Improving Performance of Arrays of K9AY Loops

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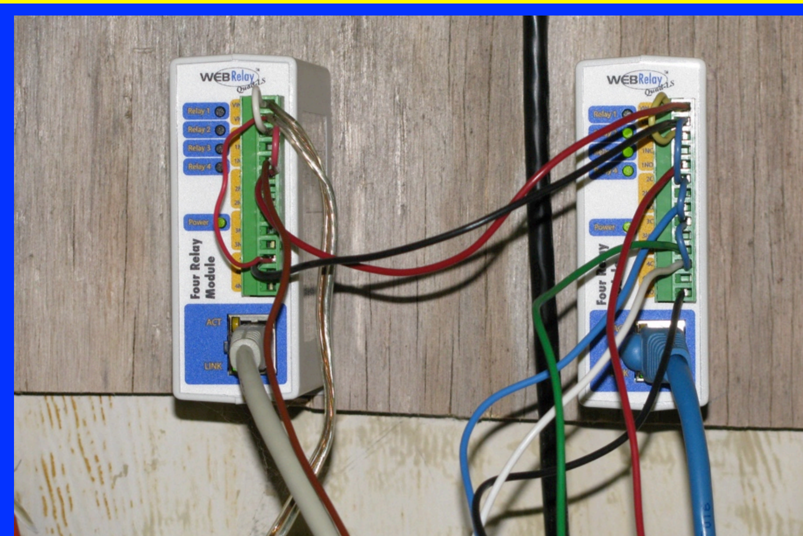
INTRODUCTION

- Introduction & Background
  - RDF Definition
  - Basic K9AY Loop Pair
  - Antenna/Array Comparisons
- Focus on Two-element Arrays
  - K9AY Array – Design & Simulation
  - Array Implementations
  - Filling in the Gaps (8-Way Switching)
  - Results
- Discussion / Observations

INTRODUCTION
Remote Installation

Tentec Omni VII



Control by Web Relays

Needed Antenna for Remote Antenna Site

Decided to Try BOG & Two-element Loop Arrays

"Quick & Easy"

INTRODUCTION

- Poor Ground Conditions
  - Very rocky with rock shelves and red clay
  - Ground conductivity: 2-3 mS/m
- Loops Seem Most Effective Receiving Antennas in My Locations
- Presented 3 Element End-fire Array Last Year
- This Presentation Concentrates on the Performance of Two-Element K9AY Arrays
  - Straight-forward implementation
  - Low sensitivity to phase & amplitude errors

INTRODUCTION
Two-Element Arrays

- Second Element Offers Significant RDF Increase
  - As in a Yagi, the second element adds the most
- Straight-Forward Implementation
  - Hi impedance amplifiers or matching transformers
  - Robust to both phase & amplitude errors
  - Loop direction switching required
- Potential Problems
  - Beam width narrows (98^o)
  - RDF reduced by 2.5 dB at ±45^o points
- Explore 8 Direction Switching

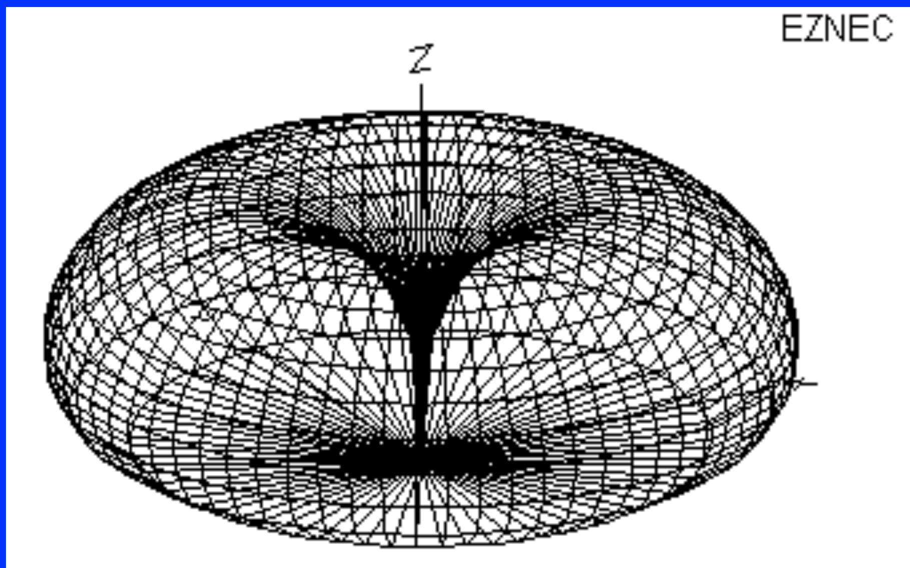
BACKGROUND
RDF: Receiving Directivity Factor

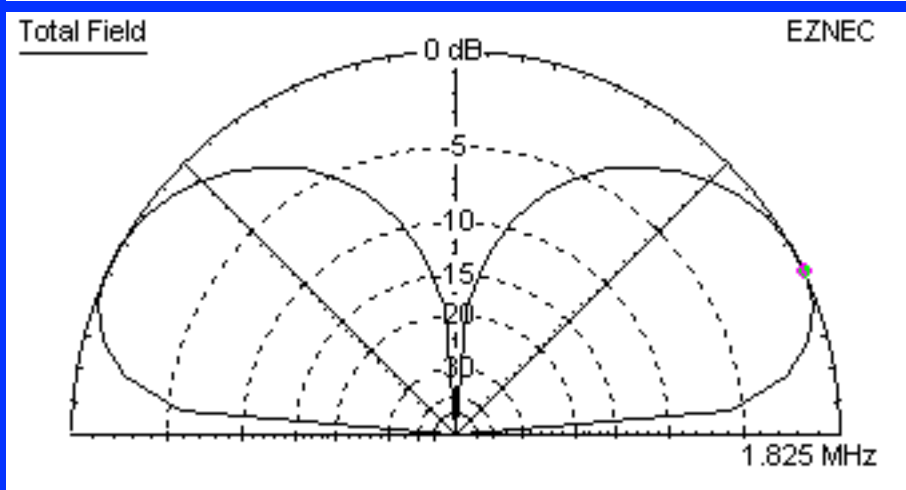
- Design Goal Here: Maximize RDF

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

  – Noise generally comes in from all directions
  – RDF compares the main antenna lobe gain to the average gain over the whole hemisphere of the antenna
  – Attributed to W8JI

BACKGROUND
Reference Antenna – Short Vertical (20')





Forward Gain: 1.0 dBi

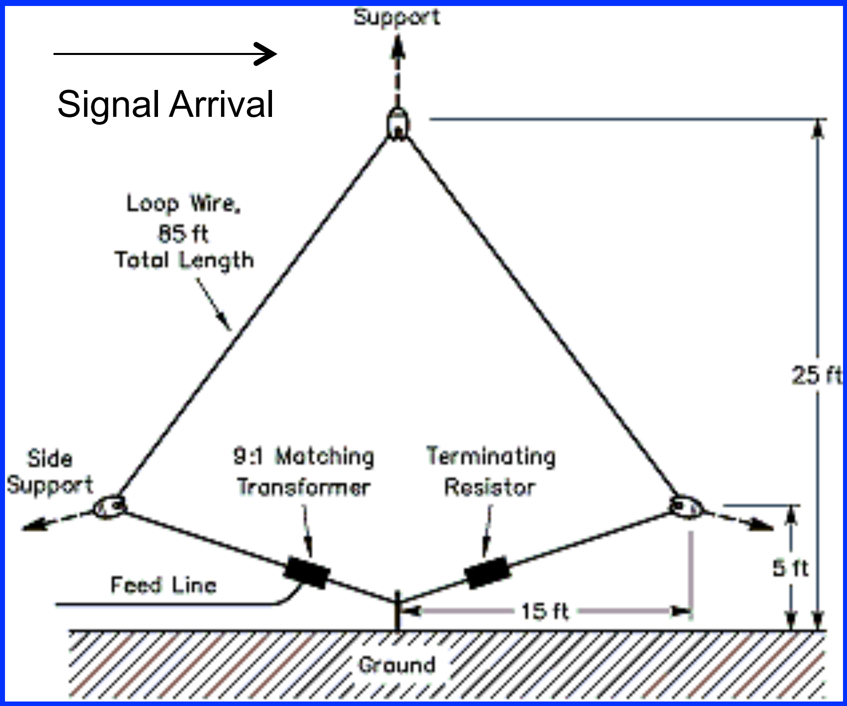
Average Gain: -3.9 dBi

RDF: 4.9 dB

Omni Directional

W/C F/B: 0 dB

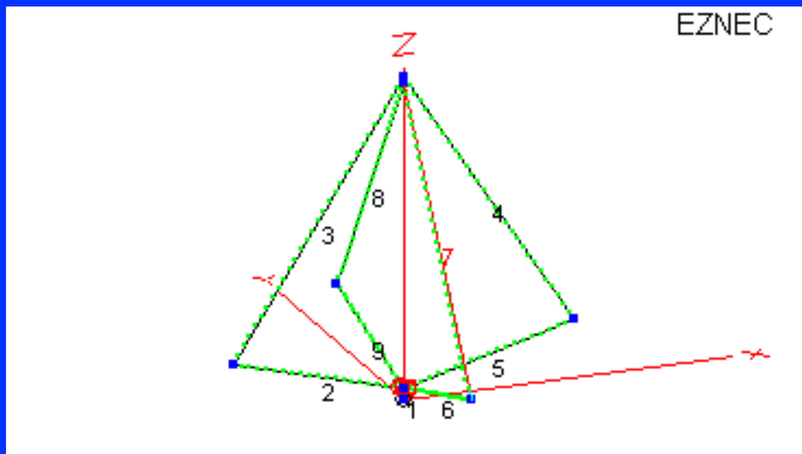
BACKGROUND
Basic K9AY Loop

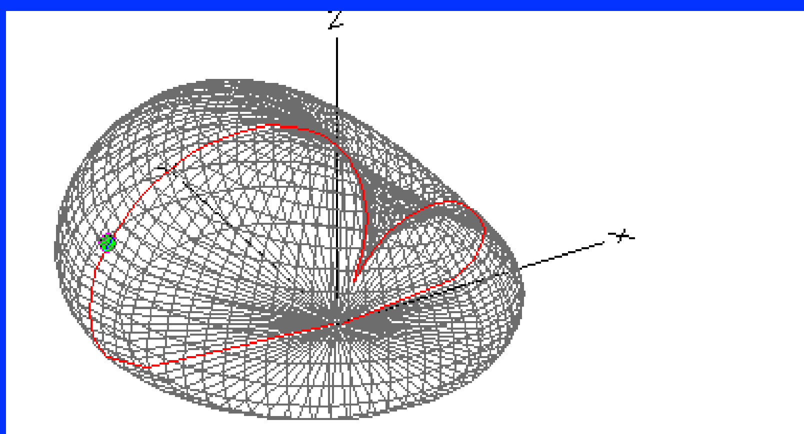


- 85' Triangular Loop
- 25' High, 30' Wide
- Resistive Termination
- Directional Antenna
  - Easily switched in 2 directions
  - 4 directions with an orthogonal pair of loops
- 9:1 Matching Transformer to Coax

Gary Breed, "The K9AY terminated loop – A compact, directional receiving antenna," QST, vol. 81, no. 9, pp. 43-46, September 1997.

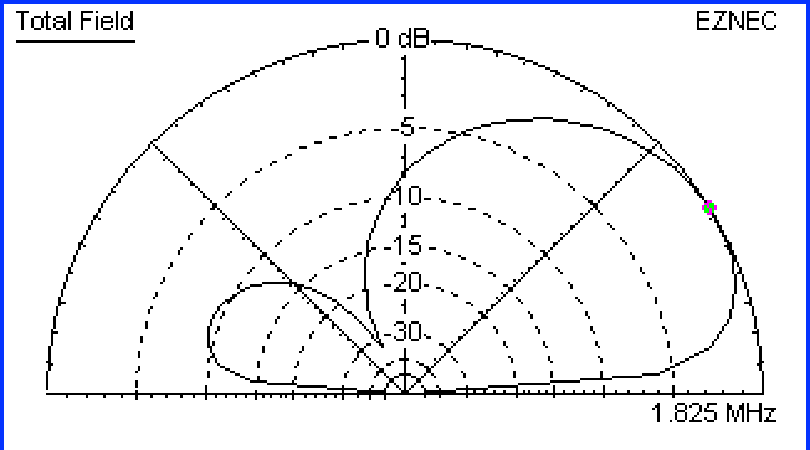
BACKGROUND
Single K9AY Loop Characteristics

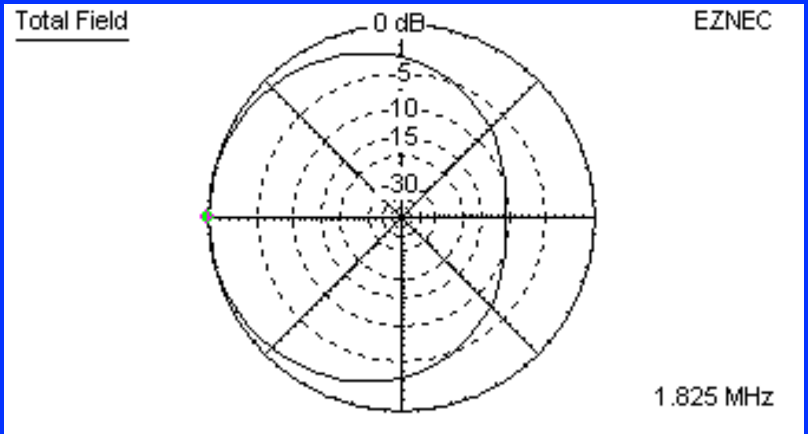




- 2.5 dB RDF Increase Over Vertical
- Broadband (Flat to 20 MHz)
- Gain -25 dBi (<< Vertical)
- Directional Antenna
  - End-fire (In plane of the loop) opposite termination
  - Similar to a cardiod pattern
  - Reduced response in rear direction

BACKGROUND
Single K9AY Loop Characteristics





30º Elevation

Forward Gain: -25.4 dBi

Average Gain: -32.9 dBi

RDF: 7.5 dB

Beamwidth: 167º

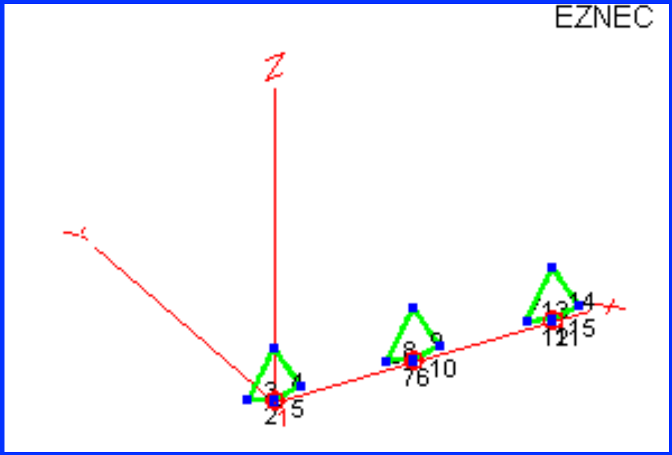
Take Off Angle: 32º

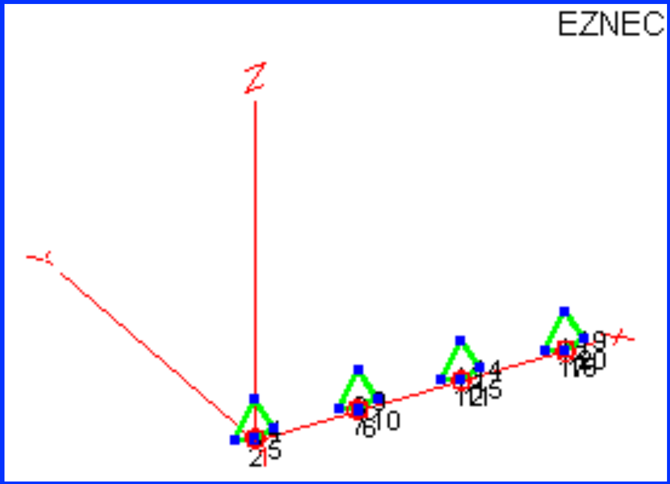
Rear - Deep High Angle Null

W/C F/B: 9.5 dB

Down 0.8 dB at ±45º points

BACKGROUND
Multi-Element Endfire Arrays





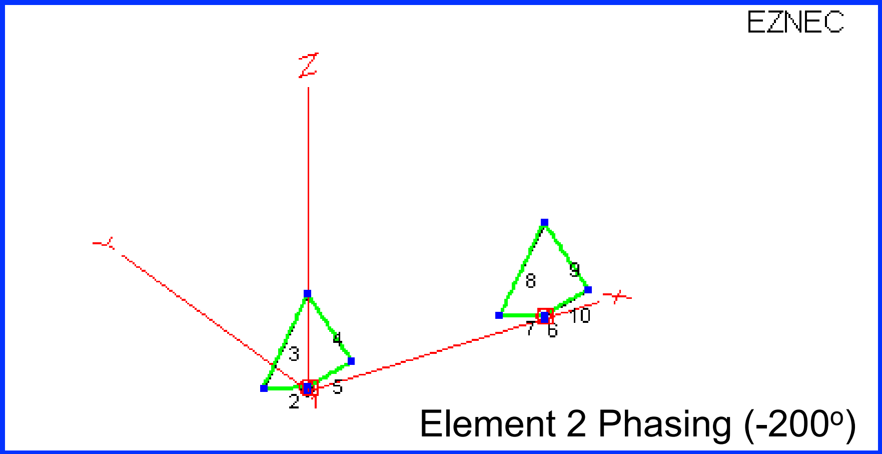
- 2-3-4 Elements or More
- “Lossy” Antennas
  - Resistive termination
  - Essentially no mutual coupling
- Array Output Decreases as number of Elements Increases
  - (-24 dBi) → (-40 dBi)

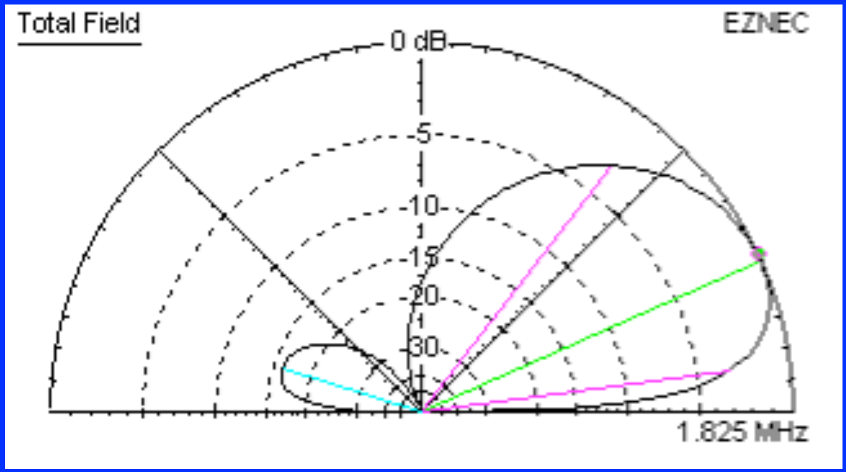
K9AY ARRAYS
RDF Comparisons

Table I - Comparison of End-Fire Arrays with a Single Loop - 80' spacing			
	160M RDF	80M RDF	160M / 80M - Crossfire Phasing
Short Vertical	4.9 dB	4.9 dB	---
Single Loop	7.4 dB	7.4 dB	---
2-Element Array (1-1)	10.5 dB	10.0 dB	-200° / -220°
3-Element Array (1-1.84-1)	12.5 dB	11.3 dB	0,-200°,-400° / 0,-220°,-440°
4-Element Array (1-2.6-2.6-1)	14.6 dB	13.8 dB	0, -195°, -390°, -585°

Focus Now on 2-EL Arrays

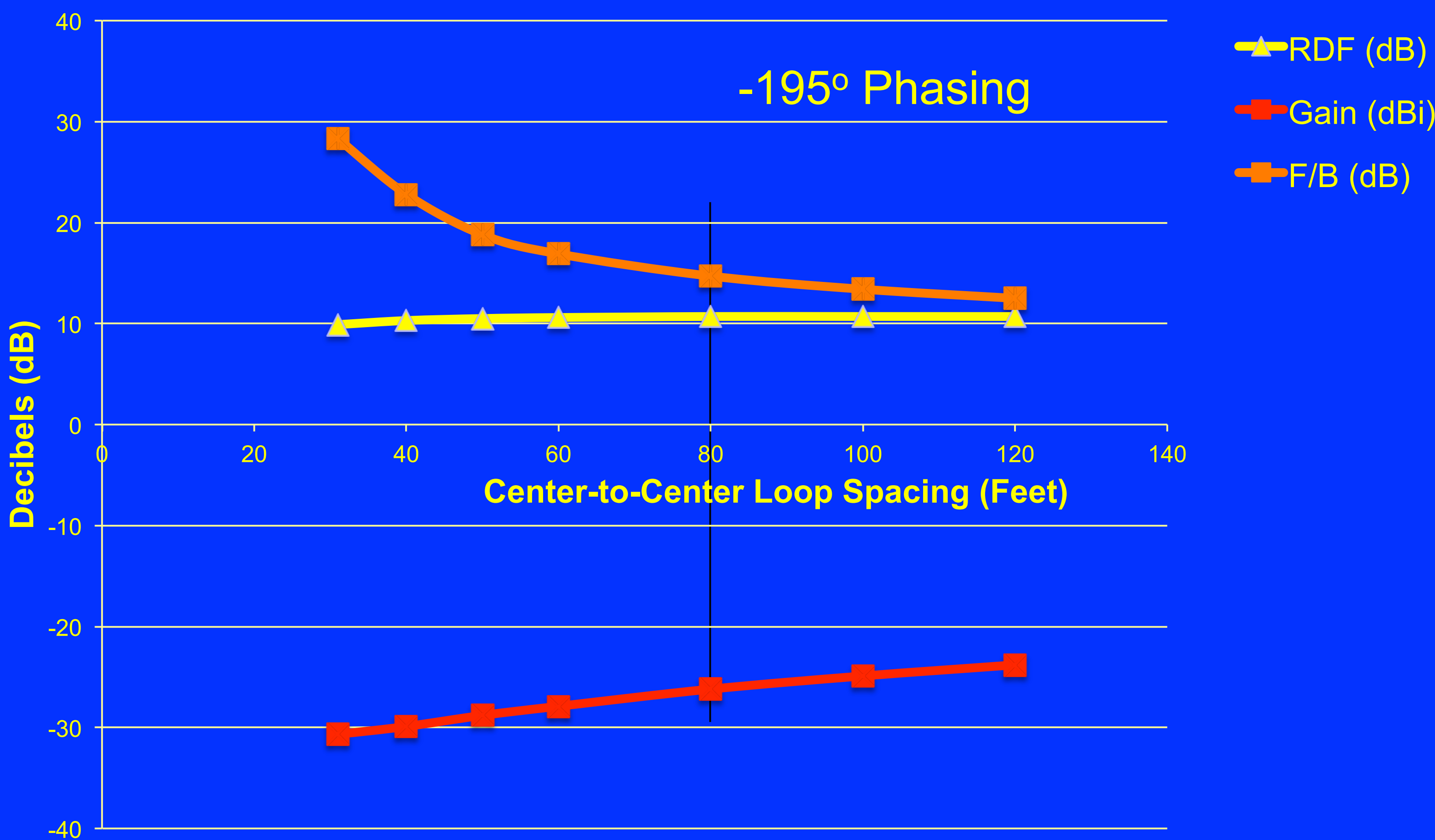
Two-Element End-Fire Array
Array Optimization - 160 M / 1.825 MHz



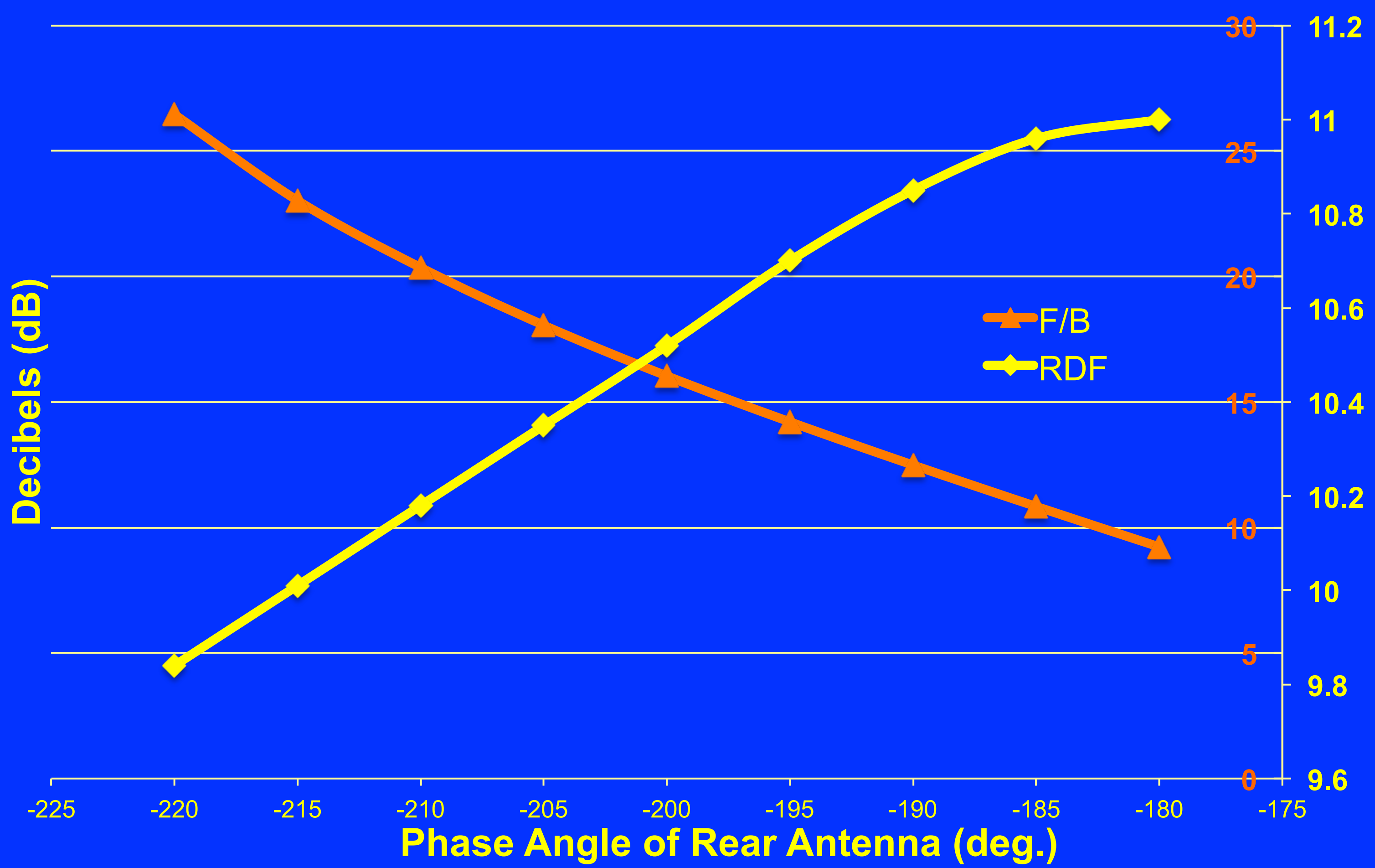


- Two-Element Array
  - Equal amplitudes
  - Single phasing line
  - Rear element lags front element by > 180°
- Gain: -25.7 dBi
- RDF: 10.5 dB (+3 dB)
- Beam Width: 96°
- W/C F/B: 16.6 dB
- Take Off Angle: 25°

2-ELEMENT ARRAY OPTIMIZATION
Performance vs. Spacing

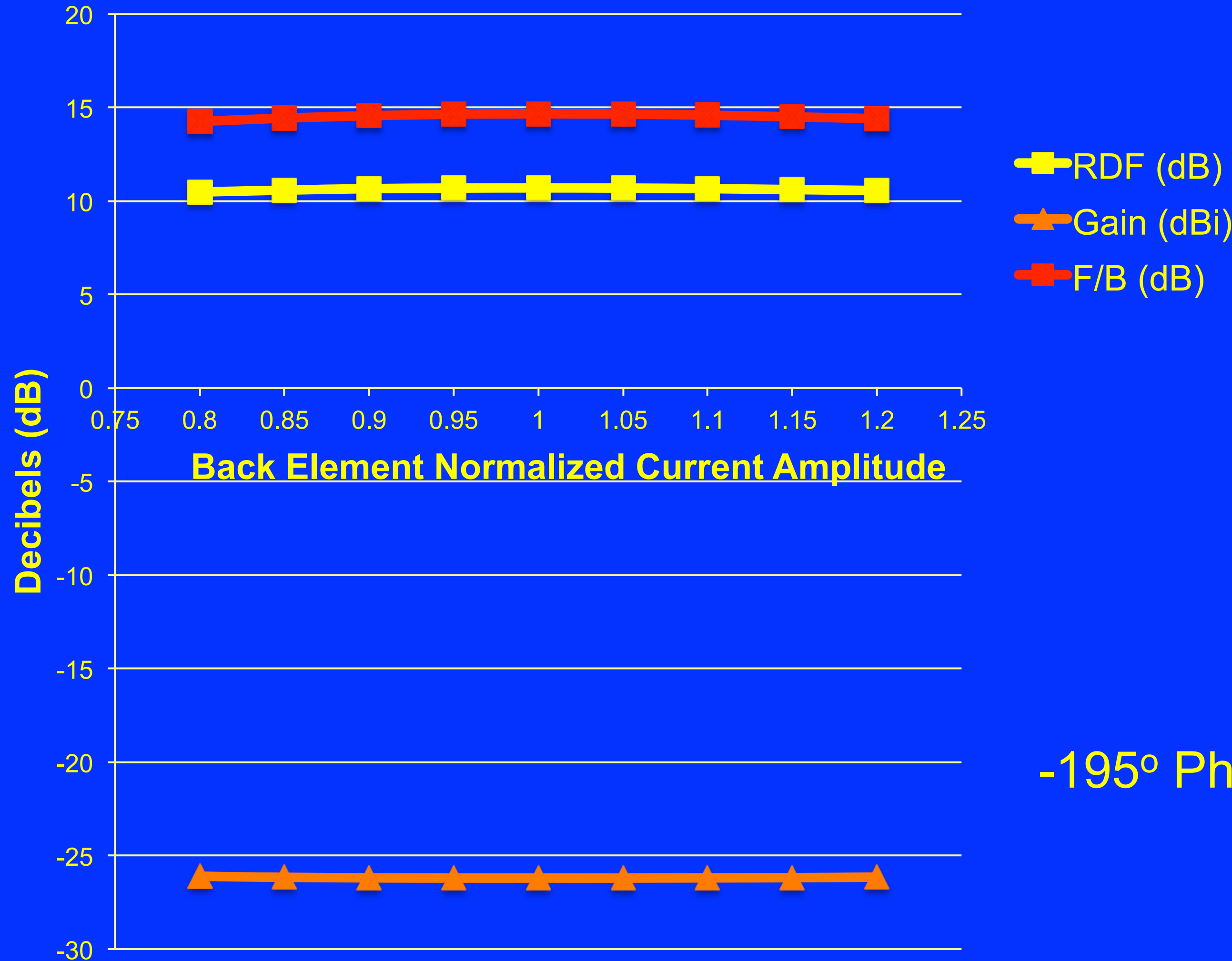


2-ELEMENT ARRAY OPTIMIZATION
RDF & F/B vs. Phasing for 80' Spacing



2-ELEMENT ARRAY OPTIMIZATION

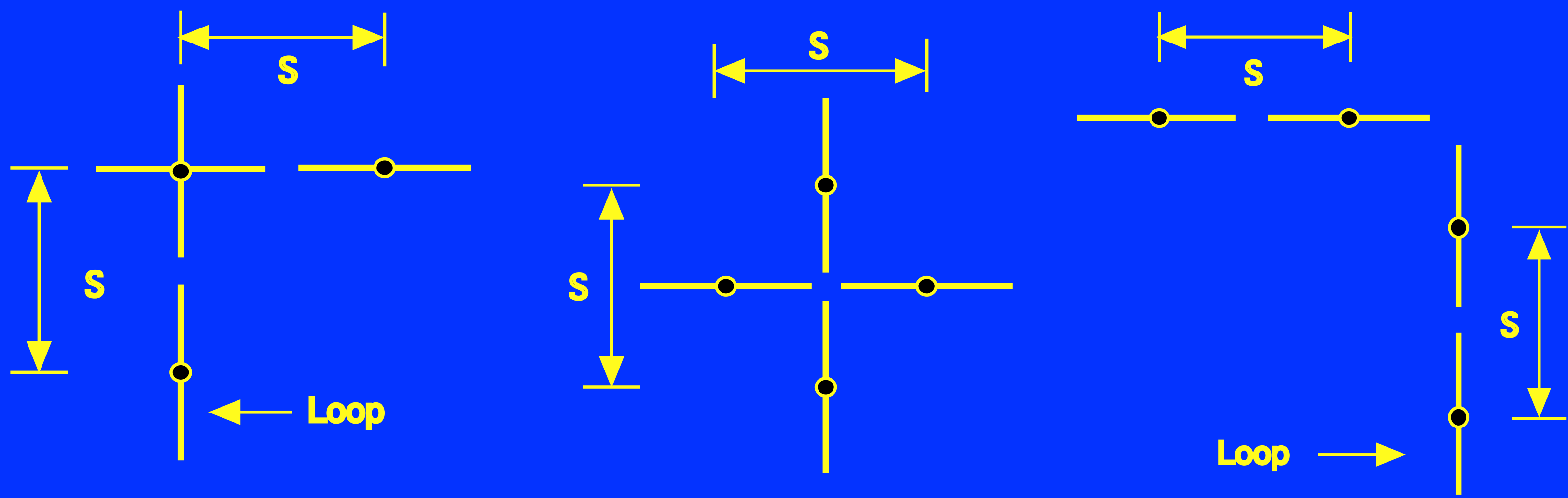
Performance vs. Back Element Amplitude



-195º Phasing

ARRAY IMPLEMENTATION

Possible Array Layouts



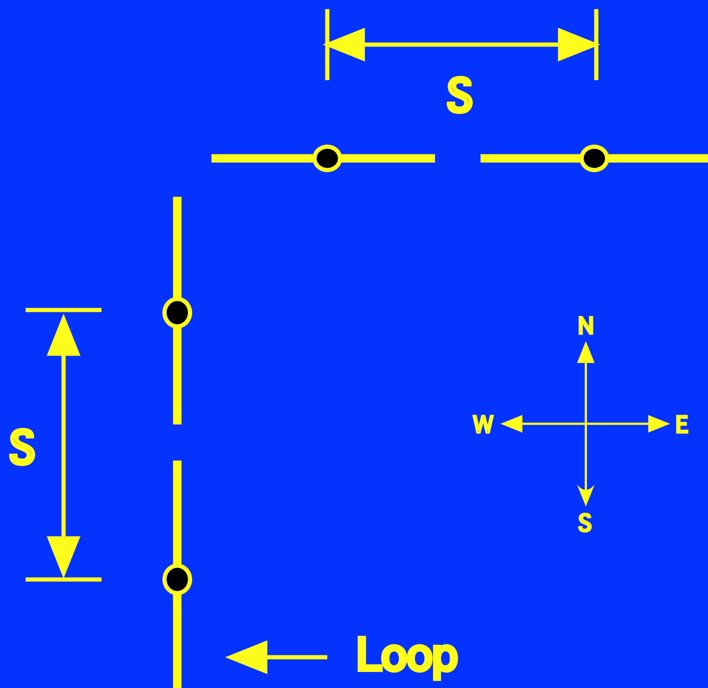
“L” - Crossed Pair at Corner

Symmetrical Array

“L” - Separated Arrays

(S: 30-120 ft)

ARRAY IMPLEMENTATION
L-Shaped Layout – N/S & E/W Arrays



- Along Border of Large Field
- Field is in Use Much of the Year
- Keeps Antennas Out of Field

- S = 80 feet
- Phase: -195^o

ARRAY IMPLEMENTATION Cross-Fire Feed (W8JI)

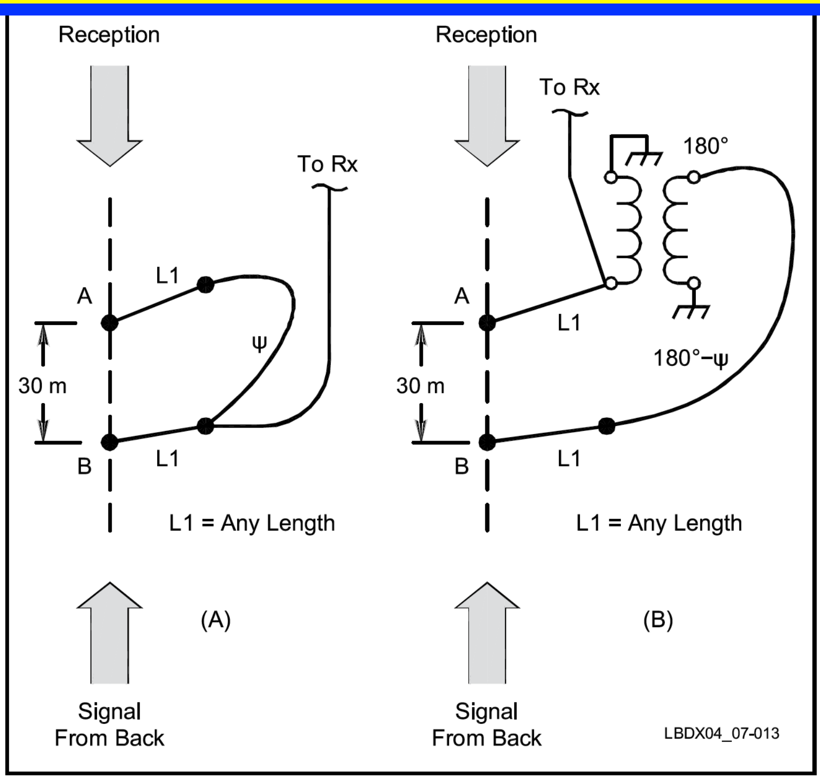


Fig 7-13 — Two ways of feeding the 2-element end-fire array. The system on the left is good for one frequency, while the system on the right can be used with the same length of phasing cable over a very wide range of frequencies (easily two bands).

Reverse feed line position

Transformer adds 180° phase shift

Phase line length reduced from Ψ to $(180-\Psi)^{\circ}$

e. g. $\Psi = 165^{\circ}$, $180-\Psi = 15^{\circ}$

John Devoldere, *ON4UN's Low-Band Dxing, Fifth Edition*, ARRL, Newington, CT: 2011, p. 7-19.

ARRAY IMPLEMENTATION
0^o Hybrid Combiner

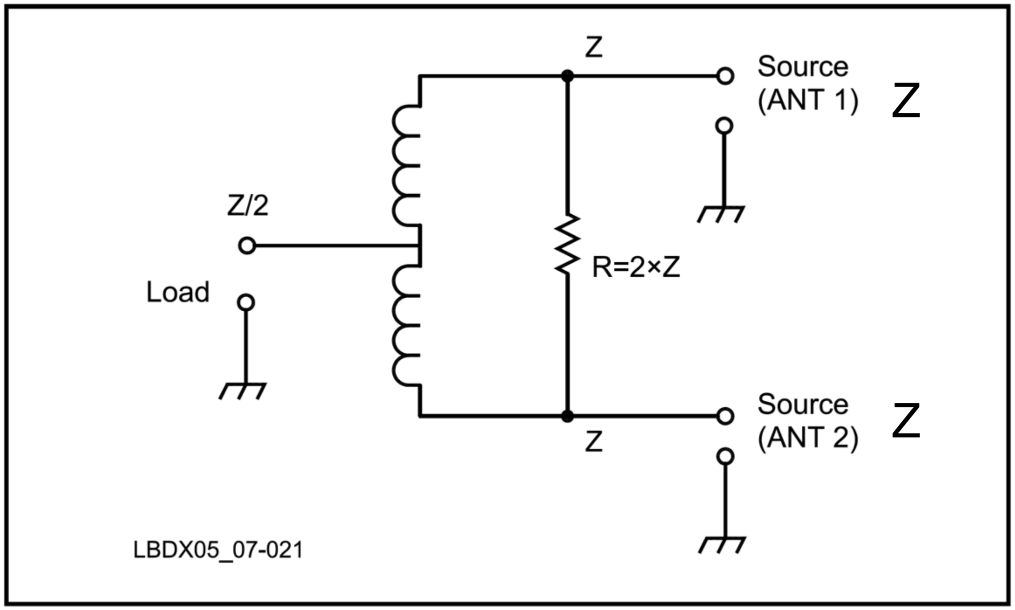


Fig 7-21 — Simplified schematic diagram of the 0° hybrid combiner.

Provides Matched Termination (Z) for Both Antennas

Excellent Isolation Between Antennas

Z = 75 Ohms

John Devoldere, *ON4UN's Low-Band Dxing, Fifth Edition,* ARRL, Newington, CT: 2011, p. 7-22.

ARRAY IMPLEMENTATION
Two-Element Array Feed System

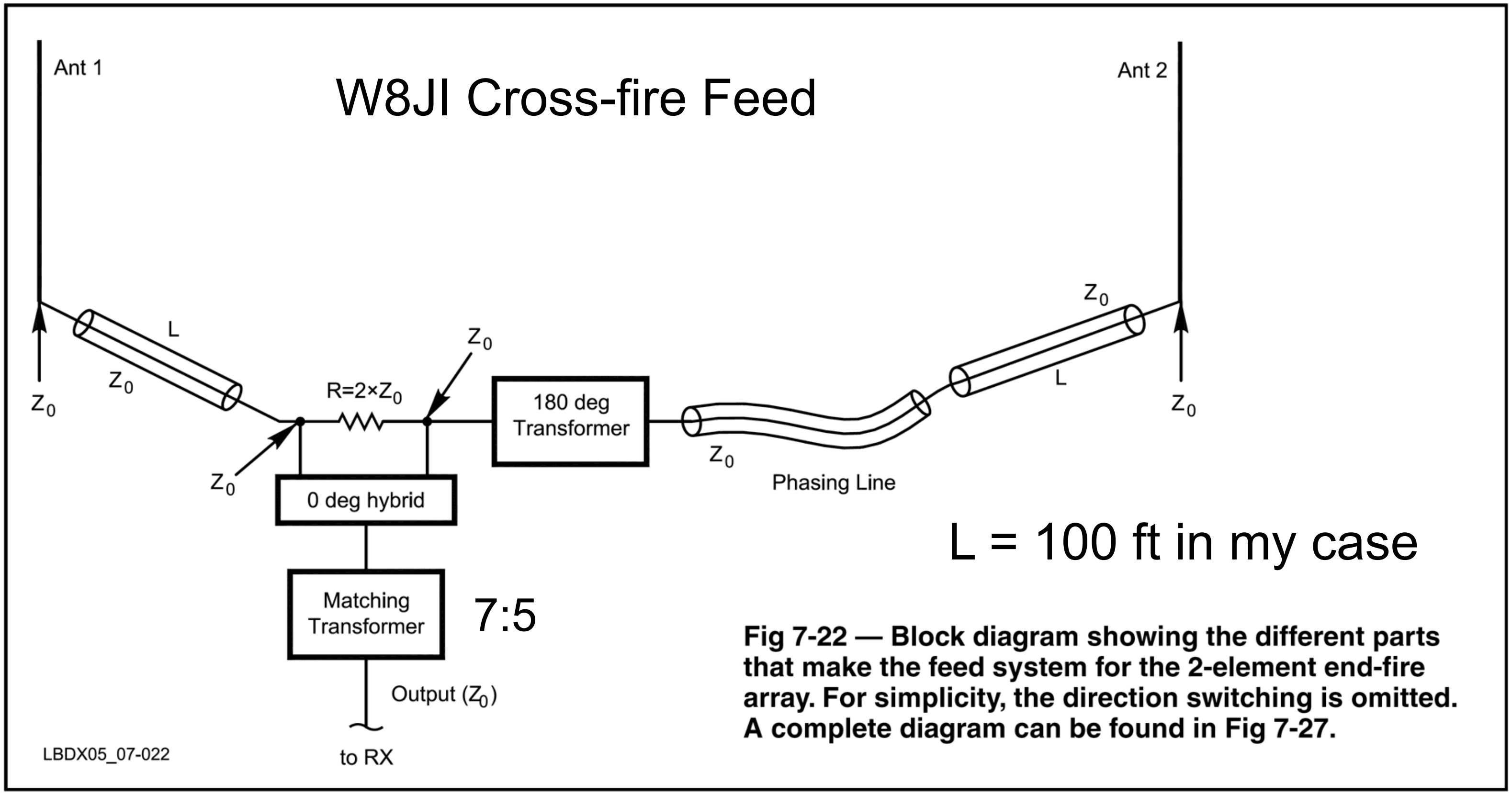


Fig 7-22 — Block diagram showing the different parts that make the feed system for the 2-element end-fire array. For simplicity, the direction switching is omitted. A complete diagram can be found in Fig 7-27.

John Devoldere, *ON4UN's Low-Band DXing, Fifth Edition,* ARRL, Newington, CT: 2011, p. 7-22.

ARRAY IMPLEMENTATION
Coax Phasing Lines

Phase Shift of Phasing Lines – Calculated from Open Circuit Measurements				
	N/S 1.825MHz	**N/S 3.505MHz**	**E/W 1.825MHz**	**E/W 3.505MHz**
Phasing Line	**19.0 ft / 15.2^o**	**29.1^o**	**15.2^o**	**29.1^o**

- Nominal Phase Shift for 160M: 195^o-180^o = 15^o
- Phase Shift Expected on 80M: 29.1^o
  - 15.2^o*(3.505/1.828) = 29.1^o
- Network or Antenna Analyzer
  - Measure the resonant frequency or fault of open-circuited line
  - Calculate phase by frequency scaling

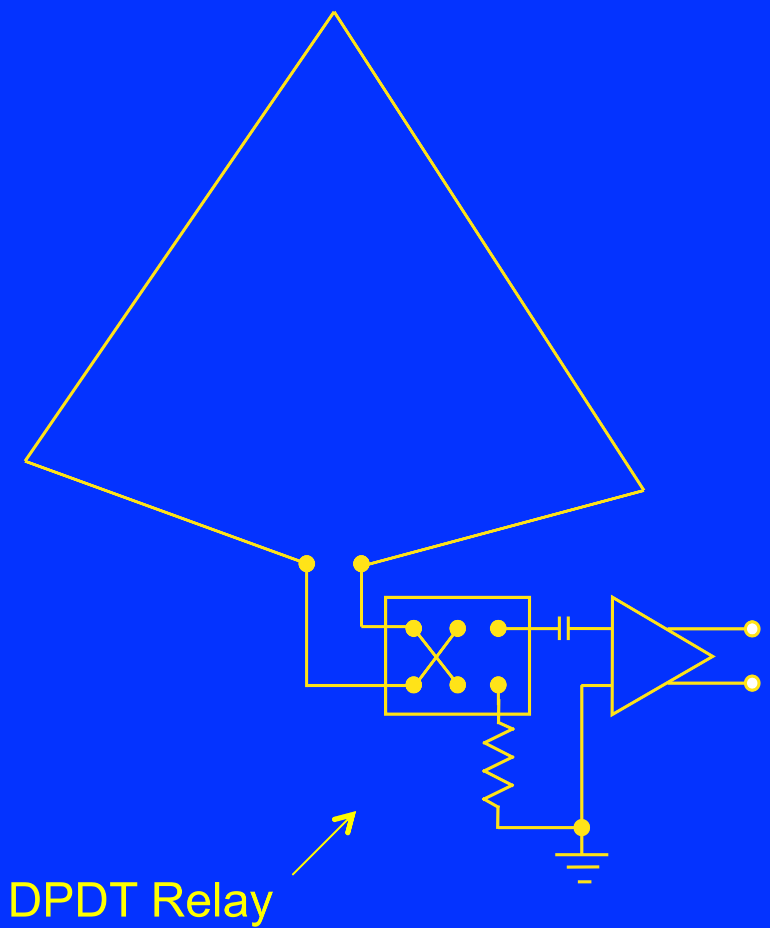
ARRAY IMPLEMENTATION
Loop Antennas – N/S & E/W Arrays

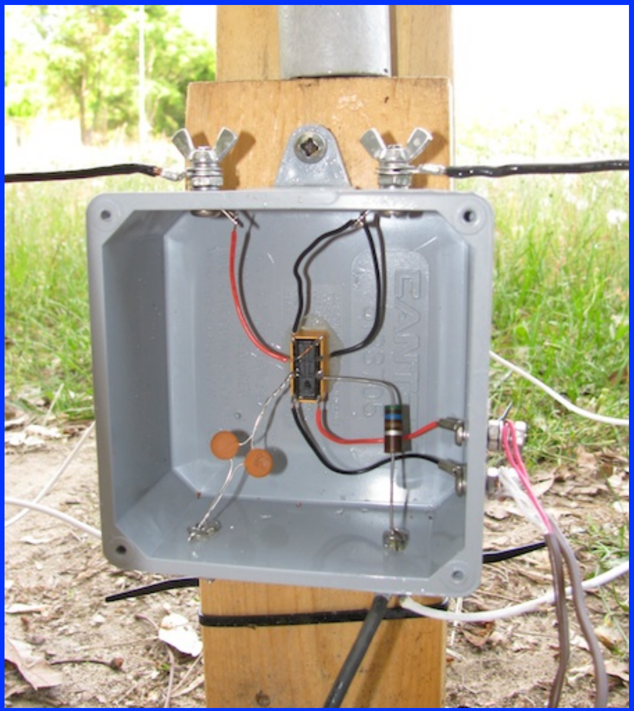
N/S Array

E/W Array

Fiberglass Support Poles (Max-Gain Systems)
Control Cables and Coax in PVC on Ground

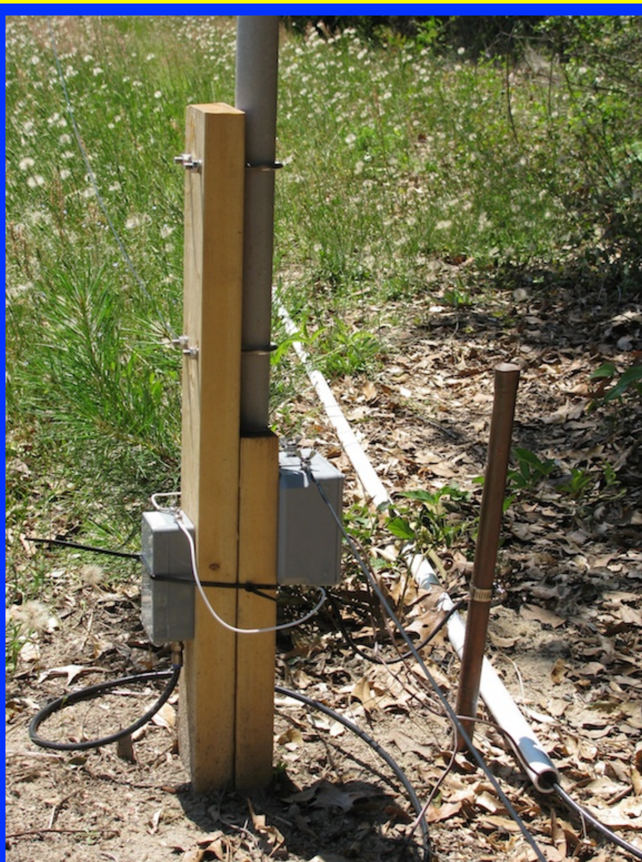
ARRAY IMPLEMENTATION
Loop Termination and Switching

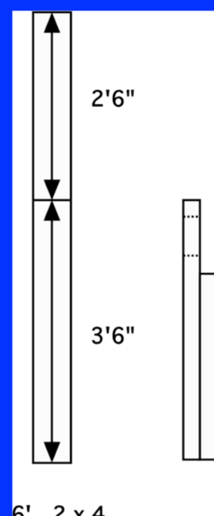




- DPDT Relay, 510-Ω Termination
- ac Coupled
- Water Tight Box (Lowes)
- All Stainless Steel Hardware

ARRAY IMPLEMENTATION
Loop Support and Array Control


Loop Support, Direction Control Box, Hi-Z Amplifier



- Loops as Identical as Possible
- High Impedance Amplifiers
  - (Hi-Z Plus 6)
- ac Coupled (loop dc short)
- Single 510-Ω Termination
- Flooded RG-6 Coax
- DPDT Relay Switching
- A 3' Ground Stake at Loop Center
- Four 20' Radials Under Each Loop (45º relative to loop)

RESULTS
Experimental Setup

- Array Solutions VNA 2180 (50 Ω)
- Port A drives 50 Ω coax with 50-Ω termination at Input of Loop Switches (loop removed)
- 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^{o}

RESULTS
Array Characterization

Set Up Ready for Measurements on the Arrays

RESULTS
Measurements: Array Element Matching

Table IV - Amplifiers + Controller Normalized Gain and Phase Matching				
1.827 MHz Results				
Loop	N/S Gain	N/S Phase	E/W Gain	E/W Phase
Front	-0.254 dB	0° (ref)	+0.457 dB	0° (ref)
Back	-0.375 dB	-195.4°	+0.171 dB	-193.7°
3.505 MHz Results				
Loop	N/S Gain	N/S Phase	E/W Gain	E/W Phase
Front	-0.331 dB	0° (ref)	+0.365 dB	0
Back	-0.336 dB	-205.2	+0.302 dB	-206.0

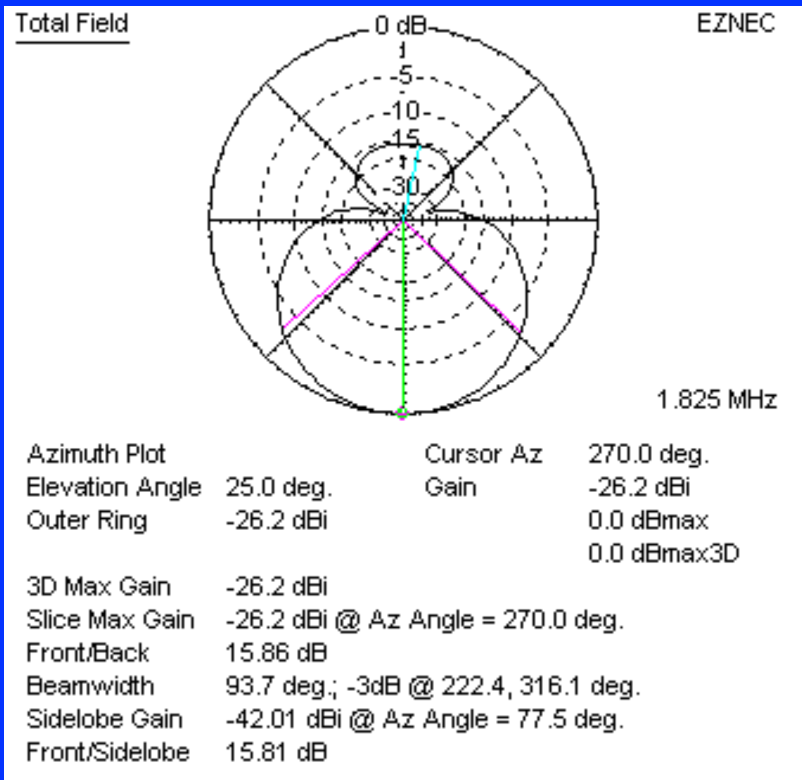
Note: Cross-fire phasing line on 160 & 80 M

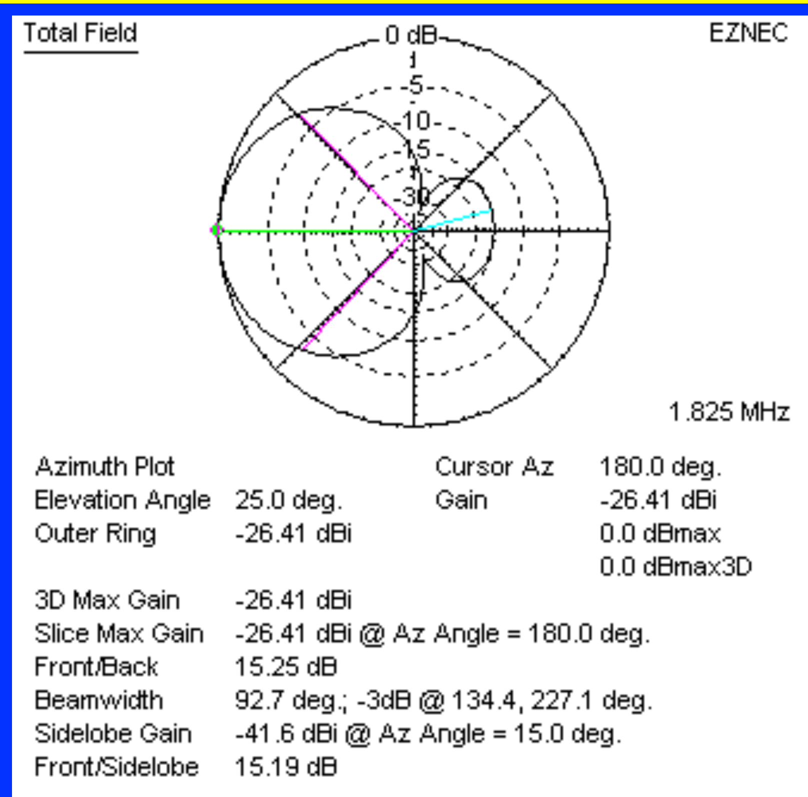
Gain matching within ±0.13 dB between the element pairs on both 160 & 80 m (± 0.4 dB ≈ ± 5%)

Phase shift a few degrees less than expected on 80 m

RESULTS

Final Simulations - 160 M



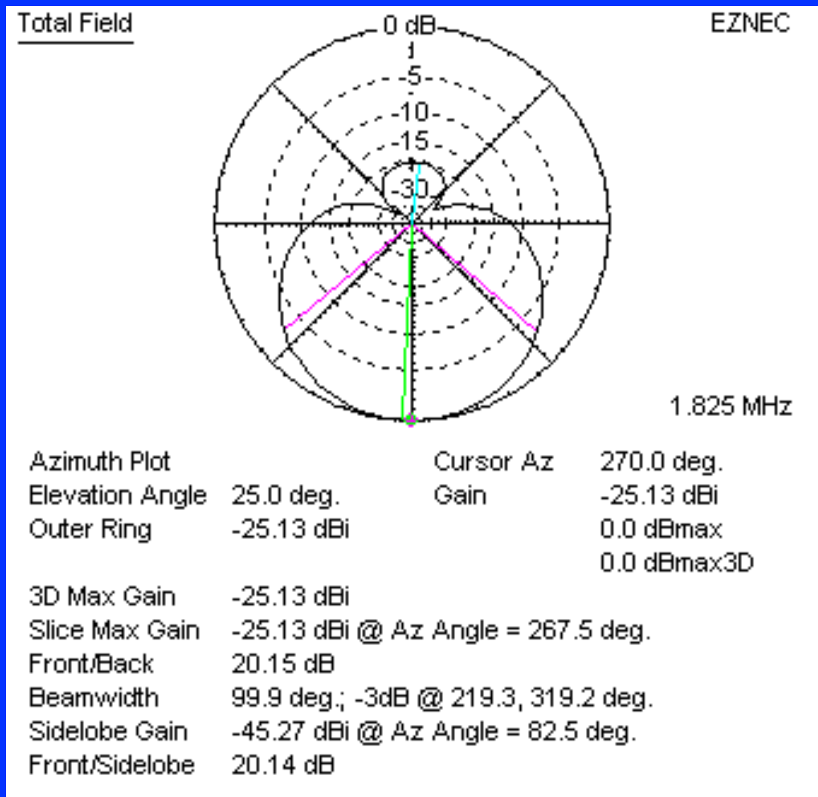


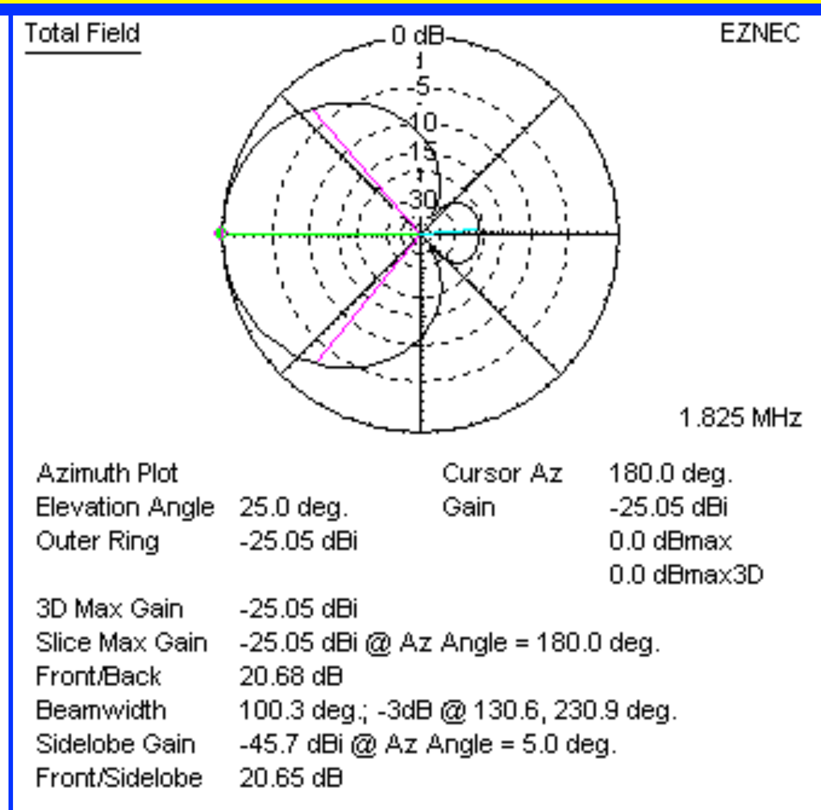
RDF 10.7 dB
Gain -26.2 dBi
F/B 15.8 dB

RDF 10.7 dB
Gain -26.4 dBi
F/B 15.2 dB

RESULTS

Final Simulations - 80 M



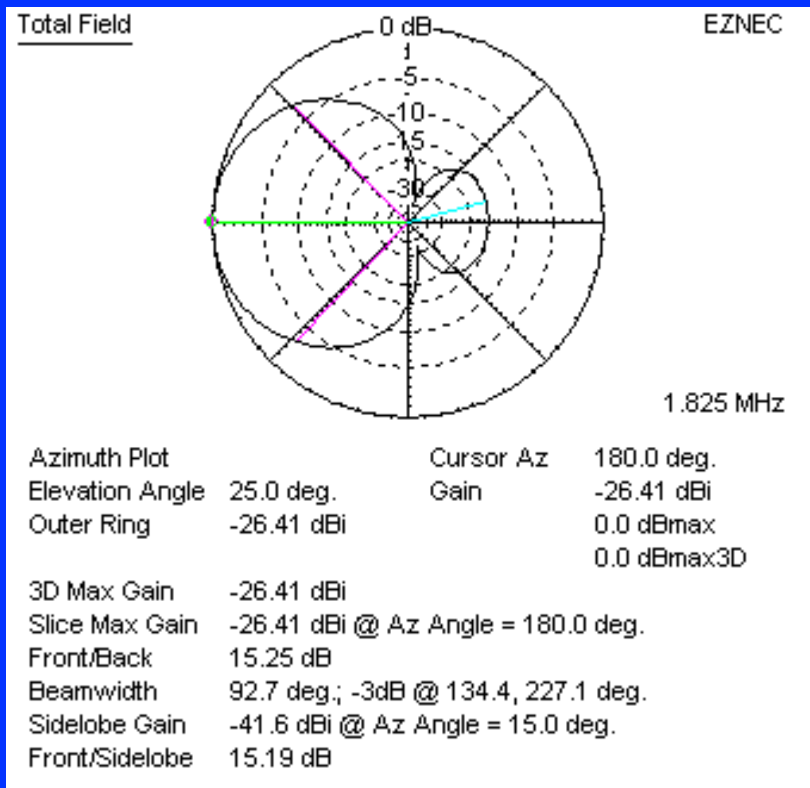


RDF 10.3 dB
Gain -25.1 dBi
F/B 19.2 dB

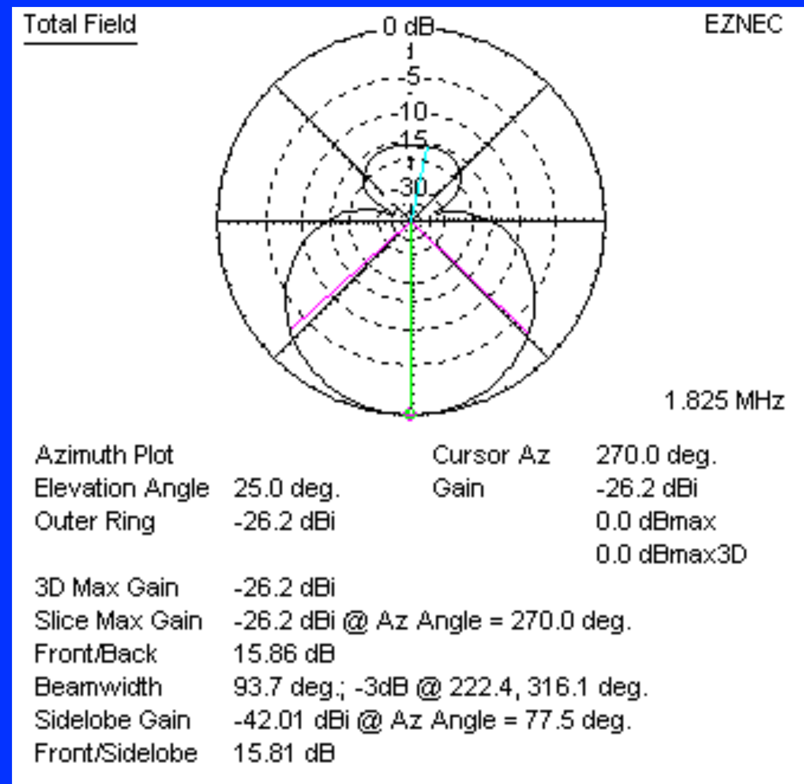
RDF 10.3 dB
Gain -25.1 dBi
F/B 19.6 dB

Two-Element Array
4-Way Switching Limitation

RDF decreases to 8 dB at ±45^o Points



Array Pointed West



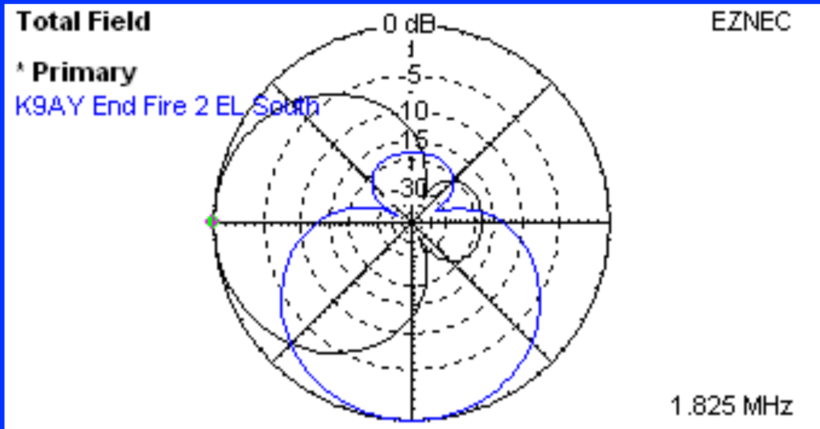
Array Pointed South

Two-Element Array
4-Way Switching Limitation

- Multi-Element Arrays Have Narrow Beam Widths
- Two-Element RDF
  - 10.7 dB in primary directions
  - RDF decreases to 8 dB at ±45^{o} points
  - Only slightly better than single loop
- Fill in the Gaps
  - Add two more arrays for ±45^{o} directions
  - Combine patterns of two N/S & E/W arrays

AZIMUTH PLOTS

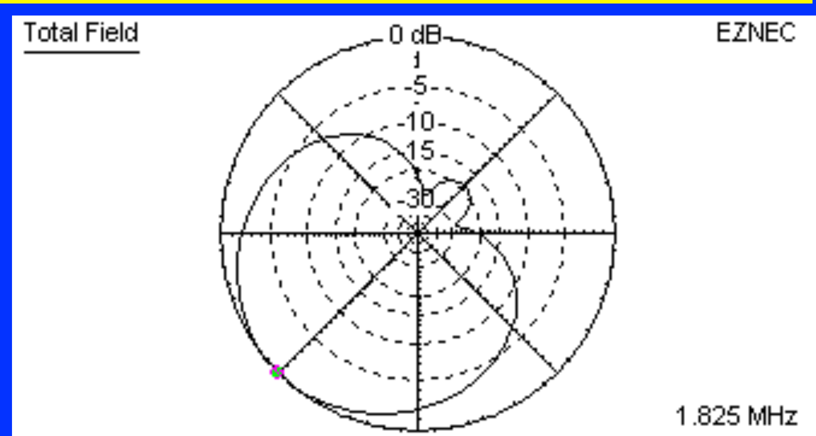
8-Way Switching by Combining Patterns



Azimuth Plot		Cursor Az	180.0 deg.
Elevation Angle	25.0 deg.	Gain	-25.67 dBi
Outer Ring	-25.67 dBi		0.0 dBmax
			0.0 dBmax3D

3D Max Gain -25.67 dBi
Slice Max Gain -25.67 dBi @ Az Angle = 180.0 deg.
Front/Back 17.81 dB
Beamwidth 96.7 deg.; -3dB @ 132.4, 229.1 deg.
Sidelobe Gain -43.44 dBi @ Az Angle = 7.5 deg.
Front/Sidelobe 17.77 dB

Arrays Pointed
South and West



Azimuth Plot		Cursor Az	225.0 deg.
Elevation Angle	25.0 deg.	Gain	-25.28 dBi
Outer Ring	-25.28 dBi		0.0 dBmax
			0.0 dBmax3D

3D Max Gain -25.28 dBi
Slice Max Gain -25.28 dBi @ Az Angle = 225.0 deg.
Front/Back 18.65 dB
Beamwidth 115.0 deg.; -3dB @ 167.6, 282.6 deg.
Sidelobe Gain -43.93 dBi @ Az Angle = 45.0 deg.
Front/Sidelobe 18.65 dB

Array Pointed
South-West

(-200^o Phasing)

Two-Element Array
8-Way Switching (-195^o phasing)

- RDF
  - 10.7 dB in 4 Primary Directions
  - 9.7 dB at 45^o Points
  - Gain Actually Somewhat Larger (+0.3 dB) in 45^o Directions

ARRAY IMPLEMENTATION
Loop Combining & Switching

Array Connection and Direction								
	N	NE	E	SE	S	SW	W	NW
N/S On	On	On	Off	On	On	On	Off	On
N/S Dir.	N	N	X	S	S	S	X	N
E/W On	Off	On	On	On	Off	On	On	On
E/W Dir.	X	E	E	E	X	W	W	W

X = “Don’t Care”

ARRAY IMPLEMENTATION
Loop Combining & Switching (Binary)

Array Connection and Direction (Binary)								
	N	NE	E	SE	S	SW	W	NW
ABC	000	001	010	011	100	101	110	111
N/S On	1	1	0	1	1	1	0	1
N/S Rev	0	0	X	1	1	1	X	0
E/W On	0	1	1	1	0	1	1	1
E/W Rev	X	0	0	0	X	1	1	1

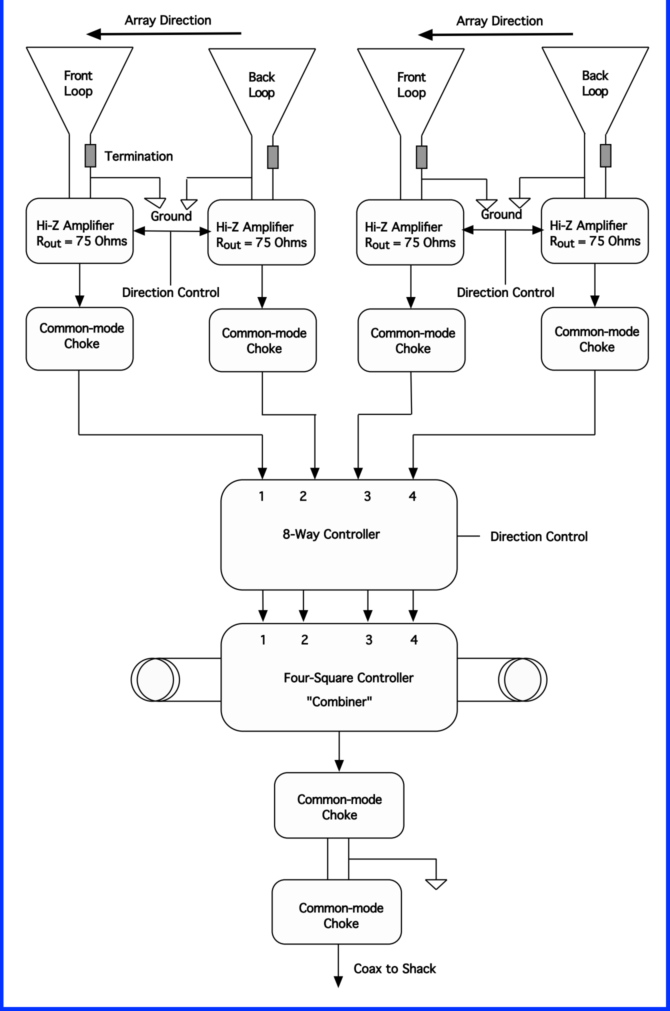
1 = Yes
0 = No

$$\mathrm{NSON} = \overline{B} + C \qquad \mathrm{NSREV} = A \oplus B$$

$$\mathrm{EWON} = B + C \qquad \mathrm{EWREV} = A$$

ARRAY IMPLEMENTATION
System Design

- 8-Way Controller Designed & Built
- Combiner – Spare DXE 4 Square Controller (Short Cut)
  - Front elements into 1 & 3
  - Back elements into 2 & 4
  - Zero long delay / 15^o short delays
- Hi-Z Plus 6 Amplifiers
  - 500 Ω antennas connected directly to amplifier inputs
- Must Switch Loop Terminations with Controller Direction
- “Common-mode” Chokes
  - (The Wireman)



ARRAY IMPLEMENTATION

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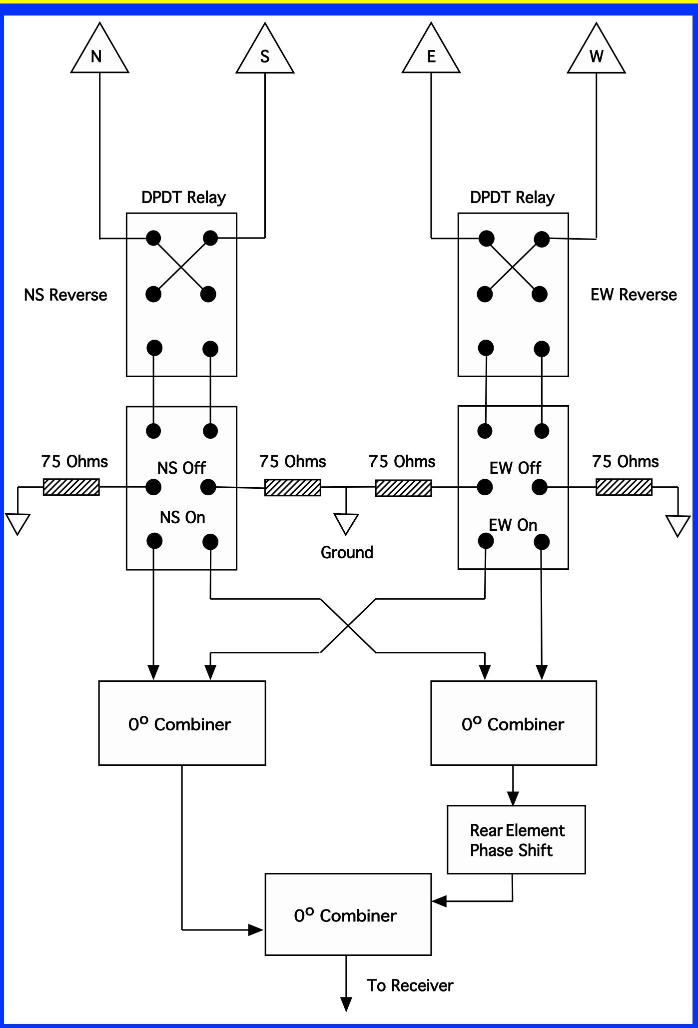
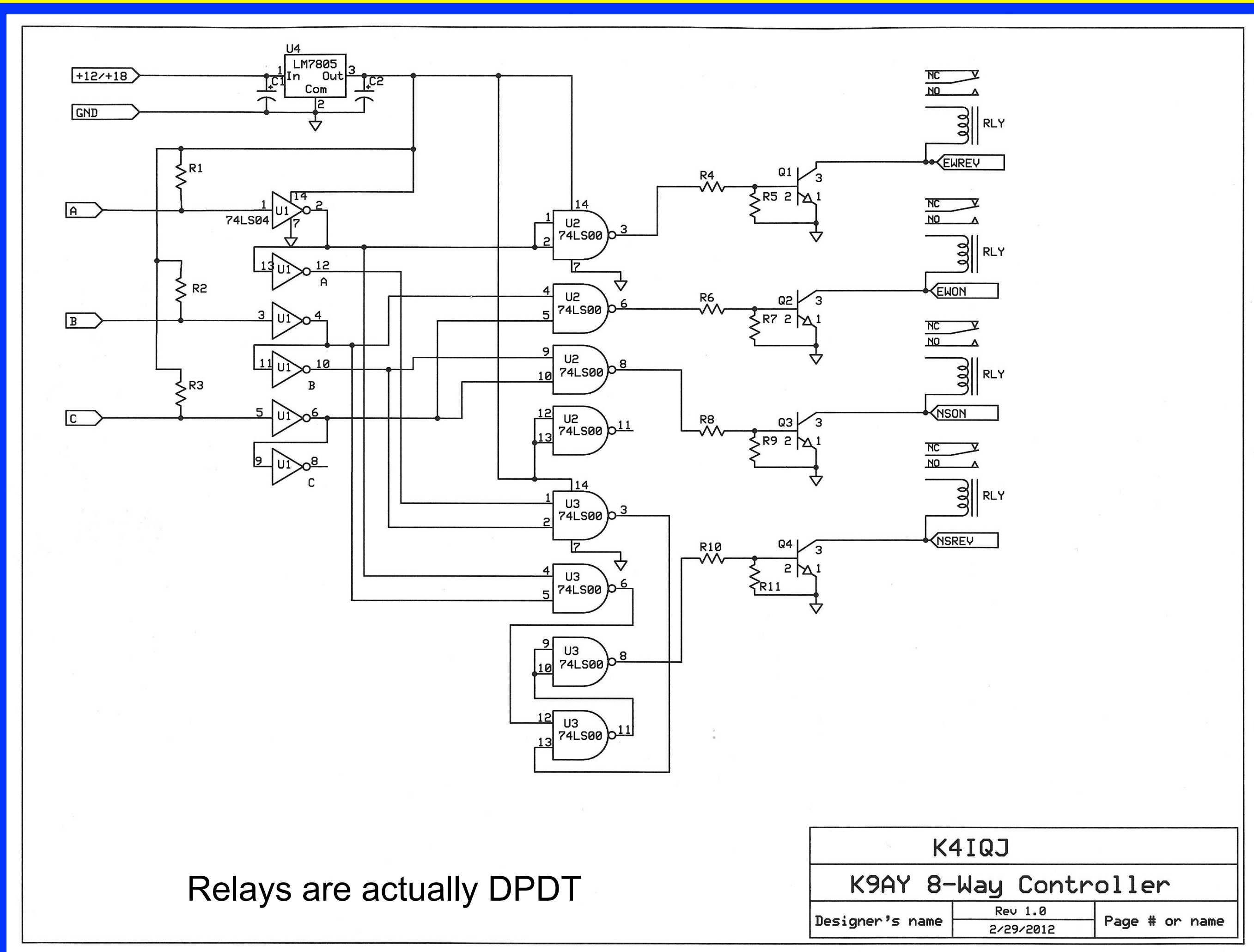
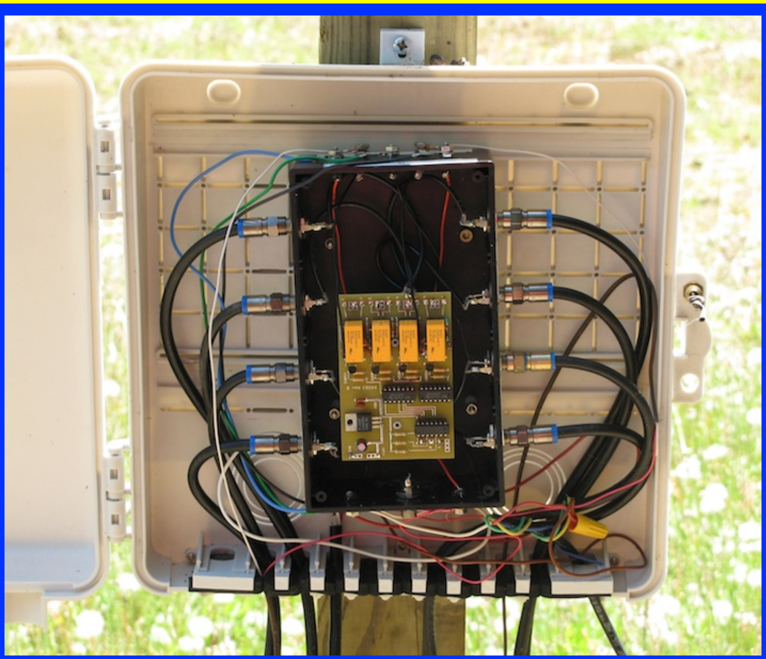


ARRAY IMPLEMENTATION

Controller Schematic (Without Combiners)



ARRAY IMPLEMENTATION
Array Direction Control / Array Combiner



Direction Control Board

DXE Controller used as
Array Combiner

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Measurements: Array Matching

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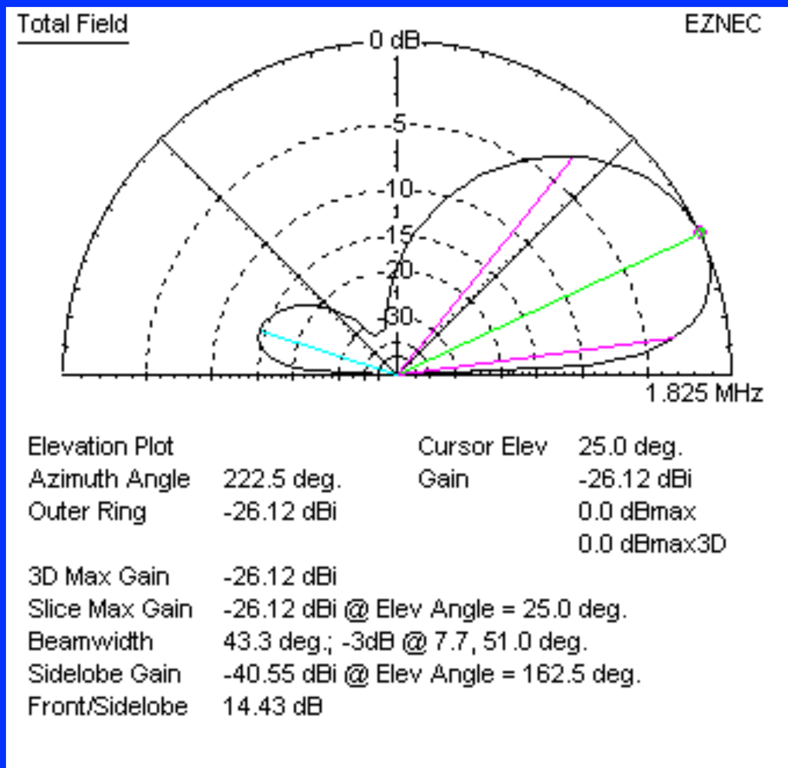
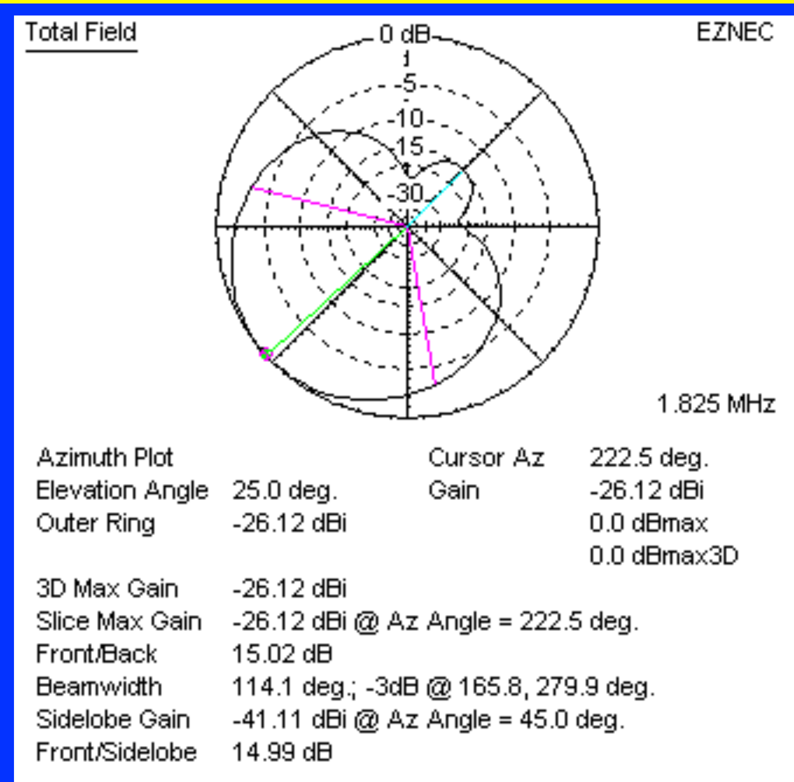
Note: Cross-fire phasing line on 160 & 80 M

Gain matching within ±0.34 dB between the arrays on both 160 & 80 m (± 0.4 dB ≈ ± 5%)

RESULTS
Final Simulations: Measured Data - 160 M

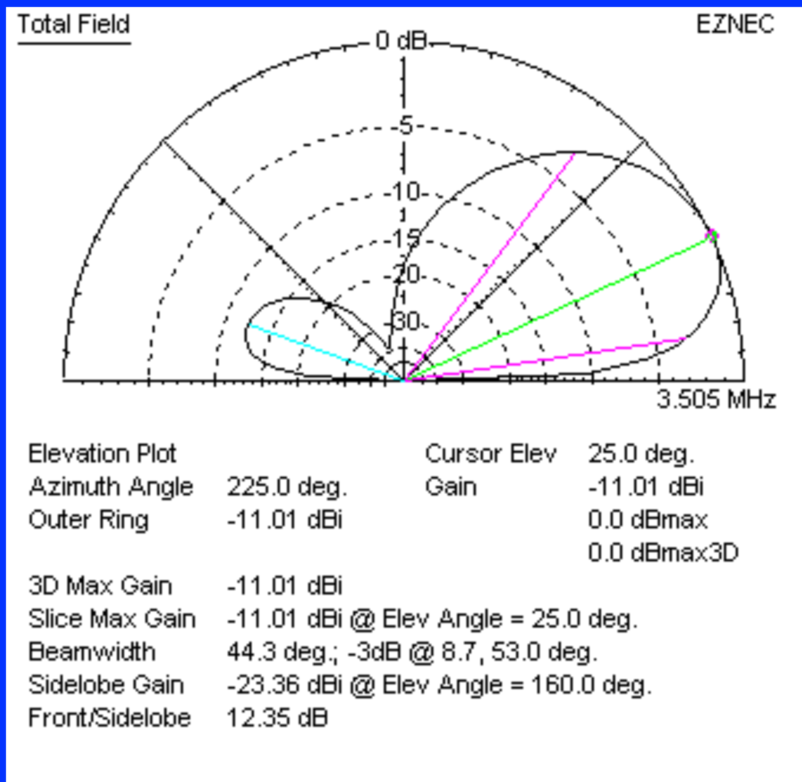


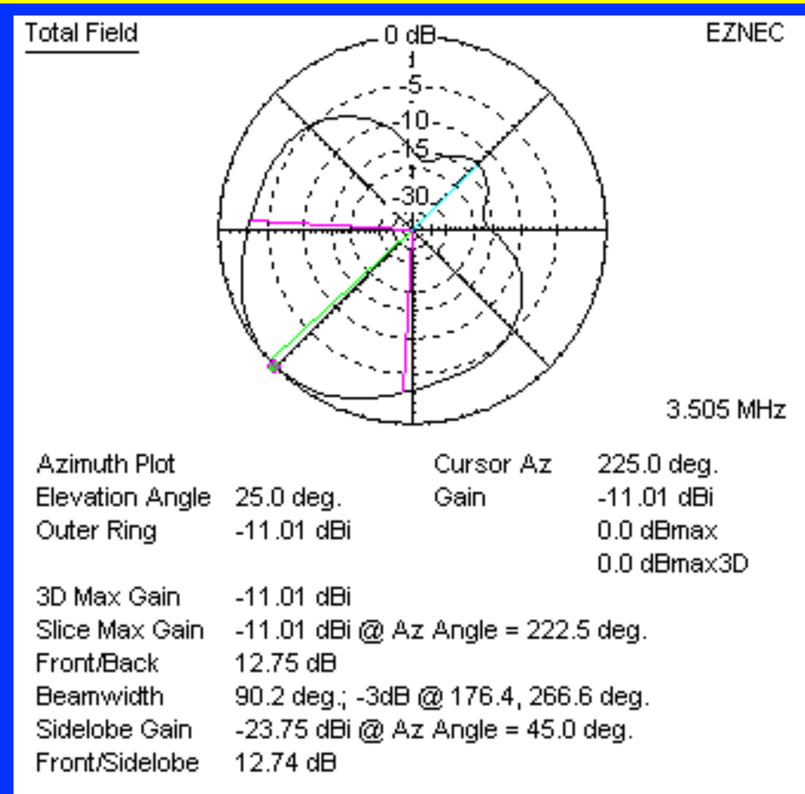


RDF 9.7 dB Gain -26.1 dBi F/B 14.4 dB

RESULTS

Final Simulations: Measured Data - 80 M





RDF 9.4 dB Gain -11.0 dBi F/B 12.4 dB

RESULTS
The Bottom Line

- Primary Array at Remote Receiver Site
- Testing
  - 1.6-1.8 MHz AM broadcast stations
  - 2.5 & 5 MHz WWV
  - 2.31 & 2.35 MHz Australian BC stations
  - 160M & 80M DX signals
- 8 Directions Readily Apparent
- 7O6T
  - 80 M
    - Solid copy NE on 5/6, 5/8 & 5/11 - 5/14
    - Good copy on 5/7 (except for nearby storm qrn)
    - Marginal copy N & E
  - 160 M
    - Gone the Best Night – (of course!)
    - Heard on 3-Element Array (but not 2-El) on 5/13 & 5/14

RESULTS
The Bottom Line (cont.)

- Similar Technique Being Used At Home QTH with Pair of Three-Element Arrays
- Should have Used Gray Code
- Will Probably Reduce Spacing
- 50-ft Array with Crossfire Feed Maintains Pattern on 40 M (9 dB RDF)
- 500' BOG Comparison (not done)
  - Chewed up into 16 pieces by unknown "critters"
  - A 60' BOG doesn't work nearly as well as the 500' version
- Wellbrook K9AY Phased Array
  - www.wellbrook.uk.com/K9AYphasedarray.html

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- THANK YOU FOR YOUR ATTENTION
- QUESTIONS?

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