A Linked End-Fed Half Wave (EFHW) for Field Use

VERSION 0.85

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INTRODUCTION

This paper documents my findings in designing and testing a linked End-Fed Half Wave (EFHW) HF antenna for field use. My intent is for this to be a living document that evolves as I improve the design and continue to develop new findings. To that end, if you build an antenna from the design below and have feedback, please send it!

This project has the following design goals in no particular order:

1. Must be small enough and light enough to be backpack portable.
2. Must be rugged enough to withstand wind, rain, or other weather conditions for a short-term deployment (anywhere from a few hours to a few days).
3. Must have a consistent, predictable radiation pattern that does not change with frequency.
4. Must support operation of up to 100W.
5. Must be more easily deployed than a comparable dipole.
6. Should achieve SWR performance of 1.5:1 or less on the amateur bands from 3.5-15mhz without a tuner. Useful performance from 15-30mhz is desirable but not required.
7. Should be rapidly deployable using trees or other expedient supports.
8. Should be easily repaired in the field with simple tools.
9. Should fit into a 10"x6" or smaller MOLLE pouch.

A properly designed linked-EFHW may be able to meet all the above criteria. Commercially available EFHW antennas, however, are usually lacking in one or more of the above areas. Notably, amateur radio equipment often fails the ruggedness requirement. Personally, I have found ultralight QRP antennas to be somewhat fragile. Also, most amateur antennas marketed for portable use have no weather resistance. An antenna with personal or community preparedness as a potential use case should deliver predictable performance in poor weather. Even when operating for recreation, I have often deployed an antenna for a few days at a time at a home or campsite where rain was more than a possibility. I don't want to worry that my antenna may fail or damage my equipment simply because it got wet.

Achieving a predictable radiation pattern is important to me. Establishing communications with known contacts requires the ability to steer your RF in useful directions. Random wire antennas are very convenient to use for multiband operation but have radiation patterns that vary widely with frequency. Everyone understands and can visualize the radiation pattern of a half-wave dipole. One of the advantages of an EFHW operated on its fundamental frequency is that it performs electrically just like a standard dipole and therefore shares its predictable radiation pattern.

While it is possible to operate on multiple bands with an EFHW using a single wire I am going to use a different approach for three reasons. First, maintaining the predictable radiation pattern requires operating on the fundamental frequency. Once you begin operating on the harmonics you introduce strong lobes and deep nulls that make steering the antenna more difficult. Secondly, using a linked design for band changes allows you to easily adapt the antenna to smaller spaces by removing unused links. Lastly, tuning an EFHW for harmonic operation involves adding inductors and capacitors in-line that add weight and bulk to the design. A linked design is optimal for portable operation as it keeps bulk to a minimum while you can quickly lower the antenna to change bands. For the fixed station operator needing multi-band capability, the linked design may be too cumbersome over the long-term.

The following section discusses the theory of the EFHW design and the test results I obtained while prototyping this project. If you are a TL;DR type of person and trust I know what I'm talking about, skip this section and proceed to the Tools Required and Bill of Materials (BOM) sections below.

DESIGN & CONSTRUCTION

Theory & Design Considerations

An EFHW is simply a variation of a dipole antenna. In fact, the IEEE defines a dipole as any antenna that performs electrically equivalent to a standard half-wave dipole.[1] As it turns out, you can feed a half-wavelength wire anywhere along its length and it will perform electrically as a center-fed dipole. This gives rise to an effectively unlimited number of potential dipole variants. As operators, we can feed our antenna anywhere that is convenient for us. Figure 1 depicts examples of these variants and the effect moving the feed point has on feed point impedance.

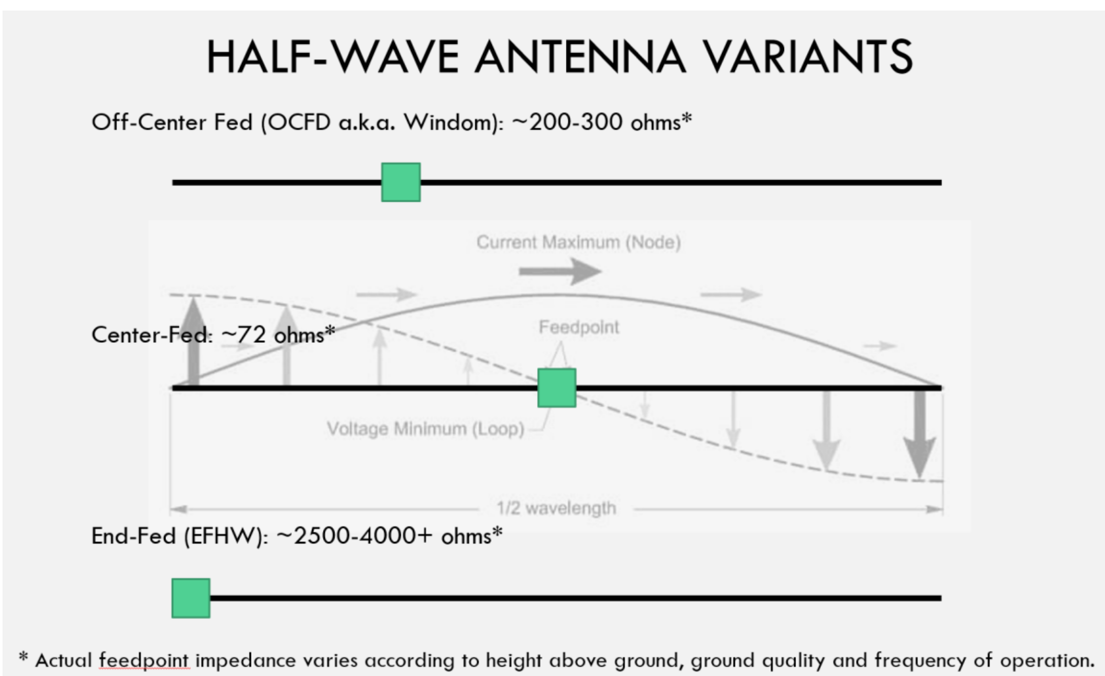

Figure 1: A half-wave antenna three ways. In each case, the voltage and current distributions across each wire match therefore each performs electrically as if it were a standard center-fed dipole.

In the field, a standard center-fed dipole is usable but often inconvenient as it generally requires three points by which to suspend the antenna. Deploying a dipole in or around trees requires extra care to avoid tangling the pair of elements. All in all, life is much easier if we can limit our number of required suspension points to two and number of wires to one. Doing so saves time, reduces frustration with tangled wires, and boosts our flexibility by increasing the number of locations and ways in which we can deploy our antenna. End-feeding our dipole is our means to that end.

All we need to do to make this practical is find a way to match the several thousand ohms impedance found at the end of our wire to our 50-ohm transceiver. The common approaches to solving the impedance mismatch problem are to build an adjustable L-C matching network[2] or a broadband matching transformer. Since we've made clear we're looking for convenience we're going to continue from this point on by exploring the broadband matching transformer as it requires no adjustment over the range of frequencies for which it is useful.

The common approach to a broadband EFHW matching transformer is to build a 49:1 Unbalanced-to-Unbalanced transformer (UNUN). Plans abound on the internet for building 49:1 matching transformers. Perhaps you've even built one. Popular as they are, these 49:1 transformers suffer from two problems. First, they are not optimized for operation over the full frequency range we are seeking in the project (3.5-15mhz). Secondly, they are not optimized for efficiency over the frequency range they are useful for. We will consider each of these problems in turn as the solutions to these problems lead me to my preferred design.

Most plans for 49:1 UNUNs, and even most commercial suppliers, advertise these transformers as being usable across the entire HF spectrum of 3-30mhz. In practice this generally isn't true if you intend to operate your antenna solely on its fundamental frequency. This is because the impedance of a practical antenna is generally highest on the fundamental frequency and continues to go up as you move down in frequency.

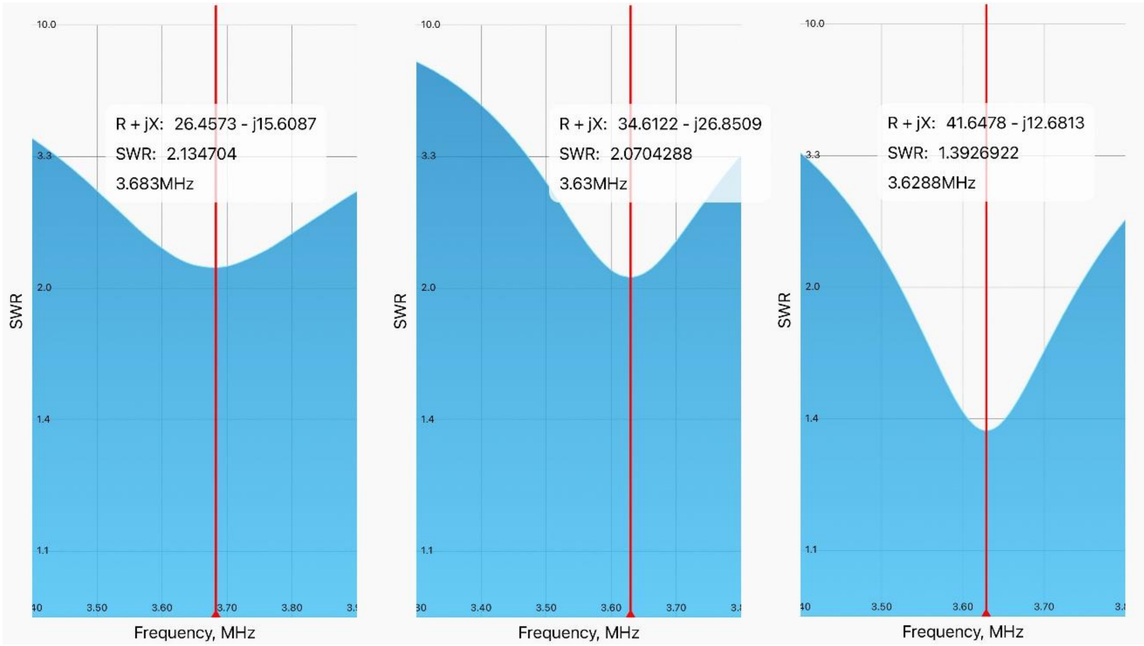

Figure 2: A tale of three UNUNs, each deployed horizontally about 20' AGL. 49:1 at left, 64:1 at center and 81:1 at right. The 49:1 was a different design using a conventional winding and two FT240-43 cores stacked.

The 80m band is not very convenient to operate on from a SOTA summit but is very useful for local and regional communication using Near Vertical Incident Skywave (NVIS) techniques. The 80m band, therefore, is very desirable for this project. In Figure 2, I show how I was unable to get an acceptable match on 80m until I ratcheted up the transformation ratio to 81:1. Since hardly anyone is using 81:1 transformers I thought I must be experiencing some kind of mistake, so I took a second look at the results of others. Surprisingly, I quickly found evidence that others experienced similar results matching 80m with common UNUNs.

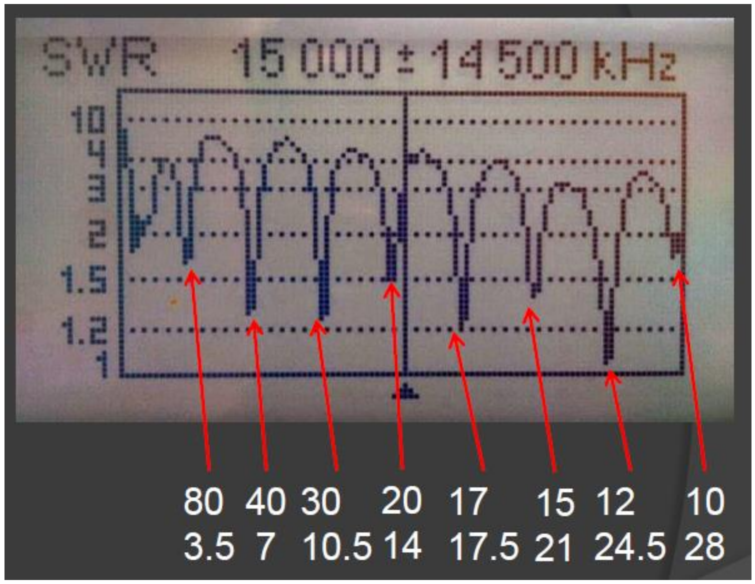

Figure 3: A sweep of a multiband EFHW using a 49:1 UNUN from K1RF's widely circulated presentation on the theory and construction of EFHW antennas[3].

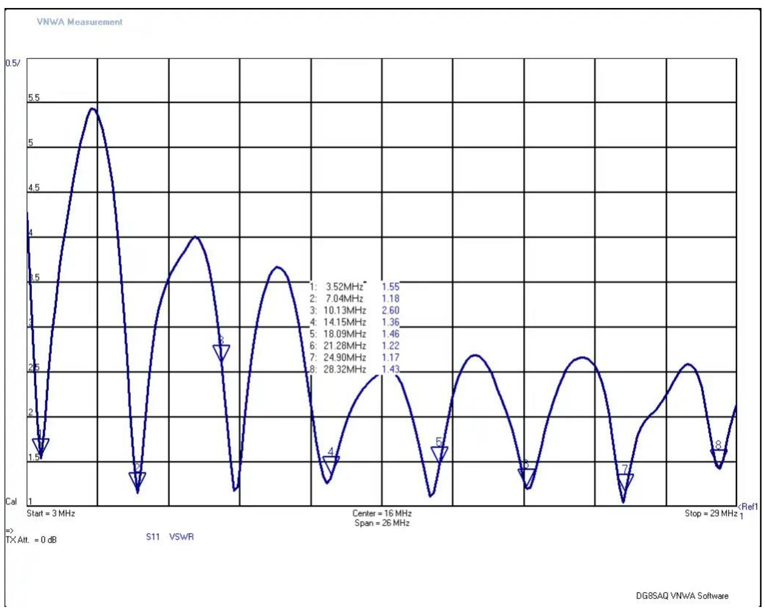

Figure 4: Another 49:1 multiband EFHW sweep. This one from commercial supplier MyAntennas[4].

Look at figures 3 & 4 carefully. Both depict sweeps of 80m EFHW antennas on 80m and its harmonic bands using 49:1 UNUNs. Both sweeps depict a higher SWR on the fundamental frequency of 80m. I am calling this observation the Fundamental Frequency Effect. For this project, in which I want to link my elements such that I am always operating on the fundamental frequency, we will need to consider the need for a matching transformer with sufficient transformation to compensate for the Fundamental Frequency Effect on 80m. This is the reason for my use of the unusual 81:1 UNUN.

Next let's look at efficiency. Most common designs for EFHW UNUNs use the FT240-43 (Fair-Rite PN: 5943003801) or FT140-43 (Fair-Rite PN: 2643802702) toroids. It turns out that the geometry of these toroids is not optimal. They are made for RFI suppression so are designed to make it easy to wind coax or other cabling around them. This property gives these components low cross-sectional area relative to their volume. Using a NanoVNA and a shunt fixture we can determine the core loss in these ferrite components[5].

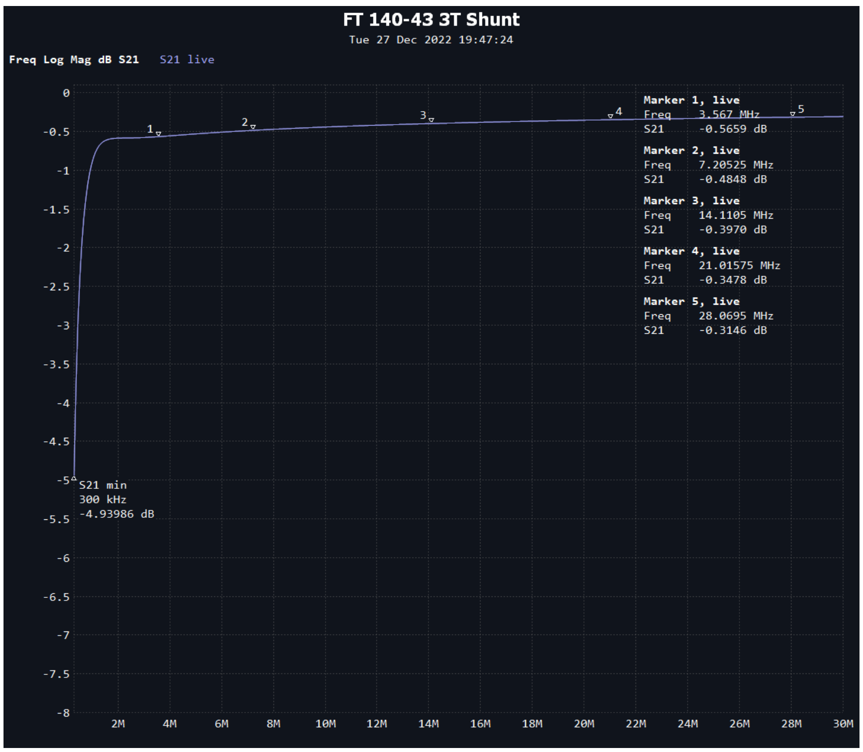

Figure 5: Core loss measured in a FT140-43 toroid with a three-turn primary.

Losses in the 3 turn primary FT140-43 core vary with frequency from .31dB to .57dB. In absolute terms, that means a loss of about 7% at 10m and 12% at 80m. Not bad but can we improve on this?

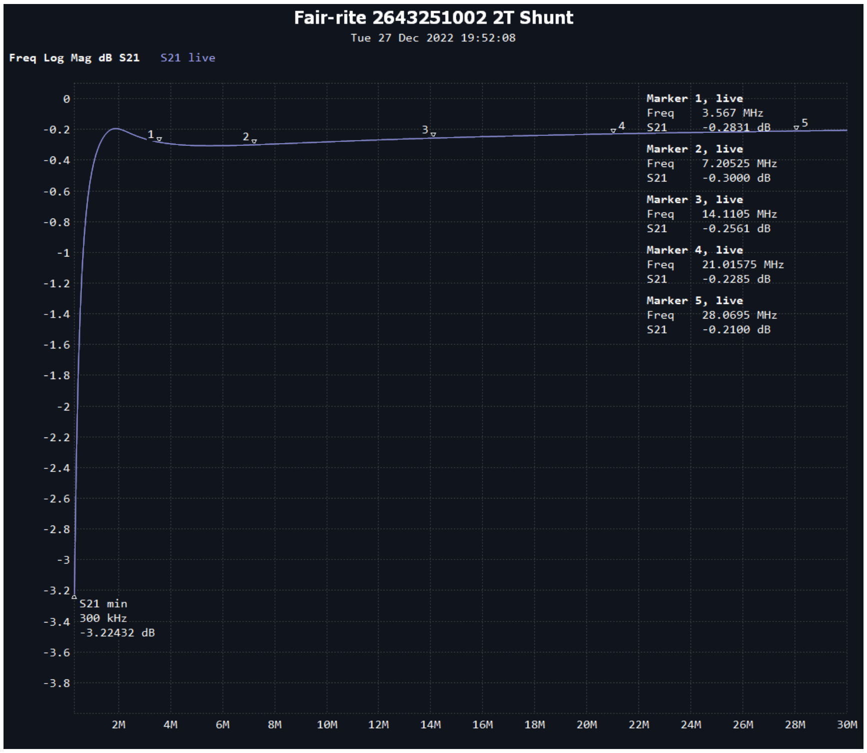

Figure 6: Core loss measured in a Fair-Rite 2643251002 toroid with two-turn primary.

Indeed, using a ferrite core with higher cross-sectional area we can improve the efficiency of our design. The Fair-Rite 2643251002 toroid has losses varying from around 5% at 10m to around 6% at 80m. A significant improvement on the low end!

Since Fair-Rite 2643251002 toroids have improved efficiency, particularly on the low bands where we are primarily interested in operating, and are readily available, there is no reason not to use them for this project.

Based on both the measurements I have taken on the bench and the results I've had in the field I'm satisfied that the 81:1 UNUN using the Fair-Rite 2643251002 toroid is optimal for this project. That said, I wanted to verify the loss measurements from the bench translate to the real world. To confirm my results, I used an RF current meter to compare a center fed dipole to my 81:1 UNUN. My control is a center fed dipole with no BALUN. While the center fed dipole with BALUN naturally performs better I

Authors Note

There are losses other than core loss that occur in EFHW transformers. Mismatch losses get cancelled out when tuning your wire elements but there is also inductive loss (a.k.a. leakage inductance) from magnetic energy that is dissipated into the space around the transformer instead of in the core. Inductive losses go up with the number of turns used in the transformer secondary and with frequency. These losses put an upper frequency limit on use of these transformers and is a limitation of using a broadband transformer versus a tunable matching network. A compensating capacitor can cancel some of the inductive loss and improve the match but that also has limits. TANSTAAFL!

have not found a practical way to replicate a choked EFHW in the field if coax is used. Additionally, many portable operators choose to save weight by forgoing a BALUN on their dipoles. The table below details the results. All measurements were taken with a PRC-174 manpack radio with approximately 20W output using CW on 7.055Mhz. The 40m band was chosen because it had the greatest loss in bench testing using the core in the 81:1 UNUN. All antennas were tested at a height of six feet AGL. The resolution of my MFJ RF current meter is fairly crude so I wouldn't attribute more than two significant digits to these measurements.

RF Current Measurement Results (approximate)					
Antenna	Wire Element RF Current	Coax RF Current	Wire Element Gain/Loss vs no BALUN Dipole (higher is better)	Coax Gain/Loss vs no BALUN Dipole (lower is better)	Wire Element Efficiency vs no BALUN Dipole (higher is better)
40m Dipole, no BALUN	600mA*	48mA	0dB	0dB	100%
40m Dipole, BALUN	600mA	1.5mA	0dB	-15dB	100%
40m EFHW 81:1 UNUN	500mA	15mA	-0.79dB	-5.1dB	83%
40m EFHW 49:1 UNUN FT240-43 2T:14	400mA	11mA	-1.8dB	-6.4dB	67%
40m EFHW 49:1 UNUN FT140-43 3T:21	420mA	10mA	-1.6dB	-6.8dB	70%

**On a previous day, I measured 530mA RF current on the dipole, no BALUN configuration, a result that makes more sense relative to the other measurements. That said, I wanted all measurements in this table to be taken on the same day so ground and weather conditions would be the same for all devices under test. This is the result I recorded on this second day so, for the sake honest reporting, it is the result I'm recording here.*

Since the EFHW has the same current and voltage distribution across its length as a dipole I consider the above RF current results to be apples-to-apples. Taking a peak current measurement of a random wire antenna and comparing it to a dipole, however, would be apples-to-oranges. If you are considering using the same technique in your own testing, keep that in mind.

In practical use, my linked EFHW and 81:1 UNUN are similar in performance to a center fed dipole with no BALUN. A single S-unit is 6dB so it is unlikely that a receiving station would be able to detect the difference in any case. It is also worth noting that the total radiated power is the sum of power radiated by both the wire element and the coax. While it is generally preferred that the coax not radiate, the low RF current present on both the dipole with no BALUN and the EFHWs do contribute to the total transmitted signal strength. While the 81:1 UNUN was measurably more efficient, the difference in performance between the various EFHWs was small. The practical benefit of improved efficiency will likely be improved thermal characteristics for longer duty cycles.

Moving on, another obstacle I encountered in field testing was the coax length I used has a measurable effect on the tuning of the antenna. As a result, I tried to isolate the antenna from the feedline with a choke. Modeling and testing, by John Huggins, KX4O, has proved that an EFHW antenna does not need a counterpoise.[6] Theoretically the feedline length problem could be solved if the feedline could be sufficiently isolated from the antenna.

Figure 7: EFHW transformer with integrated choke.

In practice, the device shown in Figure 7 did not work as intended. While tuning up this device on 20m I found the system resonated somewhere in the ballpark of 40m. Why? The best explanation I have is that my 33′ antenna element and 25′ feedline were operating something close to a center fed dipole. Remove the choke and this effect disappears. It seems the effort to isolate the antenna raised the impedance of the coax shield making it a closer match to the impedance of the intended radiating element. Thus, more power ended up transferred to the coax shield, not less.

Since the integrated choke was counterproductive, I decided to standardize the length of coax I carry with this kit. Based on my own usage patterns, I've found 25′ of RG-316 coax to be ideal. If I need more than 25′ of feedline I place a choke at the end of the feedline and attach whatever additional coax I need. N9SAB's Nano Balun is ideal for this purpose if you are operating at low power, but any choke will do.

Having gone on long enough about the theory and testing of EFHW's, let's move on to building one.

Tools Required

- Drill
- Dremel with Cut-off Disc
- Step Bit with ½″ step
- ¼″ Bit
- 7/32″ Bit
- Spring Loaded Center Punch
- Heat Gun
- Soldering Iron
- Solder
- Wire Cutters
- Uninsulated Terminal Crimper (for high quality crimps, use a ratcheting die crimper)
- Phillips Screwdriver
- Utility Knife
- Pencil

Bill of Materials (BOM)

81:1 UNUN				
Item	MFR Part #	Qty	Unit	Notes
Fair-Rite Material 43 Core	2643251002	1	ea	
Hammond Polycarbonate Enclosure IP65	RP1030	1	ea	
Amphenol Hydrophobic Vent IP68	VENT-PS1YBK-N8001	1	ea	
TDK 120pF 3kV Ceramic Capacitor	CC45SL3FD121JYNNA	1	ea	
TEMCO 18AWG Copper Magnet Wire	HM-17344	55	in	Or equivalent. The cited material uses a high temp enamel with a higher breakdown voltage.
Pomona BNC-F Bulkhead	3778	1	ea	

Connector				
Hillman 10-32 Stainless Hex Nut	2528	1	ea	Or equivalent.
Hillman #10 Stainless Split Lock Washer	2236	2	ea	Or equivalent.
Hillman #10 Stainless Flat Washer	2228	2	ea	Or equivalent.
Hillman 10-32x1" Stainless Button Socket Cap Screw	44002	1	ea	Or equivalent.
Hillman 10-32 Stainless Wing Nut	4360	1	ea	Or equivalent.
M6 Stainless Shoulder Lifting Eye Bolt		1	ea	Example: https://www.amazon.com/Stainless-Steel-Machinery-Shoulder-Lifting/dp/B08YXF3WNW/ref=sr_1_3?keywords=hillman+m6+split+shoulder+eye+bolt&sr=8-3
Hillman M6 Stainless Flat Washer	3626	1	ea	Or equivalent.
Hillman M6 Nut	6452	1	ea	Or equivalent.
Hillman M6 Stainless Split Lock Washer	43285	1	ea	Or equivalent.
Krylon Fusion Satin Khaki Spray Paint (optional)	K02740007			Optional.
Krylon Fusion Matte Spanish Moss Green Spray Paint (optional)	K02796007			Optional.
GE Clear Silicone Sealant	GE500	1	ea	Or equivalent.
Gardner Bender 4" Zip Tie	46-104UVB	2	ea	Or equivalent.
Gardner Bendner 8" Zip Tie	46-308UVBFZ	1	ea	Or equivalent.
1mil ½" Kapton Tape or Electrical Tape		1	in	
Frost King Rubber Foam Self-Stick	R338	~4	in	Or equivalent.

Weatherseal 3/8"x3/16"				
Frost King Rubber Foam Self-Stick Weatherseal 3/8"x5/16"	R538	~2	in	Or equivalent.
#10 Uninsulated Ring Terminal 22-18 AWG		1	ea	

Wire Elements				
Item	MFR Part #	Qty	Unit	Notes
DX-WIRE UL	00405	~135	ft	https://www.sotabeams.co.uk/dx-wire-ultralight-ul/ or https://www.dx-wire.de/lng/en/dx-wire-antenna-wire-litz/dx-wire-ul/
3/16" 3:1 Adhesive Lined Heat Shrink		10	in	
1/8" 3:1 Adhesive Linked Heat Shrink		1	in	
Uninsulated #10 Spade Fork Terminal Connector 22-18 AWG		1	ea	
Wirefy Heat Shrink Bullet Connectors 22-16 AWG – Female	RSFR1.25-150	6	ea	https://www.amazon.com/Wirefy-Shrink-Female-Bullet-Connectors/dp/B08BRM1V1F/ref=sr_1_1?keywords=RSFR1.25-150&sr=8-1
Wirefy Heat Shrink Bullet Connectors 22-16 AWG – Male	RSMP1.25-150	5	ea	https://www.amazon.com/Wirefy-Heat-Shrink-Bullet-Connectors/dp/B08BS2C7YT/ref=sr_1_1?keywords=RSMP1.25-150&sr=8-1&th=1
M3 Stainless Steel Wire Rope Clamp		12	ea	
S-Hook Carabiner, Coyote Brown, Black, or Olive Drab		7	ea	Choose a color or combination of colors that works for you. You need 7 in all for 20-80m. https://a.co/d/i9MRoe0

Enclosure Preparation

If using the recommended enclosure, Hammond RP1030, proceed to prepare the enclosure by drilling all the necessary penetrations and removing the lower stand-off as per the diagram in figure 3. All penetrations are centered on the enclosure wall. To prevent the drill bit from walking, mark all penetrations in pencil then dimple the enclosure with the spring-loaded center punch.

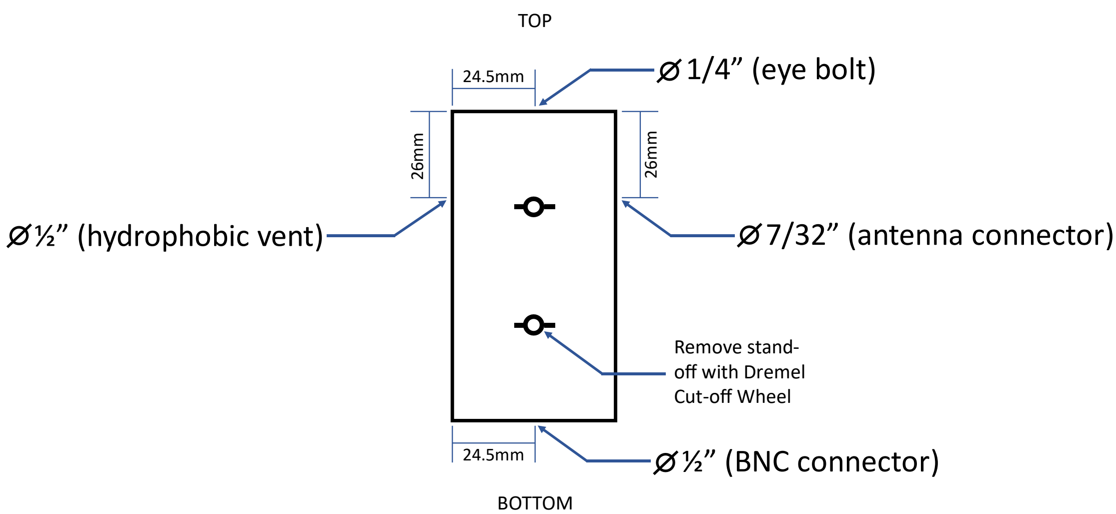

Figure 8: Enclosure preparation diagram.

Once the penetrations are complete and the lower stand-off removed, you may paint the enclosure any color you see fit. I suggest two possible earth tone colors in the BOM but these are just suggestions. Avoid use of any metallic paint or other finish that may contain conductive materials. While spray paint may be dry to the touch in 24 hours, I found in my humid climate that it takes about seven days for the paint to fully cure. If you opt to paint your enclosure plan accordingly.

UNUN Construction

To wind the transformer core will require about 55" of 18AWG magnet wire and a Fair-Rite mix 43 core 2643251002. The core will be close wound as an autotransformer for 18 turns with a tap on turn two. To minimize loses, do not use a Reisert crossover or bifilar coupled primary. The tap on turn two may be achieved by either soldering on a small lead or by cutting the wire and using a bifilar twist with the wire that continues to the secondary. That later method is depicted below in Figure 5 and is slightly more convenient to wind. I have tried both methods and have not detected a performance difference in testing. If you elect to solder a tap at turn two, I recommend insulating the connection with Kapton tape due to the high voltages that can occur within the transformer under high power or high SWR conditions.

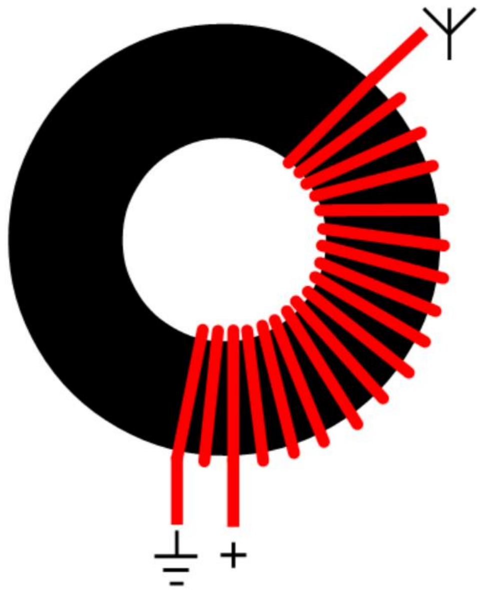

Figure 9: Winding Pattern for 81:1 UNUN.

To count turns, count the wire each time it passes through the center of the core as one turn. Once complete, secure your windings tightly with zip ties. The completed UNUN should appear as in Figure 5 below.

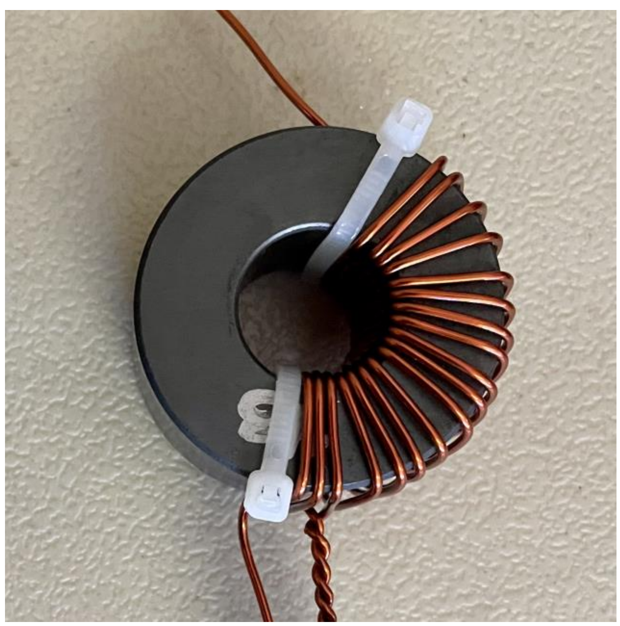

Figure 10: Completed core winding.

Assembling the UNUN

If you painted your enclosure, ensure the paint has cured before proceeding. Before trimming any wires, examine the detailed photos of an assembled UNUN found at the end of this section to ensure you understand the intended placement of each component.

Install the eye bolt, hydrophobic vent, and BNC connector onto the enclosure. The hydrophobic vent self-seals with an O-ring. For the eye bolt and BNC connector, seal each penetration with silicone by applying sealant around each hole before inserting the component. The eye bolt fastens with a M6 washer, M6 split ring washer, and M6 nut inside the enclosure. Tighten down each component then wipe away any excess sealant.

Cut three strips of 3/8" x 3/16"" self-adhesive foam weather stripping. Each will need to be roughly 1.25" in length. Apply the weather stripping inside the enclosure to cushion the ferrite core. Apply two of the strips vertically, one on each side of the enclosure. Apply the last strip horizontally across the bottom of the enclosure. Allow a gap for hot air to pass through the center of the core into the enclosure. Applying this foam weather stripping is optional but ensures the core cannot rattle inside the enclosure following assembly.

Attach a zip tie to the core and trim off the excess leaving a ½" tab. Orient the tab so it is on the bottom of the core facing up as it is placed into the enclosure. Test fit the core into the enclosure. Trim off excess wire from the ground, positive, and antenna connections such that the ½" zip tie tab lies comfortably on top of the remaining stand-off.

Solder the positive and ground connections to the BNC connector. Solder the #10 ring terminal to the antenna connection on the core. Take care to orient the ring terminal so it can be fit onto the antenna stud. Ensure you strip the enamel from each magnet wire connection before soldering.

Bend the leads on your 120pF capacitor 90 degrees and parallel. Solder it in shunt across the positive and ground connections of the BNC connector taking care not to loosen the connections to the core windings.

Work a washer in between the ring terminal and the enclosure wall. Insert the #10 socket head screw. Apply silicone sealant around the hole and place another washer onto the #10 screw on the outside of the enclosure. Place a split ring washer on the #10 nut. Tighten the antenna stud assembly and wipe away any excess sealant.

Using an appropriately sized bit, drill a small pilot hole through the zip tie tab on the core. Use one of the screws included with the enclosure to fasten the core through the zip tie tab to the remaining enclosure stand-off.

Apply a roughly 2" strip of 3/8" x 5/16" foam weather strip vertically to the inside of the enclosure cover.

Install a #10 split washer and wingnut to the antenna stud. To prevent losing the wingnut in the field, I recommend staking the #10 stud. You can use a large vice or vice-grip pliers to accomplish this.

Figure 11: The completed UNUN ready for final assembly. Carefully note the placement of each component before cutting and soldering.

Figure 12: Detail view of the antenna stud. Note the orientation and 90-degree bend in the ring terminal attaching the core to the stud.

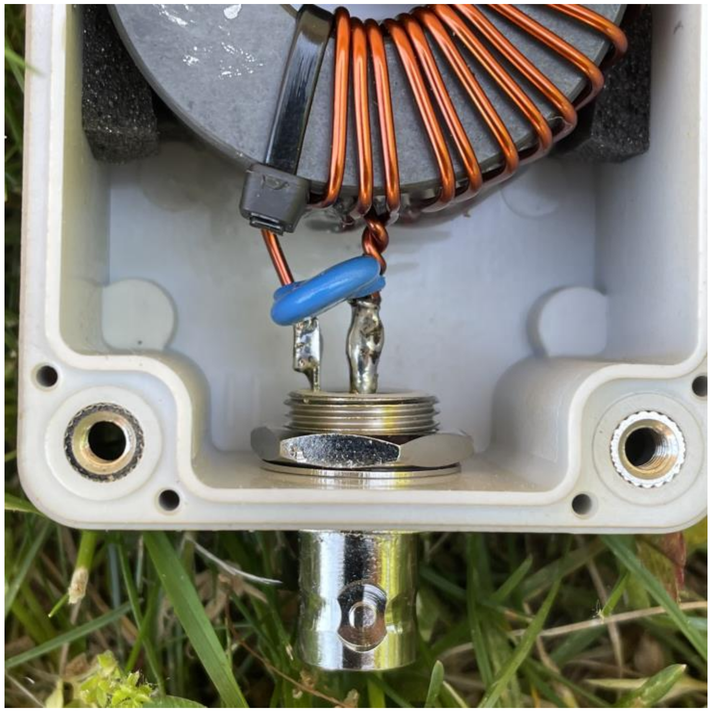

Figure 13: Detail view of BNC solder connections.

Construction of the Wire Elements

The following discussion covers how I build my wire elements using DX-WIRE UL. DX-WIRE UL is an aramid core (like Kevlar) wire that is both very lightweight and very strong. The yield strength is roughly 125lbs making it perfectly suitably for most deployments. This wire only has six strands of conductor, however, so it needs to be prepped carefully to maximize the strength of the connections. I will describe my process for constructing linked wire elements using this wire below. Of course, any suitable wire may be used and the UNUN was designed to make it easy to use improvised antenna elements in the field. Additionally, my use of wire rope clamps is deliberate. While there are lighter alternatives I could use in their place, such as crimp ferrules, wire rope clamps allow for the elements to be maintained in the field with a common multi-tool.

When constructing the wire elements for the linked EFHW begin with the 20m element first. The 20m element will have a spade fork connector on the end nearest the UNUN and a female bullet connector at the end furthest from the UNUN. Each subsequent

> ***Author's Note***
>
> *The feedline used on an EFHW becomes part of the antenna system. While the current that flows on the coax shield is low, it will affect the tuning of your wire elements. I recommend standardizing on a length of coax that works for your use case. Personally, I have standardized on 25′ of RG-316. If I need a longer feedline I place a choke on the end of the 25′ coax and attach whatever length I need beyond that. With this technique the antenna performs consistently. If you vary your coax lengths without using a choke expect the tuning to change.*

element will have one male and one female connector. Minimize the chances of contact with high voltage by assembling your wire elements with the female connector at the distal end of each element.

Carefully build and tune each element and proceed only when you are satisfied that it is tuned correctly. Each proceeding band builds on the wire elements that preceded it. If any of them are tuned incorrectly you will need to redo any subsequent elements. When tuning, establish a controlled location with no nearby metal objects, sources of interference, or unusual ground conditions.

Prepare the bullet connectors by stripping and discarding the included heat shrink coating with a utility knife. We will be replacing this heat shrink later in the build but at this stage we need to expose the entire connector. The bullet connectors specified in the BOM have double wall crimp sleeves and crimp nicely onto the very light gauge DX-WIRE UL. I have not yet found a source of uninsulated double wall barrel connectors. If you find such a source, please write me to let me know. Standard single wall barrel connectors are suitable for conventional wire.

Prepare the wire by stripping enough of the jacket material away to allow the wire to be fed into the window on the bullet connector or slightly exposed on the spade fork connector. DX-WIRE UL has six conductors. Due to their small size, count them to ensure you did not inadvertently break one while stripping the wire.

With the jacket stripped, separate and trim the aramid fiber core as shown below in figure 6. Trimming the aramid core will keep it from interfering with the soldering we will do momentarily.

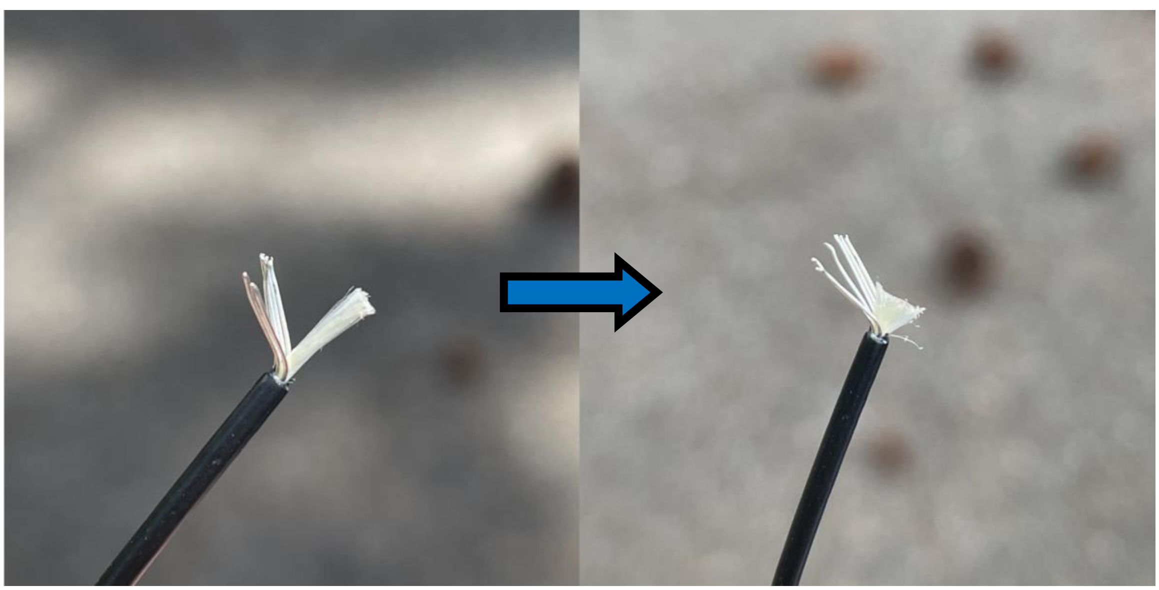

Figure 14: With the wire stripped, separate the six wire elements from the aramid fiber core then trim the aramid core leaving a little exposed for strain relief. If you elect to skip soldering your terminals you may leave the aramid core untrimmed.

Now crimp your terminal on the wire ensuring the small aramid core tail is enclosed by the crimp. Doing so reduces the strain on the six wire strands.

The next step is soldering the terminals to weather seal the crimps. This step is optional and admittingly in contravention to conventional wisdom. More likely than not it is overkill and done improperly it can embrittle the wire. The DX-WIRE UL and the specified bullet connectors are tin coated to protect the underlying copper from corrosion. There is a small chance, however, that water could wick into the crimp and remain trapped there causing corrosion over the long term. The bullet connectors have open seams that may allow water to enter the inside of the connector. Solder, carefully applied, may prevent this water from affecting the connection with the wire. If you choose to apply solder, do so to the small amount of exposed wire showing through the window in the bullet terminal. Use a high heat setting on your iron to ensure the solder flows before the jacket on the wire melts. Use of a clip-on heat sink or third hand can also help prevent the jacket from melting. If not soldering, skip to applying the heat shrink tubing.

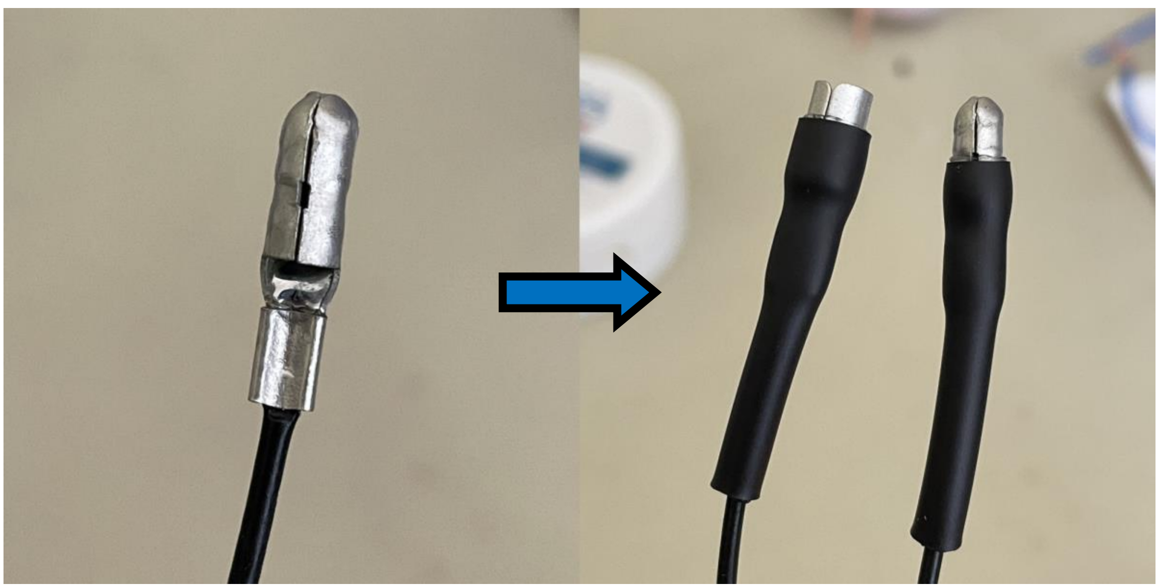

Figure 15: At left, a properly crimped and soldered bullet connector. At right, the completed bullet terminals with adhesive-lined heat shrink strain relief. Leaving a small portion of the female bullet connector exposed makes inserting and removing the male connector easier.

Once each end of your wire element is terminated, measure 6" back from each end, fold the wire back at this point and install a wire rope clamp taking care to leave about a ¾" loop. Connect adjoining wire elements by connecting the wire loops with a s-hook carabiner.

Figure 16: Completed fork spade terminal connection for 20m element.

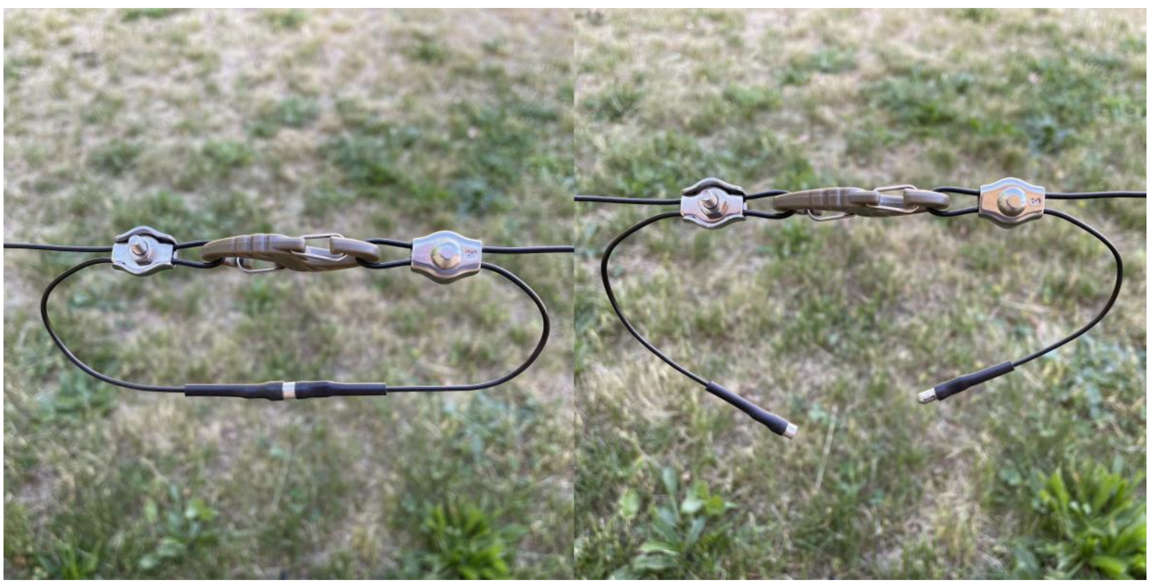

Figure 17: Completed link assembly showing connected and disconnected states.

Recommended Tuning Frequencies & Wire Lengths

The following table depicts the wire lengths and tuning frequencies I am using for each element of this antenna using DX-WIRE UL. I am providing these for reference, but you should expect your wire lengths to vary slightly based on your ground conditions, style of deployment, and wire used. Cut your elements longer and trim them to match your operating conditions and desired center frequencies. If you find that your elements are deviating substantially from these values, however, it may be prudent to examine your surroundings to determine if stray capacitance is interfering with your antenna (see employment recommendations below).

Wire Element Lengths		
Band	Target Center Frequency	Length
20 meters	14.175 mhz	31′ 4.5″
30 meters	10.125 mhz	14′ 2″
40 meters	7.150 mhz	20′ 3″
60 meters	5.367 mhz	22′ 4.25″
75 meters	3.915 mhz	33′ 1.5″
80 meters	3.585 mhz	11′ 9″

These values were obtained using a low horizontal configuration with the antenna 5-6′ AGL. On the bands 20-60 meters there is sufficient bandwidth that precise tuning isn't critical and variations in deployment will likely have negligible effect on your SWR. On 75 and 80 meters, however, you will need to chose your center frequencies carefully and tune for the deployment orientation you will use most often. This is because the bandwidth becomes narrower as you move down in frequency and the 80m band is very wide relative to its frequency. As a safe planning factor, assume the 2:1 SWR bandwidth on 80 meters to be about 150khz to account for worst case conditions. You may use short jumpers give you additional flexibility on 80 meters.

EMPLOYMENT

Kit Assembly

At a minimum, you will need to add coax and two lengths of cordage to the components constructed above to make the antenna usable. Cordage can be any convenient type. Common parachute cord will work although lighter line works better with a throw weight if you intend to use one. Coax can be RG-316, RG-58 or equivalent. In portable HF operation, there is little to be gained besides excess weight from using lower loss coax such as RG-8X or LMR-400.

Presented below is a potential kit using a 10″x6″ MOLLE pouch. This is the kit I use. It covers 20/30/40/60/75/80 meters on HF as well as 2m and 70cm with the addition of an Ed Fong roll-up dual band J-pole. This kit is presented simply to demonstrate what is possible. Tailor your kit to your own needs.

Figure 18: K8JOK's antenna kit. From top left to lower right, Packtenna RF choke, Ed Fong dual band J-pole, 10"x6" MOLLE pouch, 81:1 UNUN, 25' RG-316 coax, miscellaneous adapters for the J-pole, MAT-10 antenna tuner in a MOLLE pouch, 3' RG-316 jumper, 14oz throw weight, 180' & 90' arborist throw line on winders, linked EFHW wire elements on winders, 20/30/40m elements on one winder and 60/75/80m elements on the other.

Although it is seldom used with the linked EFHW, I still carry a small automatic tuner in my kit. Almost all commercial and military manpack portable radios have tuners for a reason. Sometimes, for reasons you can't explain, your antenna does not match well in a particular location. With a tuner, you can also contrive all manner of improvised antennas.

General Recommendations

Always try to keep the UNUN at least six feet from other objects such as buildings or tree trunks. Stray capacitance near the UNUN can affect the tuning of the antenna. While metal objects are obvious sources of stray capacitance, plants contain significant amounts of water, especially in the springtime, and can occasionally detune the antenna.

Tuning will change with configuration. I will make an effort below to demonstrate how much shift may be expected but this will vary by location. You will need to test this in your AO to understand which configurations are acceptable. Optimize your wire elements accordingly.

Dense objects such as buildings or hills will attenuate or block your signals. This is generally a disadvantage but can occasionally be used to block noise sources or limit reception of your signal in certain directions or take off angles. For instance, deploying your antenna in a valley can block distant noise sources and limit your ground wave signal without affecting your NVIS performance.

Remember that the EFHW performs electrically like a dipole. This means there are nulls off the ends of the wire on the higher frequencies. Orient your antenna perpendicular to your desired contact. If operating on the low bands ¼ wavelength AGL or lower most of the radiation is directed upwards and there is no null.

WARNINGS: Never deploy your antenna near power lines. Never use an arborist throw line near power lines. Do not use utility poles as a support as high voltage may be present. Do not allow people or pets to come in contact with the UNUN or antenna wires as RF burns will result.

Connecting the UNUN

Begin by tying a 7-8" loop into the end of your cordage. This loop can be left in place permanently. Use it both for the arborist throw weight, if you chose to use one, and for attaching to the UNUN. Once your line is fastened to your tree or other support, slide your loop through the eye bolt in the top of the UNUN until you can pull it down around the bottom and then tighten it to form a girth hitch on the eye bolt. Then clip the s-clip carabiner from your 20m element to the UNUN and fasten spade fork connector to the antenna lug.

Figure 19: Establish your girth hitch first, then attach the 20m wire element to the UNUN.

Wet Weather Operations

The UNUN enclosure is weather sealed but the BNC connector on our coax is not. For extended operation in wet weather, seal this connection with electrical tape. Start 2-3" below the connection and work the tape up in a spiral. This will create a shingle effect to encourage water to shed down and away from your BNC connector. The electrical tape seal doesn't need to be submersible. Rather it simply needs to give the water a path away from the connector, so water doesn't penetrate the coax and degrade it over time. I've used this technique successfully numerous times and have never had coax damage.

Low Flat-Top (Horizontal) Configuration (5-6' AGL)

This configuration is rapidly deployable almost anywhere using tree trunks, portable masts, or other supports. A trained solo operator can deploy this configuration in about five minutes. It is an excellent hasty NVIS deployment. Performance is generally 6-12dB down from the high flat-top deployment covered in the next section. Losses may increase substantially if the ground is very wet or if you deploy lower than 4'. If both parties communicating are using efficient antennas and reasonable power (20 watts or more) then these losses usually won't pose a problem. During good propagation, even effective QRP operation is realistic and possible.

If deploying this configuration in a public place, take care to ensure it does not pose a hazard to other people.

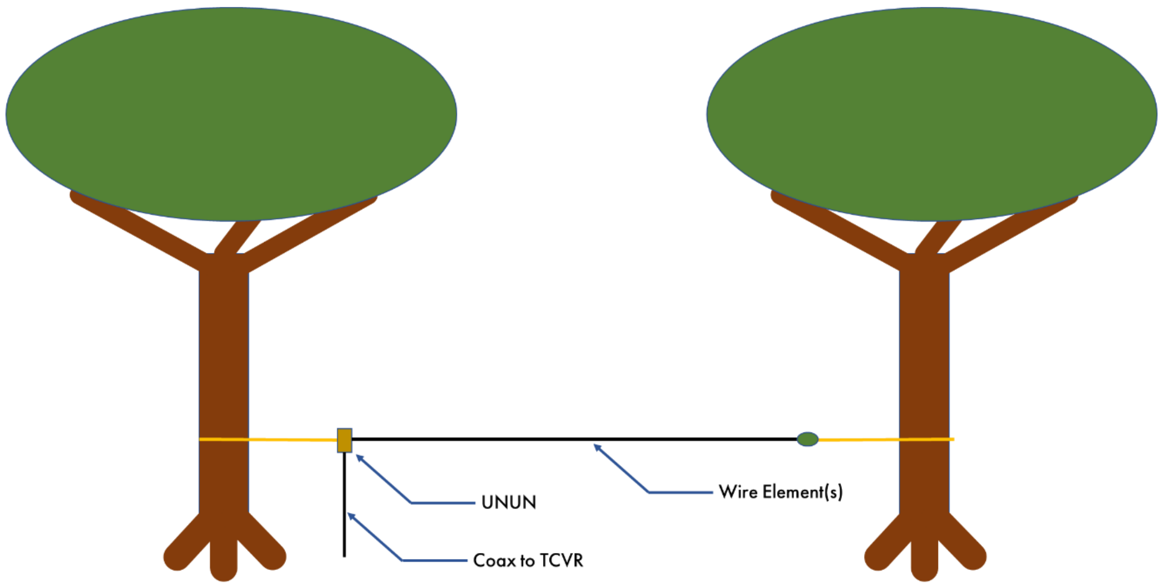

Figure 20: Low Flat-Top Configuration. Easily deployed 5-6' AGL using tree trunks as supports.

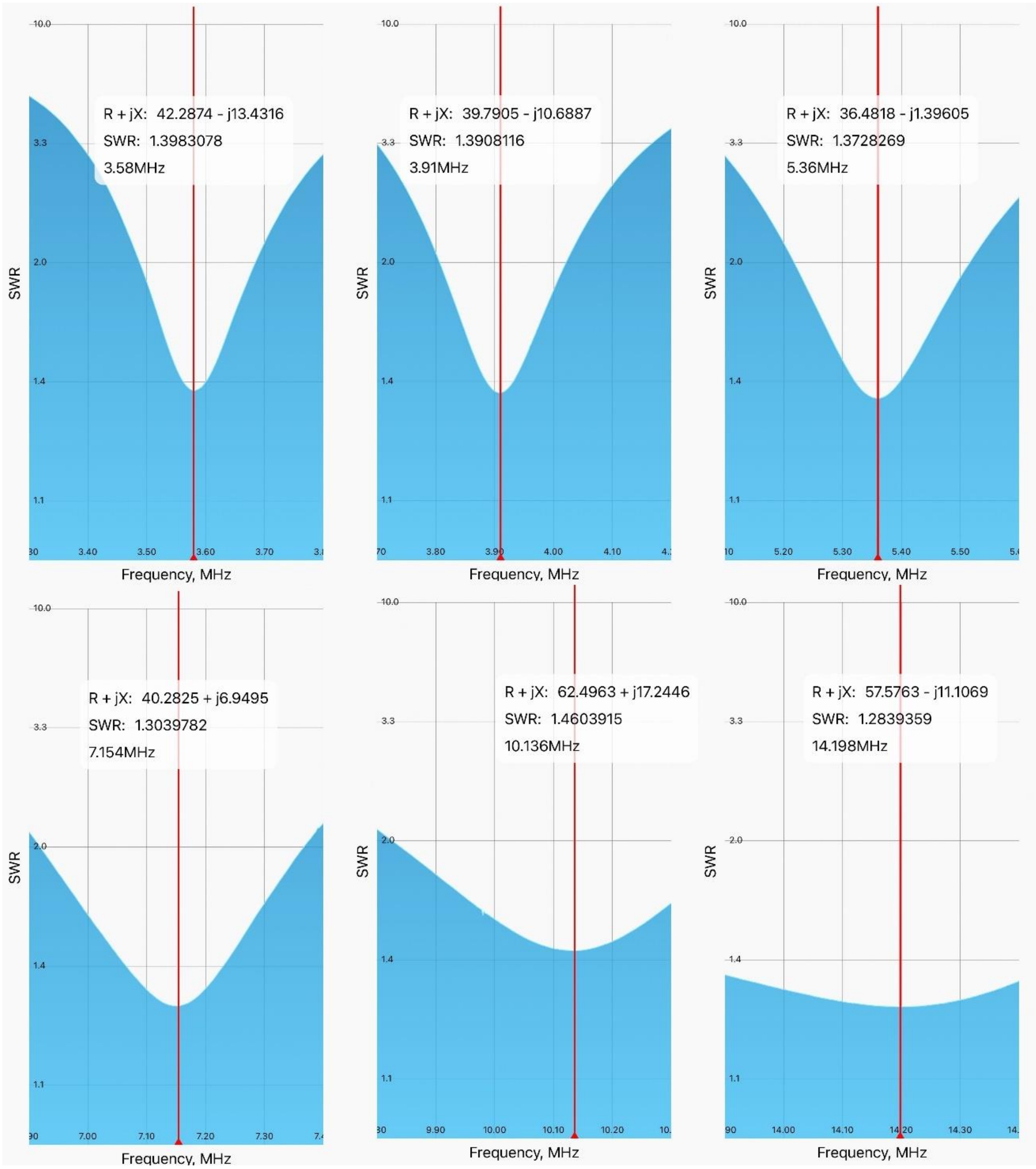

Figure 21: Typical SWR measurements for the linked EFHW in low flat-top configuration at 5-6' AGL. Results will vary.

High Flat-Top (Horizontal) Configuration (20-25' AGL)

This is my preferred setup for a deliberate deployment when time and space permit. A trained solo operator can deploy this configuration in 10-15 minutes. Generally, this configuration provides the best overall performance for both NVIS on the low bands and distance communication on the higher bands. In my AO trees are everywhere so I commonly deploy the high flat-top configuration into trees. Portable masts or other supports may also be used. While higher deployments are possible in trees, 20-25' is realistic and provides good performance.

This configuration is preferred when in a public place as it keeps all dangerous energized components out of reach of those who may be unaware of RF safety considerations.

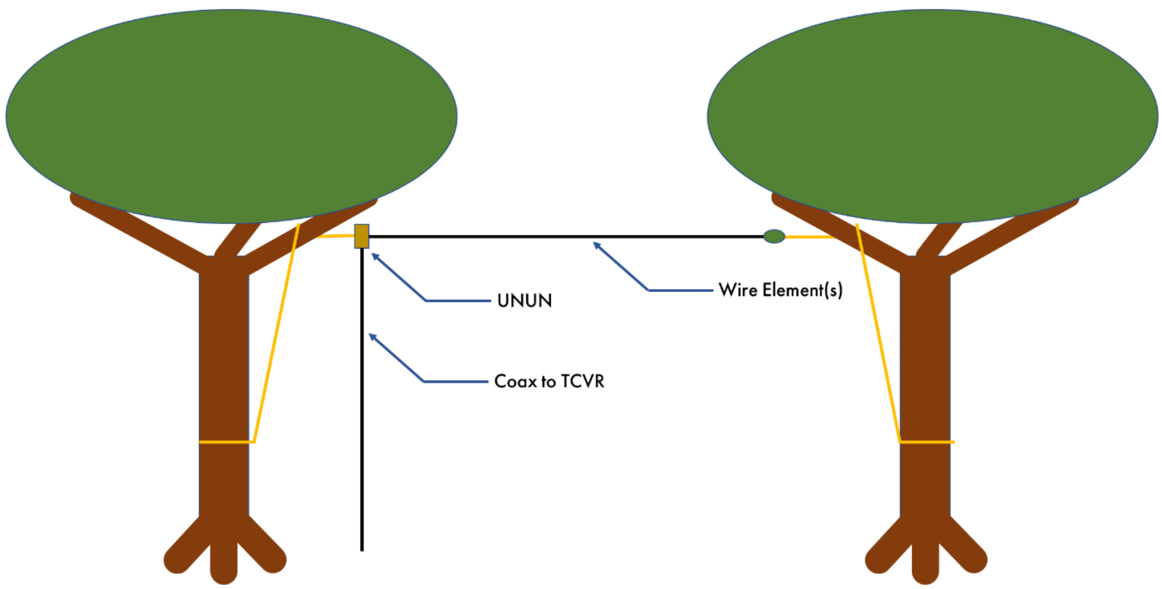

Figure 22: The High Flat-Top Configuration. Use two trees or other supports. If using trees, 20-25' is a good target height for deployment.

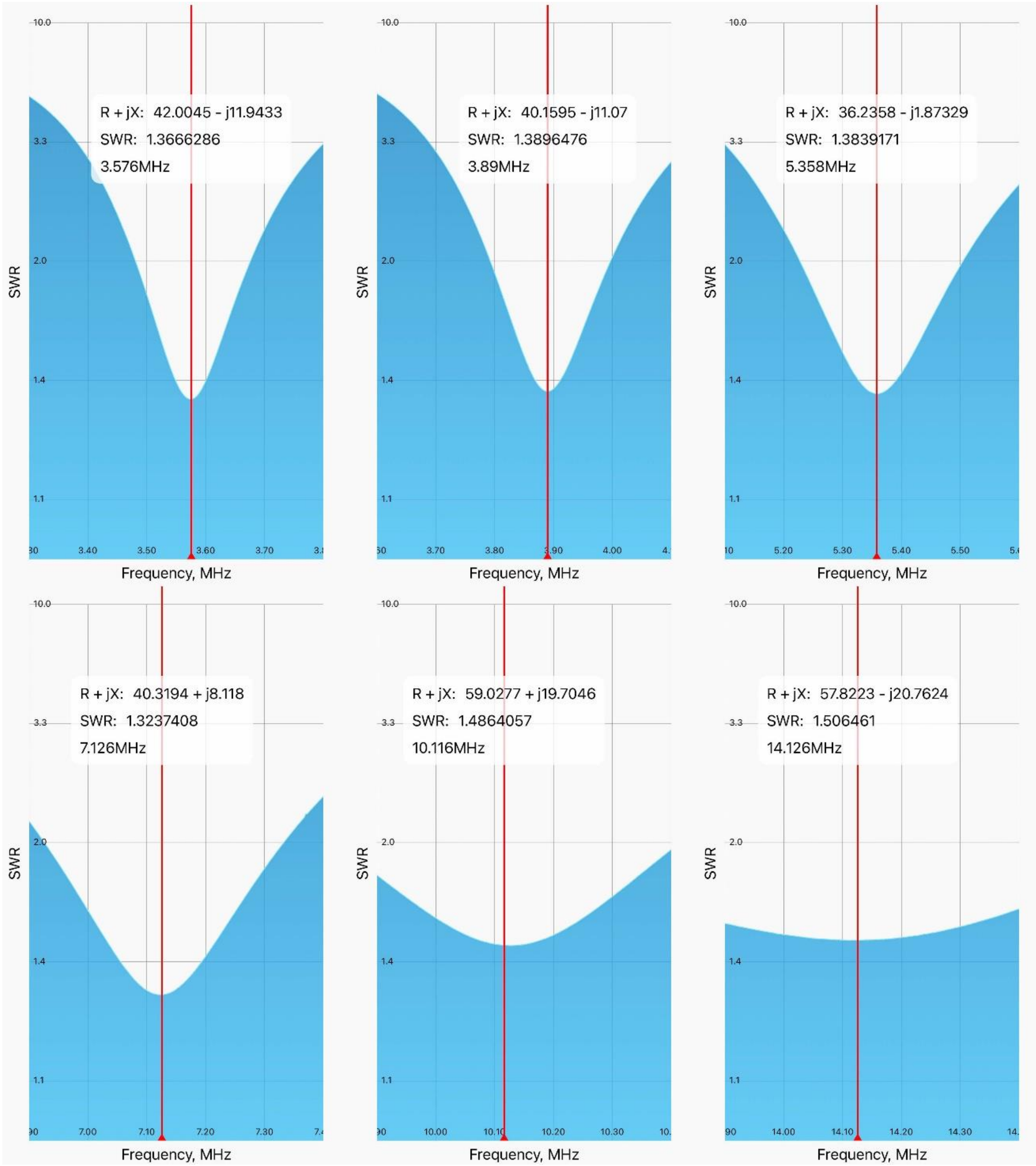

Figure 23: SWR Measurements for the linked EFHW in high flat-top configuration @ 20ft AGL. Results will vary.

Sloper

This configuration will outperform the low flat-top for distance communication while being quicker to setup than a high flat-top. Additionally, this configuration can be used when only one tall support is available. I have used this in the field with a tree as my tall support and my backpack as an anchor on the ground for the low end. Best performance is obtained when the UNUN remains about six feet above the ground. A trained solo operator can deploy a sloper in 10 minutes or less if suitable supports are available. The sloper is also mildly directional. If attempting a planned distance contact and a horizontal configuration is working poorly, try the sloper instead. Orient the sloper away from your desired contact.

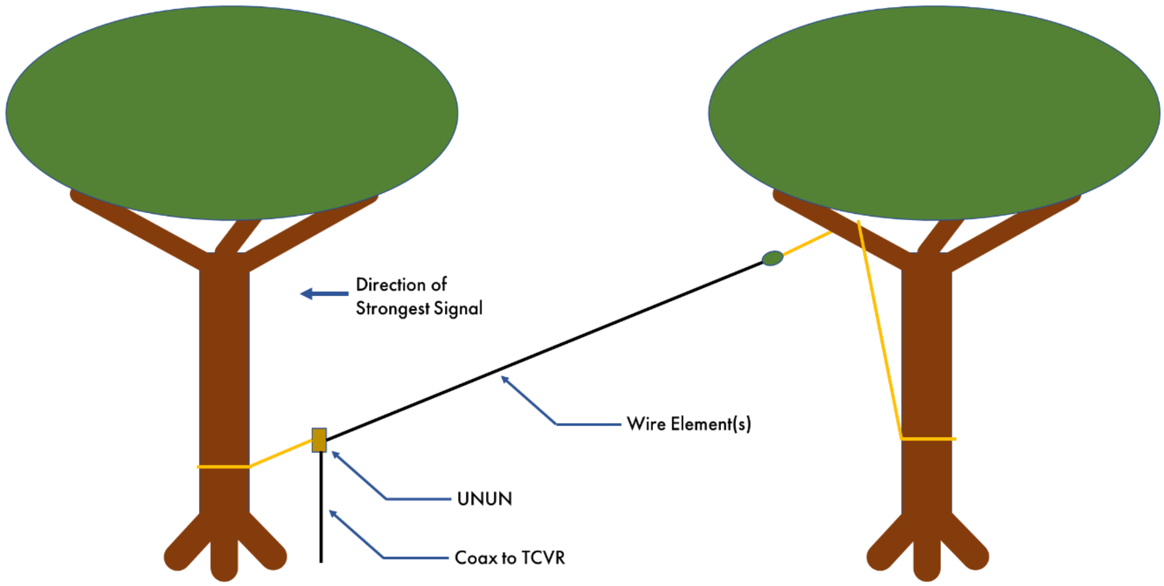

Figure 24: Sloper Configuration. Useful when directional performance is desired or there is only one high support available.

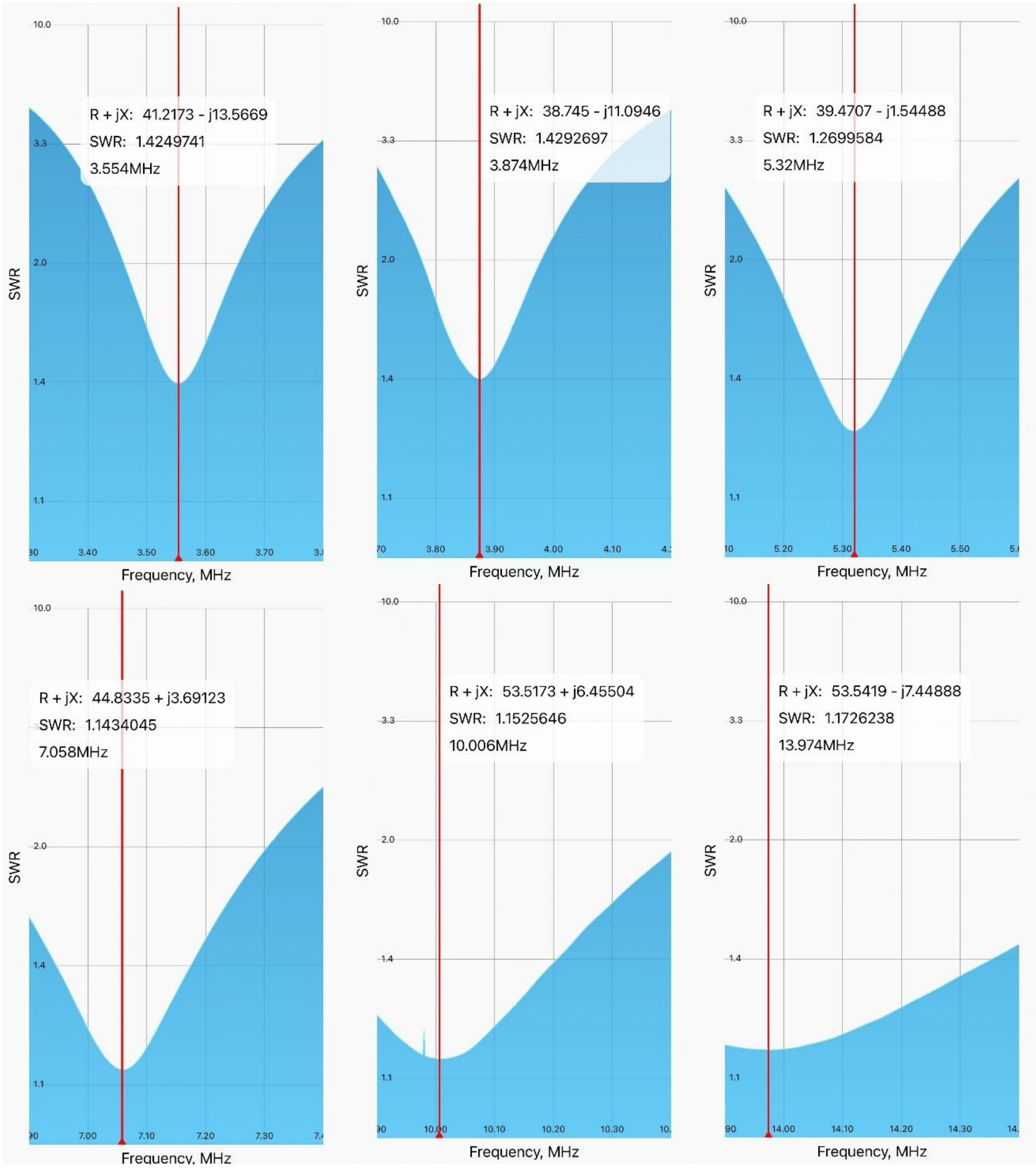

Figure 25: Typical SWR measurements for the sloper configuration. Note the shift in resonance.

Emergency Configuration

You may encounter a situation where ground conditions or some other factor outside your control is causing unusually high SWR. If you have an antenna tuner available you should use it. Most likely your SWR is under 3:1 under worst case conditions and even the internal tuner on most radios will address your problem.

If you do not have a tuner available, run your antenna as a reverse sloper leaving about 10% of the wire on the ground. Provided the ground is sufficiently conductive, your wire will capacitively couple with the ground. In this way it will behave like an antenna with a terminating resistor. The ground will absorb reflected power and prevent a standing wave from forming on the antenna. This will rob some of your efficiency but is a good technique to practice and know in case you are faced with no alternative.

In the desert or other dry place you may need to moisten the ground to make it sufficiently conductive for this technique to work.

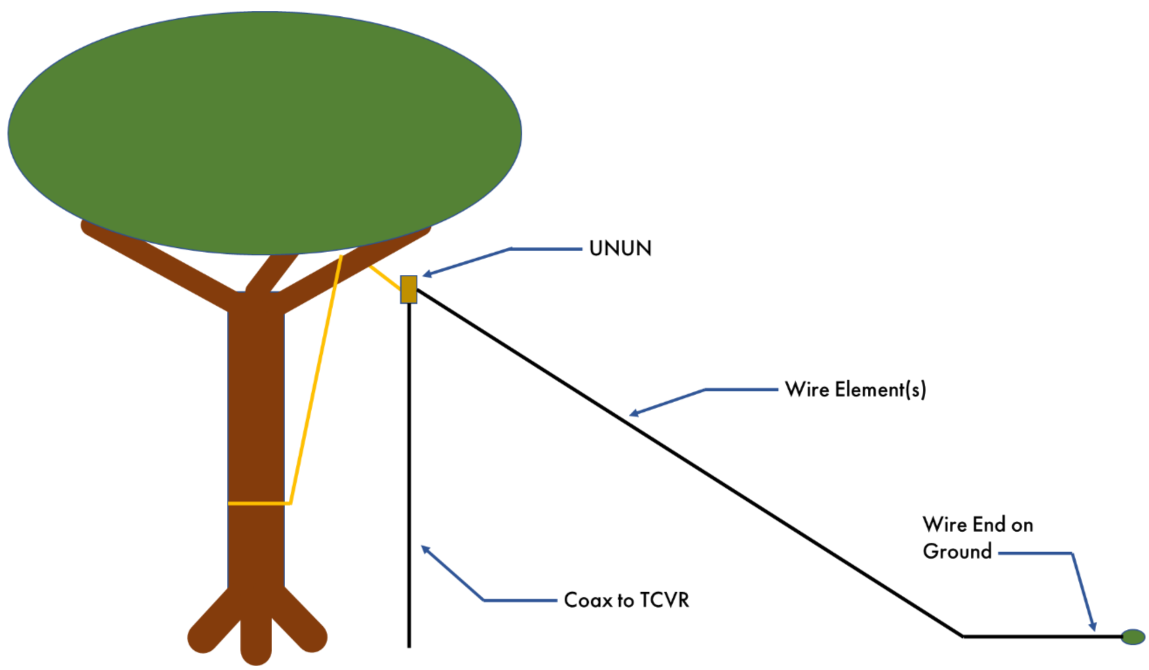

Figure 26: Emergency Configuration. A good technique to know in the event of unexplained SWR excursion and you are without a tuner.

Other Configurations

You may find the Inverted-V and/or Inverted-L configurations useful based on your preferred radiation pattern and the availability of trees or other supports in your AO. Both of these configurations lend themselves well to deployment with a portable mast. While, I have not yet evaluated these configurations myself, I am confident they will perform well provided you tune your wire elements accordingly.

CONCLUSION & ACTION ITEMS

Let's review the requirements presented in the introduction to this guide and grade how this project met each objective.

1. Must be small enough and light enough to be backpack portable. *Good*
2. Must be rugged enough to withstand wind, rain, or other weather conditions for a short-term deployment (anywhere from a few hours to a few days). *Good*
3. Must have a consistent, predictable radiation pattern that does not change with frequency. *Good*
4. Must support operation of up to 100W. *Good*
5. Must be more easily deployed than a comparable dipole. *Good*
6. Should achieve SWR performance of 1.5:1 or less on the amateur bands from 3.5-15mhz without a tuner. *Good, with the caveat that 80m needs to be monitored closely.* Useful performance from 15-30mhz is desirable but not required. *More testing required.*
7. Should be rapidly deployable using trees or other expedient supports. *Good.*
8. Should be easily repaired in the field with simple tools. *More testing required.*
9. Should fit into a 10"x6" or smaller MOLLE pouch. *Good.*

Overall, I rate this effort as a success and intend to use this antenna as my primary for portable operations for the foreseeable future. There are still some tasks, however, I would still like to accomplish when time permits.

1. Conduct thermal performance measurements. Commercially, the core used in this project has been rated for up to 250W but the enclosure I'm using is as small as possible and may reduce the cooling rate of the transformer. I have derated the performance accordingly until I can perform formal thermal measurements on a live antenna to remove all doubt.
2. Improve my technique for making loss measurements. Based on what I've accomplished so far, I'm satisfied my design is indeed more efficient than other common designs but I'm hesitant to say by how much. In relative terms, the RF current measurements agree with the NanoVNA shunt measurements using various ferrite cores but I need to validate my process for using the RF current meter to improve the consistency of those measurements.
3. Design a 3D printed enclosure. Using a simple inverted cone section to surround the BNC connector it should be trivial to improve on the weather resistance while eliminating the need for electrical tape to seal the coax connection. Additionally, I suspect the eye bolt is acting as stray capacitance and would like to experiment with an enclosure using minimal conductive components.
4. Build a multi-tap transformer. Broadband performance may be improved above 22Mhz by adding a tap on the transformer for a lower impedance ratio (i.e. 36:1 or 49:1).
5. Build a SIMSMITH model for this transformer. The discussion on theory would be improved with an equivalent circuit diagram and a model for understanding the losses present in an EFHW transformer.

ACKNOWLEDGEMENTS

This effort is not revolutionary. Rather, it is an attempt at evolutionary improvement in my understanding and use of EFHW antennas. It builds substantially on prior art and the work of other amateur radio operators. I would like to acknowledge their contributions here.

Youtuber Evil Lair Electronics[7] is probably the first to suggest both different winding techniques and use of the Fair-Rite 2643251002 as improved alternatives to the commonly recommended EFHW transformer designs. Around the same time, Owen Duffy, VK1OD, also began exploring alternatives to the conventional 49:1 UNUN design[8]. His efforts cover several years of work modelling and measuring various transformer designs so I encourage the reader to explore his site.

In the last year, Colin Summers, MM0OPX, conducted an extensive survey of various cores and winding techniques to find the optimal solution for his needs[9]. While I'm not convinced that his measurement technique is completely accurate, I give him great credit for actually building and using the antenna based on his results. Like me, he found that he needed to increase the transformation ratio as you move down in frequency.

Thank you to John Oppenheimer, KN5L, for his patient instruction on the QRPTECH groups.io group. He explained to me the shunt technique for measuring core loss and the pitfalls of back-to-back measurements[10].

Thank you to Jim Garner, K4JKG, for operating the transmitter while I took RF current measurements.

Lastly, thank you to Scott Davis, Parks Director for the city of Millbrook, Alabama, for allowing me use of the trees in my local parks for testing.

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