Some DIY EFHW and OCF Antennas, Baluns, and Transformers

WVARA Nov 13, 2024

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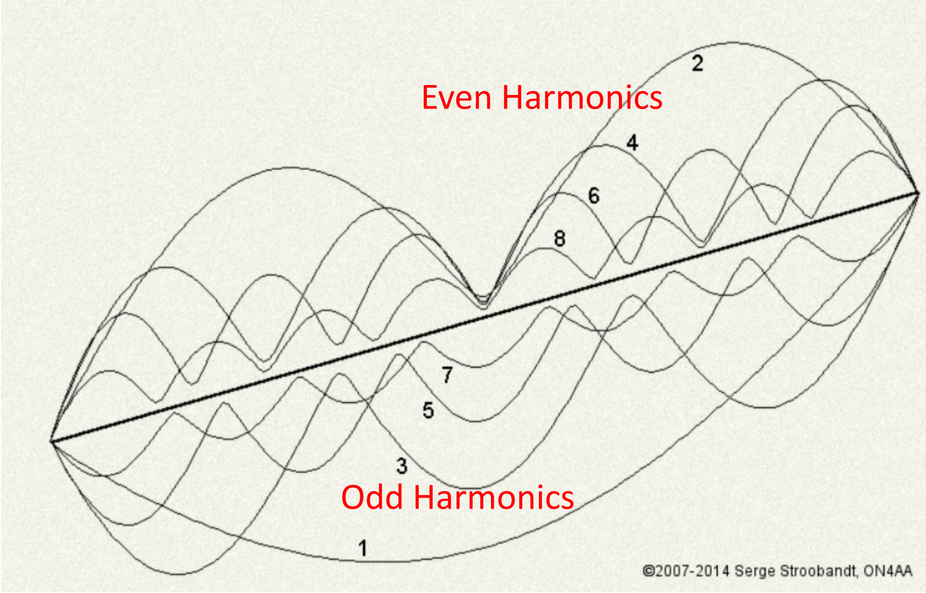
Agenda

- Half Wave Wire Antenna Summary
- EFHW 80, 40, 20, 17, 12   49:1 Unun
- OCF HW 40, 20, 15, 10   4:1 Balun & CM Choke
- Unun   2:1   1-51 MHz
- Current vs. Voltage Transformers

Half Wave Wire Antenna

- Current in the Wire Causes Radiation (and Vice Versa; They Exist Together)
- Current Appears in Standing Waves on a Half Wave Wire,
  - Due to Current Waves Reflecting at the Open Circuit Ends of the Wire, and Adding with Forward Waves.
- Harmonic Currents on the Antenna at Multiples of Half Wave:
  - Even Harmonics, Current is Almost Zero in the Middle of the Wire
  - Odd Harmonics, Current is High in the Middle
  - All Harmonics, Current is Almost Zero at Wire Ends
- Below Depicts Peak Current Levels for First Eight Harmonics [1]

[1] ON4AA "Multiband HF Center-Loaded Off-Center-Fed Dipoles" https://hamwaves.com/cl-ocfd/en/index.html



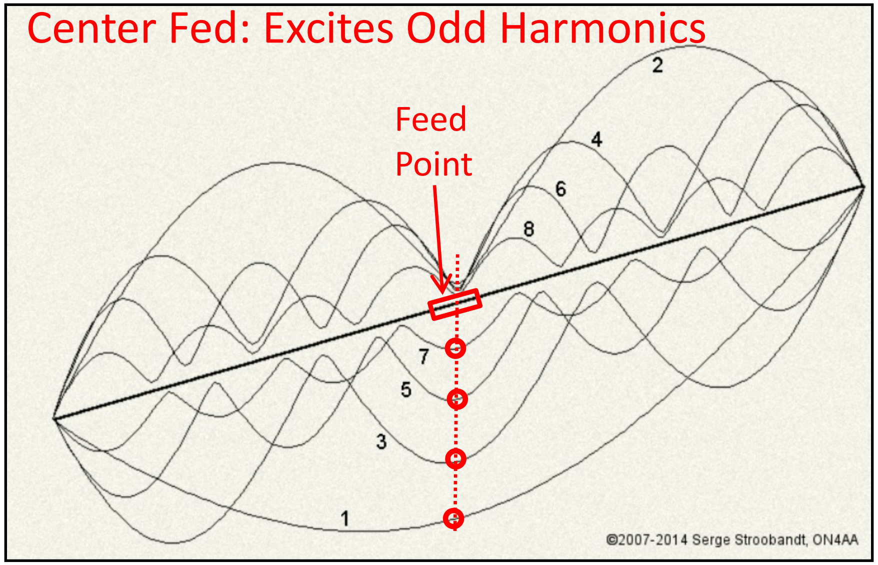
Standing Wave Visualization:

https://en.wikipedia.org/wiki/Standing_wave

GIF File

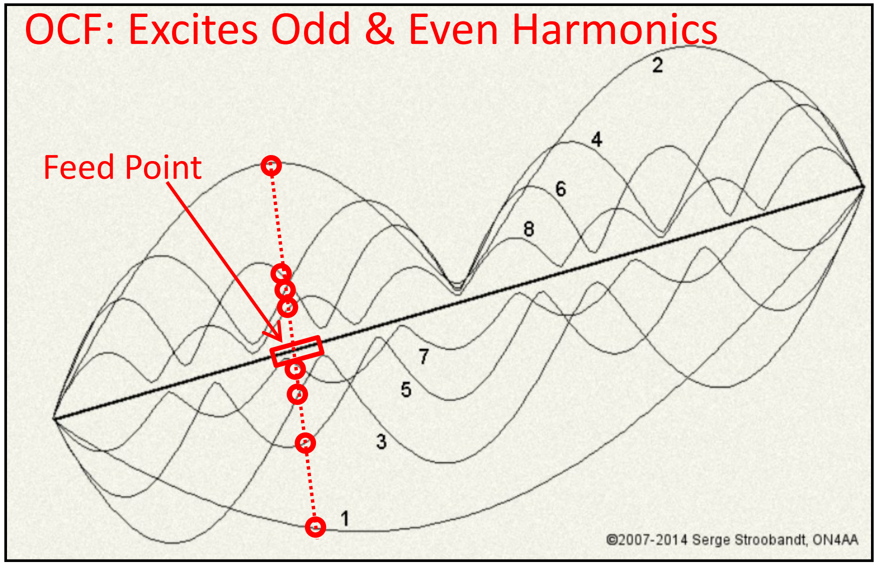
Half Wave Wire Antenna
Center-Fed

- Only Odd Harmonics, Even Harmonics are Null
  - Eg, 40 Meter Dipole Works on 15 m, but not 20 m
- Typical Feedpoint Impedance is 40-73 ohms
  - Matches to Coaxial Cable
- Nice Radiation Pattern, Broadside to Wire
- Easy to Install, Elevate at Both Ends, Feedline in Middle



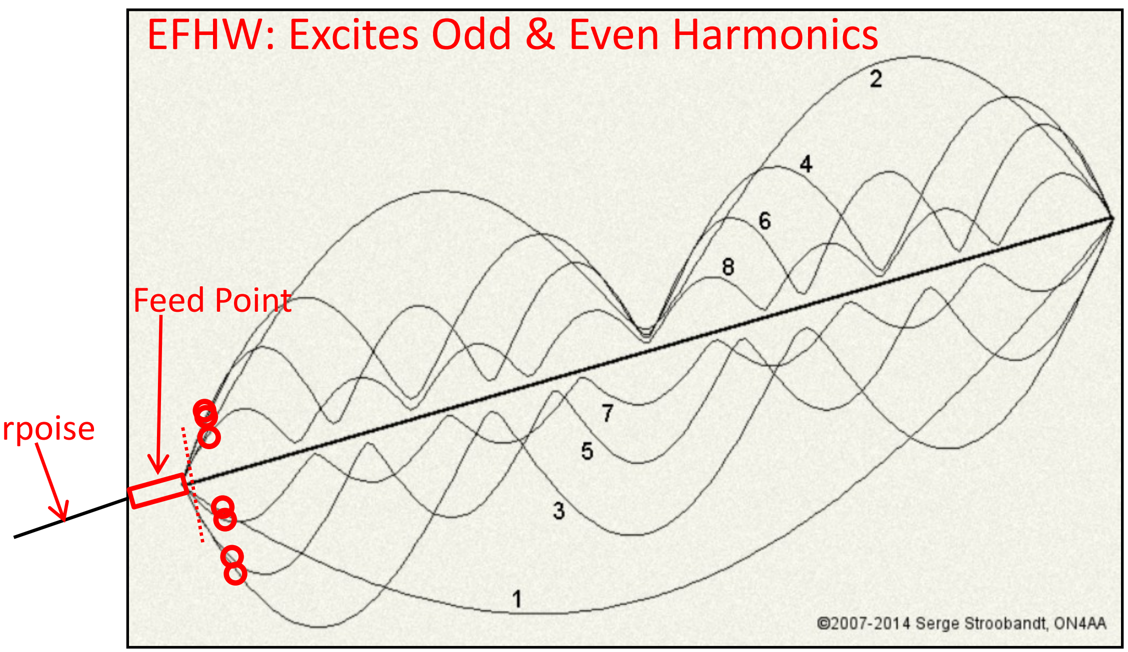
Half Wave Wire Antenna
Offset Center Fed (OCF)

- Odd & Even Harmonics - MULTI-BAND - Radiation Pattern may be Poor
- Typical Feedpoint Impedance is ~200 ohms, About 1/3 From the End
- Very Popular, Seem to Have Lower RF-in-Shack Than EFHW
- Some Variations:
  - "Slightly OCF Dipole" https://fivecountyhre.org/a-slightly-off-center-fed-dipole/
  - "Center Loaded OCF Dipole" https://hamwaves.com/cl-ocfd/en/index.html



Half Wave Wire Antenna
End-Fed (EFHW)

- Odd & Even Harmonics - MULTI-BAND - But Radiation Pattern may be Poor
- High Impedance - Typically 2500 ohms
  - Low Current and High Voltage at Ends of Wire
  - Very Popular, Generally Fed with 49:1 Impedance Transformer, Unun
- **CAUTION - High Voltage at Feedpoint - 100 watts to 2500 ohms is 707 V_{PK}**
- Easy to Use – Elevate One End; Shorter Coax than for CF – Offsets Unun Loss



Half Wave Wire Antenna
EFHW Counterpoise Wire

- Need Counterpoise (CP) Wire for Ground Return Current to Transformer
- Bottom of Transformer is a High Impedance Point; Current is Small
  - Short CP Wire Couples to Nearby EM Field to Complete the Circuit
- Best Length for Good SWR is Found Experimentally
  - Can Use as a “Tuning Lever” to Optimize Multi-Band
- Can Use the Coaxial Cable Shield as the CP Wire
  - With CM Choke on Coaxial Cable as Open Circuit to set CP Length
- Grounding the Counterpoise Wire
  - May Improve SWR
  - But Can Introduce Noise to Rx and Conduct Tx Signal to House Wiring

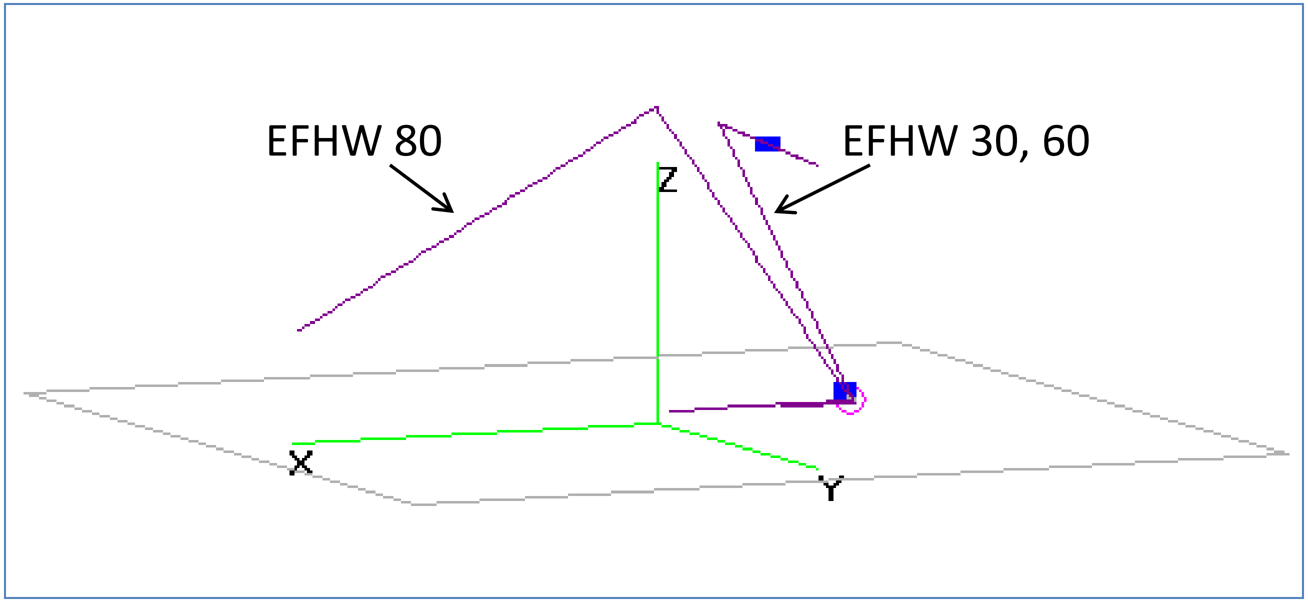
Great Introduction to EFHW Antennas:
End Fed Wires Can Be MAGICAL Multi-Band Antenna, NR5NN
https://www.youtube.com/watch?v=CWkuCvhW28w

DIY EFHW 80, 40, 30, 20, 18, 12

- EFHW Inverted-V: End Fed at Roof, then goes to Apex in Tree at 55 ft High
- Feed-point at Roof with Unun Transformer, Wire about 152 Feet Long
  - Typical Half Wave Wire Length: $L_{FEET} = 468 / F_{MHz}$
- Adjusted the Wire Length and Added Coil for Best SWR on All the Bands

DIY EFHW 80, 40, 30, 20, 18, 12

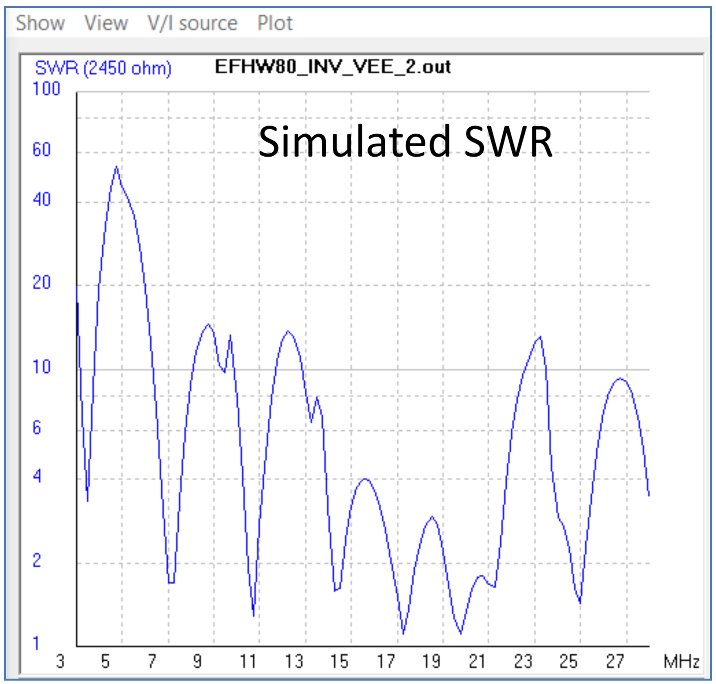
- Simulated with 4NEC2 - Results Generally Agree With Measured
- The EFHW 80 Inverted-V is on the Left
- An EFHW 30, 60 is on Right; Minimal Interaction Between Them
- Feedpoint is Red Circle, Blue Squares are Loading Coils

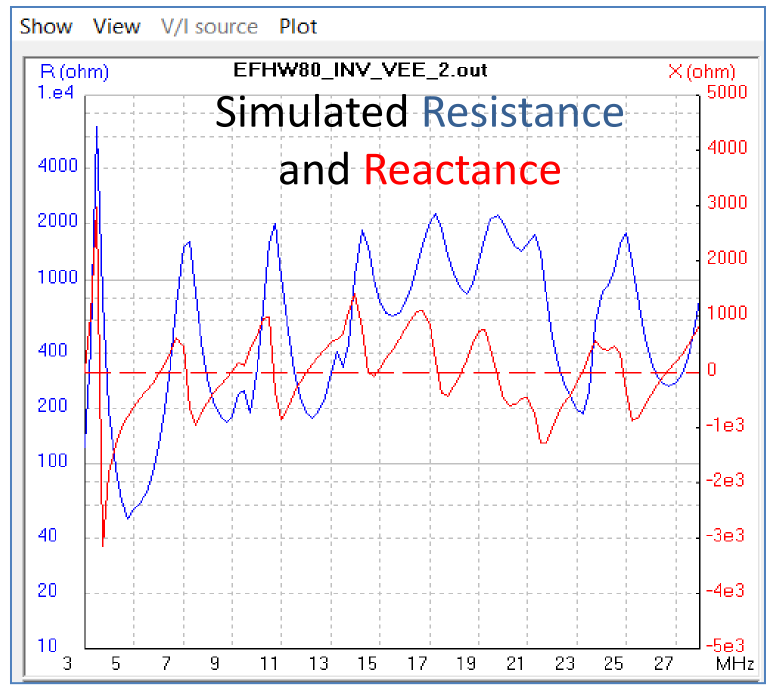


DIY EFHW 80, 40, 30, 20, 18, 12

4NEC2 Simulated Results

- Plot on Left is SWR referenced to 2450 ohms
- Plot on Right is Feedpoint Resistance (Blue), Reactance (Red) in ohms
  - Input Resistance at 80 m ~6000 ohms, Other Bands ~2000 ohms
  - Tricky to Impedance Match at 80 m, and All The Other Bands

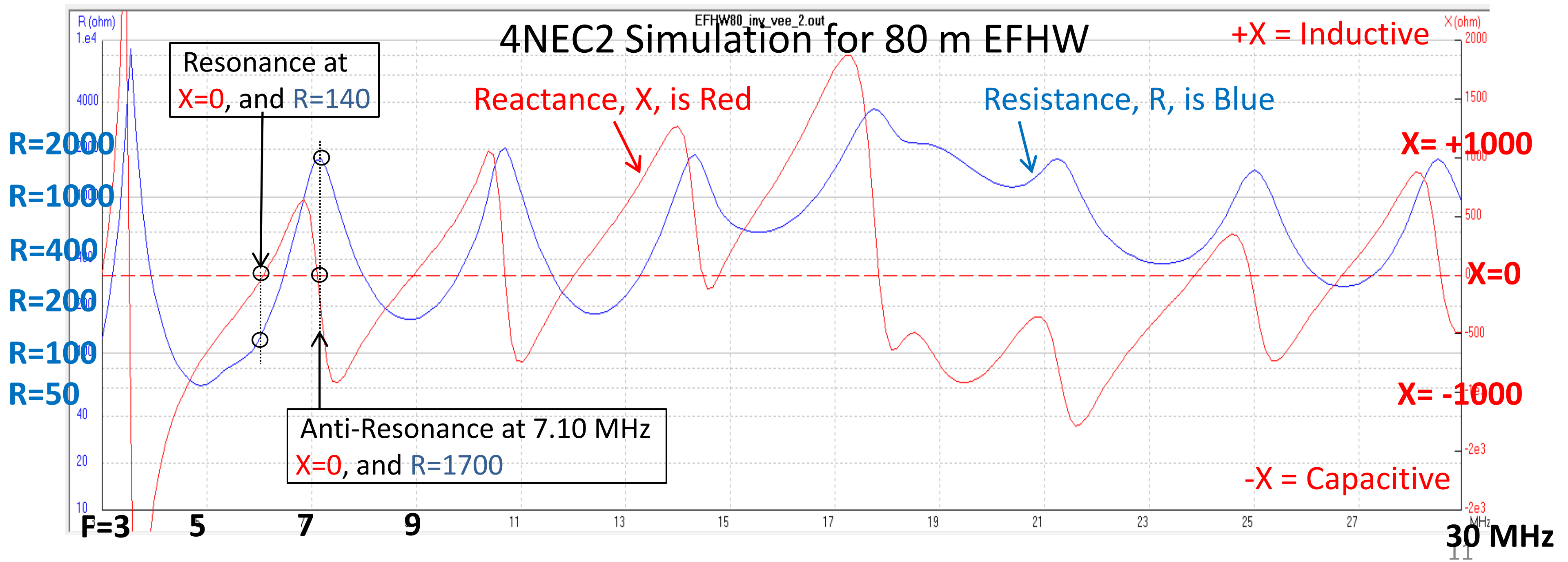




DIY EFHW 80, 40, 30, 20, 18, 12

Resonance & Anti-Resonance

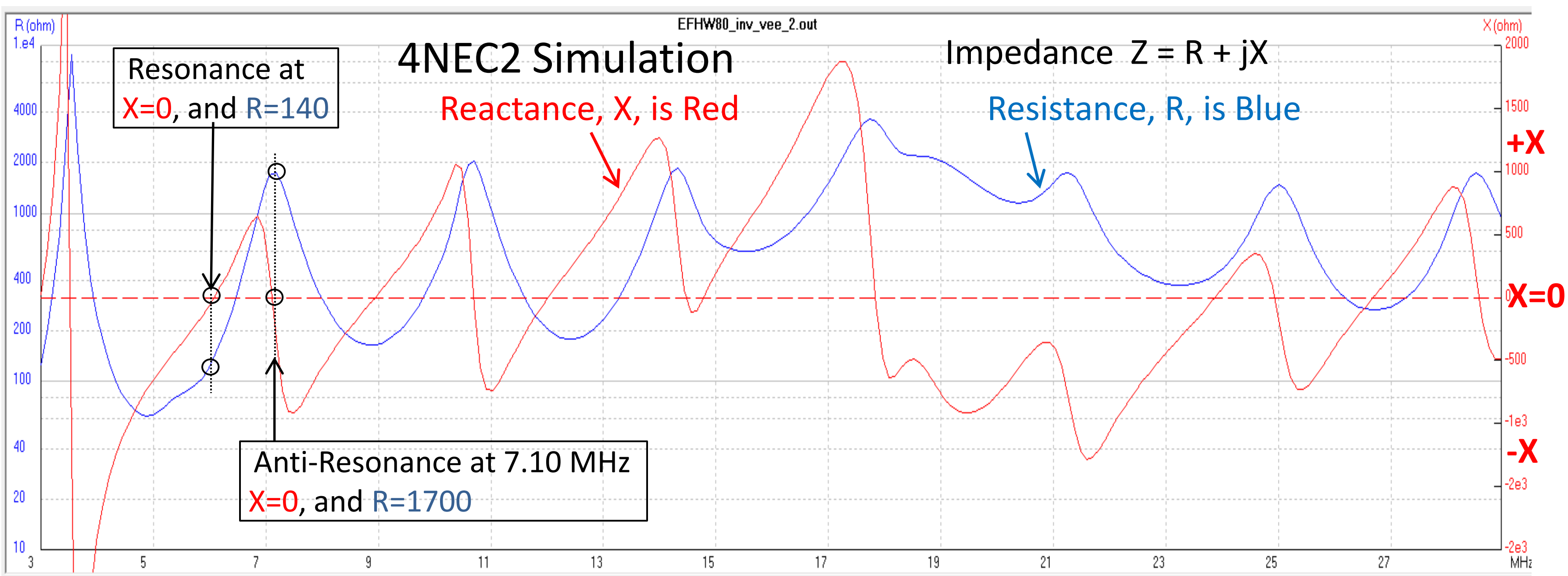
- Both Occur at Reactance, X = 0; Impedance Z = R + jX
- Anti-Resonance
  - Reactance has Negative Slope (Inductive to Capacitive)
  - Resistance is High (~2500 ohms) so Good for EFHW
- Resonance
  - Reactance has Positive Slope (Capacitive to Inductive)
  - Resistance is Low (50-200 ohms), so good for Center and OC Fed Dipole)



DIY EFHW 80, 40, 30, 20, 18, 12

Antenna Tuning "Levers" → Low SWR on ALL Bands

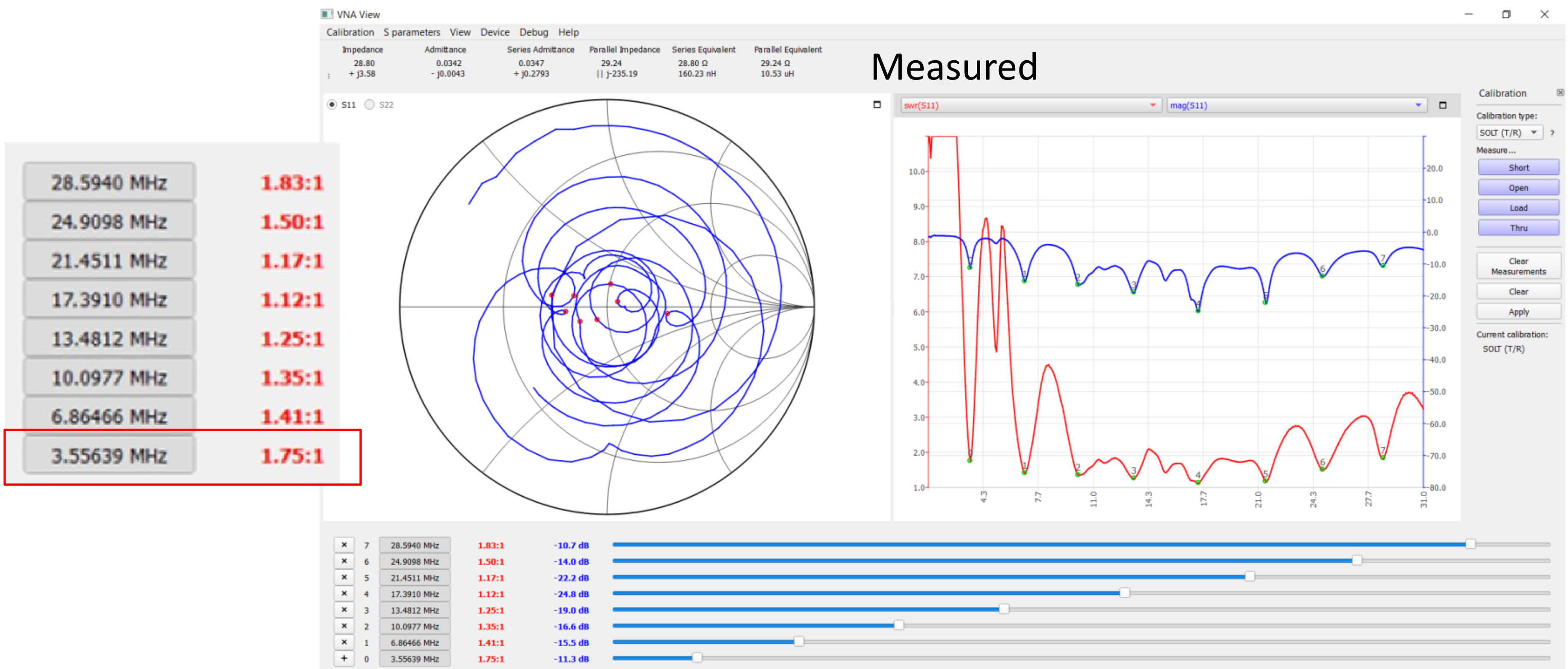
- Reduce Wire Length, Moves Red Line to the Right (and vice-versa)
- Add Series L, Moves Red Line UP (Increasingly at Higher Freq)
- Add Series C, Moves Red Line Down (Increasingly at Lower Freq)
- Optimize Location of L, C on the Wire for Specific Bands
- Counterpoise Length



DIY EFHW 80, 40, 30, 20, 18, 12

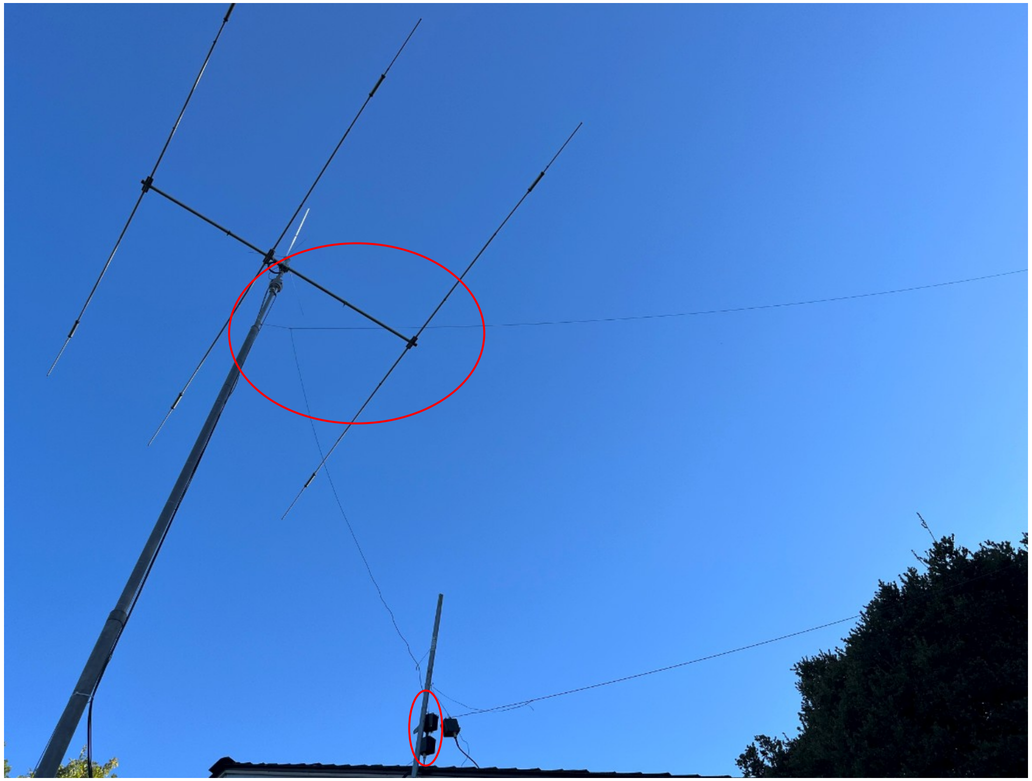
Measured SWR

- Measured with nanoVNA at end of RG8X coax cable in shack.
- Data is for 80m EFHW with 11 turn coil
- SWR at 80 m is too high...

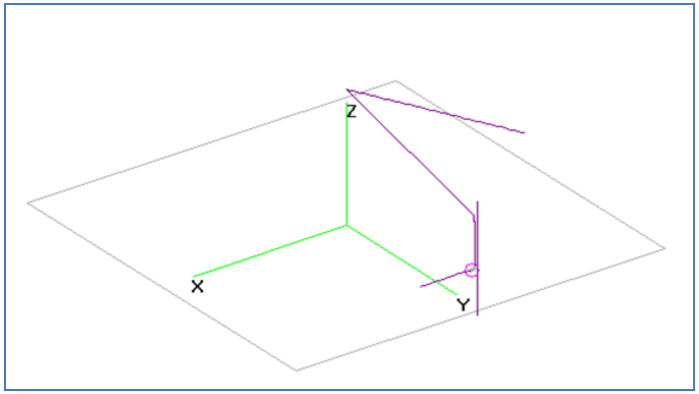


Modified EFHW 80, 40, 20, 18, 12
For Better 80, 40 SWR

- Use Existing "Pole" to Elevate Wire, Added L-shape
- Improved 80 & 40m VSWR, but Destroyed 15m
- Feedpoint: Two Black Boxes for 49:1 Unun and CM Choke.
- Single Black Box is 42:1 Unun & CM Choke for 60, 30 m EFHW

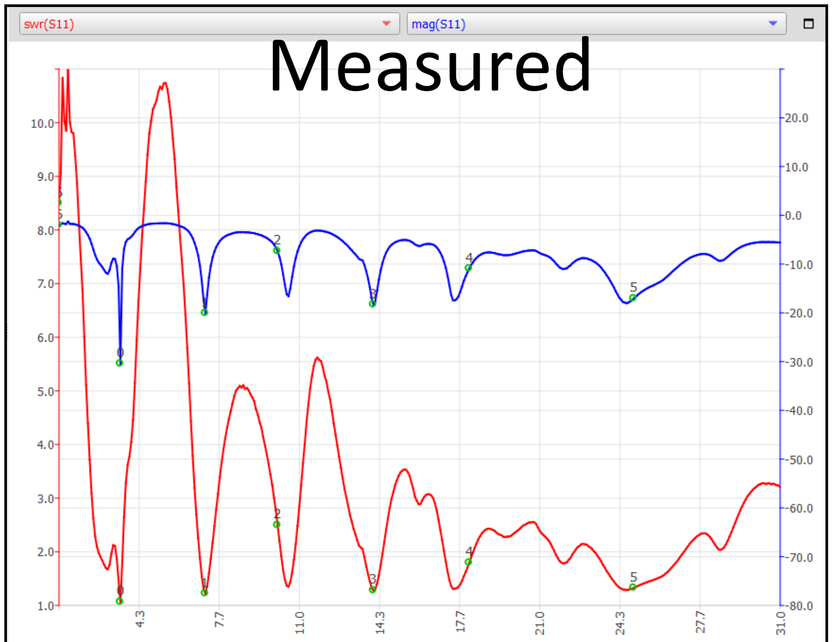


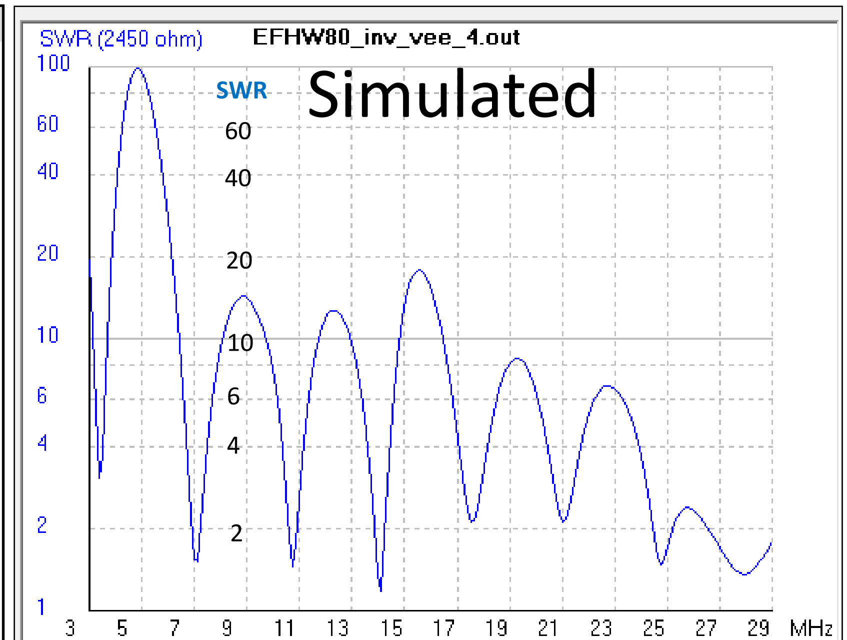
Geometry for 4NEC2 Simulation



Modified EFHW 80, 40, 20, 18, 12

- Measured the Antenna Wire with nanoVNA
  - Impedance is ~2000 for both 80 and 40 meters
- Measured SWR at 80 & 40 is 1.06:1 and 1.22:1, In the Shack
  - Agrees with Unun Measured by Itself (Opt Load Resist is 2200 ohms)





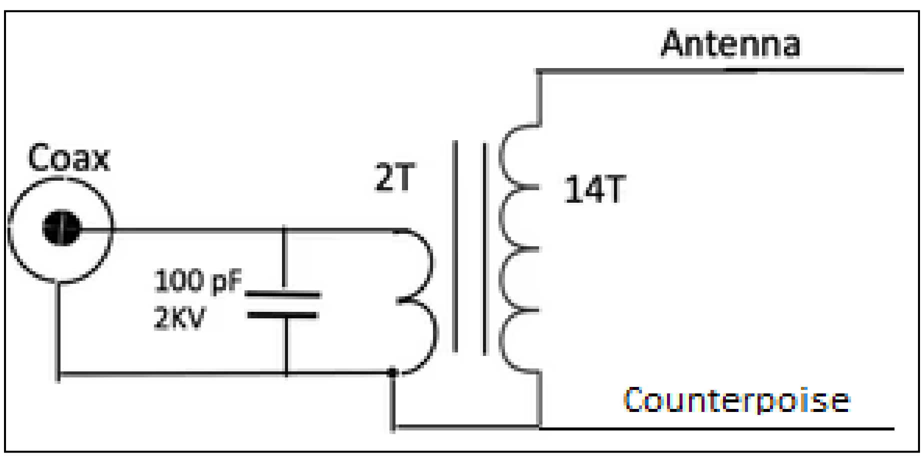
Freq MHz	SWR
3.56	1.06:1
7.09	1.22:1
14.08	1.27:1
18.06	1.79:1
24.91	1.33:1

49:1 Unun for Modified EFHW 80, 40

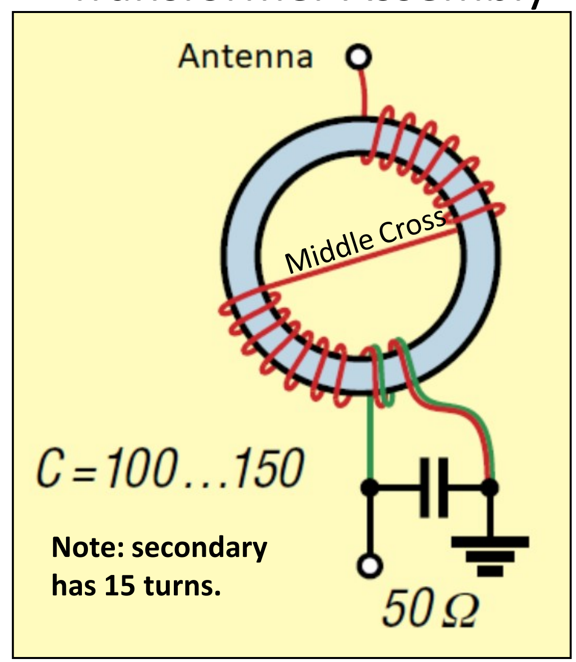
Typical Unun Transformer [1]

- 2:14 Turns Ratio → 1:49 Impedance Ratio (50 to 2450 ohms)
  - One Turn = Wire Passes Through Center of Toroid
  - Primary & Secondary Grounds are Connected
  - Capacitor Tunes out Inductance for High Freq (10 m)
  - Middle Cross is for Max Space Between Input & Output
    - And Said to Equalize Magnetic Flux in Toroid

Schematic



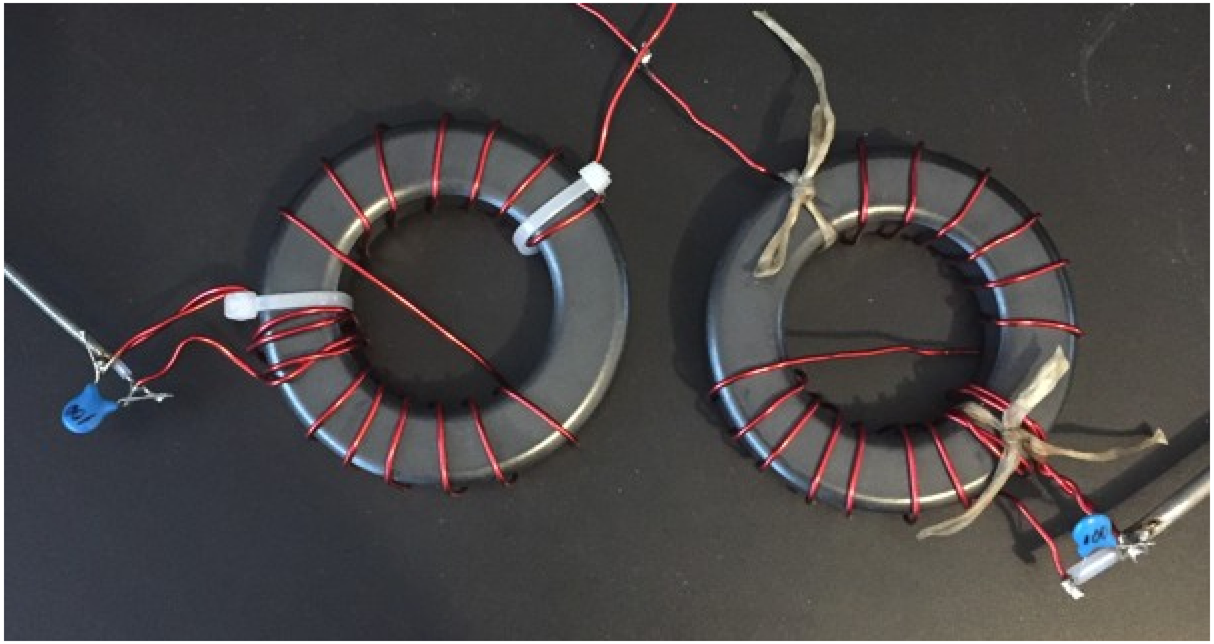
Transformer Assembly



[1] https://n7tar.org/wp-content/uploads/2023/06/The-End-Fed-Half-Wave-Antenna.pdf

49:1 Transformer Unun
Measured Insertion Loss

- Two Back-to-Back Ununs, Measure the Loss dB and Divide by Two
  - Max Loss is about 0.6 dB for two Ununs, so Each is about 0.3 dB
- High Impedance point at xfmr output is sensitive to stray capacitance
  - High output impedance causes voltage drop with small shunt capacitance
  - Package capacitance can be significant

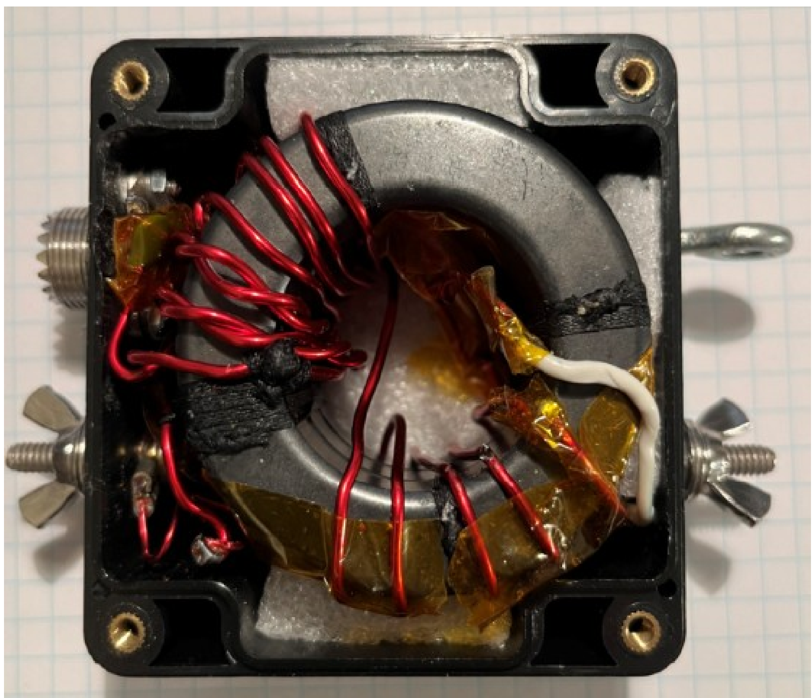


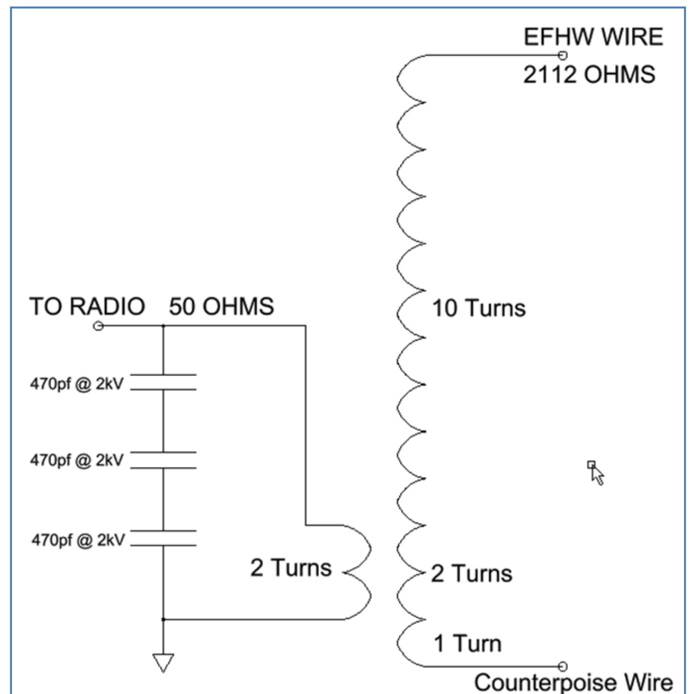
More Info: https://www.eham.net/community/smf/index.php/topic,141970.msg1331361.html#msg1331361

49:1 Unun for DIY EFHW 80, 40

Three FT240-43 Toroid Cores for 600 Watt CW

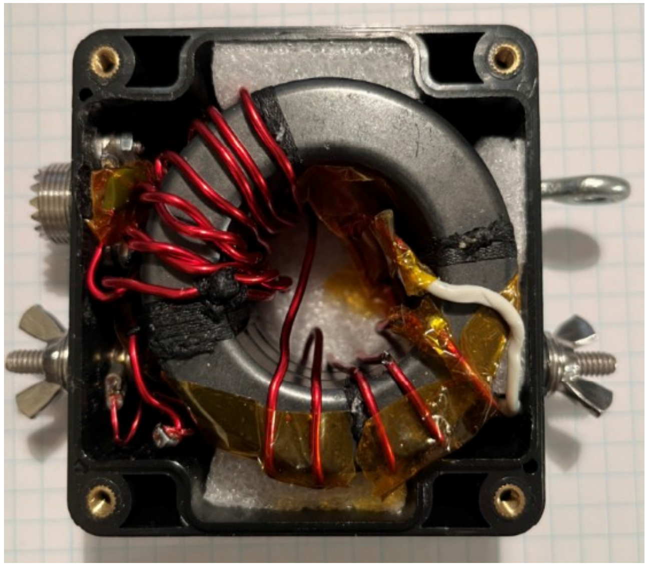
- Turns Ratio was Optimized for 80 & 40 meters
- Motto: Try Different Things!
- 2:13 turns ratio → 1:42 Impedance Ratio (50 to 2100 ohms)
- Grounds NOT Connected, Try to Reduce Conducted Noise on Coax Shield
- Added One Turn on Secondary Below the Primary Winding





49:1 Unun for EFHW 80, 40
Materials

- **Toroid**: Same as FT240-43; FAIR-RITE PRODUCTS PN 5943003801; $9.79 at Digi-Key.
- **Wire**: 14 AWG magnet wire, 20’ length, Remington Industries 14SNSP.25, Amazon, $13.93.
- **Box**: LeMotech ABS Plastic Project Box, 3.27” x 3.19” x 2.2”; Amazon $6.99 for one box.

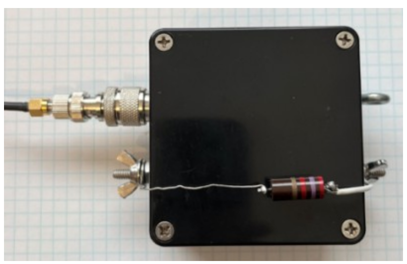


- **Great Local Suppliers:**
  - Industrial Metal Supply Co.
    569 Charcot Ave, San Jose
  - Anchor Electronics
    2040 Walsh Ave, Santa Clara

49:1 Unun for EFHW 80, 40
Impedance vs. Frequency

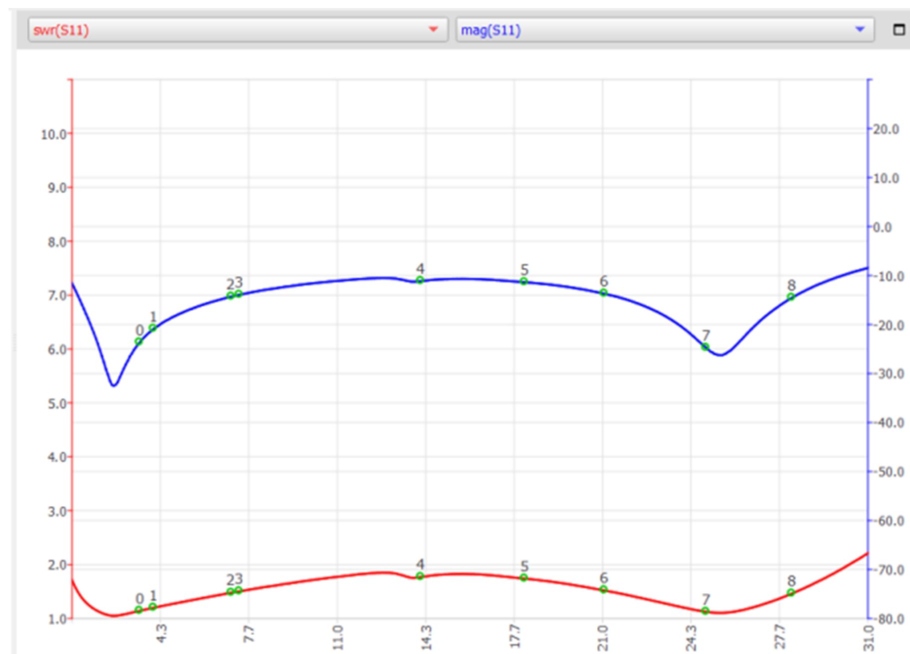
- Unun Input Impedance Measured with Various Output Resistors
  - 4700, 2700, 2200, 1000 ohms
  - Optimal Output Resistance is 2200 ohms for 80, 40 m
    - At 20 m, 1000 ohm at Output Gives Lower Input SWR
  - 2200 ohms Agrees With Measured Feedpoint Impedance of 80, 40m EFHW Wire.

Unun with 2700 ohm output resistor



28.1429 MHz	1.46:1	-14.5 dB
24.9098 MHz	1.12:1	-24.8 dB
21.0752 MHz	1.52:1	-13.7 dB
18.0677 MHz	1.74:1	-11.4 dB
14.1579 MHz	1.77:1	-11.1 dB
7.31579 MHz	1.50:1	-13.9 dB
7.01504 MHz	1.48:1	-14.3 dB
4.08271 MHz	1.20:1	-20.9 dB
3.55639 MHz	1.14:1	-23.7 dB

Measured SWR with **2200 ohm** at unun output



49:1 Transformer Unun
New Developments…

- Cylindrical 43 Cores Reported as More Efficient
  - Fair-Rite 43251002; Digikey $7.46 @ qty 1

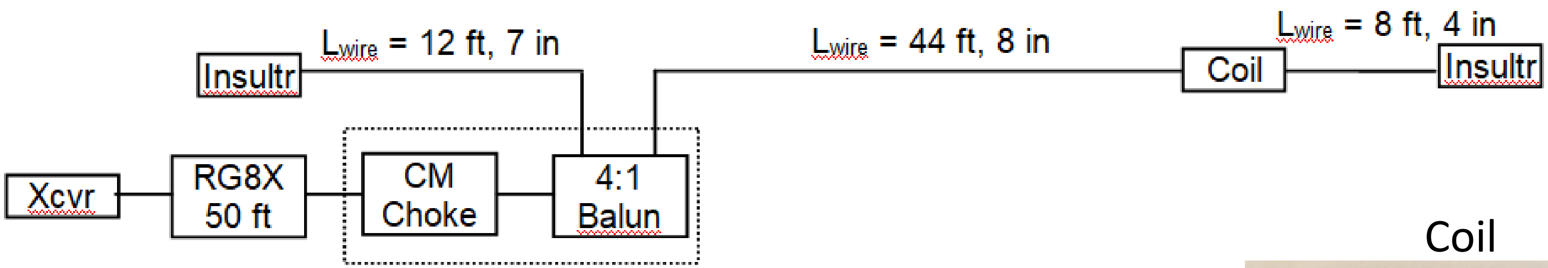
  https://www.youtube.com/watch?v=8SHvOE8dV3w

- KN5L EFHW 49:1 Unun Without Capacitor
  - Replaces Capacitor with Bifilar Wire SC Shunt Stub

  https://www.kn5l.net/kn5lEfhwUnun/

OCF Half Wave 40,20,15,10

- OCF Antenna in Back Yard, Short End Near Grnd, Long End up 30 Feet in Tree
- Stealth Antenna in a Condo Attic, Bent into a U-shape;   Works Great!



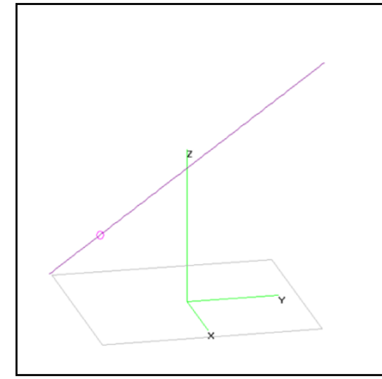
- Antenna length, Coil Turns, and Location Were Adjusted for Best VSWR on All Bands
- The Coil Allows Tuning to Both 15 and 20 m Bands

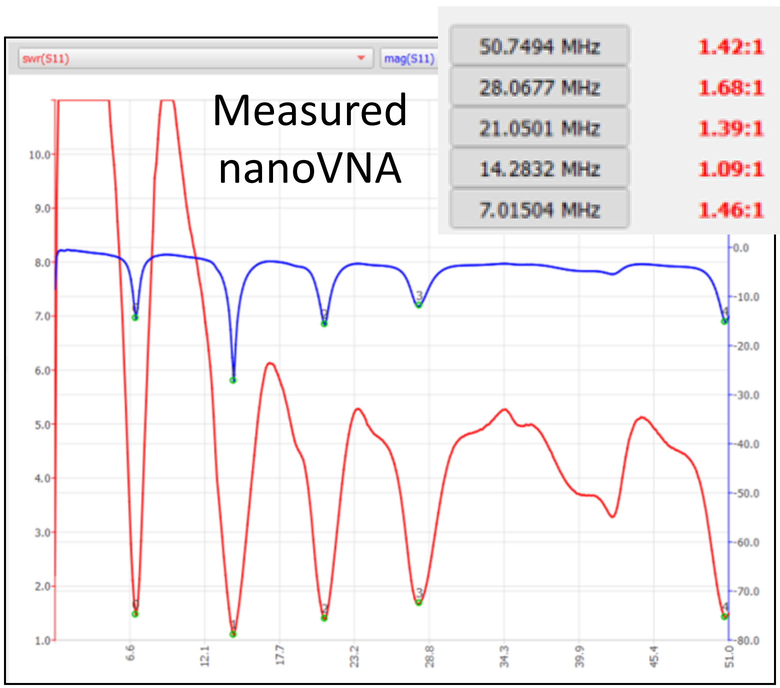
4:1 Balun/Choke

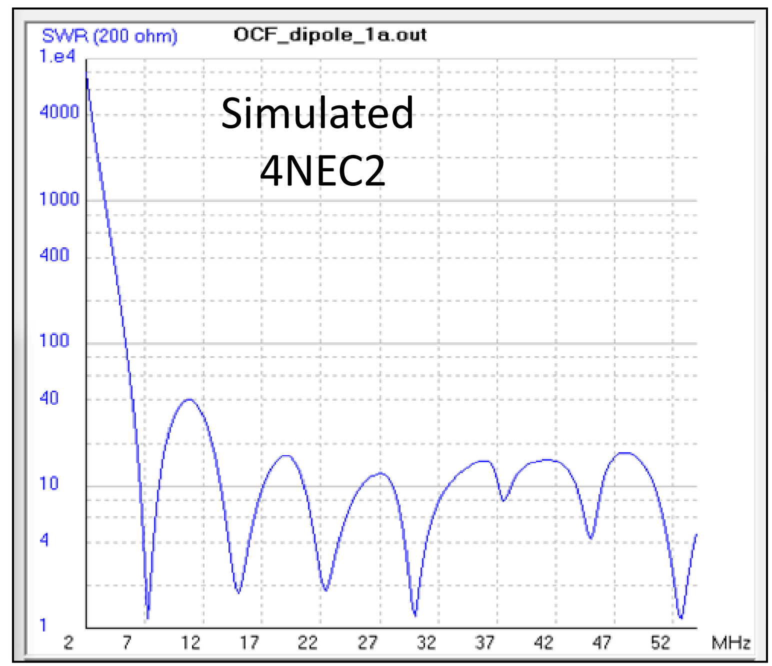
Coil

OCF Half Wave 40,20,15,10

- Measured and simulated (4NEC2) antenna SWR agree.
- Upper Right: Antenna geometry, red circle is feed point.
- Right: Simulated SWR Ref to 200 ohm impedance.
- Left: Measured SWR & Return Loss

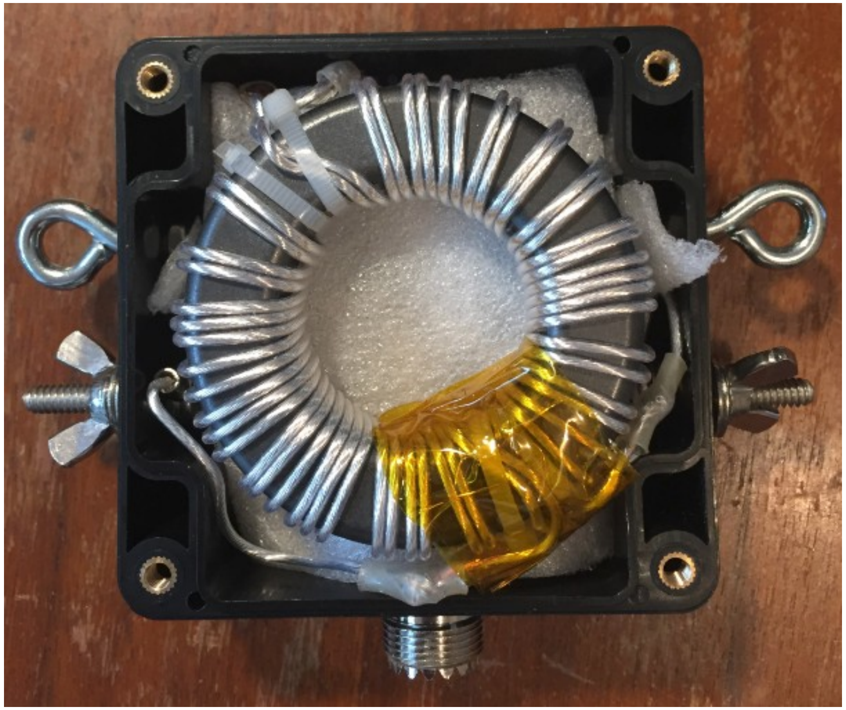






4:1 Transformer & CM Choke
For OCF Half Wave 40,20,15,10

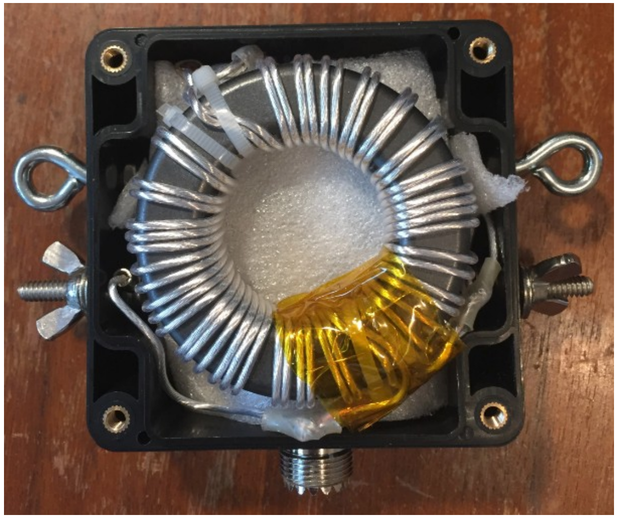
- Stacking the Toroid Cores Works Well
  - Magnetic Flux Stays Mostly Inside the Cores

4:1 Transformer & CM Choke

Materials

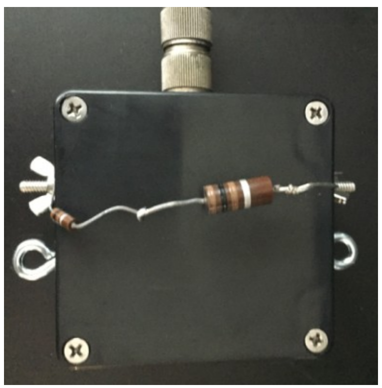
- **Toroid**: Same as FT240-43; FAIR-RITE PRODUCTS PN 5943003801; $9.79 at Digi-Key, $7 at Newark.
- **Wire**: 20 feet 18 AWG High Temperature PTGFE Silver Plated wire. Amazon $15.99.
- **Box**: LeMotech ABS Plastic Project Box, 3.27” x 3.19” x 2.2”; Amazon $6.29 for one box.

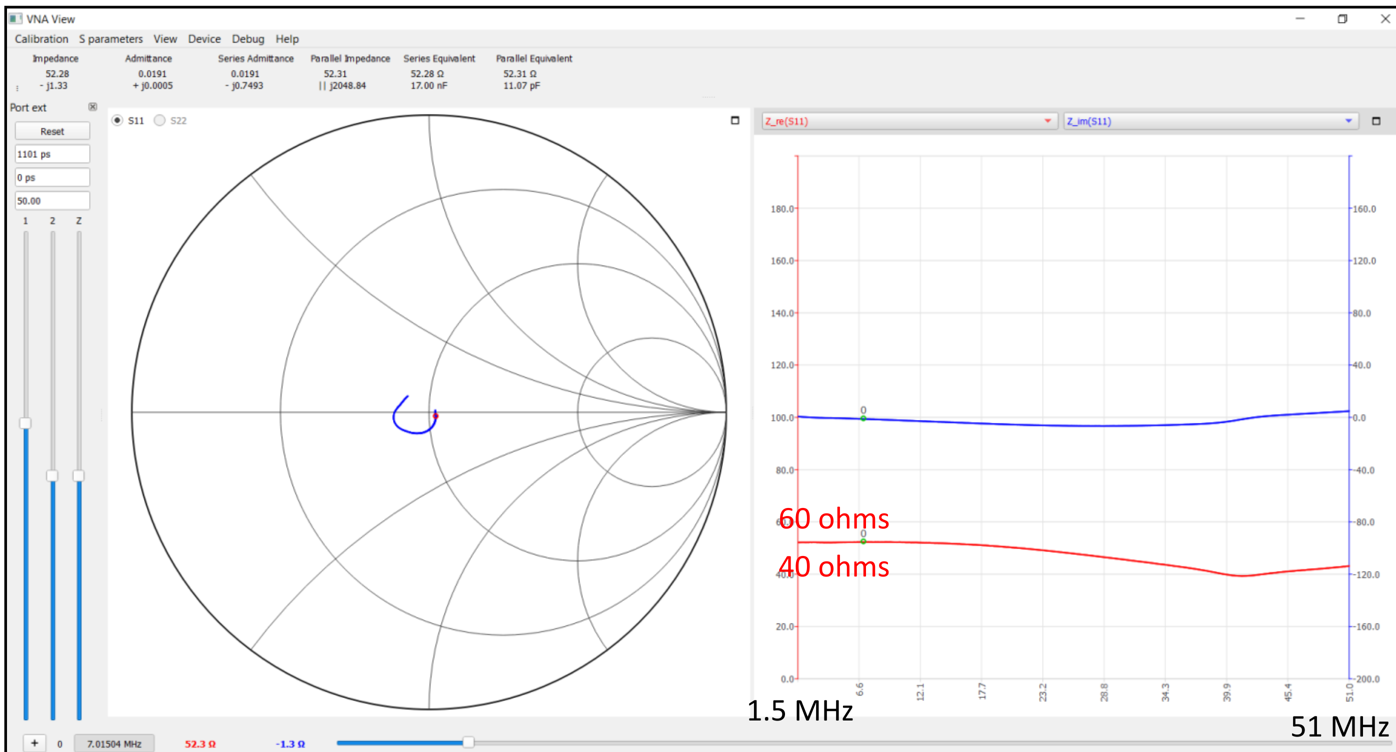


4:1 Transformer & CM Choke

Measure with nanoVNA

- Two 100 ohm Carbon Resistors in Series (Measured at 210 ohms) Across the Transformer Output (Antenna Connections).
- Measured over 1.5 – 51 MHz, Input Impedance at 7 MHz is 52 – j1.3 ohms; Smith Chart Shows Good SWR Over Full Freq Range.





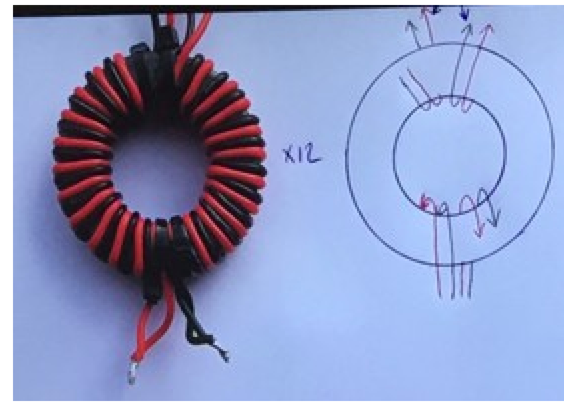
4:1 Transformer & CM Choke

Reference Used for DIY Balun/Choke

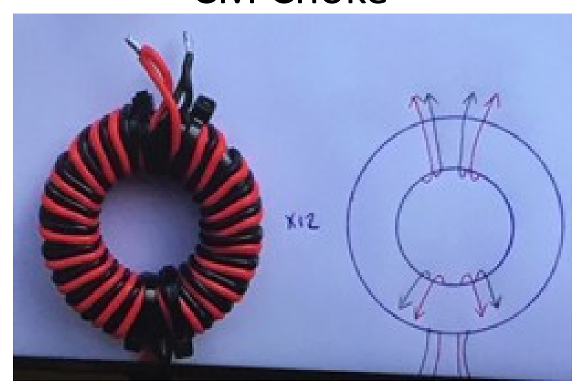
- Use Teflon Coated Wire for 100 ohm T-line Impedance
- The 50 ohm Coax From Tx/Rx Connects to the CM Choke (Bottom).
- The Choke Output Connects to the Input of the 1:4 Transformer (Middle)
- The Two Outputs of the 1:4 Transformer Connect to the OCF Antenna Wires (Top)

From YouTube: ***A Better Off-Centre Fed Dipole – Part 1***
https://www.youtube.com/watch?v=aYLseBPbxng

4:1 Transformer

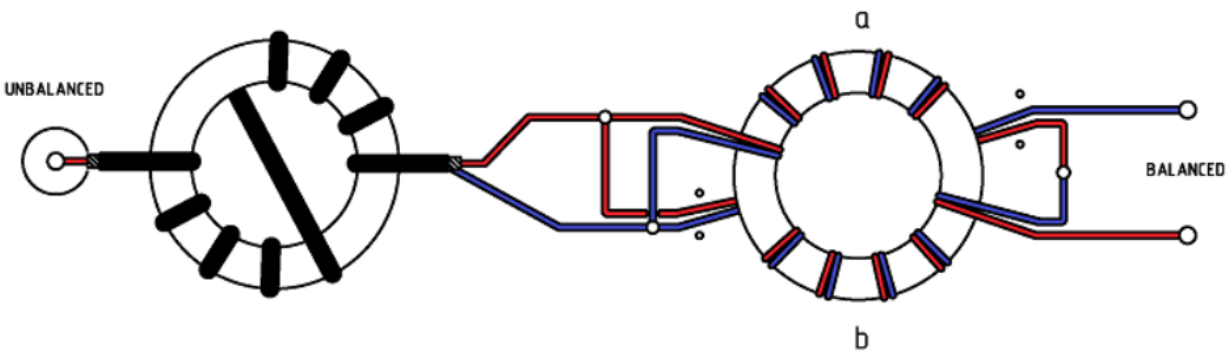


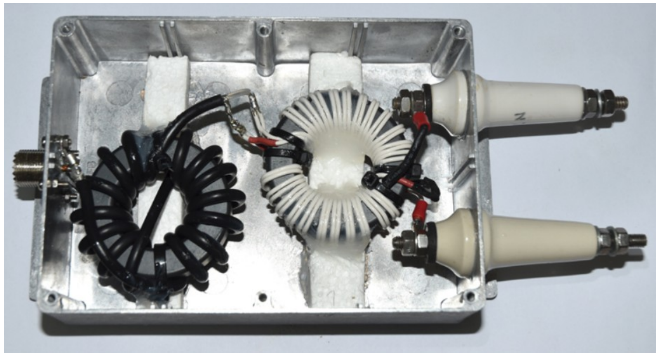
CM Choke



4:1 Transformer & CM Choke
Other Similar Examples

- Balun Designs Product: 4:1 Hybrid Balun 1.5 - 54MHz 3kW:
  - https://www.balundesigns.com/model-4116-4-1-hybrid-balun-1-5-54mhz-3kw/
- DIY Equivalent Design Article:
  - https://vk6ysf.com/hf_feed_balun_choke.htm

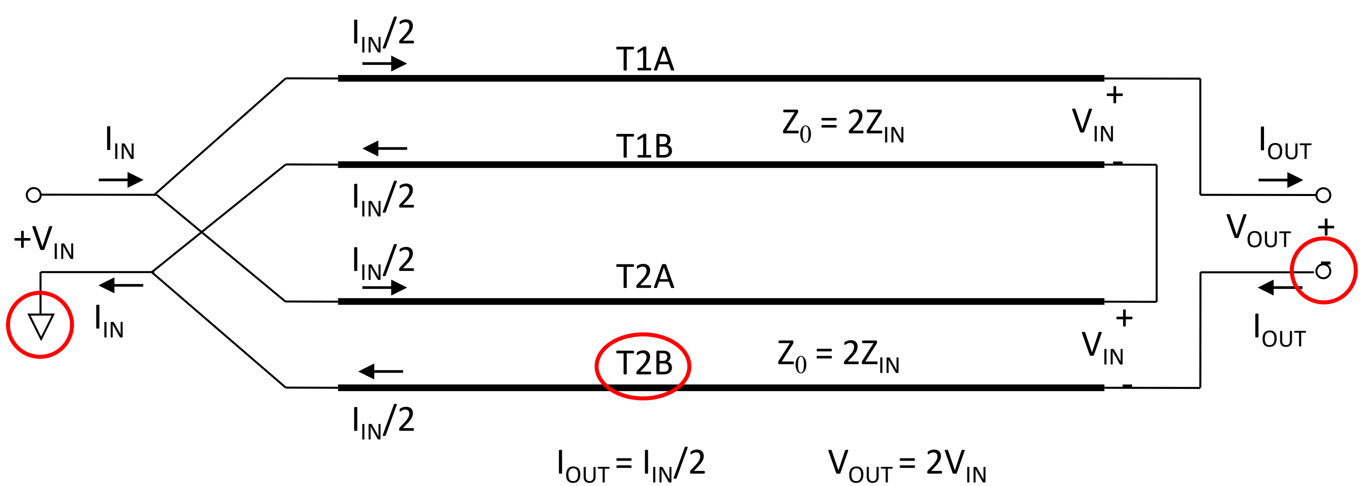




4:1 Transformer Balun – How It Works

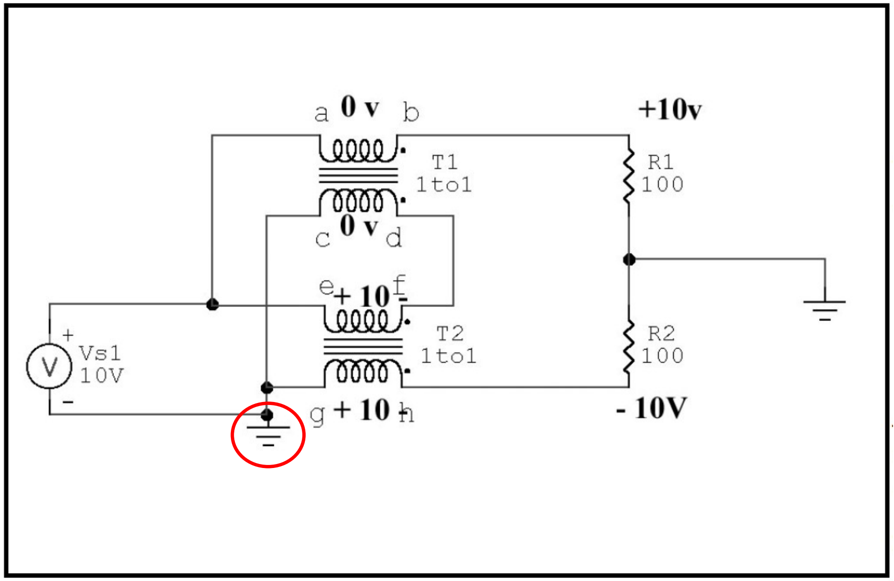
Guanella Current Balun

- 50 ohm input, 200 ohm output
- Two Transmission Lines: T1, T2 with Z0 = 100 ohms
  - Connected in Parallel at Input, Series at Output
  - $V_{OUT} = 2\ V_{IN}$; $I_{OUT} = 0.5\ I_{IN}$; so $Z_{OUT} = 4\ Z_{IN}$
- Need High Inductance in T2B to Isolate Input Ground from Output
  - Or a Common-Mode Choke to Precede the Balun



4:1 Transformer Balun
Windings on Same Core vs. Two Different Cores

- If the 1:4 xfmr input is single ended (has a ground connection), then the two windings need separate cores to function as a Balun.
  - www.w8ji.com/balun_single_core_41_analysis.htm.
- But, if a CM choke is placed before the 1:4 balun, to isolate the balun from ground, then both windings can be on a single core, and adjust to unbalanced OCF wires.



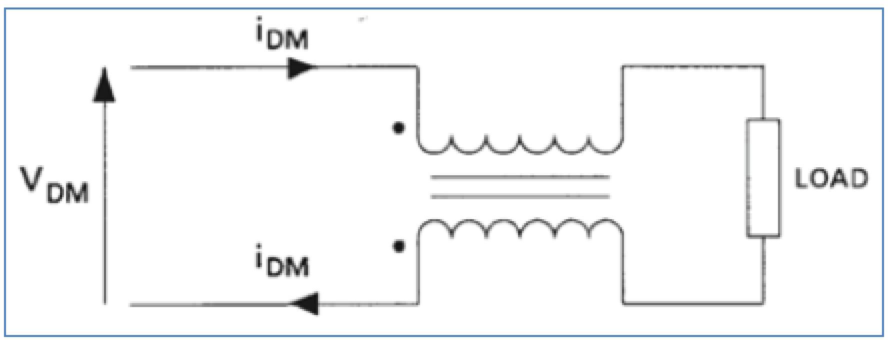
The schematic shows single ended input and balanced output. Notice the voltages across the two transformers are not equal, so they require different magnetic flux through the windings, which in turn requires separate cores. Isolating the input from ground with CM choke allows voltages at C and G to float, allowing equal voltages across the transformers, and thus same flux.

Common-Mode Choke

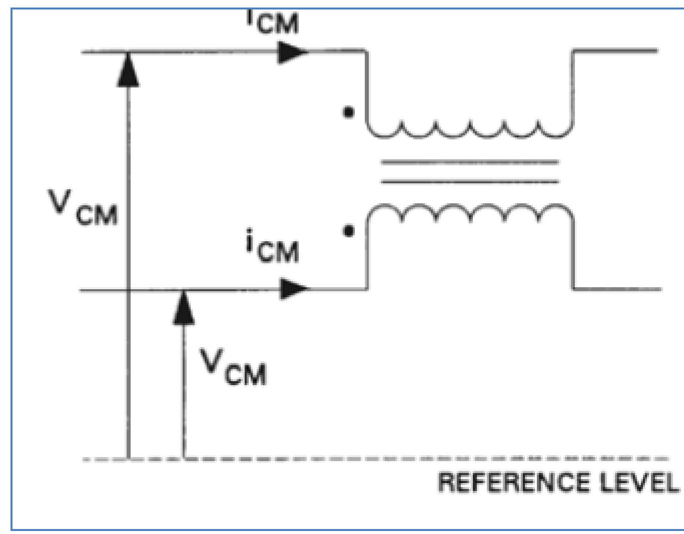
Differential-Mode & Common-Mode

- Differential-Mode (Balanced) is Equal and Opposite Currents in Each Line
- Common-Mode is Equal Currents in Same Direction in Each Line
- Unbalanced (Generally BAD) is a Combination of Differential- and Common-Mode
- A Common-Mode Choke Passes the Differential-Mode and Isolates Common-Mode [3]
  - Core Flux Adds in Common-Mode Causing High Inductive Reactance; Flux Cancels in Diff-Mode

Differential-Mode



Common-Mode



[3] Figs 17, 18 of:
https://www.pulseelectronics.com/wp-content/uploads/2020/12/Introduction-Transformer-Magnetics.pdf

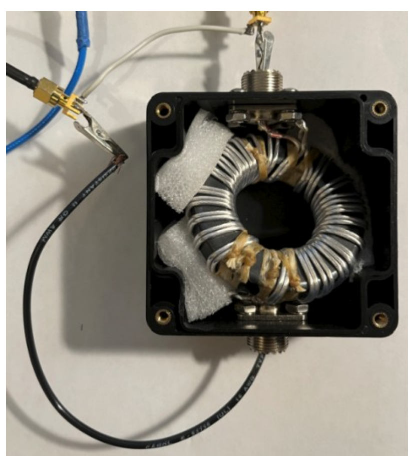
Common-Mode Choke
Measured Loss & Common-Mode Isolation

- Measure CM Rej: nanoVNA P1+ to + Input, P2+ to + Output, No Gnd Connectns
  - Get same CM Isolation Measured Gnd-Gnd or Centr-Centr.
- Guanella Choke has similar loss, but about 10 dB Better Isolation than Coax Choke

	Insertion Loss dB			CM Isolation dB		
Description	**2 MHz**	**14 MHz**	**51 MHz**	**2 MHz**	**14 MHz**	**51 MHz**
Guanella CM Choke	.1	.1	.04	22.7	37	27.6
Coaxial CM Choke	.1	.1	.1	15.1	26.5	15.5

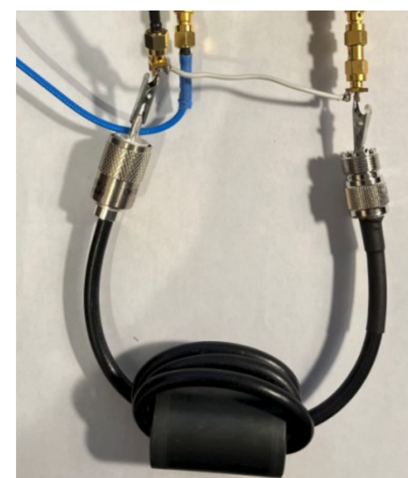
Guanella Choke

12 turns #18 Ag plated Cu teflon insulation, Fair-Rite 5943003801, 43mtl



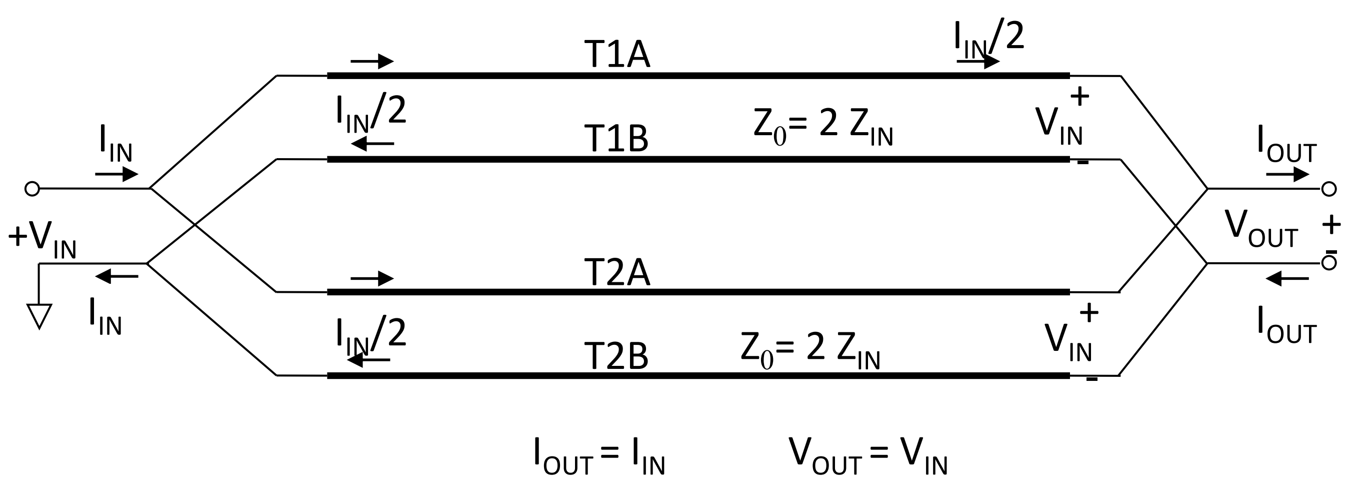
Coaxial Choke

4 turns RG8X on Fair-Rite 2631103002, 31mtl



Common-Mode Guanella Choke
How It Works

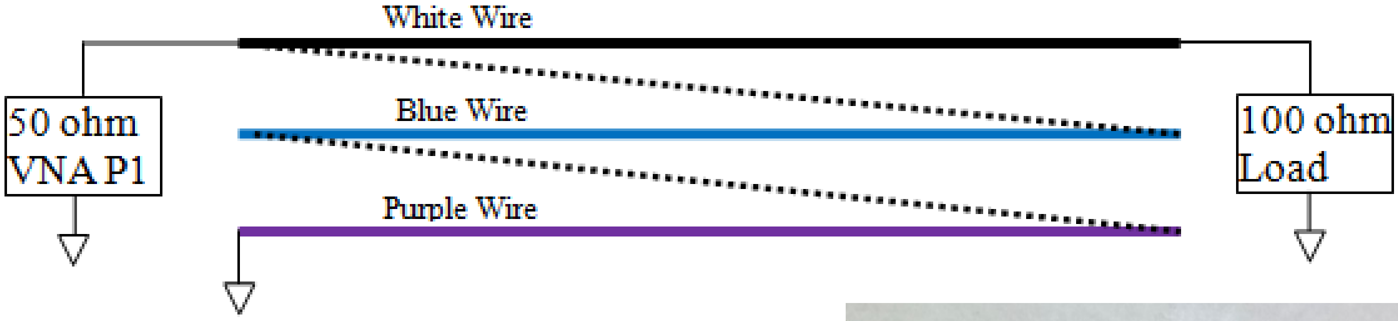
- 50 ohm Input & Output
- Two Transmission Lines: T1, T2 with Z0 = 100 ohms
  - Connected in Parallel at Input and Output
  - Magnetic Flux in Core
    - Cancels for Differential Input & Output, LOW Inductive Reactance, Low Loss
    - ADDs for Common Mode, HIGH Inductive Reactance, Open Ckt
- For Single T-line choke see Figures 17, 18 of:
  - https://www.pulseelectronics.com/wp-content/uploads/2020/12/Introduction-Transformer-Magnetics.pdf

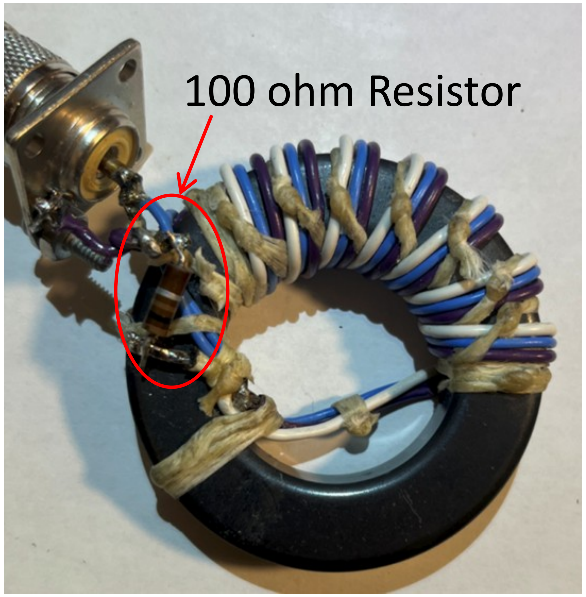


2:1 Ruthroff Transformer Unun

50 to 100 ohm

- Schematic of 50 to 100 ohm transformer. Seven turns of trifilar wire closely wrapped on a FT240-43 type toroid core.
- 2:3 turns ratio = 4:9 ≈ 1:2 Impedance Ratio, Giving 50 to ~100 ohm

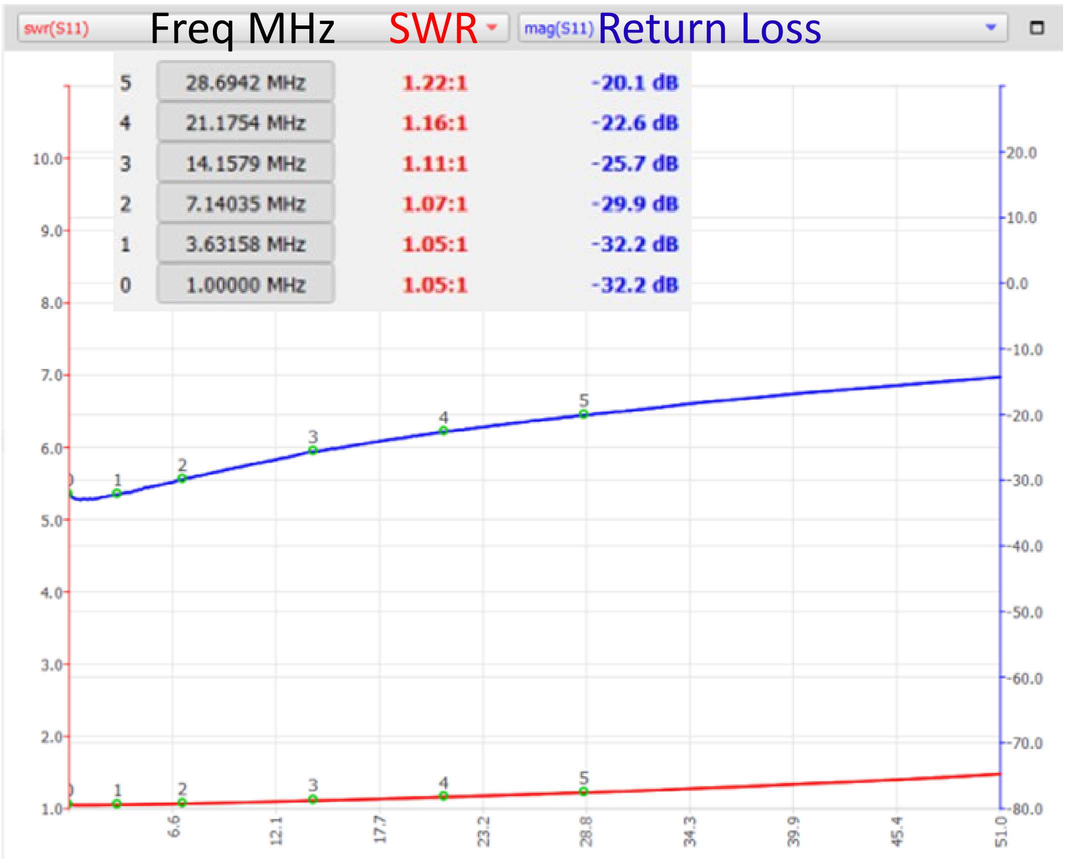




2:1 Ruthroff Transformer Unun

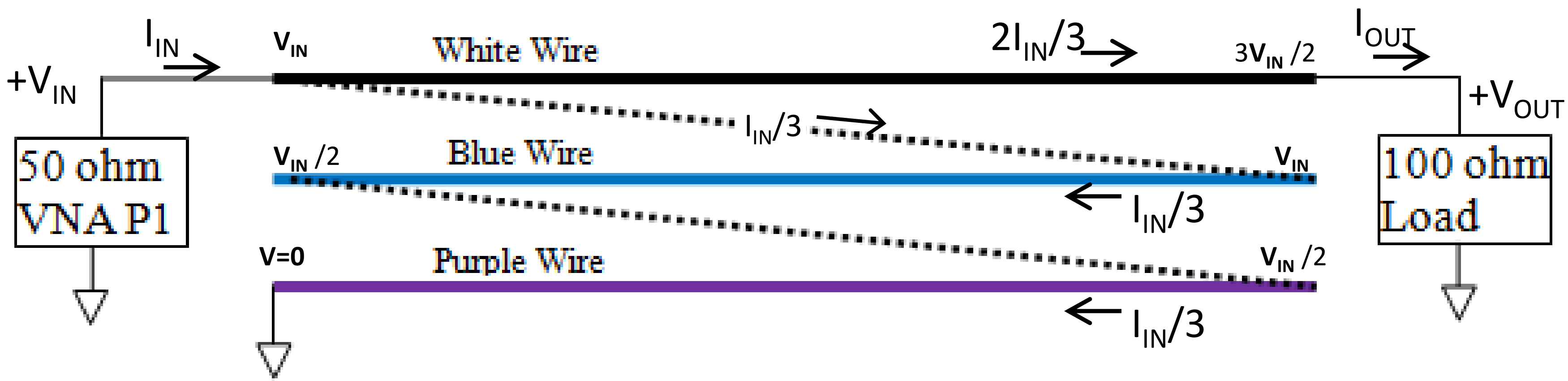
50 to 100 ohm

- Measured Return Loss and SWR with output: 100 ohm resistor
- Measured Loss is 0.1 dB at 3.5 MHz, and 0.15 dB at 29 MHz.
  - (IL Estimated at Half the RL with short or open at output).



2:1 Ruthroff Transformer Unun

50 to 100 ohm – How It Works



- $V_{OUT} = (3/2)V_{IN}$, due to 3:2 turns ratio, and equal mag flux in each wire
- $I_{OUT} = (2/3)I_{IN}$, by conservation of energy since $I_{OUT}\ V_{OUT} = I_{IN}\ V_{IN}$
- $Z_{OUT} = V_{OUT}\ /\ I_{OUT} = (9/4)\ Z_{IN}$
- Current in each wire is as shown above. Half the current in White wire couples to current in Blue wire, and the other half couples to Purple wire.
- Z0 Impedance for both T-lines (White/Blue, White/Purple) is
  - (White-Blue) $Z_0 = (V_{IN}\text{-}V_{IN}/2)\ /\ (I_{IN}/3) = (3/2)Z_{IN}$ = **75 ohms**.
  - (White-Purple) $Z_0 = (V_{IN}\text{-}0)\ /\ (I_{IN}/3) = (3)Z_{IN}$ = **150 ohms**.

2:1 Impedance Ratio Unun
Dr. Sevick on Ruthroff Transformers

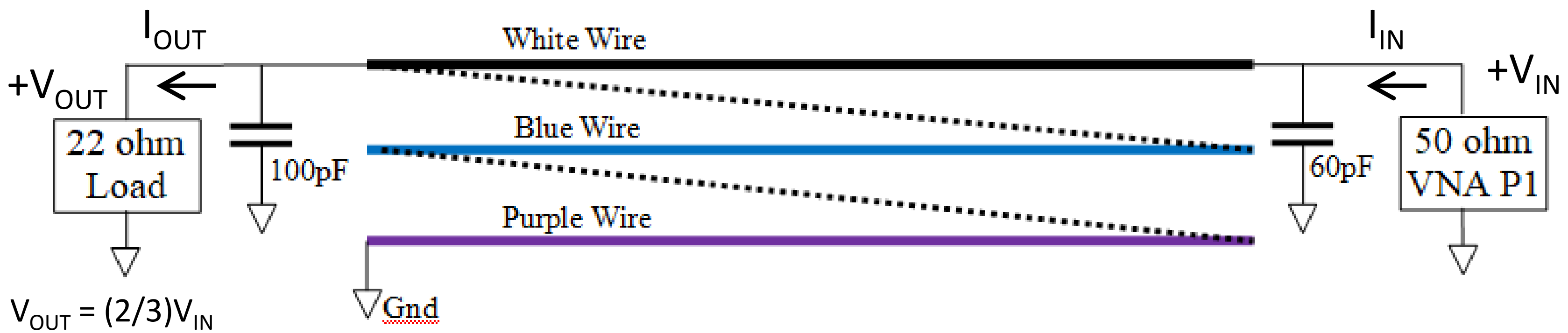
- **From Jerry Sevick re Benefits of High Permeability Core (eg type 43):**
  - Good for low freq response because it increases shunt inductance to ground.
  - Good for high freq response because fewer turns are needed, which in turn reduces the voltage delay between wires.
  - Ref: https://www.highfreqelec.summittechmedia.com/Jan05/HFE0105_Sevick.pdf
    - https://www.highfrequencyelectronics.com/Jan10/HFE0110_DesignNotes.pdf

- **Classic Books:**
  - Sevick, *Transmission Line Transformers*: https://www.okdxf.eu/files/Noble%20Publishing%20-%202001%20-%20Transmission%20Line%20Transformers,%204ed.pdf
  - Sevick, *Amidon – Transmission Line Transformer Handbook*: http://www.introni.it/pdf/Amidon%20-%20Transmission%20Line%20Transformers%20Handbook.pdf

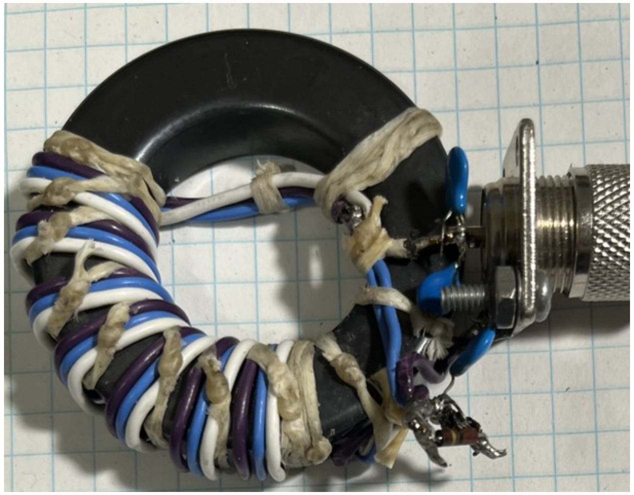
2:1 Impedance Ratio Ruthroff Unun

50 to 25 ohm

- 3:2 turns ratio gives 9:4 impedance ratio (≈ 2:1)
- Schematic of 50 to 22 ohm transformer. Seven turns of trifilar wire closely wrapped on a FT240-43 toroid core.
- Different T-line Z0 for 50 to 25 ohms, vs. for 50 to 100 ohm load.

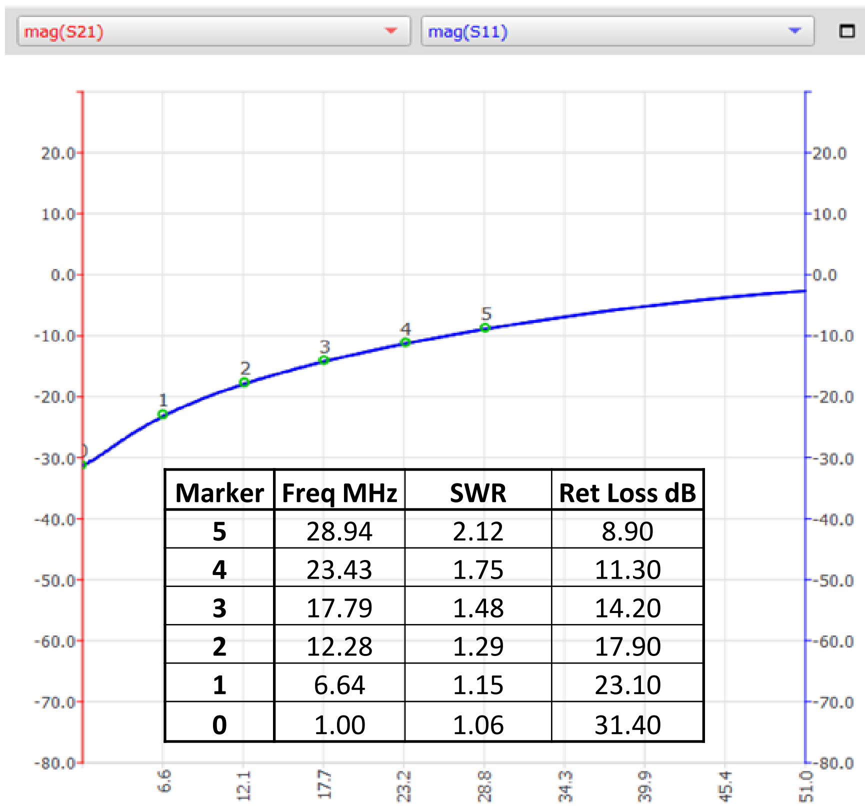


- Z0 Impedance for both T-lines, ($Z_{IN} = 50$):
  - (White-Blue) $Z_0 = V_{IN}\,(1\text{-}2/3)/(I_{IN}/2) = (2/3)Z_{IN}$ = **33 ohms**.
  - (White-Purple) $Z_0 = V_{IN}\,(1\text{-}1/3)/(I_{IN}/2) = (4/3)Z_{IN}$ = **67 ohms**.
  - Needs shunt C at 22 ohm Load; to compensate T-line Z0 that is too high.



2:1 Impedance Ratio Ruthroff Unun
50 to 25 ohm

- Measured Return Loss with output 22 ohm resistor in parallel with 100 pF cap
- Same Return Loss as 50-100 ohm Unun at Low Freq, but Worse at High Freq

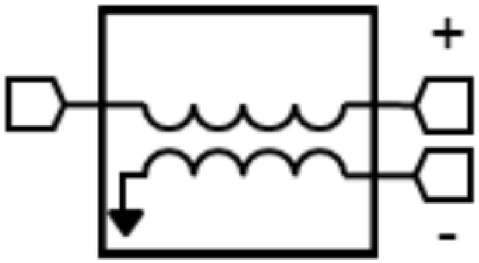


Marker	Freq MHz	SWR	Ret Loss dB
5	28.94	2.12	8.90
4	23.43	1.75	11.30
3	17.79	1.48	14.20
2	12.28	1.29	17.90
1	6.64	1.15	23.10
0	1.00	1.06	31.40

Voltage vs Current Balun

Current Balun

- Operates by forcing equal and opposite currents on the balanced lines due to magnetic flux in core, eliminating common-mode currents, [1,3,4] regardless of the differential output impedances. [2]



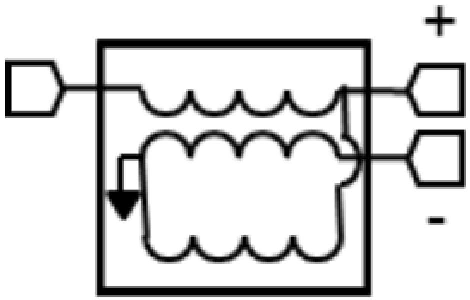
'Current' Balun

[1] https://blog.minicircuits.com/demystifying-transformers-baluns-and-ununs/
[2] https://markimicrowave.com/technical-resources/application-notes/current-vs-voltage-baluns/
[3] https://www.pulseelectronics.com/wp-content/uploads/2020/12/Introduction-Transformer-Magnetics.pdf
[4] https://www.eznec.com/Amateur/Articles/Baluns.pdf

Voltage vs Current Balun

Voltage Balun

- Voltage Balun "Boot Straps" the Voltage by Adding Turns.
- Forces Equal Voltage on Each Balanced Line
- The Voltage Balun Shown is a Compensated Version of the 1:1 Current Balun. It is Described as a Voltage Balun, Since the Extra Line Forces the Voltages at the Output to be Equal and Opposite, Regardless of Unequal Output Impedances. [2,3]



'Voltage' Balun

[1] https://blog.minicircuits.com/demystifying-transformers-baluns-and-ununs/
[2] https://markimicrowave.com/technical-resources/application-notes/current-vs-voltage-baluns/
[3] https://www.eznec.com/Amateur/Articles/Baluns.pdf

Conclusion

- Half Wave Wire Antenna Summary
- EFHW 80, 40, 20, 17, 12 49:1 Unun
- OCF HW 40, 20, 15, 10 4:1 Balun & CM Choke
- Unun 2:1 1-51 MHz
- Current vs. Voltage Transformers

Thank You!