Building an End Fed Antenna

By Eugene Morgan

In this article I will cover several topics given that the subject is about building an Antenna System and not just the antenna. There are four specific areas we will dive into, the first is the antenna, the second baluns, the third chokes, and lastly the transmission line. All of these items are necessary in virtually every antenna installation regardless if it's a simple vertical, dipole or a multi element parasitic array such as a Yagi.

This article will focus mainly on the antenna we built at Alan Parks, N7SHA, QTH. But the techniques used are applicable to any antenna installation. However we will focus on the specific of an end fed wire which apply to all end fed wires regardless of length.

After doing a survey of Alan's yard we determined that the easiest antenna and perhaps the most effective antenna we could deploy was an end fed wire. His yard was perfect for such an installation. He has a deep back yard surrounded by many tall trees with his house sitting near the front of the lot. We determined that we could run a wire over 180 feet into one of the tall trees in his back yard. The far end would be close to 50 feet high and the other end would terminate at end of his house and be connected to the electrical mast where the power comes into his house. That end would be about 20 feet in the air.

Our first challenge was of course getting the far end of the wire into the tree. Climbing was out of the question. So we built an Antenna Canon. The antenna canon is very simple design requiring only a saw and a drill. We were able to acquire the PVC and valve from the local Lowes and the gauge and valve stem at the Auto parts store. The air pressure gauge is optional. We will not go into the construction of the canon but a picture has been provided, see Figure 1 and can provide an easy example to follow.

The canon is made from 2" PVC and a length of ¾ PVC for the barrel. The valve is a gas line ball valve. The reel is an old fishing reel wound with 50 lb. Spider wire. Important note: Monofilament fishing line is not the best choice given its tendency to twist and tangle. The spider wire on the other hand is a braided fishing line that is a lot less prone to tangling and for its size it is very strong. For weights we use 2oz. egg sinkers. I painted them bright yellow to make them easy to spot. Total cost for the antenna canon was $31 not including the fishing real or line, which we already had.

Although it took us several tries we were able to get the line where we wanted it. After placing the line we pulled up progressive stronger line until we had a final haul line in place which was a 50’ length of mountain climbing rope.

The key consideration is the abrasion the haul line will take. Climbing rope is a good choice given it’s resistance to abrasion, its ability to stretch, and its larger diameter. We understand that not everyone has a bit of old climbing rope laying around. The key thing is to use as large a line as possible, not so much for its strength but for its resistance to wear.   If climbing the tree is an option then inserting the haul line through a small bit of garden hose can be employed to minimize wear on both the haul rope and the tree. This is the technique we used at N7KID’s installation. To the haul line we tied a small carabiner that we used to run our halyard through. This made it possible to lower or adjust the antenna without disturbing the haul line. We will readjust the haul line from time to time in order to move the wear spot. By using the halyard we can readjust the antenna as needed without putting any stress on the tree. See Figure 2 for details of how we rigged the haul line and antenna halyard.

Figure 1: The Air Powered Antenna Canon

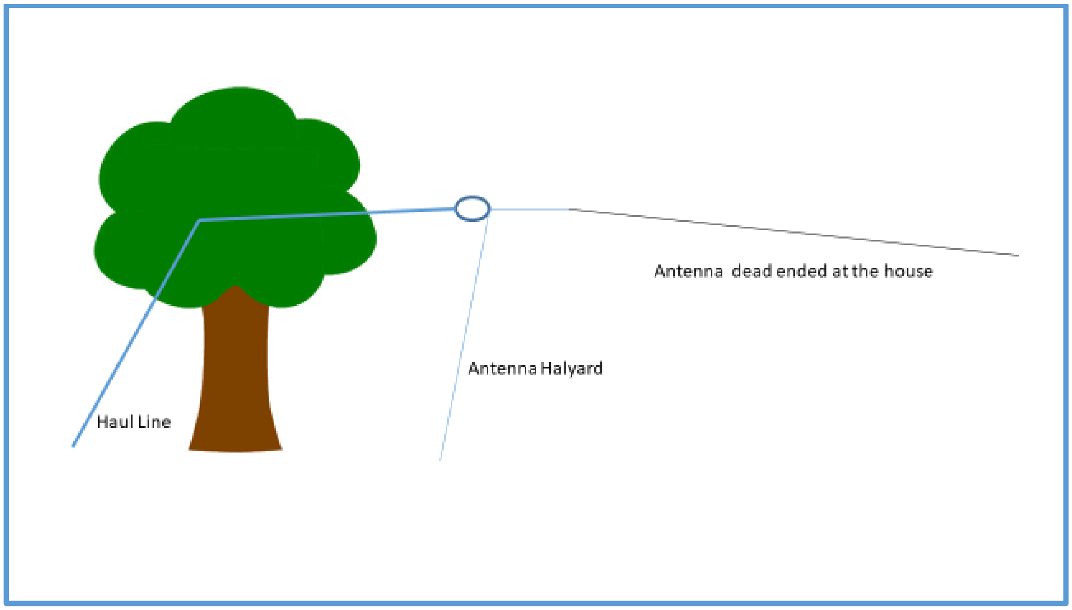

Figure 2: Line configuration

Now that the antenna is in the tree and the other end is tied off to the house it's now time to focus on connecting the antenna to radio.

How Long Should My Wire be?

We started off the article with how to install an end fed wire but we kind of skipped over figuring out how long a wire to put up. The table below should help to fill in that gap. It presents a number of options. I have personally built three of these antenna. The first was Alans (N7SHA) which we didn't measure but I suspect it would be in the 173' range. The second, was Bruce's, (N7KID) which we carefully cut to 85' with over 65' of feed line and finally my antenna at 203' feet, however my feedline is only 90' long. I took careful measurement of my antenna and here are the results:

Freq.	SWR @ Radio
1.9	5.2:1
3.574	3.3:1
7.074	1.5:1
10.136	1.3:1
14.074	1.4:1
21.074	1.7:1
28.074	2.2:1

Table 1:SWR Results with 203' wire with 90' feedline

The SWR was fairly close to predictions with the exception of 160 meters. Here the SWR was higher than expected, but still within range of the tuner in my Yaesu FT-950. I suspect the reason for the higher than expected SWR was a less than optimum feedline length, the recommended length is 130'.

Fortunately the line loss on 160 meters with a 5.1: SWR across 90' of RG8 (.6dB loss at 10mhz per 100') is calculated to be only .28dB. Remember that 6 dB = 1 S unit on a properly calibrated S meter. So the loss will be virtually undetectable. The loss on 10 meters will be a bit higher at 1.14dB, which is still

Bands Covered (meters)	Wire Length (feet)	Minimum Coax Length (feet)
40-30-20-15	35-43, 49-63, 70-85	35
40-30-20-17	35-45, 54-64, 67-77	35
80-40-30-20-17-15-12-10	38-44, 55, 60, 68-73	50
80-60-40-30-20-17-15-12-10	55, 68-73, 85, 92, 102, 120-125	65
160-80-40-30-20-17-15-12-10	135, 141, 173, 203	130

undetectable on the normal S meter.

Table 2: Optimum wire and feedline lengths

SWR for all lengths should typically be under 2.2:1 and in most cases will be under 1.8:1 for 160-10m which will allow most built in ATU's to match the antenna on all bands. Initial installation should utilize a length longer than the recommended length shown. Experimenting by slightly changing the wire length (+ or -) is encouraged to provide best overall performance for individual installations. If you can get the length close enough that your tuner can establish a conjugate match on each target band should be good enough. Remember that one S unit on your S meter is equal to 6 dB. At HF the difference between a 2:1 and a 3:1 SWR is virtually undetectable.

As you can see from the above dimensions you don't need a massive lot or a small farm to erect an end fed wire antenna. One can install an end fed wire in an attic or even on a small urban lot. Also, an end fed wire is a much simple antenna especially when compared to something like a G5RV which requires the use of twin lead, which can extremely problematic in an attic space and highly susceptible to RFI. I think the end fed wire has gotten a bad rap because they are usually not properly installed with the necessary unun and choke.

How to Feed an End Fed Wire? The Balun or in this case the Unun

The end fed wire regardless of its length presents a high impedance to the feedline. If the intention is to build a ½ wave mono band antenna then it is necessary to attach a 48:1 unun at the feed point given the extremely high impedance. But if it's a multi band antenna and is not ½ wavelength long on any of the intended bands then a 9:1 unun is necessary.

Why an Unun? Typically we find two kinds of impedance transformers, balanced and unbalanced. Given that today nearly all antennas used by the ham community are fed with 50 ohm coaxial cable. In addition a balun is often used to connect then unbalanced coaxial cable to a semi balanced antenna. You will note that throughout I use the term (semi) balanced antenna. The reason for this is that in reality the only really balance antenna is one that exists in free space. Antenna unbalance is caused by all those things that surround an antenna, buildings, trees, powerlines, fences, cars, and so on. In theory antennas, like dipoles and Yagi's, are consider balanced antennas, unless they are up high and in the clear there will be some level of unbalance in the antenna. As you will see in the next paragraph these imbalances can cause problems that in some cases is very noticeable and in other instances can be very subtle.

Coaxial cable is considered an unbalanced feed system. So if you attach an unbalance feed line to a (semi) balance antenna such as a dipole or Yagi you will get unpredictable and often unreliable and more importantly undesirable results, that are caused by common mode currents. Common mode currents on the feed line can manifest themselves in a variety of really icky ways. In worst case scenarios they can invade your shack and cause all sorts of issues with RF noise, electrical shocks, and computer mice and wireless routers that behave erratically. A much harder condition to detect is when the coaxial cable is acting like an antenna on both transmit and receive! On transmit the radiation pattern may be off, the SWR unnecessarily higher than it should be and worst of all, some of that precious RF power is being radiated where it shouldn't be radiated. During the receive mode the antenna may be picking up random electrical noise and RFI. In short **common mode currents are bad**. We will go more into common mode currents when we get into RF chokes later in this article.

In the case of the end fed antenna it is an unbalance antenna so it is possible to connect you unbalance coaxial cable to an unbalance antenna but now you have another issue, an impedance mismatch. The end fed wire has a high impedance, usually several hundred ohms, while the coaxial feedline has a much lower 50 ohm impedance. So that won't work either! So what do we do???

In the case of the end fed wire we need to use an unbalanced impedance transformer, or in other words a 9:1 Unun (unbalanced to unbalanced). It will convert the 50 ohm impedance of our coax to a 450 ohm impedance and allow us to connect the unbalanced feedline to our unbalanced 450 ohm antenna. That should help to tame the antenna mismatch to a degree that most inboard ATU's can establish a conjugate match.

In the case of the end fed wire we know what we need to do, either buy a 9:1 unun or build one. There are several good options on the market today. LDG sells one that is good for a 100 watt station for around $30. If you're running a bit more power then Palomar Engineering or Balun Designs both have good solutions, some a bit on the pricy side. Our other option is to build our own. Now don't stop reading at this point. These things are not hard to build, you can get everything you need from Amazon and Lowes. And they are not expensive. As to tools all one needs is a drill and a couple of right size bits. And there is a goodly number of YouTube videos that will walk you through the process. I think the following YouTube videos is one of the better ones: https://www.youtube.com/watch?v=VAV9Wws-Bs0 In his video he used a different core. My research suggests that Ferrite (FT) is better material for building ununs and baluns. Now that you have watched a video or two let me tell you what you will need acquire:

From Amazon:

1. If you running less than about 500 watts you will need one FT240-43 core. They run about $12. If you are running more power you will need two. The type 43 mix works best in the HF range. If you are building for UHF of VHF a different mix is necessary.

2. You will need a roll of 14 AWG enamel magnet wire. The Amazon descriptions is: "*TEMCo 14 AWG Copper Magnet Wire - 8 oz 40 ft 200°C Magnetic Coil Winding*" It runs about $20 for 40 feet. This will be more wire than you will ever need and it gives you some extra in case you flub it up. Don't worry this is not brain surgery. However, if you have actually read this article this far and are really serious about building your own unun come see me. I have part of a 40' roll and I will gladly share.
3. You will need a little more than 7' of Teflon tubing. The Amazon description is: "*PTFE Teflon tubing 5ft - 2mm ID X 3mm OD - Allen Tech PTFE Teflon Tube*" It runs $7 per 5 ft. You will need to buy two packages. You will insert the enamel wire into this tubing. This will give you a little more power handling capabilities and ensure the wire does not short out on the core.
4. You will need one SO-239. They come in quantities of 5 and will cost you a little over a buck a piece.

From Lowes:

1. You will need one electrical box. Home Depot didn't have the right kind, Lowes did. Look for the square grey 4"X4" plastic box in the electrical department.
2. You will need two 6x32x3/4 stainless steel screws with stainless steel nylock nuts. These are for securing the SO-239 to the housing.
3. You will need three small eyebolts with nuts and washers. Use all stainless steel. In mine I used a fender washer rather than a normal sized washer. The fender washers are larger than the normal washers and will help to spread the strain put on the eye bolts over a larger area of the box. One on each side for the antenna wire, one for an optional ground, and one to support the antenna and unun.

These devices are really simple to build. And if you're not sure, call me, I'll be glad to give you a hand. Figure 3 is a picture of the one I built. It's modeled after the Balun Designs 9:1 unun. See Figure 4 for a diagram of the circuit. I used color electrical tape to keep track of each wire. I will admit after you do the winding and are looking at 6 wires you may find it intimidating. Just go slow and double check your connections before you break out the soldering iron. No one's going to take away your birthday if you get it wrong. And if you mess it up, you did buy 40' of wire so you can start all over if you want.

When I tested the unun I put a 450 ohm load across the antenna attachment eyes and connected an antenna analyzer to the SO-239. I got a 1:1 reading up to 4 Mhz and a 1.1:1 reading up to 20 Mhz. I didn't test it higher. This version should be able to comfortably handle up to 600 watts. The antenna wire is attached to the right side and the left side can be attached to ground. You will note that in my unun I did not include the suspension eye bolt that normally would be mounted to the top of the box. Rather than hanging mine, I mounted mine to a 4X4 7' fence post.

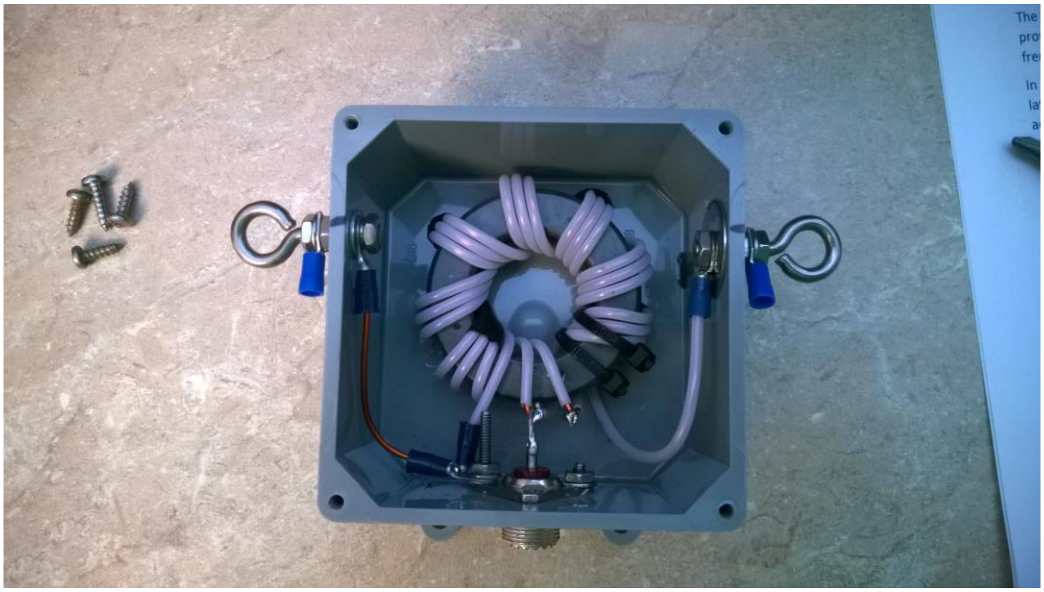

Figure 3: A 600 watt homebrew 9:1 Unun

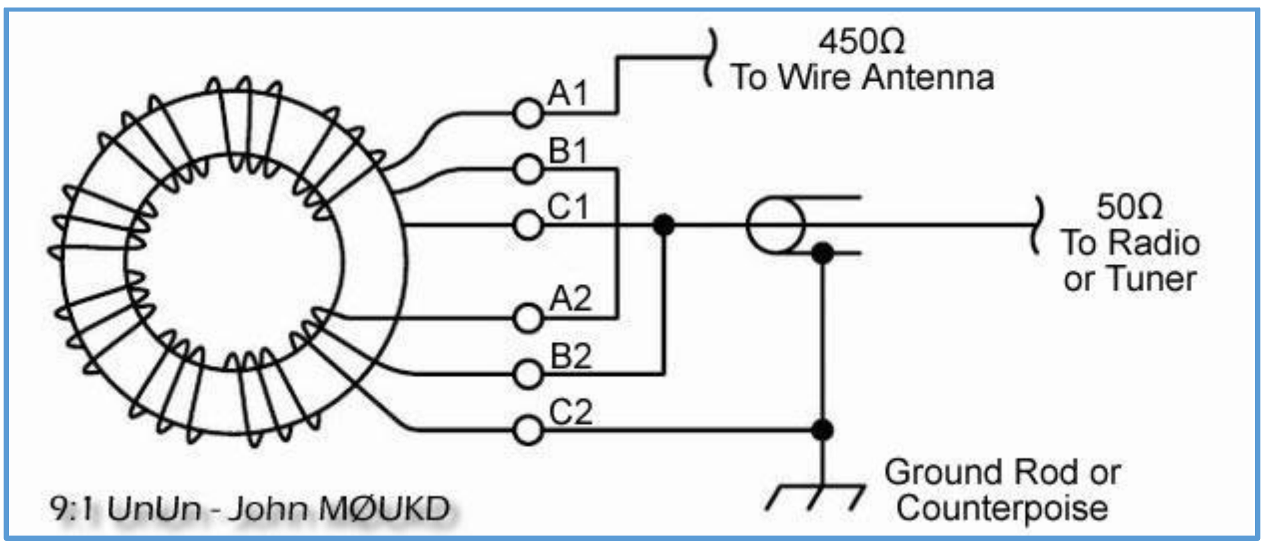

Figure 4: 9:1 Unun Circuit Design

Now that we have built our 9:1 Unun and attached it to our antenna wire it's now time to move on to our Common Mode Choke.

The Common Mode Current Choke

Virtually every antenna will benefit from an RF Choke. That unfortunately is not well understood by most hams. The purpose of the choke is to minimize the common mode currents (CMC) that are caused by a number of things, an unbalance in the antenna and or a high SWR. And the sad truth is that most hams don't know they have a problem with CMC. In the case of Alan's installation when we added the choke we saw a significant drop in the noise level on 80-20 meters. And we saw a drop in the 15-10 meter bad as well but it was not as significant. Given the design of our choke that was not surprising. Our choke was designed specifically for the 80-20 meter band. Before we get into the design of a choke let's first understand what they are for and what they do.

Common mode currents: The primary purpose of a choke is to impede current from flowing on the outside of the feed line. Understand we are talking exclusively about coaxial cable. In a perfect system what happens is the RF energy runs up and down the coaxial cable on the inside of the cable and all the energy is converted into RF and goes out the antenna. But as we all know in the real world there is no perfect system.

The reality of a typical antenna installation the halves of an antenna are rarely balanced due to the distorting effects of the antennas and there is almost always some mismatch between the feedline and the antenna. As a result, practical antennas can be very susceptible to the way they are installed and are rarely well-balanced. By being unbalanced the currents on both halves will be different.

In contrast with the messy environment the antenna is placed the story is different inside a coax cable. Without getting too technical the currents flowing on the center conductor and the inside of the shield are equal and 180˚ out of phase. The two center conductor and the inside shield of the coax are closely coupled along the entire length of the transmission line. So the equal and opposite relationship is strongly enforced. What is going on inside the cable is unaffected by what is going on outside of the cable. The skin effect causes HF currents to flow only close to the surfaces of the conductors. The inner and outer surfaces of the coaxial shield behave as two entirely independent conductors. The cable may be taped to a tower or even buried while the currents and voltages inside the cable remain exactly the same.

The problem arises when connecting a coaxial cable to an antenna. If the antenna is in any way unbalanced, which is almost always the case, a difference will appear between the currents flowing on one side of the antenna versus the other side of the antenna. Remember, in most cases one side of the antenna is connected to the center conductor and the other side of the antenna to the shield. It is the unbalance between these two halves of the antenna that flow on the outside of the shield, these are the common mode currents.

This imbalance which results in different amounts of current flowing in each half of the antenna will cause the coax to radiate by itself. This radiation would be mainly vertically polarized since most transmission lines predominantly run vertically. Here's the really icky part, the feedline radiation causes distortion of the radiation pattern, RF current on metal masts and Yagi booms plus problems with stray RF in the shack. Even worse, the RF currents may flow in the mains and on TV cables leading to all sorts of electromagnetic problems.

The side of the antenna which is connected to the coax shield and the outer coax shield form a second antenna that will also produce an impedance. This impedance, seen looking down the outside surface of the coax outer shield to ground, is called the common mode impedance.

The common mode impedance will depend on a number of factors: the coax length and the path from the transmitter chassis to the RF ground. The path from the transmitter chassis to ground may go through the station grounding bus, the transmitter power cord, the house wiring and even the power line's service ground. In other words, the overall length of the coaxial outer surface and the other parts making up the ground can actually be quite different from what you might expect or want.

In a worst case, common mode impedance will occur when the effective path to ground is an odd multiple length of λ/2, making this path a half-wavelength resonant. In this case, we have a sort of transmission line transformer that practically short circuits the antenna arm that is connected to the coax shield and resulting in a very low impedance at the antenna feed point.

Another extreme situation that might occur is when the overall effective length of the coaxial feedline to ground is an odd multiple length of λ/4. The common mode impedance transformed to the feed point is then high in comparison to the dipole's natural feed point impedance.

In short what this means is that when we see a varying SWR measurement with varying coax cable length the inference is there is an unbalance in the antenna and there is common mode current flowing on the outside shield.

So now we know what CMC are what can we do about them? There are some very basic things that every ham should do. First make sure your ham station is well grounded. We do this for a lot more than just to minimize CMC. We also ground our stations to minimize the effects of a lighting strike. Also in the case where we have high voltage transformers such as we find in high wattage power amplifiers we want to ensure the shortest path to ground is not through us or our equipment.

The other things we can do is to minimize CMC at the source at the feedline. This is done by using a choking balun and in some cases where the balun does not provide choking an RF choke. And we always want to use a choke when we are using an unun. As a rule ununs do not provide any RF choking.

What exactly does a choke do? It provides a high impedance path to ground. In short it makes all that currently flowing on the outside of feedline go away, or at the very least substantially reduces it.

The first thing to understand is that not all common mode chokes are equal. As a rule chokes will have specific design frequencies where they are effective and frequencies where they are not. And no common mode choke that I'm aware of can cover the entire HF spectrum from 160 meters to 10 meters. However it is possible to daisy chain chokes, with each choke designed for a specific set of frequencies.

Let's first consider the Air Choke, aka: the Ugly balun. The air wound choke is not a balun. It provides no balancing between the feedline and the antenna. It is also frequency specific as a choke and is not a very effective choke. The best chokes for HF are made using Ferrite cores and range from type 31 mixes to type 61 mixes. I'm not going to go much deeper into the topic other than explain how to build a choke and to provide you with a chart that show the frequency and impedance numbers for a number of chokes. Table 1 can be found on the internet at: http://k9yc.com/2018Cookbook.pdf

Table 3: Choke Cookbook

RG400	Teflon #12	NM/THHN #12

160M:		
18 turns (10KΩ)	18 turns (9.5KΩ)	18 turns (9.5KΩ)
17 turns (6KΩ)	17 turns (7KΩ)	17 turns (9KΩ)
		16 turns (6KΩ)
80M:		
16 turns (8KΩ)	15-16 turns (6.5KΩ)	15 turns (7KΩ)
15 turns (7KΩ)	17 turns (5.5KΩ)	14 turns (6KΩ)
14 turns (6KΩ)	14 turns (5.8KΩ)	16 turns (5KΩ)
17 turns (5.5KΩ)		13 turns (5KΩ)
13 turns (5KΩ)		
40M:		
14 turns (6.2KΩ)	15 turns (6.5KΩ)	14 turns (6KΩ)
15 turns (5.4KΩ)	14 turns (5.8KΩ)	13 turns (5KΩ)
13 turns (5KΩ)	13 turns (5KΩ)	
30M:		
14 turns (6.5KΩ)	14 turns (6KΩ)	13-14 turns (5.5KΩ)
13 turns (5.5KΩ)	15 turns (5.5KΩ)	
12 turns (5KΩ)	13 turns (5KΩ)	
20M:		
13 turns (5.4KΩ)	13 turns (5.5KΩ)	12-13 turns (5KΩ)
14 turns (5KΩ)	14 turns (5KΩ)	11 turns (4.2KΩ)
12 turns (5KΩ)	12 turns (5KΩ)	
15M:		
11-12 turns (4.8KΩ)	11-12 turns (4.7KΩ)	11 turns (5KΩ)
10 turns (4.2KΩ)	10 turns (4KΩ)	12 turns (4KΩ)
	13 turns (3.8KΩ)	10 turns (4KΩ)
10M:		
10 turns (4.4KΩ)	10 turns (4.3KΩ)	10-11 turns (4.2KΩ)
9 turns (3.8KΩ)	11 turns (4KΩ)	
11 turns (3.5KΩ)		
160-80M:		
17 turns (6KΩ 160M, 6K 80M)	17 turns (7.5KΩ 160M, 5.5K 80M)	16 turns (6KΩ 160M, 5K 80M)
80-30M:		
	15 turns (6.5KΩ 80-40, 5.5K 30M)	14 turns (6KΩ 80-40, 5.5 KΩ 30M)
80-20M:		
14 turns (6KΩ 80-30M, 5K 20M)	14 turns (5.8KΩ 80-40M, 6KΩ 30M, 5K 20M)	13 turns (5KΩ all bands)
13 turns (5KΩ all four bands)	13 turns (5KΩ all four bands)	
40-15M:		
13 turns (4.8KΩ 40-30M, 5KΩ	12 turns (4.6KΩ 40-30M, 5KΩ	

20M,4.8KΩ 15M)	20M,4.8KΩ 15M)	

In general, any combination of chokes can be used in series to provide the desired choking impedance over the desired bandwidth. Their combined choking impedance will be the sum of their resistance values on each band. For example, two 12-turn RG400 or Teflon chokes provide at least 8KΩ from 80 to 15M and 6KΩ on 10M. Combining 14 and 17 turn RG400 chokes provides more than 8KΩ on 160M, about 12KΩ on 80M, 8KΩ on 40M, 7KΩ on 30M, and 5KΩ on 20M.

Building a Common-Mode Choke

For our end fed wire we were faced with a dilemma. What frequency should we target? Given that most of the noise we were hearing is typically in the lower part of the HF band we opted to build a choke that would cover as much of the lower part of the HF band as possible from 80-meters up. So we opted for 16 turns of RG-58 around a single FT240-31 core. Again this is a really simple device to build. Here's is what you will need:

From Amazon:

1. One FT240-31. The Amazon description is "Toroid Core FT240-31 Ferrite" and costs about $13
2. Two SO-239

From Lowes:

1. One grey plastic Electrical box
2. Four 6X32X3/4 Stainless Steel screws with Nylock nuts.

From our junk we will need about a 4' length of RG-58 coaxial cable. If you need to build a choke with more power handling capability use either RG400 or Teflon coated wire or #12 insolated wire. Insolated wire is what you will find in common house wire aka: Romax. I chose to build my choke out of RG400 given its power handling ability. See Figure 5 for a picture of our choke.

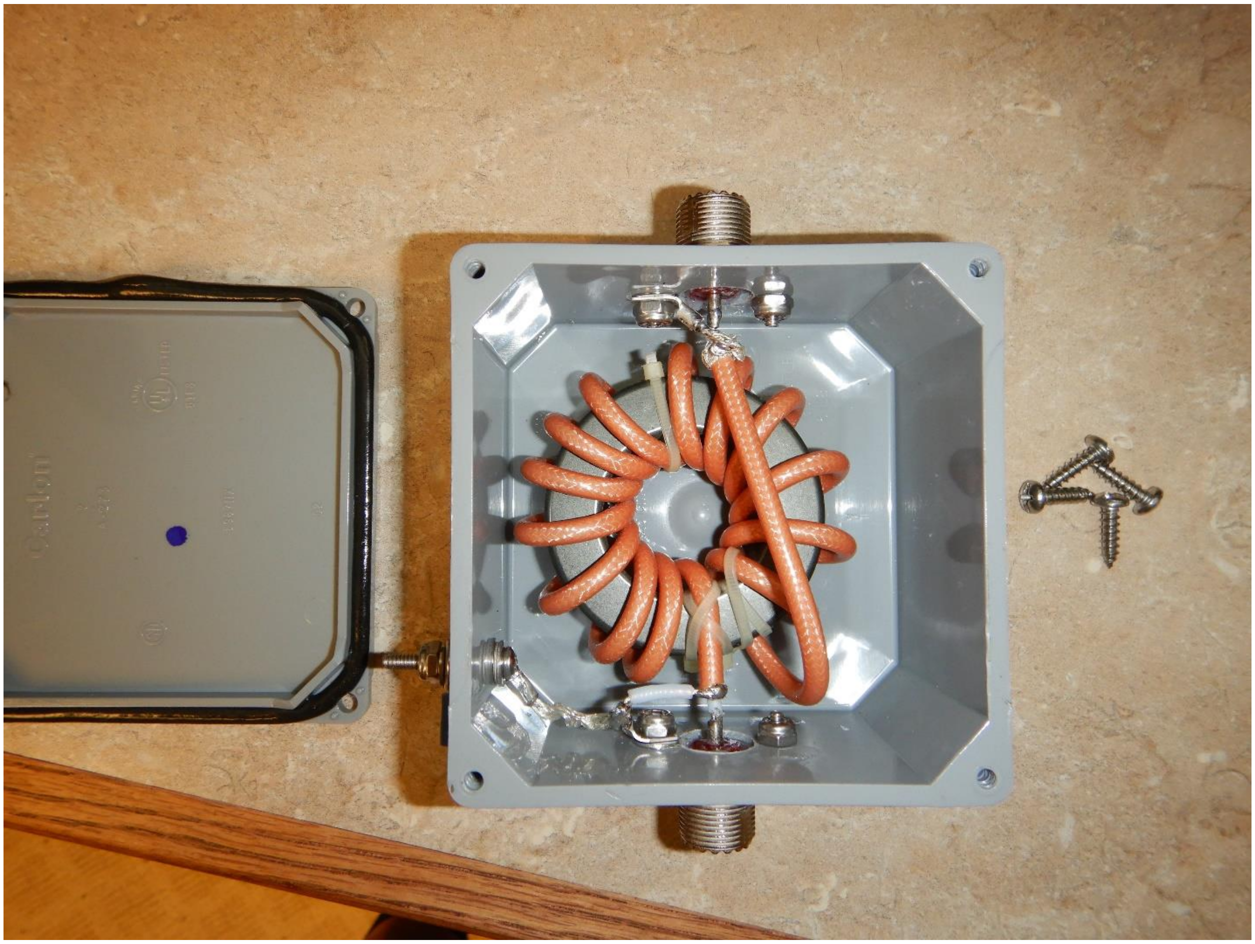

Figure 5: Common Mode Choke made using RG-400

Our Results: We took noise reading before and after installing the choke. Our results can be found in Table 2.

Band	Pre Installation	Post Installation	Change
80 meters	S4	<S1	4 S units
40 meters	S8	S4	4 S units
20 meters	S9	S3-4	4-5 S units
15 meters	S6	S4-5	1 S unit
10 meters	S6	S5	1 S unit

Table 4: Noise Level Results

The results were as expected. The most improvement appeared from 80 to 20 meters with only a small change for 10 and 15 meters. Given out design this was the expected behavior. We also noticed a small change in the SWR reading but they were still well in range of the built in tuner in the FT-1000MP.

Summary

In this article we have covered a lot of ground from the installation of an end fed wire to the in's and outs of baluns, ununs and Common Mode Chokes. Nearly every ham station can benefit by making sure their aerial is properly fed and that common mode currents have been minimized. The key takeaways from this article are:

1. All antennas installations will have some common mode currents flowing on the coaxial cable. In some case it will be noticeable in others it not so much.
2. Baluns, Ununs, and Chokes are easy to build and not necessarily expensive.
3. An End Fed Wire can make a good antenna even where space is limited.
4. An end Fed Wire needs to be properly fed using a 9:1 unun and CMC's minimized by including a CMC choke.

If you are interested in finding out more about Chokes, Baluns and Ununs visit the following web sites:

https://palomar-engineers.com/

https://www.balundesigns.com/

http://www.karinya.net/g3txq/

http://k9yc.com/2018Cookbook.pdf

http://www.yccc.org/Articles/W1HIS/CommonModeChokesW1HIS2006Apr06.pdf

https://www.hfkits.com/