# Multi-Element End-Fire Arrays of K9AY Loops


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# INTRODUCTION

- Introduction & Overview
- K9AY Array Simulation Results
- Array Implementation
- Results
- Discussion / Observations

# BACKGROUND

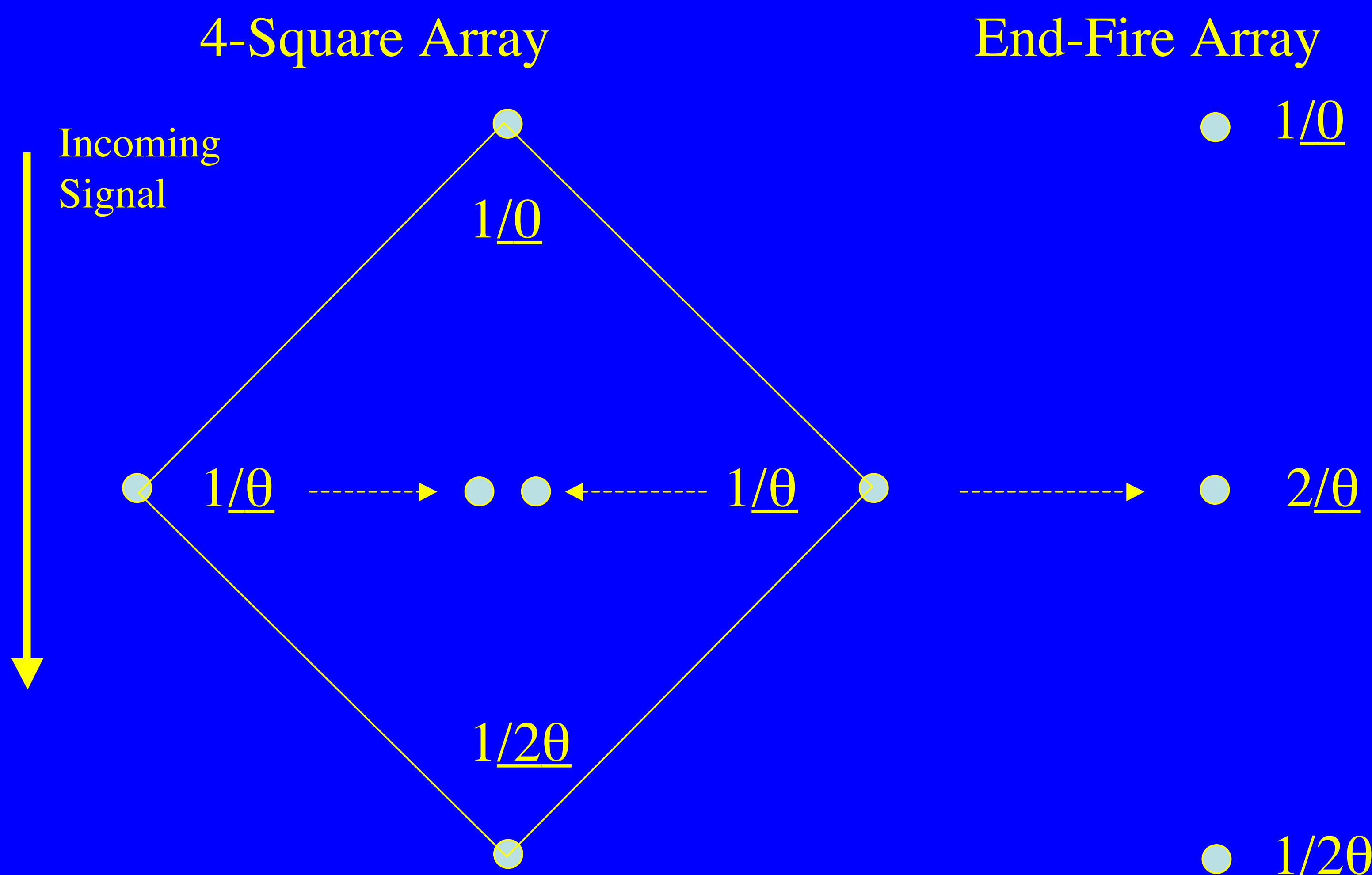
- Started with K9AY loop pair
- Added 4-square of short verticals (100’ side)
- Very poor ground conditions
  - Very rocky with rock shelves and clay
  - 2-3 mS/M ground conductivity
  - 4-Square not level
- K9AY loop generally better than 4-square

# BACKGROUND

- Wanted to try a 4-square of loops
  - Could not site the 4-square array well on my lot
  - Uneven lot + esthetic considerations
- Reviewed some existing literature
  - K9AY paper on loop arrays [1]
  - ON4UN book [2]
- Realized that the side elements of the 4-square essentially operate in parallel
- Decided to try a 1-2-1 binomial array
- Design goal - maximize RDF

# BACKGROUND

## 4-SQUARE / END-FIRE “TRANSFORMATION”

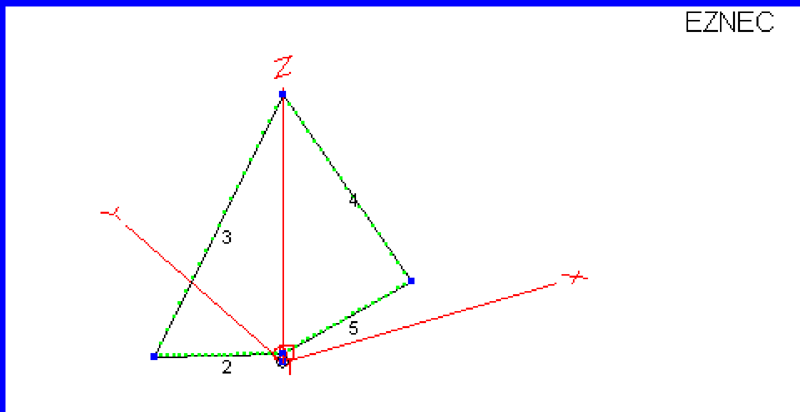


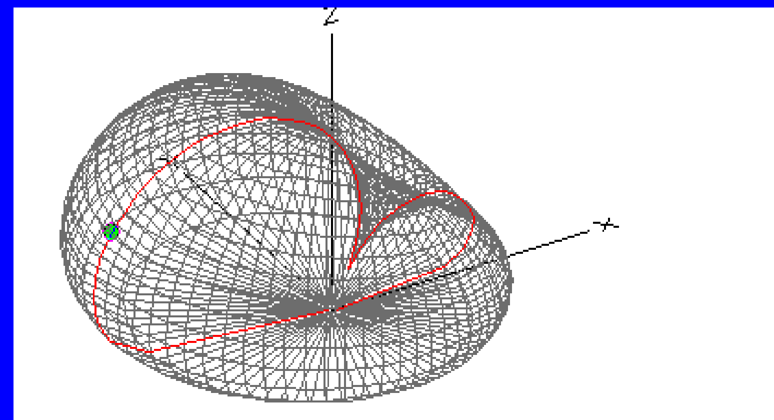
# RDF
## Receiving Directivty Factor

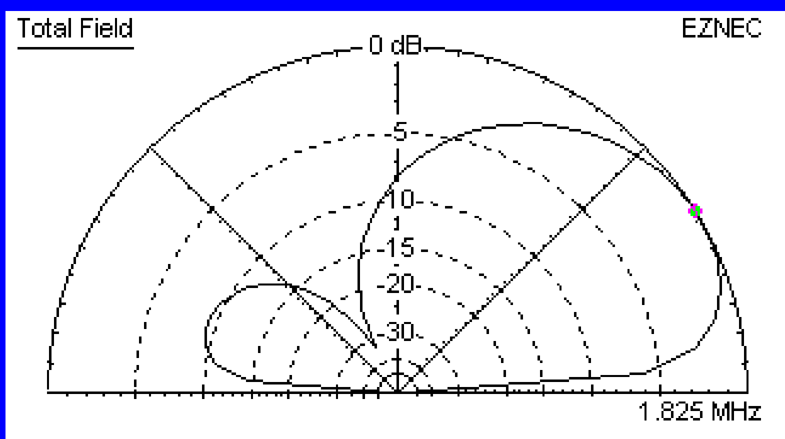
- Noise generally comes in from all directions
- RDF compares main lobe gain to average gain over whole antenna

- $RDF_{dB} = G_{for}(dB) - G_{avg}(dB)$

# ARRAY COMPARISON
## K9AY Loop




Forward Gain: -23.6 dBi

Average Gain: -31.0

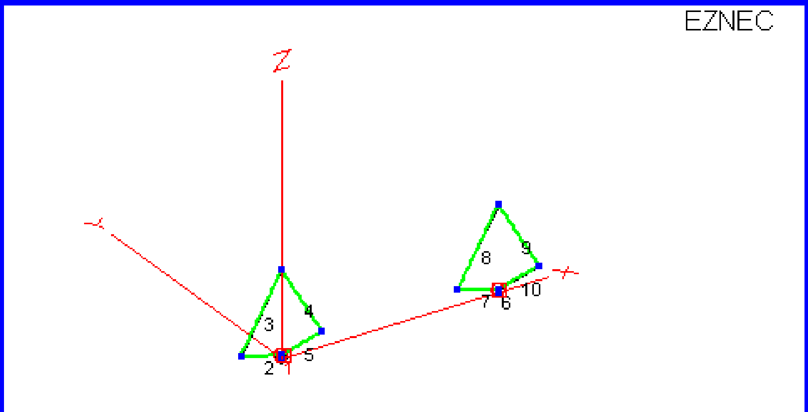
RDF: 7.4 dB

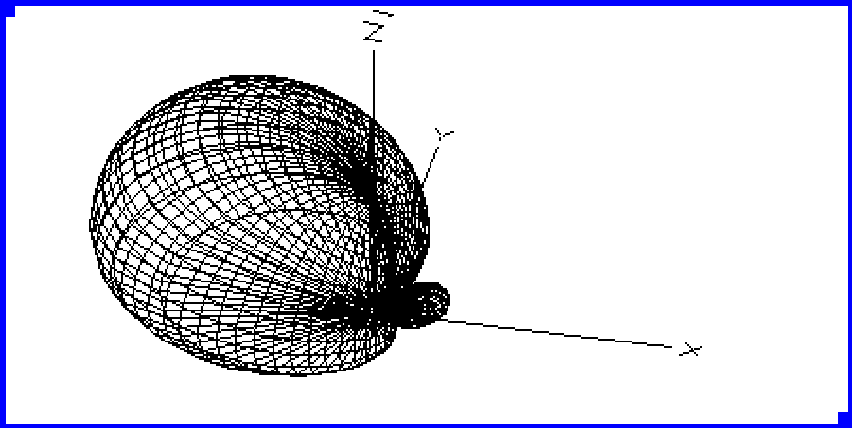
Beamwidth: 173°

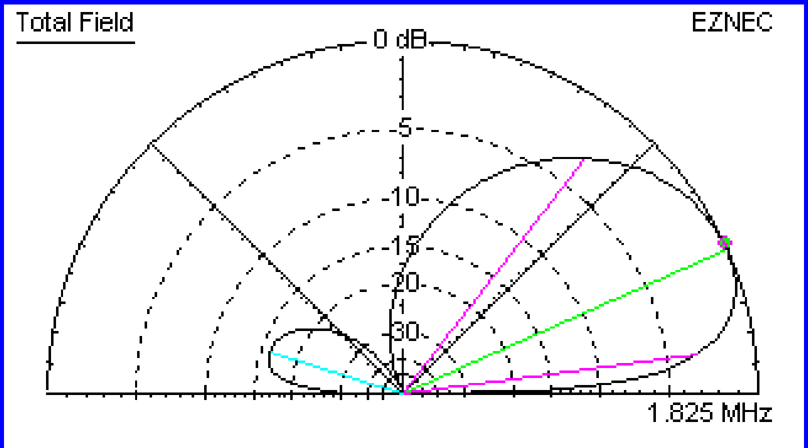
F/B: 9.5 dB

# ARRAY COMPARISON

## Two-Element Endfire Array - 80' Spacing




Gain: -25.6 dBi

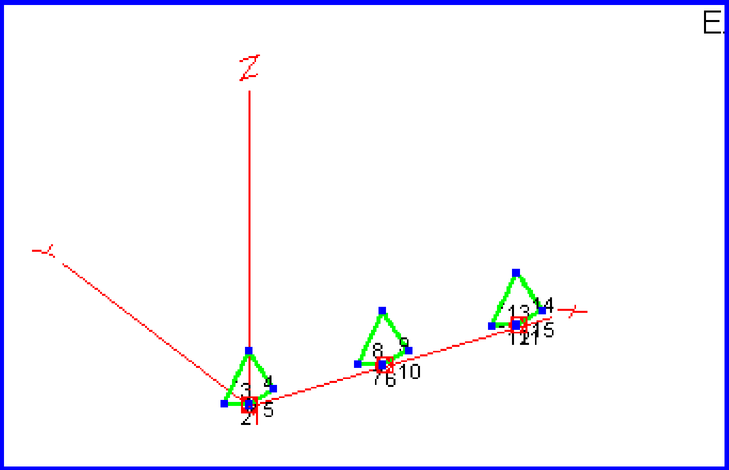
RDF: 10.5 dB

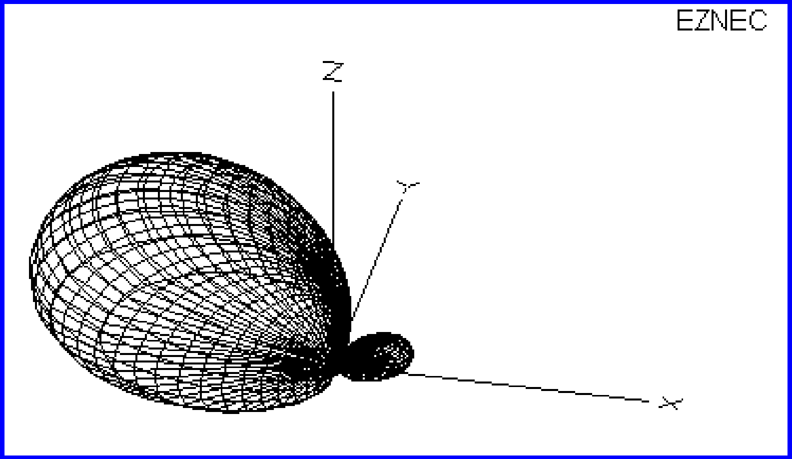
Beamwidth: 96$^o$

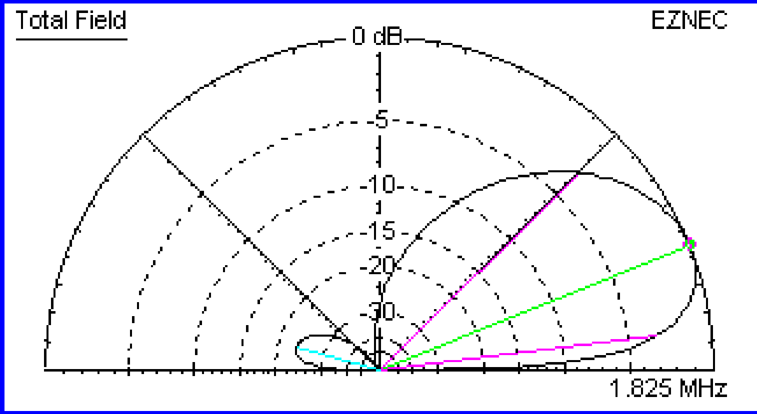
F/B: 16.0 dB

# ARRAY COMPARISON

## Three-Element Endfire Array - 80’ Spacing




Gain: -29.2 dBi

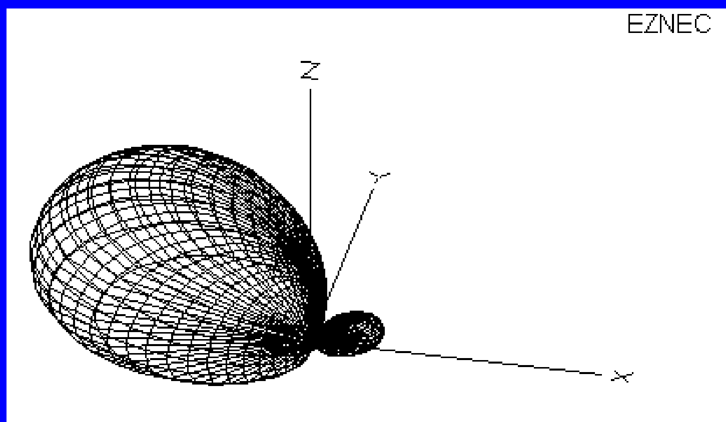
RDF: 12.1 dB

Beamwidth: 75°

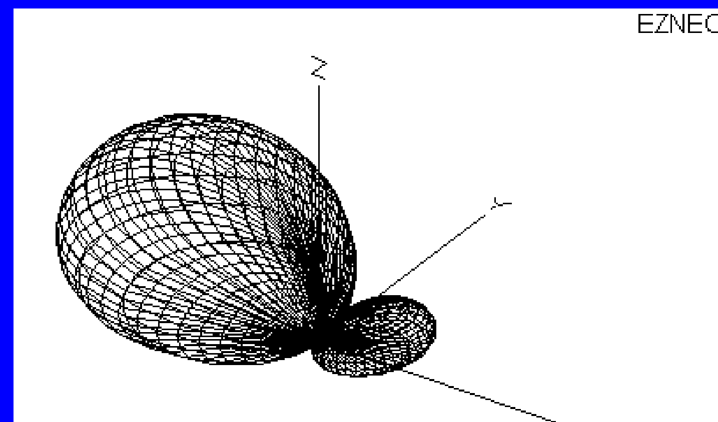
F/B: 24.0 dB

# ARRAY COMPARISON

## Three-element Array - 160M & 80M




1.825 MHz

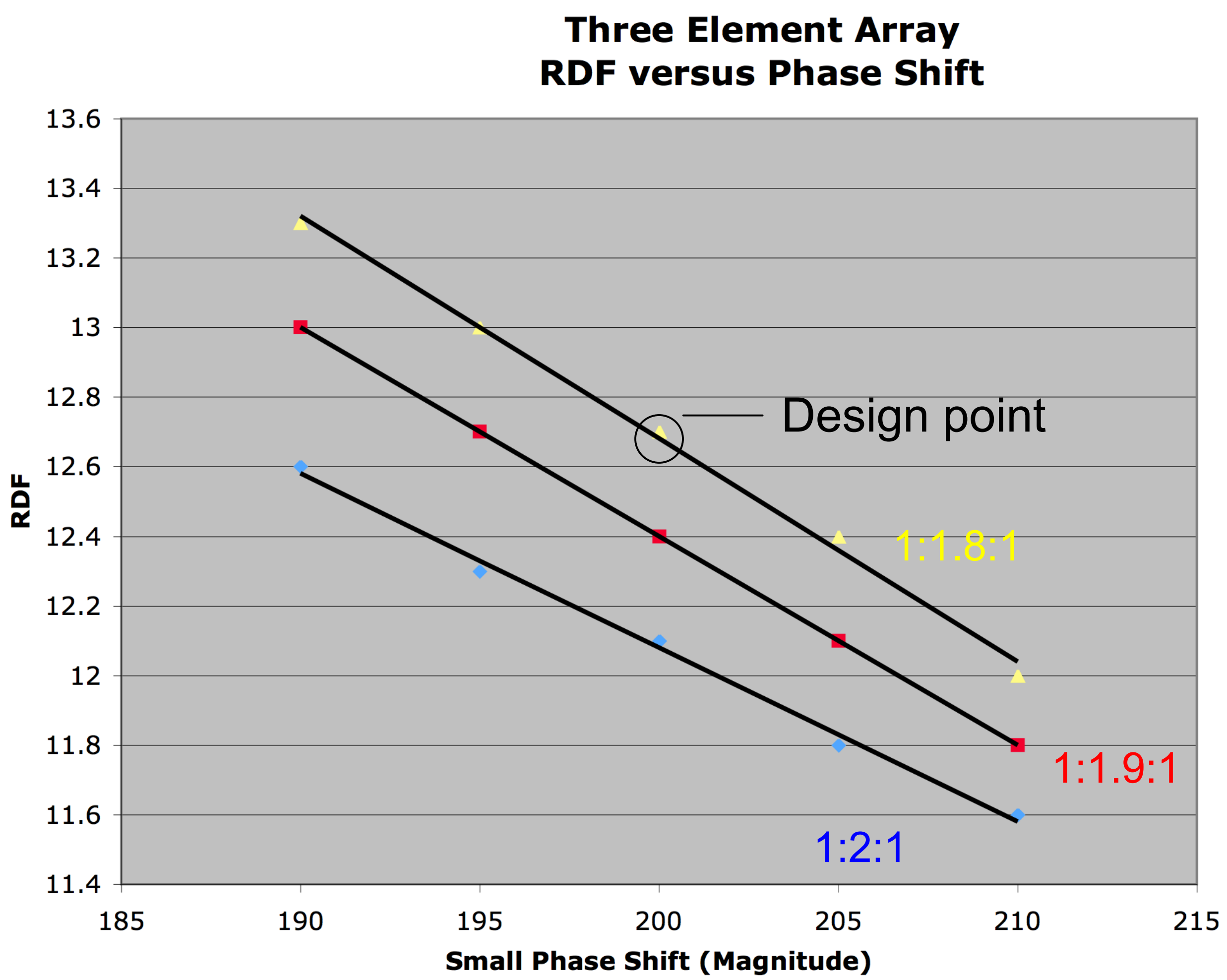



3.505 MHz

Table I - Comparison of End-Fire Arrays with a Single Loop - 80' spacing

| | 160M RDF | 80M RDF | 160M / 80M Crossfire Phasing |
|---|---|---|---|
| Single Loop | 7.4 dB | 7.4 dB | --- |
| 2-Element Array | 10.5 dB | 10.0 dB | -205° / -230° |
| 3-Element Array | 12.1 dB | 11.3 dB | 0,-200°,-400° / 0,-220°,-440° |
| 4-Element Array | 14.3 dB | --- | 0, -195°, -390°, -585° |

# 3-ELEMENT ARRAY OPTIMIZATION
## Alternate Current Ratios




3 Current Ratios

# 3-ELEMENT ARRAY OPTIMIZATION
## Alternate Current Ratios

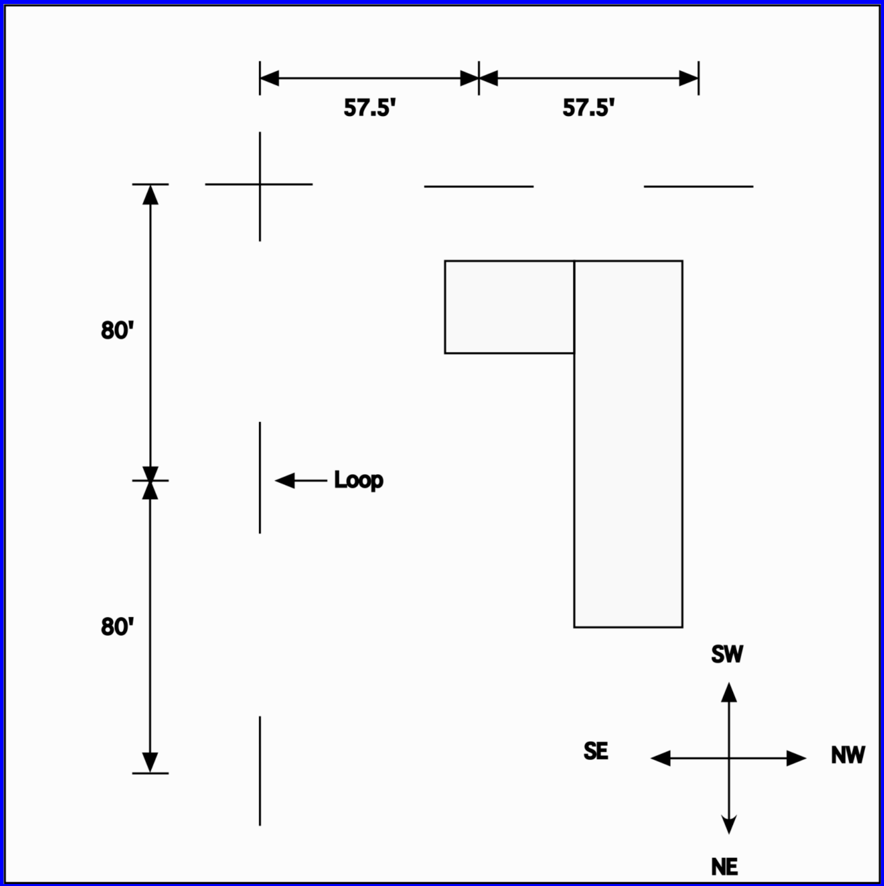
- Enhanced RDF achieved with other current ratios
- Settled upon 1:1.8:1

1:1.8:1 Binomial End-fire Arrays* - 1.825 MHz - RDF versus Crossfire Phasing

| Phasing | -190/-20 | -195/-30 | **-200/-40** | -205/-50 | -210/-60 |
|---|---|---|---|---|---|
| RDF | 13.3 dB | 13.0 dB | **12.7 dB** | 12.4 dB | 12.0 dB |
| Angle | 20° | 20° | **21°** | 21° | 22° |
| Beam Width | 62° | 66° | **69°** | 73° | 76° |
| Back Lobes | -16 dB | -18 dB | **-20 dB** | -21 dB | -23 dB |
| Gain | -33.0 dB | -31.5 dB | **-30.1** | -28.9 | -27.8 |

*Arrays with both 80 ft. and 57.5 ft. spacing are essentially the same.

# ARRAY IMPLEMENTATION
## Placement of the Arrays

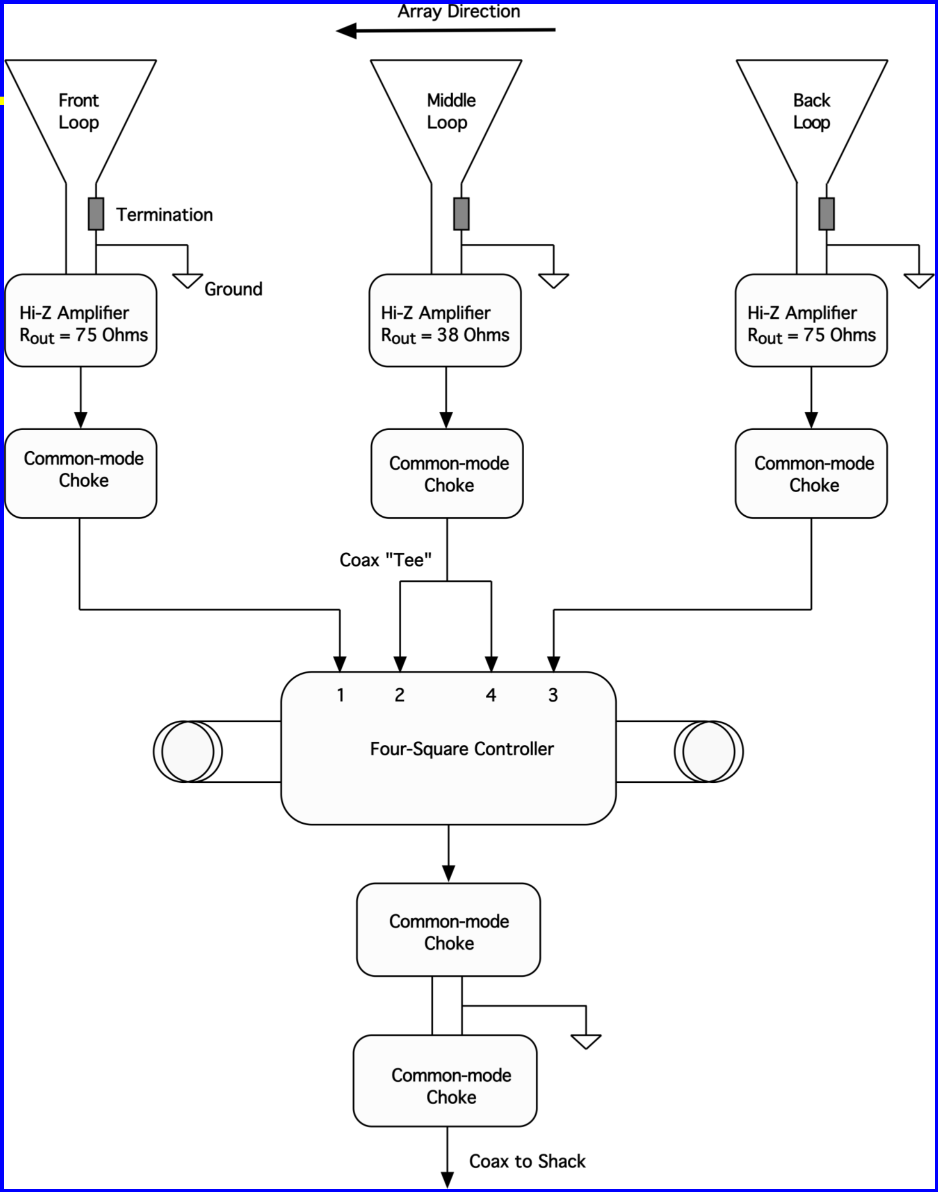



- Layout of NE/SW (160’) & NW/SE (115’) Arrays
- Heavily wooded lot
- Front yard is left of house
- Small lake off to the right
- Downhill slope to right

# ARRAY IMPLEMENTATION

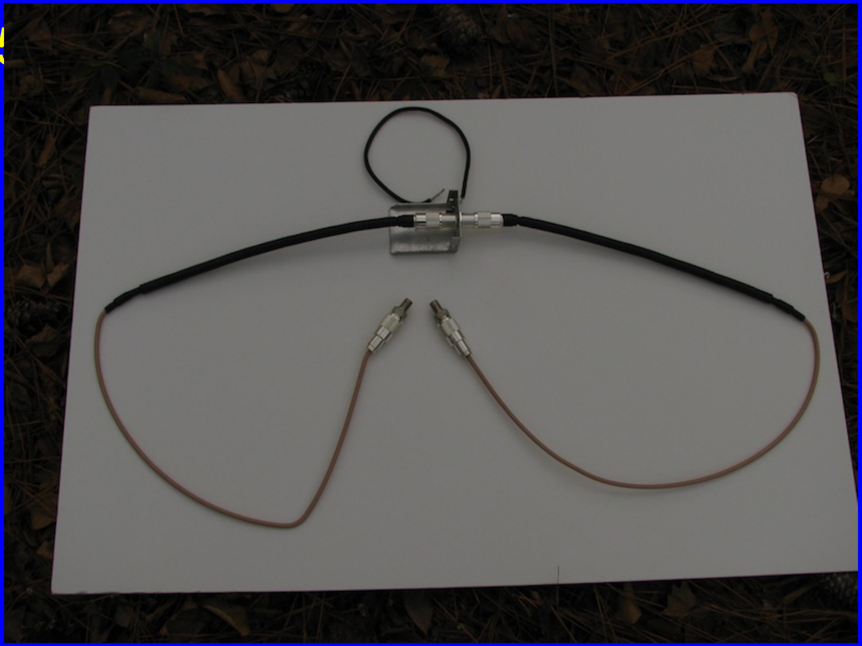
## System Design

- Controllers
  - One Hi-Z
  - One DX Engineering
- Hi-Z Amplifiers
  - 500 Ω antennas connected directly to amplifier inputs
  - Center amplifier drives a coax pair & two controller inputs
  - Output Resistance $R_{out}$
    - 75 Ω for ends
    - ≈ 38 Ω for center - adjusted for 1.8:1 output
- Must switch loop termination with controller phasing
- Beaded chokes (Wireman)
  - 50 Ω coax



# ARRAY IMPLEMENTATION
## Miscellaneous

- Make Loops as identical as possible
- Four 20’ radials under each loop (45
  relative to loop)
- Beaded chokes throughout
  - Approximately 1000 Ω on TB
- “Braid breakers” now in NE/SW array
  - No apparent difference
- No observed interaction with grounded aluminum supports
  - Simulation shows small effect
  - Plan to use as short vertical array



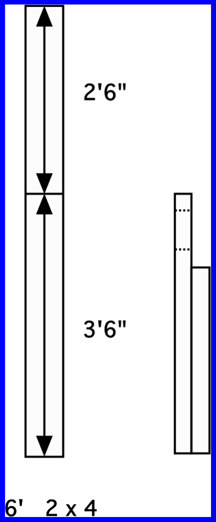
Feedline Choke

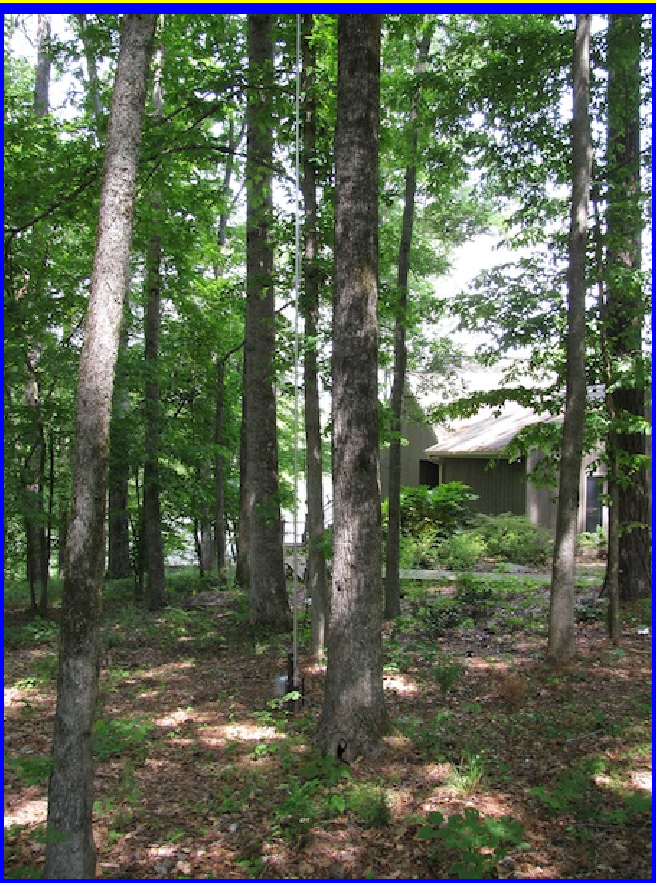
# ARRAY IMPLEMENTATION
## Phasing Lines

- Network or antenna analyzer
- Adjust by measuring the resonant frequency of open-circuited coax lines

| Table III<br>Phase Shift of Phasing Lines – Calculated from Open Circuit Measurements | | | | |
|---|---|---|---|---|
| Phasing Line | NE/SW 1.825MHz | NE/SW 3.505MHz | NW/SE 1.825MHz | NW/SE 3.505MHz |
| 1 | 21.5 ft / 17.2° | 33.0° | 16.7° | 32.0° |
| 2 | 21.5 ft / 17.2° | 33.0° | --- | --- |
| 3 | 49.0 ft / 39.3° | 75.5° | 41.3° | 79.2° |

# ARRAY IMPLEMENTATION
## Loop Antennas & Supports



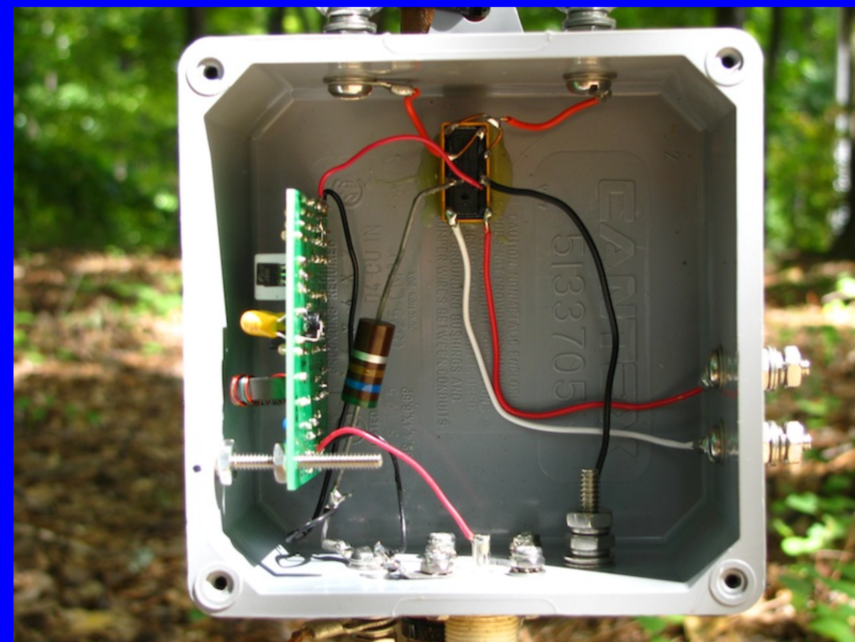
"Hidden" in Front & Side Yards - Black Wire & String
Fiberglass (NE/SW) or Aluminum Poles (NW/SE)

# ARRAY IMPLEMENTATION
## Amplifier/Switching Boxes

Single Loop


Corner Loop Pair

# ARRAY IMPLEMENTATION
## Amplifier/Switching Boxes

- Weather-Proof Boxes (Lowes)
  - Hi-Z Amplifier
  - Direction Relay
  - Termination Resistor
  - Stainless Steel HW

# RESULTS
## Experimental Setup

- Array Solutions VNA 2180 (50 Ω)
- Port A drives 50 Ω coax with 50-Ω termination at input of High-Z amplifiers
- 75 Ω coax from controller to VNA
- 75 Ω - 50 Ω Pad at input to VNA Port B
- Measurements repeatable to within 0.3 dB and less than 0.5°

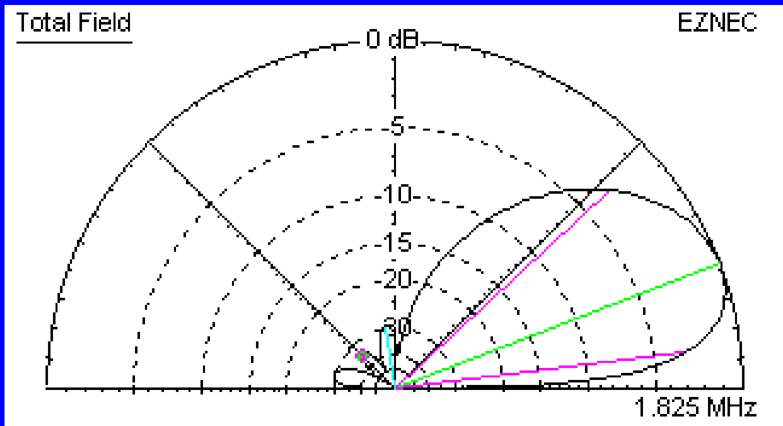
# RESULTS
# Measurements

| Table IV - Amplifiers + Controller - Normalized Gain and Phase Matching | | | | |
|---|---|---|---|---|
| 1.827 MHz Results | | | | |
| Loop | NE/SW Gain | NE/SW Phase | NW/SE Gain | NW/SE Phase |
| Front | +0.13 dB (1.01) | $0^o$ (ref) | +0.05 dB (1.01) | $0^o$ (ref) |
| Middle | +5.19 dB (1.82) | $-200.3^o$ | +5.30 dB (1.84) | $-200.1^o$ |
| Back | -0.13 dB (0.99) | $-399.8^o$ ($-39.8^o$) | -0.05 dB (0.99) | $-401.5^o$ ($-41.5^o$) |
| 3.505 MHz Results | | | | |
| Loop | NE/SW Gain | NE/SW Phase | NW/SE Gain | NW/SE Phase |
| Front | +0.14 dB (1.02) | $0^o$ (ref) | -0.01 dB (1.00) | 0 |
| Middle | +5.07 dB (1.79) | $-218.6^o$ | 5.26 dB (1.83) | -220.8 |
| Back | -0.14 dB (0.98) | $-434.0^o$ ($-74.0^o$) | 0.01 dB (1.00) | -440.8 ($-80.8^o$) |

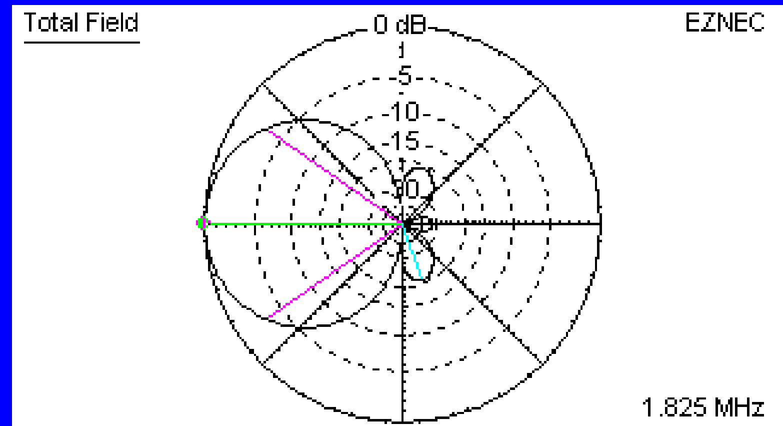
Note: Same phasing line utilized on 160 & 80 M
Gain in good agreement with SPICE models

# RESULTS

## Final Simulations - 160 M



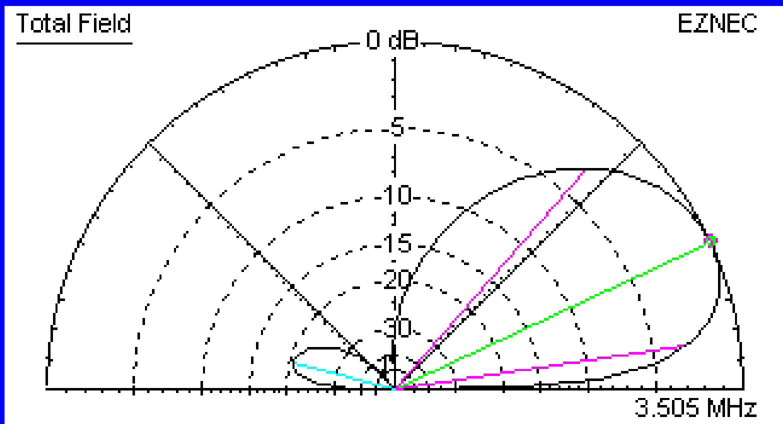

| | | | |
|---|---|---|---|
| Elevation Plot | | Cursor Elev | 135.0 deg. |
| Azimuth Angle | 180.0 deg. | Gain | -65.14 dBi |
| Outer Ring | -30.06 dBi | | -35.08 dBmax |
| | | | -35.08 dBmax3D |
| 3D Max Gain | -30.06 dBi | | |
| Slice Max Gain | -30.06 dBi @ Elev Angle = 21.0 deg. | | |
| Beamwidth | 35.6 deg.; -3dB @ 7.0, 42.6 deg. | | |
| Sidelobe Gain | -59.44 dBi @ Elev Angle = 98.0 deg. | | |
| Front/Sidelobe | 29.38 dB | | |




| | | | |
|---|---|---|---|
| Azimuth Plot | | Cursor Az | 180.0 deg. |
| Elevation Angle | 21.0 deg. | Gain | -30.06 dBi |
| Outer Ring | -30.06 dBi | | 0.0 dBmax |
| | | | 0.0 dBmax3D |
| 3D Max Gain | -30.06 dBi | | |
| Slice Max Gain | -30.06 dBi @ Az Angle = 180.0 deg. | | |
| Front/Back | 32.19 dB | | |
| Beamwidth | 70.0 deg.; -3dB @ 145.0, 215.0 deg. | | |
| Sidelobe Gain | -50.68 dBi @ Az Angle = 289.0 deg. | | |
| Front/Sidelobe | 20.62 dB | | |

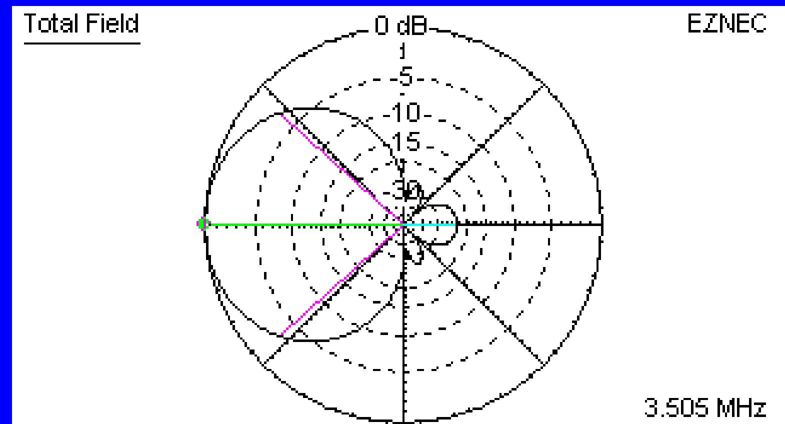
# RESULTS

## Final Simulations - 80 M




| | | | |
|---|---|---|---|
| Elevation Plot | | Cursor Elev | 25.0 deg. |
| Azimuth Angle | 180.0 deg. | Gain | -10.68 dBi |
| Outer Ring | -10.68 dBi | | 0.0 dBmax |
| | | | 0.0 dBmax3D |

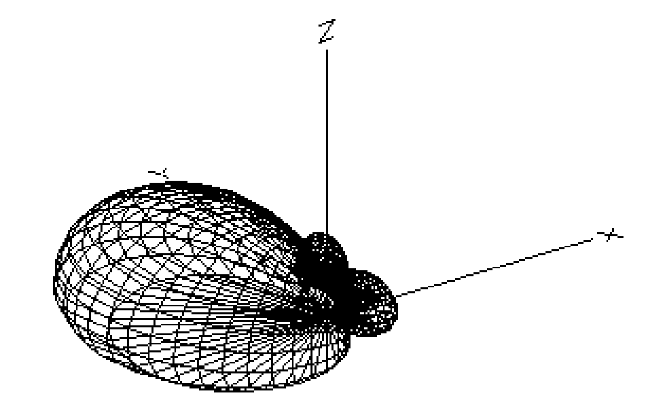
| | |
|---|---|
| 3D Max Gain | -10.68 dBi |
| Slice Max Gain | -10.68 dBi @ Elev Angle = 25.0 deg. |
| Beamwidth | 40.6 deg.; -3dB @ 8.4, 49.0 deg. |
| Sidelobe Gain | -31.31 dBi @ Elev Angle = 165.0 deg. |
| Front/Sidelobe | 20.63 dB |




| | | | |
|---|---|---|---|
| Azimuth Plot | | Cursor Az | 180.0 deg. |
| Elevation Angle | 25.0 deg. | Gain | -10.68 dBi |
| Outer Ring | -10.68 dBi | | 0.0 dBmax |
| | | | 0.0 dBmax3D |

| | |
|---|---|
| 3D Max Gain | -10.68 dBi |
| Slice Max Gain | -10.68 dBi @ Az Angle = 180.0 deg. |
| Front/Back | 22.34 dB |
| Beamwidth | 84.4 deg.; -3dB @ 137.8, 222.2 deg. |
| Sidelobe Gain | -33.02 dBi @ Az Angle = 0.0 deg. |
| Front/Sidelobe | 22.34 dB |

# RESULTS
## Final Simulation Comparisons



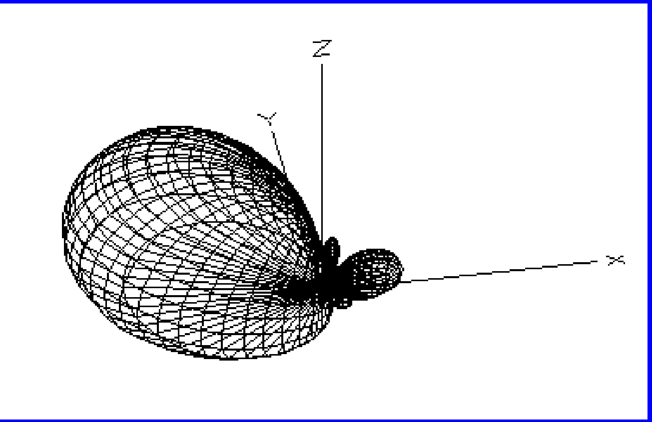




Table VI - Simulation Results Using Measured Data

| | 160' Array (NE/SW) | | 115' Array (NW/SE) | |
|---|---|---|---|---|
| Band | 160 M | 80 M | 160 M | 80 M |
| RDF | 12.6 dB | 11.5 dB | 12.4 dB | 11.5 dB |
| Angle | 21° | 25° | 21° | 24° |
| Beam Width | 70° | 84° | 71° | 84° |
| Gain | -30.1 dBi | -10.7 dBi | -33.8 dBi | -12.8 dBi |
| F/B | 32.2 dB | 22.3 dB | 25.6 dB | 54.1 dB |
| Front/Side | 29.4 dB | 20.6 dB | 18.4 dB | 27.7 dB |

# RESULTS
# The Bottom Line

- Copied FR/DJ7RJ & 5R8RJ night after night on 160
  - Not readable on inverted L transmit antenna
- Worked S79GM on both 160 M & 80 M.
  - Also could not copy on inverted L
- PJ4 - First TB qso required loop array
- Missed 9Q5ØQN - couldn't hear me
  - Consolation - Worked on 80 M for new one
- More recent successes
  - TJ9PF, 4L/UUØJM, XU7ACY, 9L5MS, 5M2TT
- Worked VK3ZL > 12 times through June-July-August QRN
- Routinely use on 160 M / 80 M to "save ears"
- Use on any frequency where there is an advantage
  - E.g. 40M, 30M and up - there are lobes pointed somewhere
  - Have used on 17M and 12M

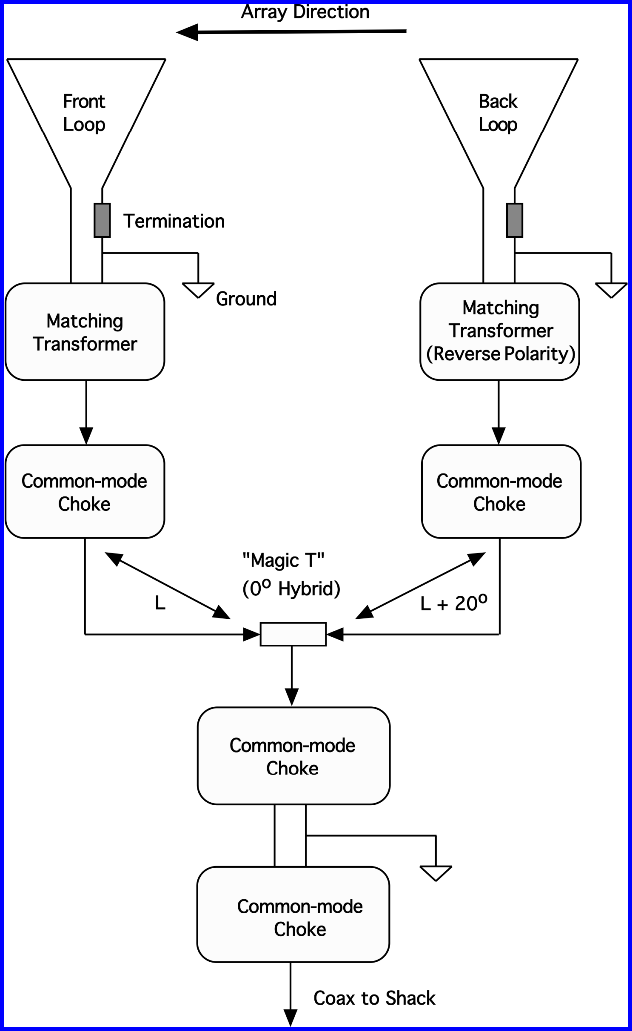
# DISCUSSION / OBSERVATIONS Loops and Short Verticals

- Second short vertical array parallels NE/SW array
  - Separated by approximately 20’
- Loops almost always better at my location
  - Vertical array better only one time in last two months
- Simulation indicates small advantage for the loops
  - Array factor should be the same
  - Inherent F/B of loop provides some advantage
- Output of wider spaced array is clearly higher
- Vertical supports on NW/SE array can operate as short (26’) vertical array elements
  - Plan to be able to switch back and forth - not implemented yet
- My skill level is much higher now than when I did first 4-square installation - phasing not optimal

# DISCUSSION / OBSERVATIONS

# Two-element Arrays

- Elements were added one at a time
- Significant improvement noted at each step
- Two-element array gives very useful improvement if space is limited
- Amplifiers not required
- With or without 0° hybrid depending upon choice of matching transformer design



# DISCUSSION / OBSERVATIONS Other Ideas

- Latest version
  - Doubly terminate loops
  - Switch single amplifier input
- An alternative for three-element array ratios
  - Use identical amplifiers & attenuate the front and rear amplifiers by a factor of 0.54.
  - Only requires one coax from the center amplifier
  - Noise figure is degraded by attenuation factor
  - Degradation was noticeable when I tried it
- Side rejection is very high. One antenna may be useful as “noise” antenna for the other.
- Combine the two array outputs, to fill $45^o$ directions
  - RDF drops to 10 dB

- THANK YOU FOR YOUR ATTENTION
- QUESTIONS?

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# REFERENCES


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