# EH ANTENNA FOR HAMS

## INCLUDES THE BACKPACKER AS AN EXAMPLE

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## INTRODUCTION:

Ham Radio has been a birthplace for and nurtured many important inventions and discoveries. I have contributed some of those and benefited from others over the last 56 years that I have held the call W5QJR. Although I have previously presented new concepts to Hams (including the Antenna Noise Bridge in 1967 and the Small High Efficiency Loop Antenna in 1984), I now have the privilege and opportunity to present one more, one that will benefit every Ham.

I have invented and patented a new antenna concept called the EH Antenna. Note that it is a concept, rather than a particular antenna, and is therefore applicable to all antennas. What will it do for Hams? It will allow reduction in the size of the antenna, increase the efficiency, increase the instantaneous bandwidth, reduce receiver noise, and virtually eliminate EMI. Maybe not all of those virtues are important to you, the reader, but the one that is important justifies using an antenna that has most or all of those features.

Sound too good to be true? That is what many have said until they actually used an EH antenna. Yes, you can buy one from the factory in Italy or Japan, but more importantly, you can build your own with very little expense in time or money. We will include details in this article. In addition to being able to construct an EH Antenna, this is a new area for experimentation that can be enjoyed by all Hams. Now you can conveniently build and test an antenna for frequencies as low as 7 MHz in the Ham shack.

## THE CONCEPT:

All antennas to date (except the CFA) are based on the Hertz concept of resonant wires. Unfortunately, Hertz antennas have very large E (electric) and H (magnetic) fields near the antenna and do not create Poynting Vector radiation until the fields have traveled about 1/3 wavelength from the antenna. This is known as the boundary between the near and far field of the antenna. The EH Antenna creates the Poynting Vector radiation at the antenna, thus it essentially moves the far field to the antenna. This effectively reduces the size of the E and H fields to the physical sphere of the antenna. Since the E and H fields have been reduced in magnitude, EMI has been virtually eliminated. When used for receiving, the EH Antenna allows transformation of radiated energy to the receiver terminals, but does not allow local E or H fields to be transformed, thus "noise" is eliminated. We need to examine each of the virtues of this new concept to allow the reader to understand and be able to apply this new concept to the reader's antenna farm.

## ANTENNA SIZE:

A small antenna will radiate as well as a large antenna – if you can feed it properly. When a wire antenna element (2 elements make a dipole or 1 element against ground makes a ground plane antenna) approaches ¼ wavelength, it becomes self resonant, meaning that the value of self capacity equals the inductance of the antenna. As the wire becomes very short compared to the wavelength at the operating frequency, there is very little inductance and very little capacity. Thus, a large external loading coil is needed to restore resonance. Unfortunately, as the size of a wire antenna is reduced, so also is the radiation resistance reduced. The loading coil has loss resistance and that resistance can be much larger than the radiation resistance, thus the overall efficiency of the antenna becomes very low. For example, a 75 meter mobile antenna with a large center loading coil is less than 3% efficient. If the capacity of a short antenna is increased by making the antenna diameter large, the necessary loading coil inductance is reduced, thus the efficiency increases. However, since the radiation resistance remains low, the efficiency has been increased but remains low.

Now, if we could increase the radiation resistance of a small antenna, we could have our cake and eat it too! Fortunately, we can convert any antenna to an EH Antenna, allowing the element length to be short, yet the antenna system can now have high efficiency. How can we convert to an EH Antenna? We will present that information later, after we have discussed the other virtues.

## INSTANTANEOUS BANDWIDTH:

Short loaded antennas and small loops are noted for their narrow bandwidth. Bandwidth is related to the ratio of the tuning inductance (loading coil) to the resistance of the antenna system (the sum of loss resistance and radiation resistance, including the loss resistance in the coil). We have already explained that the loading coil can be significantly reduced if the natural capacity of the antenna is increased. Thus, by reducing the necessary tuning inductance and increasing the radiation resistance, we can have a wide band antenna, commonly referred to as a low Q antenna. In this case Q is not quality factor, but simply the ratio of the operating frequency to the instantaneous bandwidth, and also the ratio of the inductive reactance of the tuning coil to the resistance of the antenna. In this case, low Q is good. There are special cases where resistive loading is incorporated to lower the Q (increase the bandwidth) while sacrificing efficiency. We do not want to settle for less than both low Q and high efficiency.

## NOISE:

When an antenna is used for reception, we would prefer not to hear the noise generated by motors, power line leakage, or other forms of E or H field noise, including that from lightning strikes. This type of noise is not radiated noise, but rather the presence of a local E or H field. When a wire antenna is in the presence of an E or H field, the wire will develop a current that is fed to the receiver as noise. In the case of an EH Antenna, only radiated signals will be converted to energy applied to the receiver. Again, this will become obvious later. By the way, there are three components from lightning, a radiated field and large E and H fields. The EH Antenna can only reject the E and H fields. The radiated field occurs primarily at very low frequencies, with large harmonics. If the E or H fields are exceptionally strong, they will produce much less noise than a conventional antenna, but they can still overload the receiver.

## EMI:

Either an E or H field, not a radiated signal, normally causes electromagnetic interference (EMI). This is a similar action to the noise discussed above. However, in this context we are discussing “noise” radiated from the antenna. In the case of a Hertz antenna, the E and H fields are very large to allow combining the fields to create Poynting Vector radiation at a large distance from the antenna. The E and H fields of the EH Antenna are contained within the sphere of the antenna, since the radiated field is created at the antenna. The small fields virtually eliminate EMI. The small EH Antennas have an additional feature – since the phasing is correct only over a relatively narrow frequency range, these antennas virtually eliminate harmonics.

## IMPLEMENTING THE EH ANTENNA CONCEPT:

By now you are saying WOW, was this written on April 1 as a joke? How can we improve on Hertz antennas that have been around for 120 years? Simply by aligning the E and H fields of the antenna to be in time phase, the Poynting Vector radiation occurs at the antenna, not at some far field distance. And how do we do this? Simply by adding the appropriate amount of phase shift between the source and the antenna. Actually, once the antenna has been brought to resonance, we need only add a phase delay of 90 degrees. There are many ways to do this, but I have a favorite I will share with you. In fact, I use a simple network that provides both the appropriate delay and also provides the proper impedance matching.

## E AND H FIELDS OF AN ANTENNA:

You need to understand the E and H fields of an antenna before going into the circuit details of the network. Figure 1 depicts a short fat dipole. However, a wire dipole would have similar electric (E) and magnetic (H) fields. It is important to note that the E field lines (only a few are shown) must leave or enter the surface at right angles to the surface and are circular between surfaces. The E field lines are shown in red and only a cross section is depicted. H field lines are orthogonal and surround the E field lines.

Note that there are two (2) H fields shown in Figure 1. These are explained in detail in the theory section of this web site.

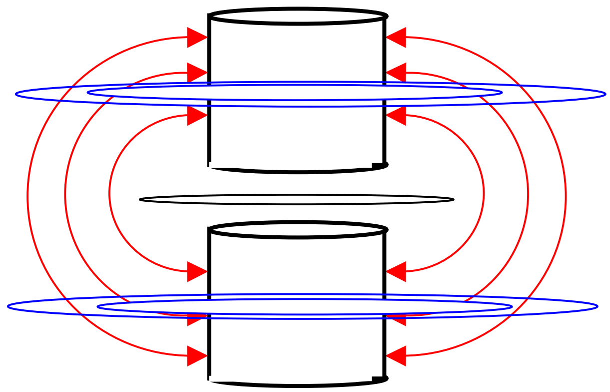


**FIGURE 1 - E AND H FIELDS OF AN EH ANTENNA**

Since the magnitude of the fields increase and decrease at the rate set by the operating frequency, we can depict their amplitude variation as sine waves as shown in Figure 2. Note that the H field lines are ahead of the E field lines in time phase by 90 degrees. The applied voltage between the two elements of the antenna creates the E field lines. The H field lines are a result of differential voltage across each cylinder. That voltage creates high current on the cylinder, which in turn creates the H field. Since current is a result of applied voltage, the current is now effectively leading the voltage in time phase. To create an EH antenna, it is only necessary to delay the current (thus the H field) relative to the voltage with a simple network between the feed line and the antenna.

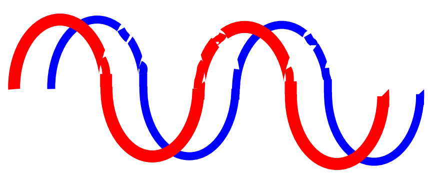


**FIGURE 2 – RELATIVE PHASE OF THE E AND H FIELDS**

By delaying the phase of the H field 90 degrees, the two fields are then in phase and radiation is created. Some persons prefer to think of this as power factor correction, where maximum power is radiated when the fields are in phase. Nature effectively does this at a distance (in the far field) from the Hertz antenna. This has been referred to as a happy accident of Nature. The independent E and H fields are considered to be reactive fields because they do not radiate power. On each half cycle the fields build up then collapse back on the antenna. If the large magnetic field encounters a ferrous object, for example a chain link fence, eddy currents will be induced on the fence creating heat. That wasted power prevents some of the H field from returning to the antenna, thus the overall efficiency of the antenna is reduced. The E field can also be affected by items in the field. An obvious example is my favorite antenna test equipment, a fluorescent tube. Another example is the variation of radiation resistance as a function of height for a horizontal dipole. Conversely, when a EH Antenna is raised above ground there is some affect on tuning only at low heights, but the radiation resistance does not change significantly because of the small E and H fields.

It is very important to note that the radiation resistance of a EH Antenna is a function of the phasing described above. For a Hertz antenna, the current and voltage applied to the antenna are in phase, thus the E and H fields are 90 degrees out of phase. When the current is delayed relative to the voltage, to align the E and H fields in time phase, the radiation resistance increases as evidence of being an EH Antenna. Tests and calculations indicate a phase shift of about +/- 3 degrees from alignment is equivalent to a change from a VSWR of 1.0:1 to a VSWR of 2:1.

To effect radiation, the ratio between the E and H field must always be 377 ohms. By increasing the capacity, a larger H field can be developed relative to the applied voltage due to a reduction in the reactance of the antenna. For wire antennas, this occurs as the wire length increases. Many years ago an equation that was empirically derived was presented in QST to quantify this relationship. $R_R = 273(LF)^2$ x10-8 where L is length in inches and F is frequency in MHz. This applies only to a wire antenna used as a conventional Hertz antenna. It is interesting to calculate the radiation resistance of a Hertz antenna of a given size, then convert it to an EH Antenna and note the difference. One example – for a wire that is 13 inches in length at 14.2 MHz, $R_R$ = 0.12 ohms. For an 8 foot mobile whip on 75 meters, $R_R$ = 0.4 ohms.

It should now be obvious why we named this new concept the EH Antenna. Many have said the EH Antenna can not be true because it violates the laws of Physics. It is true that it does not obey the same laws as the Hertz antenna, because it is no longer constrained to be a simple resonant wire antenna. It was necessary to enhance Maxwell's equations to gain an understanding of the EH Antenna.

## A PREFERED PHASING NETWORK:

With an understanding of what to do, now we turn to - - how to do. Let us assume we have an antenna with a capacity of about 10 pFd and a radiation resistance of about 35 ohms operating on 20 meters. At 14 MHz the reactance of the capacity is 1137ohms. The phase angle of the antenna impedance is a leading 88.5 degrees. Please see Figure 3 – not drawn to scale. The leading phase angle must be compensated by adding a lagging phase angle of 88.5 degrees. In other words, add an amount of inductive reactance to equal the capacitive reactance. This antenna would then be defined as being resonant. To convert the antenna to a EH Antenna, we need to add an additional lagging phase angle of 90 degrees (to correct for the phase lead of displacement current), for a total of 178.5 degrees. Therefore, we can now say the impedance of the transmitter/receiver is 50 ohms and the antenna impedance is 35–j1137, and we need a phase delay of 178.5 degrees.

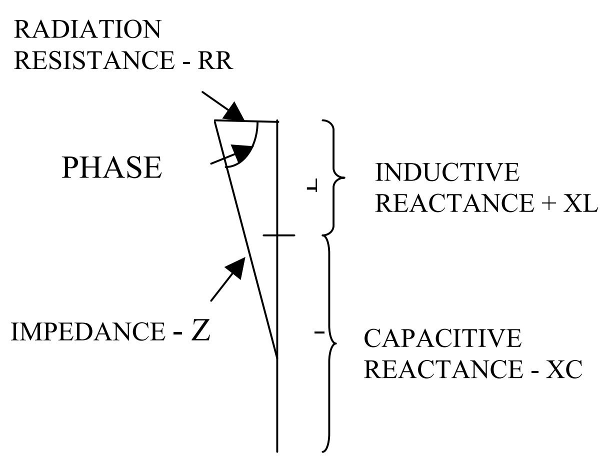



**FIGURE 3 – VECTOR DIAGRAM OF AN ANTENNA**

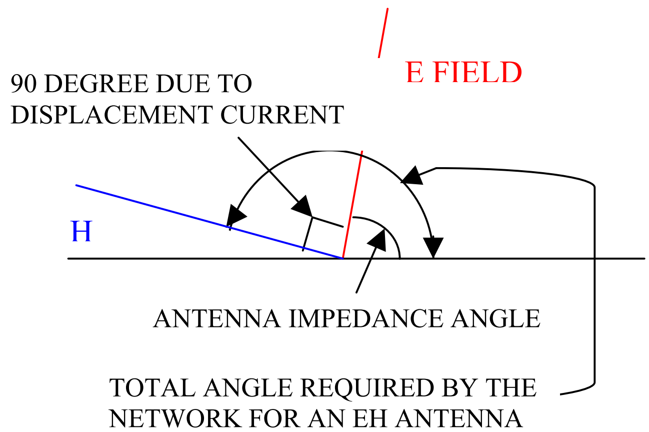



**FIGURE 4 – PHASING OF AN EH ANTENNA**

A network that will handily provide this transformation is composed of an L network followed by a T network. If we choose to allow the L network to transform from 50 to 25 ohms, there will be a corresponding phase delay of 45 degrees. Therefore, that amount of phase delay can be subtracted from 178.5 to give 133.5 degrees, the necessary design value for the T network. With that information, you can go to the web site of Dr. Grant Bingaman (www.qsl.net/km5kg) and it will readily allow you to use a program to determine the component values of the network. By the way, if you do any experimenting, this program is a must. A schematic of the network is shown in Figure 5. A T network is comprised of two coils and the L network has 1. We have combined the input coil of the T network with the L network coil, thus the overall network has been reduced to 2 coils. For most implementations, I use a single coil with taps, except I place part of L2 between the dipole elements. There are two (2) reasons for this. First, if the feed wires going to the dipole are phased properly to cause the antenna to radiate, there will be radiation from the feed wires. A few turns at the antenna will cause a phase difference in the feed wires and prevent radiation from them. Secondly, there is a concern of high voltage.

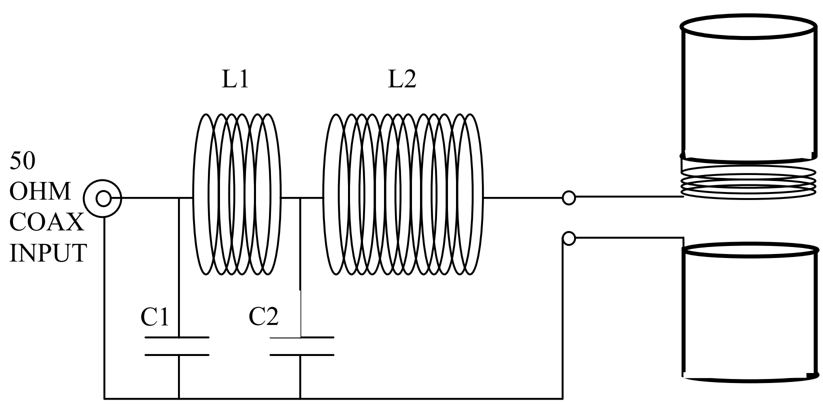



**FIGURE 5 – A PREFERRED NETWORK TO FEED AN EH ANTENNA**

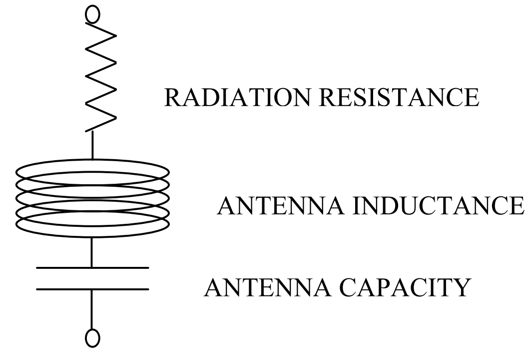



**FIGURE 6 – ANTENNA EQUIVALENT CIRCUIT**

The equivalent circuit of an antenna, as shown in Figure 6, has the following items in series;

1) radiation resistance
2) antenna inductance
3) Antenna capacity

The radiation resistance is self-explanatory. The antenna capacity is also obvious. Since we have a very small antenna, how can there be inductance? We have shown that large currents flow on the cylinders. Where there is a current, there is inductance. Maybe that is easier to understand if we say that current flowing on a wire creates an inductance. Note that it is not the wire, but rather the current that creates the inductance. The inductive reactance subtracts from the capacitive reactance, thus effectively creating a larger virtual capacitor. At 14 MHz the capacity increases by a factor of about 1.4.

The current through the antenna is calculated from the equation $P=I^2R_R$. The voltage across the antenna is calculated as the current times the impedance of the antenna, or $V=Ix\ (R_R+j(X_L-X_C))$. As you will see from the example 20 meter antenna, the current is high due to the small radiation resistance, and the small capacity results in high capacity reactance, thus the voltage is high. This is another reason the L+T network was chosen. The capacitors are low voltage, while the high voltage is developed across L2. The tradeoff requires the capacitors to have high current capability. The amount is specified in the Bingo program.

For those of you who do not have a technical background, please have someone in your Ham club explain all of this to you. It simply is not possible to explain this new concept without getting into this level of detail. Later we will present an example antenna you can duplicate without doing any math.

## VARIATIONS ON THE THEME:

Antennas come in many physical configurations. We want to first detail a 20 meter EH dipole and feed network that you can easily duplicate. All you need is a piece of pipe that is made of insulated material such as wood or, preferably, plastic pipe. The dipole elements for 20 meters will only be about 6 inches long – **yes, 6 inches long on 20 meters** – and can be made of aluminum foil from the kitchen. You will need a couple of capacitors and some wire for the coils. You can readily build the antenna and tune it in a single evening. Then you can test it to prove to your self that it performs as well on DX stations as that commercial 20 meter vertical (16 feet tall) with a large ground radial system. There is a lot of room for experimenting with the EH Antenna. Just so you know, I prefer to use 45 degree cones for the bi-cone antenna with a sloping radius of 1% of a wavelength or greater. However, I have had excellent results with cones that are only 0.5 % of a wavelength, but larger cones give more gain. To put that in perspective, on 20 meters a wavelength is 984/14x12 = 843 inches. Therefore, 0.5% = 0.005x843 = 4.2 inches. That is a small antenna. Please understand that we prefer dipole element lengths of 6 times (or more) the diameter to work low angle DX, but on the low bands (below 10 MHz) we prefer elements that are 12 times the diameter to give a broader antenna beam width for general Ham communications. So why did we pick 6 inch elements (6 times the diameter) for our example? There are a large number of back packers that use portable QRP rigs, and they need the smallest high performance practical antenna to stuff into their bag, and the extra gain will help and has a minimal increase in size or weight.

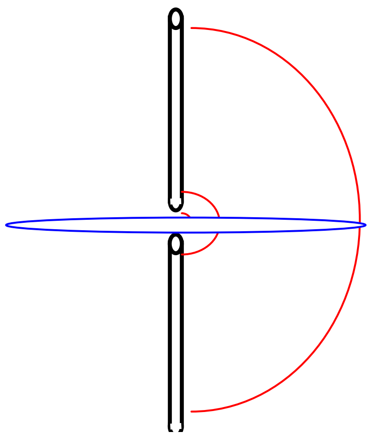


**FIGURE 7 – E FIELD LINES FOR LONG ANTENNAS**

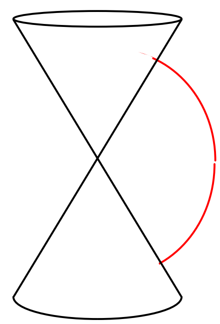


**FIGURE 8 – BI-CONE TO ENHANCE THE E FIELD**

## ANTENNA HEIGHT:

Although we can build very small antennas with very good bandwidth, there is one very important concept that must be emphasized – the laws of Mother Nature. The antenna can not radiate at low angles unless the center is about ¼ wavelengths above ground, or a multiple of odd quarter wavelengths, with a null along the horizon when the antenna is ½ wavelengths above ground. 1/4 wavelength at 14 MHz is 17.5 feet. Any value between 12 and 20 feet is good.

## A 20 METER DIPOLE:

Now we will design and construct a very real and very practical 20-meter antenna. This antenna can be scaled to other frequencies. For this antenna, purchase a piece of plastic pipe that has an outside diameter of about 1-inch. The pipe is for water, thus the pipe will be specified as an inside dimension. ¾ inch pipe will have an OD of about 1-inch.

**Step 1.** Wrap the pipe with aluminum foil, copper, or other conductive material to make 2 six inch long elements spaced the diameter of the pipe. You can put glue on the pipe or wrap the foil or metal with either clear tape or scotch tape. We had some thin sheet copper, and that is what you see in the photograph.

**Step 2.** Measure the capacity between the elements. Ours has a value of about 7 pFd. Because the displacement current adds inductance, the effective capacity is multiplied by 1.4.

**Step 3.** – Since we do not currently have an equation to predict the value of radiation resistance, we will begin an experiment with a value of 30 ohms. Later we will determine the exact value.

**Step 4.** Now we have the necessary information to calculate the network values. They are as follows:

- C1 = 225 pFd and must handle a current of 1.4 amps at 71 volts RMS for 100 watt transmitters.
- C2 = 291 pFd and must handle a current of 3.4 amps at 133 volts RMS for 100 watt transmitters

Buy, beg or steal the necessary capacitors. Beware of the current rating for the power you operate with. Any capacitor will work for QRP. Mica compression trimmers are good for any power thru 100 watts. Those old AM Broadcast variables in the junk box will do.

- L1 = 1.04 uHy. This translates to 9.25 turns on #14 wire around the plastic pipe. See the photograph for detail. L1 is the sum of 0.28 uHy from the L network and 0.74 uHy as the input L of the T network.

- L2 = 12.9 uHy. This translates to 32 turns of #14 wire around the plastic pipe plus 4 turns between the antenna elements. Space the lower coil about 1 diameter below the lower cylinder.

**Step 5.** **A** – Tuning the antenna requires adjusting the amount of total inductance to set the desired resonant frequency. Course adjustment is determined by the number of turns, final adjustment is done by spreading the turns. Alternately, to make a tuning capacitor, I put a small piece of wire about 2 inches long soldered to the bottom of the lower cylinder and placed near the coil. Bending that wire allows frequency adjustment of several hundred KHz. If a thin wall plastic pipe is used to cover the antenna, installing the cover will lower the resonant frequency about 100 KHz. If a sleve made of copper or aluminum is installed over the cover and placed over the coils, the resonant frequency can be varied by about 700 KHz. Therefore, set the frequency with the wire capacitor close to 14 MHz.

**Step 5.** **B** – To achieve minimum VSWR it is necessary to adjust the value of the T capacitor (C2) and where it is tapped on the coil. C1 can be a fixed value because it is not necessary to adjust it. I prefer to do my initial tuning with a signal generator and a simple diode field strength meter. The signal generator allows changing frequency while the field strength meter indicates the frequency of maximum signal, then the relative signal power while adjusting the T capacitor. Antenna experimenters will have their own techniques and test equipment. Final adjustment is then done by trimming the T capacitor and spreading L1 for perfect VSWR. Once the VSWR is set, the frequency can be changed over a wide range with almost no change in VSWR. Caution, if you use a transmitter at low power to measure VSWR, be aware that the VSWR Bridge in the transmitter does not allow testing at low power. Most do not function below about 10 watts. Therefore, connect a resistor or a known antenna and test your VSWR Bridge to ensure the lowest power at which it will work.

**Step 6.** Record the 2:1 VSWR bandwidth. This one measured about 232 KHz.

**Step 7.** Measure the +/- 3 dB bandwidth. For this antenna it is about 600 KHz, greater than the instantaneous bandwidth of a full size dipole. This is a Q of 23. Now, since Q = XL/R, then R = XL/Q. Since XL =1136, then R = 49 ohms. Since the RF resistance of the coils is 2.18 ohms (from the program), the radiation resistance is the total minus 2.18, therefore the radiation resistance = 47.2 ohms. Now, we can calculate the efficiency as $R_R/(R_R+R_L)$ = 96.3%. This is equal to -0.16 dB, not bad for a very small antenna. Now you see the true effect of the EH Antenna concept. . For fun, compare the radiation resistance of the same antenna length if it were a Hertz antenna. Previously we calculated a value of 0.124 ohms. Therefore a Hertz antenna this same size would have an efficiency of 0.124/(0.124+2.18)= 40%. This is equal to -4 dB. Another way to look at the comparison – if you put 100 watts into the EH Antenna 4 watts goes up in smoke – 60 watts would be converted to heat (smoke) if it were a Hertz antenna.

**Step 8.** Calculate the current thru the antenna. For 100 watt transmitter power it is P = I^2R, therefore I = (P/RR)^.5 = 1.4 amps.

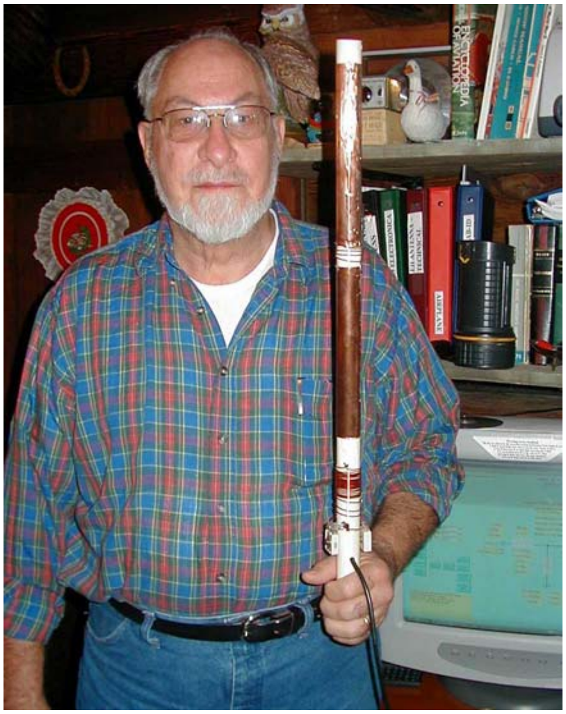
**Step 9.** Calculate the voltage across the antenna where V =IZ, where Z = the sum of the radiation resistance and the effective capacitive reactance. For a100 watt transmitter V = 1.4*(47.2+j1136) = 2272 volts. Just be careful of RF burns near the center of the antenna.

The result of this activity is shown in Figure 9, a photograph of the antenna (with the author in the background).

**SUMMARY**:

If there is a mystery surrounding the EH Antenna, it must be to find an answer to the following question: Since the concept is so simple, why has it taken so long to discover the EH Antenna concept?

It is my hope that all hams will benefit from this new concept.



What you have just read was written at a time when the L+T design was the best we had. Later we came up with the *STAR* version of the EH Antenna. That is the design I prefer and have been using for all applications since its inception, including the AM broadcast antenna. The demonstrations in this section of the web site provide details of that design. There is nothing wrong with the L+T or any of the other variations, but for Hams the *STAR* version is preferred primarily because of low cost. It does not need variable capacitors, just some wire, some copper or aluminum for the cylinders, and some plastic pipe for support.

We hope you will experiment with the various versions and enjoy the fruits of your labor on the air. Do not be surprised that a large number of the Hams you talk to will tell you that the EH Antenna you are using is not possible because it is too small or that it does not conform to conventional theory, therefore it can not work. You will find that very interesting after they give you an S9+ report then tell you that it will not work.

Best 73's

Ted W5QJR