End Fed Half Wave MultiBand Antennas

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What motivated this presentation

- I got into a long running debate about EFHW on QRZ.com Antenna Forum
- It has been going on for months...
- The key issues:
  - Need for a “counterPoise”
  - Coax is the other half of the antenna
  - Effects of Current on the coax
What is an **End Fed Half Wave Antenna**?

- Let's call it a **“EFHW”**
- Works on a similar principle to a Zepp and J-Pole
- ~0.5 Wave-Length wire on lowest band (130ft on 80m, 67ft on 40m)
- Fed from one end using a transformer in a box
What is an **End Fed Half Wave Antenna**?

- Transformer is a 1:49 or 1:64 UnUn (not 1:4 or 1:9 used on random wire antennas)
- 50 Ohm Coax from transformer to station
- Multi-Band (works on all harmonics)
- Deploy it horizontal, sloping, inverted-L, inverted-V
- Commercial example: MyAntennas EFHW-8010-2K
- Pass it around (I want it back!)
1:49 Transformer schematic

Notes:
AutoTransformer Primary is three turns. Secondary is 21 turns, the first three of which are twisted with the primary. C1 flattens SWR at higher frequencies. Turns ratio = 3:21, Z ratio = 1:49
Coax shield is common to short wire.
My test set-up for the 8010

- Mostly Horizontal
- ~35ft Above Ground
- Tried Variable Coax length
- Grounded only at IC7300
- Optional external grounds
- CM current measurement
Actual SWR measurements

- Started with 58ft of foam RG8 (benign)
- No ground connection except at IC7300
  - On purpose to see if any RF “problems”
  - No CMC
- Measured SWR using RigExpert AA-600
- Actual Plots for 80m to 10m follow:
- Fq = 3.581 MHz
- SWR = 1.59
- Return loss = 12.86 dB
- Z = 31.7 + j3.6 Ohm
- |Z| = 31.9 Ohm
- Phase = 6.6°
- L = 162 nH
- Zpar = 32.2 + j279.7 Ohm
- Lpar = 12436 nH
- Cable: Length(1/4) = 13.81 m, Length(1/2) = 27.63 m
Range: 7.150 ± 0.200 MHz, 120 points

Fq = 7.090 MHz
SWR = 1.72
Return loss = 11.58 dB
Z = 75.6 - j21.7 Ohm
|Z| = 78.7 Ohm
Phase = -16.0°
C = 1031 pF
Zpar = 81.9 - j284.7 Ohm
Cpar = 78 pF
Cable: Length(1/4) = 6.98 m, Length(1/2) = 13.95 m
Range: 10.150 ± 0.150 MHz, 120 points

Fq = 10.150 MHz
SWR = 3.62
Return loss = 4.92 dB
Z = 67.0 - j77.9 Ohm
|Z| = 102.7 Ohm
Phase = -49.3 °
C = 201 pF
Zpar = 157.6 - j135.5 Ohm
Cpar = 115 pF
Cable: Length(1/4) = 4.87 m, Length(1/2) = 9.75 m

Points in the graph: 120+1
Range: 14.175 ± 0.225 MHz, 100 points

Fq = 14.175 MHz
SWR = 1.56
Return loss = 13.26 dB
Z = 74.9 - j11.2 Ohm
|Z| = 75.7 Ohm
Phase = -8.5°
C = 1005 pF
Zpar = 76.5 - j513.3 Ohm
Cpar = 21 pF
Cable: Length(1/4) = 3.49 m, Length(1/2) = 6.98 m

Points in the graph: 100+1
<table>
<thead>
<tr>
<th>Frequency (MHz)</th>
<th>SWR</th>
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<td>18.125 ± 0.075 MHz</td>
<td>100 points</td>
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<tr>
<td>18.108 MHz</td>
<td>2.36</td>
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<tr>
<td>Return loss</td>
<td>7.85 dB</td>
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<td>$Z = 97.7 - j39.5$ Ohm</td>
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<tr>
<td>$</td>
<td>Z</td>
</tr>
<tr>
<td>Phase</td>
<td>-22.0°</td>
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<tr>
<td>$C = 222$ pF</td>
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<tr>
<td>$Z_{par} = 113.7 - j280.9$ Ohm</td>
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<tr>
<td>$C_{par} = 31$ pF</td>
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</tr>
<tr>
<td>Cable Length$(1/4) = 2.73$ m, $Length(1/2) = 5.46$ m</td>
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</table>
Range: 21.225 ± 0.275 MHz, 100 points

Fq = 21.198 MHz
SWR = 1.98
Return loss = 9.69 dB
Z = 50.0 - j34.7 Ohm
|Z| = 60.9 Ohm
Phase = -34.7°
C = 216 pF
Zpar = 74.1 - j106.8 Ohm
Cpar = 70 pF
Cable: Length(1/4) = 2.33 m, Length(1/2) = 4.67 m
Range: 24.950 ± 0.100 MHz, 100 points

Fq = 24.944 MHz
SWR = 1.54
Return loss = 13.48 dB
Z = 75.2 + j8.6 Ohm
|Z| = 75.7 Ohm
Phase = 6.5°
L = 54 nH
Zpar = 76.1 + j667.1 Ohm
Lpar = 4258 nH
Cable: Length(1/4) = 1.98 m, Length(1/2) = 3.97 m

Points in the graph: 100+1
Range: 28.975 ± 1.025 MHz, 150 points

Fq = 28.592 MHz
SWR = 1.16
Return loss = 22.46 dB
Z = 53.3 - j7.1 Ohm
|Z| = 53.7 Ohm
Phase = -7.6°
C = 785 pF
Zpar = 54.2 - j408.0 Ohm
Cpar = 13 pF
Cable: Length(1/4) = 1.73 m, Length(1/2) = 3.46 m

Points in the graph: 150+1
Summary of SWR measurements

- 3.5 to 3.82Mhz: IC7300's internal 1:3 tuner
- 80m band: **external** manual tuner (Palstar)
- 40m band: no tuner needed
- 30m band: **external** tuner
- 20m band: no tuner
- 15m band: no tuner
- 17m band: internal 1:3 tuner
- 12m band: no tuner
- 10m band: internal tuner
Modeling the EFHW

- Using NEC to learn how it works
- Compare it to Center-Fed Dipole
- Show feed-point impedences
- Overlay current distributions
- Overlay SWR plots
- Overlay Patterns
- Show CM effects
Prototype Center-Fed Dipole

Peak current = 1.35A

Resonant at 3.600MHz

Wire Length = 131.25ft, Z = 54.6 - j0.6 Ohms, Swr50 = 1.094
Height = 35ft, average dirt

Prototype End-Fed Antenna

Counter-Poise

Peak current = 1.35A

Resonant at 3.600MHz

Feed current = 0.201A

Feed-Point 5.7% from end, Wire Length=134.6ft
Z=2469 - j11.8, Swr2450=1.009
SWR of EF vs CF

![SWR Graph](image)

- **End Fed, relative to 2450 Ohms**
- **Center Fed, relative to 50 Ohms**

**Graph Details**
- **Y-axis**: SWR(2450) at Src1
- **X-axis**: Frequency (MHz)
- **Zoom Levels**: INF, 10, 5, 3, 2, 1.5, 1.2

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Takeaways from CF/EF simulations

- Current distribution almost identical on fundamental band
- 3.6 MHz Azimuth Patterns identical
- Tail (counterpoise) is a required part
- EF tail is tiny, only 7.7ft out of 134.6ft
- Ratio is for 2450 Ohm (1:49 transformer)
- Tail current is only 15% of peak in wire
- Not a big stretch to cut off tail
EFHW as a multi-band antenna

- EF resonates on all harmonics,
- Resonance not exact integer multiples
- Requires Compensation coil, about 6ft from transformer
- Aligns the SWR dips on harmonics
- Coil makes it “longer”
- Show simulation
- Show Patterns
3.6 MHz EFW on its sixth harmonic

\[ Z = 36.55 - j2.6 \text{ SWR}=1.37 @ 23.06\text{MHz} \]
Compensated EFHW

Variables: Coil inductance, Dist from Transformer

SWR(50) vs Frequency

- Compensated
- Plain EFHW

Frequency (MHz)
Move the first SWR null to 75m

- The EFHW-8010 has the lowest SWR at ~3.58MHz
- Not good if your interest is 75m
- There is a new EFHW-7510-2K model
- Adds a 300pF capacitor to center of the long wire.
- How does that work?
Evolution of EFHW-7510 antenna

Coil

Added 300pF capacitor

Transformer

---

SWR(50) vs Frequency

- EFHW-8010 EzNec model
- Added 300pF capacitor

- SWR(50) at Src1
- Frequency (MHz)

INF

5

3.5  3.55  3.6  3.65  3.7  3.75  3.8  3.85  3.9  3.95  4

Ref Zo

EZNEC Scaling

Snapshots
Compensation capacitor

- 80m: current is max at center of long wire
- 40m: current is min at center of long wire
- Capacitive reactance makes antenna shorter only on 80m
- not on 40m on up
- Capacitor becomes a short on higher bands
- Position juggled with compensation coil.
Azimuth Patterns

- Identical to dipole on fundamental
- On Higher Harmonics:
  - “lobes”
  - Some Gain
  - Deep Nulls
- Might need two antennas?
- Look at what the simulator predicts:
- Observed
Coax is really three conductors

- **Two are Center-to-Inside-of-Shield**
  - Called Differential (TEM) Mode of coax
  - Carries power to antenna.
  - Fields completely cancel inside coax

- **Third conductor is the outside of Shield**
  - Acts as a real wire in the near-field
  - Modifies the pattern/SWR
  - Follows the coax back to the shack

- **Called Common Mode (CM) on coax**
Effect of small CM current on Coax

Unbalance

Peak Current = 1.11A

0.48wl Dipole

0.43wl of Coax

Peak Ground current = 0.26A

Dipole without a balun

-- Graph --

Changed coax length from 0.43wl to 0.50wl

CM at rig

Currents on Segments

Coax

Dipole

Wires 1-6 Segments in Tabular Sequence

7.150 MHz
End fed, coax near, but not connected

Small CM case, Coax = 0.49wl
Coax Connected to Transformer

Small CM, Coax = 0.49wl

Currents on Segments

- Coax length = 0.3 wl (ok)
- 0.75 wl (bad)
- 0.5 wl (ok)
- 0.25 wl (bad)

* Gnd current

Wires 1-5 Segments in Tabular Sequence

7.150 MHz
Vary coax length on EFHW

- 80m EFHW (coax only)
- Coax grounded
- No CMC
- Vary coax from 45ft (0.16wl) to 265ft (0.97wl)
- Watch the movie:
Now let's fix it

- Mitigation
  - Common Mode Choke (see example)
  - Ground near transformer.
Mitigating the CM current

Choke no closer than 0.1wl
What simulation shows about coax shield

- **CM Current on coax shield comes from:**
  - Mutual coupling between EF wire and coax, especially if coax-to-ground path becomes resonant (dominant effect)
  - Transformer secondary current (small effect)
- **When Standing-Wave forms on coax shield**
  - Radiates and distorts pattern
  - Changes feed-point Z and SWR
  - Conducts RF < into shack
  - Conducts noise > to receiver front-end
CM on coax during testing

- I used the EFHW-8010 test set up shown
- 100W to antenna, Max wire current ~1.4A
- I used a CM current meter I built (0.6A f.s.)
- Tried w/wo CM choke, Ground at window
- Tried various coax lengths to find resonances
- Tried all bands where no tuner needed
- Highest CM sometimes outside (Standing W)
Current Transformer/Detector for measuring CM current on coax
Measured CM at rig end (circled values cause “buzz” in computer speakers)

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Finding the Coax “monopole” resonance on 80m

- Added coax in 2ft steps
- 0.25wl resonance in coax shield at 66ft
- CM meter pinned at 100W (0.6A = f.s.)
- Had to reduce power to ~10W
- Can see the coax resonance in SWR plot:
Coax resonance shows in 80m SWR plot

- **F₀**: 3.760 MHz
- **SWR**: 1.14
- **Return loss**: 23.51 dB
- **Z**: 47.6 + j6.1 Ohm
- **|Z|**: 48.0 Ohm
- **Phase**: 7.3°
- **L**: 256 nH
- **Zpar**: 48.4 + j379.6 Ohm
- **Lpar**: 16077 nH
- **Cable**: Length(1/4) = 13.16 m, Length(1/2) = 26.31 m
Grounding coax shield at Entry Panel

- Shunts CM current to earth
- Eliminates it inside shack (verified)
- Changes the path length (for better/worse)
- CM might still be high between entry panel and the transformer to:
  - Distort pattern
  - Pick up noise
  - Change SWR
Adding Common Mode Choke

- CMC = 10 to 17t of small coax on FT240-31
- Analogy: break resonance in guy wire
- Placement (recall simulation)
  - No closer than ~0.1 lowest-band wl to Xfrmr
  - Optimum location on one band may not be optimum on others
  - Locate where coax turns corner below antenna.
- May not need; if CM, then experiment.
Grounding coax/transformer

- Add second earth ground to coax shield under antenna
- Low-mounted transformer (inverted V or L), use Gnd wingnut on box?
- Horizontal/Sloper EFHW fed from tower case study, have some inconsistency between simulation and measurement of actual ant.
Home-building

- Certainly do-able
- Just wire, toroids, capacitor, coax, insulator, box and hardware
- Web is full of resources, some of it bad
- Steve Ellington's videos on YouTube
- FT140-43 toroid for QRP
- Use two or three stacked FT-240-43 for 100W to QRO.
Conclusions: Advantages

- Useful antenna for multi-band operation
- Lots of bands with no-tuner or tuner built-in rig
- Fed from one end sometimes more convenient
- Simple to deploy Horiz, Sloped, V or L
- Useful for limited space, RV, SOTA, FD
- Home-brewable
Conclusions: Disadvantages

- Patterns with deep nulls on certain headings
- Common-mode can be problematic
  - RF in the shack
  - Noise coupled to coax in the shack
- I would:
  - Plan for CM Choke (added cost)
  - Plan for a ground rod
So, to summarize my take on the debate as far as it has come:

1. There is no such thing as an End Fed Half Wave (EFHW) antenna.
2. There is such a thing as an Extremely Off Center Fed (EOCF) Antenna, which is what we have been discussing.
3. An isolated EOCF antenna requires at least a minimal (0.05wl) counterpoise to work.
4. The current into the counterpoise is small compared to the peak current in the active part of the antenna (~20%).
5. The counterpoise can be a 0.05 to 0.4 wl wire without affecting SWR hardly at all.
6. If a coax feeds a three-terminal auto-transformer, the coax shield can be the counterpoise, and the short wire is redundant.
7. The current on the coax shield can be choked, as long as the choke is no closer than 0.05wl to the transformer.
8. The current on the coax shield can be shunted into the earth with a ground rod.
9. In certain installations, you might have to do both 7 and 8 to prevent RF getting into things in the shack.