Loop Array
Runs Circles Around
The Beverage

What to remember?

K3NA 3-loop array:

- Low-band RX antenna
  - o 160m & 80m
  - o Insensitive to out-of-band signals
  - o Tolerates wide range of ground conditions
- Compared to optimized, full-size beverage:
  - o Equal or better performance
  - o < 1/3rd space
- Works well "out of the box"
  - o ~ 1 day assembly
  - o Complex lab tools not required

Progress report:

K3NA loop array

Agenda

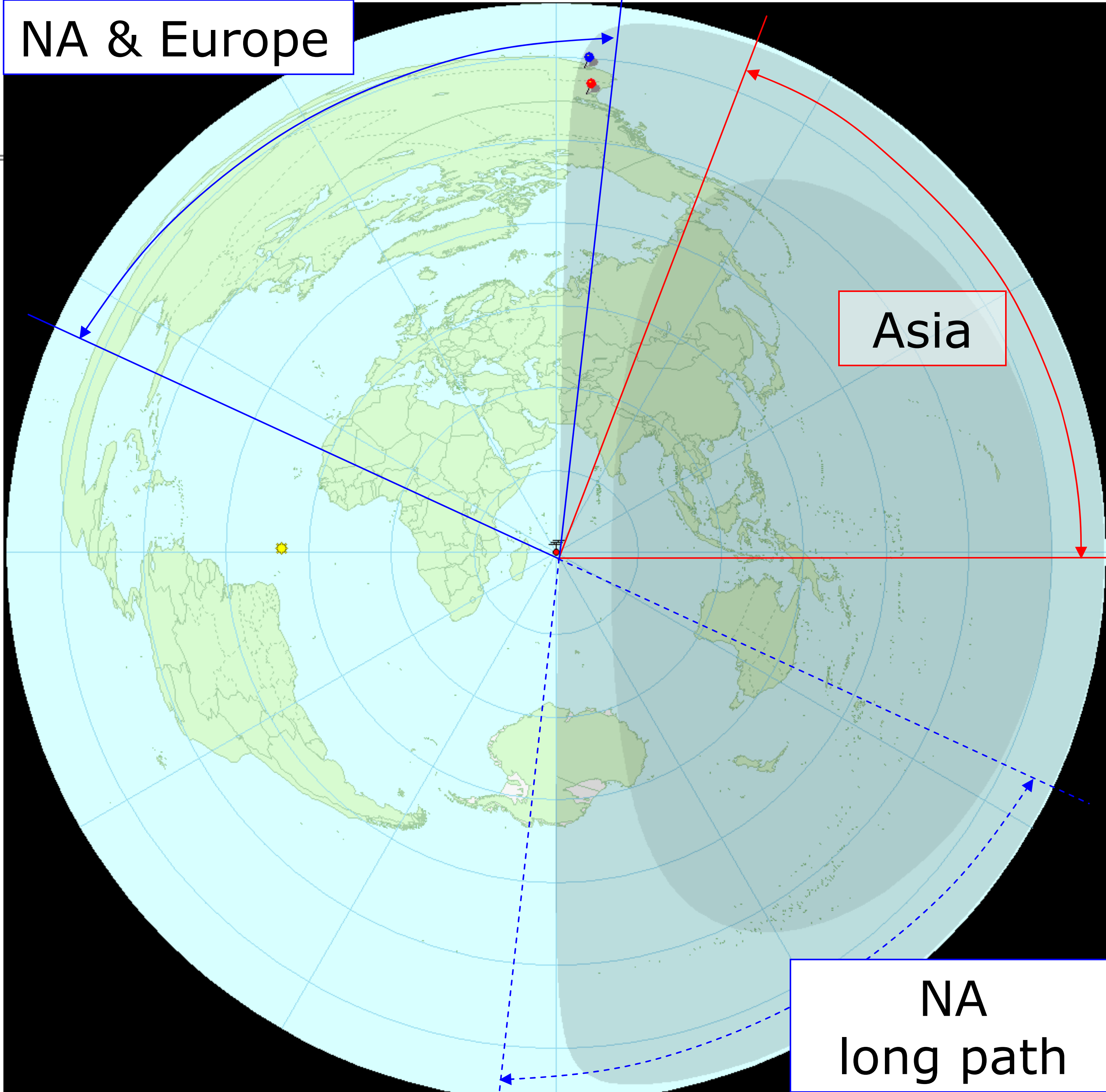
- Problem
- Existing alternatives
- New approach
- Implementation
- Results
- Dual-band operation
- Diversity reception
- Variations
- Future research
- Summary

Problem

RX antenna:

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

Problem



Problem

RX antenna:

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

Problem

RX antenna:

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

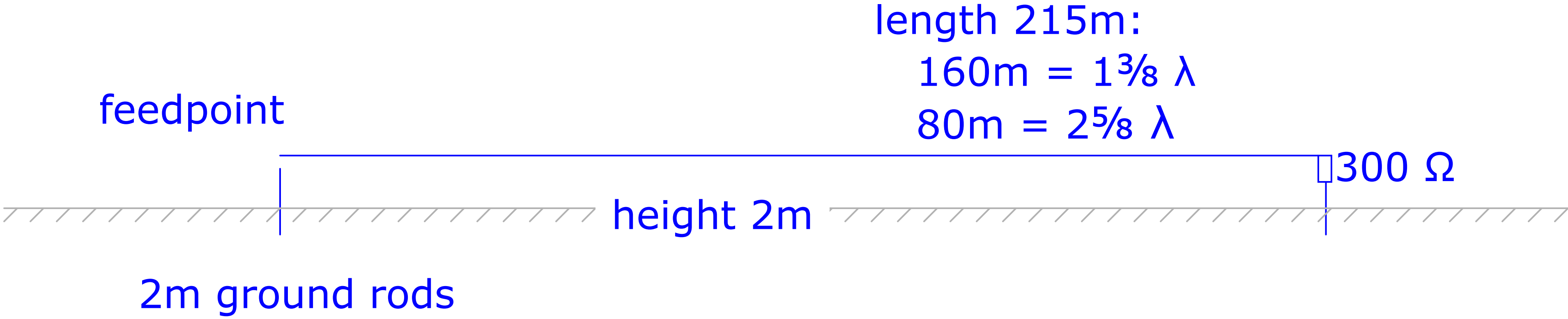
Agenda

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

Existing alternatives

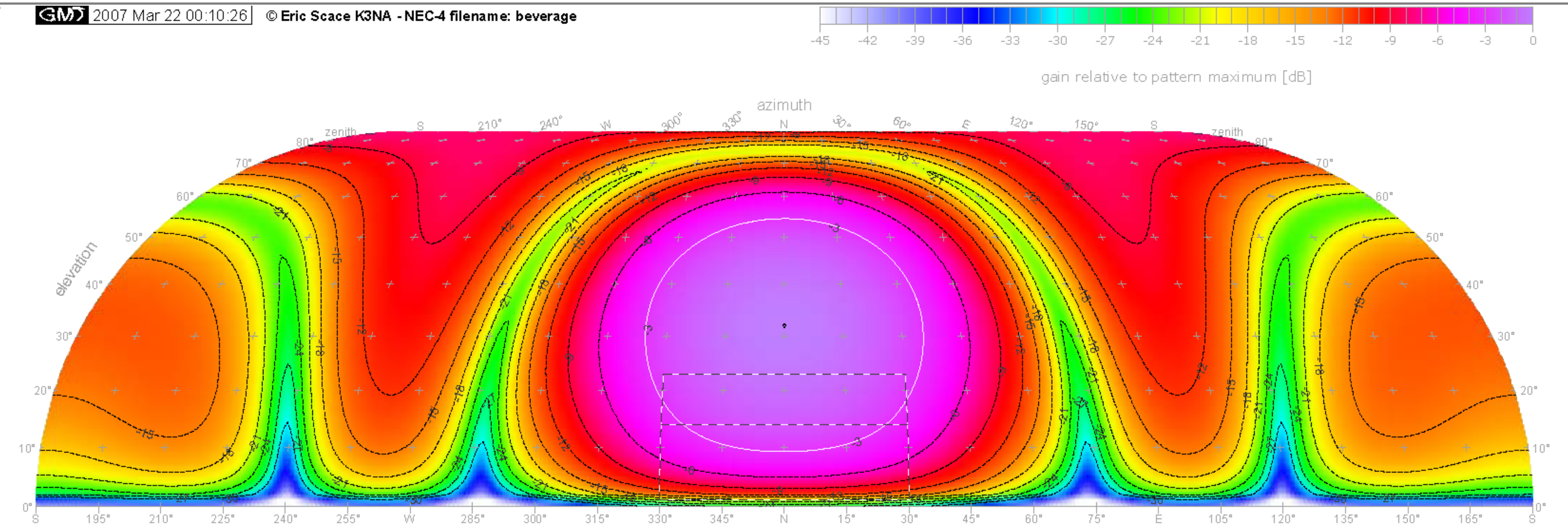
- Beverage antenna

Existing alternatives:
Beverage antenna



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

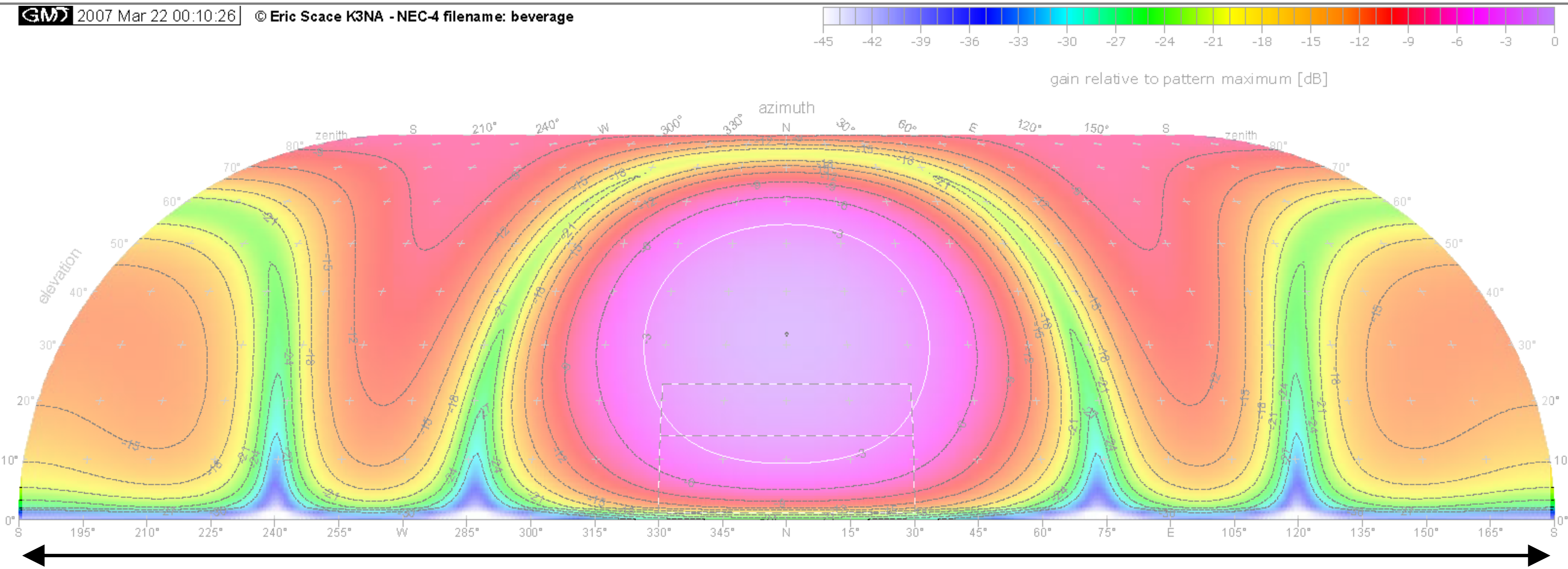
Existing alternatives:
Beverage antenna: NEC4 – average earth



NEC4 model output:

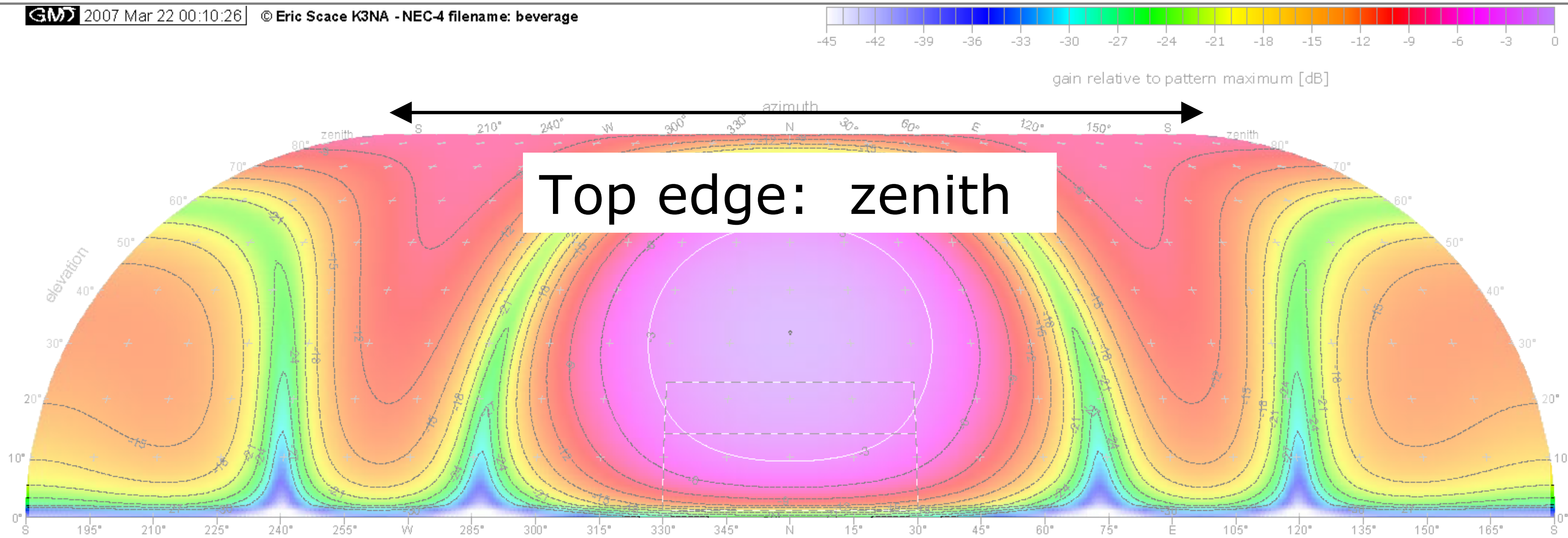
pattern map for entire sky

Existing alternatives:
Beverage antenna: NEC4 – average earth

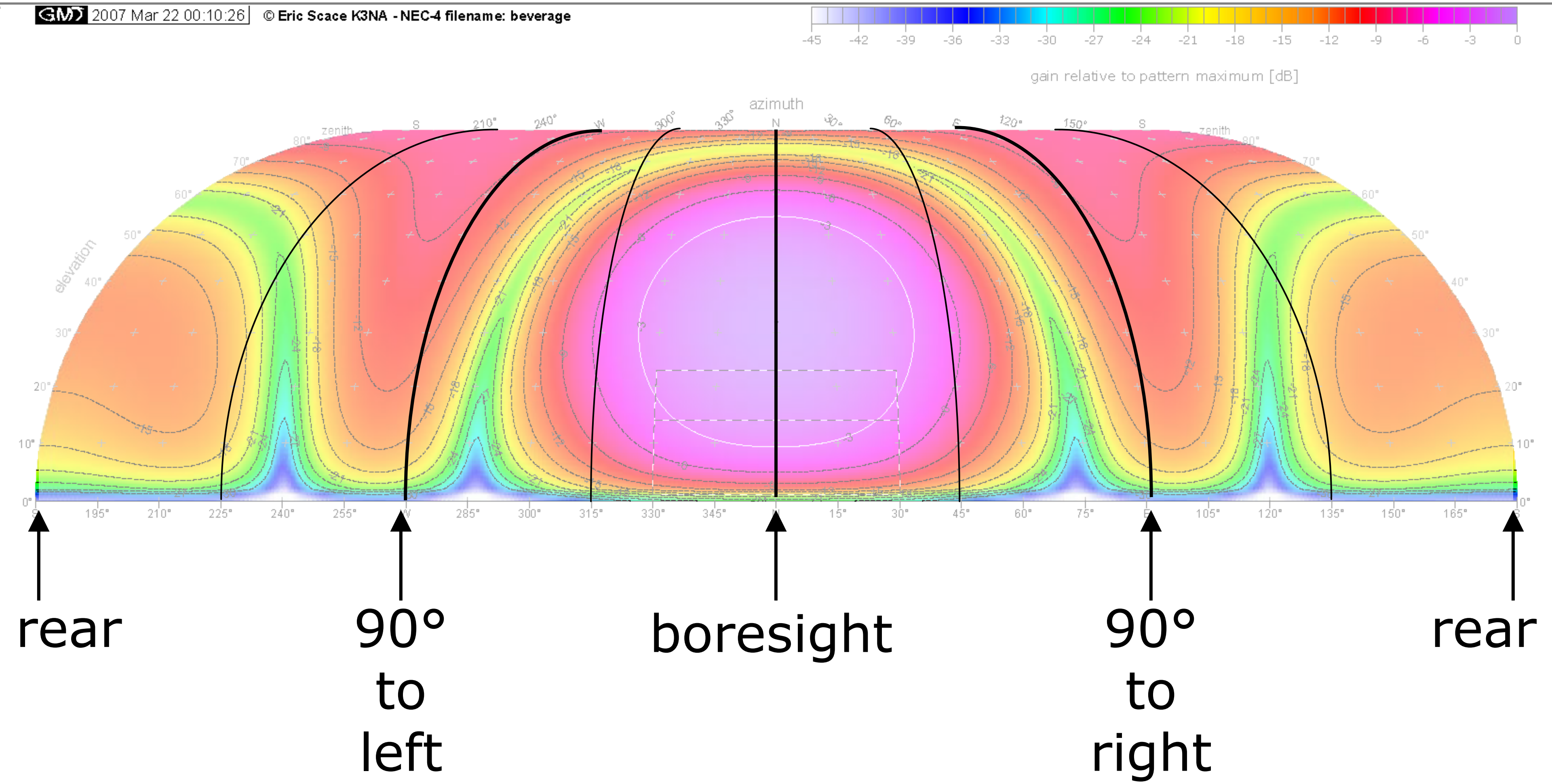


Bottom edge: horizon

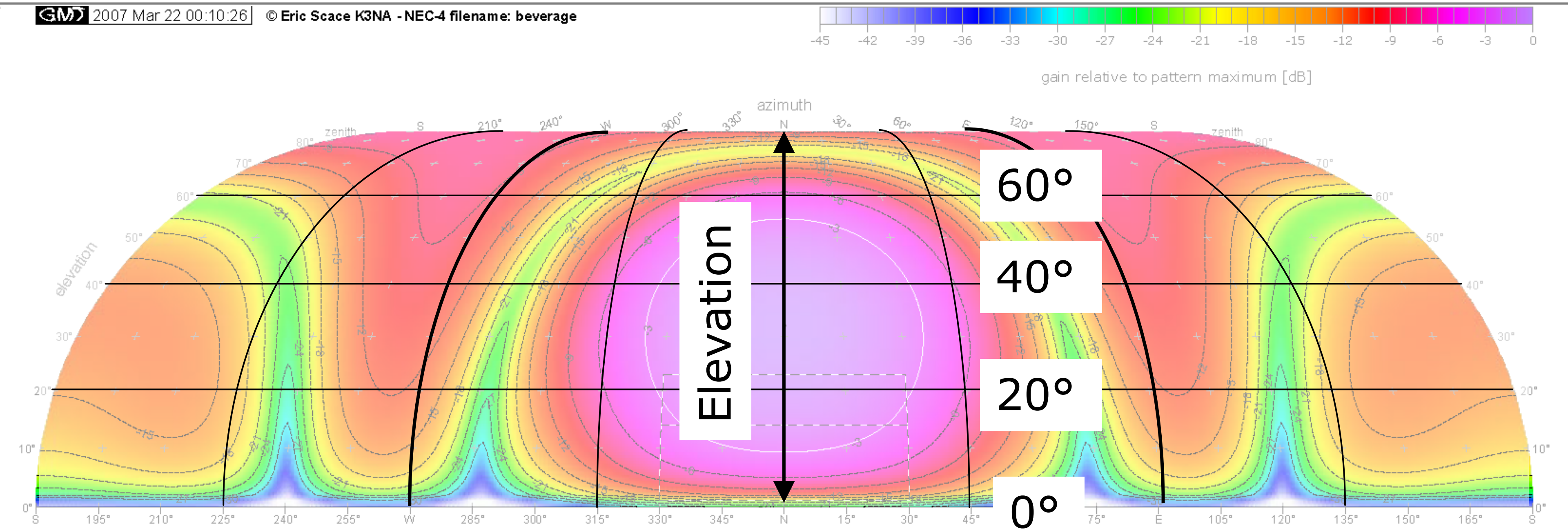
Existing alternatives:
Beverage antenna: NEC4 – average earth



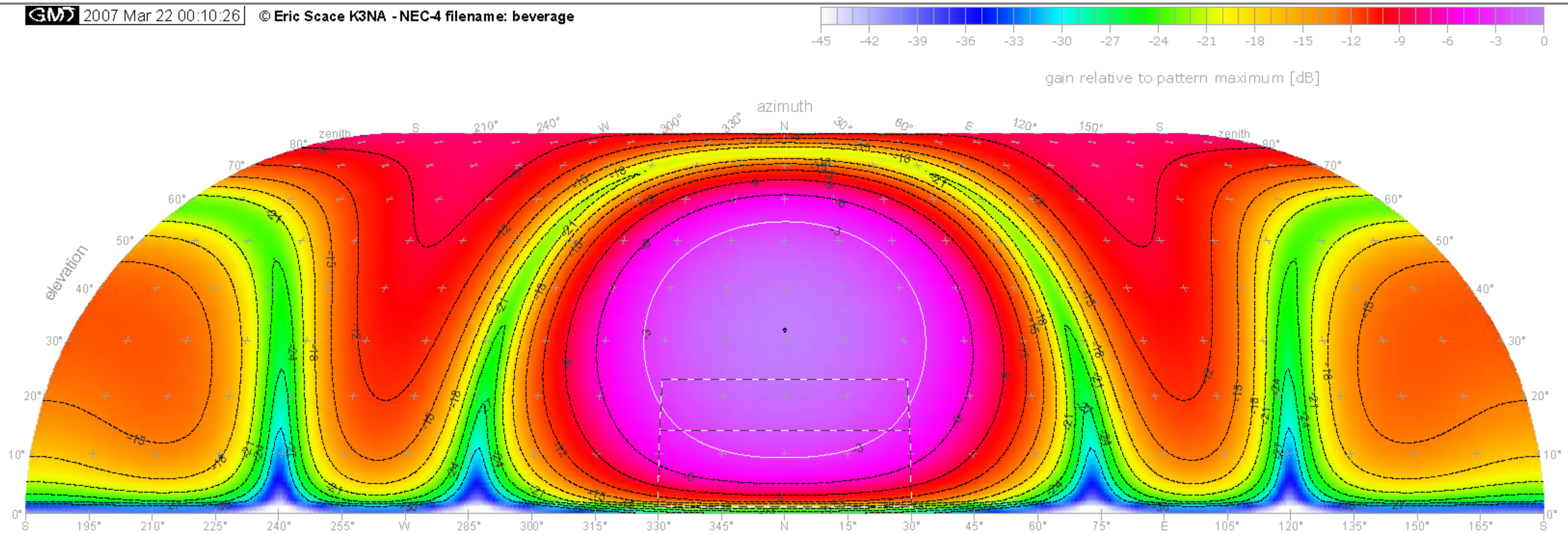
Existing alternatives:
Beverage antenna: NEC4 – average earth



Existing alternatives:
Beverage antenna: NEC4 – average earth



Existing alternatives:
Beverage antenna: NEC4 – average earth

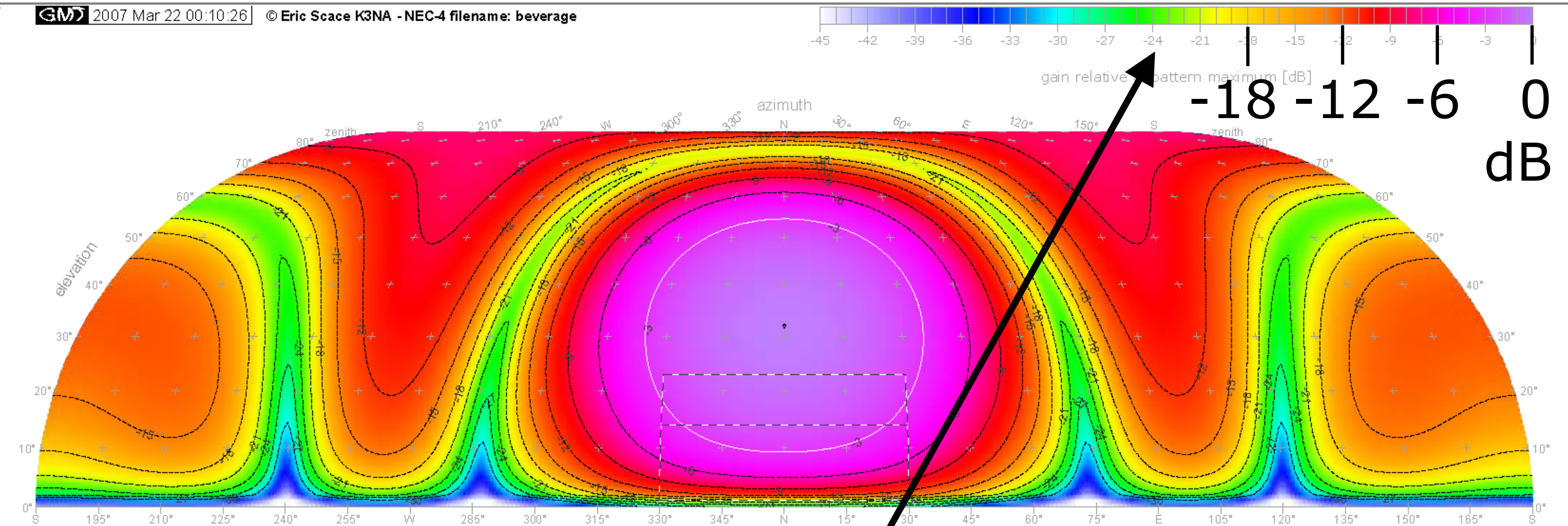


Pattern gain in color:

- Scale: 0 db = peak gain

Existing alternatives:

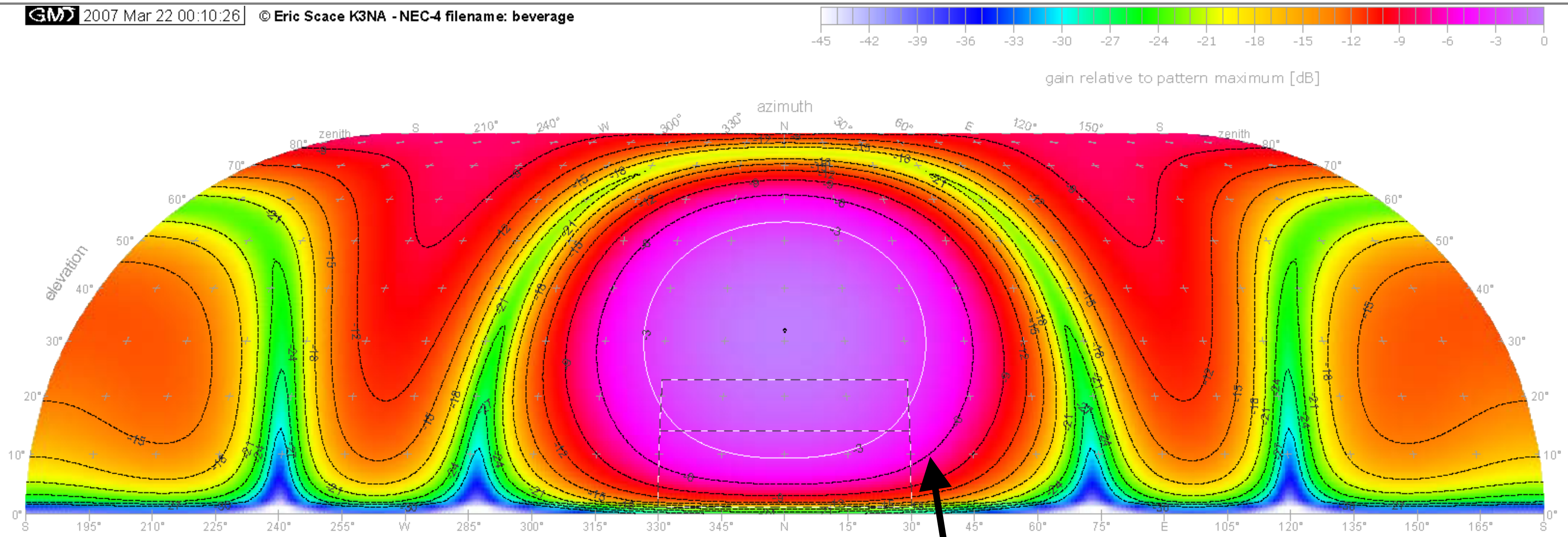
Beverage antenna: NEC4 – average earth



Pattern gain in color:

- Scale: 0 db = peak gain
- Color code at top right

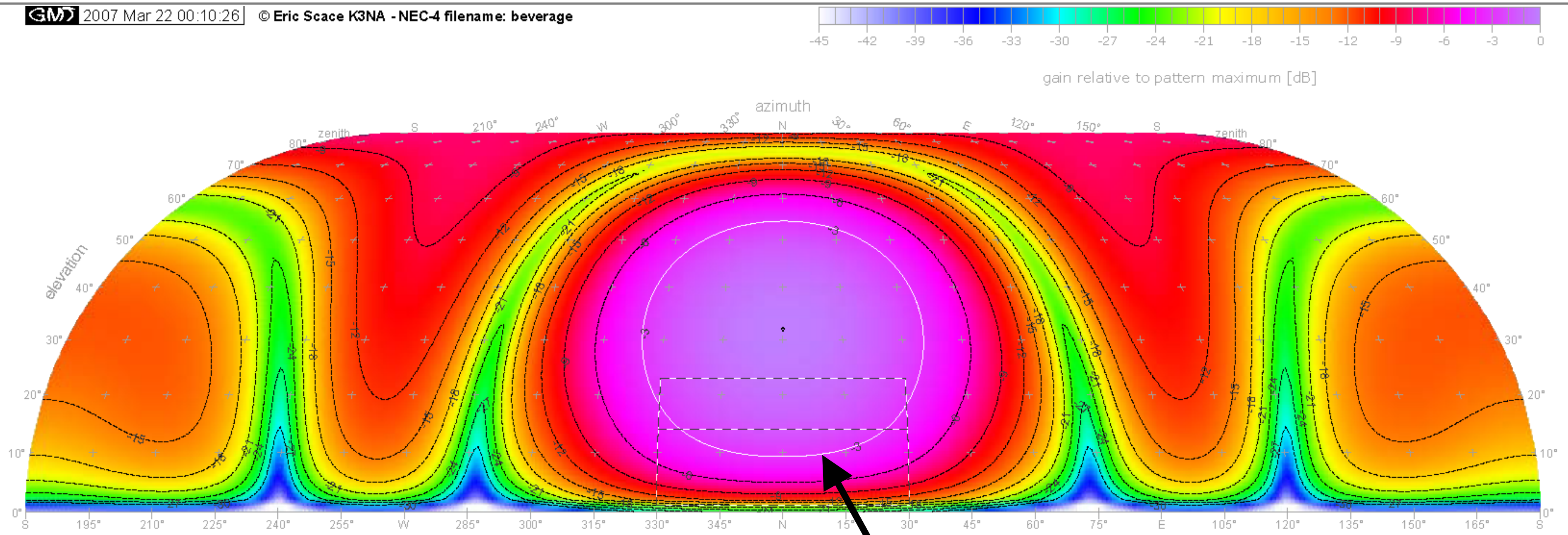
Existing alternatives:
Beverage antenna: NEC4 – average earth



Pattern gain in color:

- Scale: 0 db = peak gain
- Color code at top right
- Contours every 3 dB

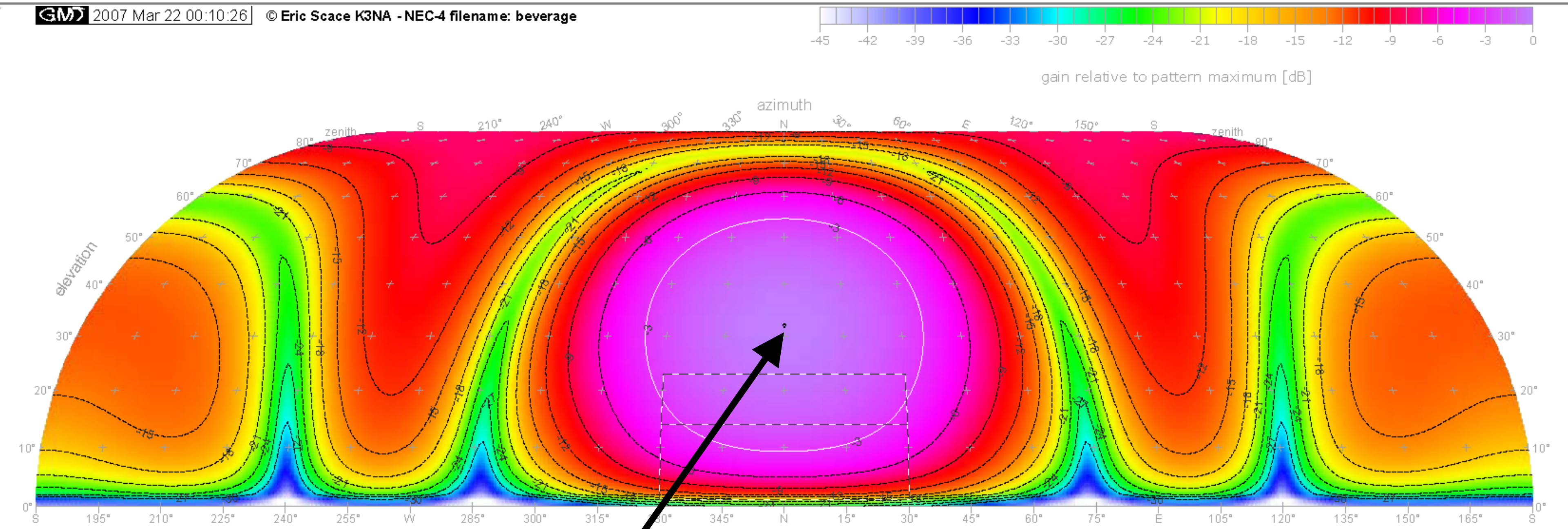
Existing alternatives:
Beverage antenna: NEC4 – average earth



Pattern gain in color:

- Scale: 0 db = peak gain
- Color code at top right
- Contours every 3 dB
- White contour: -3 dB beam edge

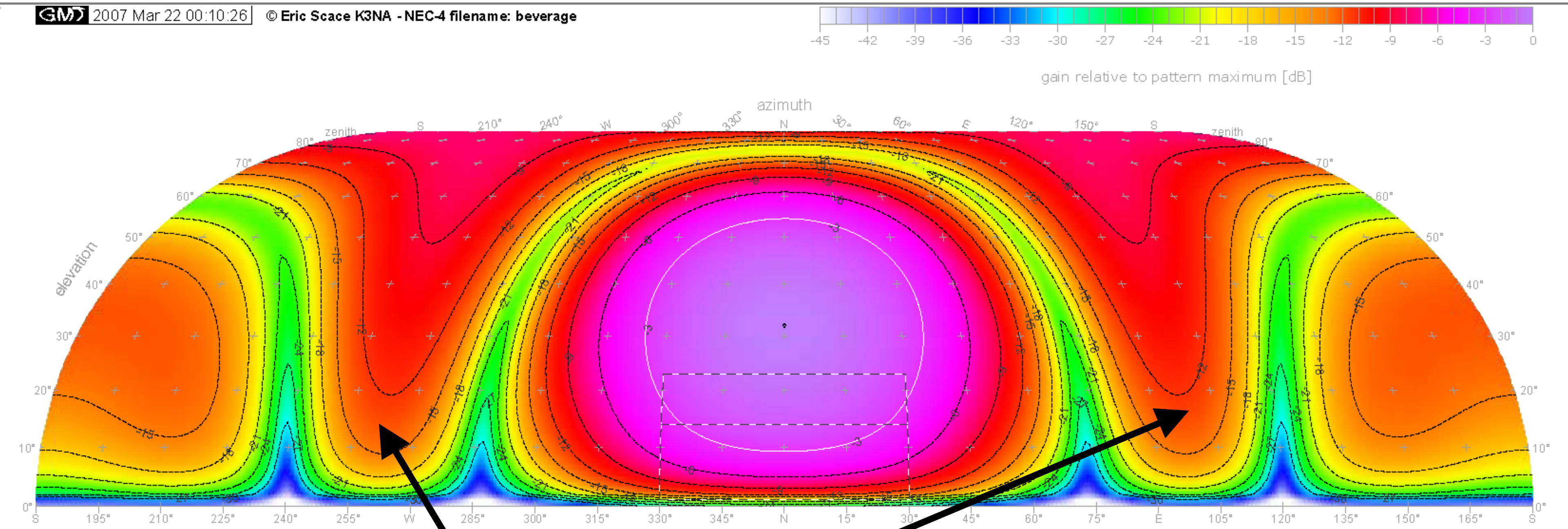
Existing alternatives:
Beverage antenna: NEC4 – average earth



1825 kHz pattern:

- Main beam

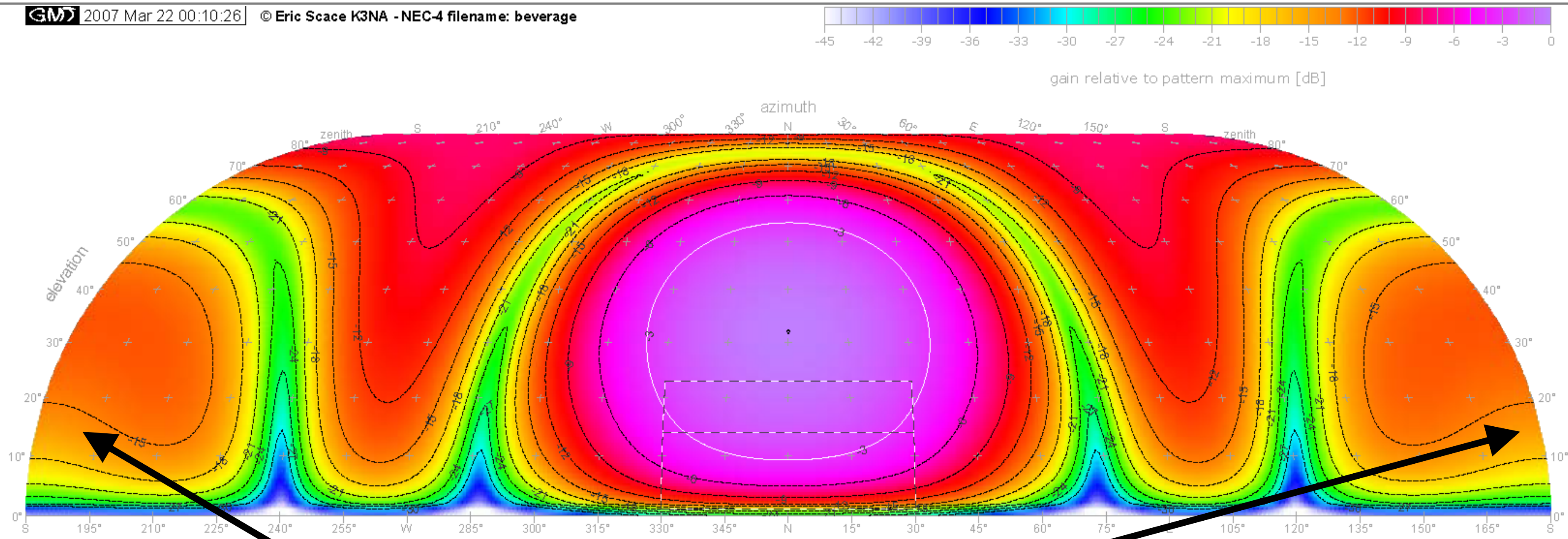
Existing alternatives:
Beverage antenna: NEC4 – average earth



1825 kHz:

- 2 side lobes
  -12 to -15 dB down

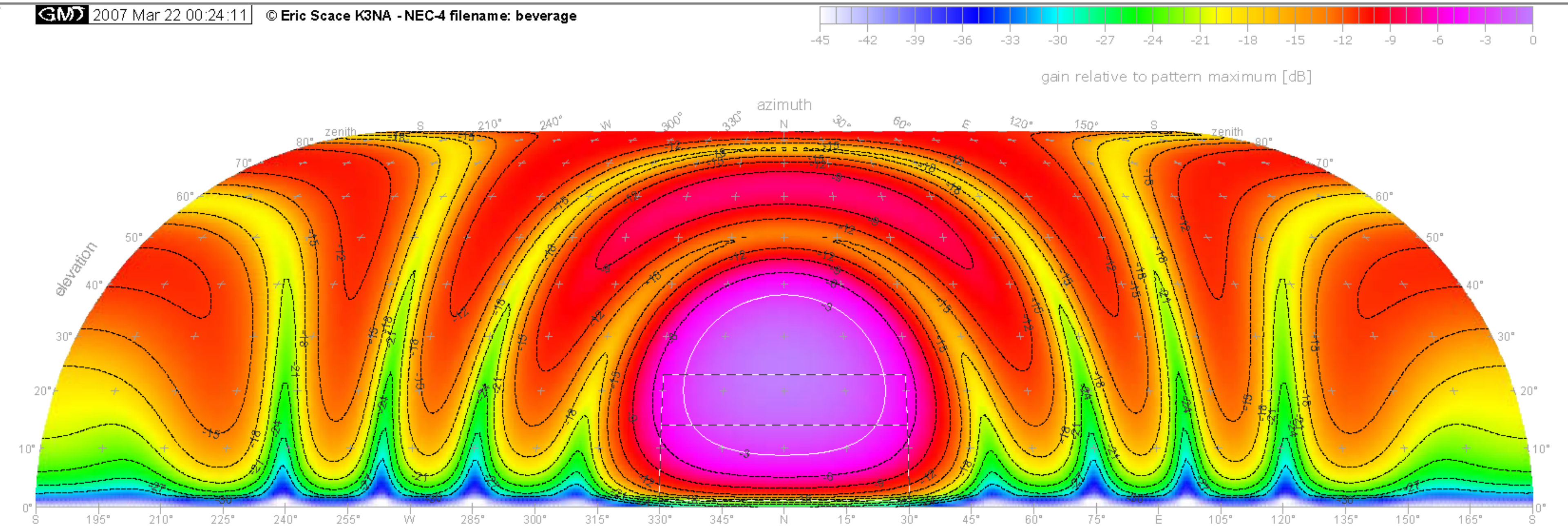
Existing alternatives:
Beverage antenna: NEC4 – average earth



1825 kHz:

- rear lobe
  -15 to -18 dB down

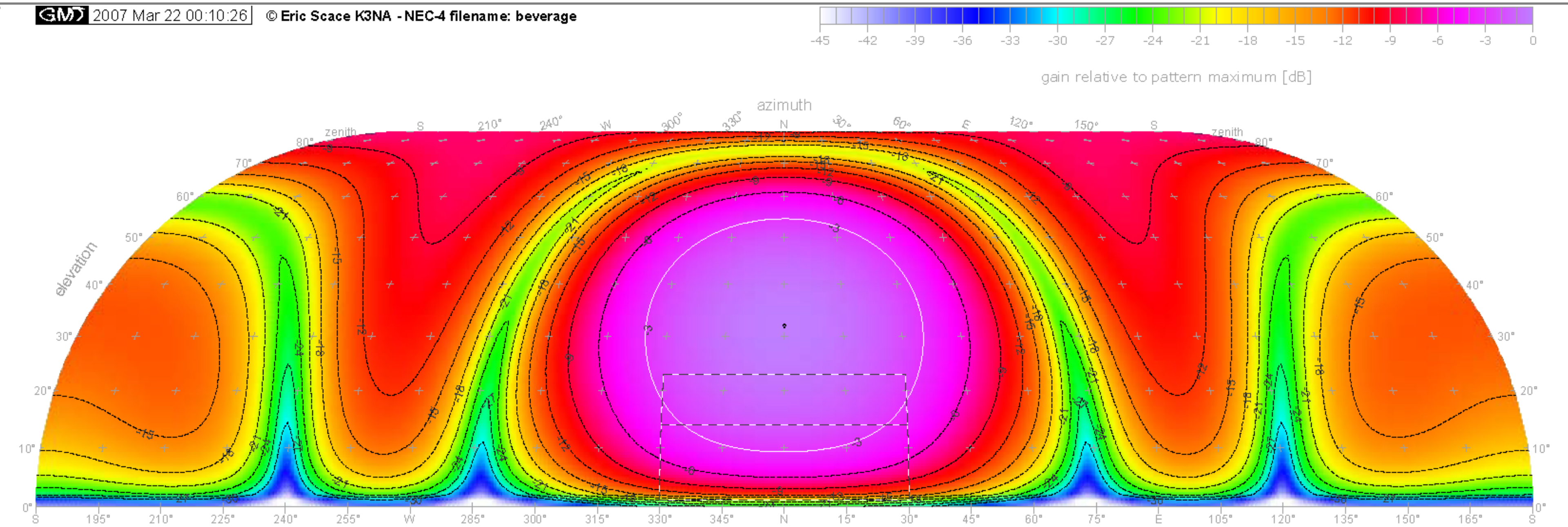
Existing alternatives:
Beverage antenna: NEC4 – average earth



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:

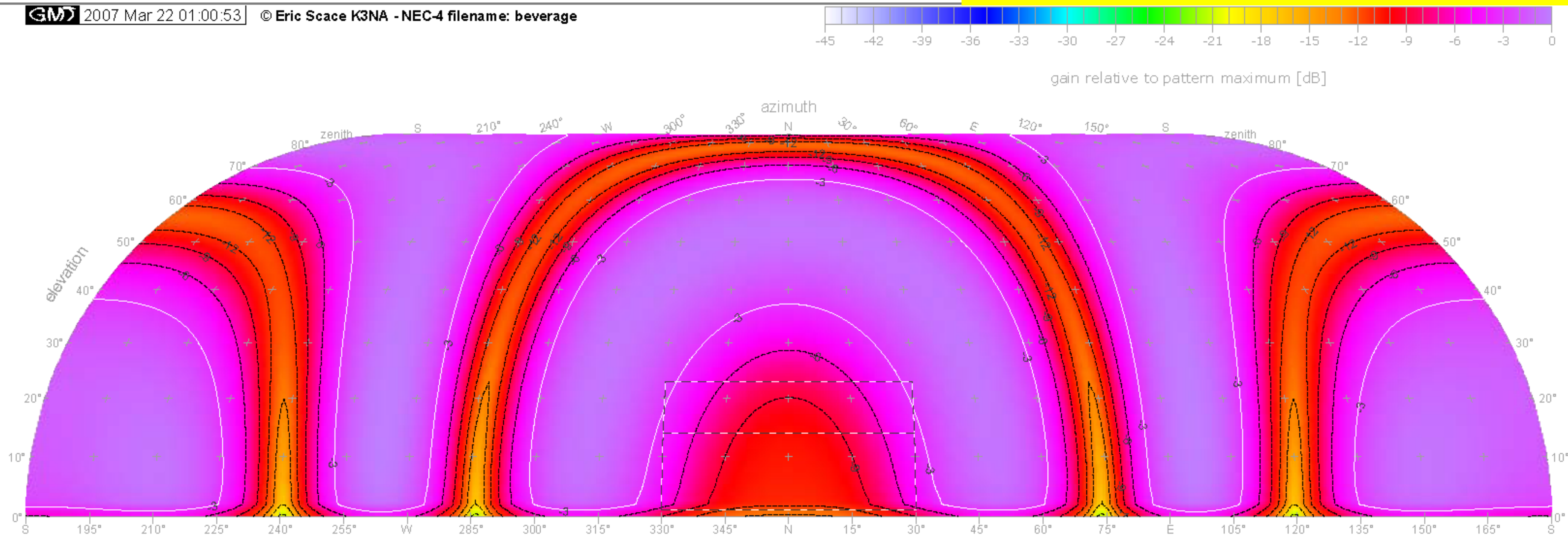
  40% sky below -15 dB of peak

  3% below -30 dB of peak

- RDF* = 8.4 dB

$$* \frac{\text{fwd peak gain}}{\text{avg gain}}$$

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

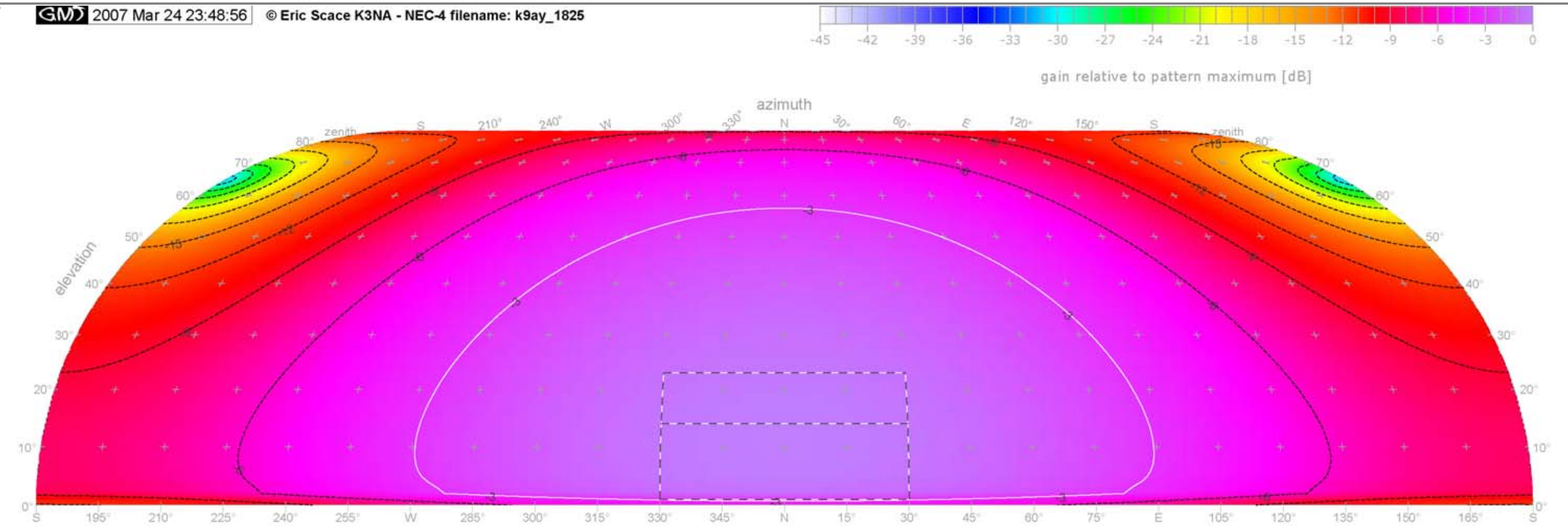
Existing alternatives:
Beverage antenna

- Beverages do *<u>not</u>* work over high conductive earth.
- Beverages work fine *<u>next to</u>* salt water.

Existing alternatives

- ~~Beverage antenna~~
- K9AY loop

Existing alternatives:
K9AY loop



1825 kHz numbers

- Gain: -23.4 dBi *requires pre-amp*
- Rejection: *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

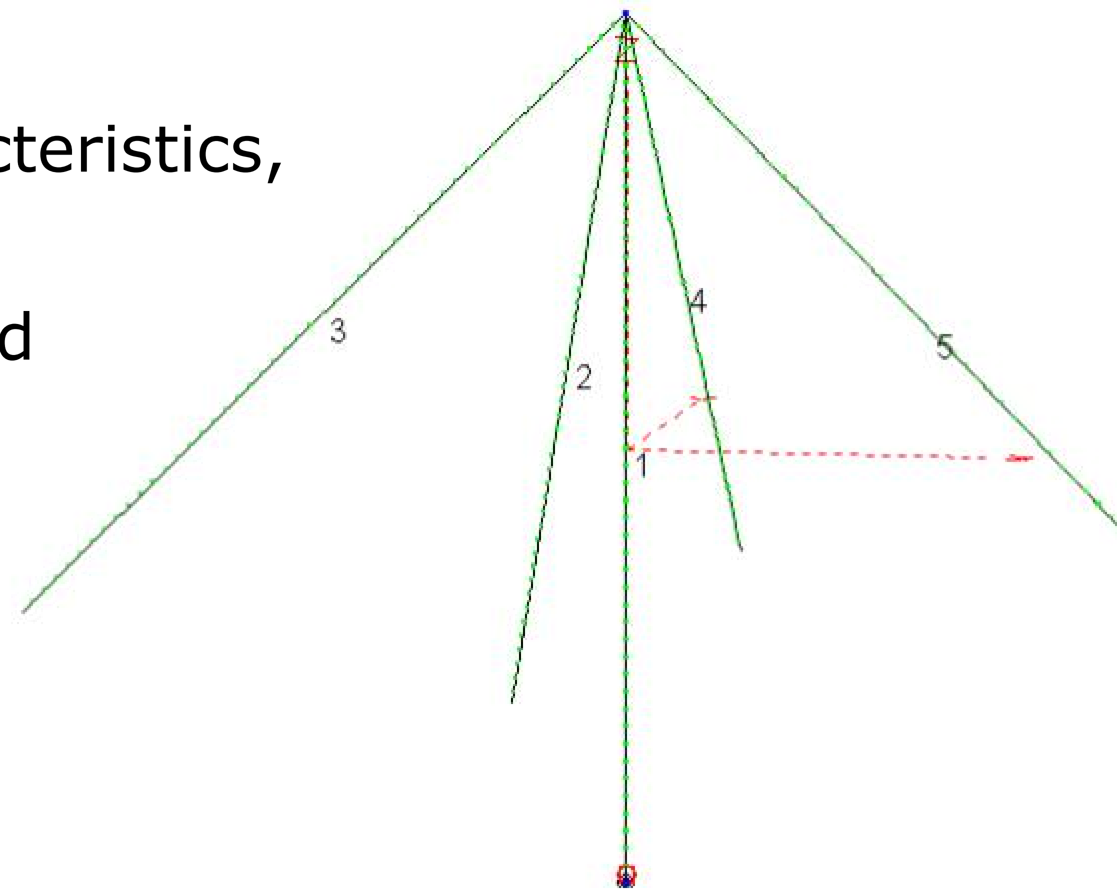
W8JI approach:

- Low-Q, lossy (swamped) elements:
  - o Wide bandwidth.
  - o Eliminates mutual coupling between elements.
  - o 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

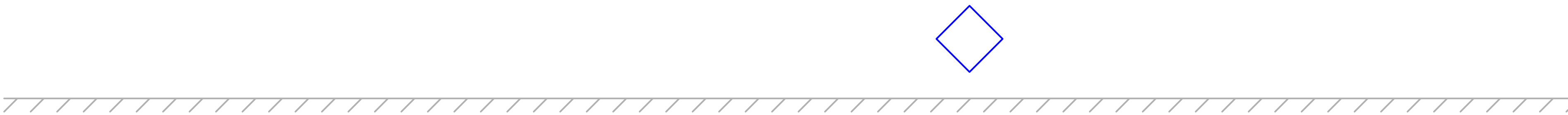
160m gain: -17.4 dBi

Existing alternatives

- ~~Beverage antenna~~
- ~~K9AY loop~~
- ~~Short vertical array~~

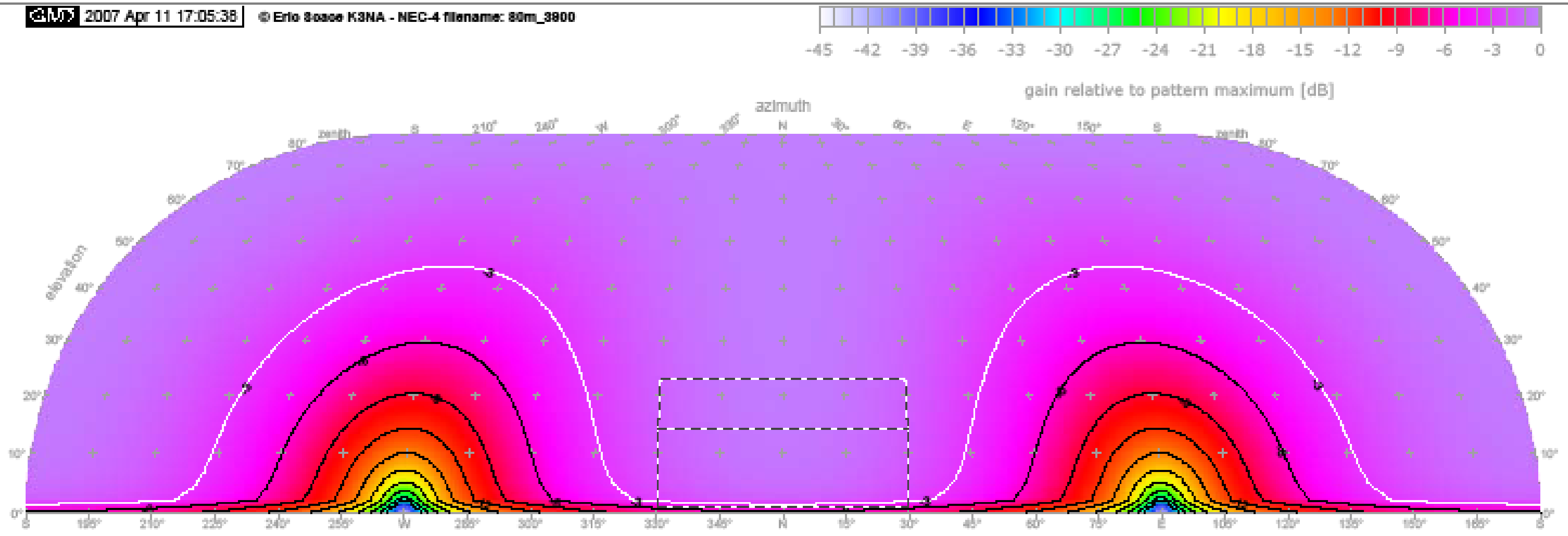
What now?

New approach:
K3NA loop array



- Loop element:
  - o Insensitive to earth characteristics.
  - o 0.1λ circumference: nulls off sides

New approach:
K3NA loop array



Sharp side nulls at low elevation angles

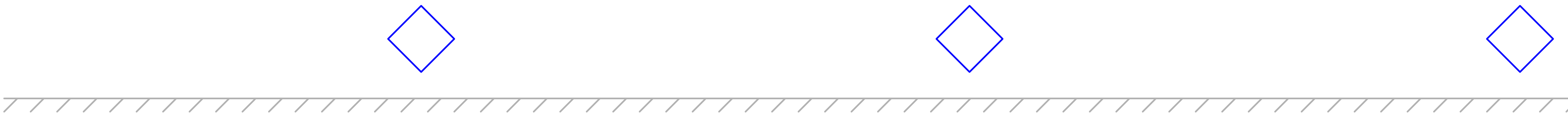
- Gain: -9.5 dBi before matching
- Rejection:

  2% sky below -15 dB of peak

  0% below -30 dB of peak

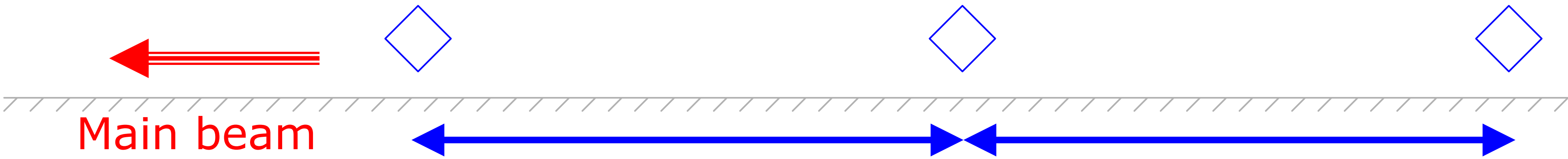
- RDF = 2.0 dB

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

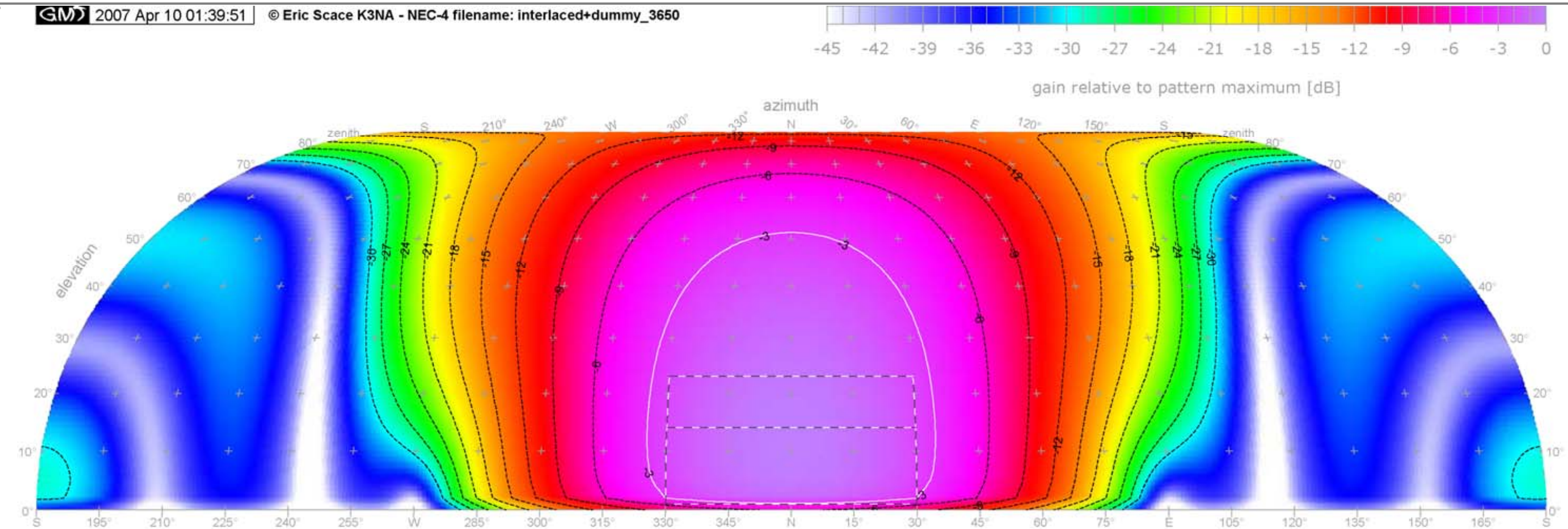


Spacing = 70° at center freq:

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	

	front	middle	rear
Power:	0.54	2.00	1.00
Delay:	270°	135°	0°

New approach:
K3NA loop array



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

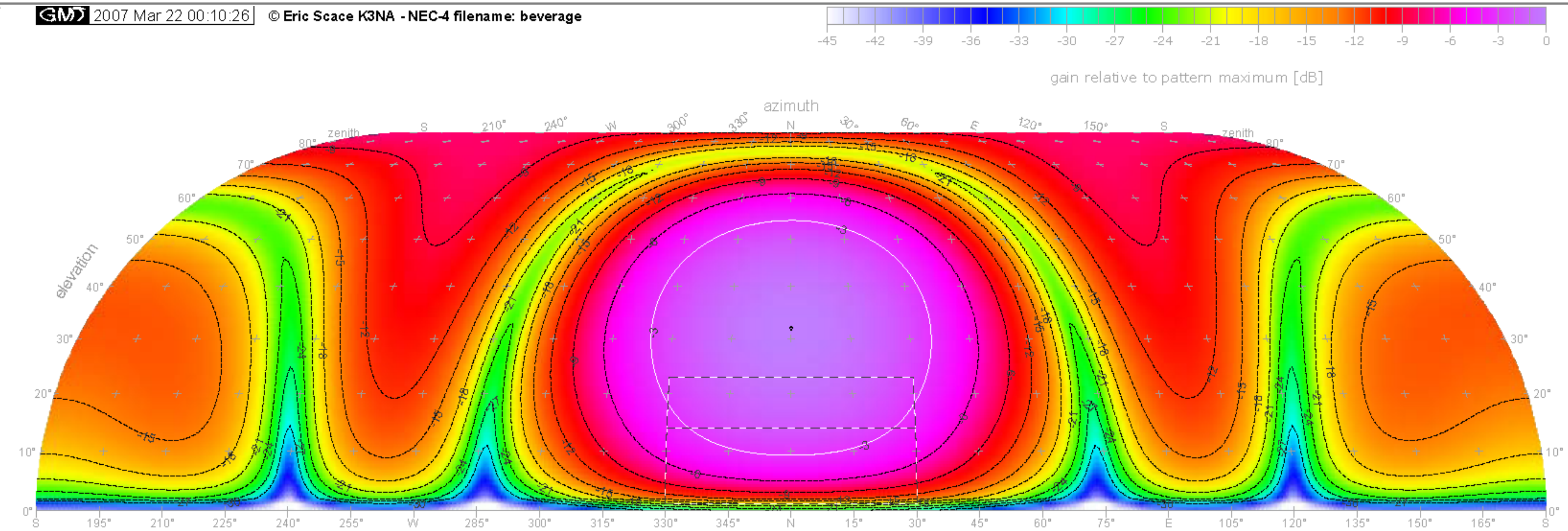
- Gain: -9.7 dBi
- Rejection:

  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

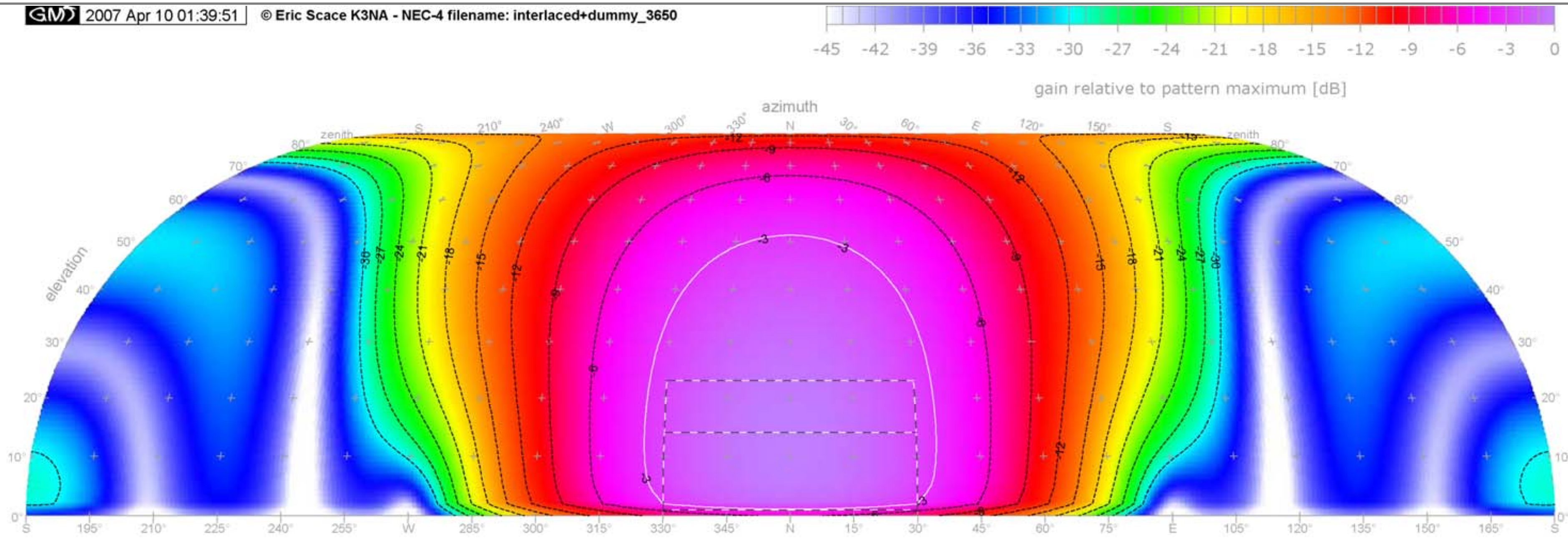
- Gain: -9.8 dBi
- Rejection:

  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

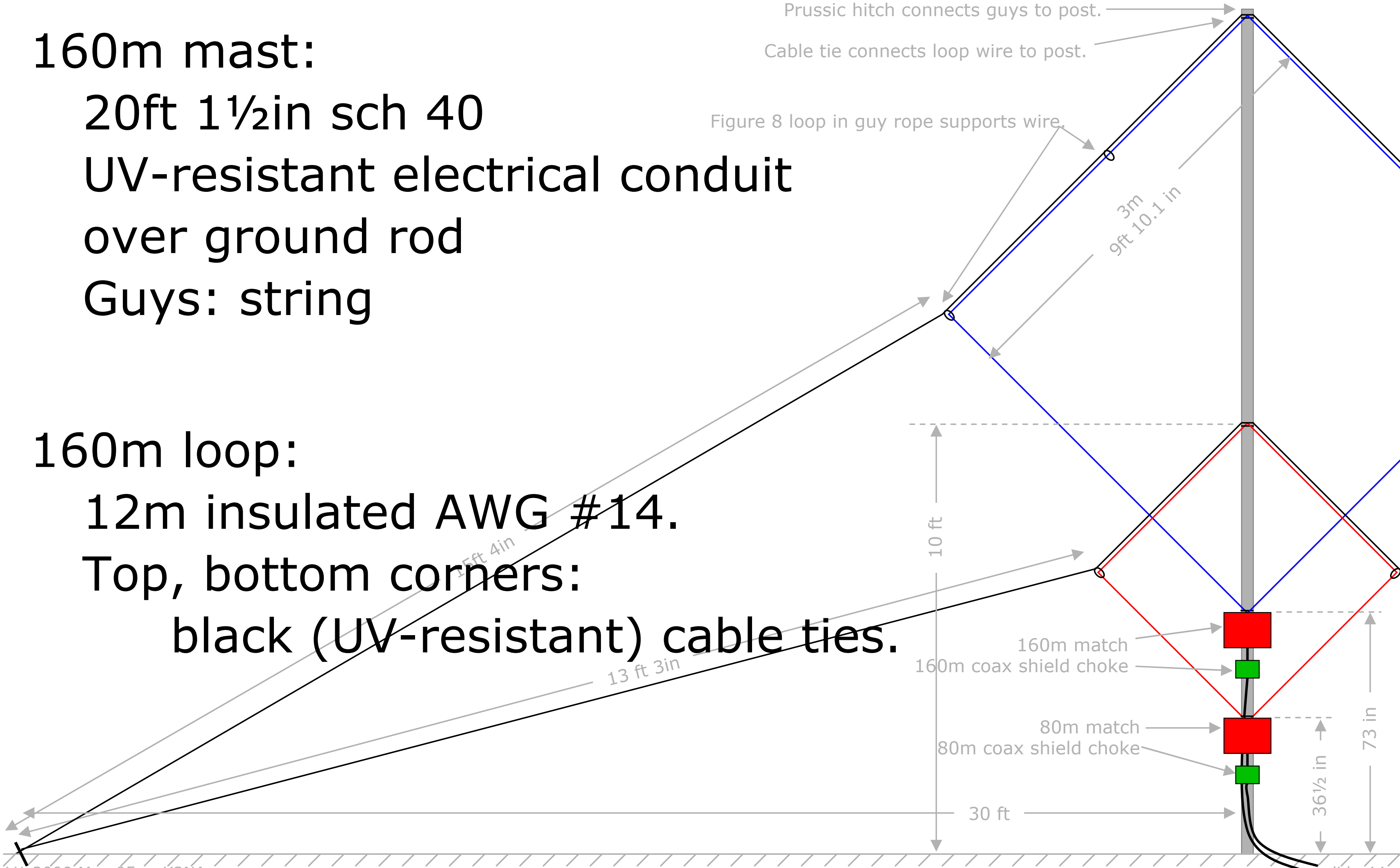
Implementation: Loop

160m mast:

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

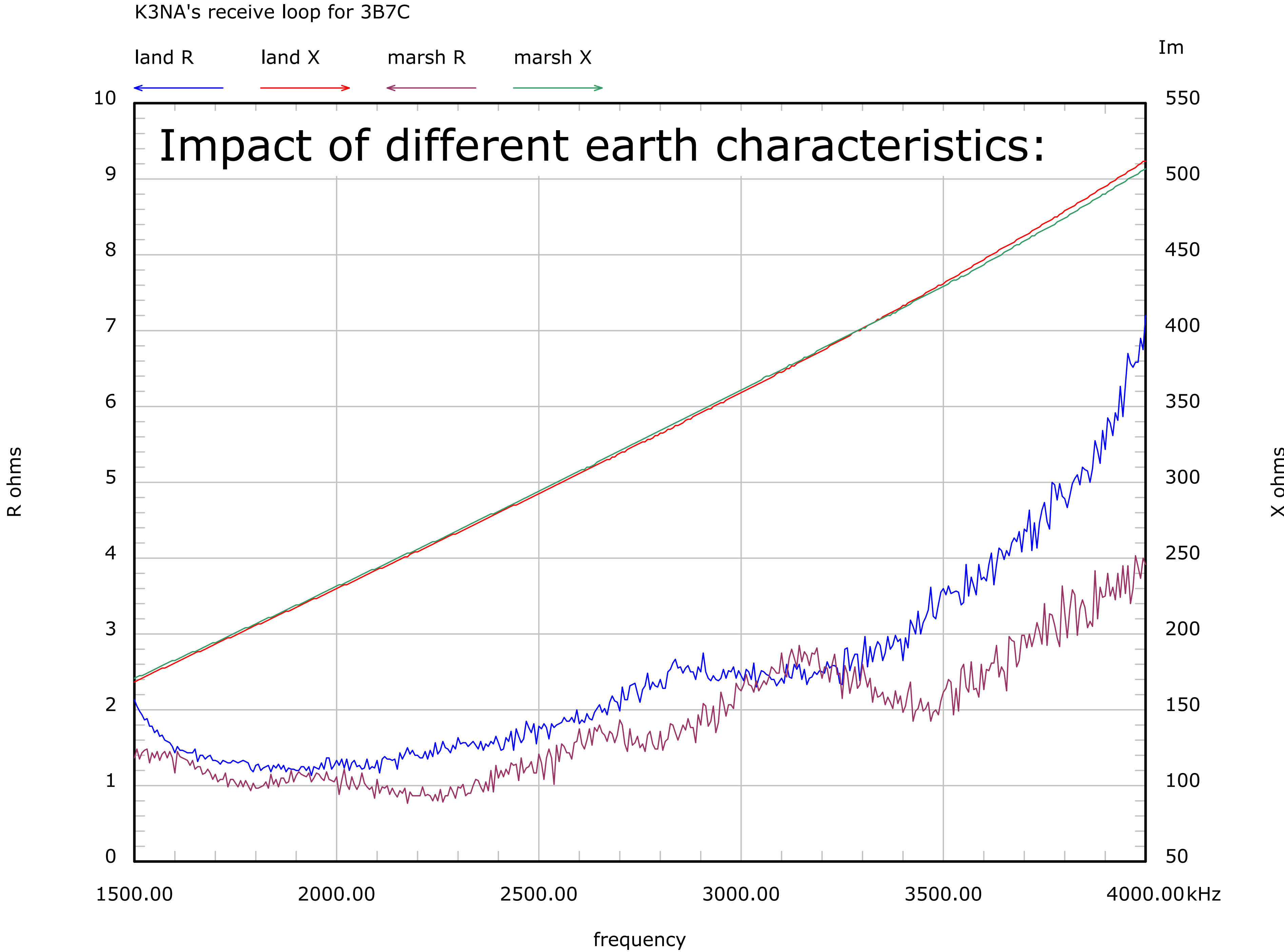
160m loop:

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



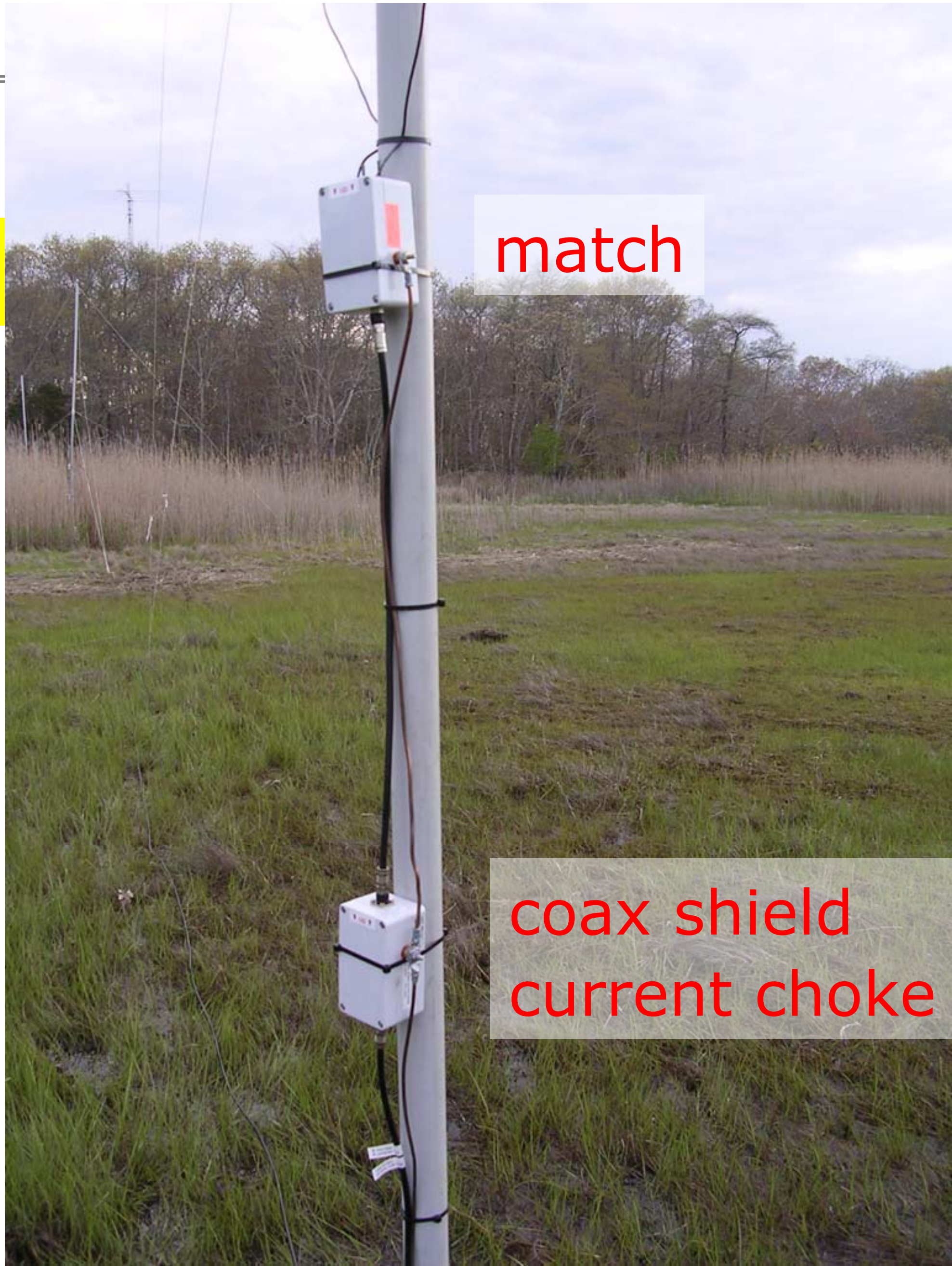
Implementation: Loop

Lab in the salt marsh:


K3NA's receive loop for 3B7C
land R
land X
marsh R
marsh X
Im
Impact of different earth characteristics:
R ohms
X ohms
10
9
8
7
6
5
4
3
2
1
0
550
500
450
400
350
300
250
200
150
100
50
1500.00
2000.00
2500.00
3000.00
3500.00
4000.00
kHz
frequency

Implementation

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



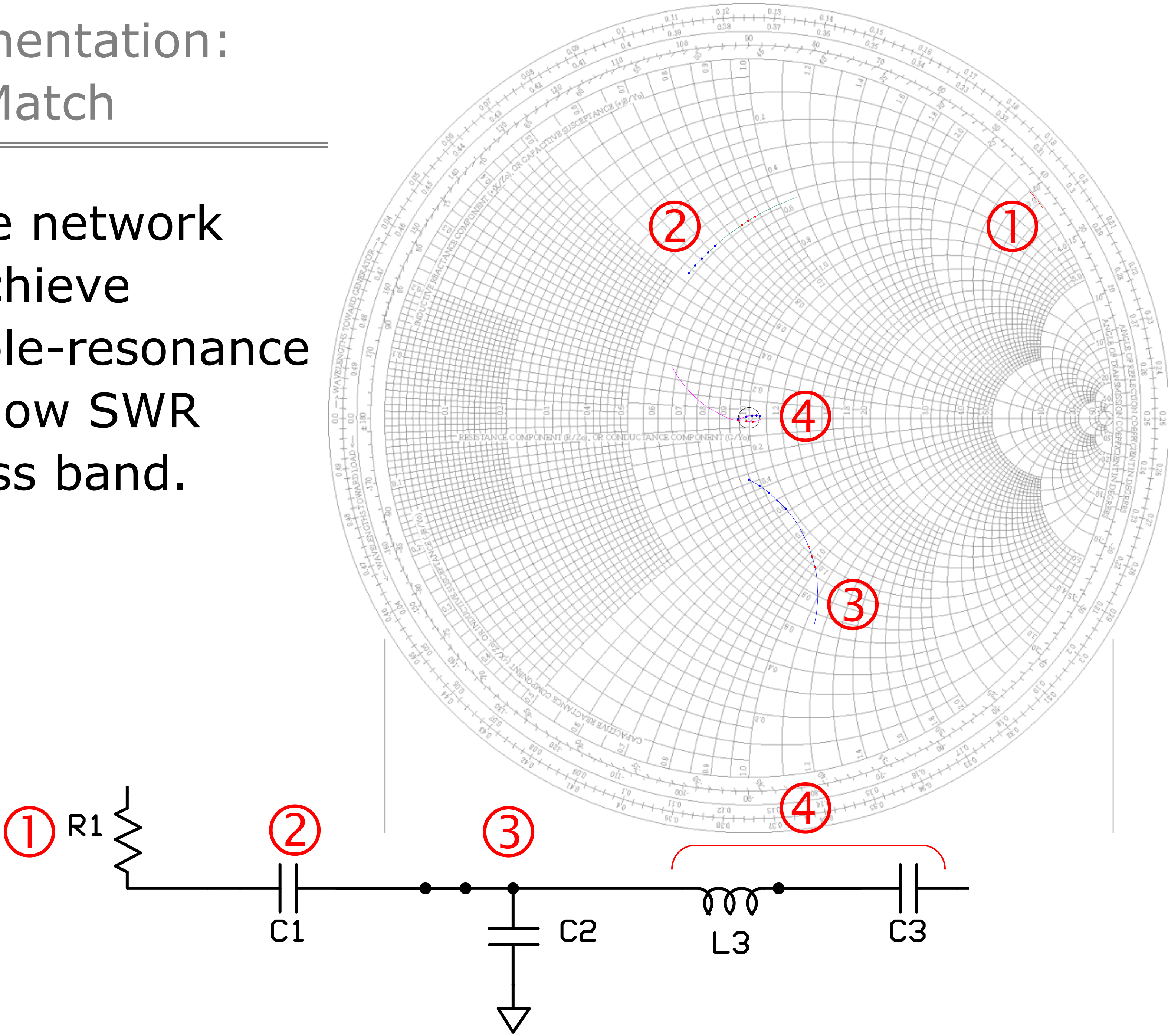
Implementation: Match

Match network goals:

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

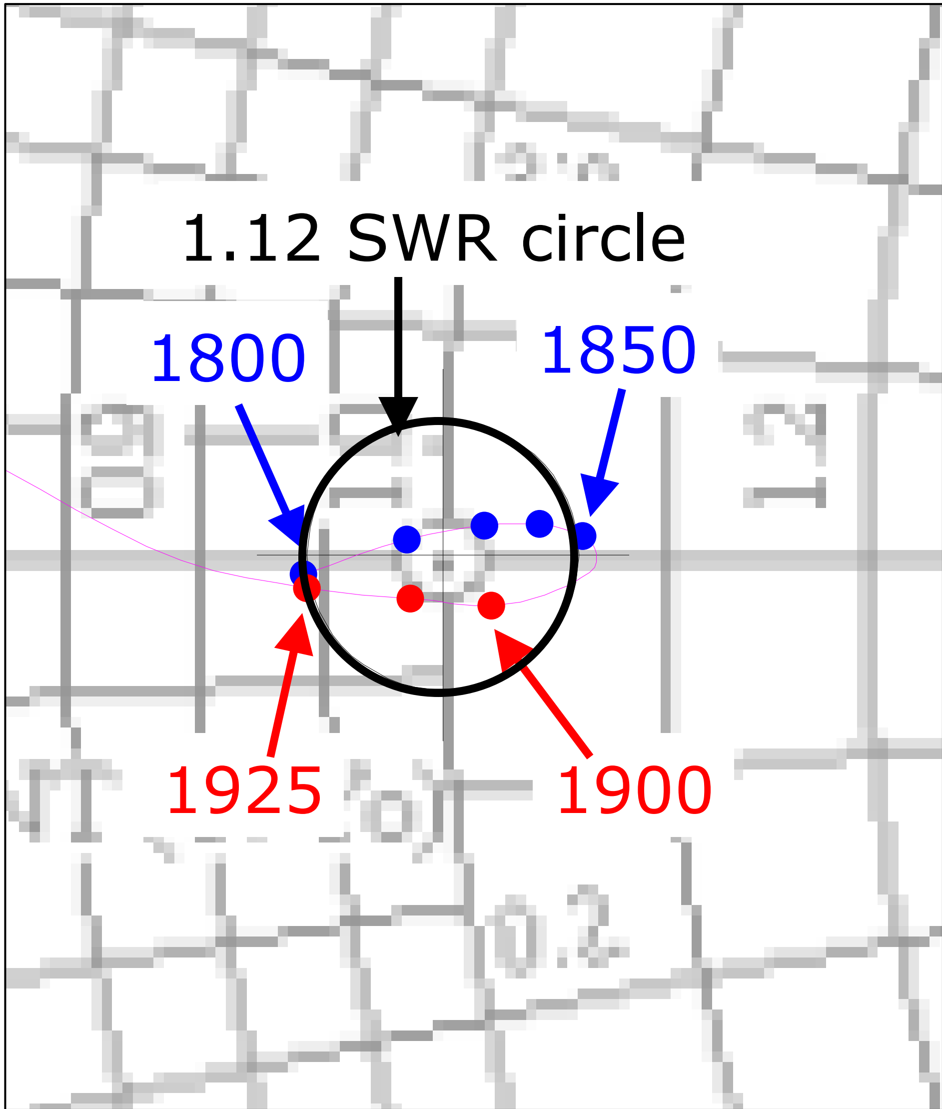
Implementation: Match

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

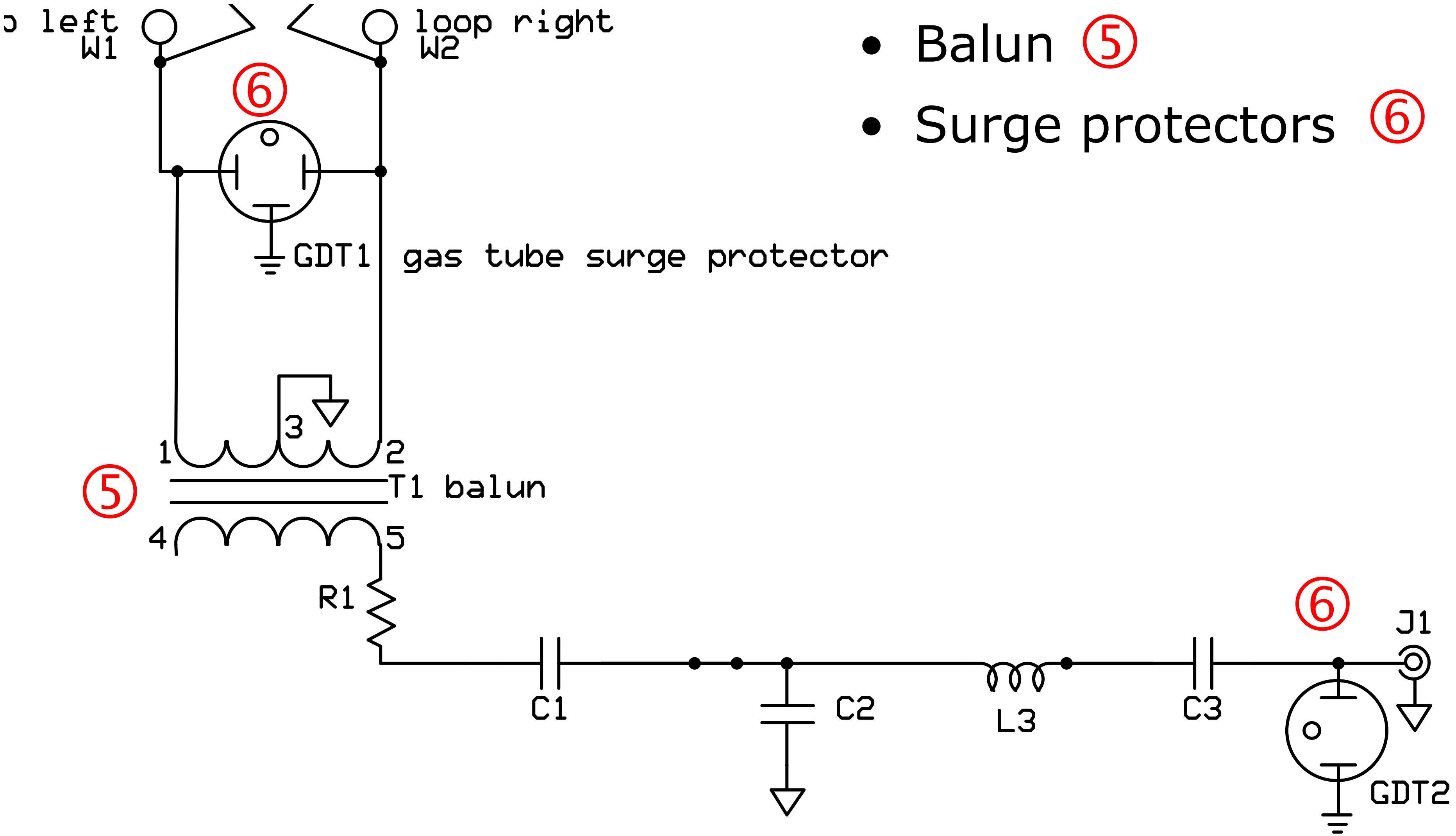


Implementation:
Match

- Theoretical match



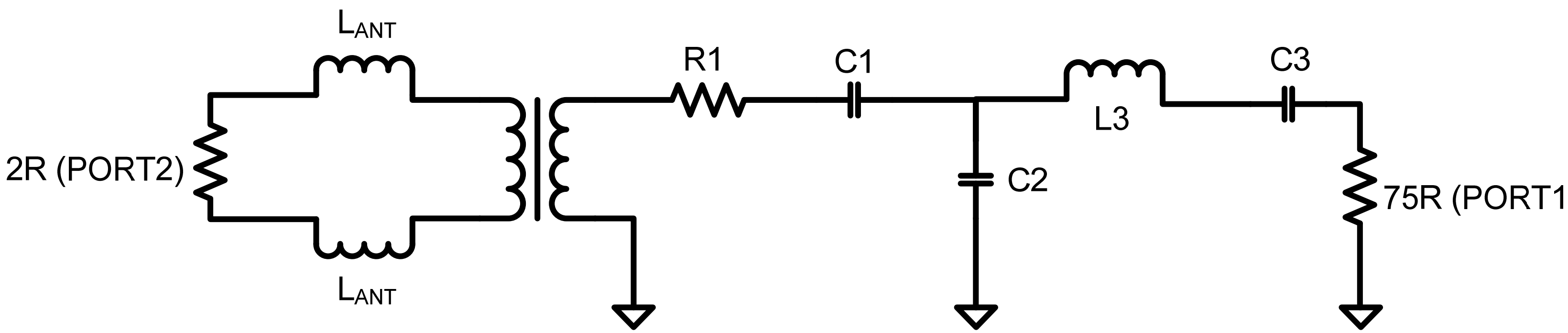
Implementation:
Match



Add:

- Balun ⑤
- Surge protectors ⑥

Implementation:
Match: K2TJ monte carlo analysis

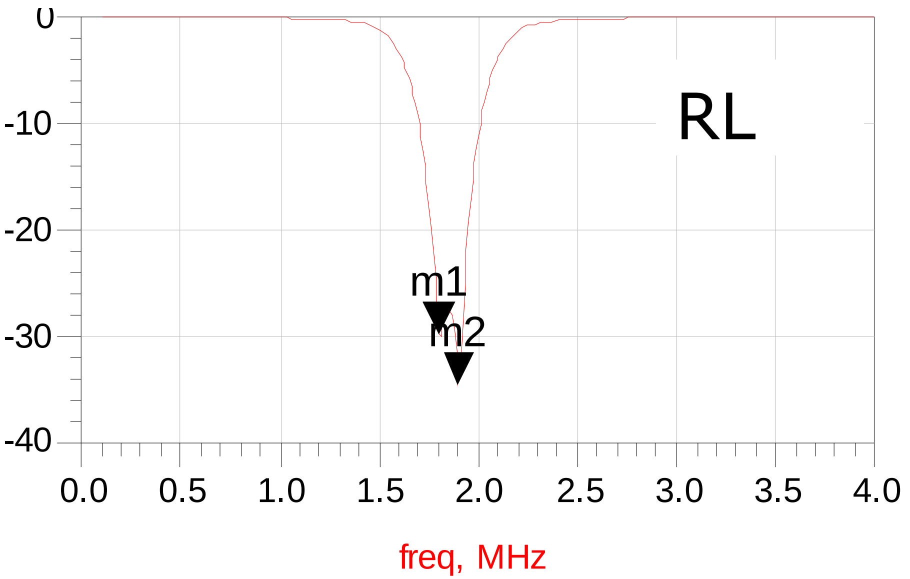


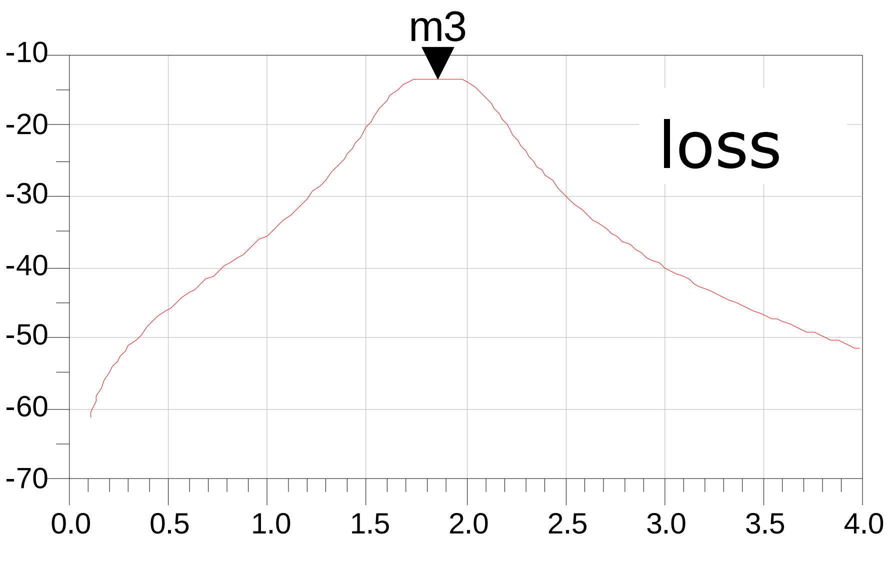
- Above model used for simulation
- Assumed R = 2Ω for 160m and 80m
- Lant = 9.3 uH (160m) Lant = 4.1 uH (80m) – rough approximation
- Transformer leakage inductance will probably have a small effect – absorb into C1.

Implementation:
Match: K2TJ monte carlo analysis

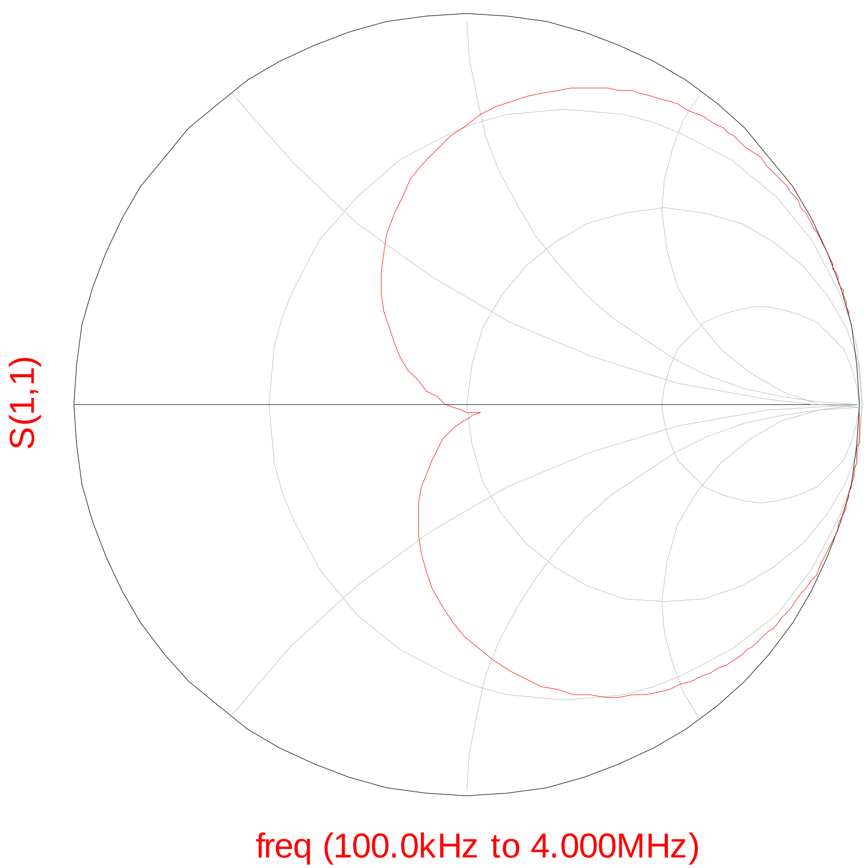
- C1, C2, C3, L3 used as random variables.
- Simulated for tolerances of 1%, 5%, and 10%.
- R1 kept at constant tolerance of 1%.
- 30 iterations of component values within the tolerance range for each sweep.

Implementation:
Match: K2TJ monte carlo analysis

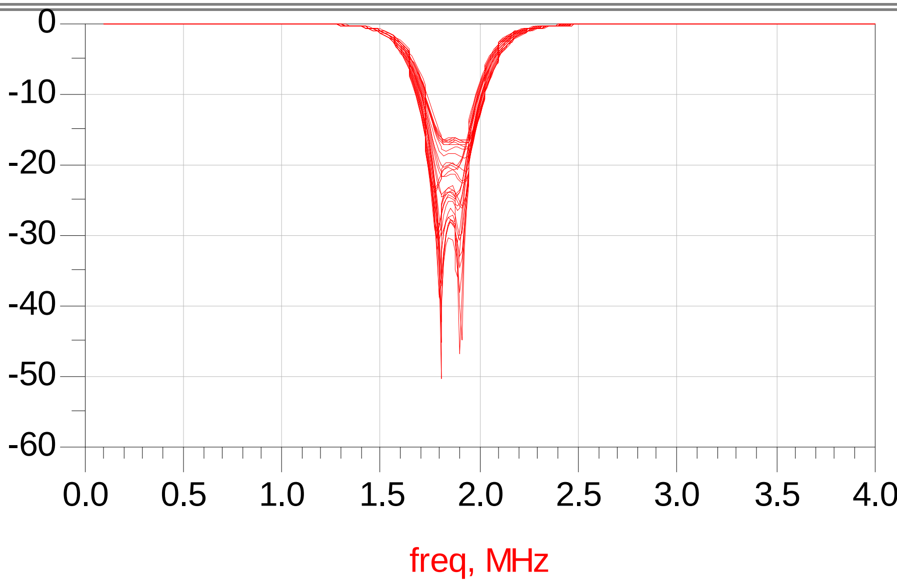




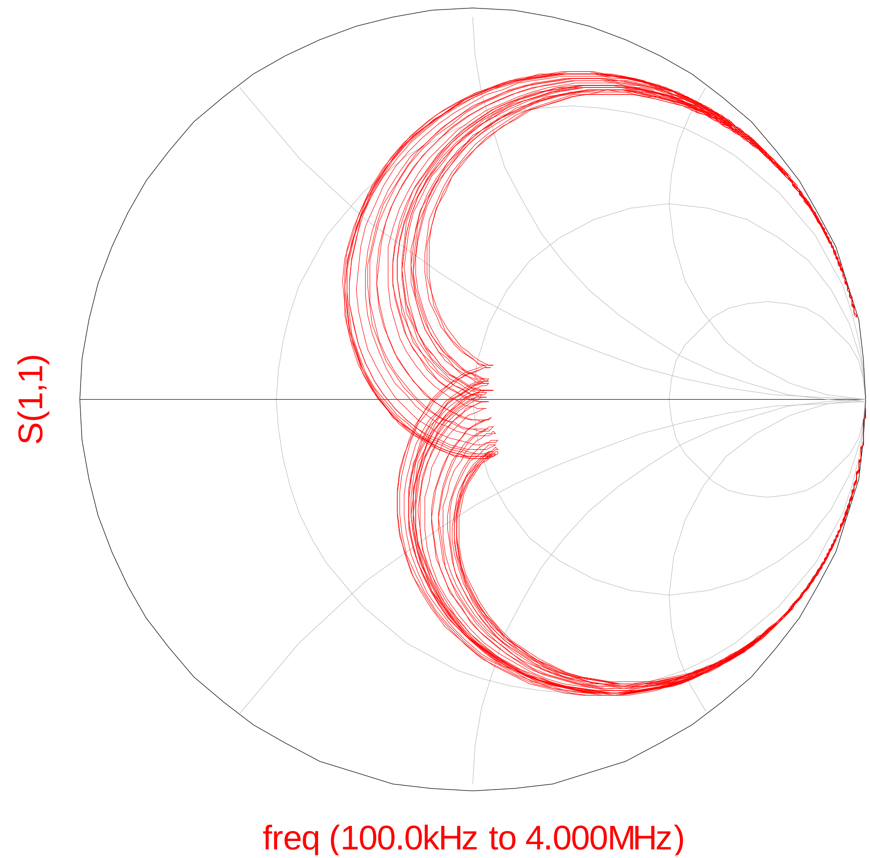
As designed:

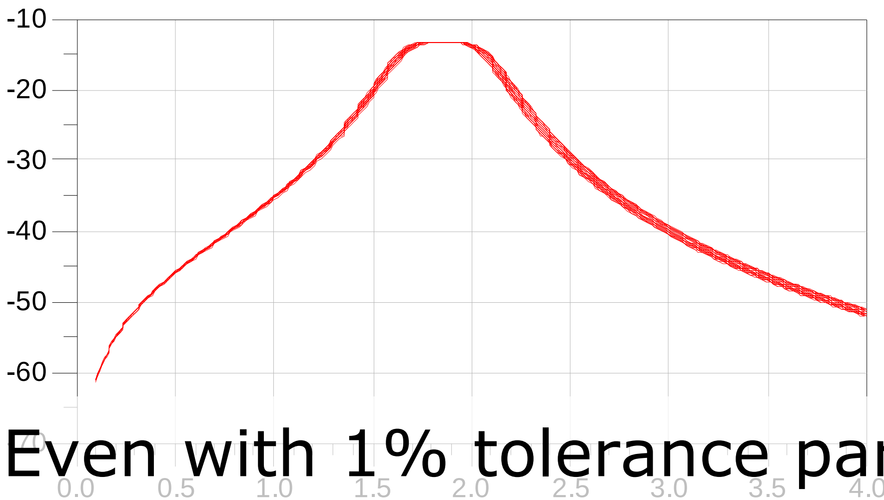


Implementation:
Match: K2TJ monte carlo analysis



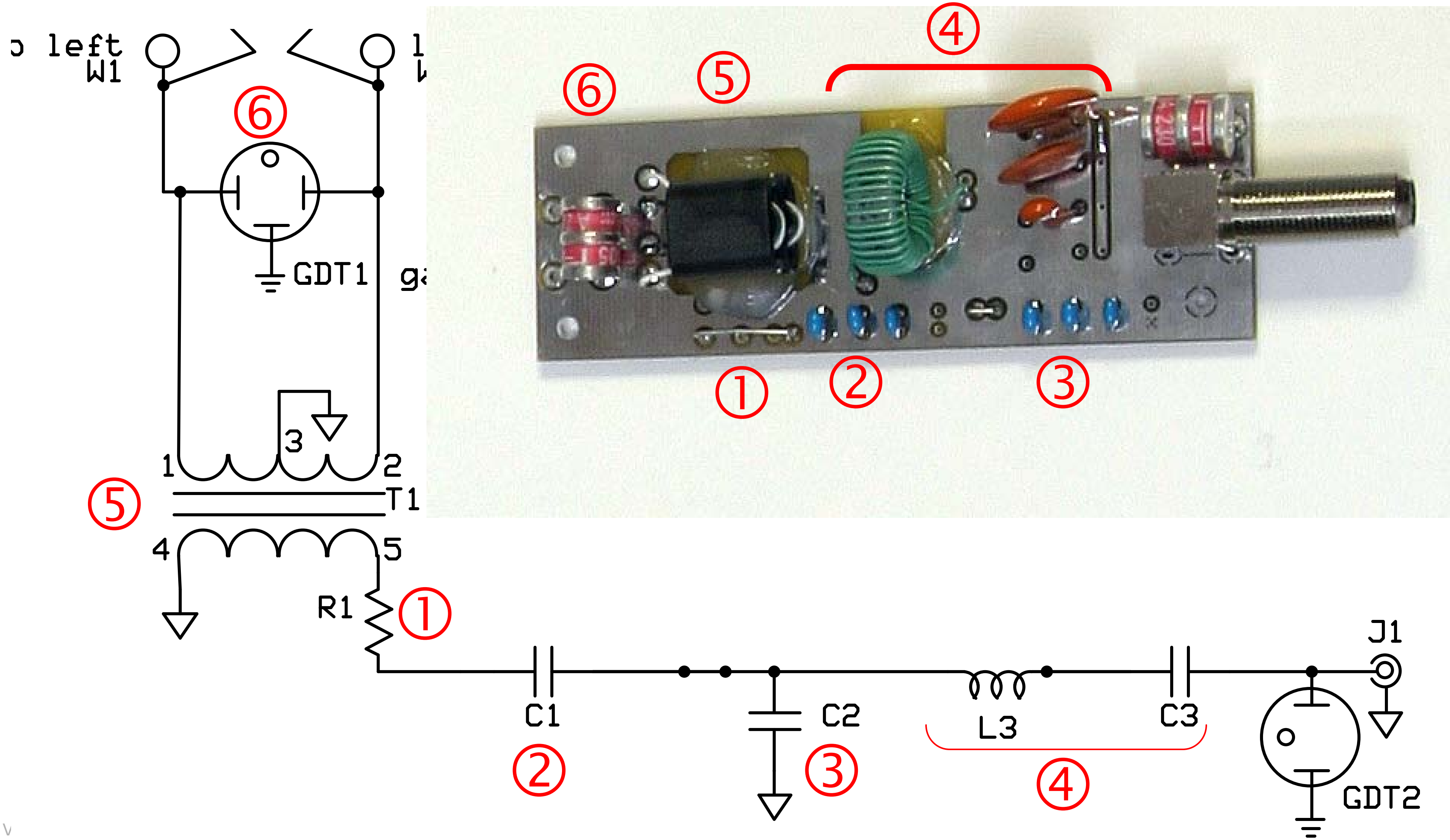
C: 1%   L: 5%





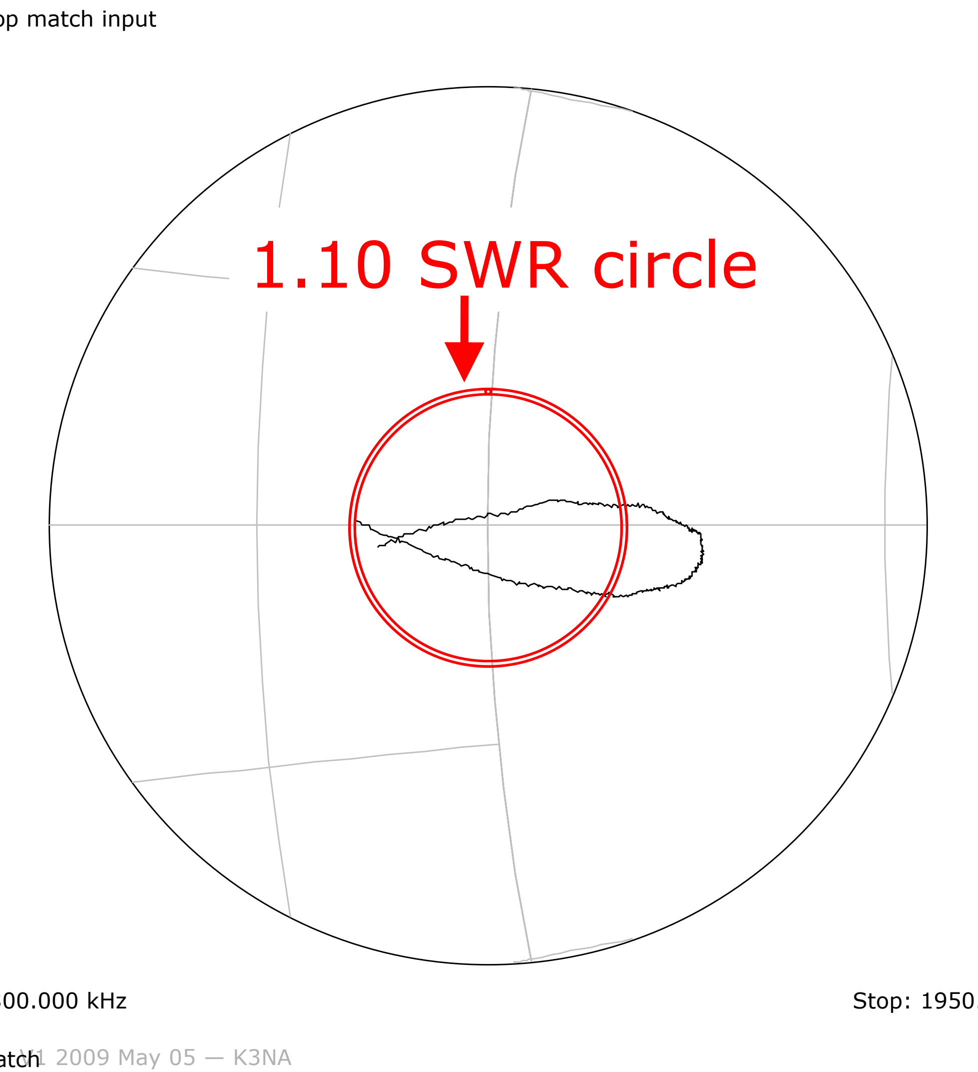
Even with 1% tolerance parts, alignment required to bring matching network to near-identical performance.

Implementation:
Match

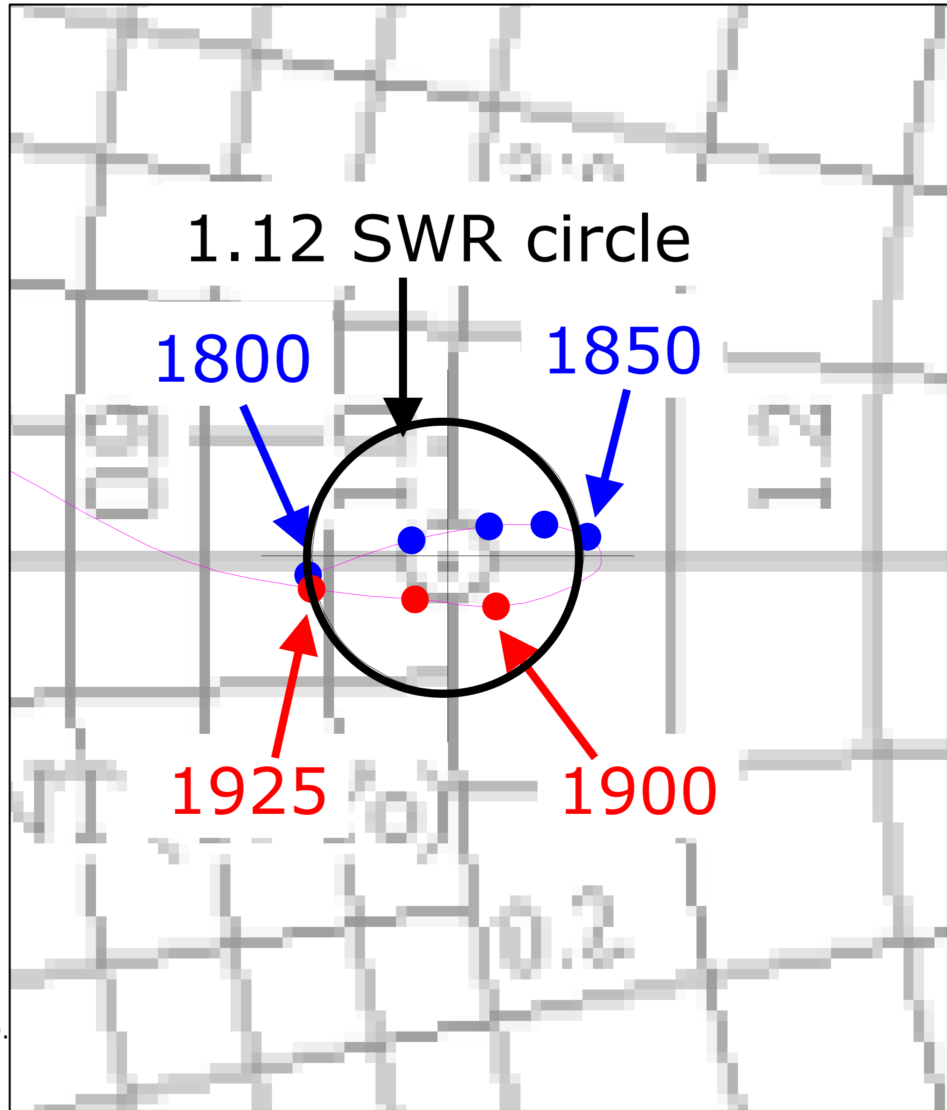


Implementation:
Match

Actual 160m match:

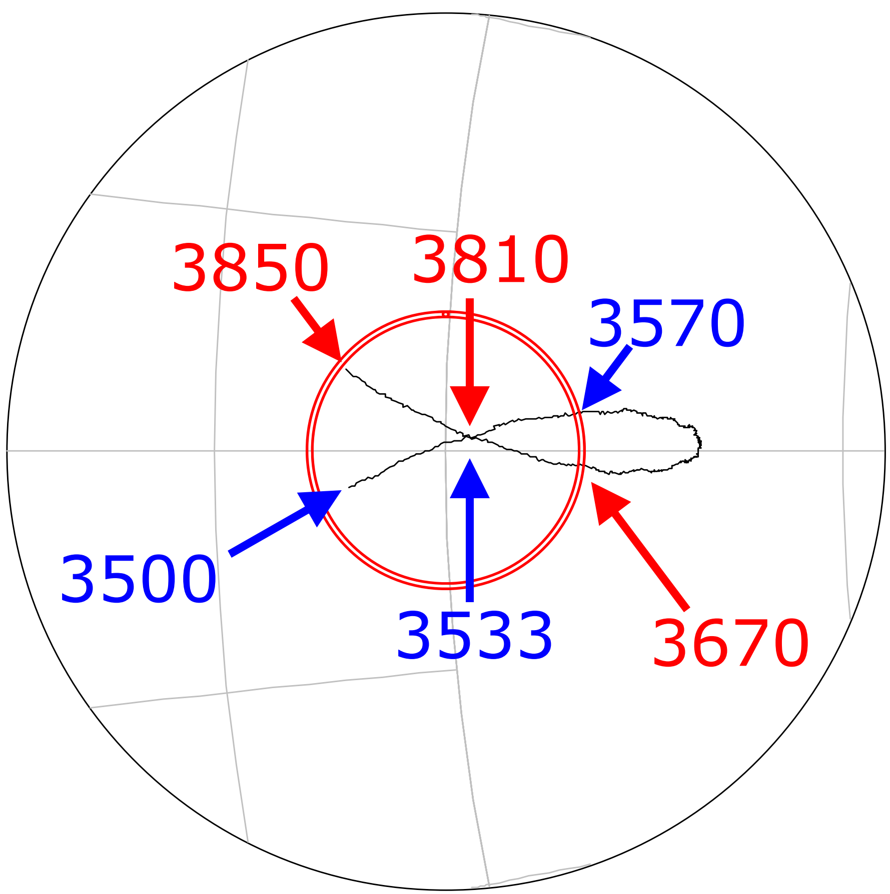


Theoretical:

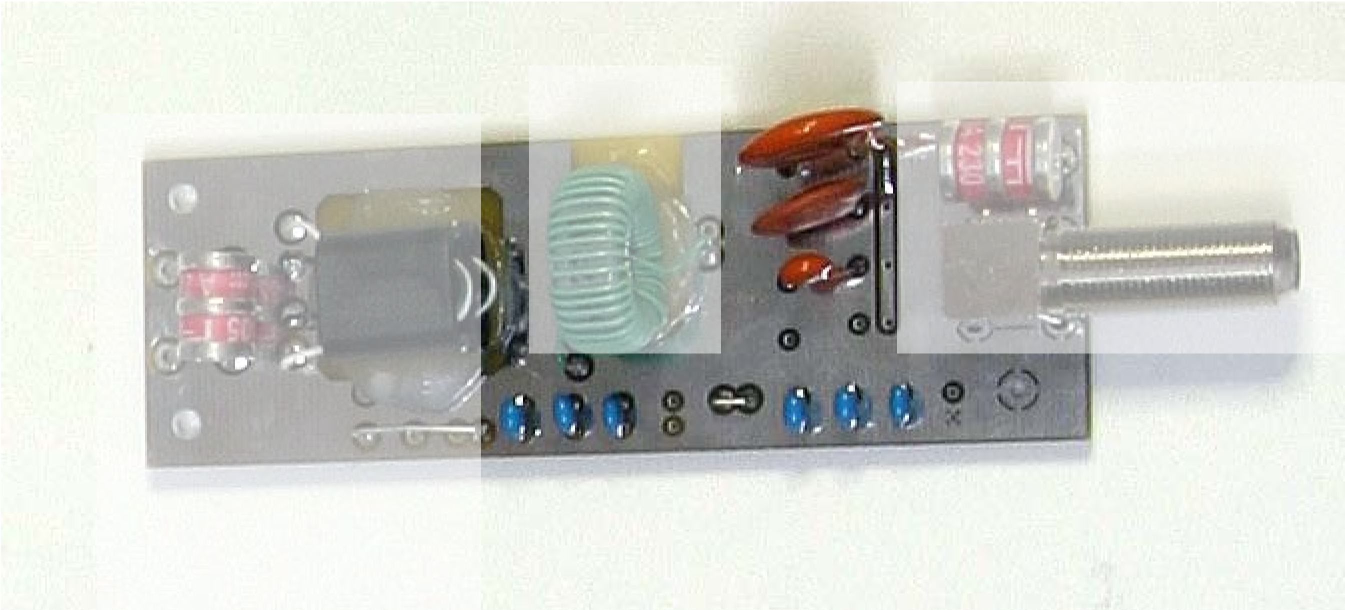


Implementation:
Match

Actual 80m match:



Implementation:
Match



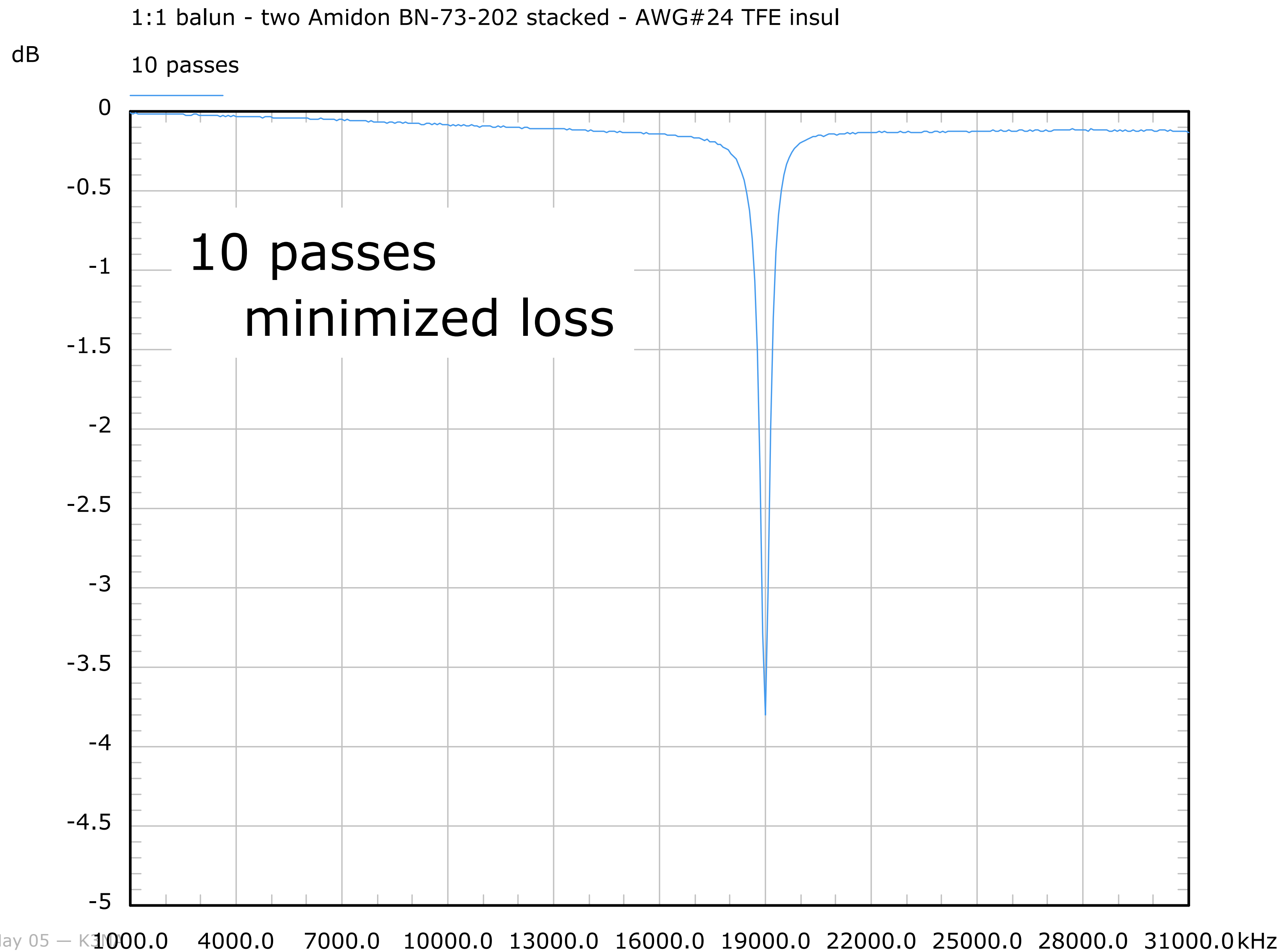
- Trimmer capacitors not temperature-stable.
- Used small parallel capacitors to trim as close as possible to identical behavior.

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_{load} is low, increasing phase error, losses. Minimize with double core stacking and special winding pattern.

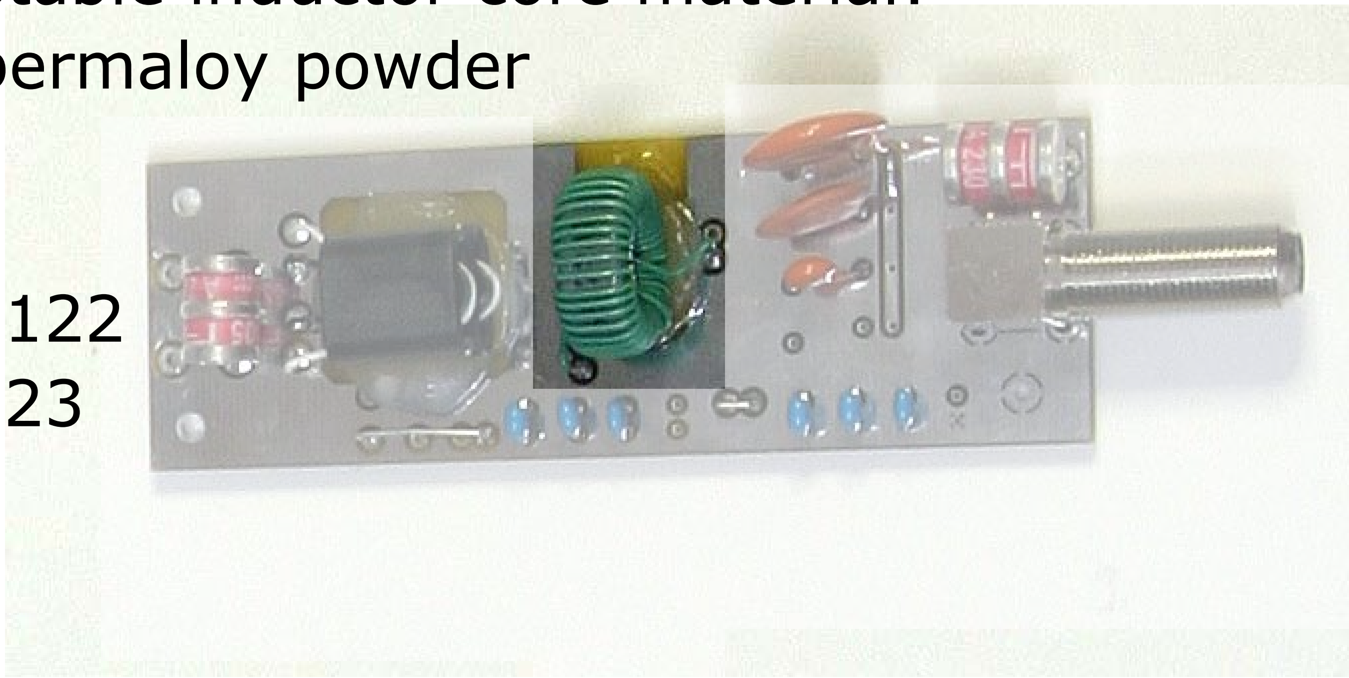
Implementation: Match



Implementation:
Match

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

Magnetics
160m C0-55122
80m C0-55123



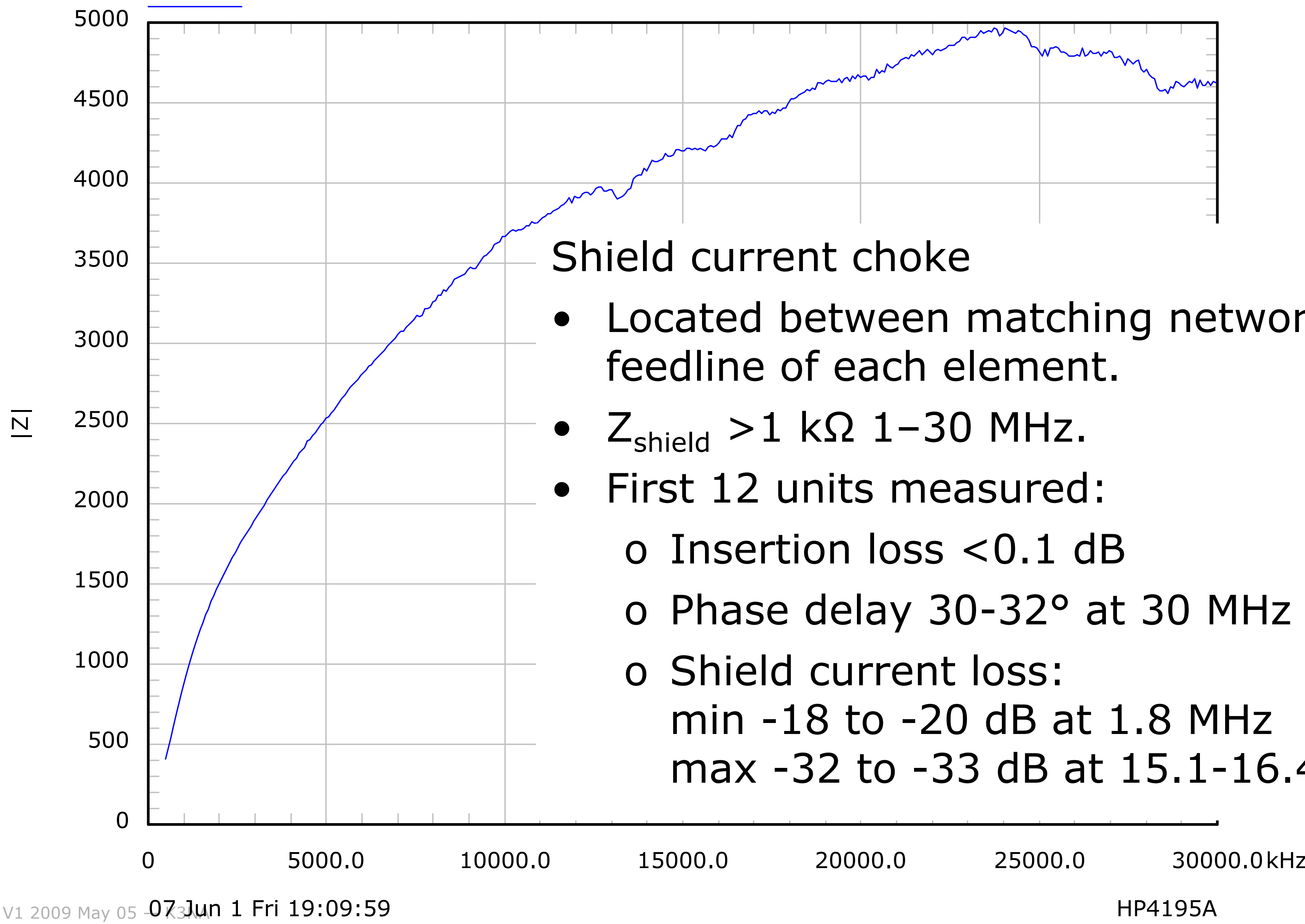
"Freezer test":
Stable match down to -15C.

Implementation:
Shield current choke

Two stages:

- FairRite 2843009902 type 43 binocular core
- 75Ω video cable
- 5 passes per stage

Implementation:
Match: shield current choke

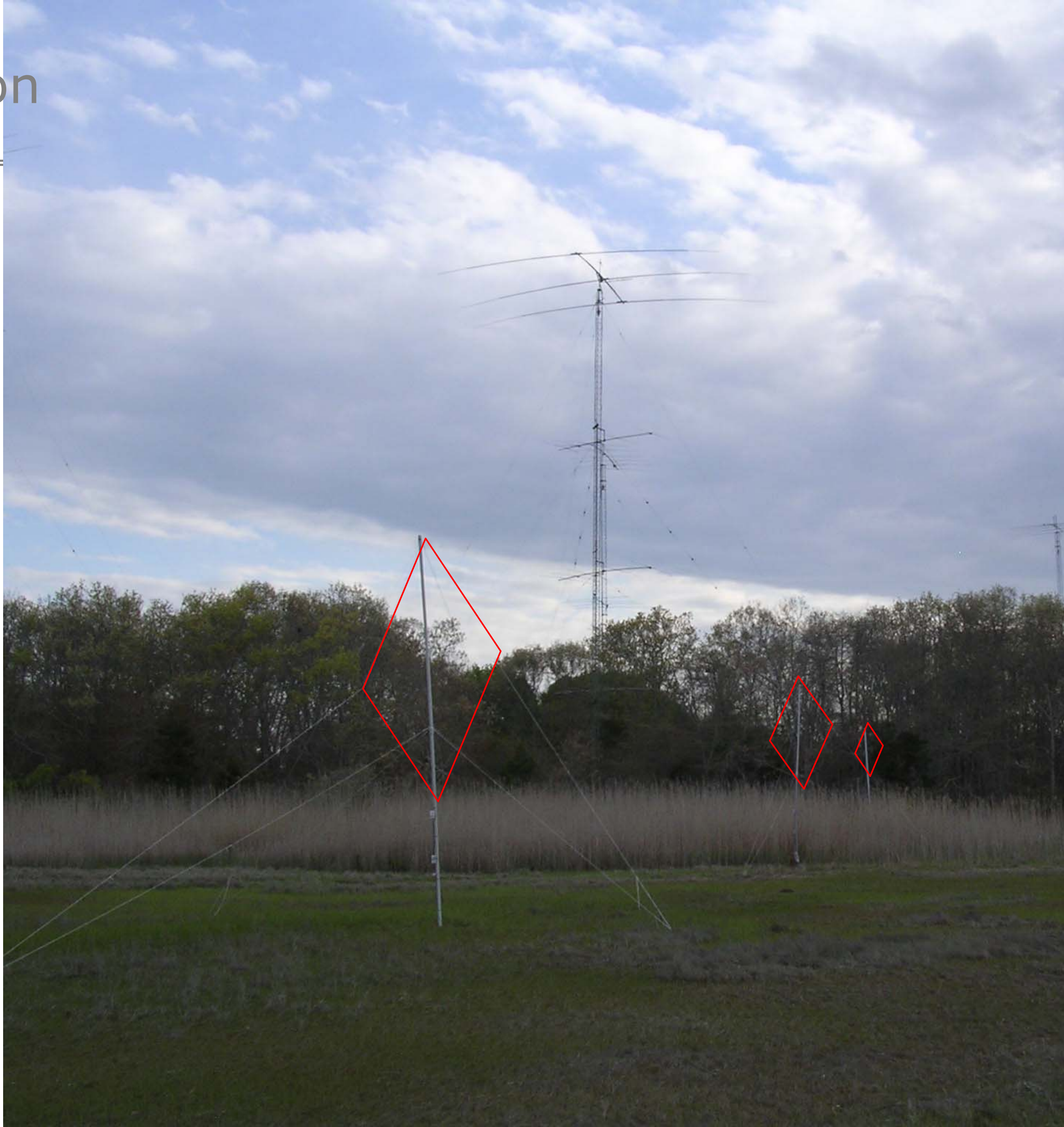


Shield current choke

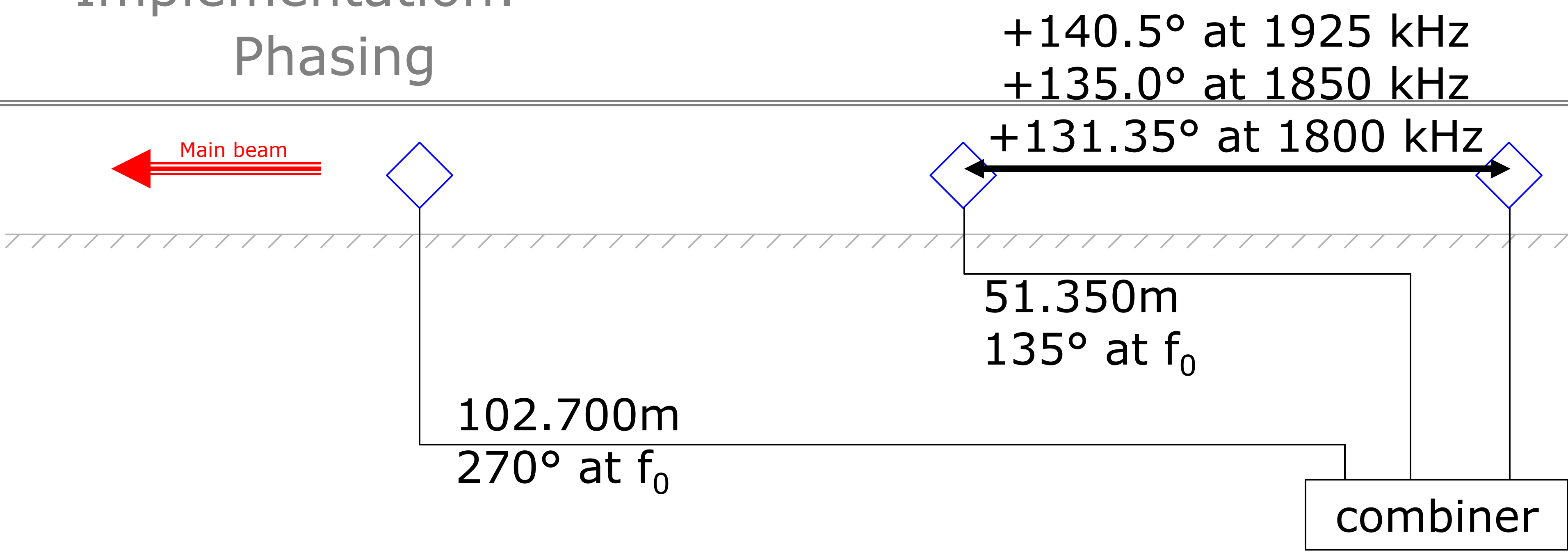
- Located between matching network and feedline of each element.
- Z_{shield} >1 kΩ 1–30 MHz.
- First 12 units measured:
  - o Insertion loss <0.1 dB
  - o Phase delay 30-32° at 30 MHz
  - o Shield current loss:
    min -18 to -20 dB at 1.8 MHz
    max -32 to -33 dB at 15.1-16.4 MHz

Implementation

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



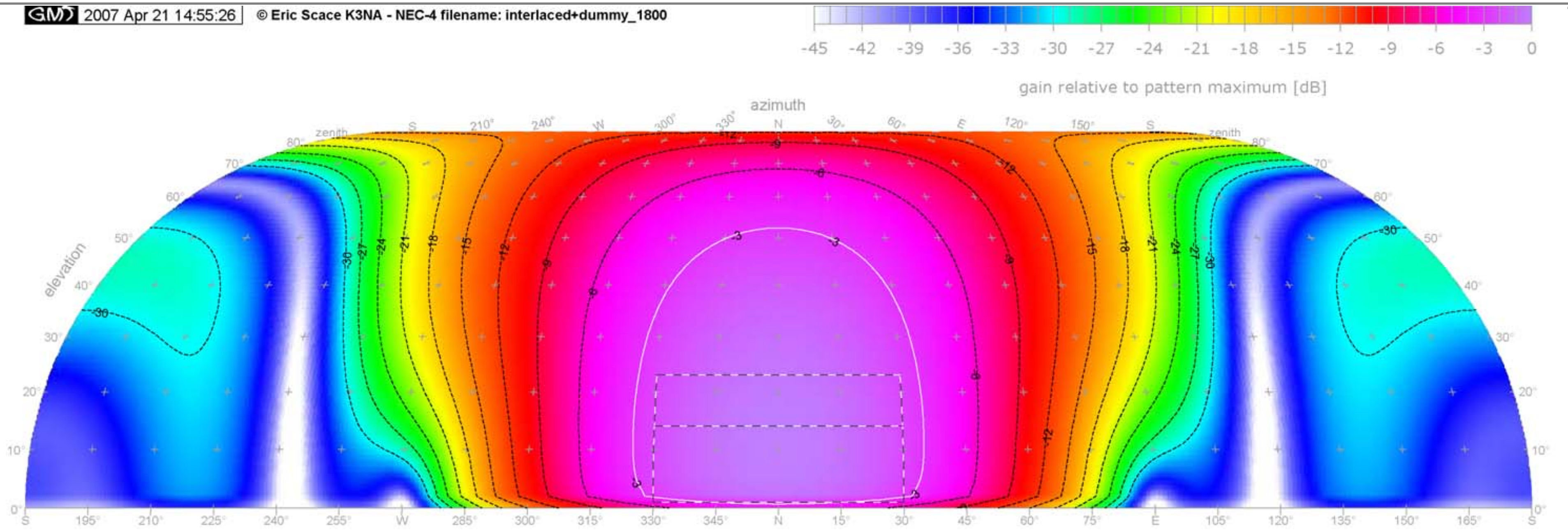
Implementation: Phasing



Simple, brute force approach:

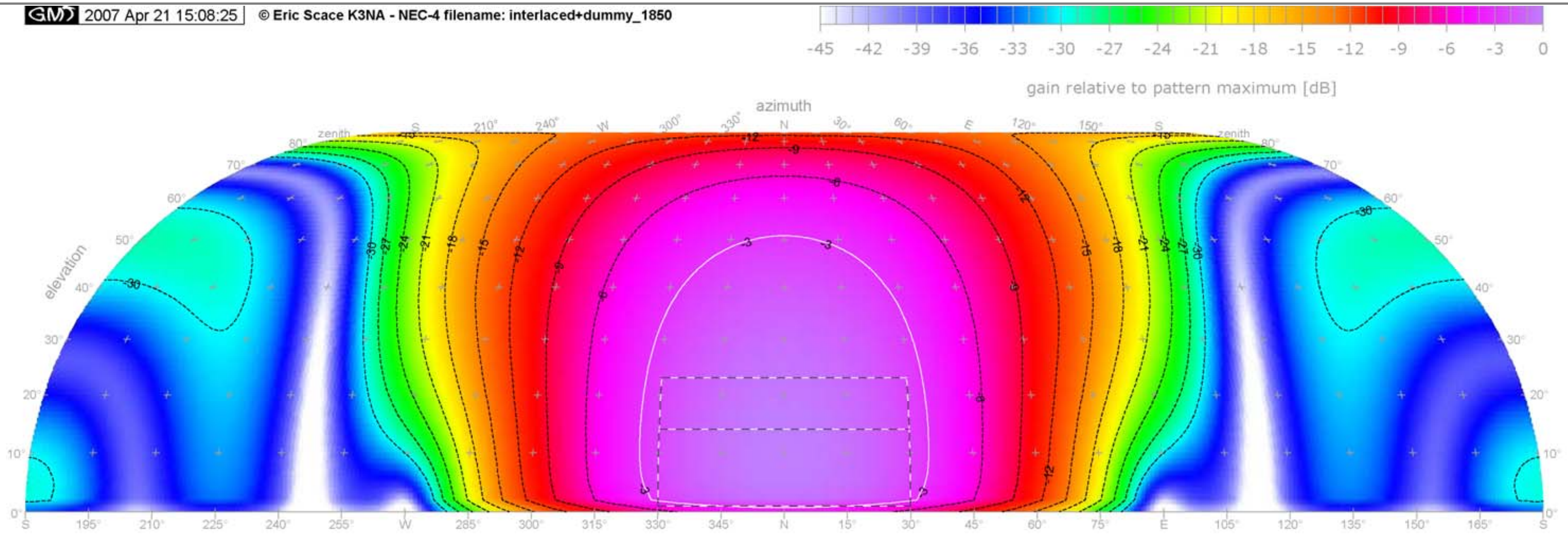
- Uses:
  ~155m RG-6 on 160m
  ~80m RG-6 on 80m.
- Unidirectional.
- Pattern stable across band.

Implementation: Phasing



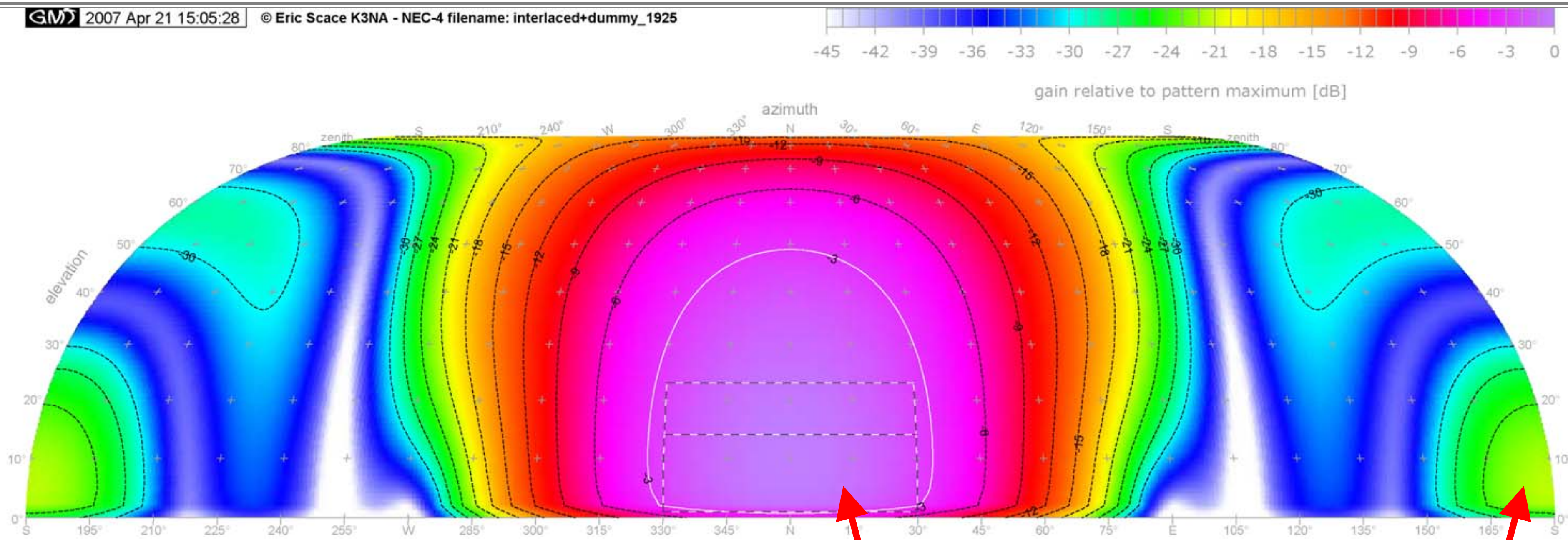
1800 kHz

Implementation: Phasing



1850 kHz

Implementation: Phasing

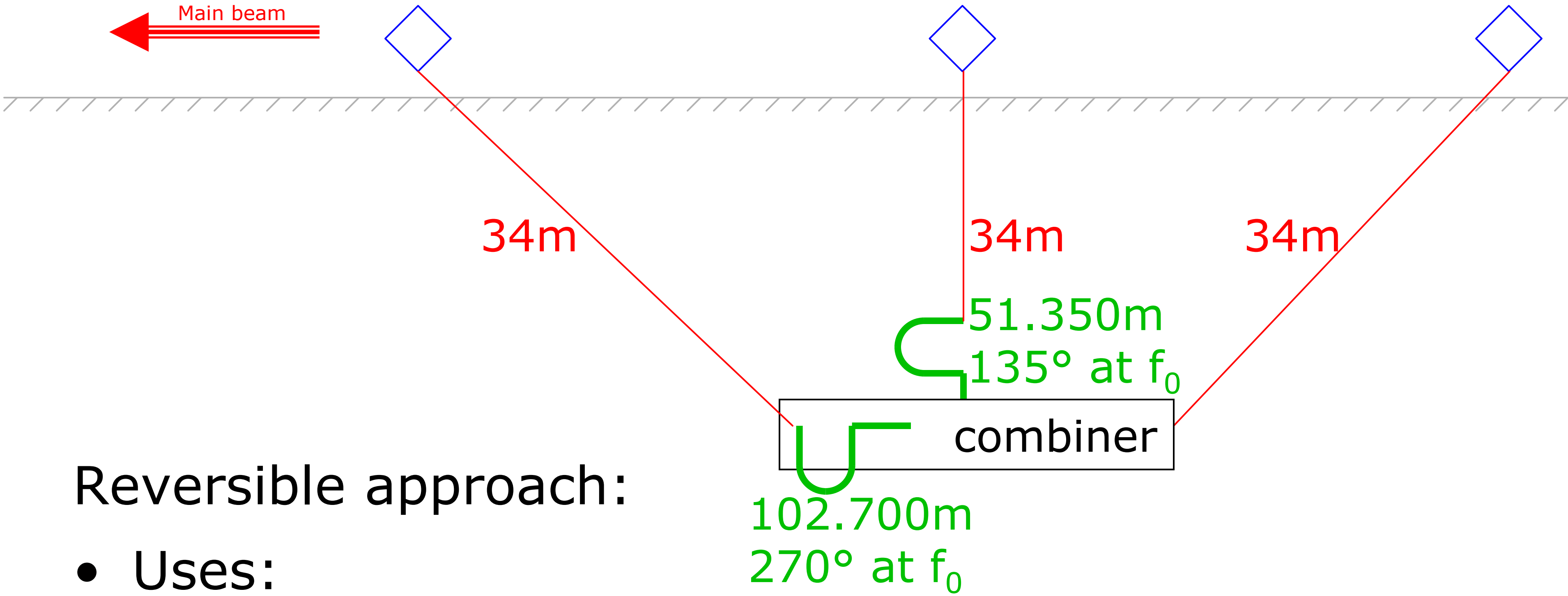


1925 kHz

Main beam narrower at high elevation

Rear lobe increased ~ 9 dB

Implementation: Phasing



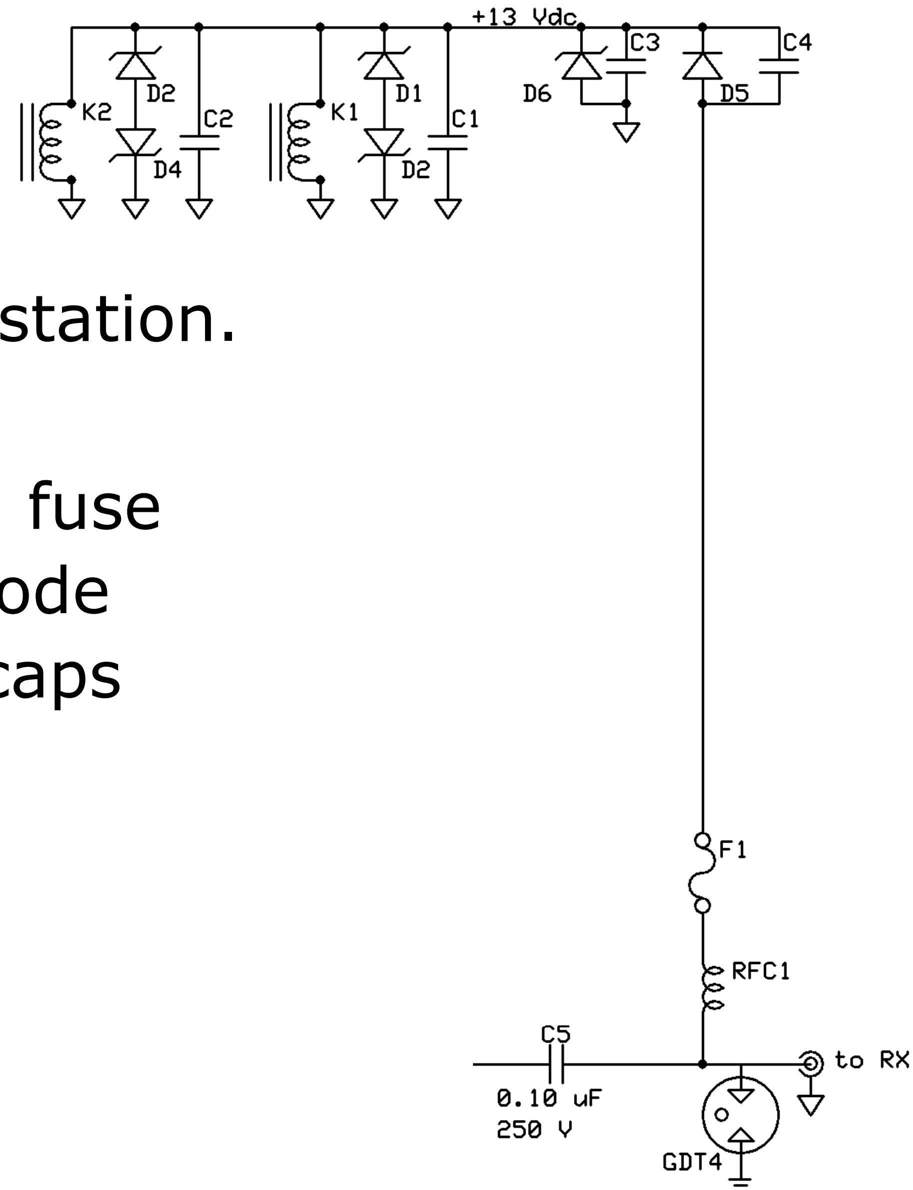
Reversible approach:

- 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

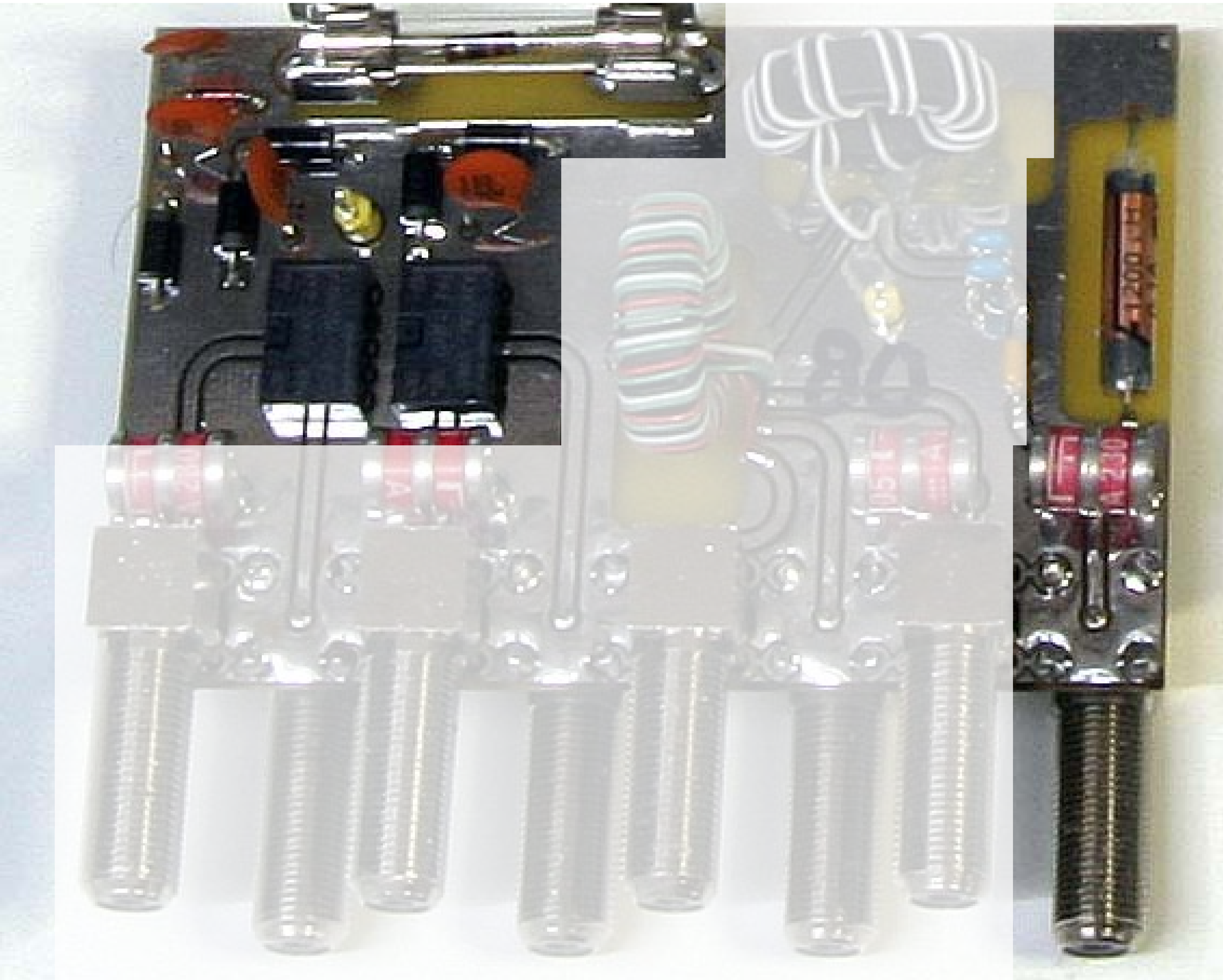
- Loop
- Match
- Phasing
- Combiner
- Preamp
- Construction practices

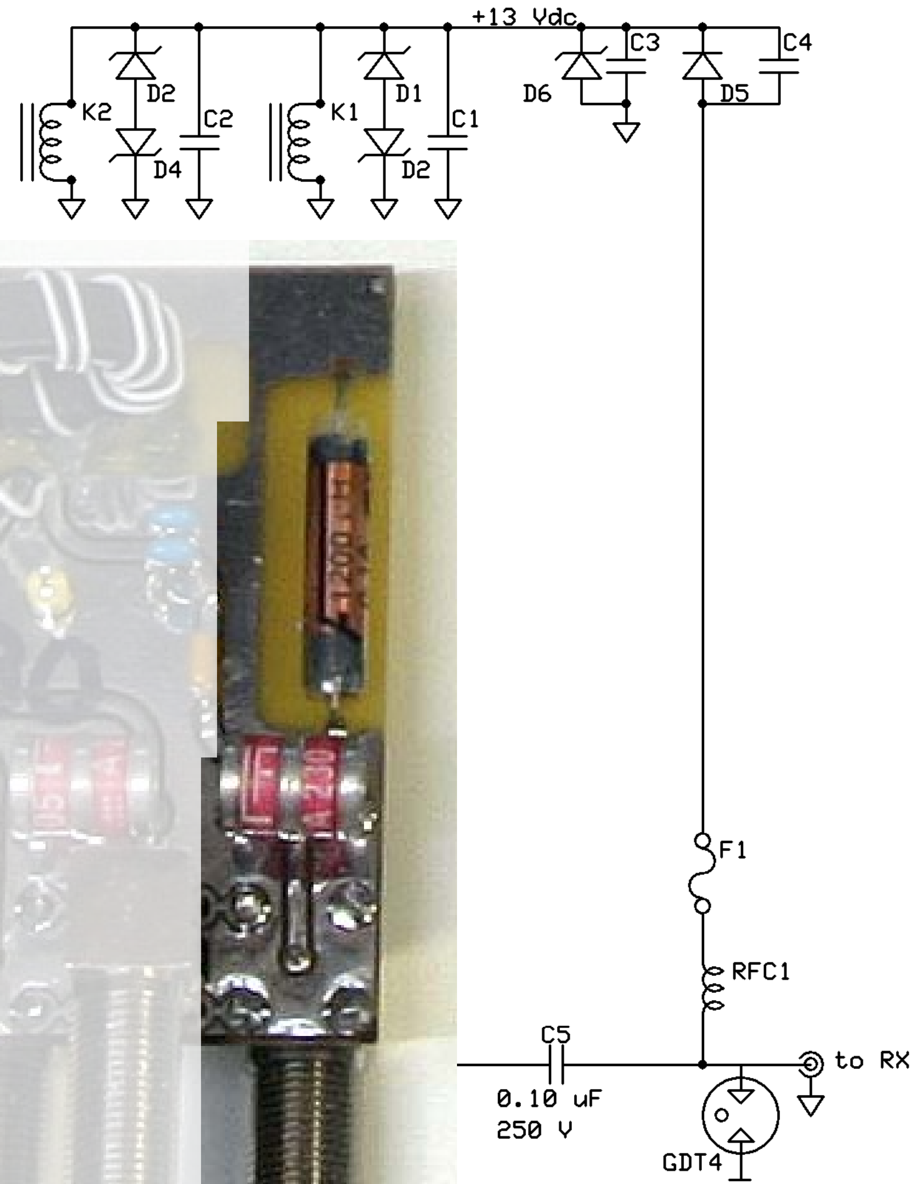
Implementation: Combiner



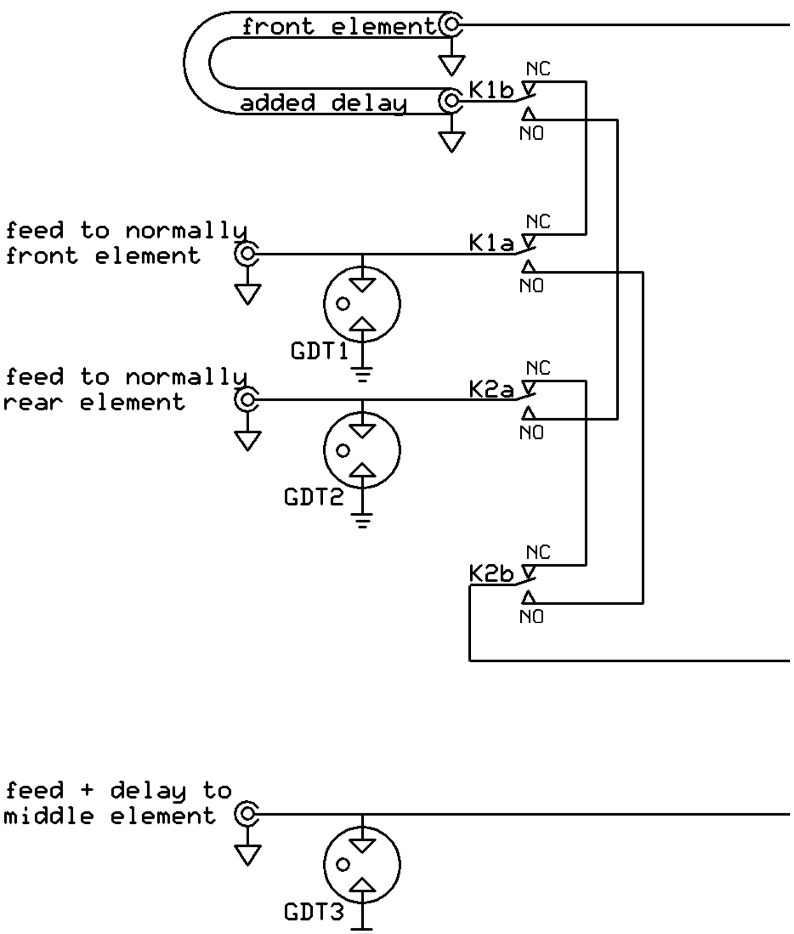
- Extracts Vdc from coax to station.
- Protection measures:
  surge: gas discharge tube, fuse
  voltage: zener, steering diode
  spikes: snubbers, bypass caps

Implementation:
Combiner



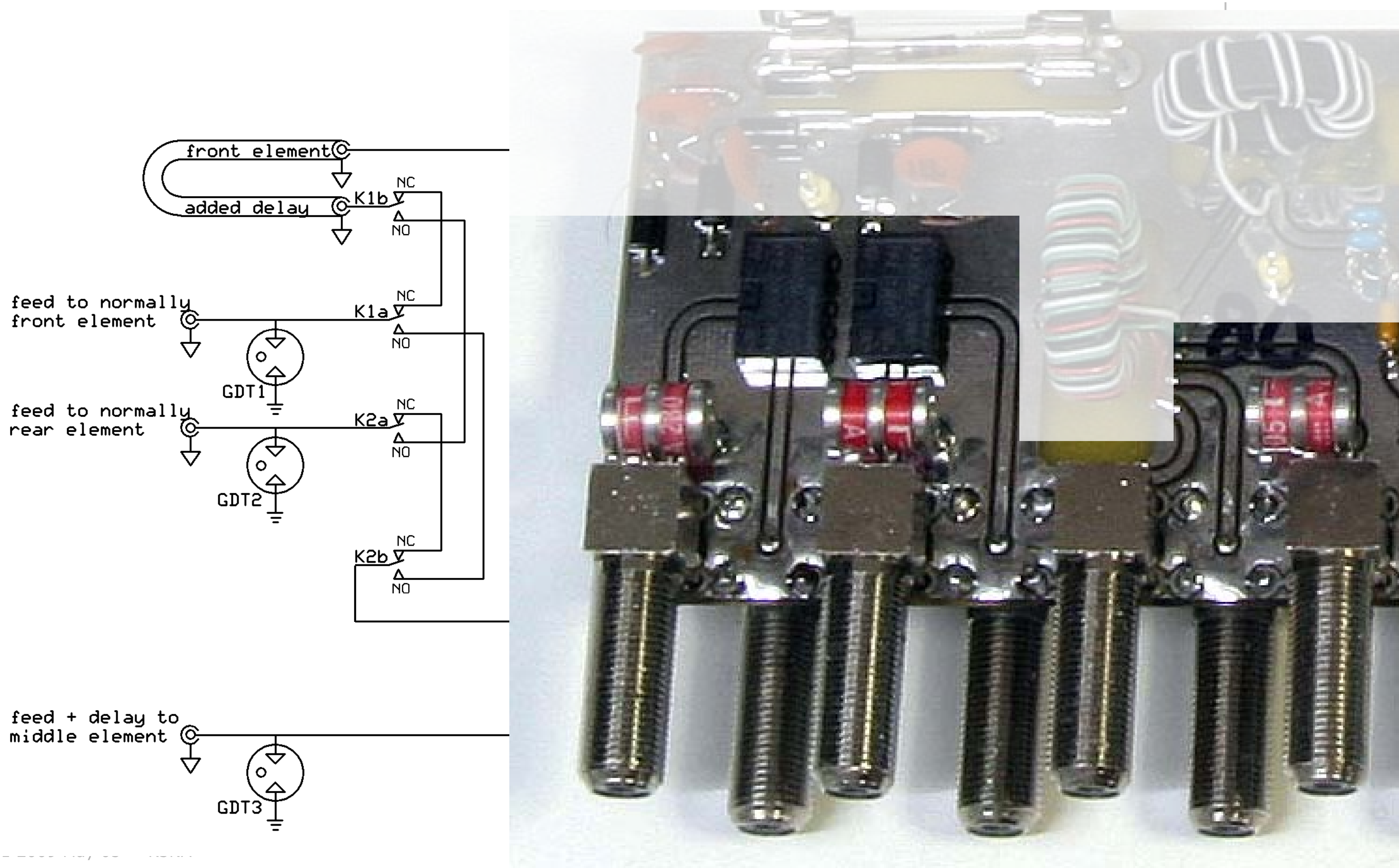


Implementation: Combiner

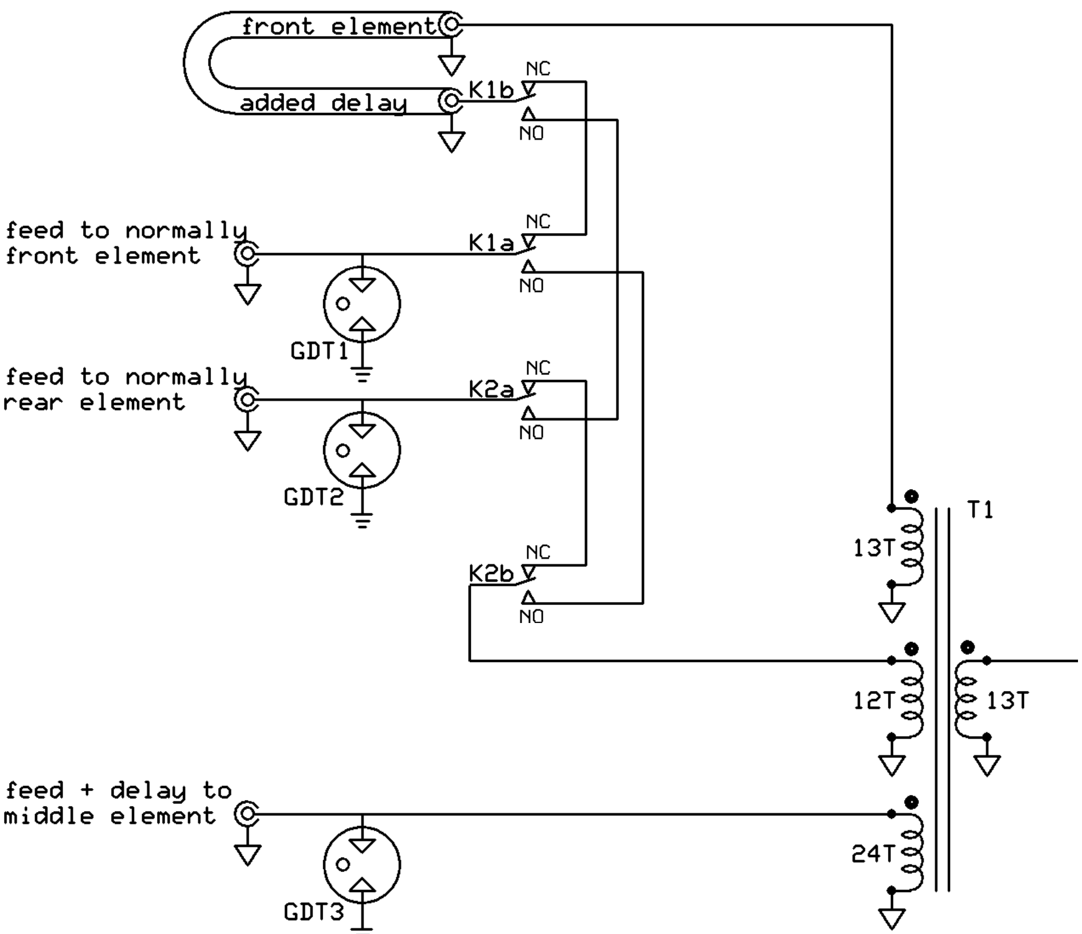


- Exchange front/rear loops to reverse pattern.
- Axion FP2 relays:
  - o Inexpensive
  - o Hermetically sealed
  - o Gold contacts
  - o Negligible loss, SWR

Implementation: Combiner

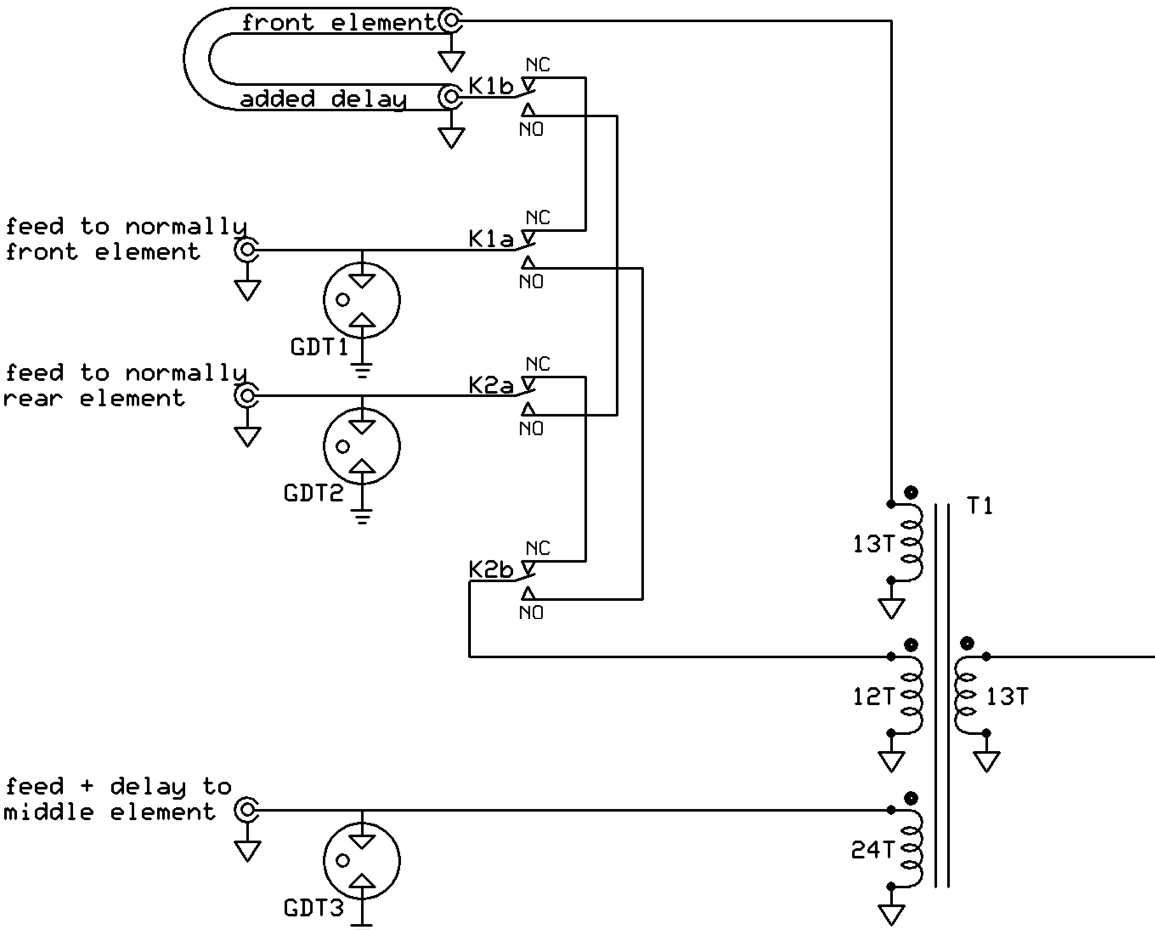


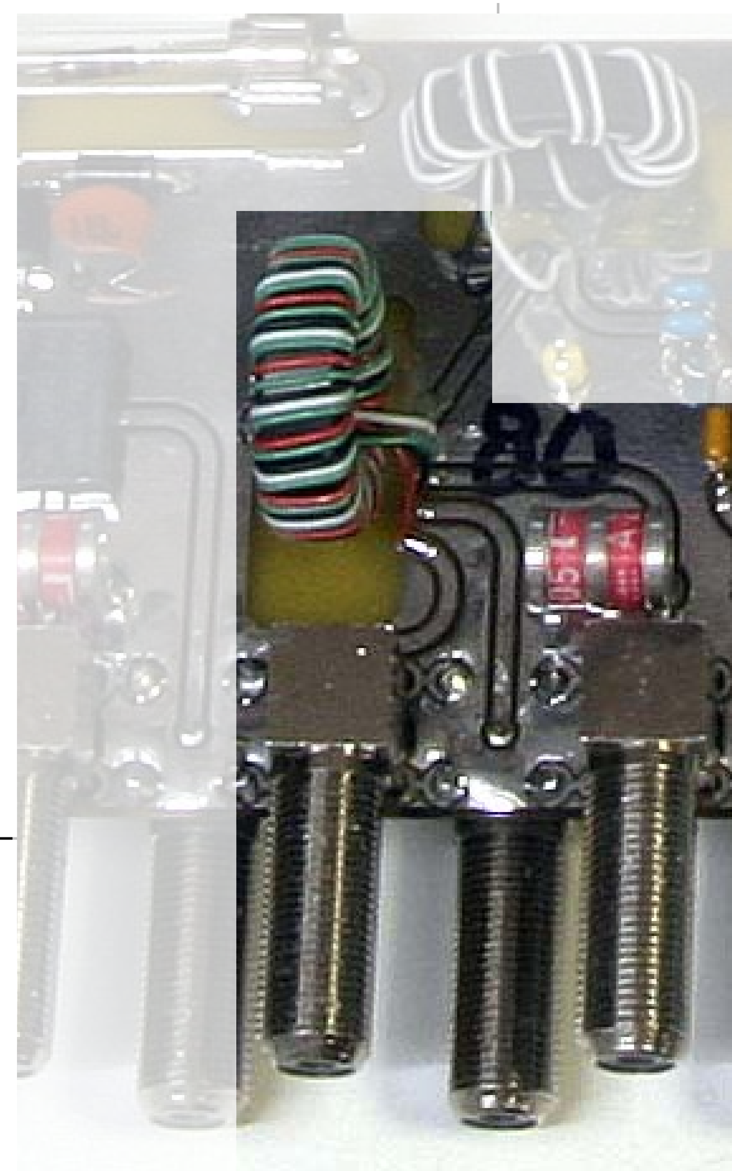
Implementation: Combiner



- 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



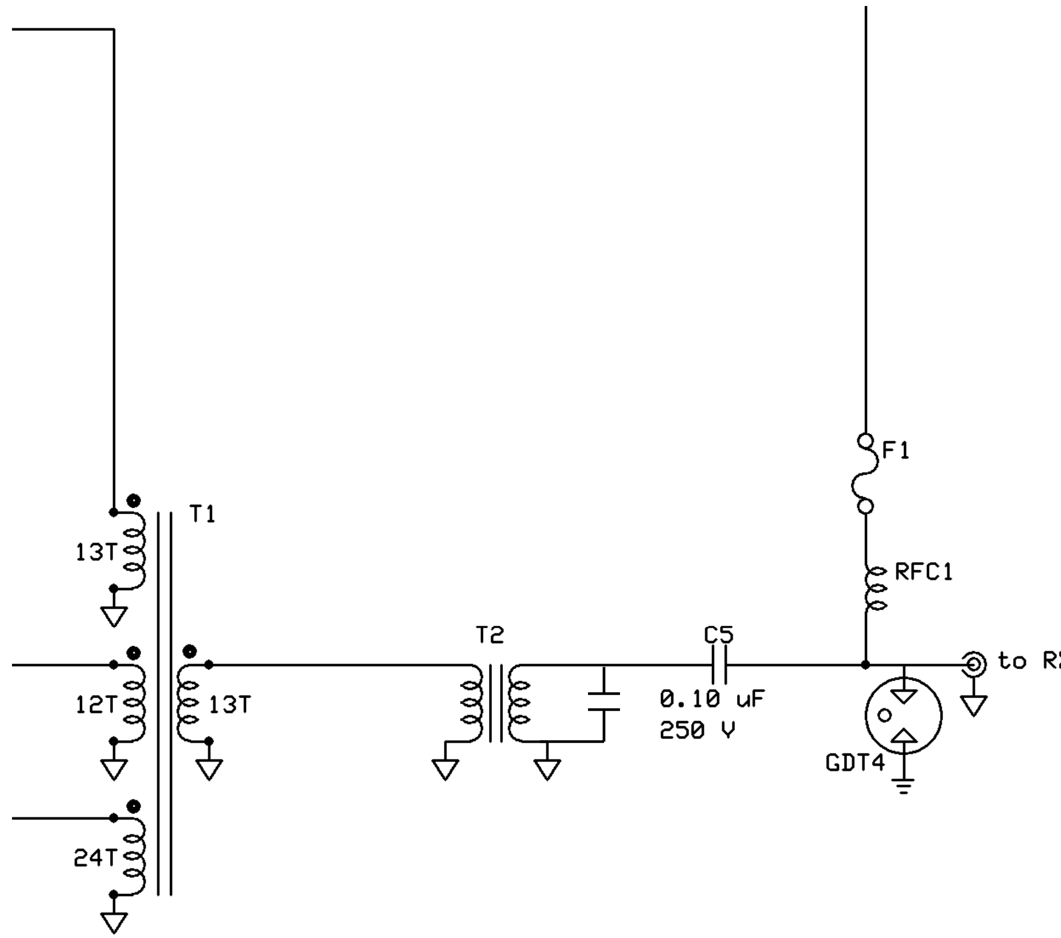


Implementation: Combiner

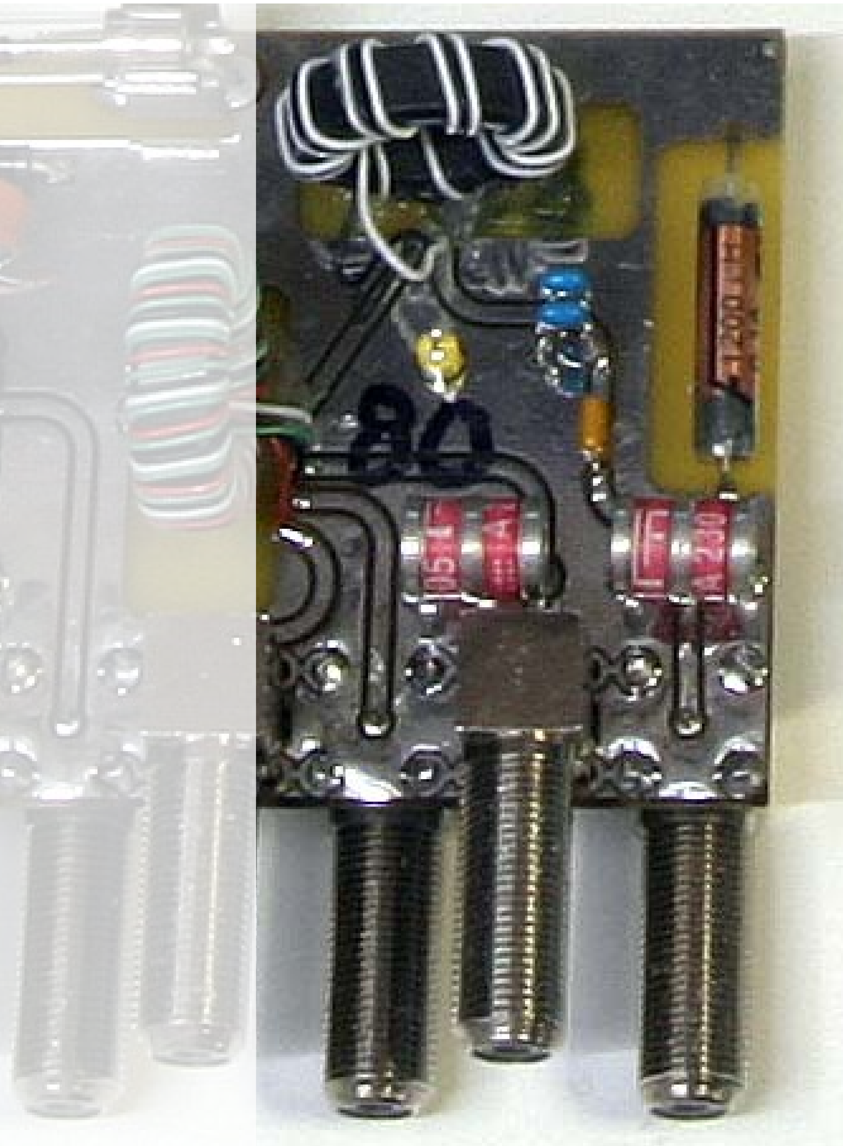
- Xformer output:
  160m: 14.5+j2.5
  80m: 14.5+j4.7

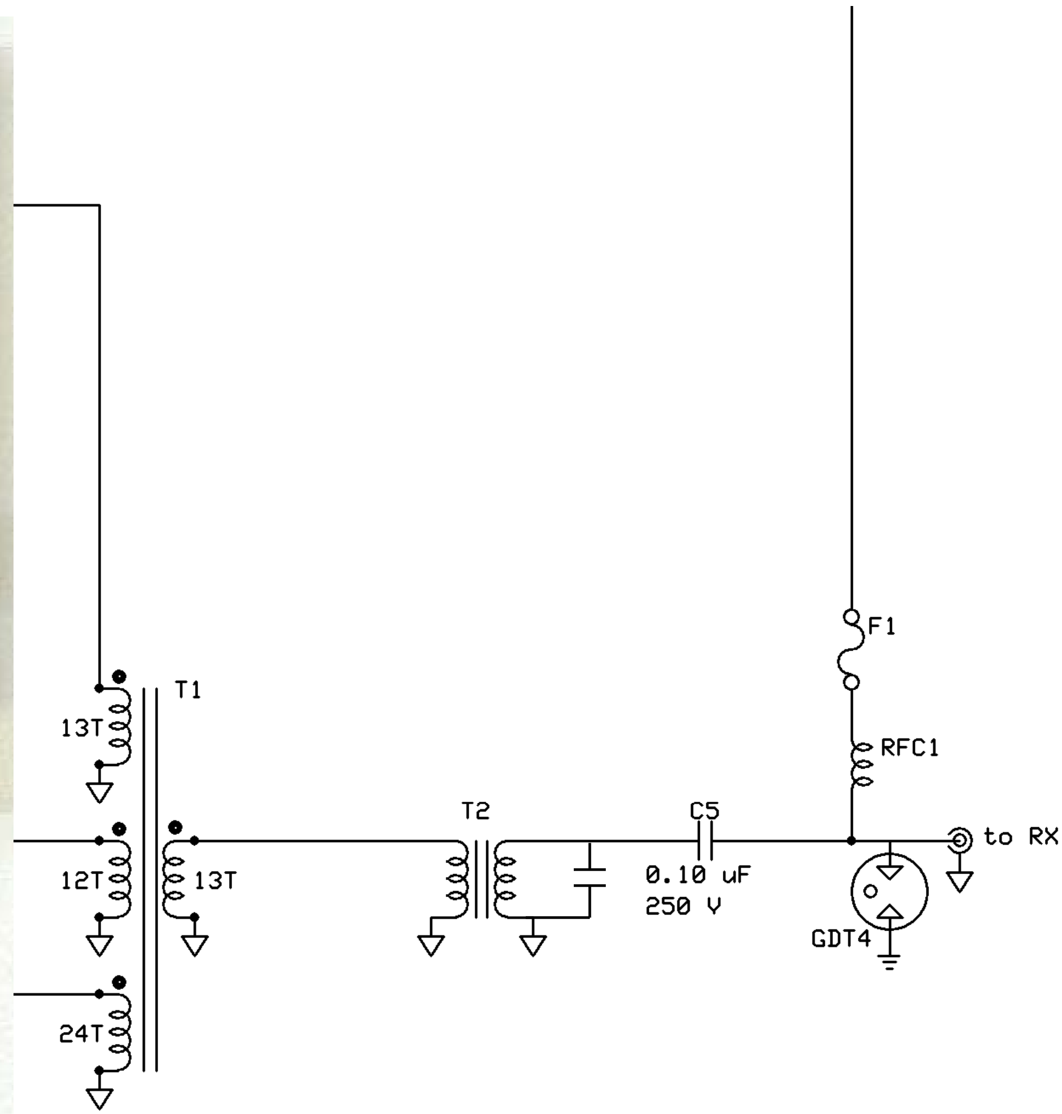
- T2: step-up 7:16
  160m: 76+j15
  80m: 79+j38

- Parallel cap cancels residual X.



Implementation: Combiner



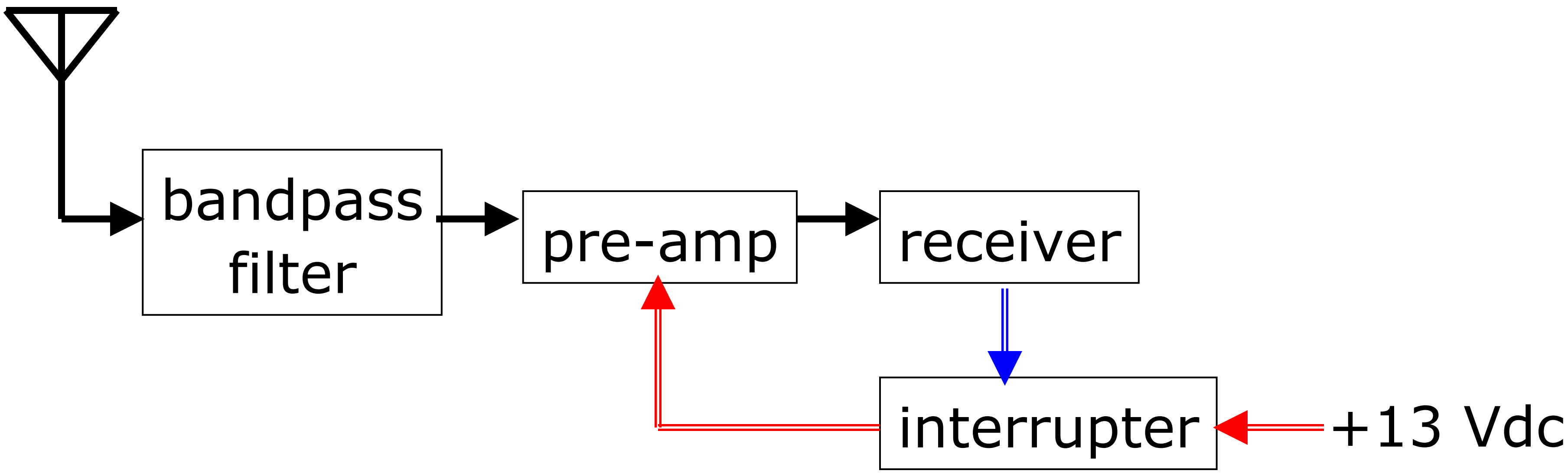


Implementation

- 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
  - o Anti-oxidant / anti-seize
  - o 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.

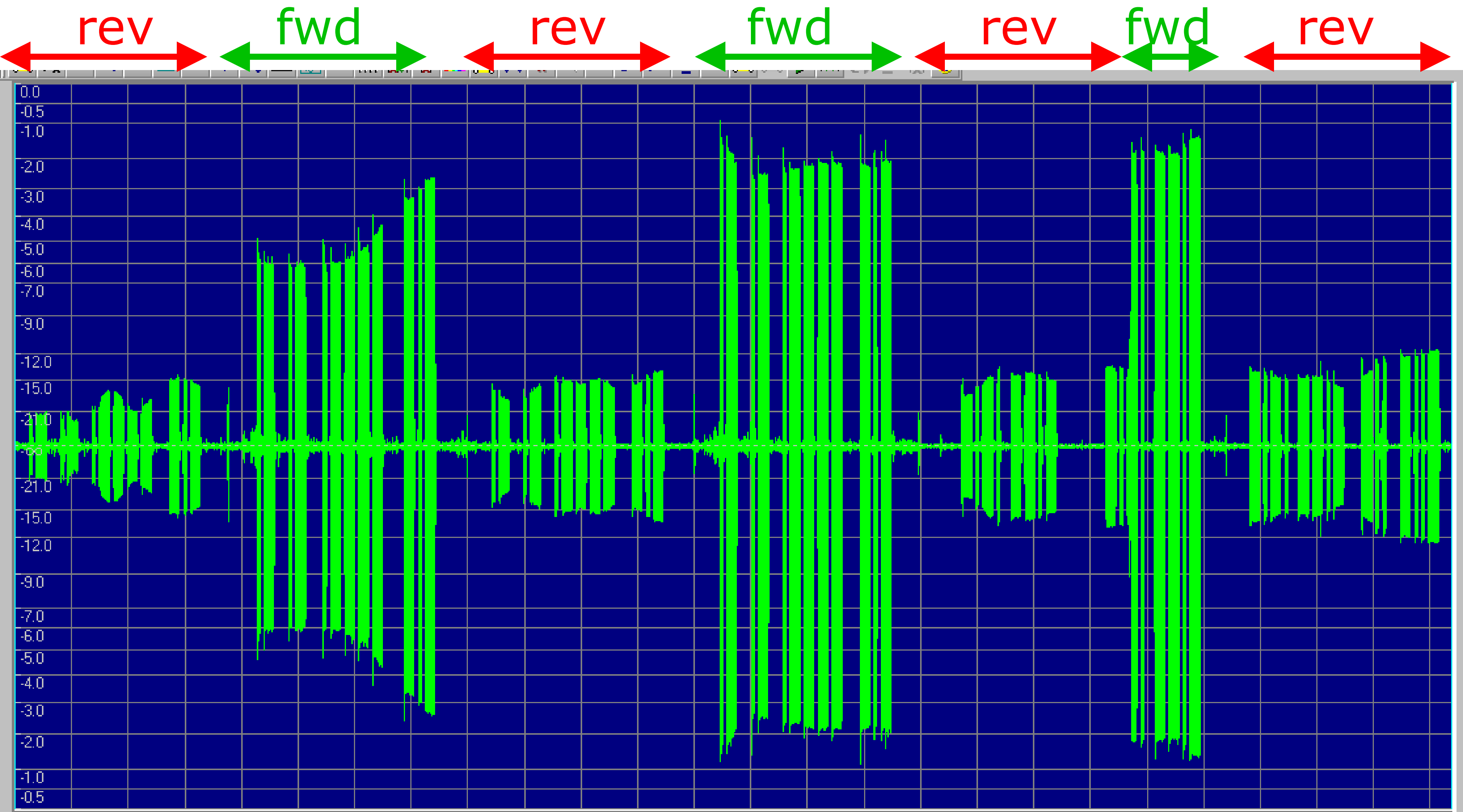
Agenda

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

Results:

Forward – reverse

~15 dB front-back on AA1K



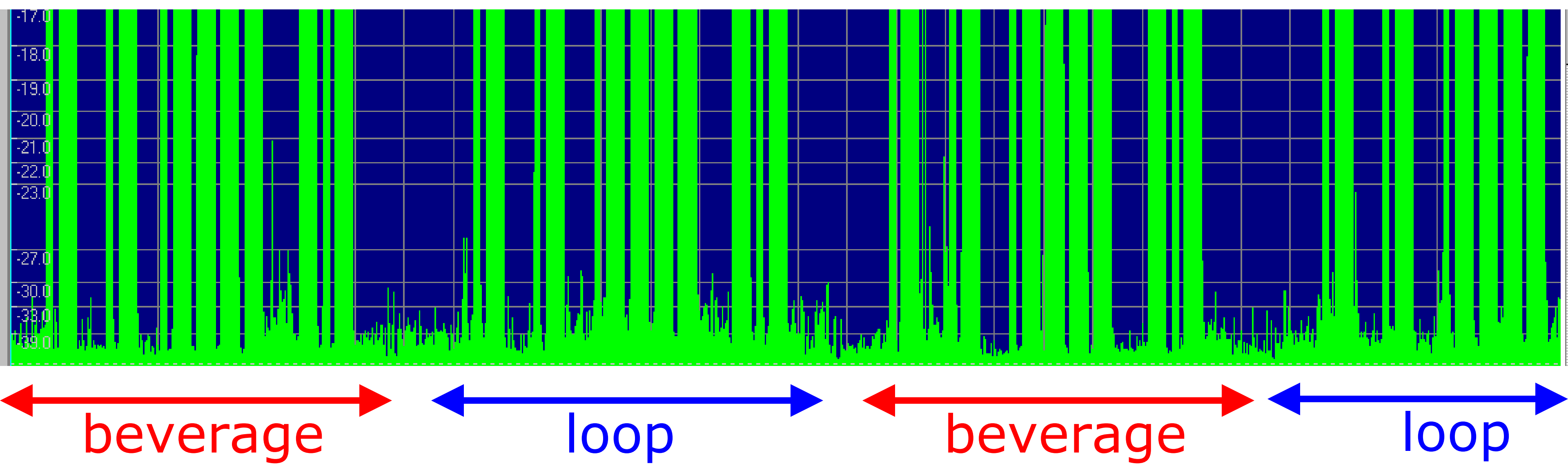
S/N vs beverage

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:

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

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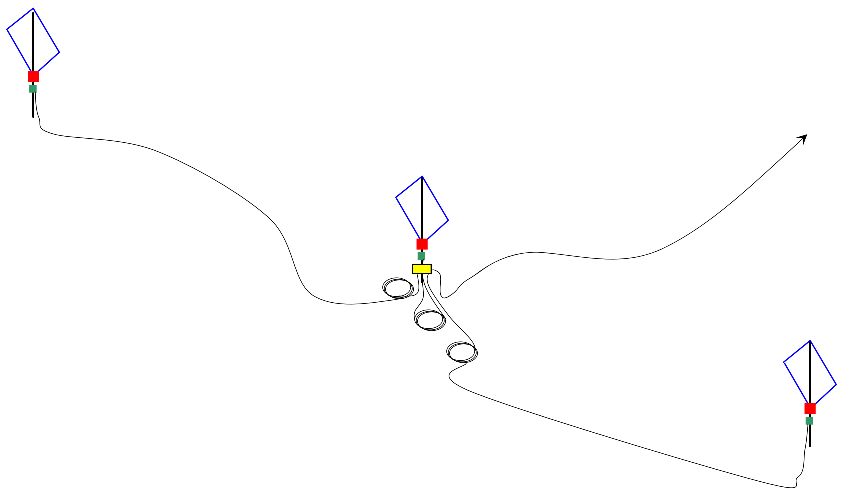
Dual-band operation

Approach #1:

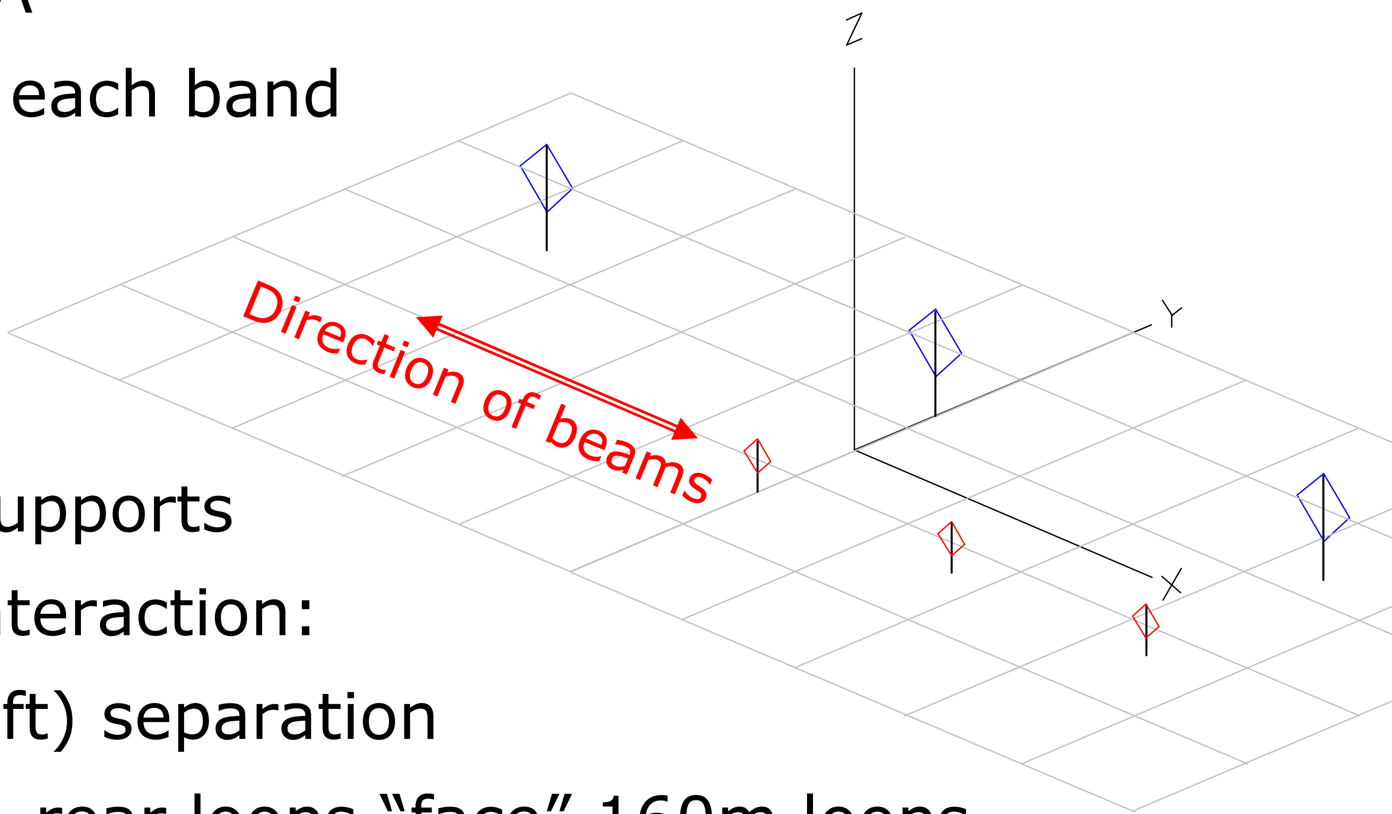


- 3 loops on 3 posts spaced for 160m:
  - o Clean pattern on 80m.
  - o Much narrower.
- But…
  - o Matching network?
  - o SO2R or multi-op access to antenna?
  - o May be solved with more R&D time…

Dual-band operation

Approach #2A

- 3 loops for each band



- Separate supports
- Minimize interaction:

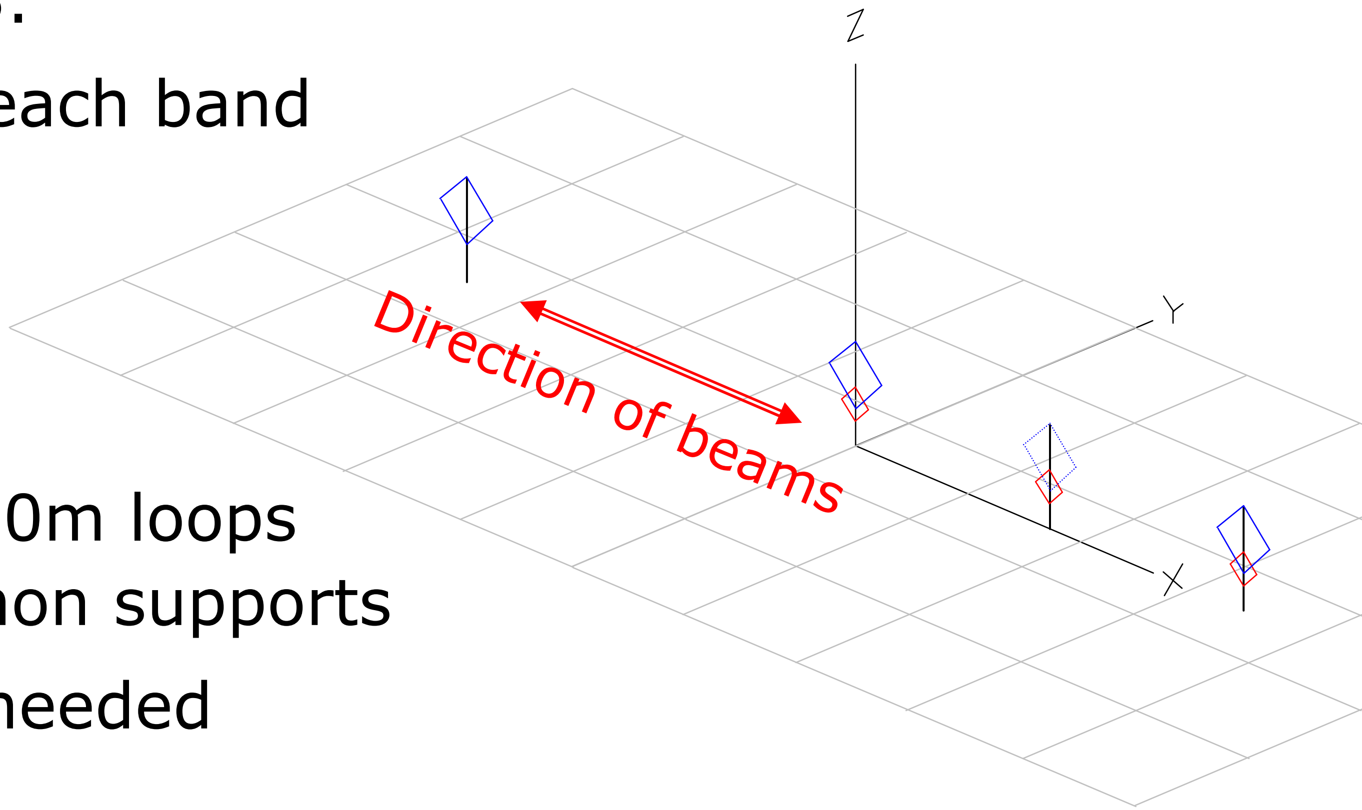
  ≥ 8m (26 ft) separation

  80m front, rear loops “face” 160m loops.
  (Exploits nulls.)

Dual-band operation

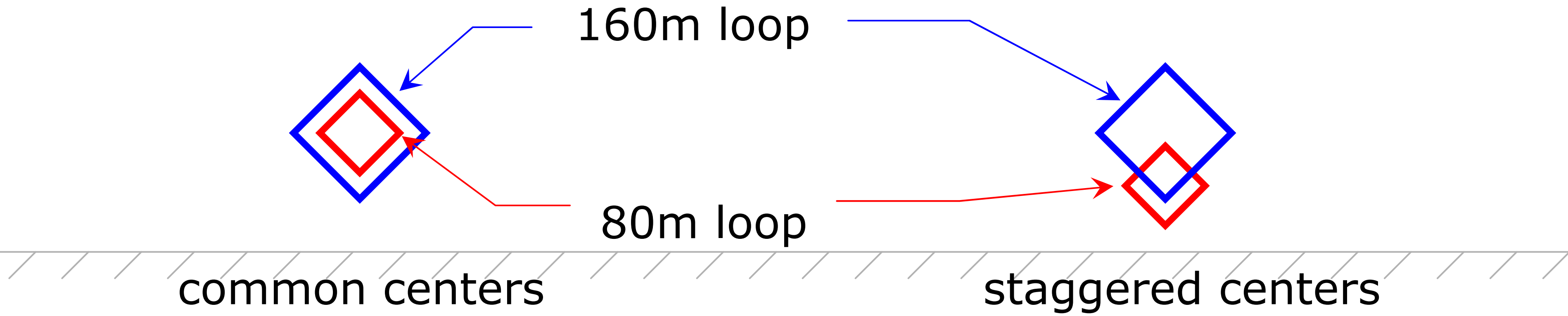
Approach #2B:

- 3 loops for each band



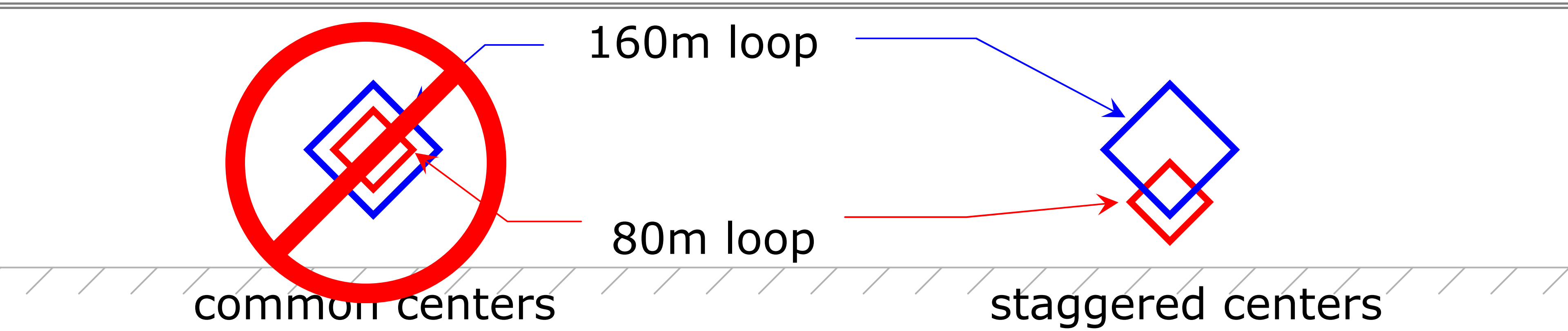
- 80m and 160m loops share common supports
- 4 supports needed

Dual band operation



Which is better?

Dual band operation

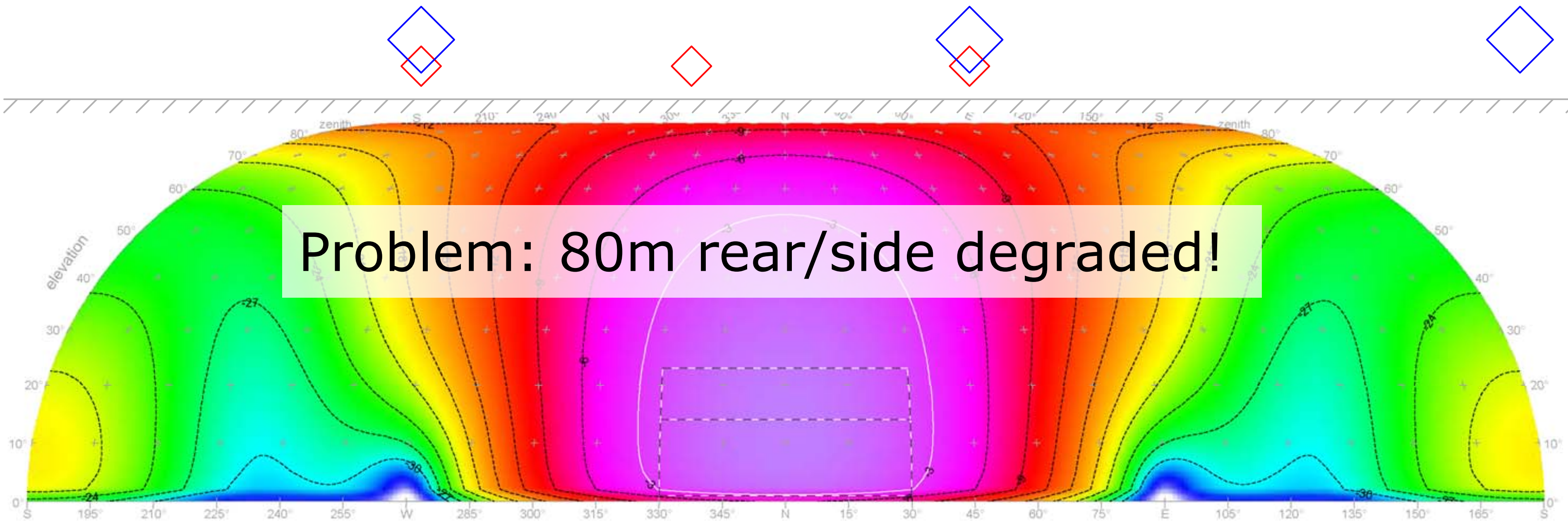


Problem with common center:

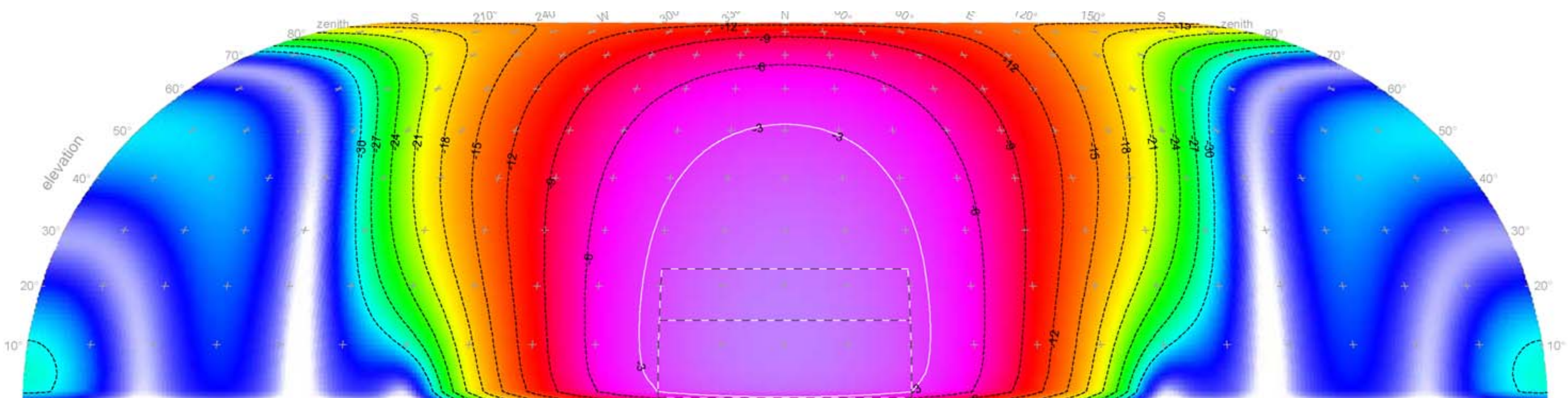
- Shifts 80m loop Z
- Reduces 80m loop output -3 dB

160m loop:
impact immaterial for either approach.

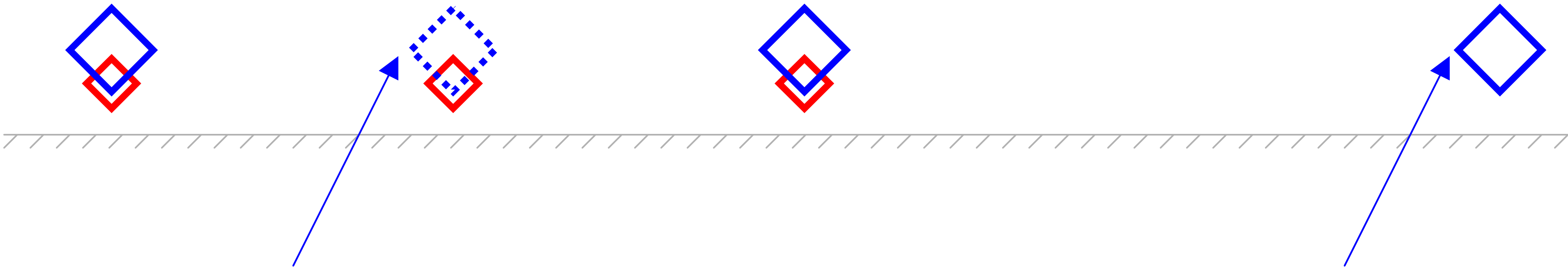
Dual band operation



80m should be:



Dual band operation:
Dummy loop



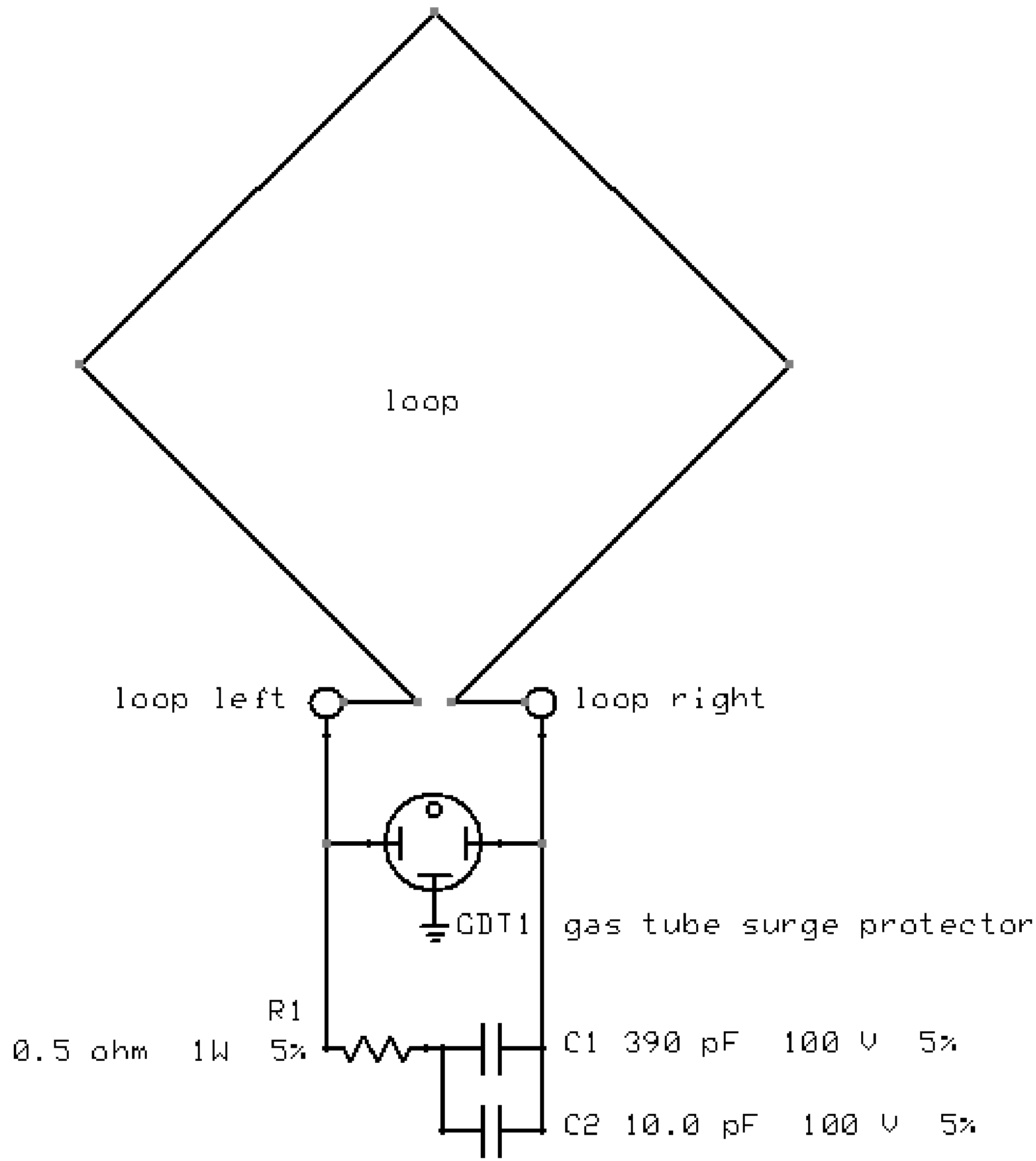
“Dummy” 160m loop:

- 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.
- ~ ½ λ separation required for full effect.

“To Do” list: Smaller footprint

Can array be even smaller?

Potential solution:

- 2 loops, ⅛ λ in-line separation
- 145° 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.

Acknowledgments

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Five Star DX Assoc

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