74.85	3.36	Short	0	Ser
	V4				1000000	Short	Short	0	Ser
3	V5				74.85	3.36	Short	0	Ser
	V6				1000000	Short	Short	0	Ser
4	V7				74.85	3.36	Short	0	Ser
	V8				1000000	Short	Short	0	Ser

Receive Four Square

File Edit View Options Reset



Azimuth Plot		Cursor Az	90.0 deg.
Elevation Angle	20.0 deg.	Gain	-29.43 dBi
Outer Ring	-29.43 dBi		0.0 dBmax
Slice Max Gain	-29.43 dBi @ Az Angle = 90.0 deg.		
Front/Back	46.35 dB		
Beamwidth	81.2 deg.; -3dB @ 49.4, 130.6 deg.		
Sidelobe Gain	-44.39 dBi @ Az Angle = 212.0 deg.		
Front/Sidelobe	14.96 dB		

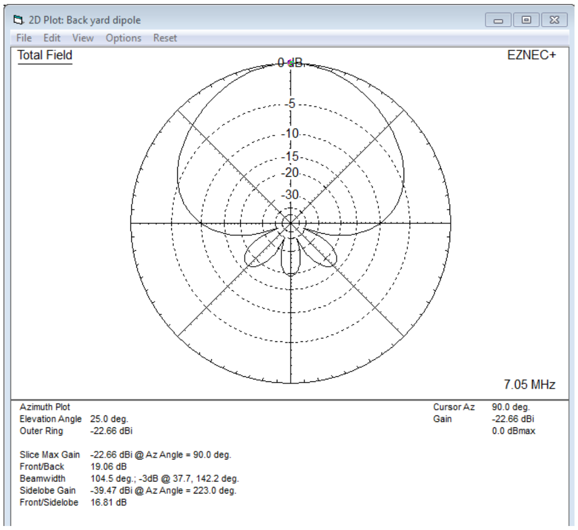
Transformers

Xfmr Edit

Transformers

No.	Port 1 Specified		Port 1 Act	Port 2 Specified		Port 2 Act	Port 1	Port 2	Rev/Norm
	Wire #	% From E1	% From E1	Wire #	% From E1	% From E1	Rel Z	Rel Z	
1	1	0	2.38095	V1			1879	75	N
2	2	0	2.38095	V3			1879	75	N
3	3	0	2.38095	V5			1879	75	N
4	4	0	2.38095	V7			1879	75	N
5	5	50	50	V9			37.5	37.5	R
6	6	50	50	V10			18.75	75	N

At 7.05 MHz



At 7.05 MHz the driving point impedance of the 8.5 ft vertical is $1.589 - j907.5\,\Omega\,1$

Therefore, the transformers have primary:secondary values of 907.5 : 75 Ω. The additional lumped elements are then R = 74.75 Ω and L = 1.693 uH.

