Simple 3 Element Phased Array Construction

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1 Abstract

The disjoint nature of this document will probably be due to my own failings as a technical author. Please forgive me :).

Initially this document was conceived as a way to track down all of the tasks I had to learn, formulas I had to use, and the sources I used to learn about them. Eventually I realized that someone else may find this information quite useful.

This document *is not* meant to be a complete discussion of the various phasing techniques available to amateurs, nor, is it intended to be an exhaustive description of the *ideal* phasing network. My goal is to give a practical discussion of the implementation of the phasing network in use here at *KC0VKN*. I make no claim that my design, construction, or use is optimal. The point is that it does work. I've tried to avoid the self deception that Greg, W8WWV mentions[1]!

Notification of failings in my description, design, or assumptions would be greatfully accepted at kc0vkn@bitjanitor.net.

2 Initial Design Plan

This begins with me wanting a little gain on 40M from my backyard for contesting and DXpedtion chasing. It ends with me acquiring some practical knowledge on how to construct, test, and use fairly basic building blocks of radio.

My requirements were:

- Portability

- Simple construction

- Simple setup and tuning

- Noticiable gain and directivity

You'll note that "High Performance" wasn't on the list.

I felt that I'd be more likely to use the array if it were simple to setup and transport, given that my main use is to be temporary operation from my QTH or another location. I maintain 1 permanent $1/4\ \lambda$ aluminum vertical for 40M and wanted to be able to either travel with this array, or, suppliment the single vertical in my back yard as I needed.

The final array consists of 2 temporary fiberglass poles place $1/4\lambda$ apart in an

equalateral triangle configuration. Each element passes through Hybrid Coupler described by Fred Collins, W1FC[1][3].

The fiberglass poles come out when there is an interesting DXPedition (maybe one day they'll actually go *on* a DXPedition!) out and about, or, a contest I'd like to operate in. The rest of the time they live in my garage; neatly stacked with a small box containing the phasing box and the associated feedlines.

3   Research

This odyssey began with a Google search for something irrelevant that landed me at W8WWV's excellent site[1] where he described his experimentation with hex-arrays on 80 and 160M. In it he references descriptions of phasing networks located in ON4UN's excellent tome *ON4UN's Lowband DXing*[3]. Further forays into this excellent resource led me to believe that I could have a little gain on 40M to capture some DX with my 100W sigs from 0-land!

I was a bit shy on construction, initially. How to do it? What network? What element configuration?

Initially I was looking at the *Gerhke Method*[4] because that's what Greg seemed to like the best and it seemed very flexible[1].

Alas it seemed somewhat complicated for my needs; though I still feel that it is an excellent choice. If I were constructing a permanent array, it is probably the design I would utilize.

For a time I thought about the W7EL *Current Forcing Method*[3][11][2] but discarded it

as *too* simple –go figure! I felt that I'd acquire more knowledge by constructing some sort of phasing network with components; plus I was still infatuated with the K2BT design.

Additional research directed me to 2 more web sites[5][9].

Patrick and Johan had opted to use the W1FC network, which uses a Quadrature or Hybrid Coupler, in their designs. I believe this to be the design used by ComTek Systems, and ON4UN gives plenty of space to it in his book.[3].[1]

It seemed like just the ticket for my needs. It was:

- Portable

- Simply constructed (2 guys had already done it!)

- Simple Setup and Tuning (None?)

- Noticiable gain and directivite (TBD!)

4   Construction

4.1   Phasing Network

4.1.1   Theory and Background

Figure 1 shows the schematic of the Hybrid Coupler used in my array. The coupler is

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[1]Also note that the relative merits and drawbacks of the W1FC, K2BT and other phasing networks are discussed at length by both ON4UN and W8WWV and I will not cover them here.
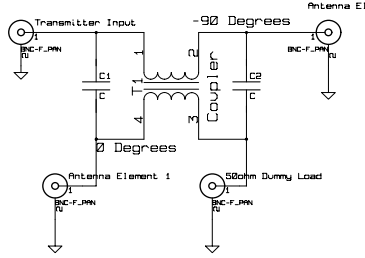
Figure 1: W1FC Hybrid Coupler

quite simple. 2 capacitors 1 transformer.[2] My own coupler uses 500V Mica caps and 16AWG zipcord wrapped around a **T130-2** core which has a published range of 250khz - 10Mhz[6]. Incidentally, this core was procured from http://KitsAndParts.com A core this small is probably not the best choice for QRO operation. I happened to have it on hand and knew I would only be putting 100W through my coupler. TK5EP and ON4UN indicate larger cores, such as the **200-2** or **225-2** would be a better choice[9][3].

Now that we've selected a core, and our capacitors, we need to determine values for the phasing network. *Table 1* contains precalculated values of C and L for a few frequencies.

I ended up using these as guide calculating my own values and then performing measurments to determine if the phasing network was operating as expected.

The following equations will be needed should you wish to do the same:

In *Fig.* 2 and 3 we demonstrate:

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[2]Coupler schematic done in wonderful OpenSource package *KiCad* located at http://www.lis.inpg.fr/realise_au_lis/kicad/

Frequency	C1 C2	L1 L2
3.525	451pF	2.26μH
7.025	226pF	1.13μH
10.110	157pF	$.79\mu$H
14.025	113pF	$.57\mu$H

Table 1: Sample Network Values

$$X_C = \frac{1}{2\pi FC} \Rightarrow C = \frac{10^6}{2\pi FX_C}$$
(a) Calculating C

$$X_L = 2\pi FL \Rightarrow L = \frac{X_L}{2\pi F}$$
(b) Calculating L

$X_C =$**100**ohms, $X_L =$**50**ohms, L in μ**H**, C in **pF**, F in **Mhz**

Recall that C1 and C2 in *Fig*1 are the same value. Thus, C1 = 226pF and C2 = 226pF. As I'll note later, these values may need to be adjusted.

Now that we have our L we need to figure out how to wind our toroid to get it! Figure4 shows the equation for solving turns on a toroidal inductor where A_L is the value published by the core manufacturer.[3]

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[3]W8DIZ has the A_L values for the cores he sells on his site[6]. Otherwise these should be in the vendors datasheet for the core. For T130-2 $A_L = 110$ and T200-2 $A_L = 120$

Figure 2: Solving for C

$$F = 7.025 \tag{1}$$

$$X_C = 100 \tag{2}$$

$$C = \frac{10^6}{2\pi * 7.025 * 100} = \frac{10^6}{4,413.94} = 226.554 \tag{3}$$

$$C = 226\text{pF}$$

Figure 3: Solving for L

$$F = 7.025 \tag{4}$$

$$X_L = 50 \tag{5}$$

$$C = \frac{50}{2\pi * 7.025} = \frac{50}{44.139} = 1.132 \tag{6}$$

$L = 1.13\mu H$

Figure 4: Toroidal Turns

$$\mu H = (AL * Turns2)/1000 \Rightarrow turns = 100\sqrt{\frac{L}{A_L}} \tag{7}$$

Figure 5: Determining L from X
$L =$ Inductance in Henries
$F =$ Frequency in Hertz

$$L = \frac{X}{(2\pi F)} \tag{8}$$

Figure 6: Example Determining L from X
$L =$ Inductance in Henries
$F = 1830000$hz (1.830Mhz)
$X = 190$ohms

$$L = \frac{190}{11,498,229} = 1.652 x 10^{-5} Henrys \tag{9}$$

$L = 16\mu H$

There are also several toroid calculators on the web [6][7] and a very nice free one for Windows™by DL5SWB[8].

When I had constructed my coupler, I tested it and discovered that it was not 50ohms impedance, and, that the phase difference was not 90°! I fiddled with *C1* and *C2* and saw no change and so I determined I should measure the inductor. How? I had used the calculators hadn't gotten me quite where I needed to be. I thought didn't have an *LC* meter. After some prompting from K0KK and W5FH it occurred to me that I had everything I needed in my VK5JST Antenna Analyst!

The process is fairly simple. Since this is a bifilar core and L is the same for each winding, tie both together and put each on the Analyzer (my Analyst has binding posts; you may have to construct something or use an adaptor if you have some other connec-

tor style.). Now, tune the analyzer to the frequency of interest; for me 7.025Mhz. You should make note of the X and F it was taken at on your analyzer and plug it into the equation in Fig.5.

And once again I think an example is in order ;). Please see Fig.6.

4.1.2 Physical Construction

How did I put this all together? The first rendition of my coupler is built for 40M and housed in a small plastic box. RF enters and leaves via 3 BNC and 1 SO239. Fig. 7

Initially I performed the calculations from Fig.4, but found that the finished coupler did not exhibit a 90° current-phase difference.

Basically I found my toroidal inductance using the method described in the previous section (Fig. 6) (in my case I had to unwind

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Figure 7: Completed Phasing Network
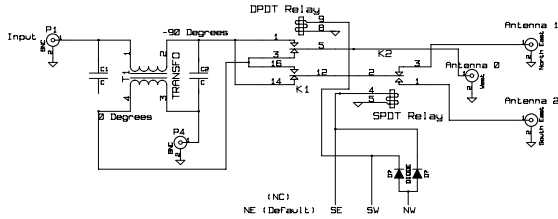

Figure 8: 40M Phasing Box
<photoplaceholder>

a couple of turns to get to the target inductance of $1.13\mu H$). I calculated the interwinding capacitance and subtracted that from the calculated values for C1 and C2 and got out the soldering iron!

The reality of the network is that it's *extremely* simple to construct and calculate values for. One needn't be afraid of attempting to build an array like this. In fact, my very first version only utilized 2 elements. I varied phase on elements *0* and *1* by 90° with a single relay, and a toggle switch lying on the desk of the shack. Once I was satisfied that I actually had made the thing work, I added a second relay, a more complex phasing network and a third element to arrive at the configuration described here.

Figure 9: VKN Modified Solid State Switchbox
<VKN Switchbox Schematic>

4.1.3 Phasing Lines

The design calls for 1 1/4λ *electrical* phasing line from the coupler to each element. ON4UN discusses several methods for cutting them[3]. If you've got an antenna analyzer the simplest method is to cut a line that's close to 1/4λ in physical length, short the center conductor to the shield on the far end, and attach the other end to your analyzer. Find where you hit resonance ($X = 0$) with the characteristic impedance of the lines you're using (I was using 50ohm RG8X). If it's lower in frequency than your target, trim a little off, but not to much, and repeat the exercise until you're close to your target.

4.1.4 Switching Construction

Direction	0°	-90°	Float
NE	E0	E1	E2
SE	E0	E2	E1
SW	E1	E0	E2
NW	E2	E0	E1

Table 2: Directions of Fire

I have 2 different switching networks constructed for my array. One of them is a solid state design with LED indicators for direction. This is based on a solid state RX switch designed by DJ1YFK and N2NL[10]. You see my version of it in Fig.9.

Figure 10: Shack Switchbox
<VKN Switchbox Photograph>

Figure 11: Field Switchbox
<Field Switchbox schematic>

My unit will switch 2 arrays; a 40m and 20m while sharing the directional indicator LED's as seen in Fig.10.

Another, field ready switchbox simply uses a rotary switch. Much less complicated and easier to repair if I'm portable with the array. Not as pretty though. Fig.11

4.1.5 Relay Choice

W8WWV[1] spends quite a lot of time discussing his switching network. I found little reason not to take his advice and ordered the *same* relays from Jameco, the LB2-12DS (only, in 12V coil, not 24V coil). Running only 100W, I figured whatever he built to take 1.5KW would be safe for me.

4.1.6 Setup and Deploy

Setup and deployment is quite simple. Here at VKN I have 1 permanent aluminum vertical that is tuned for 40M and has about 40 radials underneath it. When I would like to use the array, I attach 2 33' fiberglass fishing poles to a couple of posts in my yard that spend most of their days holding up bird feeders (Oh, I'm a sly one.). Each temporary element has about 16 temporary radials under it.

The three elements should be very similar in construction and feedpoint characteristics.

To verify the elements; I first get the wire taped to them and get the 2 temporary elements in the air. I ground all of the elements that I'm not testing and use my analyzer to take a feedpoint reading. I do this for each element (being sure to ground all the elements not under test.). I'll trim (or add) wire to the temporary radiators in order to get them all within the same balpark for X and R. Naturally the aluminum vertical is difficult to make look like the wire elements given it's got more radials and different element characteristics, but, I have the temporary elements as close as I can get. Not ideal, but, I'm not willing to maintain the triangle-array as a permanent fixture in my yard.

I can generally end up with 0 reactance and about 45 ohms of resistance in the wire verticals and the standard for the aluminum vertical is 0 reactance and about 40 ohms of resistance. I've found that weather seems to influence this on the wire elements (ice, snow, wind).

Mismatch will show up on the dump port in the coupler. The closer the elements are in electrical characteristics to one another, the less power is sent to the dummy load. Matched loads are what make the hybrid coupler happiest.

Once I get all of the elements close; I put the analyzer on the input of the phasing network and verify that each switch position gives me something around 1.5 SWR so that I won't have to re-tune as I switch directions back in the shack. To date, this has only been a problem when I had a bad feedline to

one of the elements. If they're pretty similar looking with the analyzer, everything works as expected.

Initially I ran a feedline back to the shack for the dummy load so that I could monitor it. I found that when I put 100W into the network, I was seeing less than 4W back. I had to go fetch my QRP wattmeter to get a more accurate measurement. Lately I've been using a 2W 50ohm resister in the magic box rather than running another feedline back to the shack. If it were a permanent installation, I might do as ON4UN has done and put a detector on to drive a meter back at the shack[3].

4.2 Measurements

4.2.1 On the Bench

Once I had the "magic box" constructed I decided some tests were in order before I built the elements and cut the feedlines, but *did it actually work?*

I've got a trusty old Tek465 dual trace scope, and the first thing I did was cable everything up to it to verify the phase relationship between ports 2 and 4 of the coupler.

I attached the feedlines to the coupler, and terminated them with 50ohm resisters. Around each resister I had a crude current probe which consisted of a couple of identical toroidal cores with 8 or 10 turns of hookup wire. I passed the 50ohm resister that was behaving as my perfect "element" through the inductor, and then attached a probe to the hookup wire.

Once that was done, I attached my antenna analyzer to the **input** port on the coupler to act as a signal generator and fired up the scope and I saw something like Fig.12.

Figure 12: Poor phasing (less than 90°)
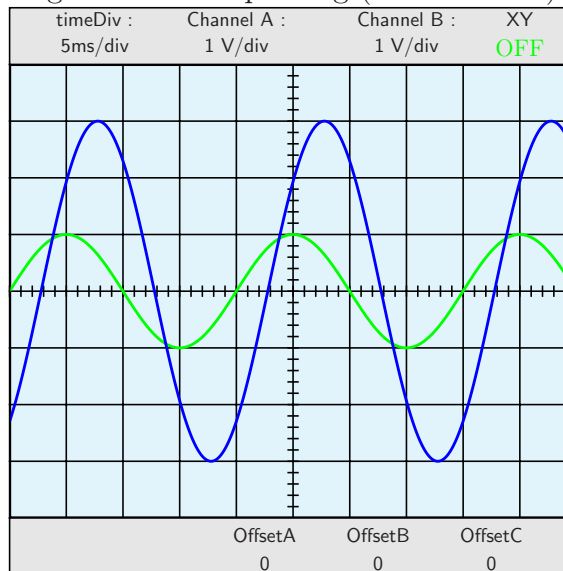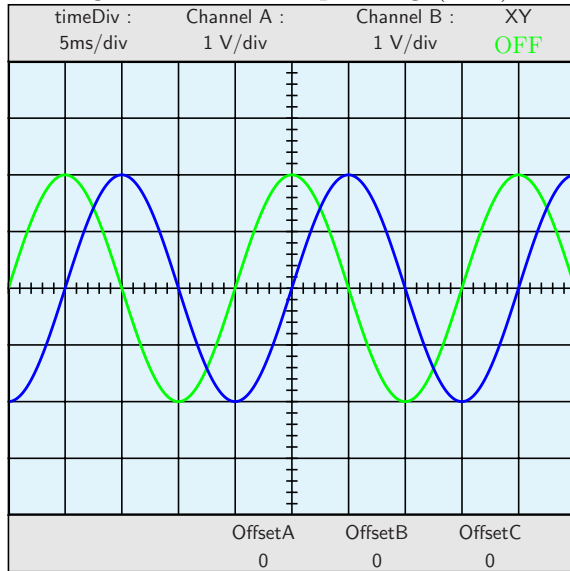
I was hoping to see something like Fig.13[4]

4.2.2 Real World Phase Measurments

W8WWV has an excellent discussion on how he measured his 6 element array[1]. I intend to do similar measurments when I get the array up and the WX is better!

The only components one needs are a dual-trace scope, some *matched* lenght coaxial lines, shunt resistance, and current probes. Greg does an *excellent* job describing the procedure and the test equipment required.

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[4]A quick Google search for "quadrature coupler" or "hybrid coupler" brings up many links on how Quadurature Couplers function. They are also very quick and easy to simulate in free LTSpice.

Figure 13: Perfect phasing (-90°)

EZNEC

EZNEC

Total Field

7.025 MHz

Azimuth Plot		Cursor Az	22.0 deg.
Elevation Angle	25.0 deg.	Gain	3.01 dBi
Outer Ring	3.01 dBi		0.0 dBmax

Slice Max Gain	3.01 dBi @ Az Angle = 22.0 deg.
Front/Back	32.17 dB
Beamwidth	178.7 deg.; -3dB @ 271.6, 90.3 deg.
Sidelobe Gain	-23.68 dBi @ Az Angle = 180.0 deg.
Front/Sidelobe	26.69 dB

Total Field

EZNEC

7.025 MHz

Elevation Plot		Cursor Elev	26.0 deg.
Azimuth Angle	0.0 deg.	Gain	2.97 dBi
Outer Ring	2.97 dBi		0.0 dBmax

Slice Max Gain	2.97 dBi @ Elev Angle = 26.0 deg.
Beamwidth	42.3 deg.; -3dB @ 9.0, 51.3 deg.
Sidelobe Gain	-11.59 dBi @ Elev Angle = 117.0 deg.
Front/Sidelobe	14.56 dB

Figure 14: Patterns

4.3   Pattern Measurments

What drew me to this configuration? A bit of gain and some RX directivity. I'll give a few brief plots of what the Modeling world says we should see, and then describe what I see in real life Fig.14

4.3.1   Theory

Using 3 elements instead of the more traditional 4-square arrangement means wider beamwidth, and less gain. Even so, the elevation plots show fair low-angle radiation and gain, and I've heard this in real-world usage.

4.3.2   Real World

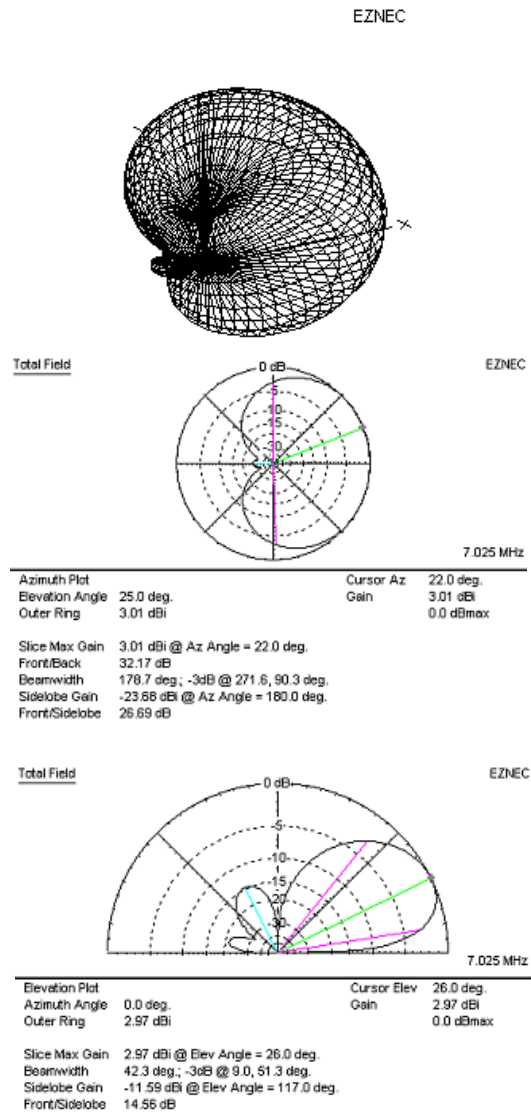This is where I use Polar Plot and drive around to get some RX pattern measurments.

8

Should have some plots of what we expect, and what I grab with polar plot.

4.4 What I learned

It isn't very difficult!

4.5 What I would change

At the end of any project, there is always the question about how one would do things differently. There are always compromises and this is no exception.

The initial goals of the array were met, but, some of the costs would be significant if this were to be a permanent array.

To begin with the Hybrid Coupler makes it difficult, as ON4UN notes[3], to *properly* feed the array for best F/B and Gain by allowing all three elements to be fed. As you'll note, in my usage, I float the unused element. I suspect that has unwanted effects on the pattern of the array, but, it was something I was willing to give up in exchange for ease of deployment and the ability to switch 4 directions.

The placement of my elements are not ideal, either. Later W1FC noted that placing the elements .29λ apart affected gain and FB for the better[3]. However, once again, I reasoned that since I was also not feeding all elements, I could live with this compromise.

The use of a hybrid coupler precludes arbitrary phase relationships that are not in quaderature (90°). Other phasing systems allow for phase relationships that both improve gain, and F/B.

Lastly, I'm going to add an "omni" position to the network. A few times I've wanted to do some A/B tests, and while I know that the directivity of the array is present, I just don't know how much difference it makes over my single vertical. There are also times in contests when trying to start a Run that it'd be nice to be in Omni, and then later focus on directions. Often I get calls from the sides where I don't have a good line of fire to a station and he's hard to work. If I could switch to Omni to work that station, it'd be helpful.

I think there are better phasing networks, but, I think for a Field Day type operation, or other temporary usage, the W1FC design is very simple to construct (few components), simple to measure and tune (little required of each), and compact.

Overall I'm happy with the performance of the array. It has allowed me to work a few weak ones with what I perceive to be less effort than a single vertical. I know it's allowed me to hear stations that I would not have been able to hear, and, it lets me keep my yard relatively uncluttered for the months of the year that I'm not as active. I'd recommend it for anyone who wants to experiment with vertical arrays as a good starting point.

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