Loop Array
Runs Circles Around
The Beverage
What to remember?

K3NA 3-loop array:

- Low-band RX antenna
  - 160m & 80m
  - Insensitive to out-of-band signals
  - Tolerates wide range of ground conditions

- Compared to optimized, full-size beverage:
  - Equal or better performance
  - $< 1/3^{rd}$ space

- Works well “out of the box”
  - ~1 day assembly
  - Complex lab tools not required
Progress report:

K3NA loop array
Agenda

• Problem
  • Existing alternatives
  • New approach
  • Implementation
  • Results
  • Dual-band operation
  • Diversity reception
  • Variations
  • Future research
  • Summary
Problem

RX antenna:

- Freqs:
  - 160m DX
  - 1900-1920 kHz ("dragon" backup)
  - 80m CW
  - 75m SSB
- Beamwidth: max ~60°, reversible
Problem

NA & Europe

Asia

NA long path
Problem

RX antenna:

- Freqs:
  - 160m DX
  - 1900-1915 kHz ("dragon" backup)
  - 80m CW
  - 75m SSB
- Beamwidth: max ~60°, reversible
- Insensitive to local earth
Problem

RX antenna:

- Freqs:
  - 160m DX
  - 1900-1915 kHz ("dragon" backup)
  - 80m CW
  - 75m SSB
- Beamwidth: max ~60°, reversible
- Insensitive to local earth
- Easy assembly; minimal on-site adjustment
Agenda

- Problem
- **Existing alternatives**
- New approach
- Implementation
- Results
- Dual-band operation
- “To Do” list
- Summary
Existing alternatives

• Beverage antenna
Existing alternatives: Beverage antenna

- Well-known standard solution.
- Performance near salt water?
  - Try comparing NEC4 results.

**feedpoint**

- length 215m:
  - 160m = $1 \frac{3}{8} \lambda$
  - 80m = $2 \frac{5}{8} \lambda$

**height 2m**

**2m ground rods**

300 Ω
Existing alternatives:
Beverage antenna: NEC4 – average earth

NEC4 model output:
pattern map for entire sky
Existing alternatives:
Beverage antenna: NEC4 – average earth

Bottom edge: horizon
Existing alternatives:
Beverage antenna: NEC4 – average earth

Top edge: zenith
Existing alternatives:
Beverage antenna: NEC4 – average earth

- Rear
- 90° to left
- Boresight
- 90° to right
- Rear
Existing alternatives:
Beverage antenna: NEC4 – average earth
Existing alternatives:
Beverage antenna: NEC4 – average earth

Pattern gain in color:
• Scale: 0 db = peak gain
Existing alternatives:
Beverage antenna: NEC4 – average earth

Pattern gain in color:
- Scale: 0 dB = peak gain
- Color code at top right
Existing alternatives:
Beverage antenna: NEC4 – average earth

Pattern gain in color:
- Scale: 0 dB = peak gain
- Color code at top right
- Contours every 3 dB
Existing alternatives:

Beverage antenna: NEC4 – average earth

Pattern gain in color:

- Scale: 0 db = peak gain
- Color code at top right
- Contours every 3 dB
- White contour: -3 dB beam edge
Existing alternatives:
Beverage antenna: NEC4 – average earth

1825 kHz pattern:
• Main beam
Existing alternatives:
Beverage antenna: NEC4 – average earth

1825 kHz:
- 2 side lobes
  -12 to -15 dB down
Existing alternatives:
Beverage antenna: NEC4 – average earth

1825 kHz:
• rear lobe
  -15 to -18 dB down
Existing alternatives:
Beverage antenna: NEC4 – average earth

3650 kHz:
- Main beam: smaller, lower – OK
- More side lobes but weaker
Existing alternatives:
Beverage antenna: NEC4 – average earth

1825 kHz: numbers

- Gain: -9.8 dBi
- Rejection:
  40% sky below -15 dB of peak
  3% below -30 dB of peak

- RDF* = 8.4 dB

* fwd peak gain avg gain
Existing alternatives:
Beverage antenna: NEC4 – salty earth

1825 kHz: numbers

• Peak gain: -18.5 dBi in side lobes

• Rejection:
  1% sky below -15 dB of peak
  0% below -30 dB of peak

• RDF = 3.2 dB
Existing alternatives:
Beverage antenna

- Beverages do *not* work over high conductive earth.
- Beverages work fine *next to* salt water.
Existing alternatives

- Beverage antenna
- K9AY loop
Existing alternatives: K9AY loop

1825 kHz numbers
- Gain: -23.4 dBi \textit{requires pre-amp}
- Rejection: \textit{about 5 dB front-to-back}
  - 4\% sky below -15 dB of peak
  - 0\% below -30 dB of peak
- RDF = 4.0 dB
Existing alternatives

- Beverage antenna
- K9AY loop
- Short vertical array
Existing solutions:
Short vertical array

W8JI approach:
- Low-Q, lossy (swamped) elements:
  - Wide bandwidth.
  - Eliminates mutual coupling between elements.
  - No impedance variations.
- Matched to 75 Ω line.
- Combine verticals to form pattern
Existing solutions:
Short vertical array

Drawbacks:

• Requires:
  stable earth characteristics,
  ≥ 4 radials

• Each element tuned for SWR < 1.2 at band edges.

• Cannot use on two bands simultaneously.

W8JI 11 ft vertical with top hat
160m gain: -17.4 dBi
Existing alternatives

- Beverage antenna
- K9AY loop
- Short vertical array

What now?
New approach:
K3NA loop array

- Loop element:
  - Insensitive to earth characteristics.
  - 0.1$\lambda$ circumference: nulls off sides
New approach: K3NA loop array

- Sharp side nulls at low elevation angles
- Gain: -9.5 dBi before matching
- Rejection:
  - 2% sky below -15 dB of peak
  - 0% below -30 dB of peak
  - RDF = 2.0 dB
New approach: K3NA loop array

- Match closely to 75 Ω line across band.
  - Coax now becomes freq-independent delay line.
- Combine elements to form pattern:
  - Spacing
  - Power ratio
  - Delay
New approach: K3NA loop array

Spacing = 70° at center freq:

160m: 31.51 m 103.4 ft ~220 ft overall
80m: 15.75 m 51.7 ft ~110 ft overall
beverage: 215 m 705 ft

Power:
front 0.54 middle 2.00 rear 1.00

Delay:
front 270° middle 135° rear 0°
New approach:
K3NA loop array

70° wide main beam. Other lobes ≤30 dB down.

- Gain: -9.7 dBi
- Rejection:
  - 54% sky below -15 dB of peak
  - 38% below -30 dB of peak
  - RDF = 8.0 dB
Existing alternatives:
Beverage antenna: NEC4 – average earth

1825 kHz: numbers

- Gain: -9.8 dBi
- Rejection:
  - 40% sky below -15 dB of peak
  - 3% below -30 dB of peak
  - RDF = 8.4 dB
New approach:  
K3NA loop array

Compared to beverage:
- Pattern independent of earth characteristics.
- Much quieter outside of main beam.
- Significantly smaller space required.
Agenda

- Problem
- Existing alternatives
- New approach
- **Implementation**
- Results
- Dual-band operation
- Diversity reception
- Variations
- Future research
- Summary
Implementation

- Loop
  - Match
  - Phasing
  - Combiner
  - Preamp
  - Construction practices
Implementation:

Loop

160m mast:
20ft 1½in sch 40
UV-resistant electrical conduit
over ground rod
Guys: string

160m loop:
12m insulated AWG #14.
Top, bottom corners:
black (UV-resistant) cable ties.
Implementation:
Loop

Lab in the salt marsh:
K3NA's receive loop for 3B7C

Impact of different earth characteristics:

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Implementation

- Loop
- Match
- Phasing
- Combiner
- Preamp
- Construction practices

match

coax shield
current choke
Implementation:  
Match  

Match network goals:  

- Balanced-unbalanced conversion.  
- Match $Z_{\text{element}}$ to $Z_0$ across band:  
  - SWR < 1.07.  
  - Identical phase delay through the network.  
  - Stable over outdoor temp range.  
- Tolerate 100 mW.  
- Surge protection.  
- Suppress currents on coax shield.
Implementation: Match

4-stage network to achieve double-resonance and low SWR across band.
Implementation: Match

• Theoretical match
Implementation:

Match

Add:
- Balun ⑤
- Surge protectors ⑥
Implementation:
Match: K2TJ monte carlo analysis

- Above model used for simulation
- Assumed $R = 2\Omega$ for 160m and 80m
- $L_{\text{ant}} = 9.3\ \mu\text{H (160m)}\ L_{\text{ant}} = 4.1\ \mu\text{H (80m)}$ – rough approximation
- Transformer leakage inductance will probably have a small effect – absorb into $C_1$. 
Implementation:
Match: K2TJ monte carlo analysis

- C1, C2, C3, L3 used as random variables.
- Simulated for tolerances of 1%, 5%, and 10%.
- R1 kept at constant tolerance of 1%.
- 30 iterations of component values within the tolerance range for each sweep.
Implementation:

Match: K2TJ monte carlo analysis

As designed:

freq (100.0kHz to 4.000MHz)
Implementation:
Match: K2TJ monte carlo analysis

Even with 1% tolerance parts, alignment required to bring matching network to near-identical performance.
Implementation:
Match
Implementation: Match

Actual 160m match:

Theoretical:

1.10 SWR circle

1.12 SWR circle

Stop: 1950 kHz

Actual 160m match:

Theoretical:

1.12 SWR circle

1800

1850

1925

1900

Stop: 1950 kHz
Implementation:
Match

Actual 80m match:
Implementation: Match

- Trimmer capacitors not temperature-stable.
- Used small parallel capacitors to trim as close as possible to identical behavior.
Implementation:
Match

Balun construction:
• Variation on W8JI design
  o 2×binocular cores
  o type 73
    FairRite 2873000202 or Amidon BN 73-202
  o AWG #26 Teflon wire
  o 10 passes,untwisted

• Note: $R_{\text{load}}$ is low, increasing phase error, losses. Minimize with double core stacking and special winding pattern.
Implementation:

Match

1:1 balun - two Amidon BN-73-202 stacked - AWG#24 TFE insul

10 passes

minimized loss
Implementation:
Match

Temperature-stable inductor core material:
MPP: moly-permaloy powder

Magnetics
160m C0-55122
80m C0-55123

“Freezer test”:
Stable match down to -15C.
Implementation:
Shield current choke

Two stages:
- FairRite 2843009902 type 43 binocular core
- 75Ω video cable
- 5 passes per stage
Implementation:

Match: shield current choke

- Located between matching network and feedline of each element.
- $Z_{\text{shield}} > 1 \, \text{k}\Omega \ 1\text{–}30 \, \text{MHz}$.
- First 12 units measured:
  - Insertion loss $< 0.1 \, \text{dB}$
  - Phase delay $30\text{-}32^\circ$ at $30 \, \text{MHz}$
  - Shield current loss:
    - min $-18$ to $-20 \, \text{dB}$ at $1.8 \, \text{MHz}$
    - max $-32$ to $-33 \, \text{dB}$ at $15.1\text{-}16.4 \, \text{MHz}$
Implementation

- Loop
- Match
- Phasing
- Combiner
- Preamp
- Construction practices
Implementation: Phasing

Simple, brute force approach:

- Uses:
  - ~155m RG-6 on 160m
  - ~80m RG-6 on 80m.
- Unidirectional.
- Pattern stable across band.
Implementation: Phasing

1800 kHz
Implementation: Phasing

1850 kHz
Implementation: Phasing

1925 kHz

- Main beam narrower at high elevation
- Rear lobe increased ~ 9 dB
Implementation: Phasing

Reversible approach:

- Uses:
  - ~266m RG-6 on 160m
  - ~130m RG-6 on 80m.
- Relays in combiner switch front/rear loops.
- DC sent thru coax from shack to activate relays.
Implementation

- Loop
- Match
- Phasing
- Combiner
- Preamp
- Construction practices
Implementation: Combiner

- Extracts Vdc from coax to station.
- Protection measures:
  - surge: gas discharge tube, fuse
  - voltage: zener, steering diode
  - spikes: snubbers, bypass caps
Implementation: Combiner
Implementation: Combiner

- Exchange front/rear loops to reverse pattern.
- Axion FP2 relays:
  - Inexpensive
  - Hermetically sealed
  - Gold contacts
  - Negligible loss, SWR
Implementation: Combiner
Implementation: Combiner

- Combine loops in required ratio: 0.54 : 2.00 : 1.00 13 : 24 : 12 (front:middle:rear)
- Ratio error <0.1%
- Phase delay errors: front = ref mid = -2.2 to -2.5° rear = +1.0° (less on 160m)
- Flat winding best.
Implementation: Combiner
Implementation: Combiner

- Xformer output:
  160m: 14.5 + j2.5
  80m: 14.5 + j4.7

- T2: step-up 7:16
  160m: 76 + j15
  80m: 79 + j38

- Parallel cap cancels residual X.
Implementation: Combiner
Implementation

- Loop
- Match
- Phasing
- Combiner
- Preamp
- Construction practices
Implementation:
Pre-amp

- -14 dB loss in K2TJ model of matching network.
- DX Eng pre-amp in shack.
- Pre-amp disabled on transmit.
- Pre-amp protected by bandpass filter.
Implementation

- Loop
- Match
- Phasing
- Combiner
- Preamp
- **Construction practices**
  - Anti-oxidant / anti-seize
  - High-dielectric silicone grease
Implementation:
Construction practices

Aluminum, copper conductive petroleum base

Prevents:
- Oxidation
- Moisture penetration.
- Intermittents.
- Galling / binding.
Implementation:
Construction practices

Insulating lubricant.
Fills voids, seals.
Also good under heat shrink.

Flexible ring seals threads against box.
Agenda

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• Results
  • Dual-band operation
  • “To Do” list
• Summary
Results:
Forward – reverse

~15 dB front-back on AA1K
Results:

S/N vs beverage

Same or quieter S/N ratio than beverage.
With preamp, -5 dB weaker than beverage:
Consistent with design.
Band noise above receiver floor.

AA1K normalized for both antennas in this recording:
Results

Even “out of the box” with no tune-up, very competitive with full-size beverage.

Next R&D steps at W1KM:

- Correct for phase delay errors in combiner.
- Verify alignment.
- Blind test during contests.
- Attempt to measure patterns.
Agenda

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Dual-band operation

Approach #1:

• 3 loops on 3 posts spaced for 160m:
  o Clean pattern on 80m.
  o Much narrower.

• But...
  o Matching network?
  o SO2R or multi-op access to antenna?
  o May be solved with more R&D time...
Dual-band operation

Approach #2A
• 3 loops for each band
• Separate supports
• Minimize interaction:
  \[ \geq 8\text{m} \text{ (26 ft) separation} \]

  80m front, rear loops “face” 160m loops.
  (Exploits nulls.)
Dual-band operation

Approach #2B:

- 3 loops for each band
- 80m and 160m loops share common supports
- 4 supports needed
Dual band operation

Which is better?
Dual band operation

Problem with common center:

- Shifts 80m loop $Z$
- Reduces 80m loop output -3 dB

160m loop:
  impact immaterial for either approach.
Problem: 80m rear/side degraded!

80m should be:
Dual band operation: Dummy loop

“Dummy” 160m loop:
• not part of 160m array!

This 160m loop does not require an 80m dummy loop.
Dual band operation:
Dummy loop

Dummy loop terminated in conjugate match.
Agenda

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“To Do” list:
Diversity RX

Diversity reception
   listening in 2 directions
   one in each ear

Solution:
   • Split output of each loop.
   • Two sets of delay lines / combiners.
“To Do” list:
Narrower pattern

Down to 35° main beam
Even quieter!

Solution:

• Two parallel arrays, combined in phase.
• $\sim \frac{1}{2} \lambda$ separation required for full effect.
“To Do” list:
Smaller footprint

Can array be even smaller?

Potential solution:
• 2 loops, $\frac{1}{8} \lambda$ in-line separation
• $145^\circ$ delay
• Same match, current choke
• Combiner: change transformers.
"To Do" list:
Faster assembly

Faster assembly time?

Potential solution:
• Fiberglass mast with crossarm(s): eliminate guys
“To Do” list:
R&D thoughts

- Is assertion of 0.1λ limit to circumference correct?
- Dual-band matching network?
- Measure out-of-band TX pickup; evaluate danger to preamp.
Summary

**K3NA loop array**

- Performance
  Equal/better than beverage of 3× length
- Tolerates wide range of ground conditions without adjustments.
- 2-band system may be co-located.
- Appears to be replicable.
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