Refining an End Fed Antenna

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I have always been a fan of end fed antennas. Why? They are easy to deploy because the feed line doesn't weigh down the middle of the antenna. You can feed at the bottom of a vertical or one end of a horizontal. You can even hang the antenna from your hotel room balcony… and there are never any counterpoises or radials to worry about.

This interest in end fed antennas causes me to wander around the web looking for ideas on what designs are available and how best to construct them. There are a wide variety of popular designs including autotransformers, Zepps, and JPoles. One of the less common end fed antennas is called a "Resonant Feed Line" antenna and was described by James Taylor (W2OZH) in a *QST* article back in '91. Over the years, I have found lots of articles about this antenna: how it operates, how to build it, and what to expect. In assimilating all these articles, I slowly came to the conclusion that this antenna was misunderstood and so I decided to try to design one myself starting from scratch. And perhaps, add a touch or two of my own.

Getting started

Whenever I start out an antenna project I fire up my antenna modeling software. Usually, this is EZNEC (by W7EL) because it is so simple to use. There is a free version of EZNEC which is adequate for the purposes of this project.

Nearly all of my portable operations take place on the 20 meter band and so I'll talk about my 20m antenna here. The Resonant Feed Line antenna (here-after RFL) is a half wave dipole. Electrically, this antenna is 'center fed'. So to get a handle on what I'm looking at, I will start with a vertical half wave antenna driven at the center. Figure 1 is the EZNEC drawing of the antenna. For modeling, the antenna is described by a single wire as shown in Figure 2.

Once I've described the antenna, I run a frequency sweep to compute the impedance the antenna provides across the range of frequencies. As a confirmation I'm on the right track, I check the SWR to make sure things are basically correct. Figure 3 shows the resulting SWR plot. The minimum SWR is at 14 MHz with an impedance of 93 ohms.

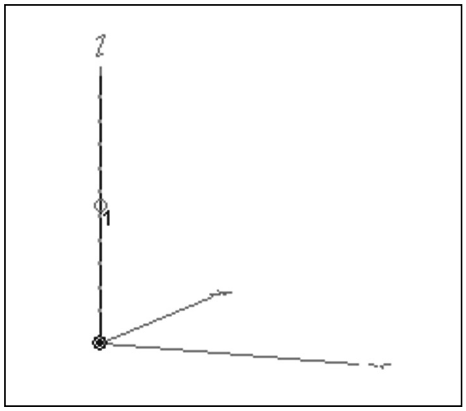

Figure 1—EZNEC drawing.

The Resonant Feed Line

The RFL antenna is unique in 'end fed' antennas in that it is truly a 'center fed' antenna. It is called 'Resonant Feed Line' because the feed line is actually part of the antenna. To see how this works, consider a piece of coax. We generally think of coax has have two conductors but at radio frequencies, the coax actually has three: the center conductor, the inside of the braided shield, and the outside of the shield. For the RFL antenna, the center conductor and the INSIDE of the shield are, in fact, the feed line while the outer surface of the coax is a radiating part of the antenna.

It might help to walk through where various currents flow. Referring to Figure 4, the feed line begins at the left. Feed currents are injected onto the inner surface of the shield and the center conductor. These currents proceed down the inside of the feed line until they reach the midpoint of the antenna. At this point, the current on the inside of the shield does a 'U-turn' and goes back to the left on the outside part of the coax shield. The current on the center conductor proceeds to the right.

From an RF radiation perspective, the currents on the center conductor and the inside of the shield cancel each other out and generate no radiation. However, the current on the conductor to the right of the mid point and the current on the outside of the shield do NOT cancel out and, as a result, radiation is created.

Impedance Matching the Antenna

Having obtained the impedance data from EZNEC I can see that this antenna has an SWR below 2 to 1 over an extremely limited bandwidth. I would like to make this bandwidth much wider for two reasons. First, my portable rig works much better with a reasonable impedance match. Second, since I deploy my antenna in so many different environments, I would like to have a good match even when the anten-

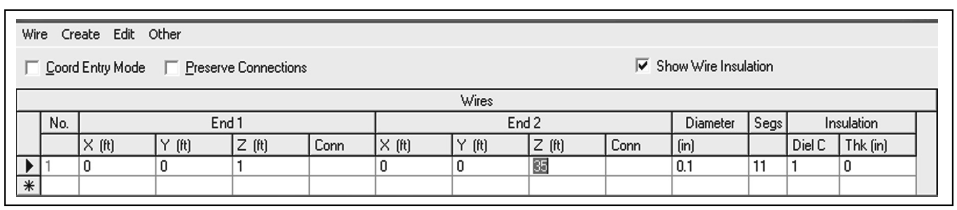

Figure 2—"Wires" definition in EZNEC.

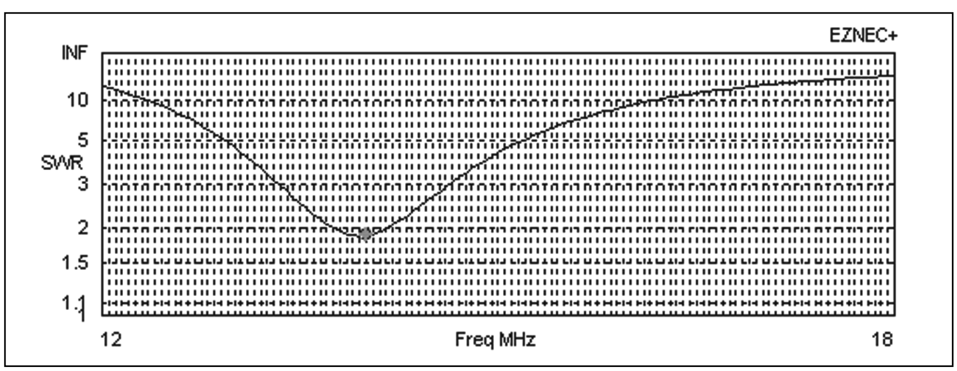

Figure 3—VSWR plot of the antenna model.

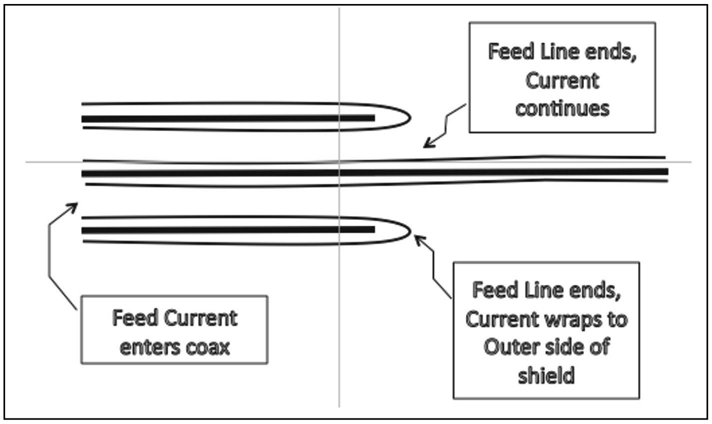

Figure 4—Current flow on inside and outside of coax shield.

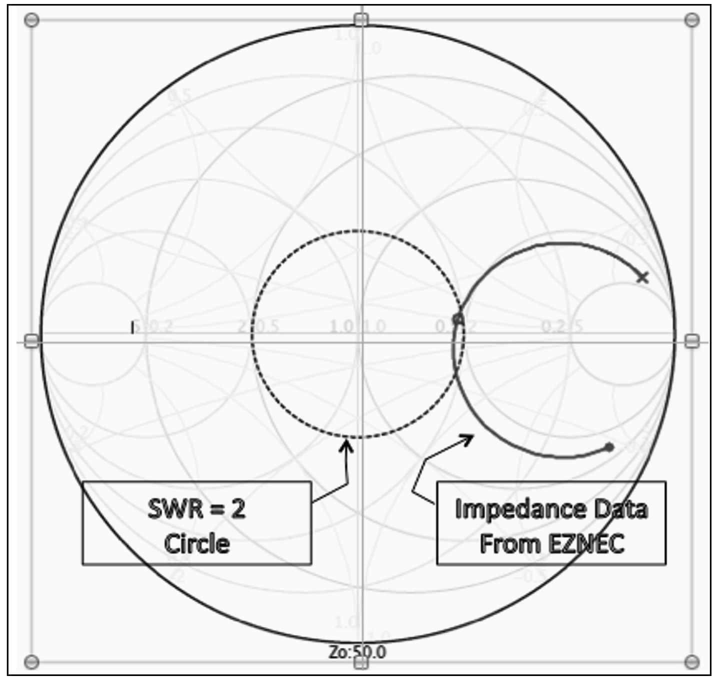

Figure 5—Smith chart plot of feedpoint impedance.

na is detuned. How should I go about matching the impedances? I could, of course, simply use a portable antenna tuner. However, this tuner is an extra box to carry around and causes additional losses in power. I'd like to leave the tuner behind if possible.

One of the easiest ways to solve matching problems is to use a Smith chart. The Smith chart allows us to view the impedance data graphically and to create simple circuits which will affect the match. Figure 5 is a Smith chart of the impedance data obtained from EZNEC. The goal of matching is to move as much of the trace from EZNEC to 'inside' the 2:1 SWR circle. There are many tutorials (including several on my web side www.ae6ty.com) describing a wide variety of techniques for doing this match. Here is how I did it in this case.

My matching is done by using the feed line itself to first rotate the impedance curve around the center of the Smith chart. Since I already have a feed line, using it to rotate the impedance curve is 'free'. Figure 6 shows an updated Smith chart with the impedance data rotated clockwise around the center of the chart using the feed line. It is important to note two things about this 'rotation'. First, the impedance curve now looks substantially different; the original curve did not curl back on itself. We will take advantage of this curl later.

The second thing to note is that while the shape of the impedance curve has changed, the shape of the SWR curve has not. I won't bother to show the graph but trust me, it didn't change.

Now comes the real matching part, which is illustrated in Figure 7. Remember, using the feed line, I rotated the impedance

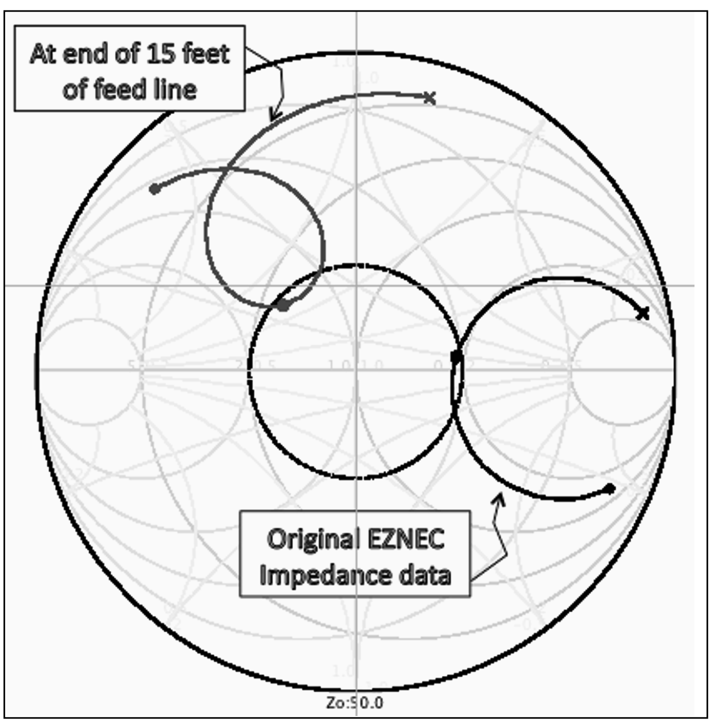

Figure 6—Impedance plot "rotated" by additional line length.

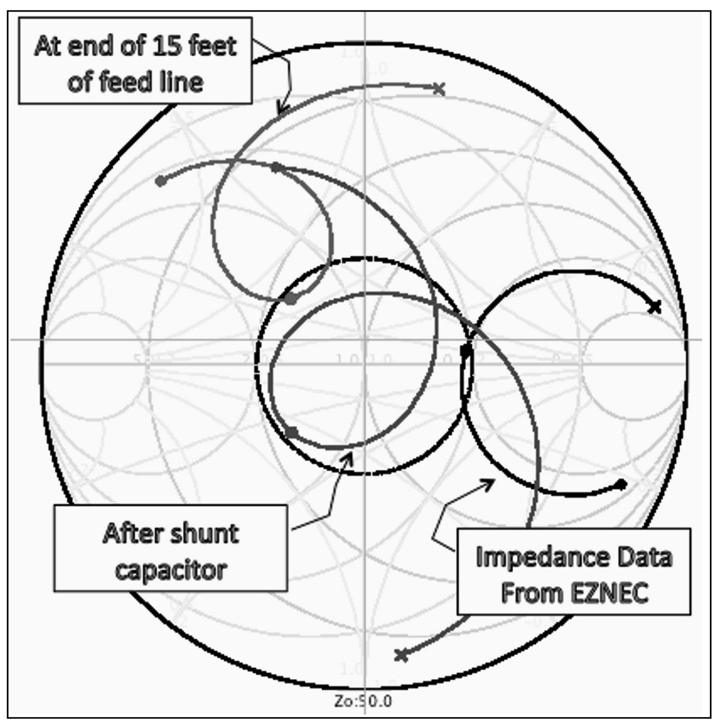

Figure 7—Impedance shifted by a shunt capacitor.

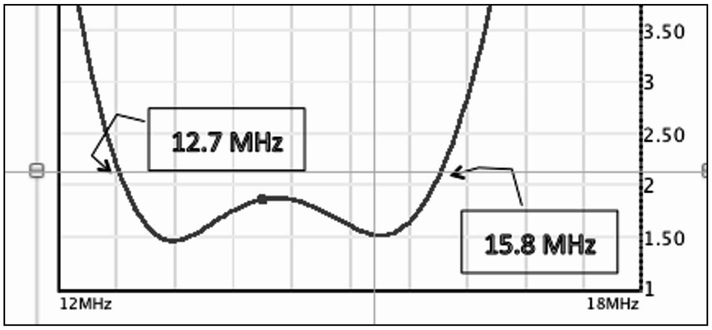

Figure 8—VSWR vs. frequency of the antenna, as shifted by the capacitor.

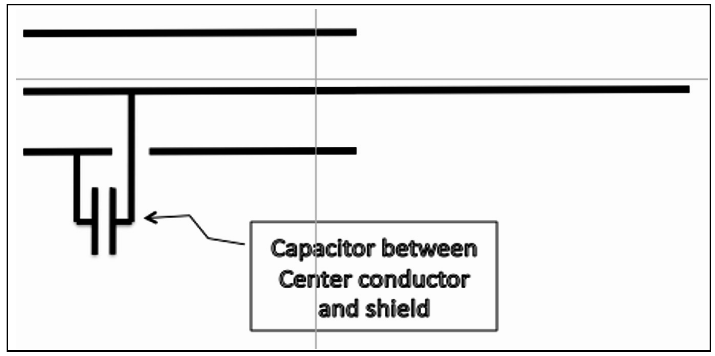

Figure 9—Location of the added capacitor.

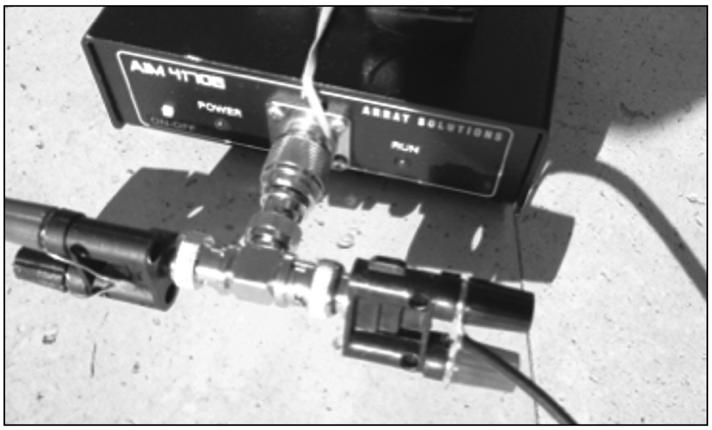

Figure 10—Antenna measurement connections.

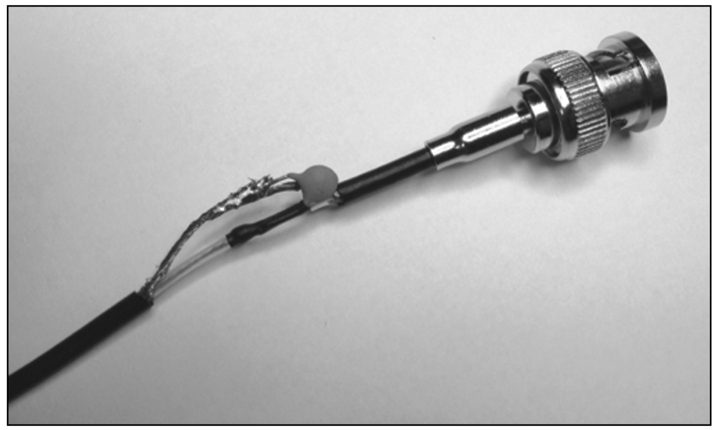

Figure 11—Installation of the shunt capacitor.

curve to a special place on the Smith chart. I can now move the impedance curve DOWN to the center using a single, shunt capacitor. A significant piece of the curve now lies within the SWR 2:1 circle. Figure 8 shows the data on an SWR chart. The SWR is below 2:1 from 12.7 MHz to 15.85 MHz. (Remember that curl that occurred because of the feed line? Well, that curl has helped make even more of the curve fit within the 2:1 SWR circle.)

Figure 9 shows how the capacitor is attached.

Construction of the Basic RFL Antenna

My antenna is constructed using RG174 coax. This coax is small and very flexible. Some folks frown on it because it is considered lossy. In this antenna, I've calculated that I lose about 0.4 dB in the cable.

Since the antenna is a half wave length long, I will need somewhere around 34 feet to make my antenna. Employing the standard practice, I will leave a couple extra feet in length because it is always easy to remove length… adding it is painful.

The first step in constructing the antenna is to cut a piece of RG174 to 15.4 feet long. These 15.4 feet will be the 'feed line' which goes from my rig up to the 'center' of the antenna. Of course, 15.4 feet is NOT the center of the antenna, but I've found it is close enough for these purposes. At one end of the feed line I put my capacitor and my connector. I use BNC connectors. Figure 10 is a picture of the rig end of my antenna constructed using BNC plumbing hardware. The T is a 'shunt' so the feed line, the capacitor and the AIM4170 are all connected in parallel. This approach lets me experiment with capacitor values but is really too expensive and fragile for deployment. Ultimately, the end of the feed line will be constructed as shown in Figure 11.

Figure 12 shows the other end of the feed line. Here, the center conductor of the feed line is connected to the shield of the other half of the coax which extends upwards another 18 feet or so completing the half wave dipole. In this way, the radiating currents always flow on the outer surface of the shield.

Having constructed the antenna it is time to tune it up. I do this in two stages. In the first stage, I leave the matching capacitor out and adjust the length of the antenna in the traditional way: I loft the antenna and measure the frequency of the minimum SWR. If the frequency is too low (which it will be if I start out with such a long dipole), I take it down and shorten the dipole. Make sure not to cut off pieces of the feed line, it should remain 15.4 feet long through this whole process.

Once the dipole length has been adjusted, I then start to adjust the matching capacitor value. Fortunately, this phase does not require me to take down the antenna. The binding posts I use for development make this stage very quick. However, the goal of this tuning phase is a little different. Instead of tuning for minimum SWR I am now going to tune for maximum bandwidth. This is a simple process using a modern antenna anlyzer such as the AIM4170B. However, it is a bit more complicated with older SWR meters. With these meters you have to search around to find the minimum and maximum frequencies where the SWR is below 2:1.

At this point the design is complete. Once you pick the capacitor value you can

Figure 12—Connection between coax sections.

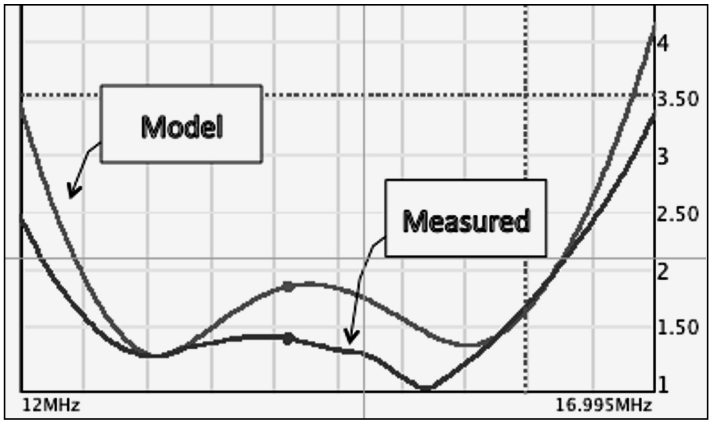

Figure 13—Modeled and measured VSWR curves. Although there are some differences, the general patterns are the same.

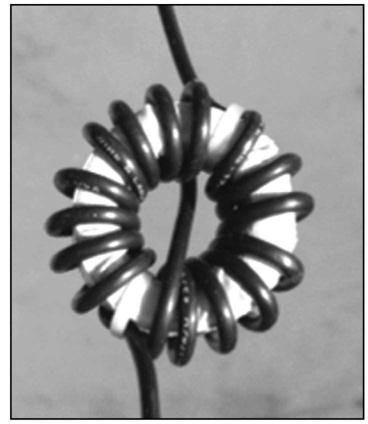

Figure 14—Toroid common-mode choke.

finalize the construction in whatever way you might like. Again, Figure 11 shows my surgery for putting the matching cap in parallel with the feed line. No doubt there are better ways to do this.

Of course when possible, it always good to 'close the loop' and measure the final impedances. Figure 13 is a comparison between theory and practice. As you can see, there are some differences but as a whole, theory and practice compare quite favorably.

Isolation

So far I have described an antenna which is attached directly to my rig. There are times, of course, where I would like to separate my antenna from my rig and here things get a little more interesting. The problem is, if I just extend the feed line from the 'antenna' further to my rig, I am also extending the 'radiating' part of the antenna and this will change its resonant frequency. In order to avoid this, I need to somehow stop the radiating shield current from continuing down the feed line while allowing the internal feed currents to continue unaffected. Said in a more familiar way, we need to stop the 'shield currents'. Traditionally, we do this by using a common mode choke also known as a 1:1 current balun. Sometimes this traditional balun is as simple as a half a dozen loops of coax. Many web sites propose exactly this, a coil of coax, as the right 'trap' for the RFL. Unfortunately, these don't work very well.

The problem is that these coils of coax have inductances on the order of 1 to 10 uH. At 14 MHz, this translates to a reactance of between 80 and 800 ohms. This may seem large, but it is small when compared to the impedances seen at the ends of antennas which is often 3 to 6 kohms. In his original work, W2OZH made these coils 'resonant' which increases their reactance to several thousand ohms, roughly comparable to the impedance at the end of the antenna. Because these coils of coax are large and must be tuned, I've searched for another way.

My solution to stopping the radiating shield current has been to introduce an old fashion, ferrite toroid. I construct this toroid using additional RG174 coax wrapped 12 to 16 times through a 2.25 inch surplus ferrite toroid. The measured inductance of this toroid is 150 uH. This delivers a calculated impedance of over 10,000 ohms. I have found this particular choke adequate to my needs. However, I would warn the non-QRP folks that this simple choke may prove inadequate at higher power levels where significant voltages will be generated across the winding and losses may cause excess heating. Figure 14 is a picture of my choke.

Improving the Match

While the SWR bandwidth is quite good, the quality of the match within that bandwidth could stand some improvement. Interestingly, I can sacrifice a little of the SWR bandwidth and improve the match using otherwise wasted resources.

Remember that the feed line uses all three conductive surfaces of the coax. So far, I've only used the outer surface of the shield of the other half of my coax. The ham in me begs to figure out how I can use those other two surfaces to my advantage. The *ARRL Antenna Book*, chapter 9 describes a mechanism for broadband matching dipole antennas. One of the techniques is to connect a resonant LC circuit to the feed point of the antenna. The idea is, as frequency increases and the dipole becomes inductive, the LC network becomes capacitive thereby compensating for the dipole's inductance. Equivalently, as the frequency decreases below the dipole resonance the dipole becomes capacitive and the LC network becomes inductive; again a compensating effect.

While the mechanism is explained using an LC network as an example, implementing an actual LC network would be awkward, adding weight and complexity. Fortunately, there is an alternative circuit which acts much like an LC network: a quarter wave long, shorted coax stub. And remember those two surfaces which were unused? Those were the very things needed to implement a shorted coax stub! Figure 15 shows how the two pieces of coax are now connected. Figure 16 shows my final antenna. Figure 17 shows the difference in SWR matching.

As you can see, there is some improvement in the match with the introduction of this stub. Deciding if it is worth the improvement is open to debate, but it is fun to see what can be done with a little ingenuity.

Tolerances

One of the chief reasons I like this antenna is that the wide bandwidth makes it easy to deploy in varying environments. A great example of this is comparing its performance when connected directly to my rig versus the performance with the trap and an extended feed line. When the

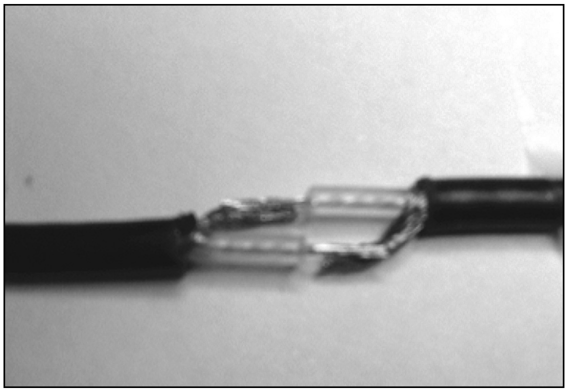

Figure 15—“Reversed” coax connection.

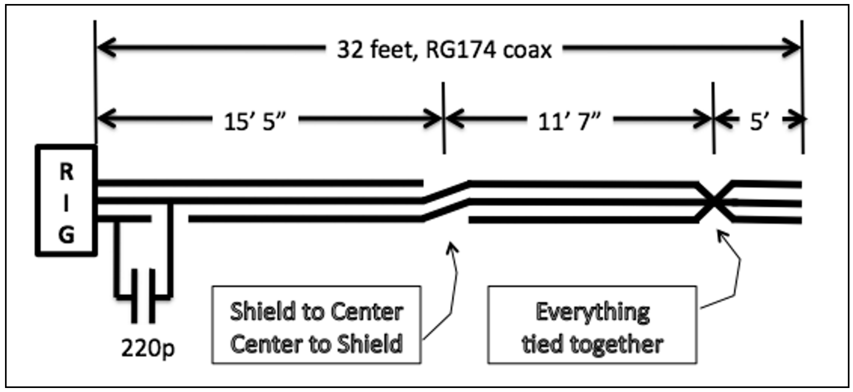

Figure 16—Diagram of the complete antenna/feedline system.

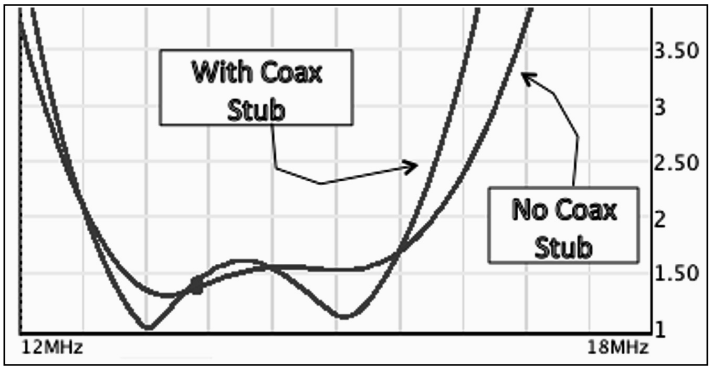

Figure 17—Antenna VSWR with and without coax stub matching.

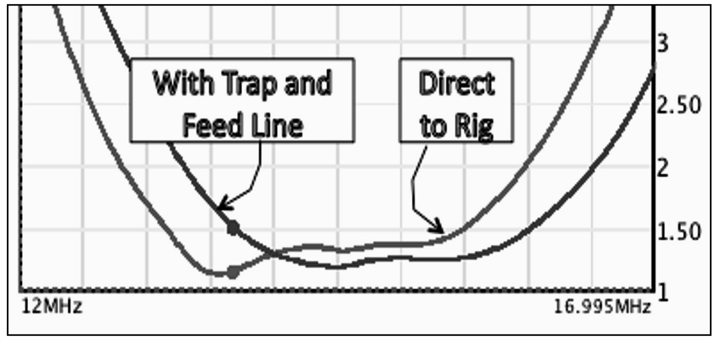

Figure 18—Comparison of VSWR with direct connection to the rig, and with the trap and extended feedline. Capacitance between rig and antenna is reponsible for the differences.

antenna is connected directly to the rig, the rig acts as a capacitor and detunes the antenna. Figure 18 shows the two SWR curves. Notice the rig has shifted the curve 500 kHz to the left (downward) but this has no substantial impact on the match over the operating band.

Another reason I like this antenna is that the wide bandwidth allows great tolerances in construction as well. For example, a few inches in length here or there make little difference. Coax velocity factor can vary between manufacturers but those variances have little impact in this antenna. The matching capacitor, also, can be off by up to 10 percent, again, with little effect. While you can tune this design to your heart’s content, such tuning is often just polishing a brick—this antenna is truly forgiving.

Summary

The “Resonant Feed Line” antenna is a very versatile, single band antenna. It has extremely wide bandwidths, can be deployed in a wide variety of configurations and environments, and requires no tuner. Optimizing the antenna can be very educational but even the most casual construction can result in a rugged, lightweight and efficient antenna. It is my antenna of choice for portable operation and an integral part of my “go bag.”

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MARK YOUR CALENDARS

HF Grid Square Sprint
9 March 2013, 1500Z to 1800Z

Spring QSO Party
6 & 7 April 2012, 1200Z April 6 through 2359 April 8

Hoot Owl Sprint
26 May 2013, 8:00 PM to Midnight LOCAL time

QRP Shootout — 15 & 16 June 2013
CW 1500Z to 2100Z on June 15
SSB 1500Z to 2100Z on June 16