EH Antenna, the BOOK

(updated on 12-Oct-02)

Following is an *almost* book on the EH Antenna. Almost, because it contains a lot of good information that can not be found elsewhere but is still a work in progress. It provides historical information as well as the conceptual theory of all three (3) classes of antennas with emphasis on the EH Antenna, then provides details on how to build your own EH Antenna.
You did not know there were 3 classes of antennas? There weren't until now.

Although this book is written for any one that desires an understanding of the EH Antenna concept, IT contains information to allow any Ham to build an HF Ham band antenna, including 160 meters, with a superb antenna that is very easy and inexpensive to duplicate, and very very small. We hope you enjoy this new class of antennas.
This is a new concept in antenna theory. Therefore, *please view this as new, rather than a modification to existing theory*. From that viewpoint, there will be no confusion when you read this. For the skeptics, let me say – prove it to your self – build a HF version of the EH antenna and prove to your self that it *does indeed perform as well or better than any Hertz antenna*. For those who really want to compare the EH Antenna to a Hertz multielement beam, build an array of EH Antennas that are all actively fed.

EVOLUTION OF ANTENNAS

Like all technologies, the communications antenna has gone through the evolution process to become what it is today. The following provides a historical background to present that evolution in prospective.

Heinrich Hertz, a German Physicist and college professor, discovered the concept that radio waves are periodic. Today, we think of sine waves with their cyclic variations. We also think of those waves in terms of angles of degrees for their motion relative to some reference. It was this thought that led to the concept of resonant antennas. This then led to defining the length of antennas as fractions of a cycle of the wavelength, most commonly referred to as 1/4-wavelength (90 degree) verticals and 1/2-wavelength (180 degree) dipoles or other fractional lengths. During the early years of radio, all antennas were referred to as Hertz antennas. These antennas have taken many shapes and have resulted in many volumes of documentation as to the effects of those shapes. Special computer programs have been developed to allow predicting the performance of these antennas. Most are based on the Numerical Electromagnetic Code (NEC) developed by the US Navy.
Today, we commonly refer to antennas in accordance with their shape and have dropped the Hertz prefix that was formerly applied. This is because, until recently, all antennas were Hertz antennas, therefore there was no need to put a prefix prior to the descriptive name. Now that there are three (3) classes of antennas, we should reassign the Hertz name to this class of antennas.
We also recognize Mr. Hertz in our daily conversations when we speak of the operating frequencies of antennas and all other periodic wave (alternating current) frequencies. For many years we used the term "cycles per second". This has been replaced with the term "Hertz" and has the same meaning.
The concept on which the Hertz wire antenna is based is as follows: Current flows on the antenna conductor due to applied power. Current flow creates a magnetic (H) field that surrounds the current. A changing magnetic field (due to the RF current being a sine wave) in turn develops an electric field. When the electric (E) field and the magnetic (H) field have the proper relationship, radiation is developed. The fields are very large to provide proper amplitude to allow combination at a distance of approximately 1/3 wavelength from the antenna. This is also referred to as the boundary between the near and far field.
Those of you that remember the good old days before VSWR meters will remember the RF Amp Meter. Best performance occurred when the antenna system was adjusted for maximum RF current.

John Henry Poynting, a British Physicist and college Professor, discovered the components of radiation and their relationship. This occurred in the 1880's, about the same time as Hertz made his discoveries. However, it was many years later before it was determined how the Hertz wire antennas satisfied the Poynting Theorem, as the work of Mr. Poynting came to be known. In great simplification of the Poynting Theorem, we can say that the following must occur to develop radiation:

- There must be an Electric (E) field and a Magnetic (H) field; the E field is measured in volts/meter and the H field is measured in ampere-turns/meter.
- The two fields must be in phase (occur simultaneously).
- The E and H field must exist in the same volume of space.
- The two fields must exist at right angles to each other. This is to say that the H field must encircle the E field. Obviously, the H field must be a closed circle.
- The two fields must have the same curvature.
- The two fields must have a relationship of 377 ohms, commonly referred to as the impedance of free space. Poynting says that Radiation = E x H, with the x implying a crossed product of the field vectors, measured in watts/square meter.

Please look again at #2 above, "The two fields must be in phase (occur simultaneously)". This is the key to the EH Antenna as we will point out later.

Many years after Poynting, antenna engineers adopted the definition that the polarization of the radiation from an antenna is the same as the E field. This is to say that a horizontal wire has horizontal polarization, since the E field is in the plane of the wire and the H field is perpendicular to (encircles) the wire.

Maurice Hately, a Scottish college Professor, was musing about the Poynting Theorem in the 1980's, about 100 years after Hertz and Poynting. He correctly concluded that the E and H field could be developed separately, then properly combined, to create radiation. This concept created the second class of antennas known to man, and is called the **Crossed-Field-Antenna** (CFA). With his colleagues Brian Stewart and Fathi Kabbary, both Physicists, they set out to develop the concept into a feasible practical application for AM broadcast. A number of CFAs have been built based on this concept, mostly in Egypt. Those antennas consist of three (3) elements, including a ground plane. A round flat plate above the ground plane forms a capacitor. Current thru that capacitor will produce an H field both under and surrounding the plate. Above this, a cylinder is positioned. When a voltage is applied to the cylinder relative to the ground plane, the E field is created. The region where the E and H fields are crossed is called the interacting zone. A phasing/matching network is used to adjust the phase and amplitude of the fields, thus cause the fields to satisfy the Poynting Theorem.

Ted Hart, **W5QJR** is a retired Electronics Engineer and active Pecan Farmer in the state of Georgia (USA), served as a ghostwriter to document the CFA in a web publication, since the developers chose not to do so, but agreed to provide documentation and editorial help. During this process the EH Antenna was conceived, which has become the third class of antennas known to man.

A DESCRIPTION OF THE CONCEPT OF THE EH ANTENNA

The Hart EH Antenna consists of two (2) elements having a natural capacity between them. (Think of a small fat dipole or a bi-cone) When a voltage is applied to a capacitor an E field will be developed between the plates. That applied voltage will cause current through the capacitor (called displacement current) which causes the development of an H field at right angles to (encircle) the electric field. Since this is a new concept, let me say that whether current flows on a wire or displacement current between capacitor plates, in both cases the result is the development of a magnetic field.
As said above, the E and H fields must be in time phase. However, when current flows through a capacitor, the phase of the current leads the phase of the applied voltage. Therefore, the phase of the H field leads the phase of the E field and the difference in phase (time) prevents satisfaction of the Poynting Theorem for this configuration.
If the external power applied to the EH antenna is first applied to a network between the source and the antenna, the network can retard the phase of the current relative to the applied voltage. Therefore, within the antenna the phase of the voltage (E Field) and the phase of the current (which directly causes the H Field) can be made to be the same. In other words, the E and H fields can be made to occur simultaneously, thus, the name of the EH Antenna. This allows satisfaction of the Poynting Theorem and radiation occurs at the frequency where the phasing is correct.

As a result of the above, both the E and H fields are developed within the antenna. Due to the high efficiency of the integration of the E and H fields within the physical sphere of the antenna, the antenna need only be a very small fraction (less than 2%) of a wavelength. The Poynting Theorem says Radiation = E x H. Since the space between the capacitor plates is only a fraction of a meter, the E field, measured in volts/meter, is large even for small applied voltages. The H field, measured in amp turns/meter, is large but relatively low, since the H field is less than the E field by a ratio of 377, the impedance of free space.

The EH Antenna can be physically configured to allow antenna pattern gain in the E plane in two different ways. One enhancement method is similar to that of a microwave horn, even though the operating frequency is such that the physical size of the antenna is very small compared to the operating wavelength. This is most evident in the Bi-cone version of the EH Antenna, where radiation occurs between and in a very small area at the apex of the cones, and the remaining cone area enhances the gain by shaping the antenna radiation pattern. The other method is to have long cylinders relative to the diameter of the antenna for the dipole configuration.

Due to the necessity of the H field being a closed loop (circle), the bi-cone must be non-directional in the H plane. In fact, all basic EH Antennas are non-directional in the plane orthogonal to the E field. Directive gain in the H plane may be achieved with phased arrays made of active EH Antennas, or special shapes.

Due to the E and H fields being contained within the physical sphere of the antenna, Electro-Magnetic Interference (EMI) is virtually eliminated. Since the E and H fields are contained, the EH Antenna can not be used as a parasitic element in an array.

Since the antenna is not a resonant structure, the frequency of operation is totally dependent on the external-phasing network. Since the typical phasing network only covers a small range of frequencies, the EH Antenna virtually eliminates harmonic radiation.

Since antennas are reciprocal, the EH Antenna offers full performance for both transmitting and receiving. In addition, since the E and H fields are primarily contained within the physical sphere of the antenna, the antenna rejects external independent E or H fields and receives only radiation. Thus, the EH Antenna is exceptionally quiet, thus producing very high signal to noise ratios in the presence of man made and atmospheric E field or H field noise.

QUESTIONS:

1. Since the concept on which the EH Antenna is based is so simple, one must wonder why it has taken so long for this amazing discovery?
   Answer - It is the author's opinion that, due to the inherent simplicity, it has just simply been overlooked. It can also be said that Antenna Engineers have been trained in the Hertz concept, thus it was assumed that that was the only concept. This type of thought process inhibits a search for a new antenna concept based on the fundamental theory of the Poynting Theorem.
2. Why does the EH Antenna work so much better than the CFA, since they are both based on the Poynting Theorem?
   Answer - It is simply due to the manner in which they are implemented - look at the E and H fields of the two antennas and it will be obvious. The physical structure of the CFA allows only a small portion of the E and H fields to be combined to effect radiation. Thus, great care must be used to adjust a network to properly cause the desired phase and amplitude relationship between fields to satisfy the Poynting Theorem.

EH ANTENNA SYSTEMS

MORE THEORY AND PRACTICE

The following is provided for a deeper insight to the EH Antenna and gives details to enable the reader to build his own antenna. Although a single coil can be used to effect a good EH Antenna, a complete network comprised of 2 coils and 2 capacitors allows both proper phasing and impedance matching. The complete network offers superior performance and is the only network described in this document.
Jack Arnold has done extensive experimentation with a single coil and presents the results on his web site.

SHAPES OF EH ANTENNAS

If there are only two elements used in an EH Antenna, and there must be significant capacity between elements, then the elements must form **a fat dipole** or **a bi-cone,** with the bicone being a form of dipole with the elements having less than 180 degrees between them. The impedance of the bi-cone version is measured in ohms (typically less than 50 ohms), whereas the radiation resistance of a dipole is typically greater than 2000 ohms. Therefore, two separate matching networks are required.
The bi-cone finds it's useful application when a narrow elevation pattern is desired, such as in AM Broadcast service. The dipole is much preferred for general applications for Ham radio.

THE STANDARD EH ANTENNA FOR HAMS

There are many variations of the EH Antenna, but we will present only one here and call it the "standard" EH Antenna. We will tell you what to expect if you deviate from the standard. Why are we being so narrow in our presentation? It would be a very large book if we presented all of our findings, so we decided to provide a single design and a summary of the possible variations. This allows those that want a good antenna to duplicate this one, and provides some guidance for those who want to experiment. The standard antenna is the one we have selected as the best overall antenna for general use. The example we selected is a dipole for 40 meters. The primary reason is that a 40-meter EH Antenna is just the right size to play with in the comfort of the Ham shack. That is exactly where the antenna originated and where most of the experimentation was done. Of course, pattern tests and radiation comparisons to conventional Hertz ¼ wavelength verticals and 1/2-wavelength dipoles required placing the small EH Antenna outside for direct comparison with the big Hertz antennas.
The standard is built on 4-inch diameter plastic water pipe for 40 meters. Other bands can be scaled from there. A 4-inch water pipe implies the ID of the pipe; therefore the OD is about 4.5 inches for PVC water pipe and 4.25 inches for thin wall drainpipe. Either may be used. We have found that there are certain relationships that need to be considered. The spacing between cylinders should be the same as the diameter of the antenna. Also, for general Ham use the length of each cylinder should be pi (3.14159) times the diameter, which is the circumference of the pipe. A longer cylinder will reduce the beam width, and a shorter cylinder will increase the beam width.
Please do not use plastic having a color other than white unless you test it for RF conductivity and dielectric.
We have found that even thought the ratios should be maintained between the diameter, spacing and cylinder length for a standard antenna, the actual diameter is not critical. However, the instantaneous 2:1 VSWR bandwidth is a function of the diameter of the pipe. Larger pipe provides larger instantaneous bandwidth. The standard provides about 100 KHz 2:1 VSWR bandwidth on 40 meters. If you scale the antenna, for example use an 8 inch pipe on 80 meters, the Q of the antenna will remain the same, therefore the bandwidth will decrease by a factor of 2.
Reducing the length of the cylinders (shorter antenna) increases the beamwidth at the expense of antenna pattern gain. Conversely, longer cylinders increase the gain by reducing the beamwidth. Also, shorter cylinders increase the value of radiation resistance; longer ones cause it to decrease. An example of this - Steve found that the standard EH Antenna on 40 meters did not perform as well for general Ham use as a very well constructed 1/4 wave vertical, even though it was better for DX. He modified the cylinders by shortening them to a length to diameter ratio of 1.5:1. This broadened the beamwidth at the expense of pattern gain at very low angles. The modified antenna then equaled the performance of the 1/4 wave vertical.
Through extensive experiments carried out by Steve, we found that the radiation resistance of the "standard" antenna is nominally 2*pi*377, where 377 is the impedance of free space. To transform the radiation resistance to 50 ohms to match a nominal coax line, a special network is described below.
With reference to that drawing, the source is a transmitter/receiver designed for operation with 50-ohm coax. Therefore, the network is designed to provide 1) proper phasing and 2) provide proper transform matching of the radiation resistance of the antenna to the source resistance (Rs). The antenna is comprised of the capacity between the two (2) elements of the antenna and the radiation resistance (R_A) of the antenna.

The network provides phase delay of current relative to applied voltage through L1 and a nominal phase lead thru C2 at the desired operating frequency. Since the antenna is comprised of 2 elements isolated from ground, C1 and L2 provide the necessary ground returns, where the low end of the source is considered ground. It may or may not be tied to earth ground.
Many persons fail to grasp this concept, let me try another approach. Assume that you build a network to "resonate" the antenna capacity, then add an additional 90 degrees of phase delay to correct for the phase advance of 90 degrees through the antenna capacitor.
Since the radiation resistance is a constant for a "standard" EH Antenna regardless of size or operating frequency, using that value we can define the values of the network. Since a value of capacity is much easier to measure than an inductor, we recommend experimenters purchase a cheap capacity meter. The value of capacitors to use in the network is = 100*2^.5*pi/F, where F is the operating frequency in MHz. For example at 7 MHz the calculated value of the network capacitors is 63 pFd. This is a good median value to use as a start, not the final value that is determined by experimentation.

EH ANTENNAS FOR HAMS

With an exposure to the EH Antenna concept, we now turn to gain a better understanding of this new concept. We begin this section with a question: what are the major parameters a Ham would put on his wish list? A typical list is presented below, then each parameter is discussed in subsequent paragraphs.

1) Very **small size**
2) Very **wide band width**
3) Very **high efficiency**
4) Choice of antenna pattern
5) No ground plane
6) Very **inexpensive**
7) **No critical parts**
8) Very easy to duplicate
9) Virtually no EMI or Noise
10) **Excellent for receiving**

Those are the parameters that define and set apart the EH Antenna from all other antennas.

Although there are various possible physical configurations of this new concept antenna, only the dipole version is presented here. The reason - it is the only version that meets all of the parameters on the list above.
The dipole provides as much gain as is compatible with a reasonable vertical beam width for HF communications.

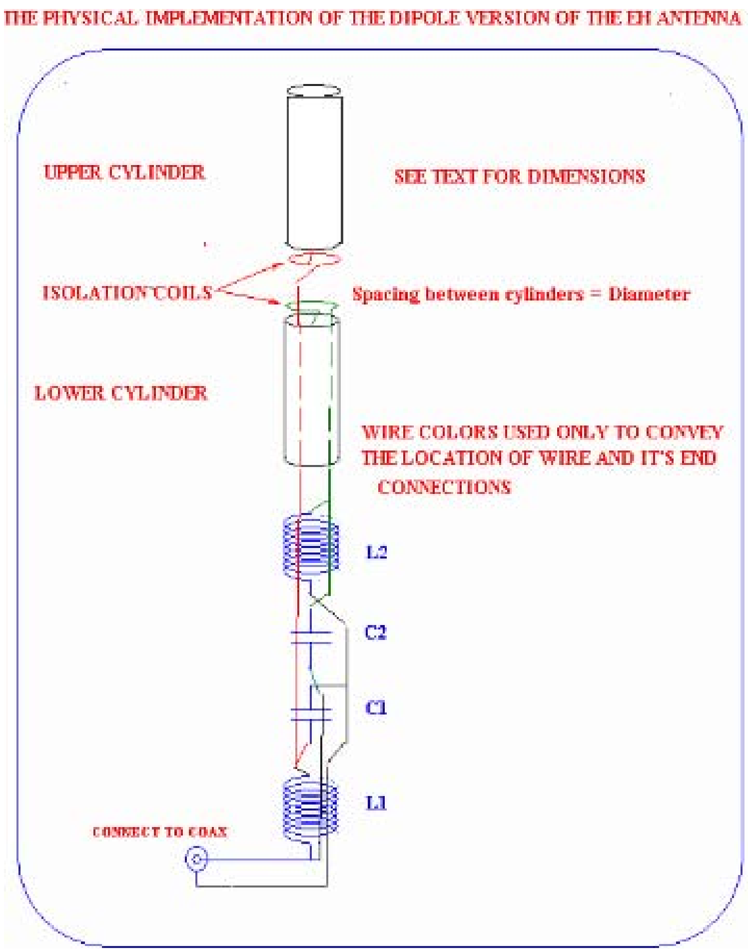
Before going further, I want to point out that even though the antenna is very small, thus essentially a point source, once the RF leaves the antenna it follows the same laws of radiation as from Hertz antennas. Therefore, give it room to breathe. For example, *mount it at least higher than any surrounding objects* such as the roof of a house. Because ground reflections may cancel vertical radiation, *if the dipole is mounted horizontally it will give poor performance*. Therefore, the dipole *is best used as a vertical radiator.*

There are 2 persons to whom you owe a debt of gratitude for helping develop the concept into a practical antenna for Hams. **Jack Arnold, W0KPH**, retired from IBM, has devoted a lot of time and effort to developing what we affectionately call the Peachy Keen antenna, and it's relatives. The Peachy Keen (and relatives) are made of tin cans salvaged from the kitchen, varying from peach cans (hence the name) to coffee cans and delectable fruit and nut containers, as well as the more staple bean and vegetable containers. The source of materials may amuse you, but the performance will astonish you. The performance of these antennas will make any Ham proud. Since Jack has his own web site, we refer you to that site, which is: **www.qsl.net/w0kph**
In addition to the cans, Jack has developed some clever mechanical concepts. We hope the cans will inspire some of you to develop other physical implementations. Jack also developed data from a very large number of HF contacts using various size cans. From that, we were able to develop a plot of effective beam-width versus the ratio of the length of each cylinder to the antenna diameter. This allows a choice of antenna gain vs beam-width.
A number of Jack's antennas are fed with a simple network, which does not allow full performance. However, the basic simplicity may justify it's use in some applications.

The other fellow's name is **Stefano Galastri, IK5IIR** in Italy, or Steve, as we would refer to him in the US. He was an Electronics Technician with Hewlett Packard, and is now a Manager with Agilent Technology, a break-off from HP. He is a very devoted antenna experimenter, as evidenced by the effort he expended on the Crossed Field Antenna (CFA).

When he learned of the EH Antenna, he contacted me for information and visited Jack's web site. In one evening he constructed an EH Antenna (using aluminum foil for the elements) and achieved better performance than he achieved after 2 years of experimentation with the CFA concept. I have provided guidance, but he has done the construction and experimental testing of the dipole antennas with the results presented here. It is remarkable that we have been able to communicate between the US and Italy to pull off this development program via the internet between us. Steve's web site is: **www.eheuroantenna.com**

Steve and his partners, Marco and Julie, have constructed a factory in Italy to produce the antennas under license of the patent. At the time of this writing, that is the only factory producing the antennas.



The schematic diagram presented here is depicted in a physical implementation below. It suggests that the required network can be constructed on the same pipe as used to hold the cylinders. Of special note - we have added "isolation" coils not depicted on the schematic. These coils are between the network and the radiating cylinders. Their purpose is to provide a small amount of phase shift, thus prevent radiation from the wires inside the antenna. This increases the external radiation (by removing internal radiation) and significantly reduces the amount of RF on the coax. Typically, two turns are adequate.

A remarkable thing about the hobby of Ham Radio is diversity. There are those who play with antennas, those who operate nets, those who rag chew, those who chase DX, those who design and build equipment - - - and the list is almost endless. The one thing that is common to all Hams is the need for a good antenna. Some day every Ham will have one or more EH Antennas, the antenna for the 21st century and beyond.

Very small size - Although the size is not critical, we recommend the following: On 40 meters use a 4-inch plastic pipe. Make the length of each cylinder 3.14 x the diameter. The space between cylinders should be equal to the diameter. Thus on 40 meters, the OD of the 4 inch pipe is about 4.5 inches for water pipe (and 4.25 inches for thin wall drain pipe). Therefore, the length of each cylinder = 3.14 x 4.5 = 14.14 inches. Therefore the length of the antenna = 14.14 + 4.5 + 14.14 = 32.77 inches. At 7 MHz that is 33 inches/a wavelength = 33/((984/7)*12) = 2% of a wavelength. Compare that to a 1/2 wavelength (50%) Hertz wire dipole. The pipe needs to be a little longer to accommodate the phasing/matching network.
Extensive testing has revealed that this antenna is about optimum for the Ham bands above 40 meters, but the length of the cylinders should be reduced for the low bands. We want to point out that one antenna size can be readily used over a wide frequency range as a means to illustrate that the physical size of the antenna is not critical, except that the bandwidth of the antenna is related to the size and operating frequency.

Very wide band - When small antennas are constructed based on the concept of Hertz wire antennas, narrow bandwidth is the limiting factor on size. A small loop antenna with reasonable efficiency (-3 dB) will only have enough bandwidth on 75 meters to pass a single sideband signal. However, the EH Antenna will have a 2:1 VSWR bandwidth of about 50 KHz. The +/- 3-dB bandwidth is about twice that value, or 100 KHz. Use of an antenna tuner will allow operation over that range. You just won't find that capability anywhere else. Want more bandwidth? Increase the diameter of the pipe. On the other hand, if you are willing to live with less instantaneous bandwidth, the diameter of the antenna can be significantly reduced.
How can a small antenna have wide bandwidth? For wire antennas the bandwidth is related to the Q, which is defined as the inductance of the antenna divided by the sum of the radiation resistance + loss resistance of the antenna. For the EH Antenna, it is directly related to the physical size of the antenna. In addition, there are various ways to enhance the bandwidth but at a price. One method is the use of feedback to double the bandwidth, but the cost is reduction in radiation.
Please, when reading about the EH Antenna, you must forget all you know about conventional antennas - there just is simply no comparison because it is based on an entirely different concept.
As an example of the EH Antenna being different, consider the following: the Radiation Resistance is a <u>constant vs frequency</u> for an EH Antenna of a given size. Also, if the ratio of the dimensions are held constant, then the Radiation Resistance of the EH Antenna is a constant for any size antenna. What does that mean? It says that the Radiation Resistance (assuming that the E and H fields are properly phased) is = K*E/H - - note that there is nothing in the equation that is related to frequency or size, only that the E and H fields have a constant ratio, and they will --- <u>if the shape of the antenna is a constant</u>.
That is a very simple but important characteristic of the EH Antenna. It goes to the very concept on which the EH Antenna is based. If you reduce the length of the cylinders, the Radiation Resistance increases. For a "standard" EH Antenna (length of cylinders = pi x diameter and spacing = diameter) the radiation resistance = 2 x pi x 377 = 2368 ohms, where 377 = the impedance of free space. This further verifies the concept on which the EH Antenna is based, i.e., the fields are contained within the sphere of the antenna.
If we extrapolate this information, knowing that a very small EH Antenna has a constant impedance vs frequency, then we can say that the frequency limit is only dependent on the phasing/matching network, not on the physical structure, and is in no way related to the concept of wavelength, as Hertz antennas are. However, the minimum size EH Antenna is determined by the desired bandwidth, since the efficiency remains constant regardless of size. This also says the future of these antennas will be related to the development of appropriate networks to increase bandwidth. We have learned that a phase change of +/- 3 degrees is equivalent to a +/- 2:1 VSWR.

Very high efficiency - An <u>antenna system</u> is comprised of the actual radiating element and the associated phasing/matching network. In the case of the EH Antenna, calculations of loss due to heat for the cylinders show it to be so small, it can be totally ignored. For example, the EH dipole with the cylinder length equal to the pipe circumference has a radiation resistance of 2*pi*377 = 2369 ohms. The current thru the elements = square root of P/R. For 1000 watts the current would be 0.649 amps. In other words, there would only be about 1/2 amp current thru the capacity between the large cylinders. Since the cylinders have a large area there is virtually no loss due to current thru the antenna. However, loss in the coils in the network may become appreciable if the size of the wire is not chosen properly. We recommend # 8 wire on 40 meters and below, smaller on the higher frequencies. A measure of inefficiency is the production of heat rather than RF radiation (both are forms of radiation). At high power levels a small amount of heat can be detected in the coils unless large size wire is used.

The depth of penetration of RF into the cylinders dictates the necessary thickness of the metal. It should have a thickness of at least 0.002 inches on 160 meters, 0.001 on 80 meters, and need be only 1/2 that value on 20 meters.

A miniature antenna with high efficiency? It was only a dream before the development of the EH Antenna concept. In 1984 I wrote a book entitled "Small High Efficiency Antennas, alias The Loop". On the back cover I wrote "There is no antenna that will provide equivalent performance in a small space". In that book I recommended a small loop for 75 meters should have a circumference of 80 feet (1/3 wavelength). Compare that to a 75 meter EH Antenna with a height of only 3 feet.

What about a small, high efficiency, broadband, high gain inexpensive antenna???

The statement declaring the loop to be the only good small antenna is no longer true; the EH Antenna has captured that title with a full knock out punch. I developed the math equations to define the loop, then wrote the book. That was then (about 1983), this is now.

Pattern gain - Because the shape of the E field is the primary controlling factor of the pattern shape of an antenna, the dipole version of the EH Antenna provides a non-directional pattern in azimuth, but a limited pattern in elevation when the antenna is mounted vertically. An EH dipole antenna with longer cylinders will have more gain, thus a more narrow pattern. Also, short cylinders reduce gain as a trade for increased beam width. A cylinder length of only 7 inches works very well on 40 meters. The Ham antennas presented here were chosen for general-purpose ham operation. All antennas are a compromise - which do you prefer? Build several and see which you like, or analyze your mode of operation to determine the specification you want to place on your antenna. You may want one for rag chewing and another for DX.

A direct comparison was made between a 40 meter EH Antenna with the cylinder length being equal to the circumference of the antenna, and a 1/2 wavelength end fed vertical Hertz wire antenna (with a good ground). The EH Antenna was about 12 feet above ground. At low takeoff angles the EH Antenna out performed the Hertz antenna by more than 4 dB on both transmit and receive. (That was before we added the isolation coils and got increased performance). At high angles the dipole was better, as evidence of a narrow pattern of the EH Antenna.

Steve performed tests of a 40-meter EH Antenna against a very good 1/4-wavelength vertical, which had a large number of 1/4-wave radials. By reducing the length of the cylinders from 3.14 x the diameter to a ratio of 1.5 x the diameter, his signal for short distances improved about 1 S-unit. He measured the same on both transmit and receive between the EH Antenna and the vertical. When the cylinder was longer, the EH antenna was better at low angles for DX, but not so good for general purpose Hamming.

No Ground plane - Based on the Hertz concept For those who enjoy chasing DX or long haul skip on the low bands, the standard is a good 1/4 wavelength vertical with a large quantity of buried radials to form a ground plane. For 160 meters, that means a large number of (preferably 120) wires each being 136 feet in length. That is why only a very few Hams have the available ground to grow such an antenna, again, *based on the Hertz concept.*

If an antenna is built on the EH concept, an excellent 160 meter antenna need only be 6 feet tall. If this short dipole, whose physical length is less than 1% of a wavelength, is physically mounted at a height sufficient to clear the roof of your home or other structures, it will outperform the best 1/4 wavelength vertical, and no ground plane is needed. The EH Antenna is the ideal antenna for apartment dwellers.

Very inexpensive; No critical parts; Very easy to duplicate

Since these three parameters are so closely linked, they are considered simultaneously.

Because most HF communication needs can be fulfilled by using the EH Antenna, our initial goal was the development of a version that provided full performance yet could be used by the average Ham. This meant low cost, very low cost, or, preferably, very very low cost. We are pleased that we have met our design goal.

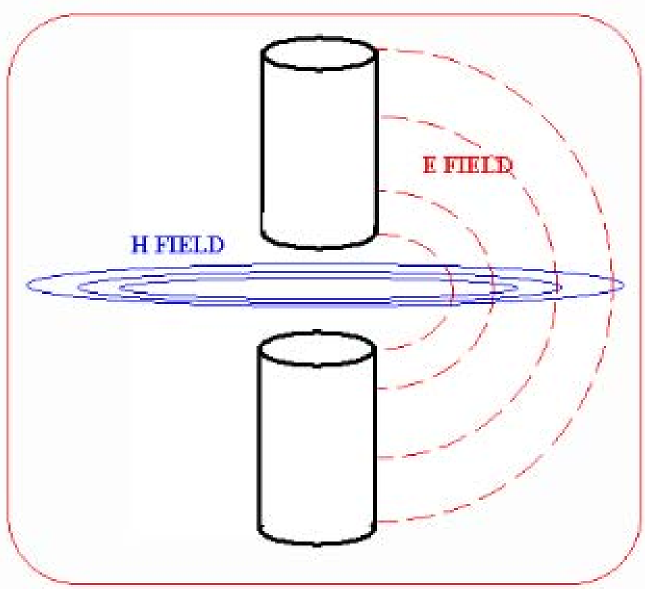
It is recommended that PVC plastic water pipe be used for the antenna support. The metal cylinders wrapped around the pipe can be any of various types including aluminum foil (borrowed from your wife’s kitchen), thin aluminum as used for roof flashing, copper, brass shim stock, or even stove pipe made of iron. Some loss will be incurred if aluminum or copper is not used, but the loss will be very small. We can’t recommend a source for copper - minimum order is a lot of copper and big bucks. It is not too bad for a club project where the cost is shared.

If the antenna were made on inexpensive plastic water pipe using reasonably priced metal, then the major cost would be in the phasing/matching network.

Since wire is cheap, the major focus of our effort was to develop capacitors that had almost no cost. Steve came up with the best design as shown in photographs of the antenna (see his web site). The capacitor is nothing more than thin copper glued to a piece of pipe. That piece of pipe is slotted to allow it to be placed inside and held to the main pipe with a bolt, which may be loosened for adjustment of the amount of capacity required. The other plate of the capacitor is affixed to the pipe externally. If transmitter power in excess of 100 watts is used, a large area for the capacitor must be used to spread the currents in the capacitor to minimize heating. Also, the separation between plates must be larger or additional insulating material must be added to prevent arching.
To properly adjust the network for maximum performance, a field strength meter is necessary. A very simple diode detector and micro amp meter is all that is required, with a wire antenna a couple of feet long. The wire antenna should be in the same plane as the antenna and can be as close as a couple of lengths of the EH Antenna under test.
Adjust both capacitors to the proper calculated value for the desired Ham band less a small amount due to stray capacity. Apply a few milliwatts of power (or minimum transmitter power) and adjust the inductors to achieve maximum radiation. This is done by using more turns than necessary, then removing a turn on both coils at a time and tuning the capacitors for maximum radiation until the values of the capacitors are close to the calculated value. This ensures that the phasing and the impedance matching are correct. Actually, it may be off a small amount, which is readily corrected by making the final adjustment for minimum VSWR by setting the capacitors. You should readily achieve a perfect VSWR at the desired frequency. When maximum radiation is achieved you also have the lowest VSWR and the widest bandwidth. It is possible to achieve good VSWR and poor radiation, thus the need for the field strength meter. 7 turns on 40 meters for the "standard" antenna is a good value, with the capacitors being about 63 pFd.

Virtually no EMI or Noise- Electromagnetic Interference (EMI) has kept me from enjoying 160 meters until now. A good 160-meter Hertz wire antenna with only 100 watts of transmitter power will cause every telephone and Hi-Fi audio system in the neighborhood to jump off the table. Only the large landowners can escape this problem - unless city dwellers use the EH Antenna with the E and H fields locally contained.
The drawing below is provided to illustrate the fields. Note that the E field must exit and enter the cylinders at right angles, then they are circular to have minimum length. This defines the shape of the E field lines.

E and H Fields of the EH Antenna.



The E field lines are constant around the cylinder - only a side view is shown here.

The shorter length E lines at the center of the antenna will obviously be more intense; thus the H field is also more intense at the center, as is the radiating RF. This is easily measured. For the old timers that only had a screwdriver to test antennas with in the old days, the use of a screwdriver to draw an arc along the cylinders will show the relative magnitude of the RF field. Please use caution, the RF fields can make deep and painful burns.

It is also important to note that if the length of the cylinders were reduced, the majority of the E field lines would have more curvature, thus the antenna pattern would be more like a sphere. Conversely, longer cylinders would increase the number of more vertical lines, thus reducing the shape of the antenna pattern. If the cylinders are replaced with cones, then the lines are more vertical, thus the antenna pattern is narrower with a corresponding increase in gain.

The following compares the magnitude of the E fields of a wire antenna and the EH Antenna: Since the E field is virtually contained within the physical sphere of the EH Antenna, the E field lines have a radius of about half the length, which is about 1% of a wavelength. We stated previously that the E and H fields of a wire antenna combine at approximately 1/3 of a wavelength from the antenna. Therefore the fields, assuming the wire antenna allows efficient combining of the E and H fields at 1/3 wavelength, have a ratio of 1%/33%, or a difference of approximately 30 dB. This is a simplistic way to compare the EMI produced by the antennas, and does not consider the fact that the field is concentrated near the center of the EH Antenna, thus the true difference is greater than 30 dB.

One reason the EH Antenna has better overall efficiency than a Hertz antenna is that the E and H fields of the Hertz antenna are very intense and large before being combined to produce radiation. Because they cover a large area (a nominal radius of 1/3 wavelength), the fields can interact with items in the area, including ground, power wiring, metal fences, and other metal objects. Any metal object in the H field will have eddy currents induced on it, thus creating heat. The antenna can be thought of as the primary winding of a transformer, with the secondary winding(s) having a load such as the eddy currents on a remote object. Those loads then reflect to the primary of the transformer and have an effect on the impedance of the antenna. The most notable example is the effect of changing impedance on a Hertz dipole as a function of height above ground. This effect is not measurable on the EH Antenna when that antenna is raised only a short distance above ground, as further evidence that the fields of an EH Antenna are confined to the physical sphere of the antenna.

It is worth a reminder that the EH Antenna is not a resonant physical structure, therefore the operating frequency is totally dictated by the phasing network. Typically, the network is narrow band, therefore the EH Antenna will not radiate spurious noise or harmonics created by the transmitter outside the pass band of the system.

Although it is not an EMI problem, there can be a problem with RF in the shack even though the antenna is mounted away from the shack. Think of the EH Antenna being a good 50 ohm load on the end of the coax. That is good. However, this small antenna exhibits a lot of radiation in a small volume that can couple to the coax. Here are some suggestions to help minimize the problem:

1) Keep the antenna well above the Ham Shack - If the antenna is vertical keep the coax coming straight down from the antenna to minimize the amount of coax in the radiation area of the antenna. If the antenna is horizontal, run the coax horizontal for at least 10 feet then down to the ham shack.
2) It is helpful to run the coax inside a metal pipe, if the pipe is grounded. Do not use toroids on the coax for RF isolation unless you want to eliminate the signal by turning your transmitter power into heat - the toroids effectively place inductance and resistance in series with both the inner and outer conductors of the coax.
3) A good RF ground is very important in the shack. If the shack is physically separated from ground more than a few feet put a loop in the coax. Let the loop go to ground. Trim back the outer insulation and connect a very good ground to the coax shield. Another approach is to use a series tuned network at the operating frequency between the radio and a very good ground. This effectively cancels the reactance of the wire between ground and the radio.

Excellent for receiving - Since antennas are reciprocal devices, the parameters applicable to transmission are also applicable for reception. This is most pronounced on the lower bands (160, 80 and 40 meters) where man made and atmospheric E and H field noise increases as frequency decreases. Since the EH Antenna responds only to a radiated field, it rejects independent electric or magnetic fields, the source of this noise. The Hertz antennas are large wires - when a E field or H field interacts with the wire, power is transferred to the receiver because - - - the wire in the presence of a field acts like a generator - the changing field causes current on the wire, thus creating power applied to the receiver.

The ratios presented above relative to EMI are also applicable as noise rejection ratios. To put the receiver noise level in perspective, while other Hams are complaining of high noise at S-9 levels, my noise level is about S-2. Further, signals that are readable on the EH Antenna are completely buried in the noise on a Hertz antenna. This is just one of those things - you have to hear it to believe it. A large majority of Hams that have bought EH Antennas from Steve report that their noise level on 40 meters has dropped dramatically, allowing them to copy stations they could no even hear previously. It should be noted that most of his customers live in apartments, which is common in Europe.

It needs to be pointed out that typical noise has a very high peak to average value (noise spikes) and the receivers normally have peak diode detectors. Thus the AGC driving the S-Meter is high in the presence of noise. The S-Meter will indicate a very low value in the same environment when using an EH Antenna. However, the signal to noise ratio (readability) of the desired signal is significantly enhanced when listening to an EH Antenna in a noisy environment. On the higher bands where noise is not a factor, the S-Meter will read about the same or slightly higher on the EH Antenna due to the increased gain over the Hertz wire antenna.

Please do not get confused with (signal + noise)/noise ratio as applied to VHF and higher frequencies. Here we are talking about typical man made noise or impulse noise as from lightning where the peak to average ratio is very high rather than being a Gaussian distribution. The high peak values typically cause saturation in the receiver IF amplifier resulting in the pulse being stretched. A more familiar example is ignition noise. The saturation results in ringing and very large signal applied to the AGC detector.

You were led to believe that the smaller the antenna the smaller the capture area. True, when you are talking about wire antennas. However, you can not compare a wire antenna to an EH Antenna. These antennas are based on different concepts. Think of it this way - if two antennas have the same radiation pattern and one is very very small and the other large, they still have the same capture area because they have the same pattern. In support of the small capture area concept, note that a small Hertz antenna can not have the same "capture area" or the same radiation pattern as a large Hertz antenna. The antenna is nothing more than a transducer to convert radiated power density to power applied to the receiver.

In a strong signal environment, receivers with wideband front ends suffer due to intermodulation products from non-linearity in the front end of the receiver. For this reason, better receivers have a switchable attenuator on the front panel that reduces all signals applied to the receiver by 20 dB. Since the EH Antenna rejects all out-of-band signals (outside the bandwidth of the phasing network), the intermodulation products are virtually eliminated.

For these reasons we can say that the *EH Antenna has no parallel as an excellent receiving antenna.*

SUMMARY

Please don't let the small size of the EH Antenna keep you from accepting the fact that, since this antenna is based on a new concept, it can be uniquely small and provide performance exceeding a "full size wire dipole". To be technically correct, the "new" concept was developed by Poynting 120 years ago; we just found a way to implement that concept.

The following sentence presents the concept of the EH Antenna: ***The E and H fields are developed simultaneously (due to external phasing) and in the proper physical arrangement to effect radiation in accordance with the Poynting Theorem****.* The EH class of Antennas are the only antennas that accomplish this feat, thus allowing full performance in a small size antenna. For general Ham use, the dipole version of the antenna is recommended. In the future we will provide information on phased arrays for enhanced directivity for pattern shaping and enhanced gain. We do want to point out that EH Antennas in an array must be active, i.e., all fed from the same source. They can not be used as parasitic elements for reasons previously presented.

Considerable time and effort has been expended by the author and by Jack and Steve to optimize the physical configuration for best performance, and develop a phasing/matching network to allow the antenna to operate properly. Further, considerable effort was expended to minimize cost. Translation - you can't build an EH Antenna any cheaper, nor can you build a better antenna - period. Now you understand why we can say we met our development goal for this new concept antenna. For construction details see Steve's and Jack's sites.

We encourage those of you who enjoy experimenting with antennas to try other configurations, but only after gaining a very good understanding of the E and H fields of a EH Antenna. For those who just want to build a good antenna, the specified design will provide excellent performance. If you have additional technical questions on the Ham version of the EH Antennas, please direct them to Jack or Steve on their web sites. The three of us hope you enjoy your EH Antenna.

The following information will be useful to those who want to build their own and is presented here as a summary of what we have previously stated.

FOR A STANDARD EH ANTENNA

HAM BAND	PIPE DIA. (INCH)	CYLINDER LENGTH (INCHES)	2:1VSWR BANDWIDTH (KHz)	CAPACITOR VALUES pFd
160	16	50.2	35	252
80	8	25.1	70	126
40	4	12.6	140	63
20	2	6.3	280	32
10	1	3.1	560	16

Please be aware that the values presented here are approximate only. Also, the <u>outside</u> diameters of standard PVC plastic water pipe or drain pipe are not exactly the values specified. However, the pipe diameter is not critical, but for a good antenna you should stay with the length of the cylinder to pipe diameter ratio. Change in the ratio will have an effect on beamwidth, bandwidth, and impedance.

When the diameter of the pipe is changed, a change in diameter by a factor of approximately 1.5 will cause the bandwidth to double or be 1/2 the value stated above.

A change in the cylinder length will cause the impedance and beamwidth to increase with a corresponding decrease in antenna pattern gain and bandwidth.

WHERE DO WE GO FROM HERE?

Obviously, this just scratches the surface for this new concept. People are still bending wires to see what happens to the Hertz antenna after 120 years. Why should we expect to know all the answers at the <u>introduction of a new concept</u>? Therefore, there is much room for experimentation and theoretical analysis leading to enhancements.

It must be emphasized that the *NEC variant programs do not recognize displacement current through a capacitor. Therefore, they can not be used to analyze and predict the performance of the EH Antenna*.

We hope some person or organization will undertake the development of math equations to define the antenna from a Physics viewpoint. This would allow development of a program to define the EH Antenna and allow prediction of performance versus various physical configurations.

We would be pleased to work with an interested party on such a project. The program would be the property of the developer. We just want a copy.

Now, ask yourself the following question:

Where will this simple concept take us in the next 120 years?
Is the Poynting Theorem the last word in radiation?
*If it is, then **the EH Antenna is the last word in antennas.***

EH ANTENNA SYSTEMS
73, de Ted Hart, W5QJR