# The End Fed Half Wave Antenna

Stan & Cliff have been working all day
on installing my clothesline, Mary.

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Steve Dick, K1RF

# In search of the Holy Grail


A simple wire antenna that is low cost, easy to build, and easy to deploy, with great performance, from single band to multiband.

# Narrowing down which antenna(s) to consider

- Operation dependent
  - Home use – semi-permanent installation, available real estate and mounting options,  bands and operating modes
  - Field Day – moderately quick deployment, available mounting provisions, co-located setups where interference is an issue
  - POTA – portable/lightweight with very quick deployment and limited mounting provisions
  - SOTA – very portable/lightweight and very quick deployment and limited mounting provisions
  - DxPeditions – Good performing antennas with moderately quick deployment, easily transportable

*Choose the right antenna for the application*

# What are the potential advantages of an EFHW compared to other wire antennas?

- Ease of installation. Only a single high point required. Makes a great antenna for field use with quick setup.
- Many configurations possible to suit your installation: Horizontal, Inverted V, Inverted L, Sloper, inverted U, half square, etc.
- No hanging feedline. Feed point can be near the ground.
- Minimal ground system or counterpoise needed – the coax feed itself can act as a counterpoise with or without a choke balun.
- Resonant on 80/40/30/20/17/15/12/10m with low VSWR. No tuner needed or just a 3:1 “Touch-up” tuner
- Reduced coax losses as a result of low antenna VSWR.
- One simple length adjustment – no interactions between bands.
- Grounded at D.C. No static buildup.
- Shortened versions possible for limited area.

# About Half-wave Antennas

- A half-wave antenna is a resonant radiating element with an electrical length of one half-wave.  Total length in feet. ~468 / freq in Mhz. Its feed-point affects its impedance. High current, low voltage at center (low impedance); low current high voltage at ends (high impedance).
- The most common half-wave antenna is the center-fed dipole, whose impedance is approximately **72 ohms**. A dipole is basically a mono-band antenna. (Third harmonic may be useable).
- If fed off center, say at the 29.7% point for 80 meters, it is known as an off- center-fed-dipole (OCFD). Its feedpoint impedance is approximately **200 ohms** and can be used on multiple bands. It needs a matching device such as a 4 to 1 impedance hybrid balun (4:1 Ruthroff Balun cascaded with 1:1 Guanella Balun).
- If fed at the end (a.k.a EFHW), antenna impedance is in the **2000-4000 ohms** range. It requires a high impedance matching device such as a 49 to 1 impedance UNUN transformer or tapped parallel resonant circuit (Fuchs antenna tuner).

# Multiband operation of a Half-Wave Antenna

- If the half-wave antenna can be impedance matched on all of its harmonics, you now have a multiband antenna.
- On the fundamental frequency, antenna pattern is identical no matter where you feed it
- Harmonic relationship is imperfect due primarily to end effect, requiring additional passive components (in subsequent slides)

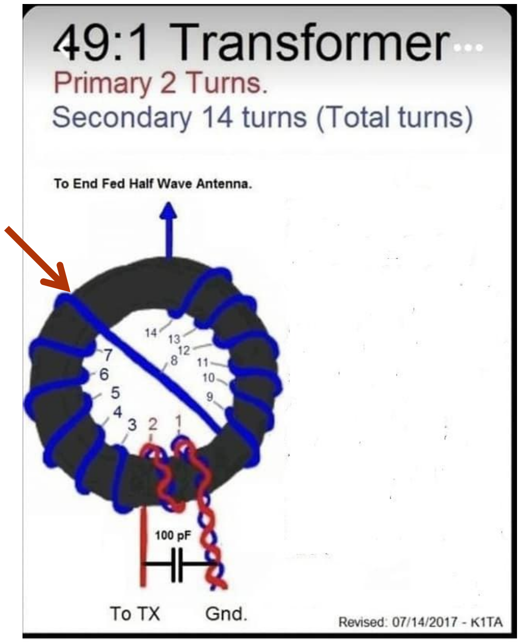
| | |
|---|---|
| 3.57 x 1 = 3.57 MHz | 80M |
| 3.57 x 2 = 7.14 MHz | 40M |
| 3.57 x 3 = 10.71 MHz | 30M |
| 3.57 x 4 = 14.28 MHz | 20M |
| 3.57 x 5 = 17.85 MHz | 17M |
| 3.57 x 6 = 21.42 MHz | 15M |
| 3.57 x 7 = 24.99 MHz | 12M |
| 3.57 x 8 = 28.56 Mhz | 10M |

*A key characteristic that <u>does</u> change with feedpoint location is the <u>radiation pattern</u> of each harmonic.*

# UNUN transformer for EFHW Antenna

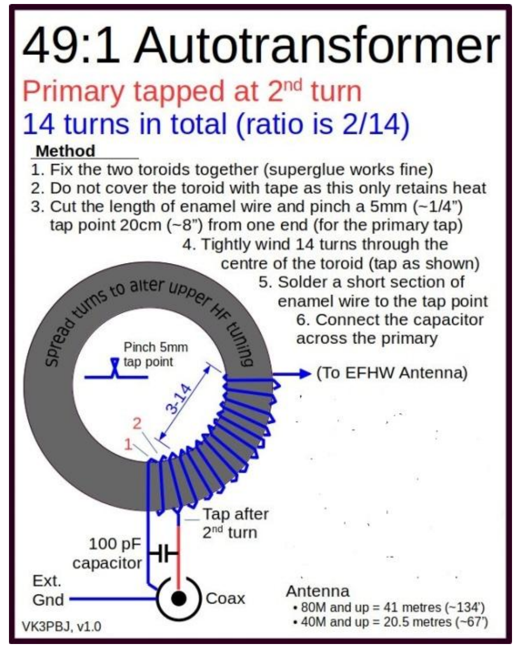
Conventionally wound

Crossover mainly for mechanical reasons




Courtesy Tom Alessi K1TA

Autotransformer Wound



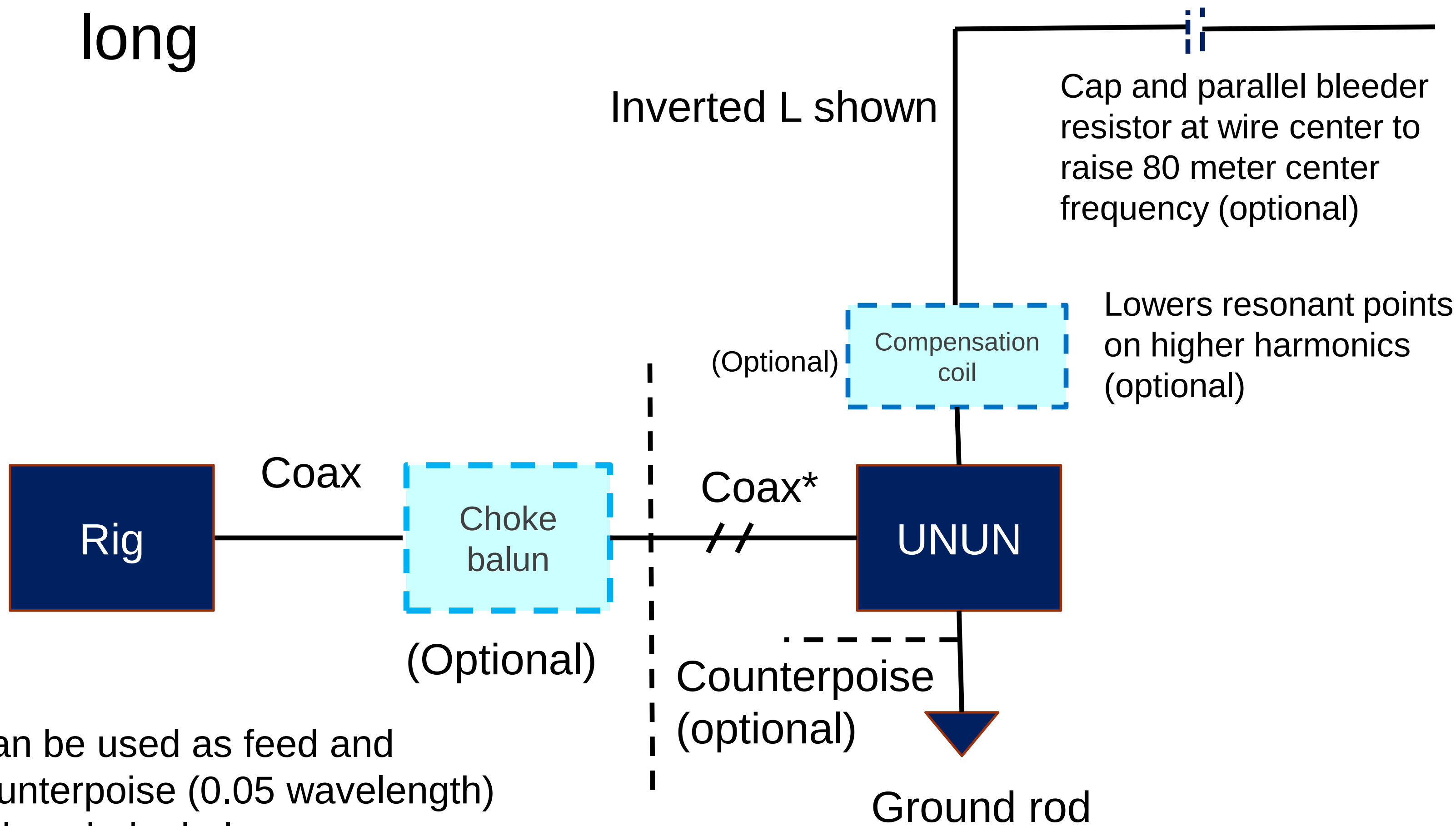

Courtesy Steven Pimpernel

- The EFHW UNUN has a high impedance ratio (49:1 to 64:1)
- Not feasible to use transmission line transformers whose practical limit is about 16:1. It is a conventional transformer.
- Uses a ferrite toroidal core or cores (usually Type 43 or type 52 material).

*Performance is about the same for either winding method.*

# EfhW Antenna Construction

- 80 meter EFHW – approx. 131 ft (41 meters) long
- 40 meter EFHW – approx.   67 ft (20.5 meters) long




*can be used as feed and counterpoise (0.05 wavelength) with a choke balun

# EFHW counterpoise

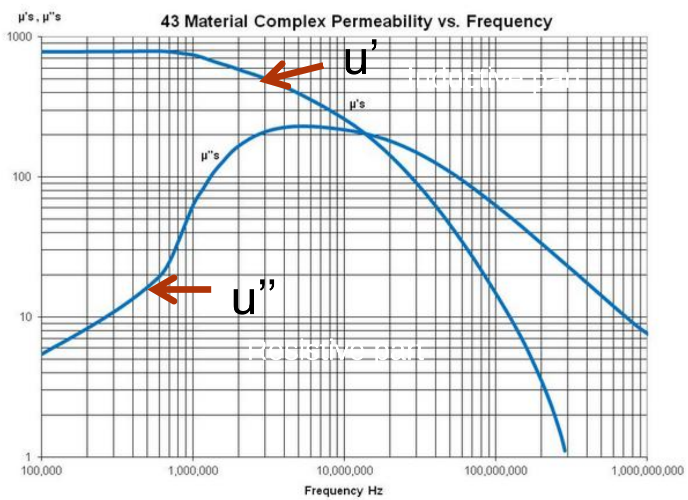
- Current flowing into the antenna's driven end must be equaled, at that end point, by the same amount of current flowing into a ground or counterpoise of some type.
- If you don't specifically provide one then the coax shield will act as the counterpoise. For a suspended counterpoise wire, the "ideal" length would be 1/4 wavelength, providing low inpedance at the feedpoint. But for multiband use, it should be non-resonant on any band. Otherwise it may approach ½ wavelength on the higher bands which makes a poor counterpoise. Because the feed impedance on an end-fed 1/2 wave is high, you can get away with a lot shorter counterpoise. The higher your counterpoise impedance, the more current will flow in the outside of the coax shield, so its a trade off. Many get away with just using the coax shield as the counterpoise (which some manufacturers advertise as "no counterpoise").
- Recommended wire counterpoise length is 0.05 wavelength at the lowest frequency of operation. (About 13.2 feet on 80 meters, about 6.6 feet on 40 meters
- If you are near a wire fence, connect the ground to it. that makes a great counterpoise.
- If you have a good radial system, that will be a great counterpoise with minimal common mode current flowing on the coax.

# Is a choke balun needed?

- Depending on the quality of your counterpoise, current splits between the counterpoise and coax shield.
- A choke balun (AKA Common mode choke or CMC) is recommended but you can often get away without one if antenna is not close to the QTH
- A choke balun can be used two ways:
  - At the rig
  - In series with the coax 0.05 wavelength away from the UNUN. The segment of coax between the CMC and UNIUN acts like a counterpoise.
- Typical high power choke balun: FT240-31 with 12 turns of RG400 coax

# Ferrite Materials

| Material | Initial Permeability | Relative cost | Core loss | Curie Temperature | Comments |
|---|---|---|---|---|---|
| Fair Rite 43 | 800 | Moderate | Moderate | >130 degC | Best for lowest cost/ 100W rigs |
| Fair Rite 52 | 250 | High | Lower | >250 degC | Best for multicore/ high power |
| Fair Rite 61 | 125 | High | Lowest | >300 degC | **DO NOT USE! Permeability too low!** |




Permeability is actually complex
- it has an inductive component (u') and a resistive (lossy) component (u'')

Inductance typically gets smaller with frequency

**Never use powdered iron cores for a EFHW UNUN – permeability is way low.**

# 100pF Compensation Capacitor

- The compensation cap improves high frequency performance of the EFHW UNUN by compensating for transformer leakage inductances. It mounts across transformer primary.
- The capacitor works by forming part of a lumped element approximation of a 50 ohm transmission line, in conjunction with leakage inductance as seen at the primary of the UNUN transformer. 50 0hms = sqrt(Leakage inductance/capacitance). Value not very critical.
- Typical value that works well is 100pF for many EFHW transformers
- An important parameter for the capacitor is **low equivalent series resistance (ESR).**
  A high voltage rating does not necessarily mean it has low ESR ("blue caps" on eBay) but high voltage caps usually have reasonably low ESR. It is current and poor ESR that usually kills caps due to overheating, not overvoltage. Capacitor power dissipation = $I^2$ * ESR
- A recommended cap for 100 watt rigs:
  - Kemet C330C101JHG5TA 100pF C0G/NPO 5% 3KV $2.41 at Digikey, $2.12 at Mouser. Low ESR rated.
- At 100 watts, VSWR=1, Vrms = 70.7 volts. Irms = **1.4 amps**. Vpeak = 70.7 X 1.414 = 100 volts. At 5 to 1 VSWR, Vpeak = 100 X sqrt 5 = 223 volts. With 50% derating, Vcap rated voltage = 446 volts.
  At 1000 watts, VSWR =1, Vrms = 223.6V. Irms **4.47 amps**. Vpeak = 316.2V. At 5 to 1 VSWR, Vpeak = 316.2 X sqrt 5 = 707 volts. With 50% derating, Vcap rated voltage = 1.41KV

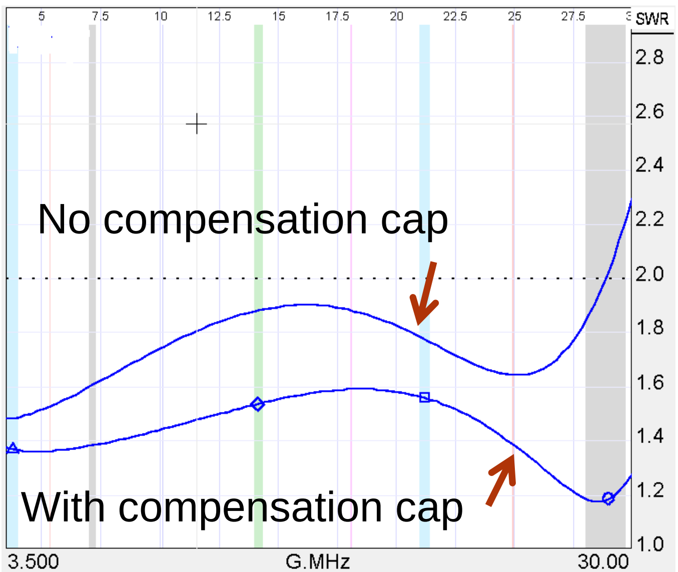
# Compensation coil (optional)

- The small coil, used on some commercial antennas,  is used to compensate the resonant point of the high bands. ~1.5microHenrys  6T on 1.25" OD inch PVC form positioned at 78 inches from the feed point whether 80M EFHW or 40M EFHW. See Steve Ellington's youtube video on this topic. lowers resonant point more and more at increasing frequencies.

- 80M – lowers 22KHz
- 40M – lowers 57 KHz
- 20M – lowers 170 KHz
- 15M – lowers 400 KHz
- 10M – lowers 1 MHz

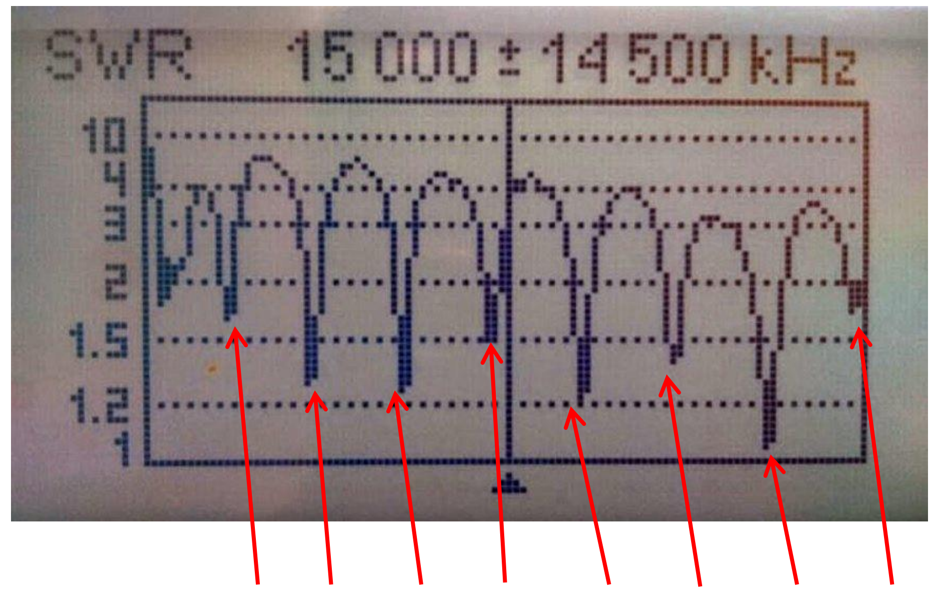
# SWR plot on real antenna vs. resistive load

- 2450 ohm resistive load




Smooth continuous curve.
Curve shape may be different with different toroids, ferrite type, ΣI/A($cm^{-1}$), leakage inductances, self-capacitance, number of turns, etc.

- 80 meter efhw antenna load



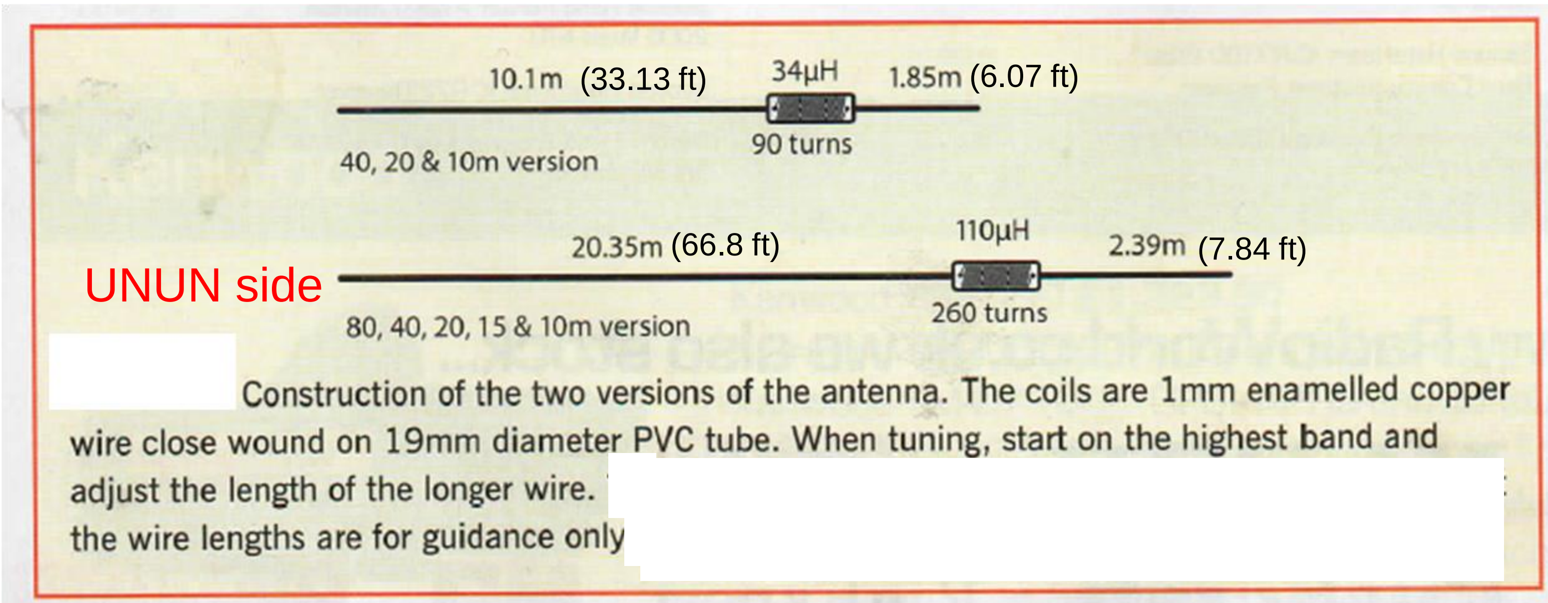

80 40 30 20 17 15 12 10
3.5 7 10.5 14 17.5 21 24.5 28

VSWR can be LOWER at resonance compared to resistive load!

# If 80 meter resonant point is too low on 80 meters

- 80 meter resonance may be too low while higher resonances look good due to end effect.
- 80 meter resonance can be raised without affecting upper harmonic resonances via the addition of a capacitor at the middle of the antenna, shunted with a resistor to bleed off static buildup. For 100 watt rigs, Silvered mica or COG/NOP capcitor, 1KV shunted with 33K 2W non-inductive resistor. If initial resonance is 3.5MHz, 470pF will raise resonant point to about 3750 KHz.
- See Steve Ellington, N4LQ's youTube video (EFHW 8010 75 meter Modification) for further information.

# Shortened EFHW antennas




Adjust the long wire first for the high end bands. Then adjust the short wire for the lowest band. Bandwidths will be narrower than full sized antennas

Courtesy Jos Van den Helm, PA1ZP, RSGB February 2016.
“A Three of Five Band End Fed Antenna”

# Adding 160 Meter Capability to an 80M-10M EFHW Antenna

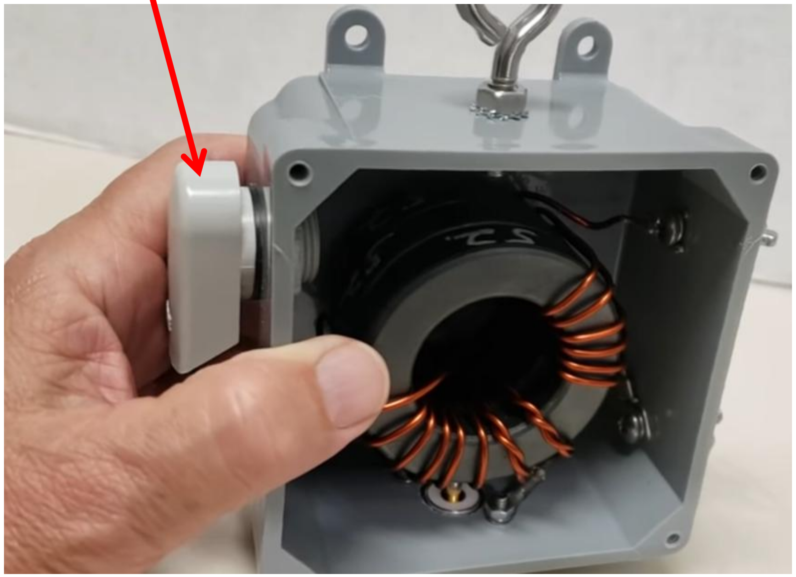
- An 80 meter EFHW is a ¼ wavelength long on 160 meters.
- Switch out the EFHW UNUN and connect the wire directly to the feed coax via a mechanical switch.  Requires good ground radials on the ground side of the coax.

- YouTube video on this concept by N4LQ, Steve Ellington

# Air vent for the UNUN housing

- A sealed box will have moisture and/or pressure buildup due to temperature changes.
- Easiest solution is 2 tiny holes drilled at bottom of box.
- Good solution is a purchased air vent.

Air Vent



Courtesy Steve Ellington N4LQ

Air vent shown similar to
Bud NBX-10911, about $4.00

# Importance of Primary Inductance of EFHW transformers

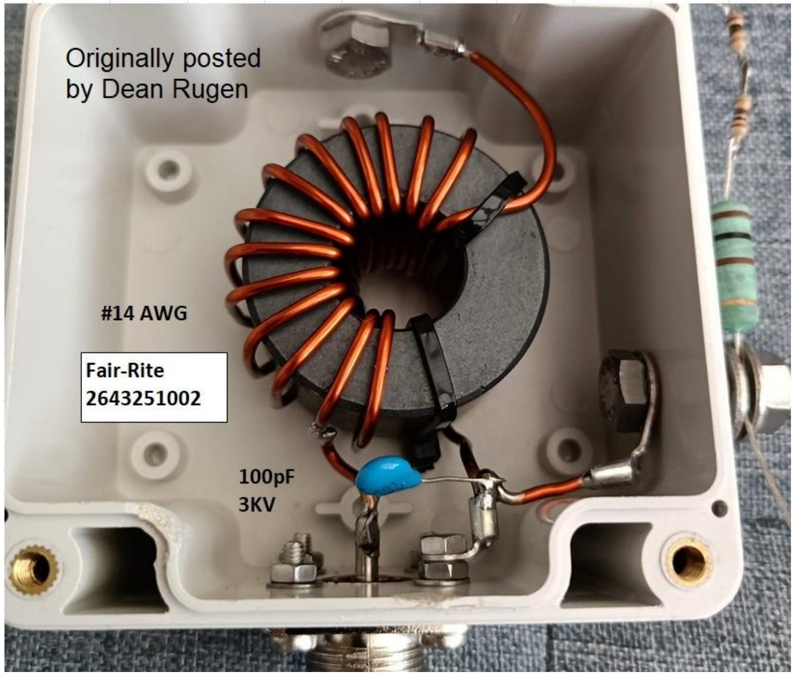
- Primary inductance
  - If primary inductance is too small at the low frequency end, Mismatch loss is significant and high VSWR results.
  - If primary inductance is too high, the high frequency performance suffers and VSWR climbs at the high end.
  - My rule of thumb: Inductive reactance ($X_L$) should be in the 88 ohm- 200 ohm range at the lowest frequency of use ($X_L = 6.28 * F * L$ where ($X_L$ is inductive reactance in ohms, F is frequency in MHz, and L is inductance in microhenrys. ). This corresponds to 4-9 microhenrys at 3.5MHz or 2-4.5 microhenrys at 7 MHz .
  - Toroid primary inductance increases with size of toroid. Two FT140 sized toroids have about the same inductance as a single FT-240 sized toroid for the same number of turns.
  - Toroid primary inductance is proportional to the number of toroids.
  - Compute inductance values at toroids.info

# Power handling capabilities of commonly used toroids (~150 degF*)

| Toroid | Fair Rite P/N | Toroid Pdiss. W* | Estimated Efficiency Midband | Digital Input pwr, W | CW input pwr,W 44% duty | SSB inp pwr W 20% duty |
|---|---|---|---|---|---|---|
| Ft114-43 2T/14T | 5943001001 | 2.2 | 0.85 | 14.7 | 33.3 | 73.5 |
| FT114A-43 2T/14T | 5943001201 | 3.4 | 0.9 | 34 | 77.3 | 170 |
| FT140-43 3T/21T | 5943002701 | 4 | 0.85 | 26.7 | 60.7 | 133.5 |
| 2-FT140-43 2T/14T | 5943002701 | 6 | 0.85 | 40 | 90.9 | 200 |
| FT240-43 2T/14T | 5943003801 | 9 | 0.8 | 45 | 102.2 | 225 |
| 2-FT240-43 2T-14T | 5943003801 | 13.5 | 0.85 | 90 | 204.5 | 450 |
| 3-FT240-**52** 2T/14T | 5952003801 | 18 | 0.9 | 180 | 409 | 900 |
| "Stubby" -43 2T/14T | 2643251002 | 7 | 0.9 | 70 | 159 | 350 |

*See Owen Duffy's temperature rise calculator

# Recommended homebrew EFHW UNUN for 100 watt radios




Note: #16AWG can also be used with easier winding.

- Fair Rite 2643251002 core ($8.13 Digikey, $8.43 Mouser)
- >90% efficiency, 80-10 meters
- Can dissipate 7 watts. At 90% efficiency, input power of:
  - 70 watts continuous for digital modes
  - 159 watts CW (44% duty cycle)
  - 350 watts SSB (20% duty cycle)

# Common Errors in Building Homebrew EFHW UNUNs

- Using wrong toroid materials.  Stay away from type 61 ferrite cores **and any powdered iron cores like -2 or -6**. Primary inductance for powdered iron cores is way too low and they won't work.
- Putting insulating tape on toroids. (doesn't need it and degrades performance by adding an air gap from wire to toroid. Ferrite toroids used in these UNUNs have very high resistivity.
- Counting wrong number of turns (turns are turns that pass through the inside or a toroid, including the crossover turn)
- Running parts of the antenna next to a metal tower (Put the UNUN at top of the tower, not at base with antenna next to tower)
- Putting a choke balun right next to the UNUN. If used, it requires a wire counterpoise or should be away from the UNUN
- Confusion about what antennas are appropriate for 4:1 and 9:1 impedance ratio transformers.  These too low impedance for EFHWs
- Putting too much power into an undersized or inefficient UNUN. Many manufacturers have exaggerated claims for power handling capability. Toroids will overheat, SWR climbs as Curie temperature reached. But the toroid(s) will recover after cooling. Hot toroids can also melt the plastic case.

# Recommended commercial EFHW Antennas and UNUN vendors

- For 100 watts and up: My Antennas antennas and EFHW transformers
  - MEF-130-LP xfmr: $89.00 – $113.99
    - Covers all Bands 160-10m
    - Low Power capability – 250W ICAS (100W@ FT8)
    - LOW insertion loss ~0.4dB 1-30MHz
  - MEF-130-2K-Plus xfmr: $179.99 – $204.98
    - Covers all bands 160-10m
    - High Power capability – 2kW ICAS
    - LOW insertion loss ~0.5dB

- For QRP: QRP Guys EFHW 40m-15m Mini Tuner
  - Fuchs antenna tuner + N7VE VSWR bridge - $40.00 YouTube review.

# Thoughts on the ARRL EFHW Antenna Kit

- The ARRL Antenna Kit $79.95
- Designed by HF Kits
- Parts for 40-20-15-10 meters. Transformer cannot be used on 80 without mods.
- Power rating: 250 W PEP
- Good quality parts, good instructions. Easy to build.
- But…fairly inefficient especially at the high frequency end. ~1dB loss (~80% efficient) on 20 meters, ~1.5dB loss (~71% efficient) on 10 meters.
- I recommend adding an additional FT240-43 before winding (Fair Rite 5943003801). Cost about $9.00 Lower losses (<.7dB through 15 meters 85% efficient, 1.2dB on 10 meters 75.9% efficient) Will need longer wire to wind it. Slightly higher VSWR. Also allows use on 80 meters.

Two FT240-43s vs Single FT240-43 provides higher efficiency and runs much cooler

# End Fed Half Wave (EFHW) vs Off-Center-Fed-Dipole (OCFD)

## EFHW

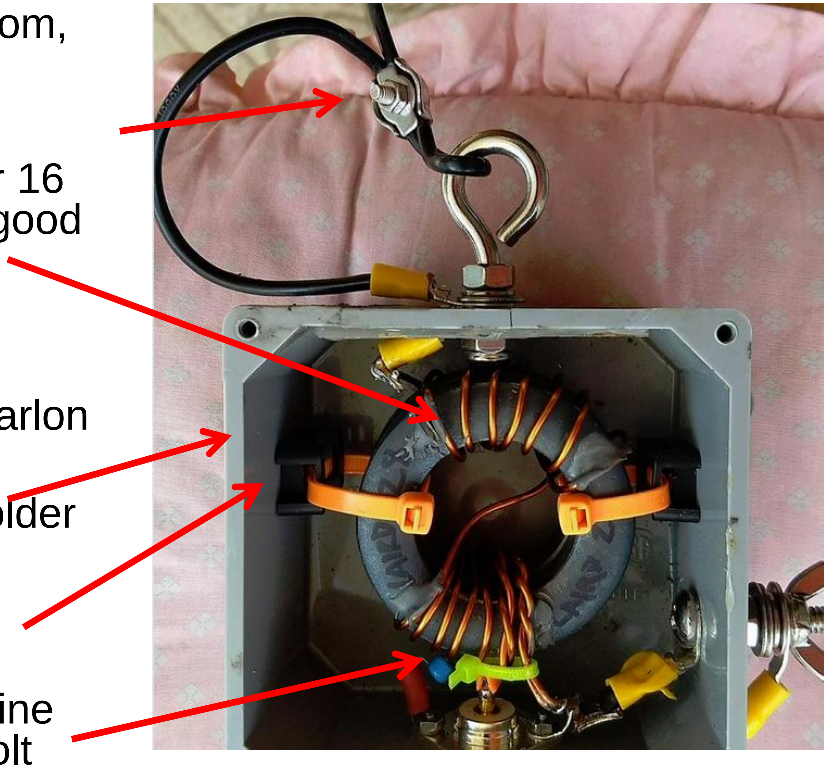
- Pros:
  - More flexible mounting provisions
  - Inherently grounded through coax
- Cons:
  - More difficult to make a high power efficient EFHW transformer
  - More RFI issues
  - Requires compensation cap

## OCFD

- Pros:
  - More efficient transmission line based transformers
  - Smaller and cheaper cores for a given power level
  - Easier to build a high power OCFD hybrid balun
  - Less RFI issues
- Cons:
  - Less flexible mounting provisions (hanging coax)
  - Good working hybrid transformers are hard to find commercially

# Sources of Materials

- Toroids – arrow.com, mouser.com, digikey.com, kitsandparts.com
- 1 post stainless wire rope clip: Amazon.com
- Enamel wire: Amazon.com. Search on 14 or 16 gauge copper magnet wire. TEMco, Essex good brands.
- Stainless steel ¼” hardware: Home Depot, Lowes, mcmaster-carr.
- 4”X4”X2” PVC junction box or equivalent (Carlon E989NNJ-CAR) Home Depot or Lowes
- Cable Tie Base Saddle Type Mount Wire Holder 100 pcs – eBay or Amazon
- 100pF high voltage capacitors – Mouser, Digikey, eBay
- Wire rope thimble (optional) Amazon or marine supply house. Relieves strain around eye bolt



# Resource Links

- Facebook group Real End Fed Half Wave Antennas
- Building the EFHW Transformer – youTube video by Steve Ellington N1LQ
- Review of MyAntennas End Fed Half Wave Antenna 80-10 meters by Joel Halas, W1ZR, QST magazine, Mar. 2016 (Needs ARRL member login)
- Endfed Halfwave antenna patterns (look under EFHW)
- toroids.info Dimensions and inductance computation for common toroids
- Ferrite complex permeability interpolations for commonly used materials
- Calculate Ferrite Core Inductor, rectangular cross section All Owen Duffy on-line calculators
- Various antenna presentations on GNARC.org by K1RF