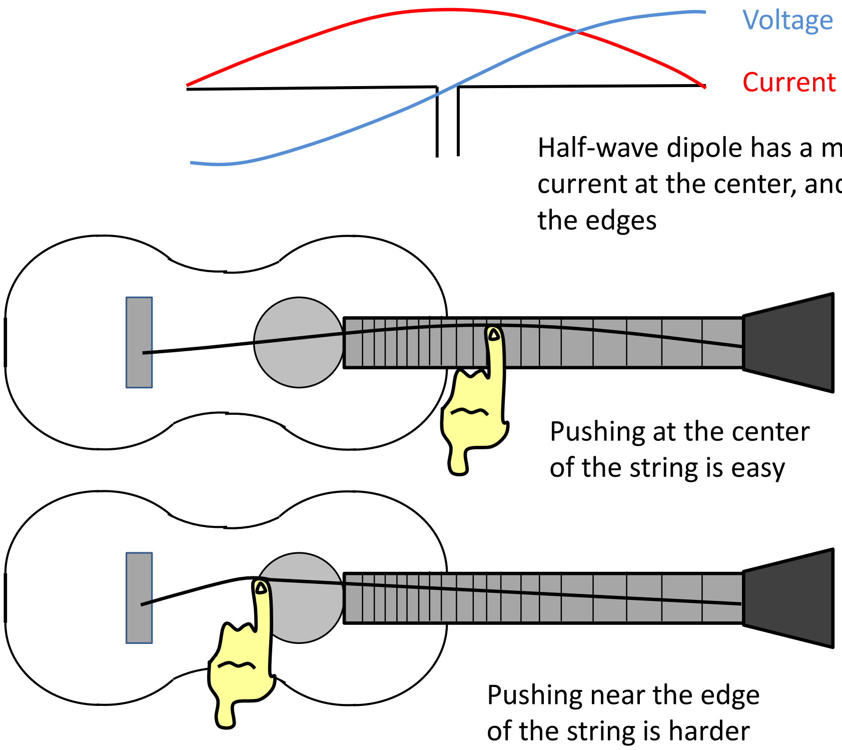
Building and Understanding Your Multiband End-Fed Half-Wave Antenna

By Daniel Marks, KW4TI

Fiddling with a complicated antenna assembly process when you're on the road is always a pain. Rather than erecting some multiple section beast of a mast to reach the into sky, wouldn't it be better just to stop at a campsite, take out your radio, throw a wire up a tree, adjust a tuning knob, and get on the air? This is exactly the convenience the end-fed half-wave antenna (EFHWA) offers. It does not require an extensive ground like a big ferrous vehicle body, only a short counterpoise wire. It is a favorite of Summits-On-The-Air (SOTA) activators and ARES/RACES that roll it up into a backpack or toss it in an emergency go kit. Furthermore, it's easy to build, low cost, does not require an automatic antenna tuner, and is a good backup antenna in case your main antenna falls down in a storm. However, must mystery surrounds the EFHWA and how it works. It's not the perfect antenna, but it's convenient and inexpensive enough to be in every ham's bag of tricks. Continuing improvements to radios, ferrite materials, and cables have made this antenna more easily built and versatile than ever, but its origin begins at the dawn of both the radio and air travel age, with the rigid airship.

The original radio antennas were monopoles or center-fed dipoles. Center-fed dipoles require two supports for each end of the antenna. A monopole antenna is like a center-fed dipole, with one-half of the antenna being the reflected image of the radiating wire inside the ground. For the Zeppelin which does not have a ground, it was more convenient to be able to support the antenna from one point only. To do this, the Zepp antenna was created, which feeds a half-wave dipole from the end it is supported from rather than its center. Problem solved, right? Not quite. The feed resistance of a center-fed dipole is a convenient 73 ohms. As one feeds the dipole closer to its edge, the feed resistance increases greatly, becoming thousands of ohms at its edge. As we know from Ohm's law, as the resistance increases of a load, the voltage must increase to pass the same current through the load. To drive the end of the wire, the transmitter would have to be designed to deliver a high voltage radio frequency signal directly to the antenna.

To understand why an ordinary dipole is driven from the center, consider a guitar string as in Figure 1. The guitar string is held down at both ends, one on the bridge of the guitar, one on the nut (don't worry about the frets for now, that's more like a trapped dipole). The length of this string is half of the wavelength at its mechanical resonance frequency. Near its center, the string is compliant and may be moved quite easily. On the other hand, the string is stiff near its edge at the bridge or the nut and must be pushed hard to move it at all. The "current" is analogous to the velocity of the string perpendicular to the string, and the "voltage" is the restoring force of the string pushing back on one's finger (hence voltage often being called "tension"). A vibration is applied to the string at the resonance frequency by pushing back and forth on the string. The amount of energy used to move the string is the restoring force multiplied by the distance pushed. A shorter, stronger push on the end of the string can achieve the same output power as a longer, weaker push in the middle. As a transmitter typically only can produce the longer, weaker push, a method must be devised to turn a long, weak stroke into a short, strong stroke. Mechanically, a lever would accomplish this. The electrical equivalent of this lever is an impedance transformer.



Half-wave dipole has a maximum of current at the center, and voltage at the edges

Pushing at the center of the string is easy

Pushing near the edge of the string is harder

Figure 1. Comparing a guitar string and a center-fed half-wave dipole antenna. The transmitter feeds current in the center of a dipole, similarly to how a guitar string is usually plucked near the middle of the string. The guitar string can be plucked near its edge using more force.

There are two basic ways that this impedance transformation is accomplished. The first, which was used on the Zepp antenna and on the J-pole antenna, is to use a quarter wavelength matching length of transmission line, usually ladder line. The second is to use a voltage balun. Consider the Zepp antenna first with its quarter-wave matching section. How can a transmission line act as an impedance transformer? Continuing with the analogy of a string, place a second guitar string tuned to the same resonance frequency alongside the first on the bridge and nut of the guitar, as shown in Figure 2. Clamp both of the strings together near the bridge. Like the first string, the second string may be pushed easily at its center. At the same time, the entire string moves when it is pushed, with the displacement being comparatively smaller near the edges of the string. If the string is pushed at a point, the string forms a triangle shape, with the three vertices on the triangle being at the bridge and nut, and the third where the string is pushed. At the clamp, the movement of the string is smaller, but the force applied by the string is comparatively greater than at the center. The second string is acting as a mechanical lever, converting the weak force applied at the center of the string to a strong force at its edge. The first string, which is clamped to the second string at its edge, is pushed hard by the second string and vibrated. The second string is acting as the impedance transformer between the two points on the string where the force is applied and at the clamp. Only the half of the second string between these two points is needed, which is a quarter wavelength long, which is why this is called a quarter-wave impedance transformer.

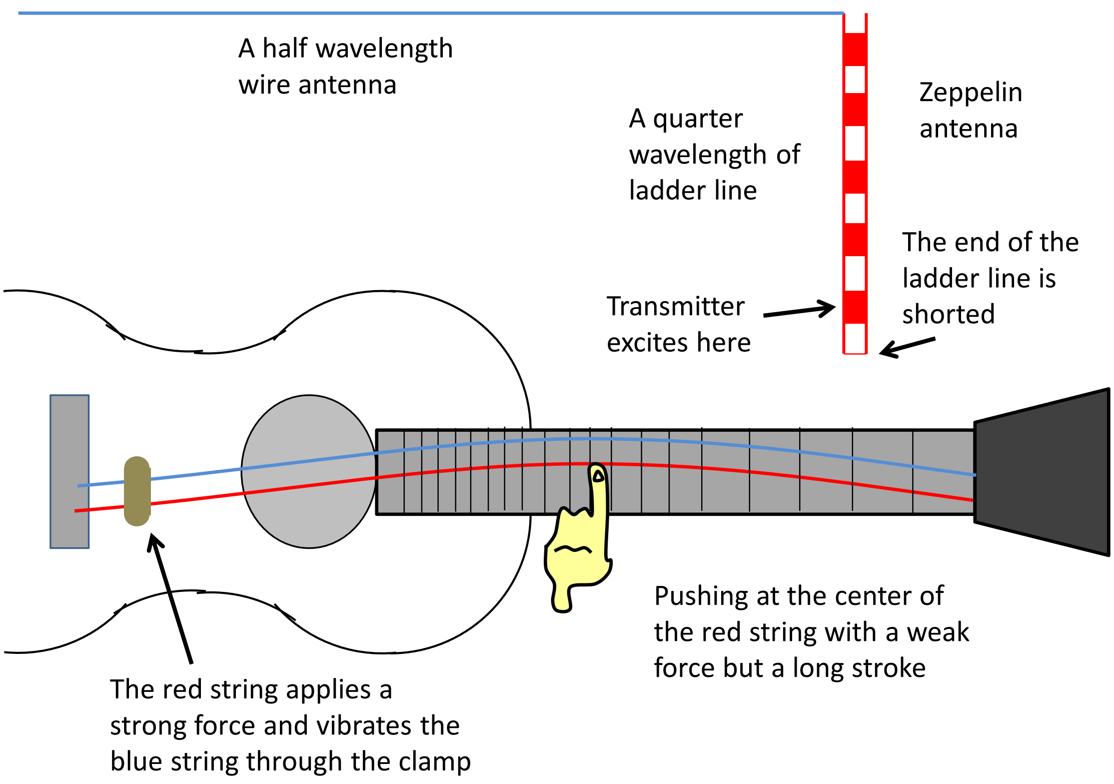


Figure 2. The red string is plucked in the center with a low force, while near the end of the string the red string vibrates the blue string with a high force. This is similar to a Zepp antenna, which excites the ladder line at a low impedance point, and the voltage is transferred between the ladder line and the half wavelength antennas at their high impedance points.

The Zeppelin antenna consists of a half wavelength of wire fed by a quarter wave length of transmission line. The half-wavelength of wire has a high feed resistance, and would require a high voltage to drive without the impedance transformer. A quarter-wavelength transmission line transforms the high impedance to a low impedance which can be driven by a 50 ohm transmitter output. There are many variations on this idea, notably the J-pole antenna. It is called the J-pole because of the shape of the conductor, with the quarter wave matching section forming a “U” shaped conductor, and the half-wave antenna part jutting out from the U. These can be built from cheaply for the VHF/UHF frequencies from copper plumbing or made into compact, roll-up versions out of ladder line such as the Slim Jim antenna. Zepps can also be built as well for HF, however, the matching section adds a significant length to an already long antenna. Furthermore, the matching section is designed to be a quarter wavelength for a particular band, and for convenience it is desirable to have an antenna that works for multiple bands. Instead of using a quarter wave matching section as a transformer, a voltage balun may be used.

To continue with the mechanical analogy, a voltage balun is like a pulley system such as a block and tackle that is used to raise heavy loads, as shown in Figure 3. To do this, there are two pulleys, one attached to a fixed support, and the other attached to the load that moves with the load. A rope is looped multiple times over both the fixed and load pulleys. When the rope is pulled, the tension of the rope is applied multiple times to lift the load, multiplying the force of the pull. The energy required to lift the load, which is the product of the rope tension and distance pulled, is the same with or without a block and tackle, as the rope must be pulled a proportionally longer distance when the block and tackle is used to raise the load a given amount. This is similar to what occurs in a voltage balun, which is an electrical transformer for radio frequencies. These consist of two sets of windings that are intimately coupled to each other so that the magnetic flux lines of one winding mostly pass through the other winding. Often the windings are wrapped around a ferrite toroid to confine the magnetic flux of the windings to better conduct the magnetic flux between the windings and reduce the flux “leakage.” A current is conducted through the primary winding by connecting it to the output of a transmitter. The electrical equivalent of pulling on the rope to lift the load is the magnetomotive force that magnetizes the toroid, which is the product of the current in the primary winding and the number of primary turns around the toroid. These magnetic flux lines pass through the secondary winding, and induce a voltage into each turn of the secondary winding. Each additional secondary winding adds an additional voltage so that many secondary windings multiply the voltage, just as each loop of rope around the pulleys multiplies the force lifting the load. The voltage increases by the ratio of the number of secondary turns to the number of primary turns. Like the block and tackle, the transformer conserves the amount of energy transmitted through it, so that the transmitted power, which is the product of the voltage and current, is the same for both the primary and secondary windings. To keep the power the same in both windings, the transformer decreases the current by the same ratio of the number of secondary to primary turns. As the transformer increases the voltage by the ratio of the turns, and decreases the current by the same ratio, it transforms the impedance from the primary to the secondary windings proportional to the square of the ratio of the turns, because the impedance is the ratio of the voltage to the current.

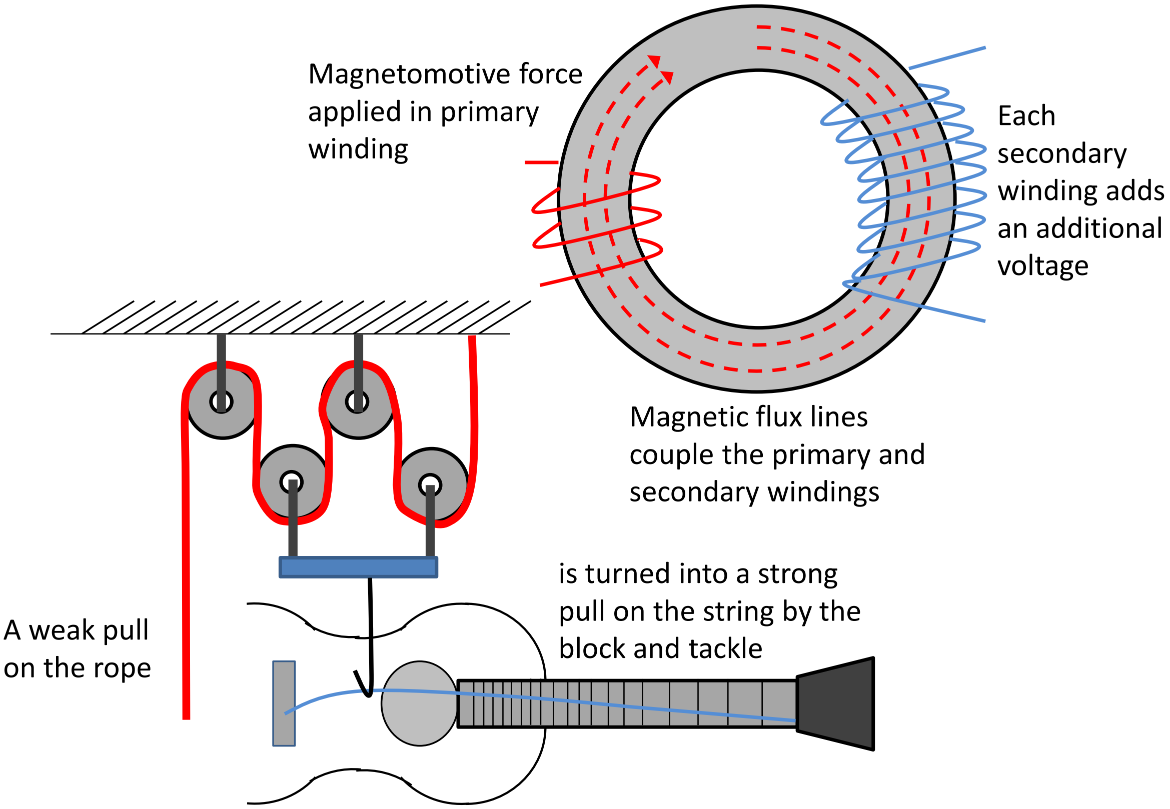


Figure 3. A block and tackle system multiplies the force of a rope pull by winding it over pulley several times. In a similar manner, each additional secondary winding of the transformer multiplies the voltage at the output of the transformer.

A half-wave antenna with its feedpoint at its end has a high impedance, however, if the feedpoint is connected to the secondary winding of a voltage balun, the effective impedance at the primary winding is decreased by the square of the turns ratio between the secondary and primary windings. A typical feedpoint resistance of an EFHWA is around 3000 ohms, so that to be transformed to the 50 ohm output of a typical transmitter, the impedance must be divided by 60. If the turns ratio is 8:1, the impedance is reduced by 64 times or 47 ohms, and if the turns ratio is 6:1, the impedance is reduced by 36 times or 93 ohms. Because the feedpoint resistance varies with frequency, often the transformer has two or three taps so that a turns ratio that best matches the feedpoint resistance may be selected.

At the resonant frequency, the EFHWA impedance is purely resistive and ideally all of the power delivered to the antenna is radiated into the air. This resonant frequency depends on the length of the wire, so that to remain exactly resonant at every frequency used, an antenna of a different length would be required. This is inconvenient unless a narrow band of frequencies is to be used. Away from this resonant frequency the antenna becomes reactive as well as resistive, so that is behaves inductively or capacitively. If the frequency is slightly lower than the resonance frequency, the antenna behaves inductively, so that the current lags the applied voltage, and above this frequency, the antenna is capacitive, so that the current leads the voltage. In either case, rather than the energy being delivered to the antenna being radiated, some of it is stored and reflected back to the transmitter, where it is turned into heat. Transmitters can be damaged by too much reflected power, so that most modern transmitters have protection circuitry to reduce the transmit power if excessive power is reflected. Don’t rely on the protection circuitry to prevent you from making expensive mistakes; it is only present to prevent a brief strong reflection from permanently damaging the expensive and delicate final amplifier circuit transistors.

To be able to use an EFHWA at frequencies where it is off resonance, a matching circuit is used. Fortunately, a full matching circuit that might be found in a general antenna tuner such as an L or T network of inductors and capacitors is not required, and this would be cumbersome for portable work. While these networks (with suitable components) could be used for an EFHWA, the antenna can be designed to be matched using a single adjustable capacitor. As the resistive component is already nearly matched, all that needs to be cancelled is the reactive component. A simple way to do this is to shorten the antenna slightly below its resonance length so that it always presents an inductive load. A variable capacitor placed in parallel with the antenna can be adjusted to cancel the inductance of the antenna and present the antenna as a purely resistive load as if the antenna was resonant. The capacitor serves as a reservoir for the energy reflected by the antenna so that this energy is not returned to the transmitter. The energy is exchanged back-and-forth between the antenna and the capacitor until the energy is radiated by the antenna. While a variable capacitor needs to be adjusted when the frequency changes, this is much easier than cutting a new wire for each frequency.

With a capacitor, an EFHWA may be tuned to achieve a low standing wave ratio (SWR) throughout a single amateur band. But can the antenna be designed to operate on multiple bands? Because the common amateur bands are chosen to be harmonics of each other, a EFHWA designed to be a half wavelength on the lowest harmonic is a full wavelength on the second harmonic, and 3/2 of wave on the third harmonic, etc. The principle of the EFHWA works when the antenna length is a multiple of a half wavelength, so that an EFHWA can operate on higher harmonic bands as well. For example, four common amateur radio bands are 7.0 to 7.3 MHz (40 m), 14.0 to 14.35 MHz (20 m), 21.0 to 21.45 MHz (15 m), and 28.0 to 29.7 MHz (10 m). Notice that all of these bands are multiples or harmonics of 7.0 MHz. A EFHWA at 7 MHz is about 66 feet long, but it also fits one full wave at 14.0 MHz, 3/2 of a wave at 21 MHz, and 2 waves at 28 MHz. Conveniently, an EFHWA antenna at the 40 m band also works at these other higher harmonic bands as well. This trick can be used at 80 m as well if you are willing to spool 132 feet of wire antenna, but as the 80 m band is very wide, it is more difficult to cover the entire 80 m band with a single wire.

So now that you understand the basics of the EFHWA, why not build your own? Here are the ingredients:

- 80 feet or more of 22 gauge stranded wire for the antenna and counterpoise.
- A ½" galvanized plumbing tee to tie on the end of the antenna wire as a weight to throw it.
- FT240-43 toroid for the transformer. If weight or space is a concern, a FT140-43 toroid could be substituted.
- 600 volt rated PVC insulated wire (for power up to 100 W), or Teflon insulated wire for high power for winding the transformer.
- Heat shrink tubing and solder
- An air-variable capacitor at least 250 pF maximum capacitance with a plastic knob. For high power (above 100 W) a 1 kV minimum rated capacitor is needed.
- A single pole, double throw panel mountable switch rated for 250 VAC
- A second single pole, double throw panel mountable switch with center disconnect rated for 250 VAC
- A plastic insulated project box.
- A SO-239 or female BNC panel connector
- A pair of black and red binding posts for the antenna and counterpoise terminals.

The schematic of the EFHWA coupler is shown in Figure 4, and a picture of the completed unit is in Figure 6. The toroid is wound in specific a way that trades off leakage inductance and winding capacitance as to allow the end fed antenna to be matched. The steps for the winding are shown in Figure 5. There are five separate windings, colored red, blue, gray, green, and yellow. The colors of the wires do not matter for operation, of course, but are shown to distinguish the various windings. In all of these steps, when wrapping a wire around the toroid, feed the first wind under the toroid to ensure all turns wind the same direction around the toroid.

Step 1: Wrap the green wire around the toroid seven times, feeding the first wind under the toroid.
Step 2: Wrap the yellow wire around the toroid seven times, feeding the first wind under the toroid.
Step 3: Wrap the blue wire around the toroid three times, feeding the first wind under the toroid.

Step 4: Wrap the gray wire around the toroid four times between the blue and yellow coils, feeding the first wind under the toroid.

Step 5: Wrap the red wire around the toroid three times, starting at a point between the yellow and blue coils. Feed the red wire underneath the toroid and bring it above the toroid between the gray and green coils. Feed the red wire underneath the toroid and bring it above the toroid between the green and yellow coils. Finally bring the red wire back to the beginning of the blue coil.

Step 6:

a. Take the end of the red coil above the toroid and the end of the blue wire coming from beneath the toroid, strip the insulation from both of the ends to a distance within a few millimeters from the toroid, and twist the wires together.
b. Take the end of the blue coil above the toroid and the end of the gray coil below the toroid, strip the insulation from both ends to a distance within a few millimeters from the toroid, and twist those wires together as well.
c. Take the gray coil end from above the toroid and the end of the green coil from below the toroid, and strip the insulation from both; however, leave about 7-10 mm of the insulation away from the toroid. Twist them together so that they bridge the red wire between them. Make sure there is a gap of a few millimeters between the red wire and the gray and green wires.
d. Take the green coil end from below the toroid and the yellow coil end from above the toroid and again strip the insulation from both but leave 7-10 mm of the insulation away from the toroid. Twist the two wires together bridging over the red wire between the green and yellow coils. Make sure there is a gap of a few millimeters at least between the red wire and the gray and green wires.

Step 7: Solder together the twisted wire pairs. If available, use miniature zip-ties to tie the red wire down close to the core so that it does not twist up and touch any other wire except the blue wire it is soldered to. Also tie the free end of the red wire and yellow wire to the core so that the winding does not unravel. It is most important to ensure that the red wire does not touch any other wire.

After you have completed the transformer, you can solder wires to the taps as marked in the figure. The connections for the tap wires are as follows. The counterpoise, shield of the coaxial connector, and the rotor of the capacitor should be connected to the ground tap of the transformer which is the free red wire. The center of the coaxial connector should be connected to the primary tap which is the blue and red wire twisted together. The two throws on the capacitor tap selector switch are connected to the tap which is the blue and gray wire twisted together, and the tap which is the gray and green wire twisted together. The two throws on the antenna tap switch are connected to the yellow and green wire twisted together, and the free yellow wire.

An insulating knob should be placed on the variable capacitor to prevent you from being stung by RF energy. When you are done, spread the wires out to be more evenly spaced around the core, keeping a minimum of two millimeters between adjacent wires if possible. It is most important to ensure that the red wire does not come in contact with any other wires.

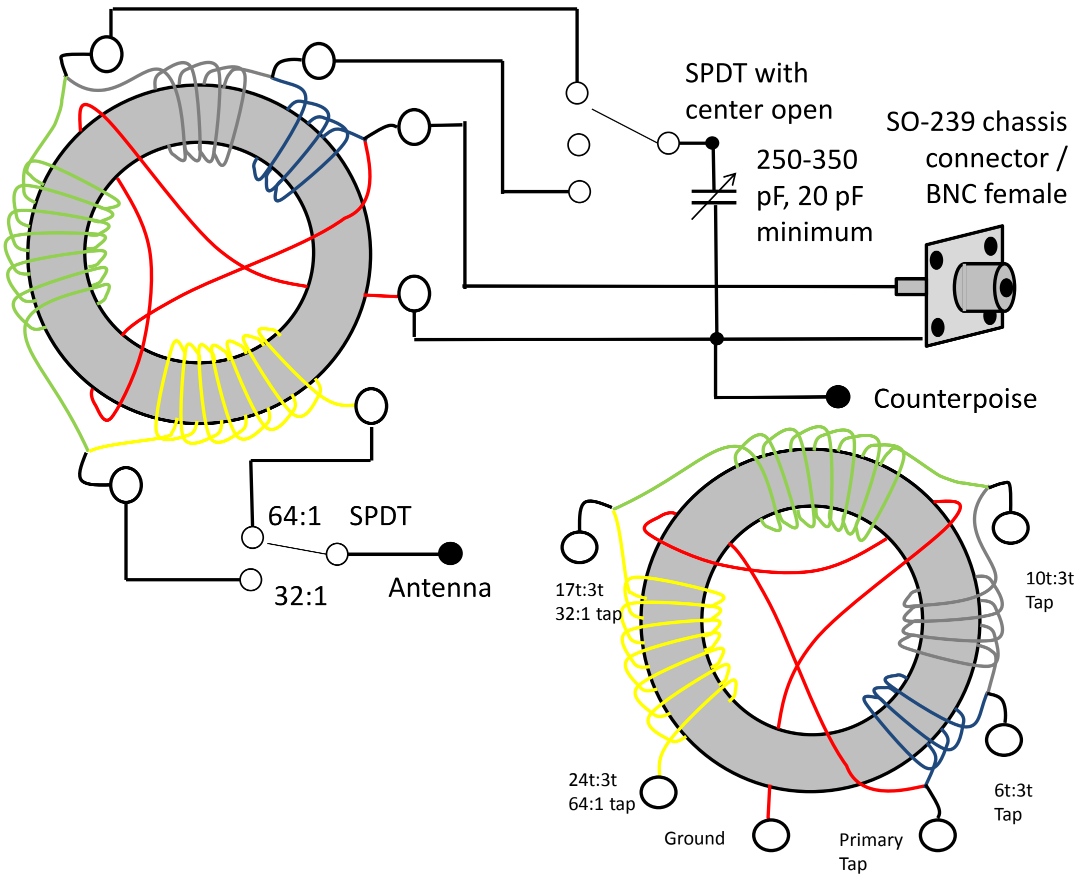
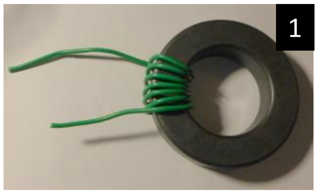
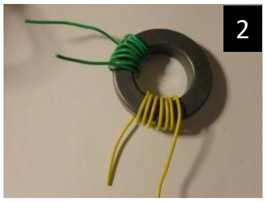
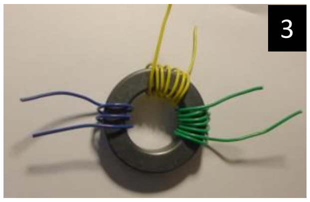
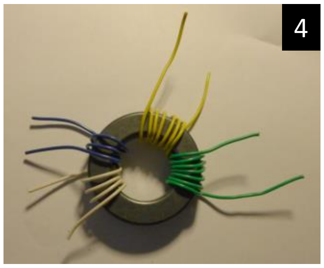


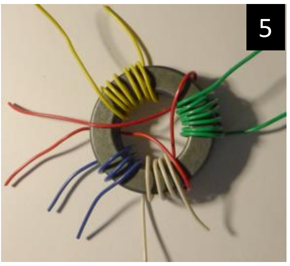
Figure 4. Schematic for an EFHWA coupler.

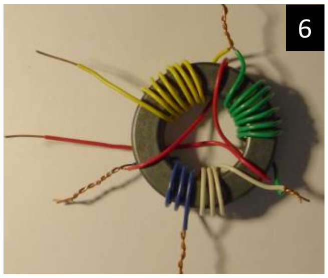












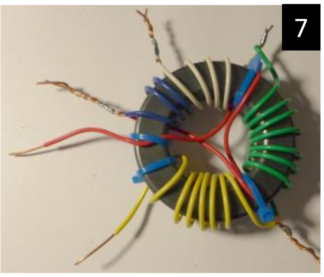


Figure 5. Steps for winding the toroid. This winding method is a compromise between separated primary and secondary windings with high leakage inductance and closely spaced windings, with high winding capacitance.

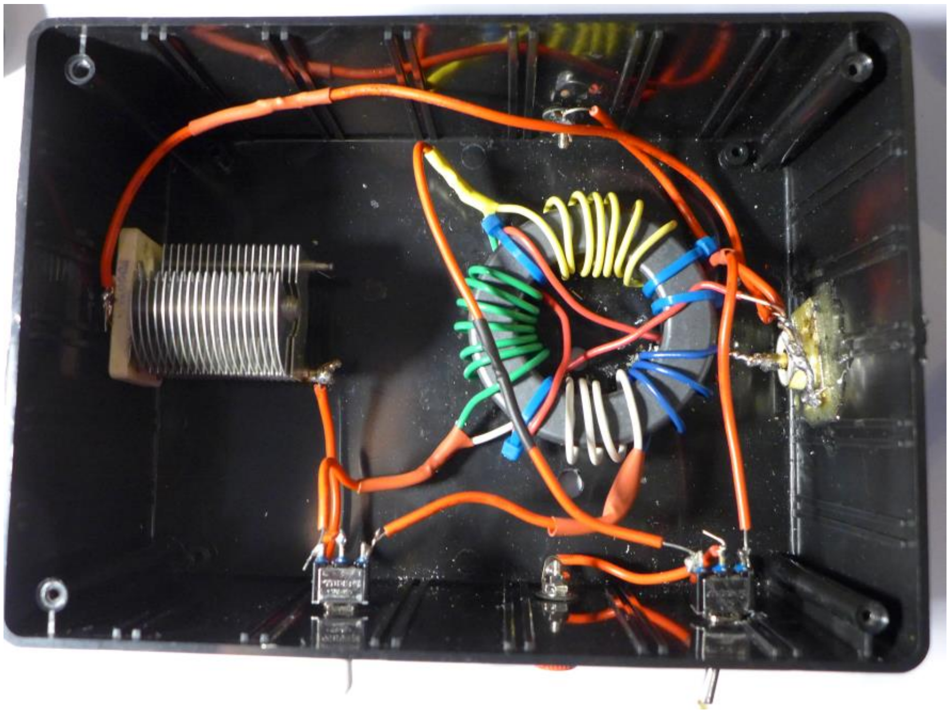


Figure 6. The completed EFHWA coupler. The left switch selects the 36:1 or 64:1 impedance transformation ratio, and the right switch selects the tap for the variable capacitor.

A LCR component tester can be used for a simple check of the coupler. The inductance measured at the coaxial connector should be about 8 to 10 μH depending on the variable capacitor at a test frequency of 100 kHz. With the antenna tap switch in the 32:1 position, the inductance should be between 250 and 300 μH, and in the 64:1 position between 500 and 600 μH.

The instructions here are to make a 40/20/15/10 m EFHWA, but the instructions can be adapted similarly to antennas for other bands, assuming space is available for the antenna. To calibrate the antenna, an antenna or network analyzer would be ideal, but a transceiver may be used with caution as long as QRP power levels (10 watts or less) are used, and power is applied no longer than necessary to measure the SWR, and the finals transistors are allowed to cool down periodically. Cut two wires, an antenna wire about 66 feet long and a counterpoise wire about 15 feet long, and strip the ends of the wires. Tie the end of the antenna wire through the plumbing tee, inserting it first into the bottom of the tee and looping around the arms and back through the bottom, so that when the tee is thrown it pulls the antenna wire straight and the tee does not tumble. Throw the weight high into a tree, preferably 20 feet off the ground or more, so that the antenna wire is well off the ground. Connect the antenna and counterpoise wires to the two terminals. The two wires should be pointed in opposite directions if possible, and away from metallic objects.

Set the transceiver to 5 to 10 watts power, enough to get a reliable SWR measurement but not damage the transceiver if excess power is reflected. This amount of power is commonly used by transceivers already for automatic antenna tuners, so transceivers are designed to handle a high SWR briefly at this power. Use a mode that produces constant power such as CW, FM, or RTTY mode. SSB mode cannot be used as it only produces a signal when audio is being transmitted. Set the frequency to near the lowest frequency that the antenna will be used for, for example, around 7.0 MHz for the 40 m band. Double check to make sure the power is low, set the transceiver to measure SWR, and briefly press the transmit button long enough to test the SWR. At first, the SWR is probably very high. Start with the 64:1 tap setting. Rotate the variable capacitor to minimize the SWR. If adding any amount of capacitance, which occurs when the plates of the capacitor are increasingly overlapped, makes the SWR worse and not better, the antenna is too long and the antenna impedance is capacitive. Therefore trim a foot or so of wire from the antenna and try again. The antenna should transition from being capacitive to inductive after being reduced in length through its resonance point, and therefore increasing the capacitance should improve the SWR. Keep trimming the antenna, adjusting the capacitance, and optimizing the SWR until the SWR drops below 1.5:1 around 7 MHz. Then test the SWR throughout the 40 m band to see if the SWR may also be adjusted below 1.5:1 throughout the band. If 1.5:1 can not be achieved, keep trimming but more slowly, perhaps removing 6 inches at a time. If the tap switch or capacitor do not seem to have an effect, inspect the connections for a broken wire or cold solder joint. If the SWR is still somewhat high (2:1) after optimization, the counterpoise length may need to be adjusted as well.

Once you have found the correct length on the antenna on the 40 m band, the harmonic bands 20, 15, and 10 m can be tried. A picture of the antenna is in Figure 6, showing the plumbing tee tied on the end as a throw weight. The variable capacitor must be retuned for each band, with progressively less capacitance required as frequency increases, and the antenna tap switch may need to be toggled. The variable capacitor tap switch in general should be at the higher tap position (10t:3t) for the lower bands where more capacitance is needed and the lower tap position (6t:3t) for the higher bands where less capacitance is needed. The center position which disconnects the variable capacitor may be used if the lowest achievable capacitance is still too high, which may occur at the upper bands.

Using 22 gauge copper stranded PVC insulated wire, I found that an antenna length of 63 feet and a counterpoise length of 14 feet was able to be matched on all four bands, 40, 20, 15 and 10 m. The counterpoise length is almost a quarter wavelength at 20 m, making it into an efficient ground for that band. As the counterpoise is lying on the ground but is still part of the antenna, it is not efficiently radiating energy into the air, and therefore it is desirable to have as little current flowing in the counterpoise as possible. A long antenna and short counterpoise is more efficient as the impedance of the antenna increases, but tends to be harder to match on several bands. Increasing the length of the counterpoise decreases the antenna impedance and reduces the efficiency, but feeds the antenna at a point more suitable for multiple bands. It is also possible the counterpoise may resonate at a high impedance in a particular band and therefore may need to be adjusted in length to operate at a band. The end of the counterpoise may be coiled to effectively shorten it if needed. If you would rather have a single, more efficient antenna on a single band, the counterpoise should be short; perhaps only 3 or 4 feet long, and the remainder of the half wave should be the antenna. Example SWR plots for the antenna are at the end of this document.

When feeding a dipole near the end, it is likely that the currents in the feeder line may become unbalanced, which may result in RF energy on the chassis and microphone of the transceiver. A common mode choke is used to block these currents, which is often a coaxial cable wrapped around a ferrite toroid. A convenient short coaxial cable for portable use may be built from thin RG174 or RG316 coax as shown in Figure 7, with a small toroid incorporated into the coaxial cable as shown. The type of ferrite is not critical, but generally is a type 31 or 43 mix ferrite. Grommets were epoxied into the PL-259 connectors to hold the coax firmly.

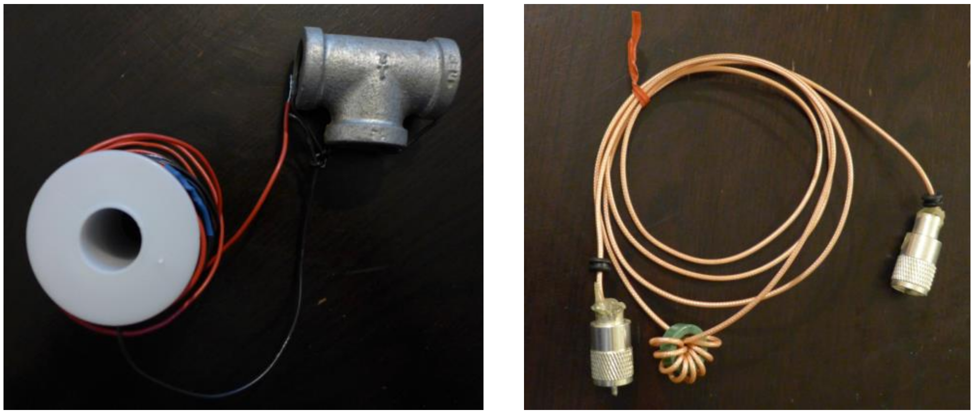
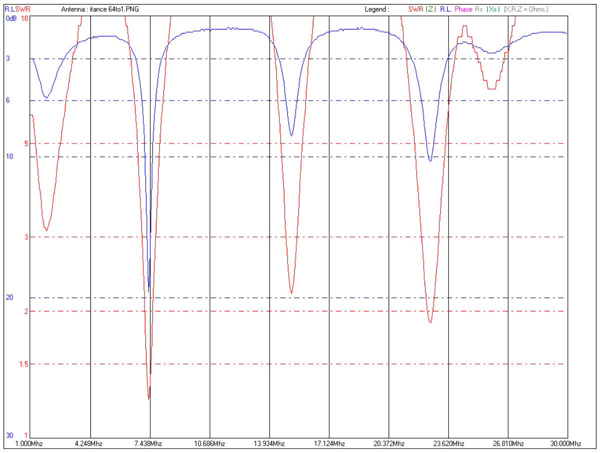


Figure 7. Left: coiled 40/20/15/10 m antenna with a plumbing tee tied on the end as a throw weight. Right: RG-316 coaxial cable with PL-259 ends, with the coaxial cable coiled inside a ferrite toroid as a common-mode choke.

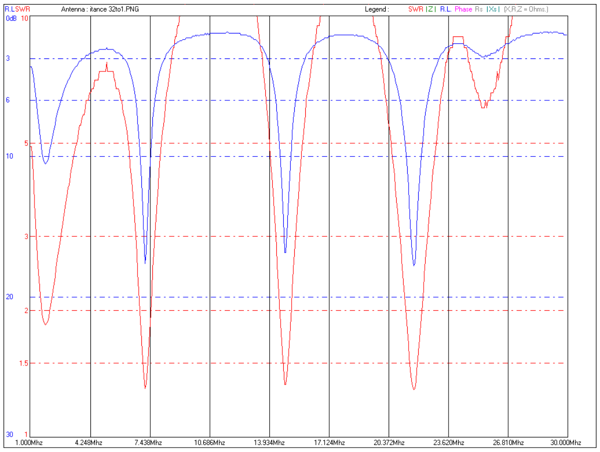
Amateur radio is unique in that it is a great opportunity to understand science and physics better, visit and activate unusual and faraway places, and talk to people all over the world virtually anywhere. The EFHWA is both immensely useful and an important part of radio history. Building one is not hard and is a great opportunity to understand antennas better, and you will have a versatile antenna at your disposal. And you will be able to brag on the airwaves that you are talking over an antenna you built yourself.

Following are SWR curves, transformer through measurements, and tests of the leakage inductance and winding capacitance to demonstrate the end-fed half-wave coupler performance.

SWR measurements of the transformer with 63 ft wire

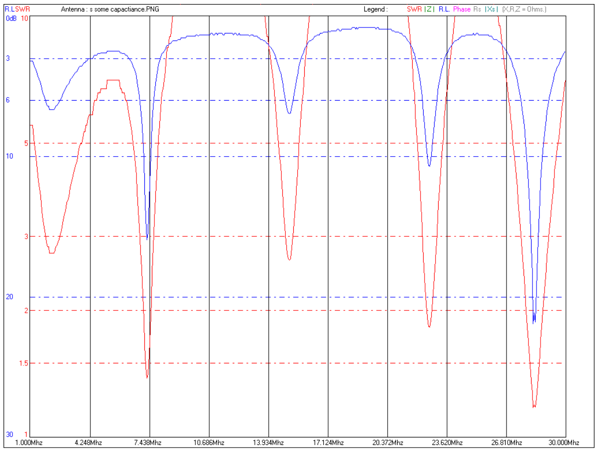


64:1 tap, no added capacitance

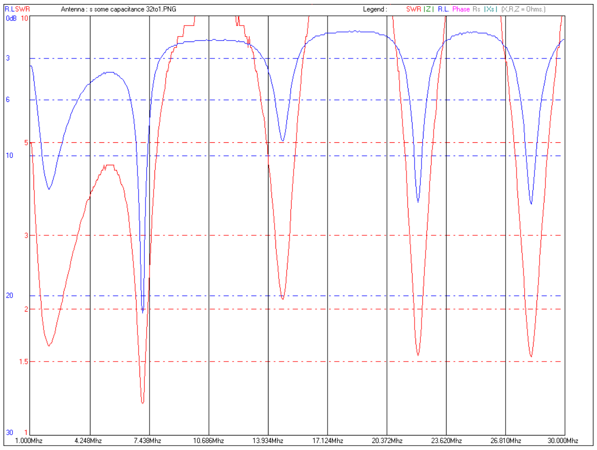


32:1 tap, no added capacitance

This is the SWR of the antenna without any added capacitance. Without added capacitance, the resonance frequencies of the antenna are high, and so added capacitance is required to bring the antenna into resonance at the desired band. As the SWR is high at the frequencies at which the antenna is not at resonance, this suggests that the shunt resistance of the transformer is not dissipating significant power and that the transformer is wound for sufficiently low leakage inductance even at high frequencies. It also suggests that the winding capacitance of the transformer is not that high, as capacitance must be added to bring the antenna into resonance on the desired band.

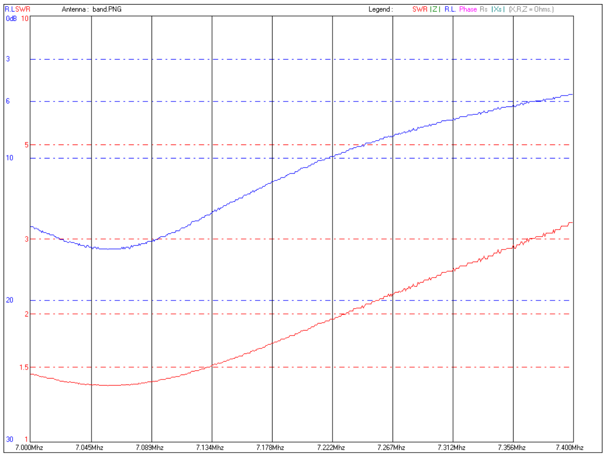


64:1 tap, with added capacitance

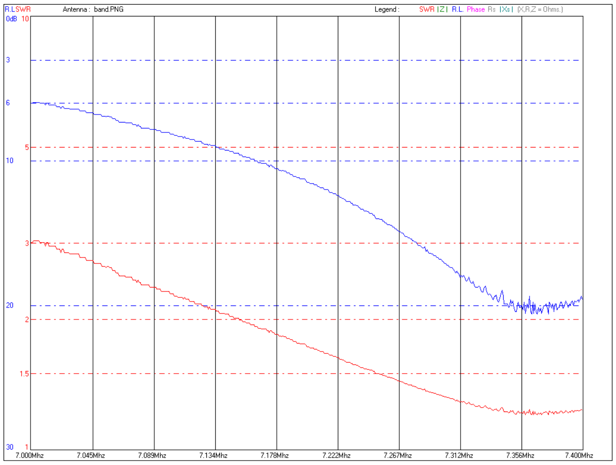


32:1 tap, with added capacitance

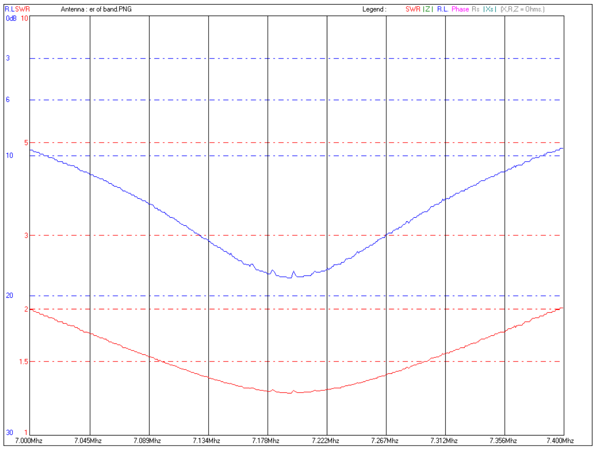
Loading the antenna with capacitance brings the bands roughly into their correct resonance frequencies, with the 15 m band being at a slightly high frequency at this setting.



64:1 tap, 40 m band tuned to low frequencies

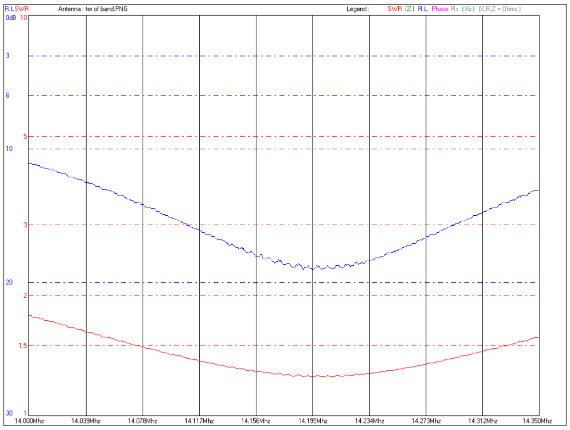


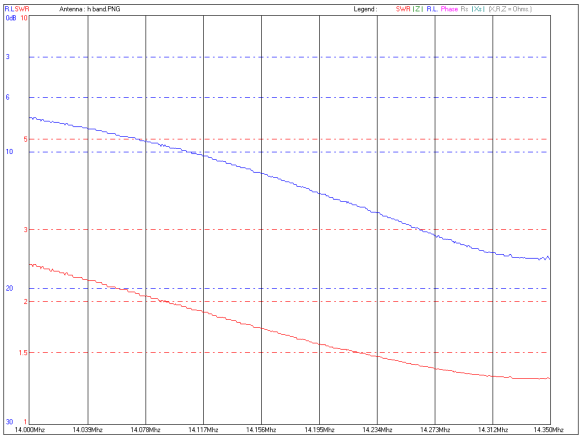
64:1 tap, 40 m band tuned to high frequencies



64:1 tap, 40 m band tuned to center frequencies

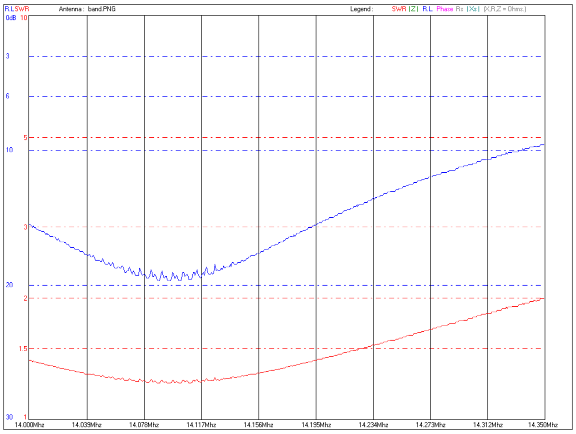
This shows the matching unit tuned to the 40 m band, with the minimum SWR tunable to about 1.25:1.

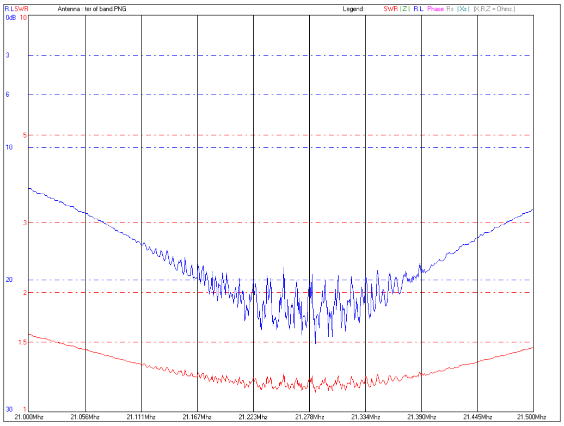




64:1 tap, 20 m band

64:1 tap, 20 m band

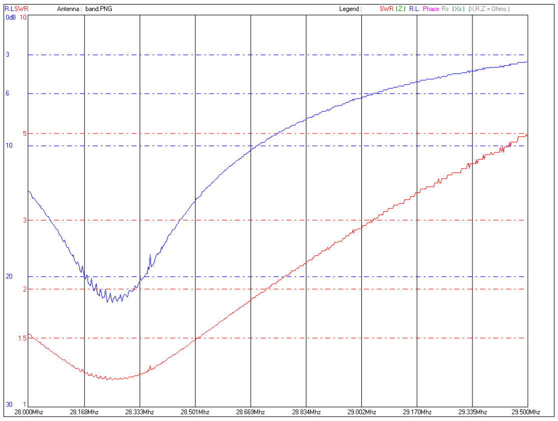




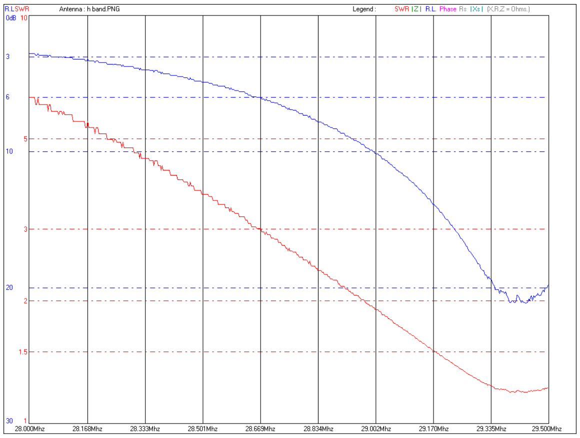
64:1 tap, 20 m band

64:1 tap 15 m band

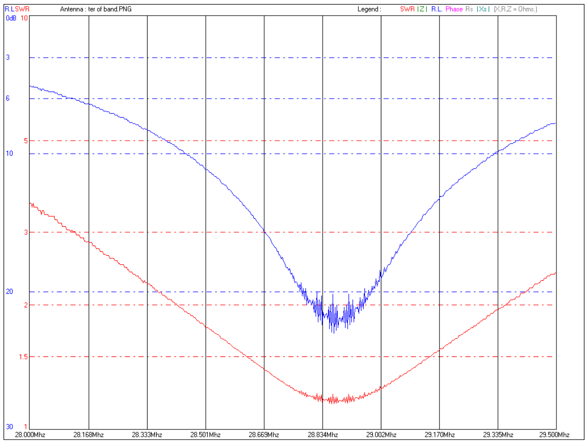
The 20m band and the 15 m band can be tuned to about 1.3:1 SWR using the 64:1 tap.



32:1 tap, 10 m band tuned to low frequencies



32:1 tap, 10 m band tuned to high frequencies

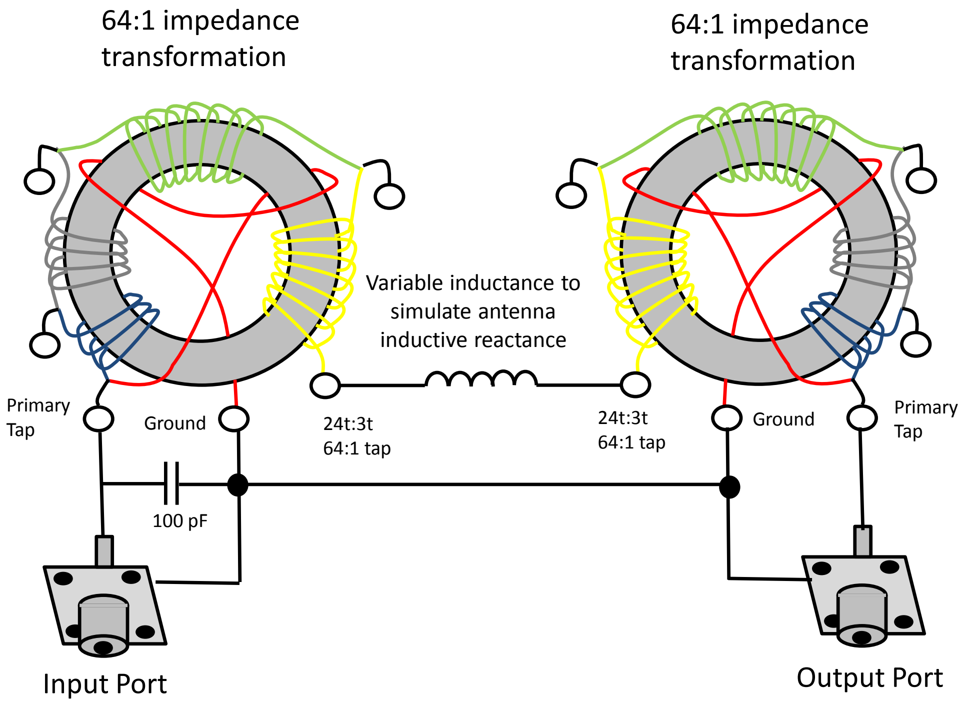


32:1 tap, 10 m band tuned to center frequencies

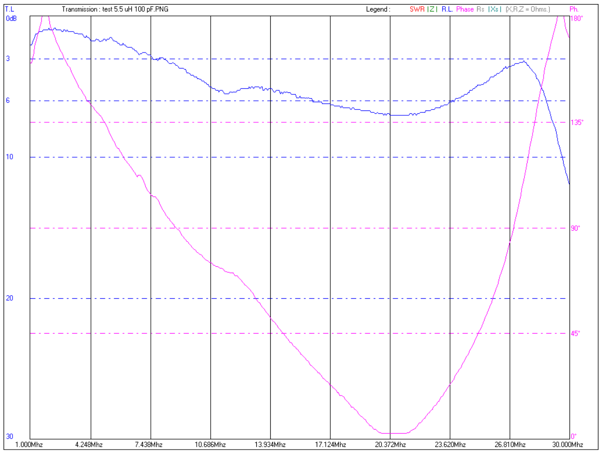
The 10 m band can be tuned to about 1.3:1 SWR throughout the band using the 32:1 tap. The capacitance control is VERY touchy, and the amount of capacitance required to change the tuning is very small at this high frequency. The counterpoise becomes somewhat more crucial as well because of the lower tap used.

Transmission of two transformers

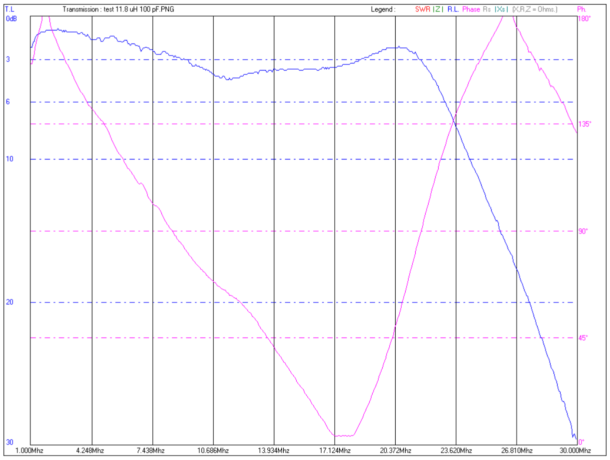
This test is a test of the transmission loss of two transformers placed back-to-back. As the transformers are designed with winding capacitance, the antenna is required to have inductive reactance to compensate for the winding capacitance. An inductor is placed between the two transformers as to simulate the inductance of the antenna. The transmission through the pair of transformers is given in the following diagrams, with the measured inductance of the coil placed between the two transformers for each measured transmission frequency response. In practice, it is not necessary to add the inductance to the antenna; the antenna itself has the inductive reactance needed to resonate the transformer when the antenna is shortened slightly below the frequency for which it has no inductance.



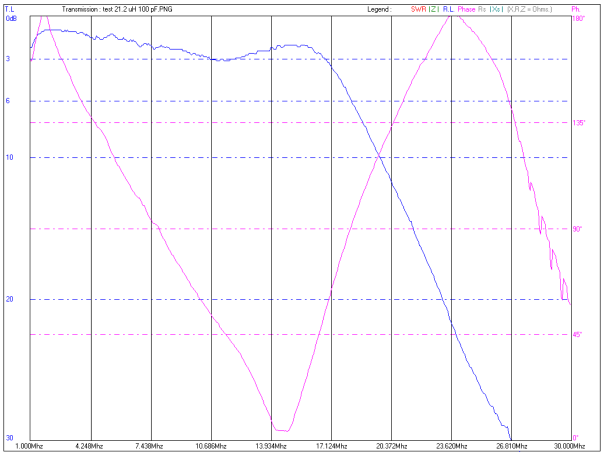
The setup used for the measurements, showing the two identically wound transformers and a coil between the two tapped for various inductances.



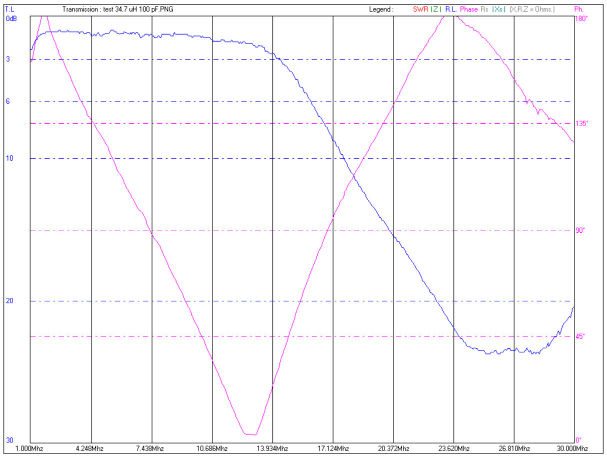
Transmission with 5.5 μH added inductance,
100 pF in parallel across primary winding
Resonance in the 10 m band, approximately
1.5 dB loss per transformer



Transmission with 11.8 μH added inductance
100 pF in parallel across primary winding
Resonance in the 15 m band, approximately
1 dB loss per transformer

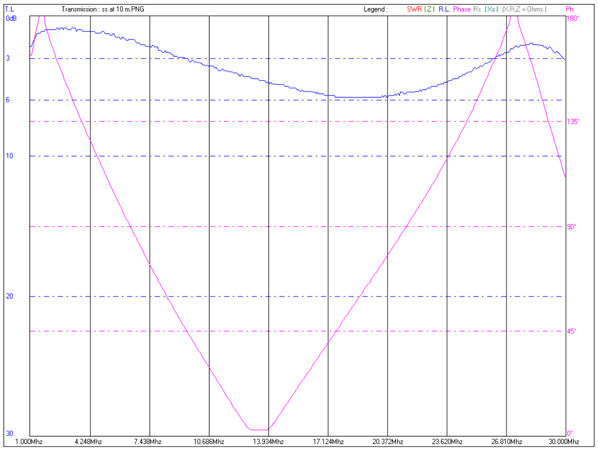


Transmission with 21.2 μH added inductance
100 pF in parallel across primary winding
Resonance in the 20 m band, 1 dB loss per
transformer

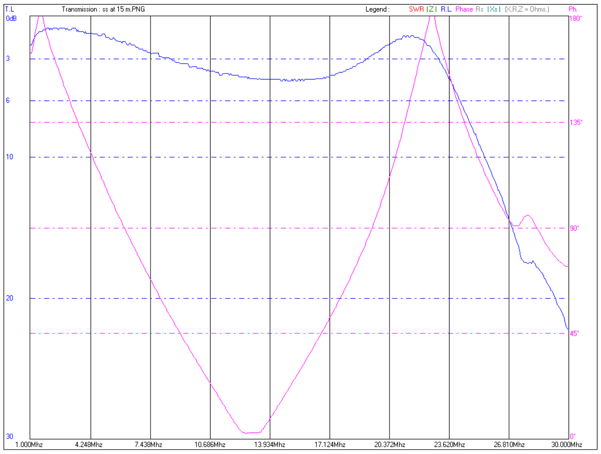


Transmission with 34.5 μH added inductance
100 pF in parallel across primary winding

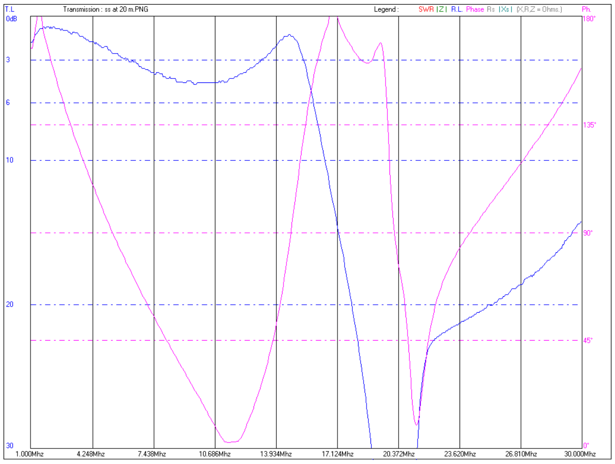
The inductor in the previous measurements was found to have a low Q when tapped for low inductances because the shorted turns were causing loss. Therefore a new inductor of 2.9 μH was wound and was placed between the two secondaries. Variable capacitors were used on both transformers rather than a fixed 100 pF capacitance on one transformer.



Resonance in the 10 m band, approximately 1 dB loss in the 10 m band, 1 dB loss in the 40 m band



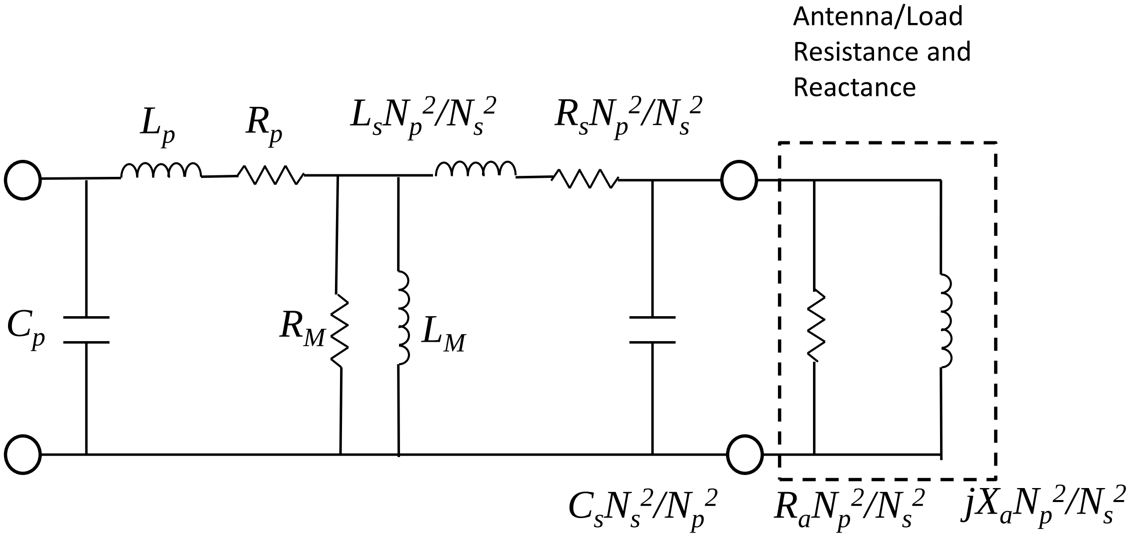
Resonance in the 15 m band, approximately 0.75 dB loss



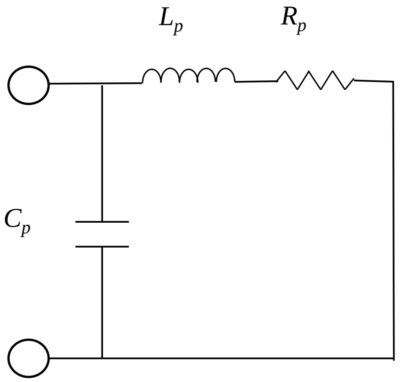
Resonance in the 20 m band, approximately 0.75 dB loss

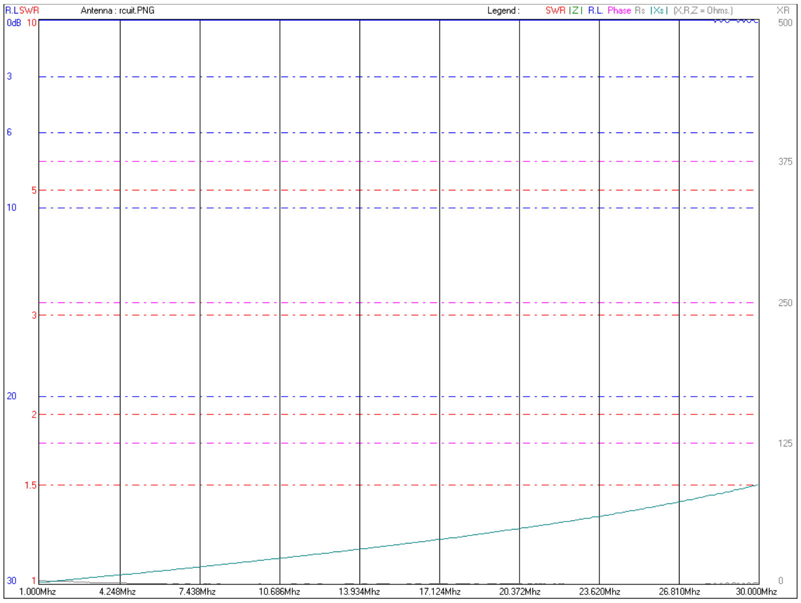
Open/Short/Inductive Load Test of Transformer

This test determines the effect of the secondary winding capacitance C_s on the performance of the transformer using an open, short, and inductive load. C_p is the capacitance of the primary windings, and is generally low because of the low number of primary windings. C_p is the capacitance of the secondary windings is in the range of 3-8 pF typically for this transformer type. L_p is the inductance of the primary winding due to leakage inductance, and R_p is the resistive loss in the ferrite due to leakage inductance in the primary winding. Likewise, L_s and R_s are the inductance and resistive ferrite loss for the secondary winding. The shunt resistance and reactance of the core is modeled by L_M and R_M. The load is modeled by its equivalent parallel resistance R_a and reactance X_a.



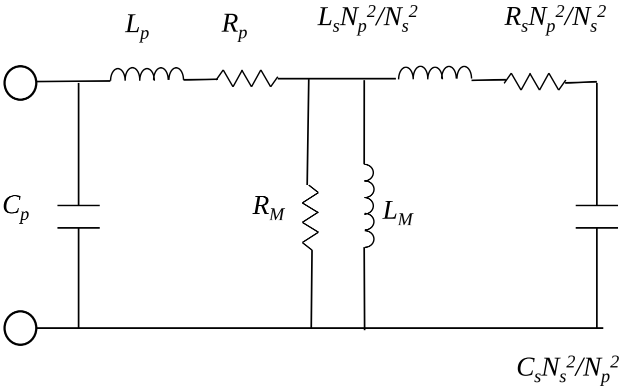
Short circuit test. For the short circuit test, the equivalent circuit is

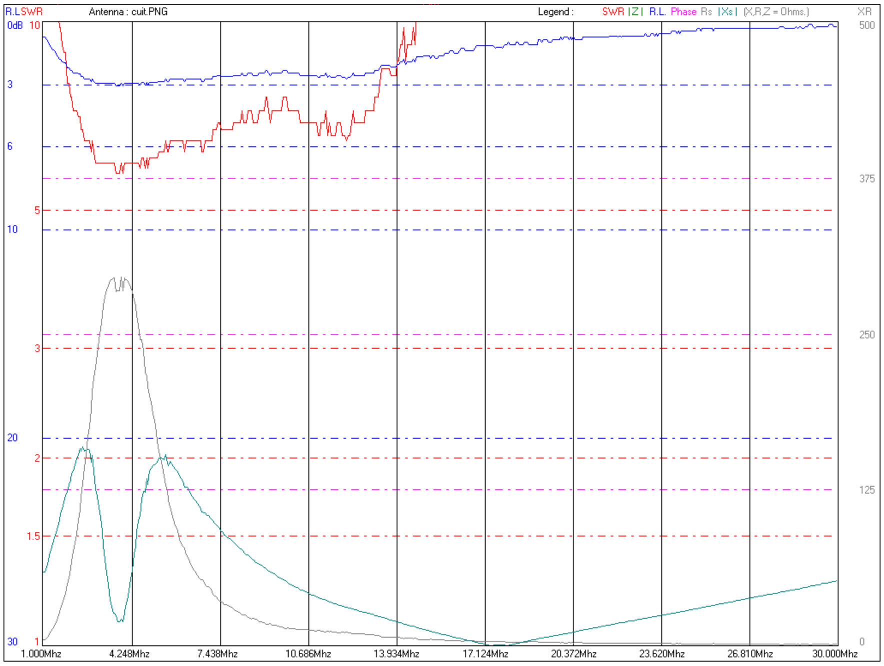




After shorting out the secondary winding, all that remains is the inductance of the primary winding. There is a resonance with the secondary winding capacitance, but it occurs at too high of a frequency to occur in the HF band. The leakage inductance is approximately 0.3 μH.

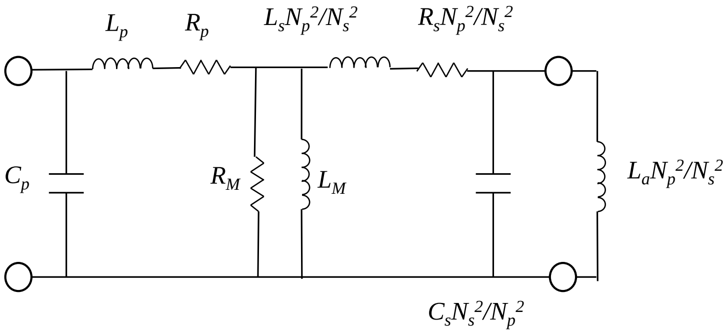
Open circuit test. For the open circuit test, the equivalent circuit is

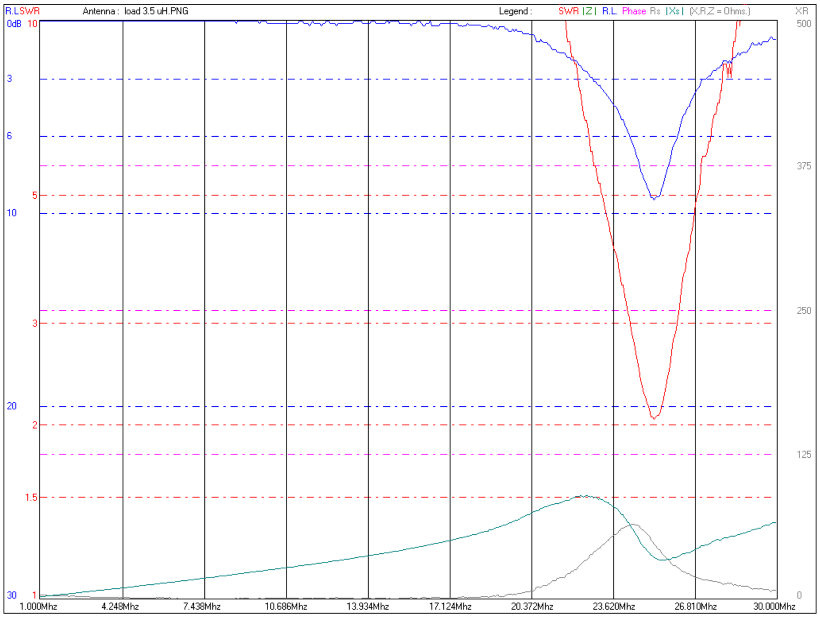




At low frequencies, the impedance of the primary winding dominates. The drop of the impedance to zero around 17 MHz is the series resonance of the secondary winding capacitance and the secondary winding inductance. This indicates a secondary winding capacitance of approximately 2 pF.

Test with inductive load. To test to see what the effect of an inductive load is, a 3.5 μH inductor was placed at the antenna terminals:





The inductor parallel resonates the secondary winding capacitance at 24.5 MHz, and so the secondary winding capacitance is an open circuit. The main load is then the shunt resistance of the core. The inductor is being used to match the high shunt resistance of the core as a nearly 50 Ω load after transformation. The inductance of the load was selected so that the transformed shunt resistance would match, but in general a given inductance does not efficiently transform the shunt resistance to a matching load. The resonance is very sharp due to the high Q parallel resonance needed to match the high shunt resistance. In practice, the parallel resistance of the antenna R_a is much less than the shunt resistance R_M. Therefore the power is dissipated in the antenna mostly rather than in the core.

However, this test shows that a transformer matching a high impedance may easily match its own shunt resistance and therefore efficiently absorb the power if the load resistance is too high.