THE EH DIPOLE ANTENNA - MORE INFORMATION ON HOW IT WORKS AND HOW IT HAS PERFORMED

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(Figures redrawn for AR Journal by Bill Roper VK3BR)

(Data on traps updated June 2004)

Introduction

In the previous article, I described how EH Dipole Antennas could be constructed for 20 and 40 metres using recycled tinned plated cans mounted on PVC plumbing tube. There are several forms of these antennas introduced by the original inventor Ted Hart but my earlier article (and this one which follows) refers essentially to the type which he has called the L+L, defined by the method of matching.

A lot of discussion has recently taken place on the principles of operation concerning the EH antenna and whether the principles which had been assumed were quite on target. Based on a lot of thought and various measurements carried out, I present some theory on how I believe this type of EH Antenna works.

In the process of experimentation it has become evident that a considerable amount of RF current runs longitudinally down the coax feeder line causing radiation directly from that feeder. In fact some opponents of the CFA and EH mode theory have strenuously argued that this is the main form of radiation. However the antenna does not need this form of radiation and it is desirable to inhibit it. This allows concentration of all the power to the EH operation, it prevents undesirable interaction between the coax and the antenna tuning, it prevents excessive RF signal getting into the radio shack and it prevents power being absorbed in the ground or objects close to the feeder.

In following paragraphs, I will decribe how this longitudinal current down the coax can be monitored and how traps can be fitted to inhibit this current. Also described are the results achieved having fitted these traps.

Some Background

To achieve Electromagnetic (EM) radiation, we require the Electric (E) and Magnetic (H) fields to be at right angles in the same plane and in time phase. The EH antenna is designed to achieve this in much smaller space than the well established Hertz antenna.

In brief, the antenna consists of two tubular plates with natural capacity between them. The E field is generated by voltage across the plates and it has been assumed that the H field is generated by the displacement current in the dielectric between the two elements. (The fields intersecting at right angles are shown in Figure 1).

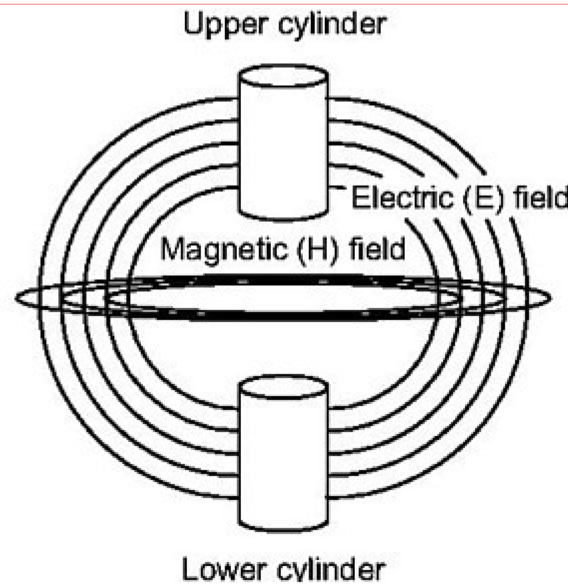


Figure 1
Fields generated between the two cylinders

Before proceeding further, I think we should discuss the concept of displacement current and a little on the generation of the Electric (E) and Magnetic (H) fields.

An H field is generated by a changing electric current in a conductor but also from a virtual changing current which Maxwell called Displacement Current and which is defined as the rate of change of an electric field. As the rate of change of the E potential is 90 degrees out of phase with that potential, so also is the displacement current.

This displacement current is assumed to occur in free space but if there are two metal plates forming a capacitance with a dielectric, then dielectric displacement current also occurs. (Dielectric displacement is really the displacement of electrons or distortion of their orbits around the atoms in the dielectric). According to my faithful old Admiralty Handbook, there is a total displacement current, the sum of these two.

So we can have an H field developed from either a changing current in a conductor or a displacement current produced by an E field.

The Theory

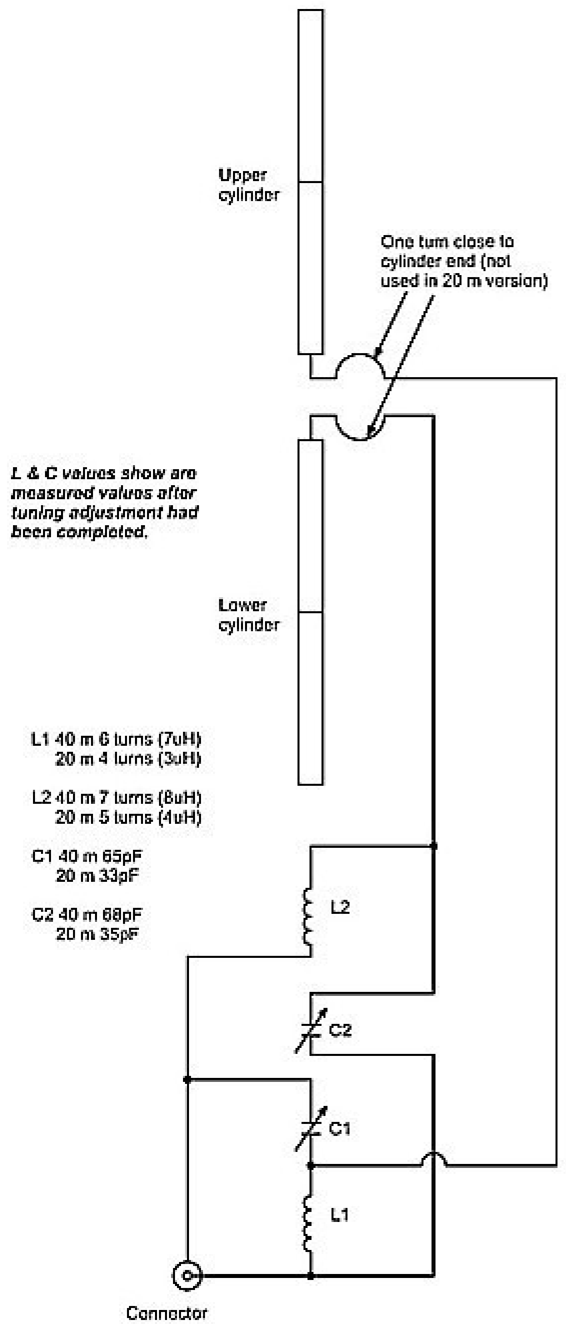


Figure 2

Circuit Diagram

Ted Hart discovered that if he introduced a phase shift (in fact 90 degrees) into the circuit feeding the EH dipole cylinders, the radiation dramatically increased, resulting in increased series radiation resistance (or equivalent reduction in the equivalent parallel radiation resistance). This was incorporated into reactive networks designed to match the new reflected antenna impedance to a 50 ohms source. The typical L+L matching network is shown in figure 2.

Initial reaction was that this phase shift somehow offset the phase of the input current (and hence the displacement current) relative to the voltage across the plates such that the displacement current (and hence the H field) was in phase with plate voltage (and hence the E field). However this theory seemed to defy some basic electrical principles concerning the antenna input as a two terminal impedance. The only way to alter the characteristics of that impedance was to alter something inside the impedance and not the characteristics of something feeding signal it.

Steve Galastri stressed to me that you can’t consider the dipole antenna in isolation and you must refer it and its phase shift network back to the coax shield input as a reference. So here is a third terminal which is important to the operation of the antenna.

As a result it came to me that there must not only be an electric field between the two cylinders of the dipole but there must be some sort of an electric field between each cylinder and the reference coax shield. In Steve’s version of the dipole, he uses a differential balanced matching network which also performs the phase shift. I assumed that in the longitudinal or common mode, that phase shift would be be vastly different to that applied to the balanced dipole input. As such, we could have displacement current produced by the longitudinal generated E field partly in phase with the E field from the balanced dipole. In turn, this displacement would generate an H field also partly in phase with the dipole E field to achieve enhanced radiation. Adjustment of the amount of phase shift could well put the second H field precisely in phase with the dipole E field as desired.

At this point I had better clarify what I mean by the longitudinal mode signal. A longitudinal or common mode signal in a balanced circuit is one in which the current in both legs is the same and in phase as distinct from a differential mode signal in which the currents in each leg are in opposite phase. For an example refer to figure 3. In this we face each end of a balanced circuit with a centre tapped transformer with their centre taps joined to earth. The current (Id) in the differential mode resulting from voltage source (Vd) flows in opposite directions in the two connecting legs. If a potential (VL) exists between the two earth points, current (IL) will flow in each leg between the two earth points but in the same direction. This is called a longitudinal or common mode current. If the circuit is perfectly balanced, no interaction can occur between the signal coupled via the transformer in the differential mode and the signal in the longitudinal or common mode.

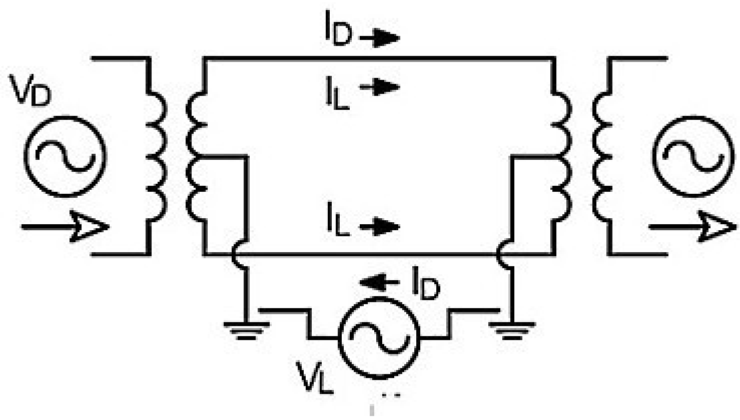


Figure 3 - Longitudinal Current

In the EH antenna we have an unbalanced to balanced matching network and in this, I refer to the Longitudinal or Common Mode potential as a voltage between the electrical centre of the two dipole cylinder connections and the reference zero point of the coax shield. This is equivalent to considering the voltage of the two dipole cylinders in parallel against zero reference. Now refer to figure 4. Vin is the voltage at the 50 ohm coax output correctly loaded by 50 ohms resistance, Vd is the output voltage across the dipole cylinders and Vl is the longitudinal voltage. For the theory I have outlined, we must find 90 degrees phase shift between VL and Vd.

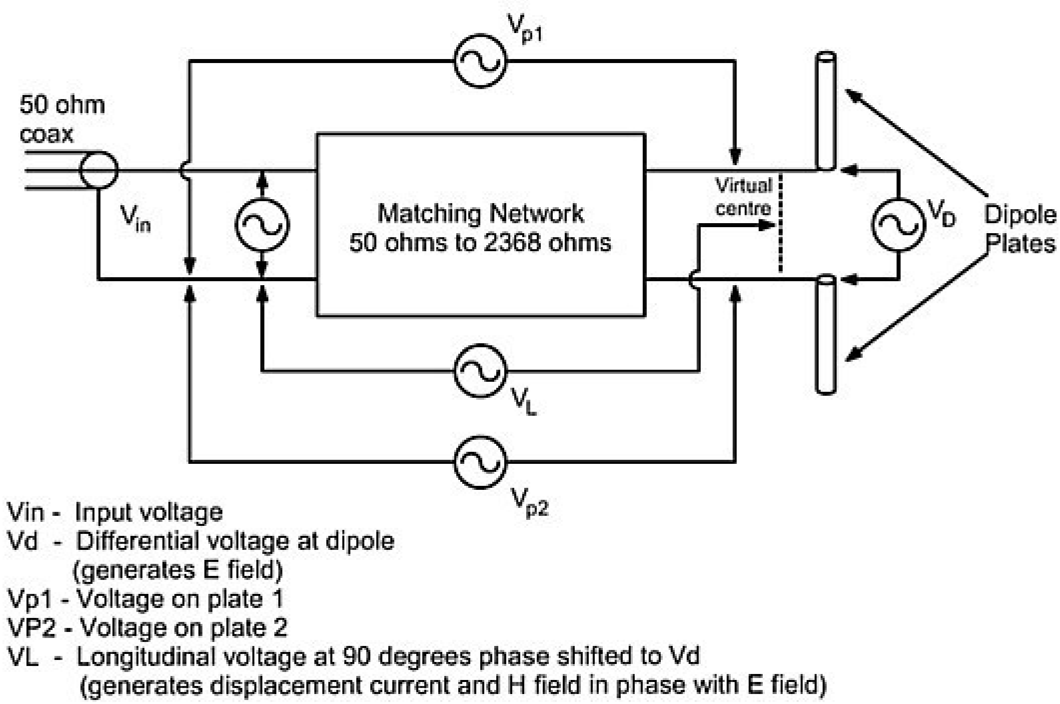


Figure 4 - EH Antenna - Voltages

The Tests

With the theory in hand, I set out to see if I could detect evidence of that field and the required phasing arrangement. Tests were carried out on my 40 metre EH dipole which I described in the previous article and which uses the balanced type matching network shown in figure 2.

The first operation was to carefully adjust the dipole tuning using about 20 watts of power and adjusting for an SWR close to 1:1 with the SWR meter connected in the coax feeder as close as possible to the antenna 50 ohm input connector.

Checking the field from the dipoles using a small fluorescent lamp showed even field distribution from the dipole cylinders. The field was strongest adjacent to the cylinders but it also extended lower adjacent to the matching elements getting weaker as the bottom of the PVC tube assembly was approached. There was certainly some field lower down than the main dipole field that wasn't above it. I thought this might be due to the longitudinal generated field.

I then turned to some phase measurements using the dual trace CRO and high impedance probes. This was not so easy. The trouble is that when a probe is placed near or on one of the dipole connections, the antenna is de-tuned and matching adjustment must be reset. Also the transmitter power must be reduced to a very low level otherwise the test leads and the test equipment get flooded with induction from the radiated signal and can give false readings.

Of course I couldn't measure (VL) as the longitudinal voltage is at a virtual centre but I could measure the voltage from each cylinder plate to the reference coax zero, shown as Vp1 and Vp2 in figure 4. In actual fact, VL is the average of Vp1 and Vp2. In measuring at these points, de-tuning is reduced by coupling to the CRO high impedance probes via 10 kohm resistors. However, even with these in circuit, it is still necessary to initially raise the power just sufficient to get a reading on the SWR meter and readjust the matching for 1:1 SWR with the probes connected. The power is then dropped for the measurement.

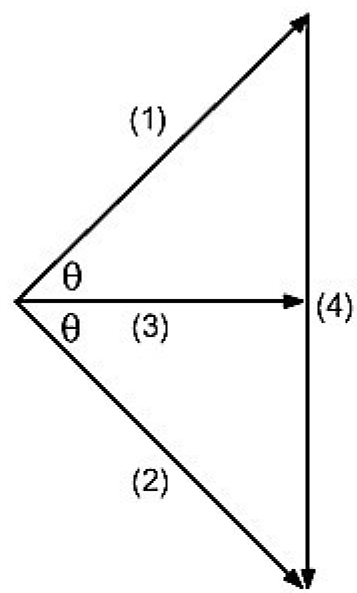
With a probe on each cylinder it was observed that the voltage at each cylinder was nearly equal and slightly out of phase with each other.

Using the gain adjustment on one of the CRO trace amplifier inputs, the traces were adjusted as close as possible for equal trace amplitude. One trace is then reversed in phase and the CRO switched to the add mode so that cancelling occurs of the two traces. A residual waveform is seen and the gain of one of the amplifiers is fine adjusted for a residual minimum level indicating precise equal setting of the two trace amplitudes. By doing this the signals from the plates to reference zero are balanced out leaving a trace of the differential signal (Vd) across the dipole pair.

Now here is the important observation. The phase of the differential signal was then compared to that of the signals on the individual dipole cylinders to show that there was a phase difference close to 90 degrees. Taking the average of these, we get 90 degrees.

The high longitudinal voltage measured must certainly generate an electric (E) field at 90 degrees phase difference to the dipole field. An H field must be generated from the rate of change of the E field (or in Maxwell's terms, the Displacement Current). This is a further shift of 90 degrees putting the longitudinal H field in phase (or in anti-phase) with the E field from the dipole. So this satisfies the requirements of the Poynting theorem.

If you read the appendix, you will see that the L matching system is actually a tuned circuit or in fact two tuned circuits making use of the low to high impedance transfer between the series and shunt connection. Using the off setting of the tuned circuits from resonance has been the method used to shift phase of the differential signal for this particular dipole. In fact I understand that the particular type of network was chosen for this purpose. To see how this works, refer to the vector diagram, figure 5



(1) Longitudinal voltage from dipole cylinder 1 to reference coax shield. (Vp1)

(2) Longitudinal voltage from dipole cylinder 2 to reference coax shield. (Vp2)
(Voltage (2) = Voltage (1))

(Phase difference between these voltages is 2.Θ)

(3) Longitudinal virtual centre voltage to reference coax shield resulting from the combination of (1) and (2). (VL)

(4) Differential voltage between the two cylinders. (Vd)
Note that providing voltages (1) and (2) are equal, this voltage is at 90 degrees to the longitudinal virtual centre voltage (3).
This is independent of the phase difference 2.Θ).

Figure 5 Phase Relationships between Longitudinal voltages and Differential Voltage on the balanced LL Network.

It can be seen from the diagram that **providing the longitudinal voltages Vp1 and Vp2 are equal and there is a phase difference of no particular value between them, there will be a differential voltage Vd at 90 degrees to the virtual longitudinal centre voltage VL. So its simply a matter of offsetting the frequencies of the two seperate L circuits, one from the other.**

As a guide line to the amount of frequency shift, a 45 degrees shift requires a frequency shift equal to fo/2Q. (The higher the Q the lesser is the frequency shift). Fortunately the longitudinal circuit is terminated in high impedance and hence longitudinal Q is high so frequency offset is not so great.

Returning to the subject of the second E field, one might suggest that power might be radiated as a monopole. My thoughts are that power radiated would be small as the matching network is set up for the higher radiation resistance of the dipole and would hardly be suitable to match the low radiation resistance of the monopole.

One might also argue that there could be a reverse condition where the longitudinal E field might also combine with the H field generated from the displacement current of the dipole E field to provide radiation in an enhanced mode. Again, the matching network is unlikely to be suitable for good power transfer. The network is designed for the dipole load and it is adjacent to the dipole where the radiation can be found.

H Field and Longitudinal Current Tests

As stated in the introduction, common mode or longitudinal current has been detected running down the coaxial line causing radiation from the line. We discussed in the previous paragraphs how a longitudinal voltage was developed to produce the secondary E field. Where there is voltage, current can flow and I assume the current is driven by that voltage. Current running down the coax line has been measured by close fitting a ferrite toroid over the coax, adding a single wire turn also through the hole and connecting to a 1 amp RF ammeter as shown in figure 6.

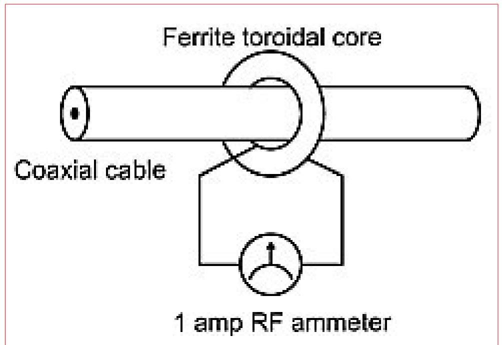


Fig 6 - Current Measurement

To make this measurement, the calibration was checked by first feeding a reference RF current directly through the ammeter. The same current was then fed via the shield of a short length of coax with the coupling device fitted. In my test device, the coupled reading showed about 80% of the direct reading. Calibration correction was derived from this.

I wanted to check right down the coax so I also made use of another larger toroid which allowed me to slide it over the end BNC connectors. To get sufficient useable reading with this arrangement, I fed the coax through the toroid hole twice. Of course the calibration procedure had to be repeated.

Measurements were carried on the 20 metre L+L matched EH dipole. Measurable current is present (and only present) when the dipole is correctly matched for the EH mode with low SWR.

Using 25 watts of power, maximum current occurs at the end of the coax coupled to the dipole and is around 0.5 amp. This decreases as the measuring device is moved down the coax becoming below a measurable value as a quarter wave is approached. Further along the coax, the current increases again to reach another peak at a half wavelength.

This confirmed that the current was present and that there was a standing wave of accountable intensity which is not offset by current within the coax centre conductor.

Inhibiting the Coax Current

20 metre trap with ferrite core

To enable tests on the 20 metre L+L with the coax shield current removed, I made up the coax line choke shown in figure 7. The balun is 10 turns of RG58 wound on a 1.25 inch diameter former with a 8 inch x 1/2 inch diameter ferrite rod down the centre. The inductance measured from one end of the outer sheath to the other is 11.5 uH. (This provides a rejection impedance at 14 MHz of over 1000 ohms.) The ferrite rod was held in place with by masking tape as a temporary means..

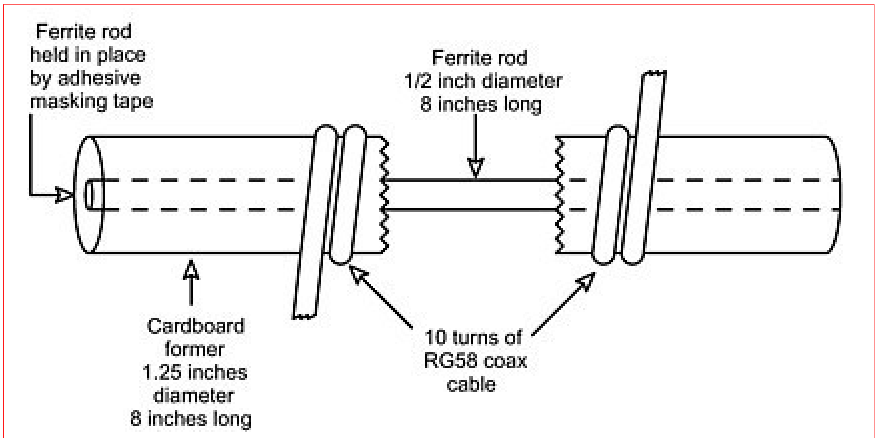


Figure 7 - Coax Cable Line Choke

Whilst the choke reduces the unwanted current to a considerable extent, it is far more effective to tune the choke with a parallel capacitor so that it forms a trap. The capacitor is connected to the coax braid between input and output of the choke. The choke described is tuned with about 10 pf of capacitance (including distributed capacity). The resonance at 14 MHz can be easily checked by inserting the coil of a dip meter into the tubular former. With a Q of around 100, the trap increases the rejection impedance to around 100,000 ohms.

One consideration using the trap, is IR loss due to circulating current within the tuned circuit. Circulating current loss is minimised by keeping the L/C ratio as large as possible. Of course the limit is when L is too large to tune in the presence of the coil distributed capacity. In the trap described, circulating current loss was derived as about 4% of the power fed differentially through the trap.

Air wound 20 metre trap

Obtaining a large ferrite rod might be difficult and expensive and a second air wound trap has been tested as shown in Figure 8. The inductor for this trap is wound on 55 mm PVC tube and requires no ferrite core. What is really required for winding the inductor is a small diameter coax and a suitable type is RG174.

The winding is arranged with sufficient turns to resonate at 14 Mhz with a 10 pf capacitor. Details of the trap formed are as follows:

Former - 55 mm PVC Tube
Cable - RG174
Winding - 13 turns
Length of coil - 36mm
Inductance - near 11 uH
Q - near 50
Measured differential through loss at 14 MHz - 0.2 dB

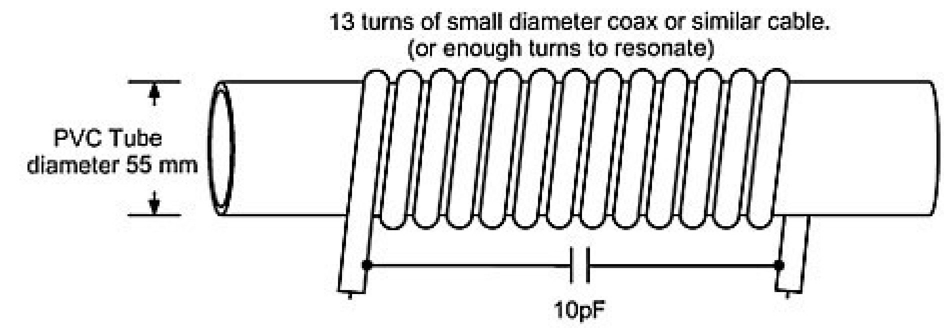


Figure 8 - 20 MetreTrap, Air Core

The tuned choke as a trap directly substituted for the original ferrite cored tuned choke. As with the ferrite core choke, interaction between the antenna tuning and the coax cable was inhibited and no coax shield current could be detected.

Circulating current through the tuning capacitor was measured as 0.28 amp for 50 watts of power transmitted. Based on the 20 ohms of loss resistance in the choke, this represents 3% of the power lost due to the circulating current.

With continuous power of 50 watts fed to the antenna, a slight warming of the choke was evident.

The air wound choke is quite good enough for the job and does away with the expense of the ferrite rod and problems sometimes experienced with flux saturation in the ferrite material.

40 Metre Air Cored Trap

A trap has also been made for 40 metres with similar construction to that described above for 40 metres.

Former - 55 mm PVC Tube
Cable - RG174
Winding - 26 turns
Length of coil - 77mm
Inductance - near 27 uH
Tuning Capacitor - 19 pf
Measured differential through loss at 14 MHz - 0.5 dB

All in all, the air cored traps are quite sucessful. There is a small through loss due to the traps. The 20 metre trap has a loss of 0.2 dB and the 40 metre trap has a loss of 0.5 dB. Connected through into a precision 50 ohm load both traps show an SWR reading of 1:1.

Where to place the trap

The trap can be placed right at the input connector to the antenna and this works OK. However I suggest putting it 1 to 2 metres down from the input connector. My tests using the 20 metre antenna produced signal reports 1 to 2 S points higher with a 1.5 metre length of coax tail between the antenna terminal and the trap. Field strength measurements without the short coax tail also indicated a skewing upward of the signal. Without the tail, the highest signal level received by a station at distance was found to be achieved when the bottom of the EH tube was tilted backwards by 45 degrees so that the skewed lobe was tilted down.

Comparison of Antennas

Tests were conducted with another radio Amateur who lives 11 km distant. I live partly up the slopes leading up to the Adelaide Hills and my friend is on the flats. Communication could be considered as close to line of site.

The 20 metre EH antenna with trap 1.5 metre down the coax line was compared with an end fed full-wave Inverted V antenna and a 2.5 metre high vertical whip. The EH antenna was erected 2.5 metres from the ground. The vertical antenna was mirrored against a large steel decking as a ground plane. The decking is 2.5 metres above the ground.

With 25 watts of continuous carrier power fed to each antenna, my friend gave the following reports:

> The EH antenna was 0.3 of an S point below the Inverted V.
>
> The EH antenna was 0.2 of an S point above the Vertical antenna.

Making corrections for the comparisons, the vertical antenna is down by 3dB because of loss in the matching. The EH antenna is down by 1.25 dB because of loss in the feeder cable and down by 1 dB because of 20% loss in its matching network, making a total of 2.25 dB loss. However its signal report was 0.2 of an S point up on the vertical antenna which could be considered as 1 dB higher. On these figures we could say the effective signal levels from the vertical antenna and the EH antenna were almost the same.

Considering the inverted V to have negligible matching loss and the fact that it was 0.3 S point (2 dB) up on the EH antenna we could also say that the corrected readings for the three antennas were very close.

I also noted the receive levels from his single sideband speech transmission:

> I recorded the Inverted V as one S point above the EH Antenna.
>
> I recorded the Vertical antenna as one S point below the EH antenna.

Summary

In this second article I have outlined a theory on how this antenna works, somewhat modified to the earlier theory first presented in the "EH Handbook" by Ted Hart. These theories assume acceptance of principles introduced by Maurace Hately relating to the Poynting Theorum and which have been open to question by some sceptics. Personally, I prefer to keep out of that particular argument as I do not believe that I have adequate background in the fundamental principles of electric and magnetic fields in space to get involved.

I have drawn attention to a phenomenon of this antenna which causes current to flow in a longitudinal mode down the coax feeder and cause radiation. I have described how a tuned trap can be used to inhibit this current.

Several tests have been described which demonstrate that even with longitudinal current inhibited, the antenna mounted at a mere 2.5 metres, can be made to radiate as well as other antennas which are larger or mounted higher.

The problem with antennas which are small compared to a wavelength is that their radiation resistance is very low in comparison to loss resistance in matching them. Hence most of the power supplied is wasted in loss in the matching network. In this EH antenna, the effective series radiation resistance is raised allowing it to operate more efficiently. Also because of the higher resistance, its Q is lower and hence its bandwidth is much wider than, for example, the magnetic loop. These are the reasons it can be made to work well as a small antenna.

I might point out that my discusion has been confined to the EH antenna with L+L type matching but there are other versions of the EH antenna. There is one type Ted Hart has called a backpacker which uses a matching network referred to as the L+T and another one new (at the time of writing) called the Star. More information on these can be found on the EH Antenna web site.

Appendix
Some notes on how to derive component values for the Matching Network

For the EH dipole discussed, we can consider the dipole input as the equivalent circuit of figure A1. For the EH antenna with tubular elements of length around Pi times the tube diameter, the capacitance is around 10 pF or less and the parallel radiation resistance would appear to be close to 2368 ohms (as given by Ted Hart).

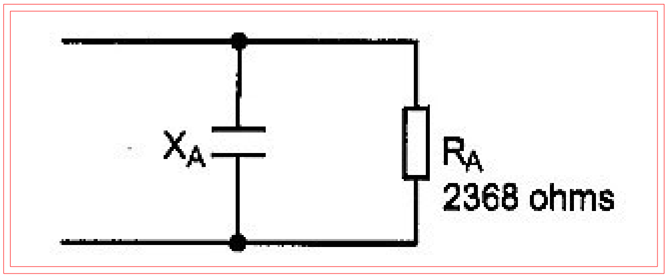


Figure A1
Equivalent Antenna Constants

If we ignore the unbalance to balance conversion and the need to address the phase shift, the 2368 ohms shunt resistance can be matched to the 50 ohms source circuit with a simple L network as shown in figure A2. We can think of an L network as a tuned circuit fed in series from the 50 ohms source and the output taken in parallel. The L and C components are selected to obtain a loaded Q such that 2368/50 is equal to (Q^2 + 1) the ratio of parallel to series resistance of any tuned circuit at resonance. So Q is close to 6.8. Hence the reactance of the series inductive arm is 6.8 x 50 = 340 ohms and the total shunt capacitive reactance (including antenna shunt reactance) is the same.

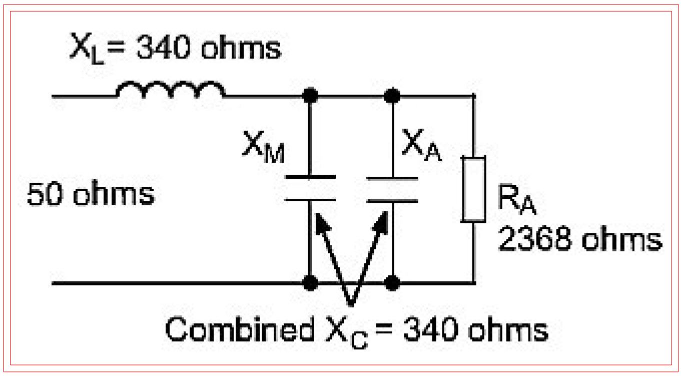


Figure A2 Basic L Match
Xa =Antenna Capacitance
Calculated Xc=Xm+Xa

However in the model of the EH antenna discussed, the balanced form of the L network is used as in figure A3. Apart from balancing the circuit to the dipole, it also provides the phase shift as described in the main text. One can consider this form to be two of the L networks previously described but with their inputs in parallel and the antenna load connected across the two L network output legs. Each L network half transforms half the output load resistance (Ra) to twice 50 ohms. The four reactive elements can be calculated from the square root of 50 times Ra which, for RA = 2368 ohms, gives reactive elements equal to 340 ohms, the same as for the simple L network. At say 14 MHz, this works out close to 4 uH for the inductors and 33 pF for the capacitors (including shunt capacitance reflected by the dipole).

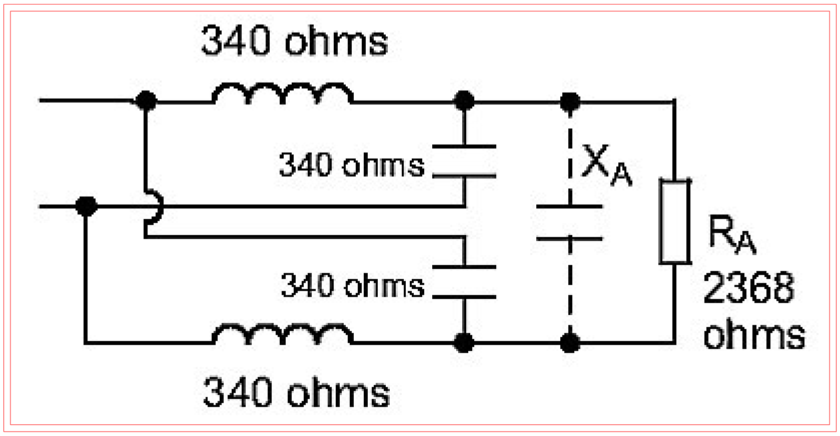


Figure A3 Balanced L Match

The calculation does not take account of the need for resonance offset between the two L circuits to get the required phase shift. First working from the calculation described above, I found it necessary to reduce the inductance of the lower coil a little by taking off one turn of the winding. The one less turn is shown in figure 2.

References

1. Original Article on the EH Antenna - Lloyd Butler VK5BR - Amateur Radio. April 2003.

2. The EH Antenna Web Site (Sponsored by Ted Hart W5QJR) - http://www.eh-antenna.com

3. Various Articles on the EH Antenna by Lloyd Butler VK5BR -