

Build Your Own DIY Wire Antennas: End Fed, Off-Center-Fed, Baluns and Ununs

Foothill Amateur Radio Society (FARS)

December 13, 2024

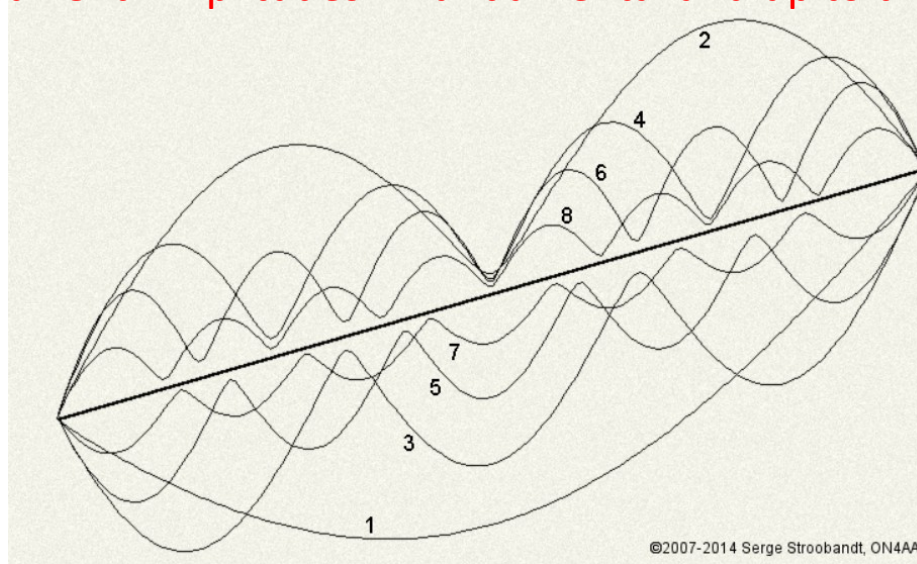
Bert Henderson, W6MSD

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

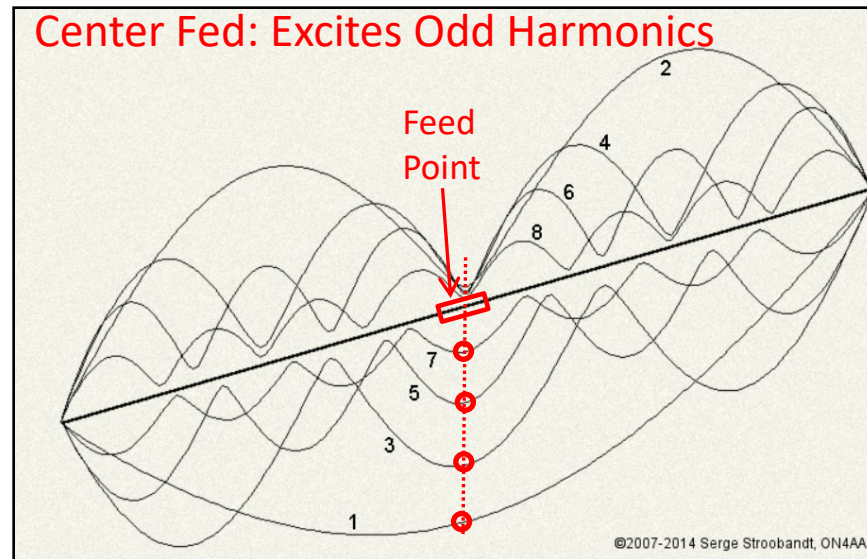
- Current in the wire causes radiation (and vice versa; they exist together)
- Current appears in standing waves on a half wave wire, due to reflections of voltage and current waves at the open circuit ends.
- Current in a Half Wave Wire :
 - Even Harmonics, Current is Almost zero in the Middle of the wire
 - Odd Harmonics, Current is Maximum in the middle
 - All Harmonics, Current is Almost Zero at the wire end points
- Below depicts peak current amplitudes for first eight harmonics in an antenna wire [1]
Depiction of Peak Current Amplitudes – Fundamental and up to the Eighth Harmonic



Half Wave Wire Antenna

Center-Fed

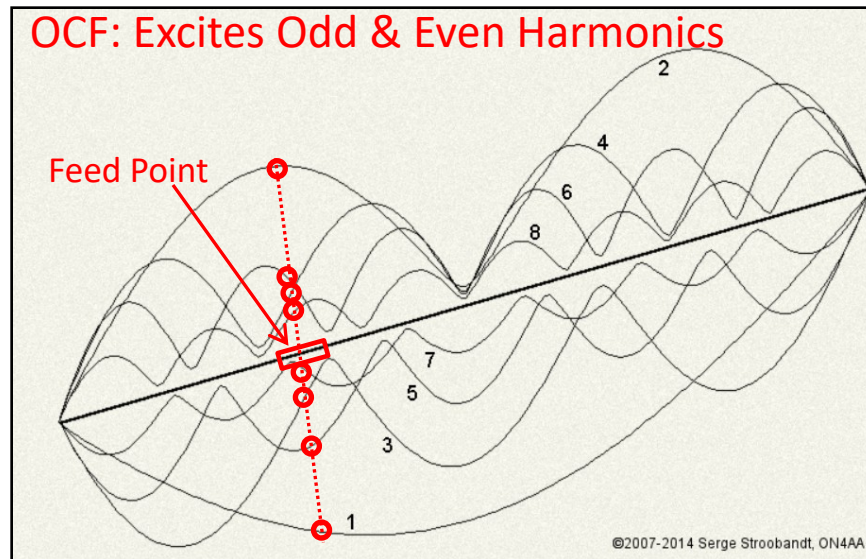
- Only Odd Harmonics, Even Harmonics are Null
 - Eg, 40 Meter Dipole Works on 15 m, but not 20 m
- Typical Feedpoint Impedance is 40-73 ohms
 - Matches to Coaxial Cable
- Nice Radiation Pattern, Broadside to Wire
- Easy to Install, Elevate at Both Ends, Feedline in Middle



Half Wave Wire Antenna

Offset Center Fed (OCF)

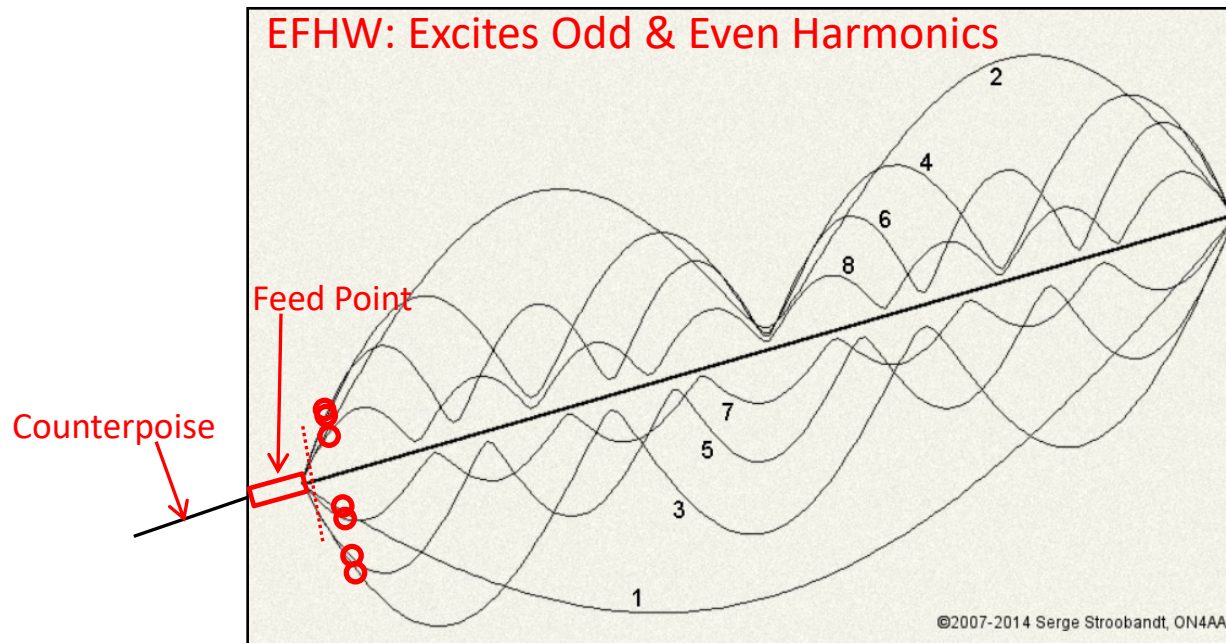
- Odd & Even Harmonics - MULTI-BAND - Radiation Pattern may be Poor
- Typical Feedpoint Impedance is ~ 200 ohms, About 1/3 From the End
- Very Popular, Seem to Have Lower RF-in-Shack Than EFHW
- Some Variations:
 - “Slightly OCF Dipole” <https://fivecountyhre.org/a-slightly-off-center-fed-dipole/>
 - “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>

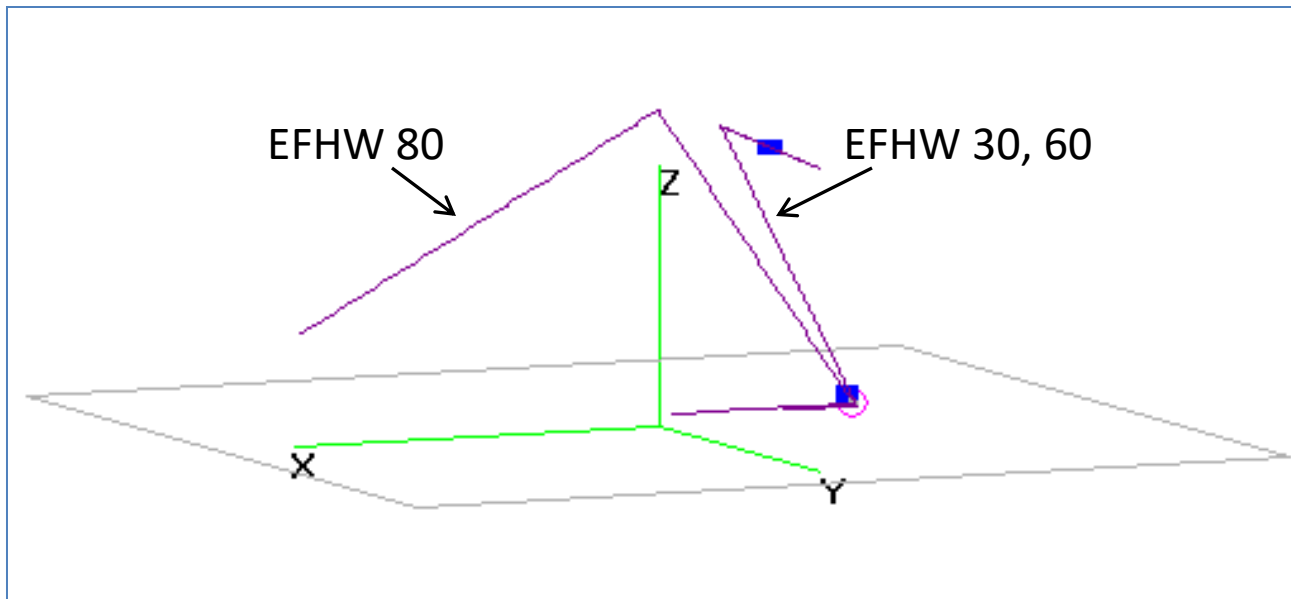
DIY EFHW 80, 40, 30, 20, 18, 12

- 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: $L_{\text{FEET}} = 468 / F_{\text{MHz}}$
- Adjusted the Wire Length and Added Coil for Best SWR on All the Bands



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

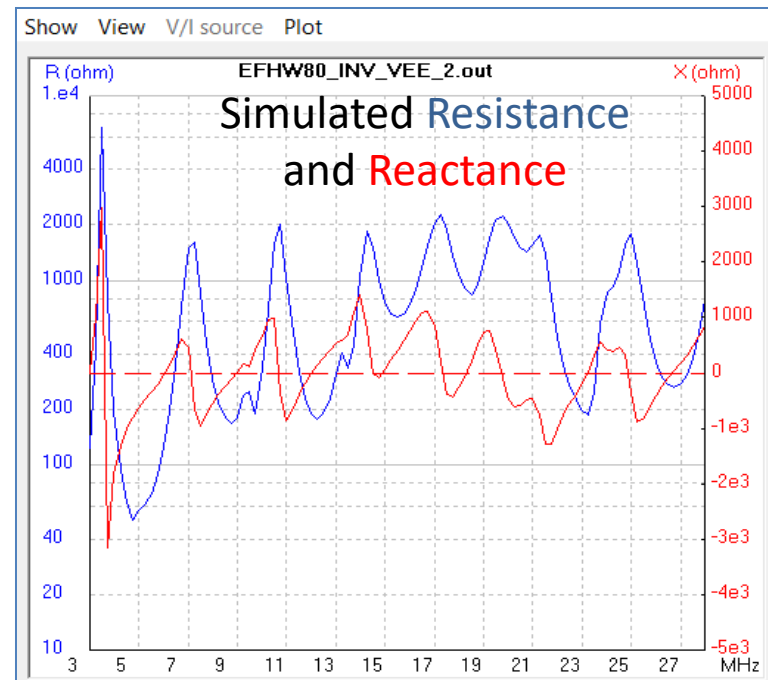
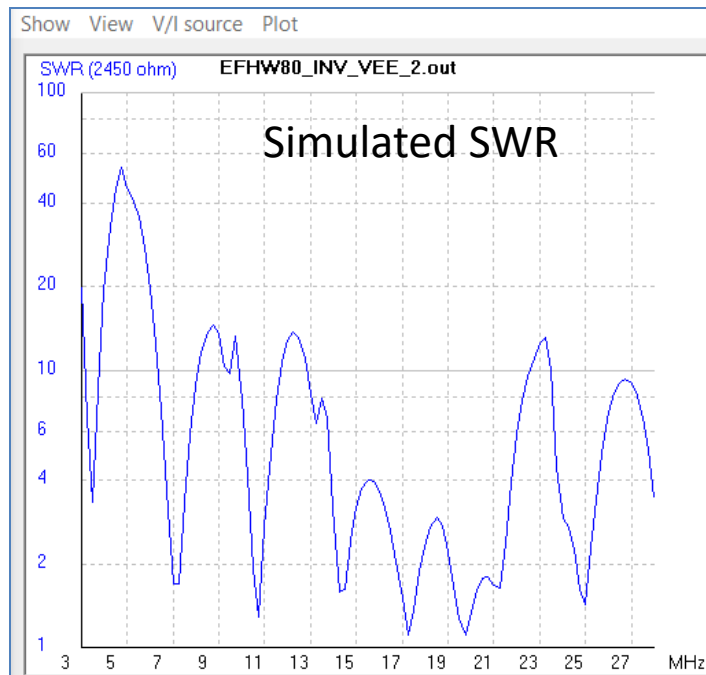
- Simulated with 4NEC2 - Results Generally Agree With Measured
- The EFHW 80 Inverted-V is on the Left
- An EFHW 30, 60 is on Right; Minimal Interaction Between Them
- Feedpoint is Red Circle, Blue Squares are Loading Coils



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

4NEC2 Simulated Results

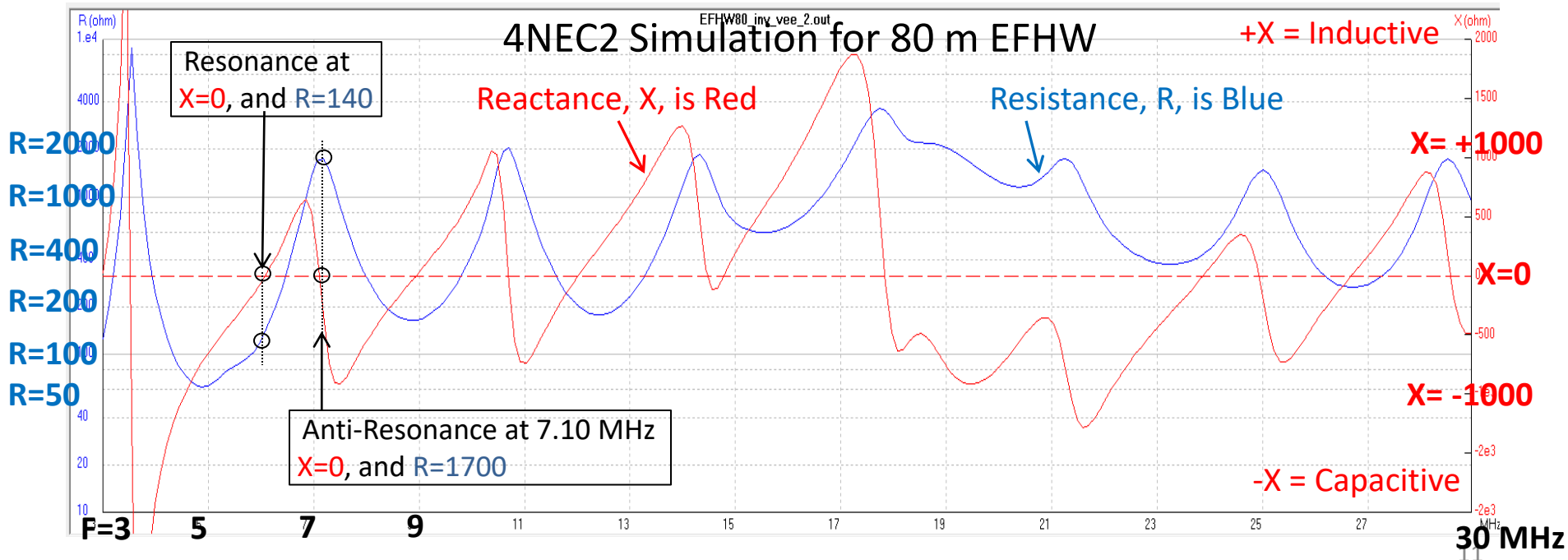
- Plot on Left is SWR referenced to 2450 ohms
- Plot on Right is Feedpoint Resistance (Blue), Reactance (Red) in ohms
 - Input Resistance at 80 m ~6000 ohms, Other Bands ~2000 ohms
 - Tricky to Impedance Match at 80 m, and All The Other Bands



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

Resonance & Anti-Resonance

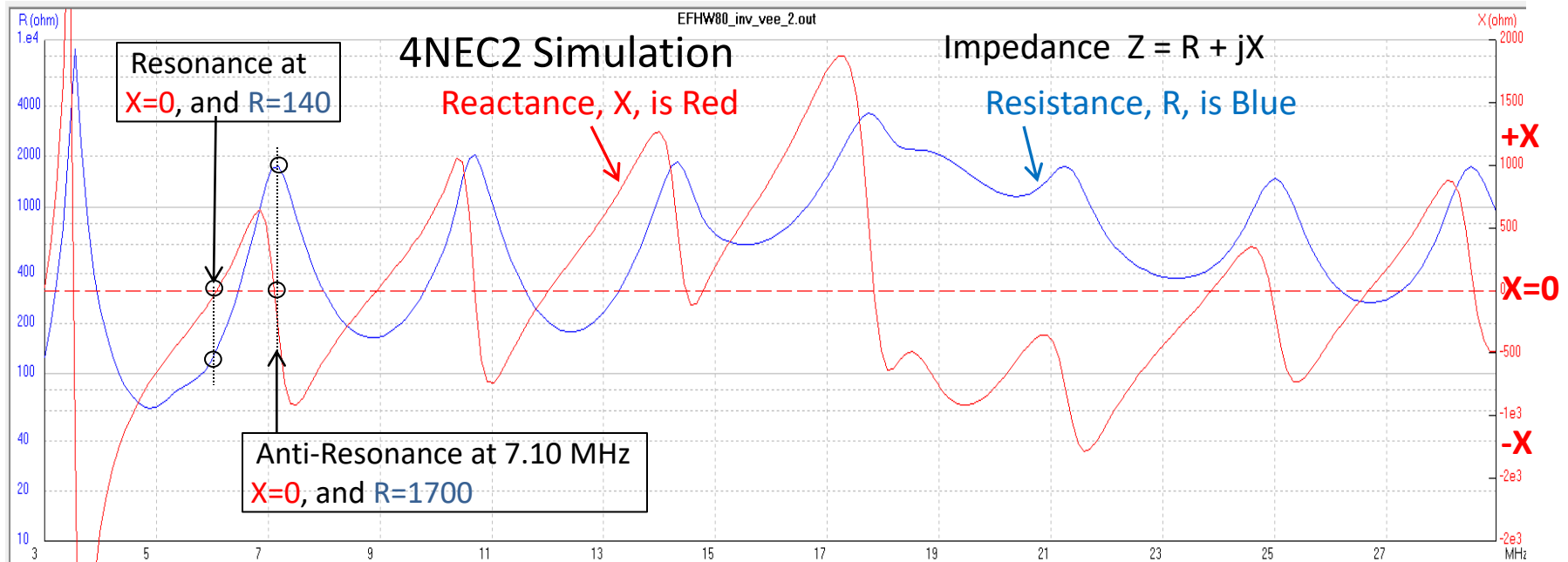
- Both Occur at Reactance, $X = 0$; Impedance $Z = R + jX$
- Anti-Resonance
 - Reactance has Negative Slope (Inductive to Capacitive)
 - Resistance is High (~2500 ohms) so Good for EFHW
- Resonance
 - Reactance has Positive Slope (Capacitive to Inductive)
 - Resistance is Low (50-200 ohms), so good for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



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

Antenna Tuning “Levers” → Low SWR on ALL Bands

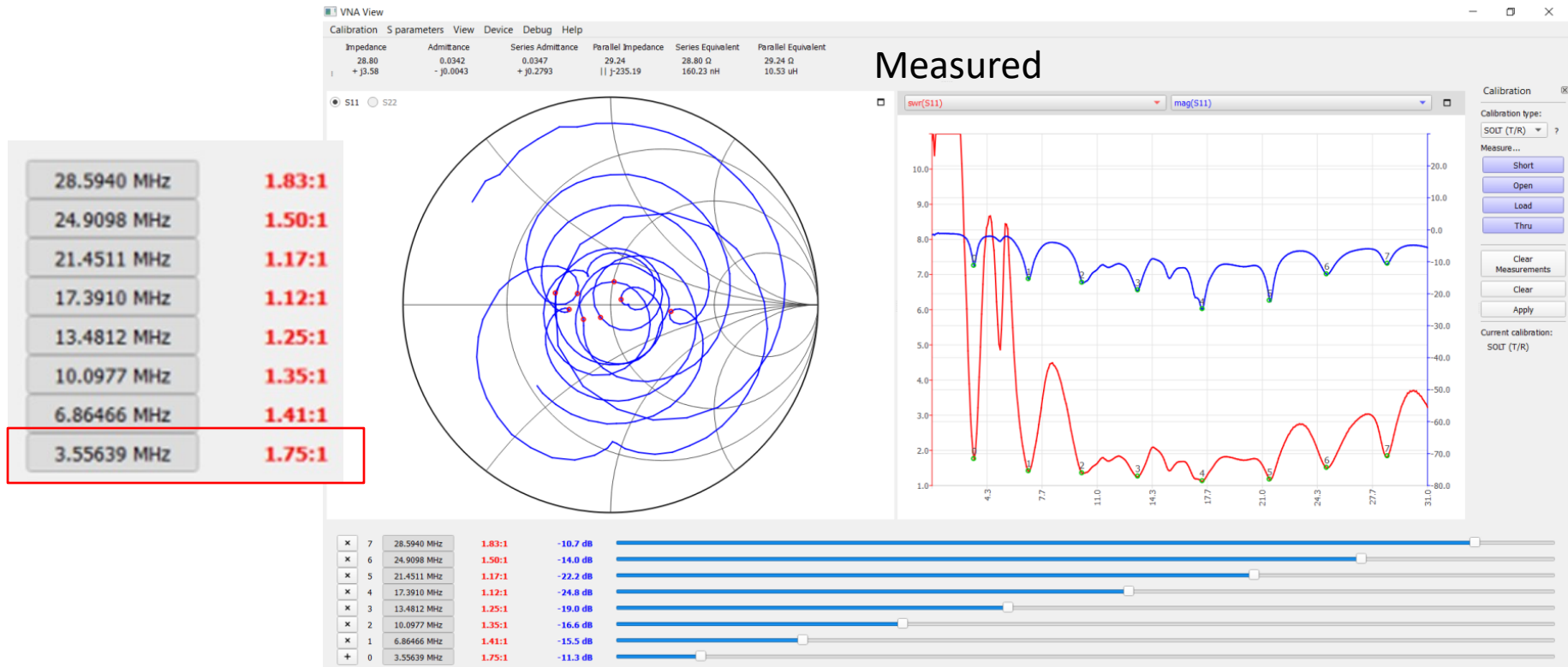
- Reduce Wire Length, Moves Red Line to the Right (and vice-versa)
- Add Series L, Moves Red Line UP (Increasingly at Higher Freq)
- Add Series C, Moves Red Line Down (Increasingly at Lower Freq)
- Optimize Location of L, C on the Wire for Specific Bands
- Counterpoise Length



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

Measured SWR

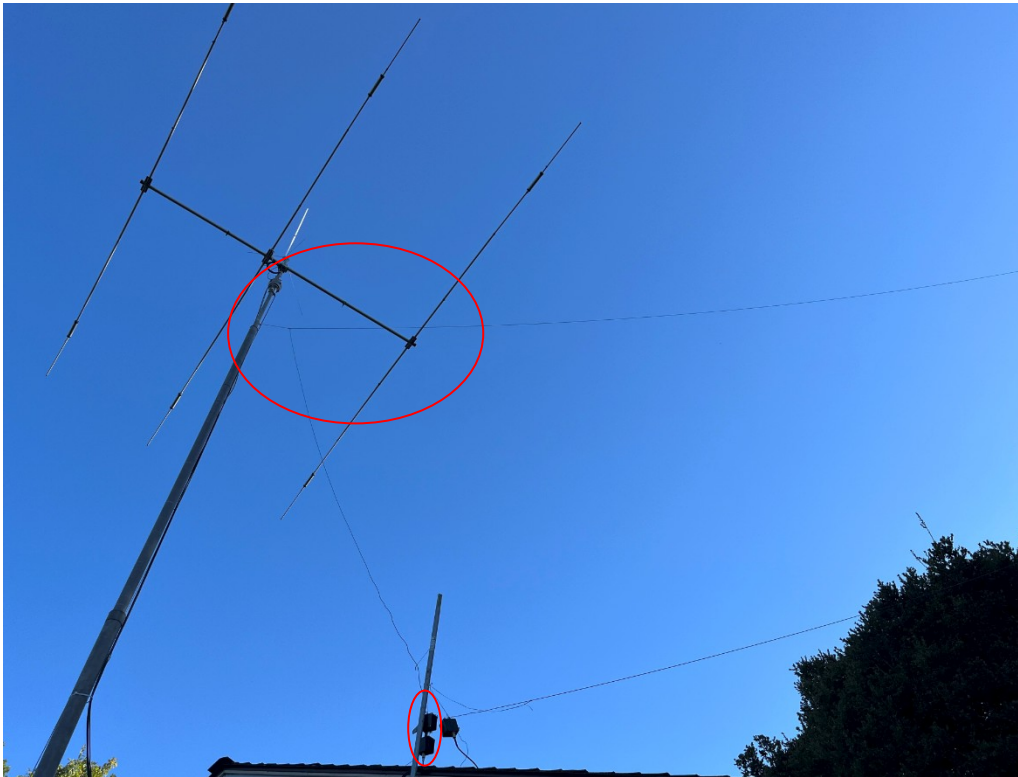
- Measured with nanoVNA at end of RG8X coax cable in shack.
- Data is for 80m EFHW with 11 turn coil
- SWR at 80 m is too high...



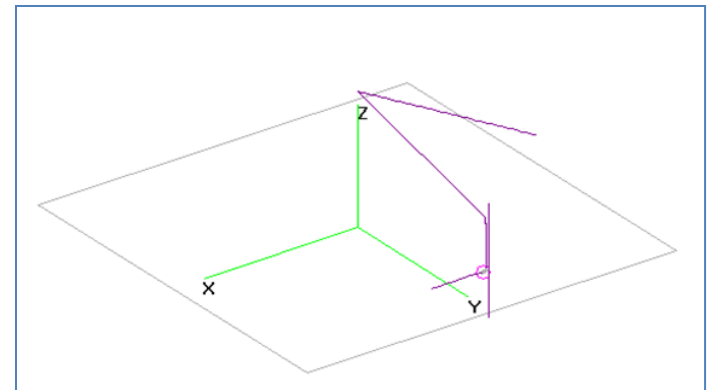
Modified EFHW 80, 40, 20, 18, 12

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 49:1 Unun & CM Choke for 60, 30 m EFHW



Geometry for 4NEC2 Simulation

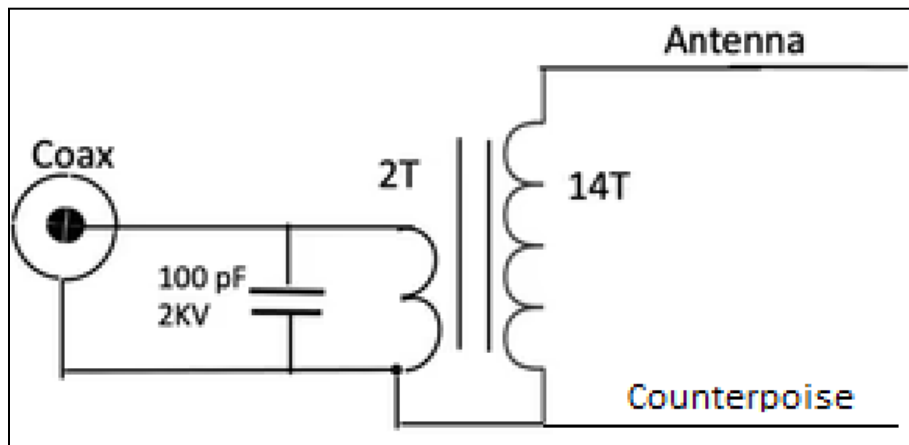


49:1 Unun for Modified EFHW 80, 40

Typical Unun Transformer [1]

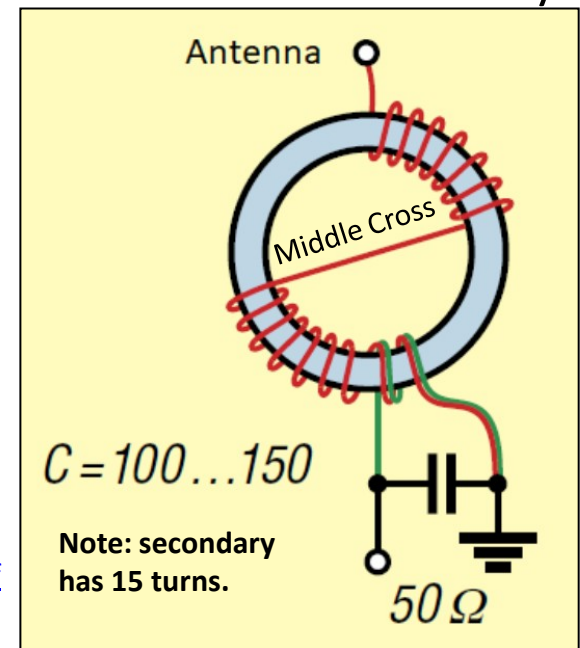
- 2:14 Turns Ratio → 1:49 Impedance Ratio (50 to 2450 ohms)
 - One Turn = Wire Passes Through Center of Toroid
 - Primary & Secondary Grounds are Connected
 - Capacitor Tunes out Inductance for High Freq (10 meters)
 - Middle Cross is for Max Space Between Input & Output
 - And Said to Equalize Magnetic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

Schematic



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

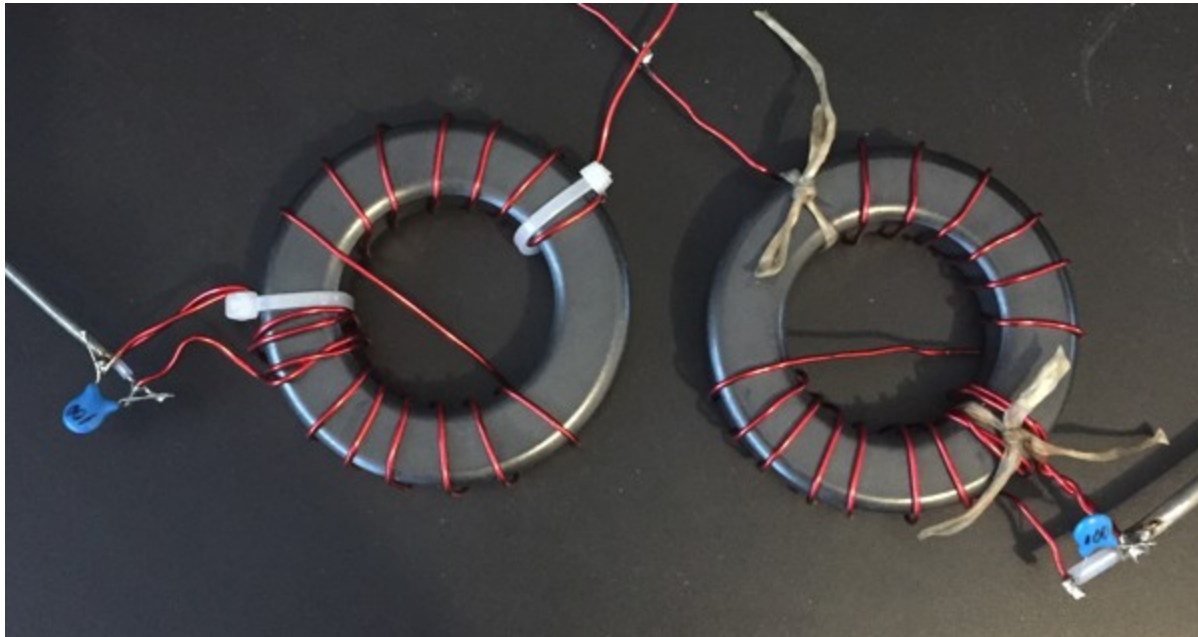
Transformer Assembly



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

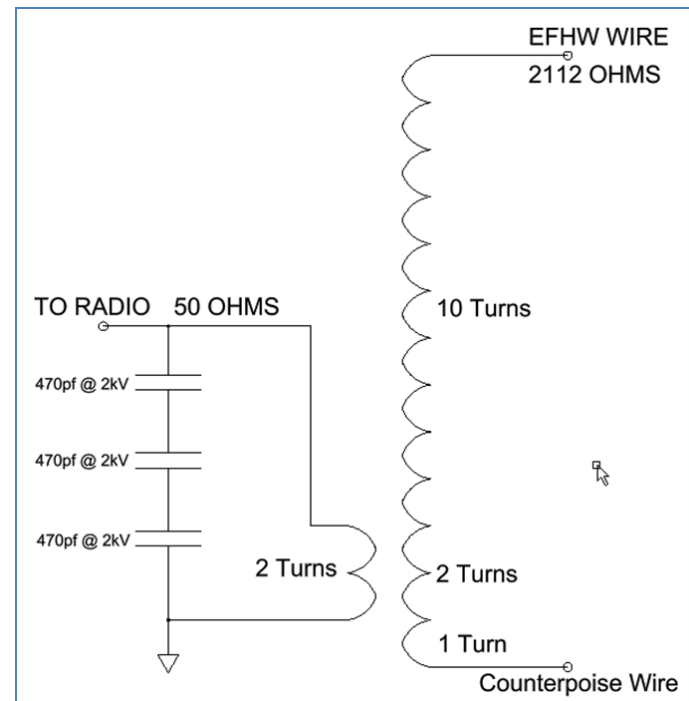
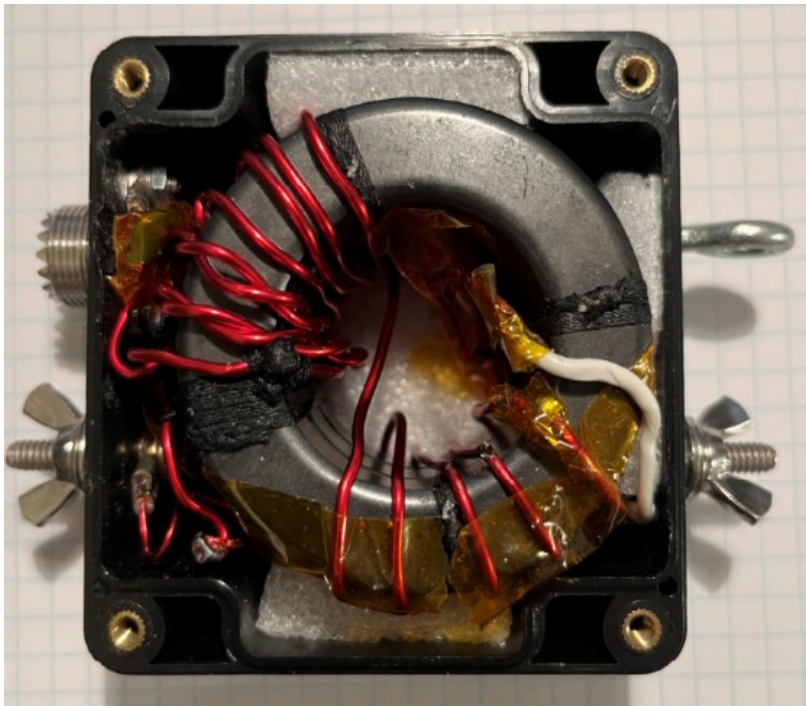


More Info: <https://www.eham.net/community/smf/index.php/topic,141970.msg1331361.html#msg1331361>

49:1 Unun for DIY EFHW 80, 40

Three FT240-43 Toroid Cores for 600 Watt CW

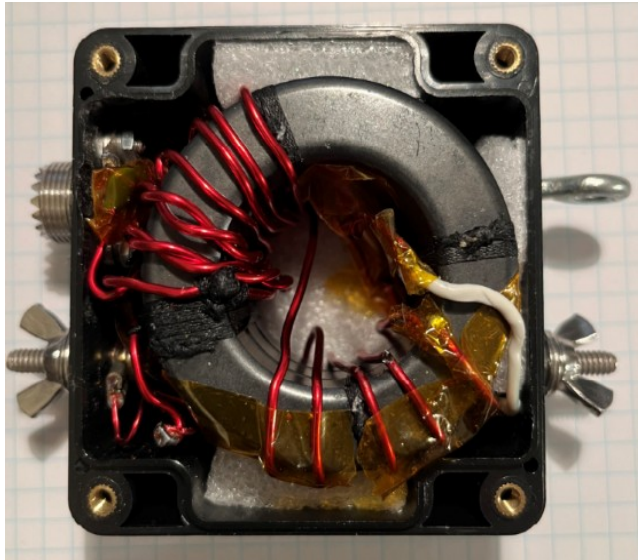
- Turns Ratio was Optimized for 80 & 40 meters (Motto: Try Different Things!)
- 2:13 turns ratio \rightarrow 1:42 Impedance Ratio (50 to 2100 ohms)
- Grounds NOT Connected, Try to Reduce Conducted Noise on Coax Shield
- Added One Turn on Secondary Below the Primary Winding
- Max Power is Limited by Heating up the Toroid Cores



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.



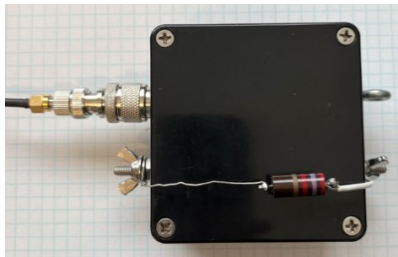
- **Great Local Suppliers:**
 - Industrial Metal Supply Co.
569 Charcot Ave, San Jose
 - Anchor Electronics
2040 Walsh Ave, Santa Clara
 - Harbor Freight, Santa Clara
 - Low priced stepped drill bit

49:1 Unun for EFHW 80, 40

Impedance vs. Frequency

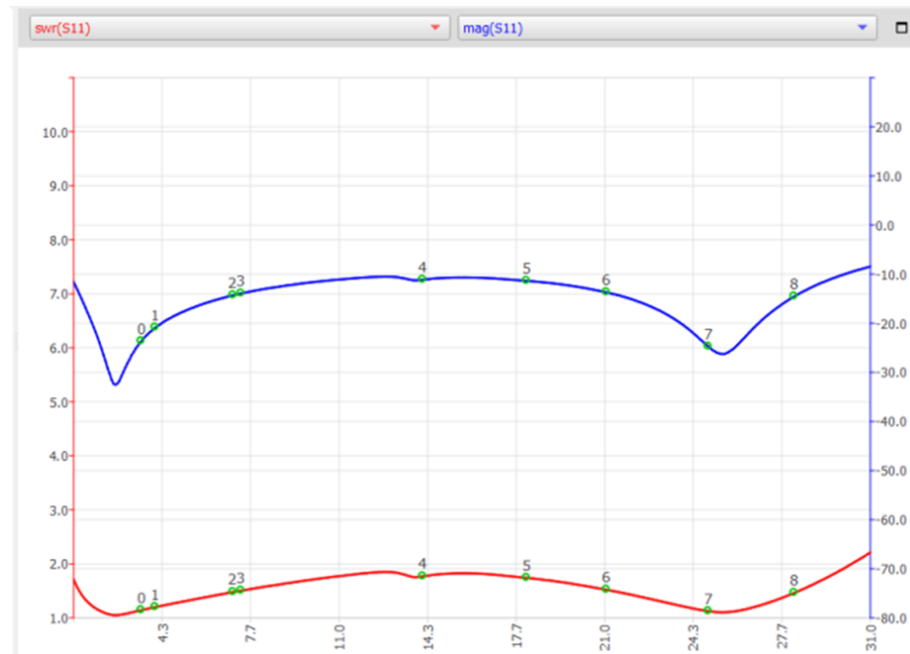
- Unun Input Impedance Measured with Various Output Resistors
 - 4700, 2700, 2200, 1000 ohms
 - Optimal Output Resistance is 2200 ohms for 80, 40 m
 - At 20 m, 1000 ohm at Output Gives Lower Input SWR
 - 2200 ohms Agrees With Measured Feedpoint Impedance of 80, 40m EFHW Wire.

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...

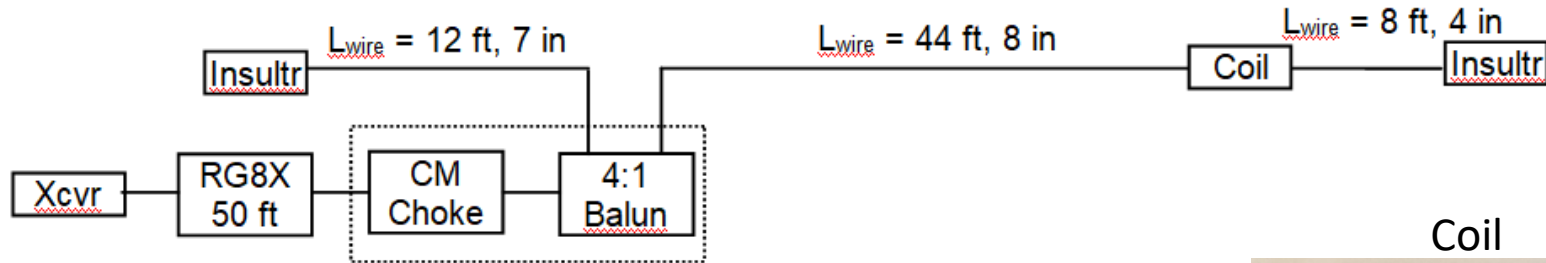
- Cylindrical 43 Cores Reported as More Efficient
 - Fair-Rite 43251002; Digikey \$7.46 @ qty 1

<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!



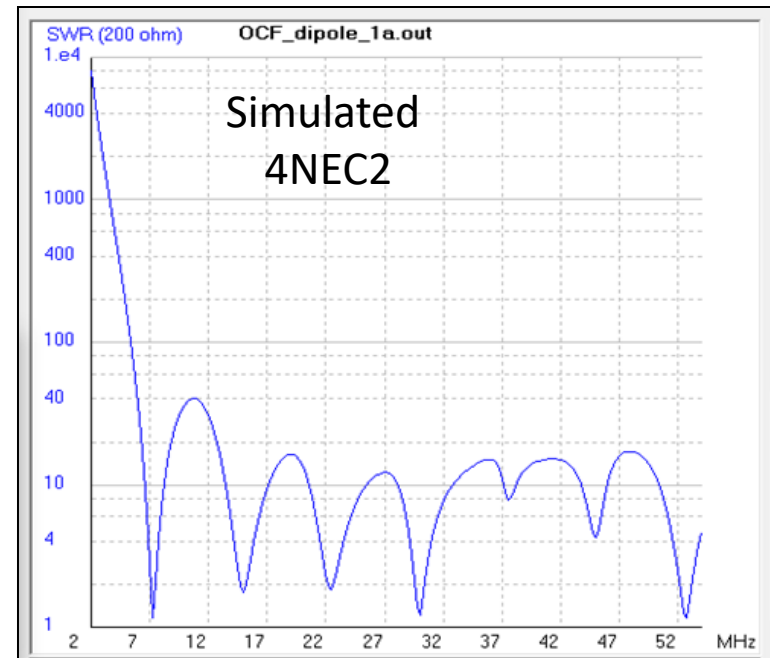
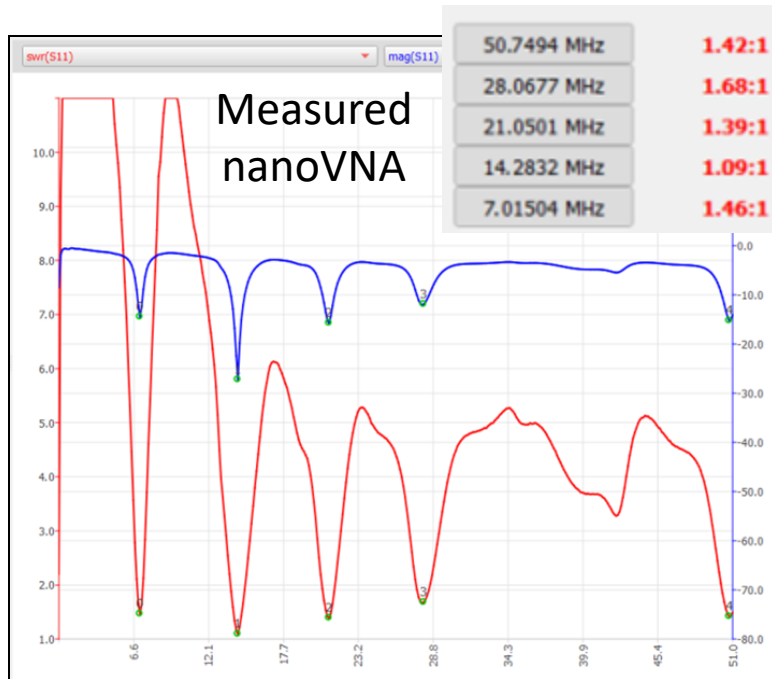
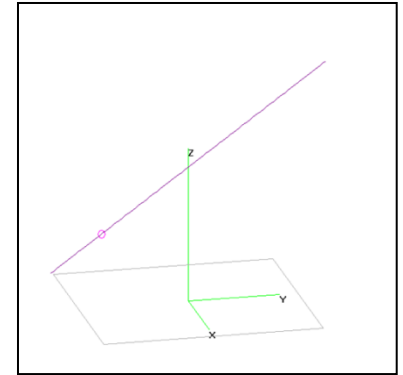
- Antenna length, Coil Turns, and Location Were Adjusted for Best VSWR on All Bands
- The Coil Allows Tuning to Both 15 and 20 m Bands



4:1 Balun/Choke

OCF Half Wave 40,20,15,10

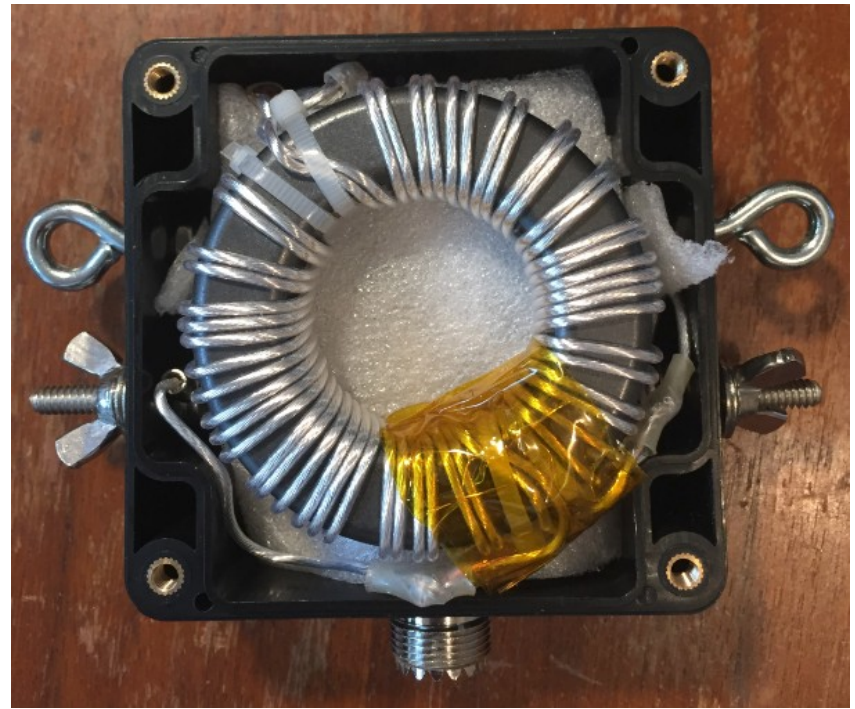
- Measured and simulated (4NEC2) antenna SWR agree.
- Upper Right: Antenna geometry, red circle is feed point.
- Right: Simulated SWR Ref to 200 ohm impedance.
- Left: Measured SWR & Return Loss



4:1 Transformer & CM Choke

For OCF Half Wave 40,20,15,10

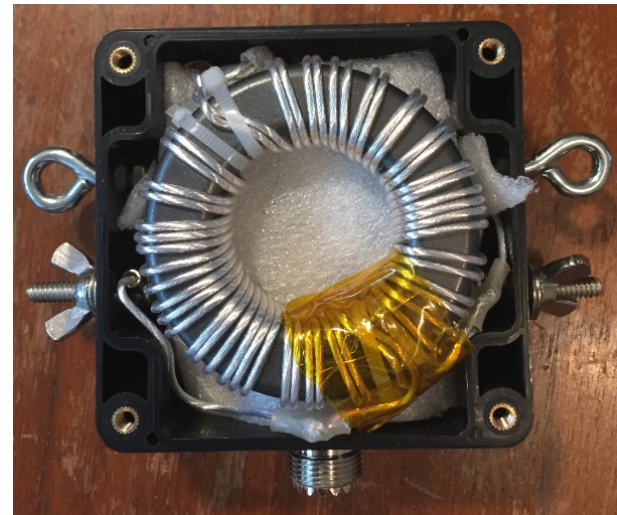
- Stacking the Toroid Cores Works Well
 - Magnetic Flux Stays Mostly Inside the Cores



4:1 Transformer & CM Choke

Materials

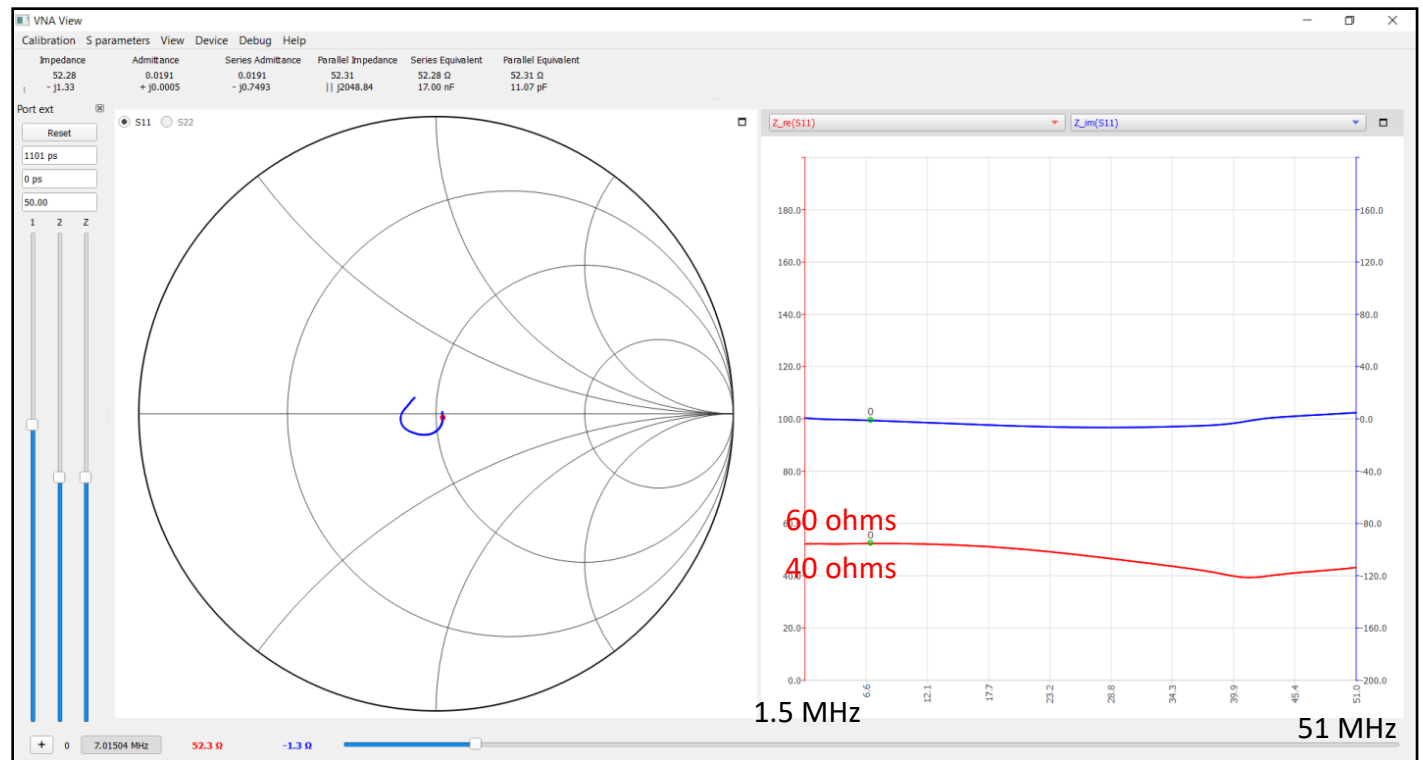
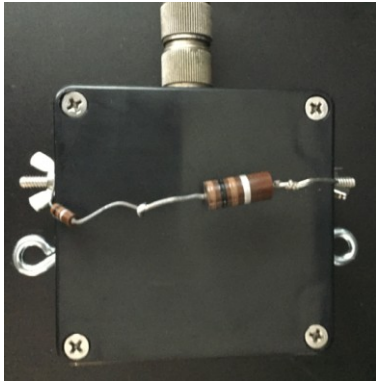
- **Toroid:** Same as FT240-43; FAIR-RITE PRODUCTS PN 5943003801; \$9.79 at Digi-Key, \$7 at Newark.
- **Wire:** 20 feet 18 AWG High Temperature PTGFE Silver Plated wire. Amazon \$15.99.
- **Box:** LeMotech ABS Plastic Project Box, 3.27" x 3.19" x 2.2"; Amazon \$6.29 for one box.



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.

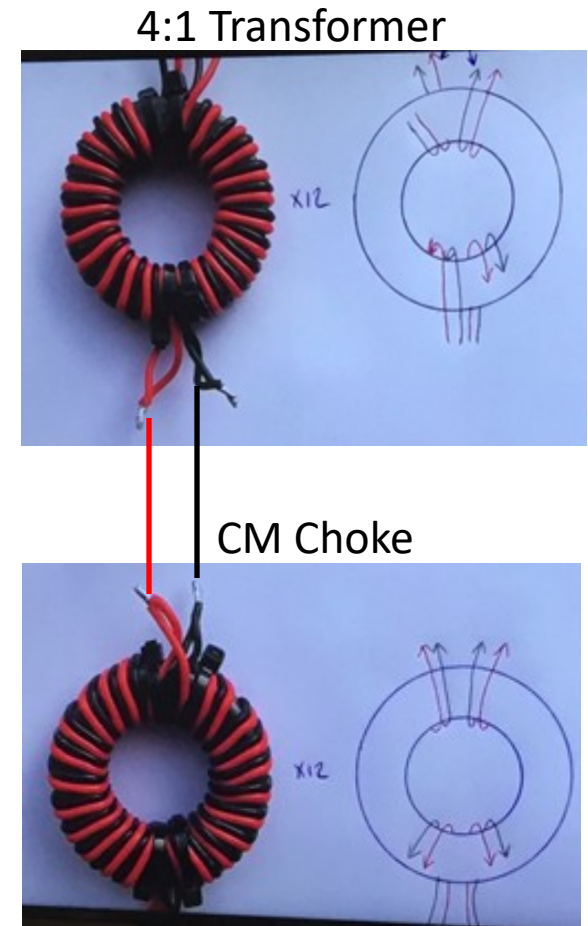


4:1 Transformer & CM Choke

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)

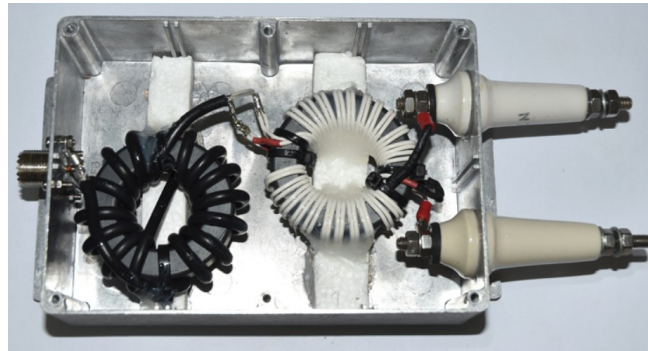
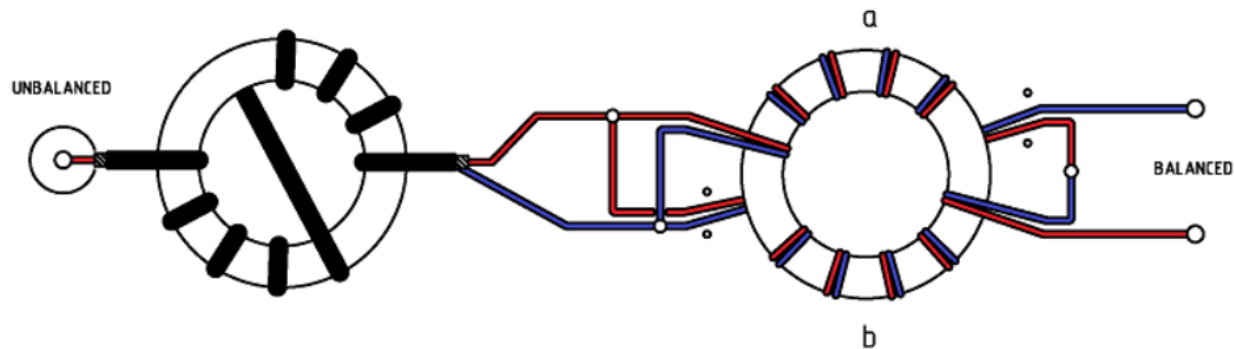
From YouTube: *A Better Off-Centre Fed Dipole – Part 1*
<https://www.youtube.com/watch?v=aYLseBPbxng>



4:1 Transformer & CM Choke

Other Similar Examples

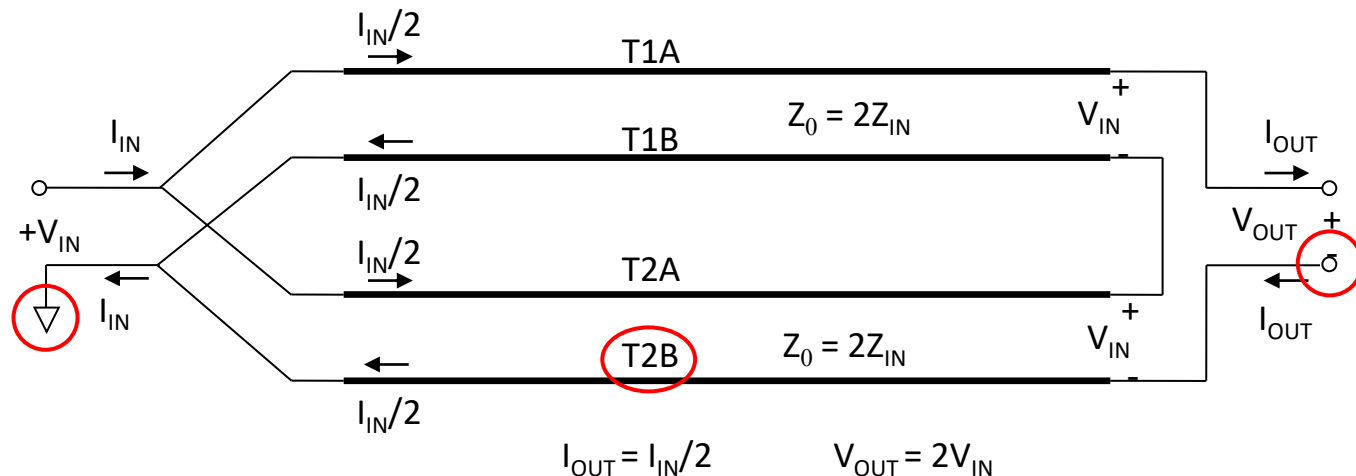
- Balun Designs Product: 4:1 Hybrid Balun 1.5 - 54MHz 3kW:
 - <https://www.balundesigns.com/model-4116-4-1-hybrid-balun-1-5-54mhz-3kw/>
- DIY Equivalent Design Article:
 - https://vk6ysf.com/hf_feed_balun_choke.htm



4:1 Transformer Balun – How It Works

Guanella Current Balun

- 50 ohm input, 200 ohm output
- Two Transmission Lines: T1, T2 with $Z_0 = 100$ 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

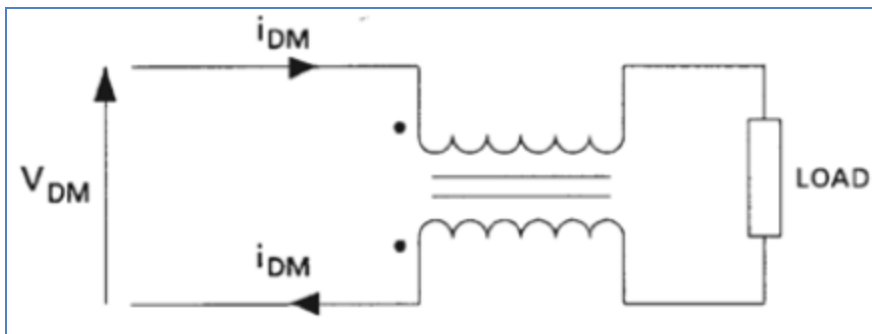
- A 4:1 Guanella current balun with single ended (neg=ground) input must have the two transmission lines wound on separate cores. Also, it seems that if the 4:1 balun is fed differentially by a CM choke, such as for my DIY choke/balun, then the 4:1 balun can have both windings on the same core. Without the input gnd ref, the CM voltage across both windings can equal each other as needed for equal flux. But two cores are still needed: one for the CM choke, and one for the balun.
- Following are some very interesting articles on this, with clear no-math explanations of how key varieties of ferrite baluns and chokes work.
- G3TXQ Analyses for different balun types *embedded pdf ->*
 - <http://www.karinya.net/g3txq/baluns/baluns.pdf>
- G3TXQ Article on Baluns & CM Chokes *embedded pdf ->*
 - <https://gm3sek.com/wp-content/uploads/2019/01/G3TXQ-RC.pdf>
- W8JI Discussion on Baluns
 - www.w8ji.com/balun_single_core_41_analysis.htm.

Common-Mode Choke

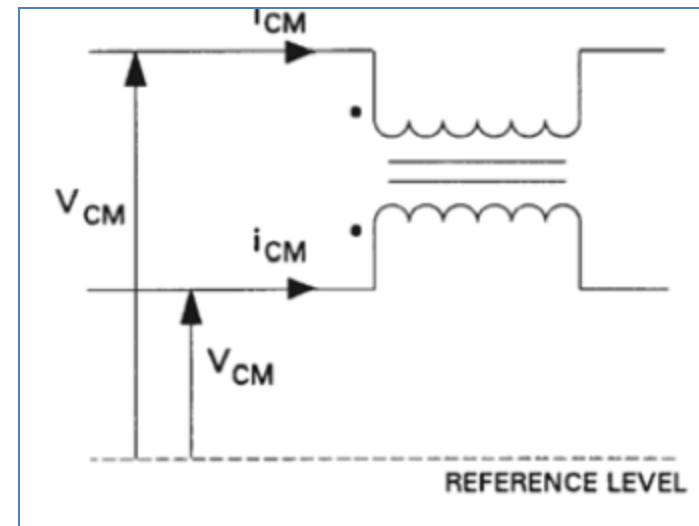
Differential-Mode & Common-Mode

- 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 Connections
 - 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

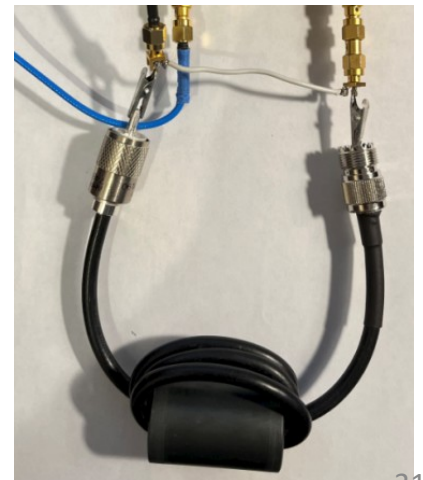
Guanella Choke

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



Coaxial Choke

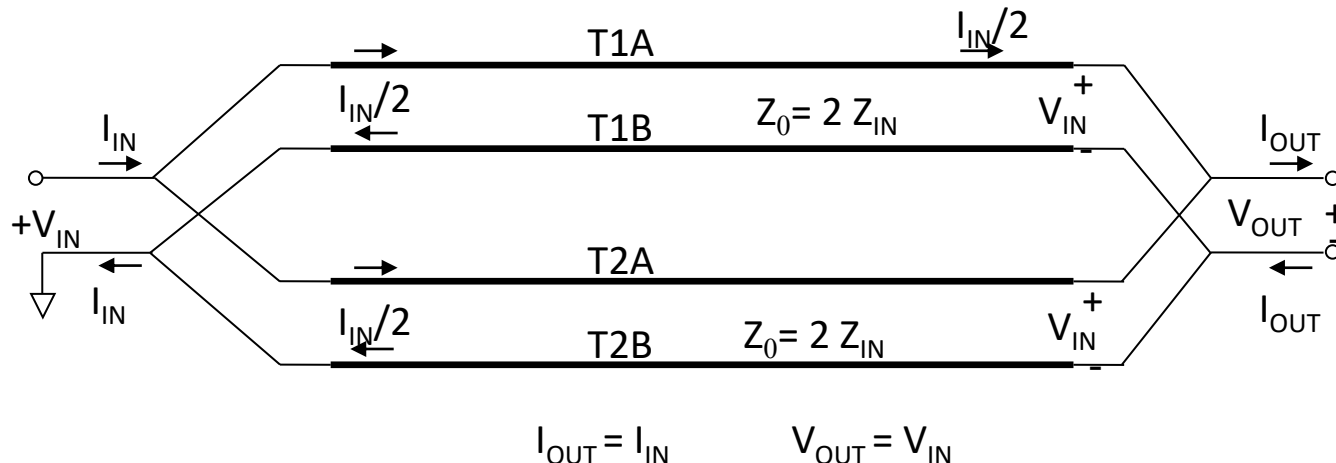
4 turns RG8X on
Fair-Rite
2631103002, 31mtl



Common-Mode Guanella Choke

How It Works

- 50 ohm Input & Output
- Two Transmission Lines: T1, T2 with $Z_0 = 100$ 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>



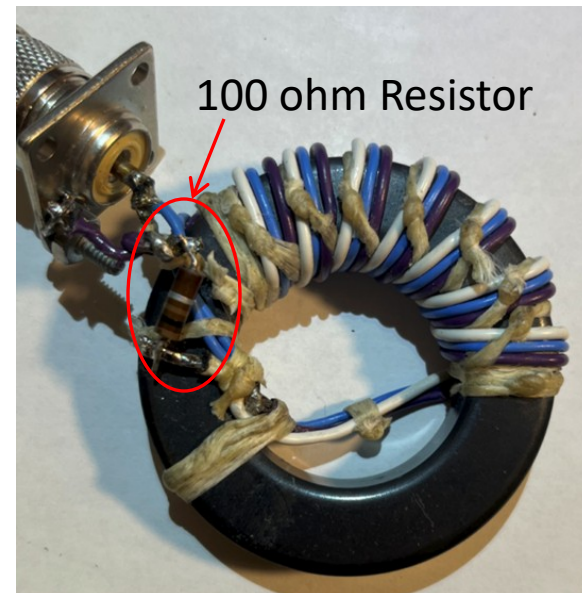
2:1 Ruthroff Transformer Unun

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 = $4:9 \approx 1:2$ Impedance Ratio, Giving 50 to ~ 100 ohm



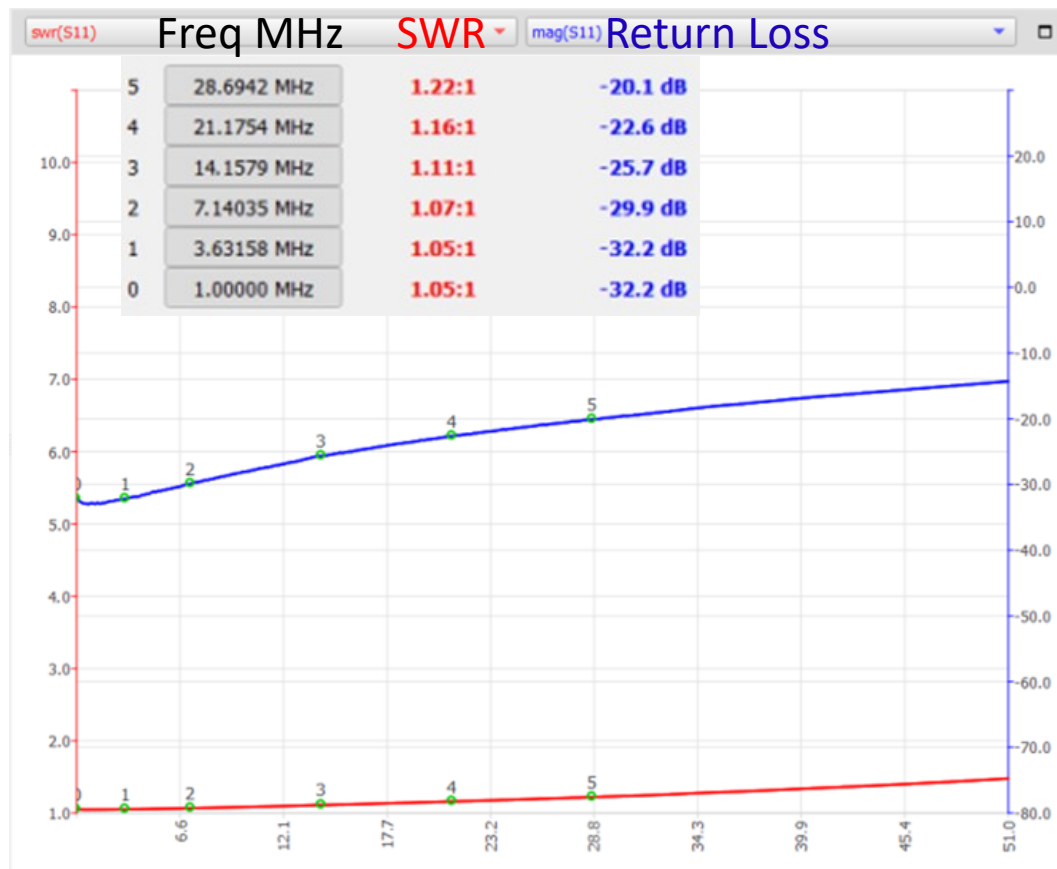
- If used for an Antenna, a Balun Should be Added Between Unun and Antenna, to Reduce Noise Pick Up and RF Leakage in the Shack. A single 100 ohm Z0 T-line of Two Wires Wrapped on FT240-43 Toroid Core, 12 Turns, Should Work Fine.



2:1 Ruthroff Transformer Unun

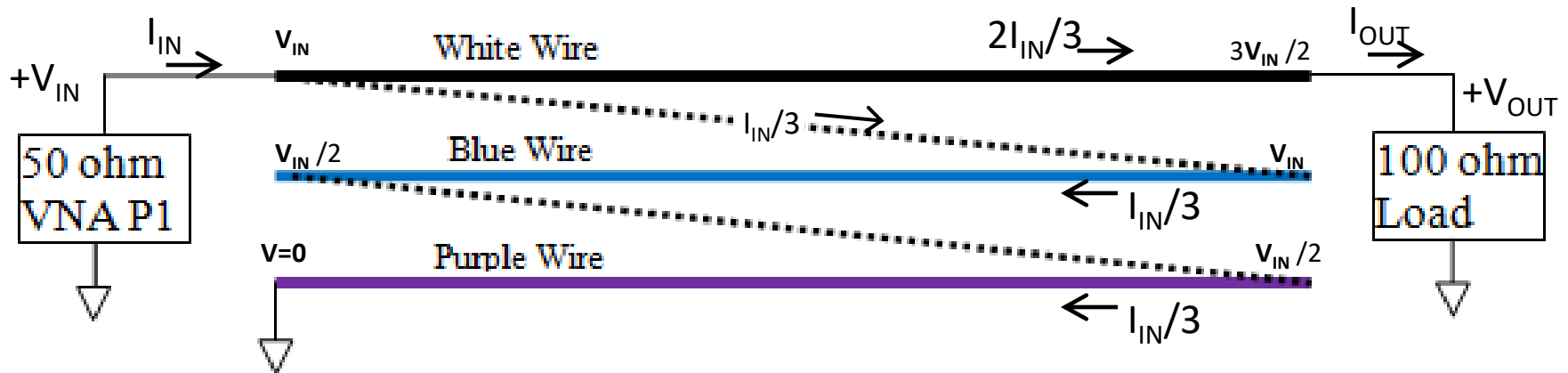
50 to 100 ohm

- 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

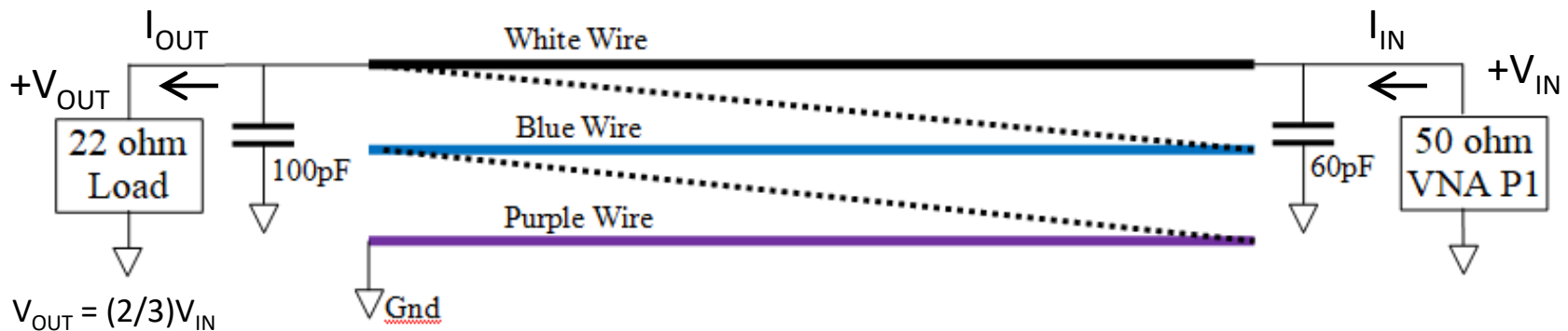


- $V_{OUT} = (3/2)V_{IN}$, due to 3:2 turns ratio, and equal mag flux in each wire
- $I_{OUT} = (2/3)I_{IN}$, by conservation of energy since $I_{OUT} V_{OUT} = I_{IN} V_{IN}$
- $Z_{OUT} = V_{OUT} / I_{OUT} = (9/4) Z_{IN}$
- Current in each wire is as shown above. Half the current in White wire couples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

2:1 Impedance Ratio Ruthroff Unun

50 to 25 ohm

- 3:2 turns ratio gives 9:4 impedance ratio ($\approx 2:1$)
- Schematic of 50 to 22 ohm transformer. Seven turns of trifilar wire closely wrapped on a FT240-43 toroid core.
- Different T-line Z_0 for 50 to 25 ohms, vs. for 50 to 100 ohm load.



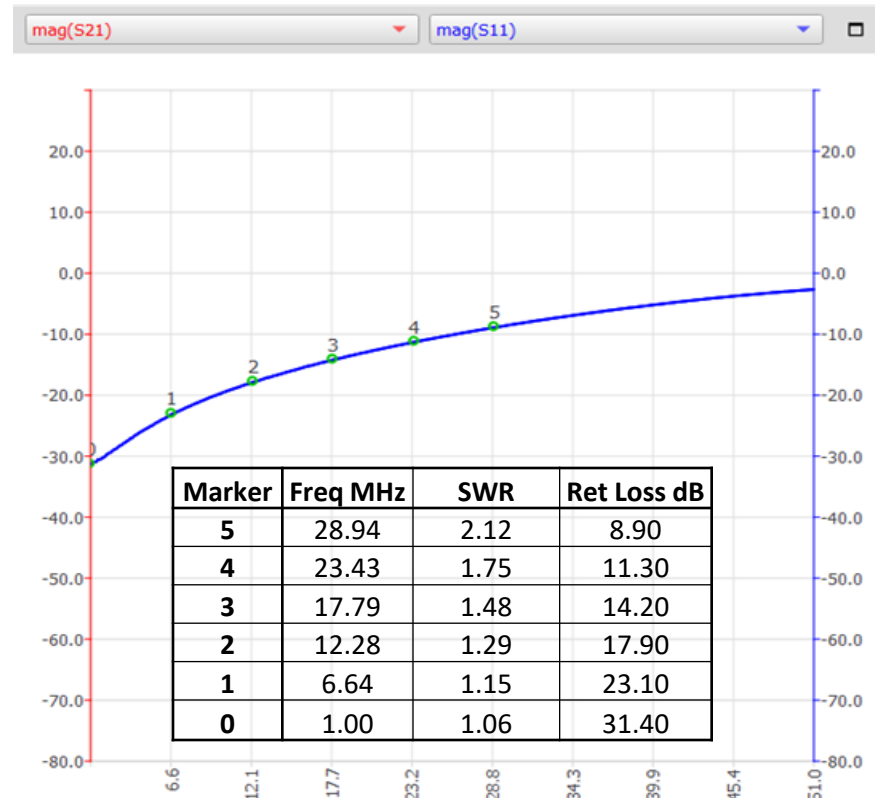
- Z_0 Impedance for both T-lines, ($Z_{IN} = 50$):
 - (White-Blue) $Z_0 = V_{IN} (1 - 2/3) / (I_{IN}/2) = (2/3)Z_{IN} = \mathbf{33 \text{ ohms}}$.
 - (White-Purple) $Z_0 = V_{IN} (1 - 1/3) / (I_{IN}/2) = (4/3)Z_{IN} = \mathbf{67 \text{ ohms}}$.
 - Needs shunt C at 22 ohm Load; to compensate T-line Z_0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



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.highfregelec.summittechmedia.com/Jan05/HFE0105_Sevick.pdf
 - https://www.highfrequencyelectronics.com/Jan10/HFE0110_DesignNotes.pdf
- **Sevick 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>

Balun and Choke

Other Excellent References

Trask Articles on Baluns:

https://www.highfrequencyelectronics.com/Dec05/HFE1205_Trask.pdf

https://www.highfrequencyelectronics.com/Jan06/HFE0106_TraskPart2.pdf

G3TXQ Analyses for different balun types:

<http://www.karinya.net/g3txq/baluns/baluns.pdf>

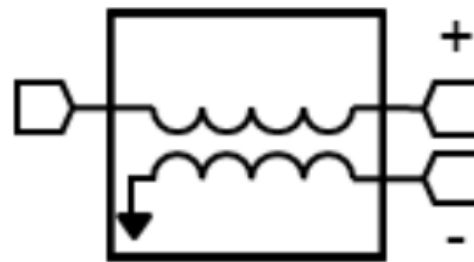
G3TXQ Published Article on Baluns

<https://gm3sek.com/wp-content/uploads/2019/01/G3TXQ-RC.pdf>

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]



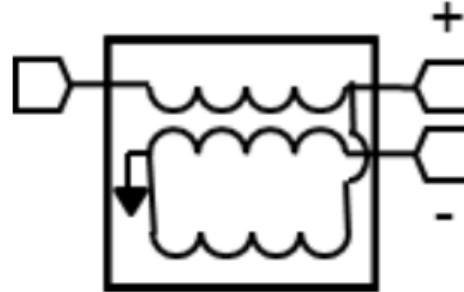
'Current' Balun

- [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> Lewallen, Baluns..., *ARRL Antenna Compendium vol 1*, 1985

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!