SOME DIFFERENT IDEAS ON THE EH ANTENNA

Photo 1

Measuring of Common Mode Current on the Coax at the input to an EH Antenna

A lot of theory has been written about the EH Antenna and its operation in a Crossed Field mode. However here are some Measurements and Test Details which support some different ideas of how and why the antenna is able to perform.

by Lloyd Butler VK5BR

Introduction - Background of Theories Concerning the EH Antenna

The EH Antenna was introduced as small dipole making use of the controversial Crossed Field Theory. One of the conditions for this mode of radiation is to arrange the magnetic (H) field in phase with the Electric (E) field. The original theory provided by the inventor was based on feeding the antenna through a 90 degree phase shift network which he claimed shifted the current fed into the antenna by 90 degrees relative to the voltage across it. This didn't make any sense as you cannot alter the phase relationships within any load impedance from outside the impedance. You either have to alter the characteristics of the impedance itself or using the phase shift network, couple in some way into the impedance from the input of the network as well as from its output.

In earlier tests on the L+L EH antenna, I observed that in addition to a differential voltage across the dipole pair, there was also a voltage developed longitudinally and this appeared as 90 degree phase shifted to the differential voltage. I figured that there must be two E fields acting, one from the differentially developed voltage and the other from the longitudinal voltage acting at 90 degrees to the other. This was described in reference 1.

Both these two earlier theories further evolved around an H field developed from Displacement Current of the E field. The idea of a displacement current in space developed from an E field seems to be more of a mathematical tool used by Maxwell to explain fields and radiation rather than a physical identity. The validity of that theory has been questioned by many.

Getting away from that theory, I moved towards using direct series current for the H field as something easier to accept. I figured that using the H field developed from the series coils would put that field in phase with the E field across the dipoles and this led to the construction of my X2/X3 antennas. To verify the theory, I set up a test to monitor the relative phases of the actual E and H fields and confirm that they were in phase. The test was described in one of my articles on the X2/X3 (Reference 2).

Antenna series resistance is easily measured using the X2 antenna circuit and this proved to be considerably higher than that of the coil loss resistance. I had always figured, for EH or any of these small antennas, that if we could show considerable resistance rise above that of the coil resistance and much more than the calculated radiation resistance of a simple dipole, then the difference increase would surely be increased radiation resistance and improved radiation. Hence, there would be proof that the two fields were interacting to enhance the radiation. I was initially convinced that the rise in series resistance was the result of those interacting fields and that the crossed field enhancement was occurring. However, as I described in reference 3, I eventually discovered other reasons for that rise in resistance.

Getting back to the EH antennas, it became apparent quite early in the experiments that due the unbalanced dipole connection in all of the EH antennas, a large amount of longitudinal or common mode current component flowed in their coaxial feedlines. I was able to eliminate this by inserting a tuned balun or trap in the coaxial line and this prevented interaction between the antenna tuning and the length or location of the line.

What also became apparent was the need for a short length of line feeding the EH antenna to make it work the best. If the trap was placed right at the antenna input or the antenna was properly balanced, about two S points in signal level was lost. All the EH amateur antennas are unbalanced and it has become clear that they need a longitudinal or common mode current component operating over at least a short section of the transmission line to achieve performance. The main

theme of this article deals with the measurement of that current component and some theories on how the antennas work without the crossed fields.

It is interesting that the VK5BR -X2/X3 antennas started off as balanced crossed field antennas. Similar to the EH antenna, their signal level improved by about two S points when the antenna was connected up in an unbalanced mode to become the X3U. This was discussed in my last article on the X3 (Reference 3).

Because of these observations, I set out to measure in more detail, currents running in the two legs of the coax feeding the EH antenna and also the currents running in the individual dipole legs. What follows is detail of the test gear used, the measurements carried out and conclusions drawn from measurements.
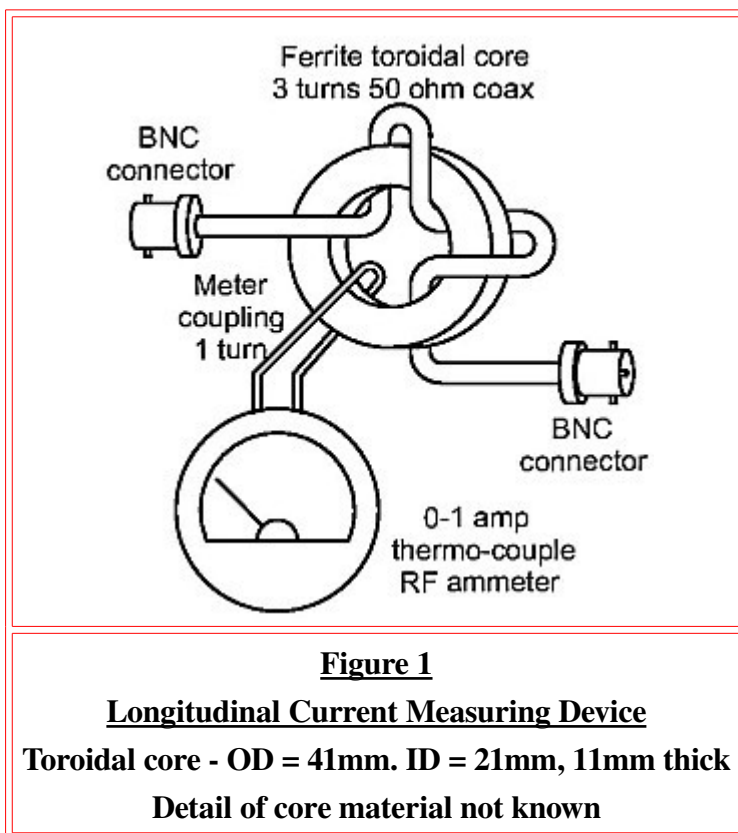
All in all, it does appear that the successful performance of the EH antenna is more to do with the longitudinal conduction path down the cable extending the effective antenna length, rather than due to the Crossed Field theory. Evidence of the conduction path is shown by the common mode current which can be tracked down the full length of the coaxial transmission line.

The common mode currents can be blocked by a trap anywhere in the coax cable to limit the length of the longitudinal conduction path to the distance between the trap and the antenna input connection. Even if this distance is quite small, it can be quite effective in increasing radiation resistance to improve radiation efficiency.

Specification of Test Gear

This section quantifies the calibration and performance characteristics of the test gear used in the common mode testing described in a later section. As the tests were carried out on a 14 Mhz EH antenna, the specifications are confined to that frequency.

Device for measuring common mode current on 50 ohms coax (Refer Figure 1)

Figure 1

Longitudinal Current Measuring Device

Toroidal core - OD = 41mm. ID = 21mm, 11mm thick

Detail of core material not known

Calibration

Tests were carried on 14 Mhz to determine the effect on the signal passing down the coax when inserting the device in series with the coax. The coax cable was loaded into a Marconi Power Meter which has a precision 50 ohm termination load. Power fed to the meter was registered by the meter scale as 20 watts.

An SWR meter in series with the cable read a precise 1:1 ratio. With the Device inserted and the SWR meter on the source side of the device, the SWR still read a precise 1:1. Registered power dropped by 1 watt - This calculates to an insertion loss in the device of 0.2dB.

Calibration of the meter current reading at 14 MHz was carried out by passing a current near 2/3 FSD through a wire ran through the toroid centre opening. This was compared to the same current with the wire directly connected in series with the RF ammeter. From this, the calibration for the device was determined as 1.2 times the reference direct reading.

Application

The measuring device is inserted in series with the coax line at any connector junction of the coax using BNC connectors so that the magnitude of common mode current can be derived. (See Photo1).

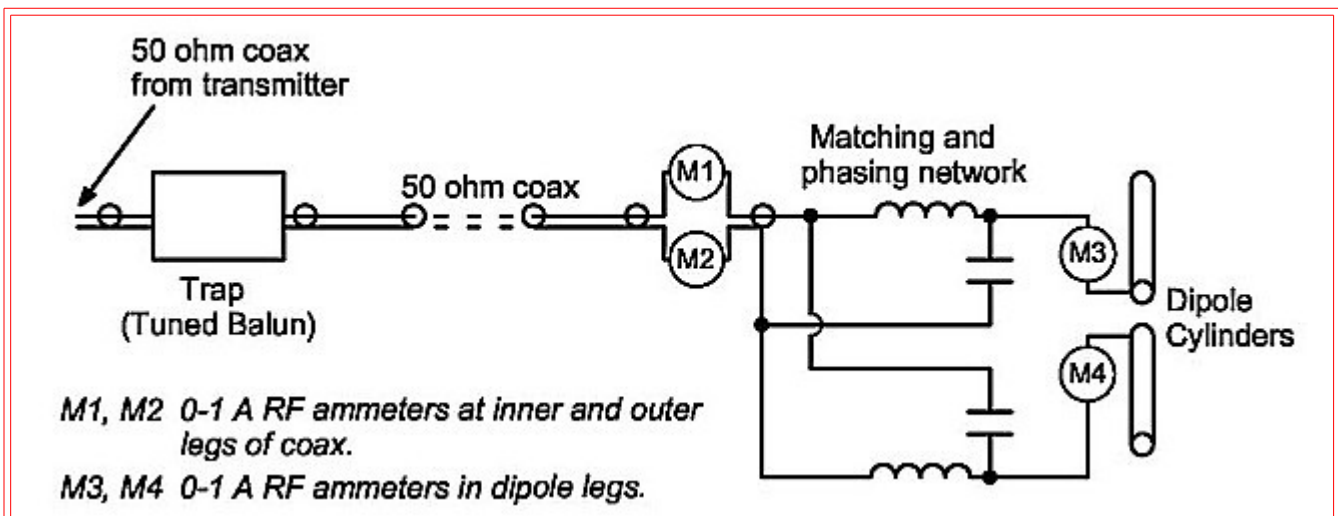# Direct Measurement of Current in Legs of Coax Line and Legs of Dipole Cylinders using RF Ammeters. (Refer Figure 2)

Figure 2

Measurement of Current in Coax Transmission Line Legs and Legs of Dipole Cylinders of L+L EH Antenna

Accuracy of thermo ammeters

As a check on the accuracy of the thermo couple RF ammeters used in the device (figure 1) and used as direct reading meters in other tests (refer figure 2), the current readings were checked against the current calculated from the power indicated by the Marconi power meter scale using $I = (P/50)^{-2}$. For the two RF ammeters used, one read 5% lower than the calculated figure and the other read 7% lower. This is about as good as one might expect from these thermo coupled instruments .

Device to Measure Maximum & Minimum Common Mode Current points down Transmission Line (Coax or 1/2 inch 300 ohm open line). Refer Figure 3.

Ferrite toroidal core

Transmission line
(Coaxial cable)

0-1 mA   47R
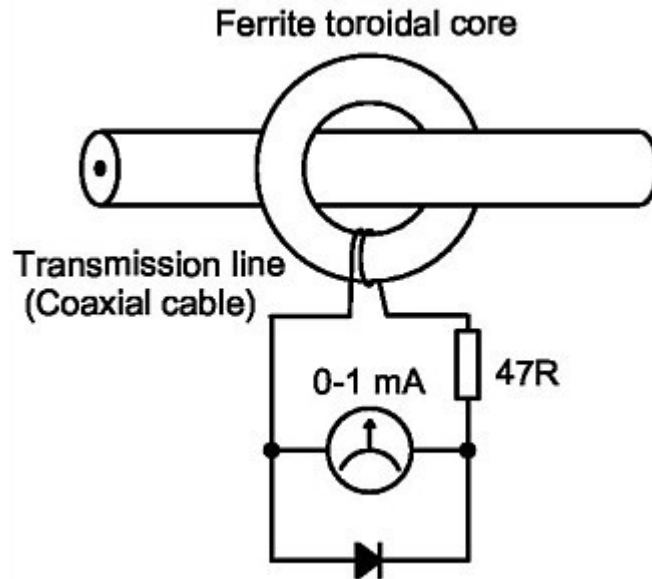
Figure 3
Device to measure Max. & Min. points of Common Mode Current
Inner diameter of toroid is large enough to slide over BNC connectors at cable ends
and also the 300 ohm 1/2 inch TV open line cable used with the X3 Antenna.
Toroidal Core - Amidon FC500 Mix 61, OD = 30mm, ID = 18mm, 6mm thick

Calibration

Tests were carried on 14 Mhz to determine the effect on the signal passing down
the coax when inserting the device in series with the coax. The coax cable was
loaded into a Marconi Power Meter which has a precision 50 ohm termination.
Power fed to the meter was registered as 20 watts.

An SWR meter in series with the cable read a precise 1:1 ratio. With the Device
inserted and the SWR meter on the source side of the device, the SWR still read
a precise 1:1. Negligible power loss is assumed as there was no discernible
change in the power reading.

With 20 watts fed down the cable to the load, the 0-1 mA meter in the device
read 0.1 ma. This device is quite sensitive and it has to be used with currents
down the line more appropriate to powers around 1 or 2 watts. As such, 0.1 mA
represents a very low degree of common mode current relative to the differential
currents running for the 20 watts into the load. The device has essentially been
used to determine comparative values of common mode current measured at
different locations down a transmission line. However I did determine that 0.22
amp of RF current at 14 MHz corresponded to 1mA, the full scale deflection of
the meter. A reading of 0.1 ma on the meter is therefore 22 mA and 29 dB down

Photo 2

Measuring of Common Mode

Current on open wire line

to the X3 Antenna

on the differential current for 20 watts into 50 ohms.

Application

The toroidal core is slid down the whole length of the transmission line to record the relative change in common mode current over the length of the line. Points of maximum and minimum common mode current can easily be determined. As a calibration was carried out on the meter relative to actual RF current, it could also be used determine the magnitude of the current in real terms. Photo 2 shows measurements being taken on the line pair of the X3 antenna.

Tuned Longitudinal Current Trap for 14 MHz (Photo 3)

The winding is arranged with sufficient turns to resonate at 14 Mhz with a 10 pf capacitor fitted inside the PVC tube and connected between the coax outer conductor two ends.
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
    Estimated longitudinal rejection impedance - 48 Kohms

Photo 3 - 20 METRE TUNED TRAP

Measurements of out of balance currents in coax legs and resultant common mode current component.

This section records measurements taken which show the extent to which currents in the coax legs and the dipole legs are out of balance and measurements of the common mode current component which is developed. The figures show that current in one leg can be as high as twice the current in the other.

Some initial measurements of Out of Balance Current on the 20 metre L+L EH antenna

The following is one set of measurements recorded to demonstrate the unbalance which occurs between the inner and outer legs of the coax cable feeding the L+L EH antenna. (Refer Figure 2).

Test series A1   No Trap fitted With about 35-40 watts of power and 5 metres of 50 ohms coax between the transmitter and antenna terminal, the line currents measured as follows:

0.5 metres down from antenna:
   inner coax conductor - 1 amp
   outer coax conductor - 0.4 amp

At transmitter end:
   inner coax conductor - 1 amp
   outer coax conductor - 0.5 amp

Test series A2   Trap fitted at 2 metres down from the antenna

input. With about 20 watts fed from the transmitter, the line currents measured as follows:

0.5 metres down from the antenna:
   inner coax conductor - 1 amp
   outer coax conductor - 0.5 amp

Near the output of the trap:
   inner coax conductor - 0.7 amp
   outer coax conductor - 0.6 amp

On cold transmitter side of trap
   inner coax conductor - 0.58 amp
   outer coax conductor - 0.58 amp

At transmitter end of coax:
   inner coax conductor - 0.58 amp
   outer coax conductor - 0.58 amp

This demonstrates the extent of the unbalance of currents between the inner and outer legs of the coax, the difference being the common mode current. Without the trap fitted, this out of balance current condition extends right from the antenna to the transmitter output.

It also demonstrates that the trap is effective in restoring balance in the currents on coax connection between transmitter and trap.

People have been talking about induced current running down the coax shield - but observe that the higher current is in the inner conductor not the outer.

Note also that even with the trap, there is probably about 3 metres of considerable longitudinal conduction component flowing between the trap output point and probably near the top of the antenna.

More measurements of Out of Balance Current on the 20 metre L+L EH antenna
(Refer Figure 2)

Test series B1 - 50 ohm coax cable - 9 metres long - Trap fitted at transmitter end of this coax length.

Power used about 30 watts to get adequate reading on 1 amp FSD RF ammeters.

RF Ammeters inserted directly in the wire connected at each dipole leg

Top Cylinder - 0.35 amp

Bottom cylinder - 0.1 amp (Note 1)

RF ammeters connected in coax legs 1.5 metres down cable from antenna

Inner conductor - 0.5 amp
Outer conductor - 0.2 amp
Current difference - (0.5 - 0.2) = 0.3 amp
Check with toroid coupled instrument (figure 1) around whole coax - 0.3 amp (common mode)

Measurement with toroid coupled instrument (figure 1) right at antenna. - 0.45 amp (common mode)

Test Series B2   - Trap moved to 1.5 metres down cable from antenna

RF Ammeters inserted directly in the wire connected at each dipole leg

Top Cylinder - 0.3 amp
Bottom cylinder - Barely readable (note 1)

Measurement with toroid coupled instrument (figure 1) right at antenna - 0.4 amp (common mode)

Test Series B3   - Trap moved to antenna input point.

RF Ammeters inserted directly in the wire connected at each dipole leg ,

Top Cylinder - 0.1amp (note 1)
Bottom cylinder - Almost no deflection (note 1)

Measurement with toroid coupled instrument (figure 1) right at antenna - No meter deflection (little common mode)

I noticed that one of the two matching inductors was getting quite warm.

Note 1 - with the cramped scale for low readings on the RF ammeters, it is almost impossible to interpret a reliable figure below 0.2 amp.

The Tests clearly show that the unbalance of currents extends beyond the transmission line legs to the dipole itself.

Tests to determine where best to Locate the Isolation Trap

The best place to have maximum common mode current seems to be right at the antenna where it can be most effective for radiation. The test was carried out on the 20 metre L+L EH Antenna to determine what length of common mode active cable provided maximum unbalanced current near the antenna input. The active length is set by the location of the trap in

the cable. To check this out, the detector (Figure 3) is run down the selected length of the active coax cable section.

Putting the trap (Photo 3) at 4.5 metres down from the antenna input connector seemed to work out well. That provided maximum unbalanced current at the top end of the cable, whilst still maintaining a high value right down to 2.5 metres from the top. Beyond that it tapered down to almost nothing at the output connection of the trap.

Experimentation with placement of the trap showed that the trap could be put at less than 4.5 metres but if it was put at a greater length, the maximum unbalanced current point moved down the cable away from the top. So it appears that for the 20 metre antenna, 4.5 metres down from the top is a desirable place to put the trap. With the addition of the antenna itself, that represents a length of about 1/4 wave.

Explanation of Longitudinal or Common Mode Current.

Let us consider any two wire transmission line. Each leg of the line develops a magnetic field. The currents in the two legs run in opposite direction and if these currents are equal, the fields cancel and there is no resultant field. If the currents are not equal, then there is a resultant field equivalent to being generated by a current equal to the difference between the two individual currents in the two legs. This equivalent current difference is called the longitudinal mode current or common mode current. Note that its vector direction is that of the leg which has the highest individual current of the two.

The concept might be easier if you think of the two legs in a balanced line pair such as open wire line or twisted cable pair. Of course there is also the electric fields around each leg of the pair and for balance each leg must also have equal capacitance to ground or other adjacent objects.

The coaxial cable is different in that the electric fields are confined to within the dielectric space between the inner and outer conductors and are shielded from venturing into outer space by the concentric nature of the outer conductor.

In trying to understand something like this, one has to first consider the case where frequencies are lower. Hence, the line lengths are short enough compared to a wavelength such that standing waves are practically non existent..

In fact you can take the balanced line pair which feeds your home telephone.

Any competent telecommunication technician could tell you that if you get an unbalance to ground due to resistive leakage or capacitive unbalance, some of the current in one line leg can return via the ground path instead of via the other leg. So we get an imbalance of current flowing in the two line legs. Because the individual fields around the line legs no longer cancel, the line can induce crosstalk into other circuits and vice versa the line can pick up noise from other fields in the vicinity..

Of course for the EH antenna, we are concerned with coaxial lines but the process I have described is the same. If there is an unbalance of resistance or reactance to earth by the antenna at the coax end, then some current from one leg returns via earth. The vector sum of the current in the two legs plus the current in earth must be zero. Hence there has to be more current in one leg than the other.

The effect of unbalanced capacitance to ground and how longitudinal or common mode current component is generated was described in reference 1. However I did not explain how the effect is multiplied by the Q factor of the antenna tuned circuit. This is demonstrated in more detail by figure 4.

Figure 4

Shows how Antenna Q multiplies Common Mode Component on the Coax Line
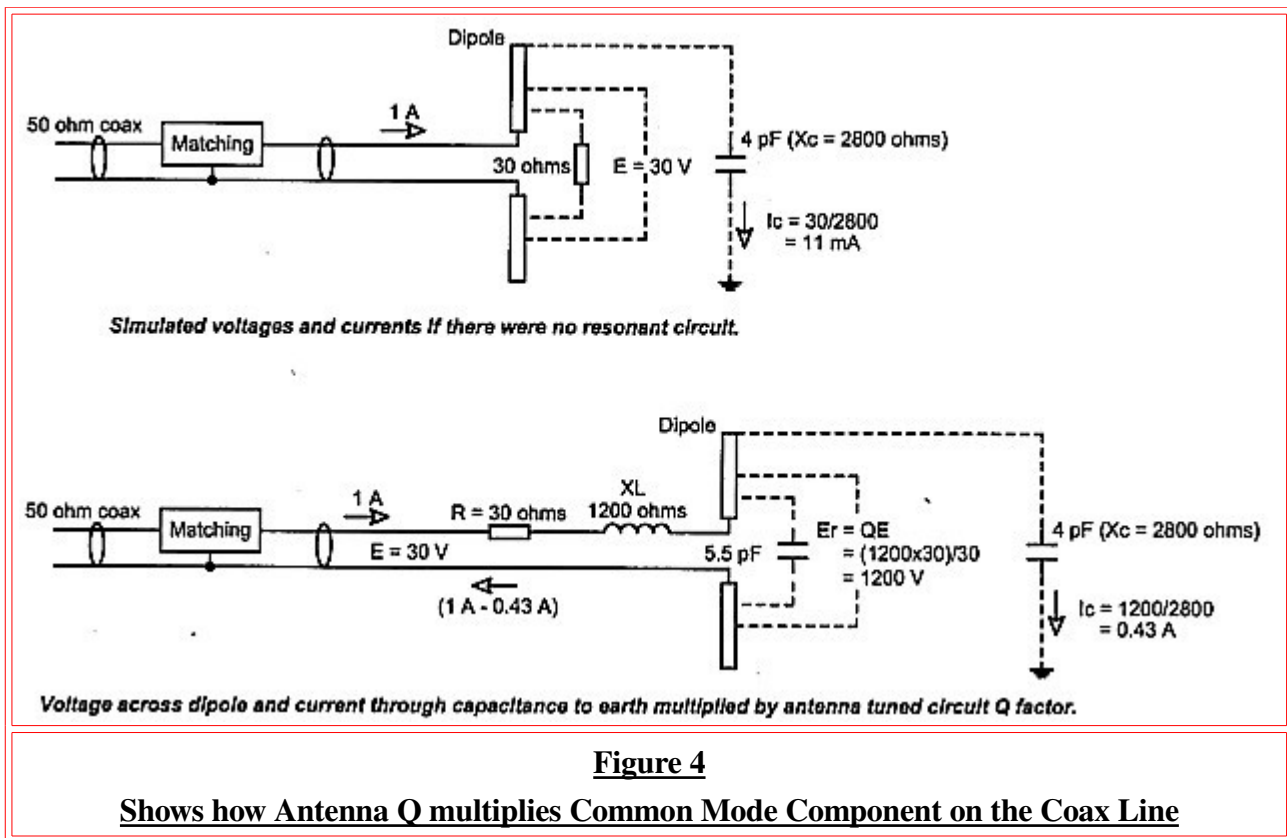
The diagram is typical of circuit conditions for a tuned 14MHz small antenna such as the EH with an antenna resistance of 30 ohms. If we first imagine the antenna with a 30 ohm load but without any resonant circuit, we see that 1 amp of differential current develops 30 volts across the 30 ohm load. Return current via a 4 pf capacitance to ground merely accounts for 10 mA of current. (The 4 pf is an arbitrary figure and will depend on closeness of the antenna to earth or nearby objects)

But bring it to resonance by loading with a typical 1200 ohms reactance and we get the voltage multiplied by Q = (30x1200)/30 = 1200V. Since the bottom dipole half is connected to the coax shield it is essentially at earth potential (this might change due to the effects of the common mode current itself but let's leave that for the purposes of the argument). So we can consider the potential applied from the top dipole element to ground is also 1200 volts and this will now pass a Q multiplied current of 0.43 amp through the 4 pf to ground to return via the earth loop.

Because there is 0.43 amp returned via the ground loop, there is 0.43 amp less returning to the source via the coax outer conductor. So the two currents are out of balance and we have a magnetic field developed around the coax cable from the difference current (or common mode current).

Some have argued that there is not enough capacitance to ground for what I have described. However I know from my experience with the X3 antenna that there is considerable coupling to ground which shows up in the measured antenna series resistance and which alters value with change in height. Whether that coupling is capacitive, inductive or due to radiation absorption, I cannot be certain. However whatever that form of coupling takes, if there is different degree of coupling from one leg than from the other, the result is the same as I have described for capacitance coupling.

The common mode component will run as far as you let it, either over the whole the coax length, or to a point where it is stopped by the trap. If you make length between the trap and the antenna too great, you get standing waves on the common mode component. Keep it less than 1/4 wave and you get a fairly constant value of current over the common mode active length.

With a longitudinal current component fairly constant over nearly 1/4 wave length of the coax cable, this section of the cable provides additional antenna length to aid radiation.

One can be misled by the strong electric field developed across the dipole due to the high voltage

and which will light up a fluoro lamp so brilliantly. If you balance the dipoles against ground, voltages from each dipole leg to ground are in opposition, no current returns via ground and there is no common mode component in the coax. As we know from our tests, it then doesn't radiate as well even though there is still brilliant illumination of the fluoro lamp.

Earth Currents

I have been questioned whether induction into ground really takes place in the EH antenna causing current to return via ground. Here are some more interesting facts concerning current measurements taken at the transmitter output connector:

1. If I run a bypass jumper via an RFammeter from the shield side of the connector or the coax shield direct to ground, I measure high current. The jumper provides a path for some of the current returning via earth.

2. If I break the coax lead and insert ammeters in each leg of the coax I get about twice the current in the inner conductor as in the outer conductor. Quite clearly there has to be a balance of current returned and the only path is via the transceiver earth connection or via its mains earth.

These facts prove conclusively that much of the return current is via earth and as the antenna and the other end of the feeder coax are all floating, the only way it can get into earth is by some form of induction or radiation from the antenna.

In effect there is a longitudinal current loop which includes the coax feeder. The loop can be broken by inserting the tuned trap anywhere in the coax line and this presents high impedance to any longitudinal or common mode current component running in the line. However, when the loop is broken, a standing wave of the longitudinal component is set up between the point where the trap breaks the loop and the top end of the antenna.

Theory on Short Coax Tail

In the introduction I pointed out that the EH antenna radiates about two S points better with a short length of coax tail as part of the unbalanced antenna circuit. The following is an explanation of why this occurs:

Suppose we fit the trap several metres down from the antenna input. If we monitor the longitudinal current component anywhere on the transmitter side of the trap or immediately on the other side, we see negligible common mode current component. However if we monitor along the coax closer to the antenna we again see a longitudinal component. There can be a very good explanation for this using basic antenna principles:

Unless the antenna is balanced, there is longitudinal conduction path between the top tip of the dipole to the connection point at the trap and this conduction path forms a radiating element. As with any radiating element, current distribution is such that maximum current is at the centre of the element and there is zero current at the ends. So as you move away from the trap towards the centre of that element, up goes the current. Clearly the coupling of signal into the radiating element must be off-centre. But anyone familiar with the Windom antenna knows that this is a valid method of feed.

Fig 5 shows the 20 metre EH antenna with a dipole 0.5 metre long and trapped to block longitudinal current in the coax cable beyond 2 metres below the top of the dipole. On its own, the radiation resistance of the dipole calculates to a mere 0.2 ohm. However with unbalanced connection to the coax providing a longitudinal path extending to the trap output connection, there is an effective radiator length of 2 metres. The calculated radiation resistance at the center of the 2 metres is 3 ohms but it is even higher at the off-centre point where it is fed. Hence is value is high compared to the series loss resistance and the efficiency is very much higher than that achievable for the simple 0.5 metre dipole operating when the antenna circuit is balanced.
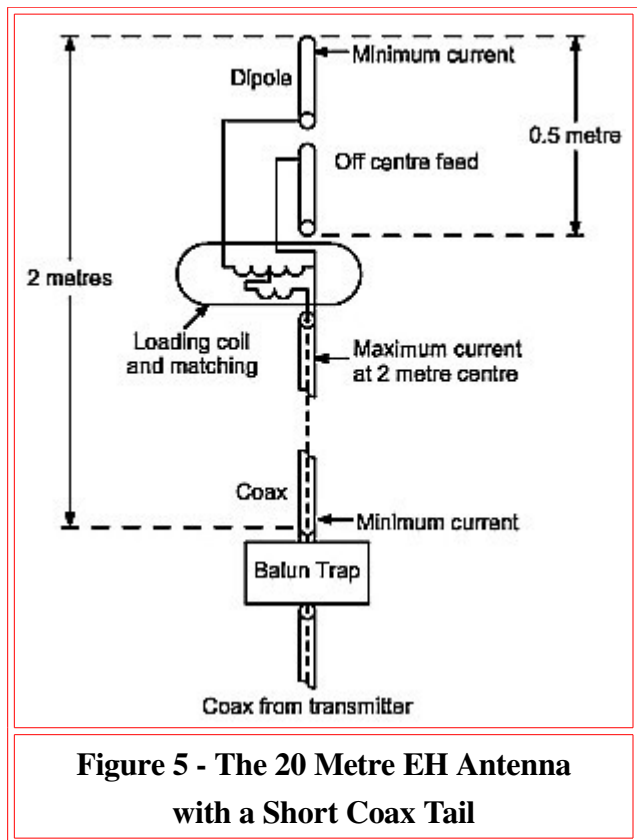
**Figure 5 - The 20 Metre EH Antenna with a Short Coax Tail**

The antenna works better in its unbalanced connection because radiation resistance increases with the square of the radiating element length and the radiation resistance of the longer radiation element formed is greater than that of the shorter dipole on its own. As the efficiency is related to the ratio of radiation resistance to loss resistance, radiation is improved.

Conclusions

I have reported on a lot measurement details relating to the longitudinal or common mode current component reflected to the EH antenna transmission line.

Much as I did with my own VK5BR-X2/X3 short antennas operating in an unbalanced mode, I have eventually reached the conclusion that the successful performance of the EH antenna is more to do with its unbalance causing an extension of effective antenna length down part of the feeder than due to the controversial crossed field theory.

A tuned balun or trap can be placed somewhere in the coax line to prevent RF getting back into the radio shack, to inhibit earth loop current and to set the length of line which operates active in a longitudinal mode. The trap should be placed down the cable where current is kept high over a considerable length of the cable. A point a bit less than 1/4 wave down the cable from the dipole works fine, but if made much longer than 1/4 wave, the current
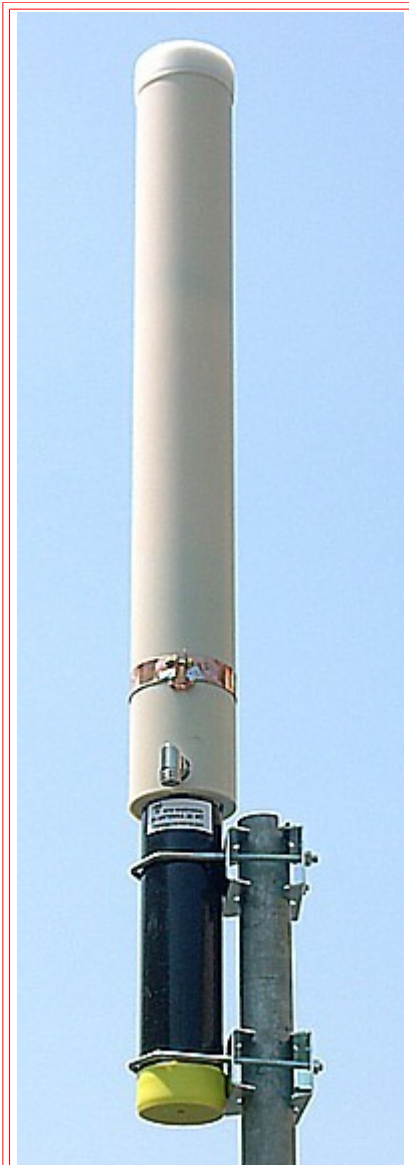
Photo 4
A 20 metre Star EH Antenna
made by Arno Electronica

maximum will move down the cable away from the dipole.

Even with longitudinal current blocked with a trap only a short distance down the cable from the antenna, the antenna operates efficiently because the effective length of the radiating element is increased by the short unbalanced length of cable .

References

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2. The VK5BR-X Antennas - Some modified ideas on how they perform - Lloyd Butler VK5BR - Amateur Radio, (to be published).

3. The VK5BR-X2/X3 Antennas - Operation when Unbalanced. - Also see Amateur Radio, (Reference 2).

4. Other articles by VK5BR in Amateur Radio - April 2003, May 2004, July 2004, Sept 2004.
    Also refer to VK5BR Web Site
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