THE EH AND X2/X3 ANTENNAS - WHAT REALLY MAKES THEM WORK

A Summary of Experimental Work carried out by the Writer and published in the CW Operator's QRP Club journal "Lo-Key" December 2005.

Demonstration of 10 metre & 40 metre EH Antennas by VK5BR at a meeting of the CW Operators QRP Club (Photo by Don Callow VK5AIL)

[We thought these antennas worked in a Crossed Field Mode but having built a number of these antennas and subjected them to some vigorous testing, the writer has some different ideas on what makes them work.]

by Lloyd Butler VK5BR

Introduction

I have spent several years building and testing EH antennas as well as my own X2/X3 antennas, all of which were supposed to operate on the Poynton based controversial crossed field theory first introduced by Maurice Hately. However it now appears that operation is really based on effects which result from unbalancing the antenna so that a longitudinal radiation element is established from the antenna down the feedline.

The article is really a summary of my involvement with the antennas and the path I have taken which leads me to various conclusions I have drawn. Much more detail of the experiments can be found on my web site or in articles in "Amateur Radio".

Some Background

The EH Antenna was introduced as small dipole, about 2% of a wavelength long, which made 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 Ted Hart 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.

Three versions of the EH antenna for amateur radio have been introduced by the inventor using different types of phasing and matching networks. These have been called the L+L antenna, the L+T or Backpacker antenna and the Star antenna as shown in figure 1. (L+L and L+T refers to the type of network used). Most of my tests were carried out on L+L version.

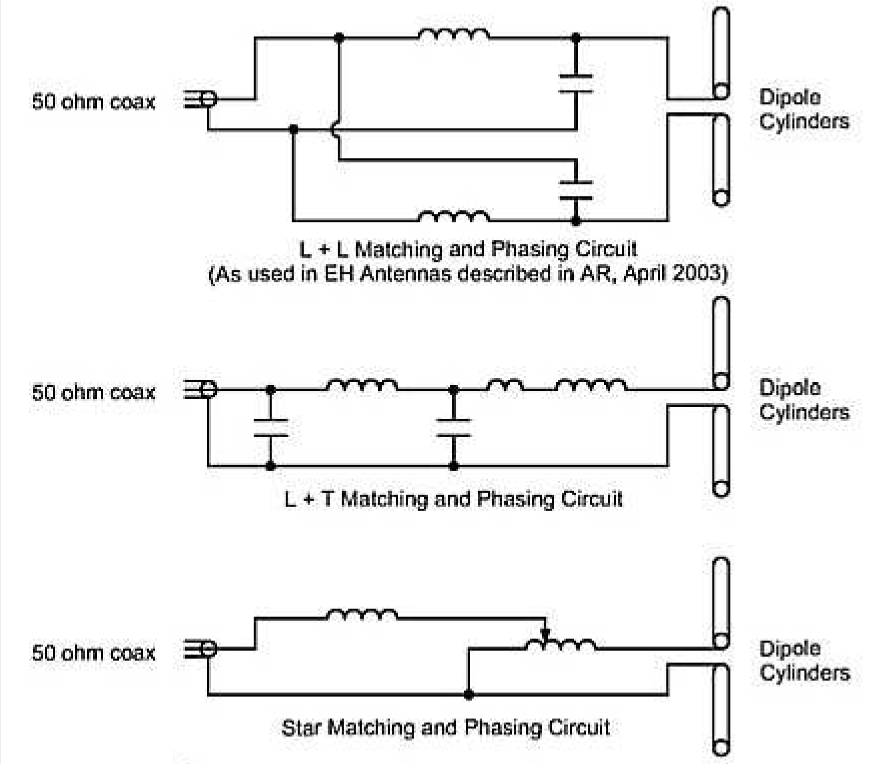

Figure 1 - Phasing and Matching Networks of EH Antennas

VK5BR
40 Metre
L+L EH Dipole

Arno
Elettronica
40 Metre Star
EH Antenna

In my earlier tests on these antennas, 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. The X2/X3 tubular dipole elements are similar to the EH antenna although, for construction reasons, they are square rather than round. The coils are placed so that their dominant magnetic fields are at right angles to the electric field between the dipole elements.(see figures 2 and 3).

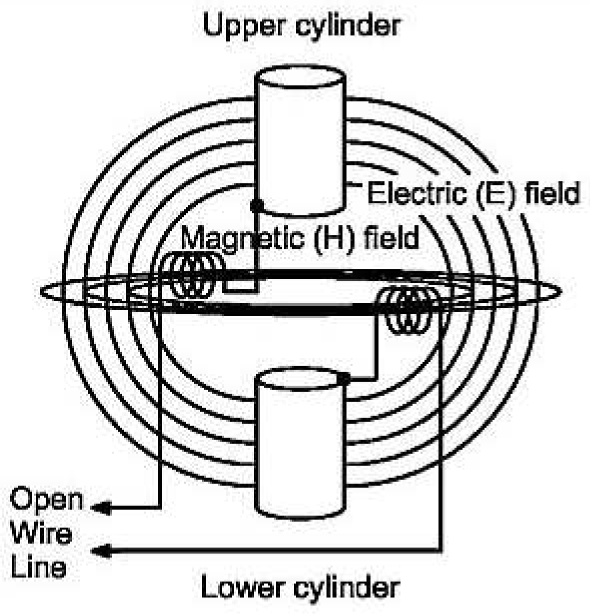

Figure 2 - VK5BR_X2/X3 Antenna Field

Figure 3 - VK5BR_X3 40 Metre Antenna Coil Assembly

Tuning and matching in the X2/X3 system is made easier from within the radio shack by feeding the antenna via open wire ladder line and allowing resistance and reactance to be fed up the line from a Z Match Tuner in the radio shack. The X2 and X3 systems are shown in figures 4 and 5.

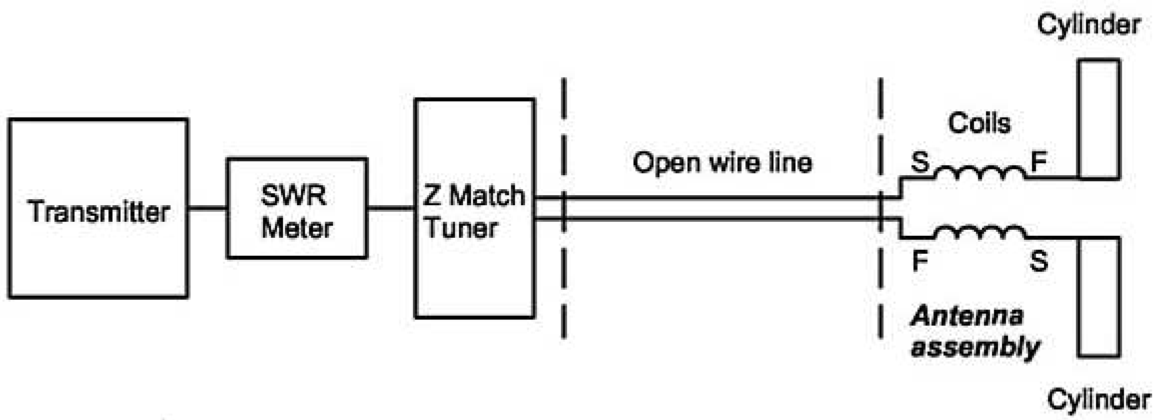

Figure 4 - VK5BR_X2 Antenna Tuning & Matching System

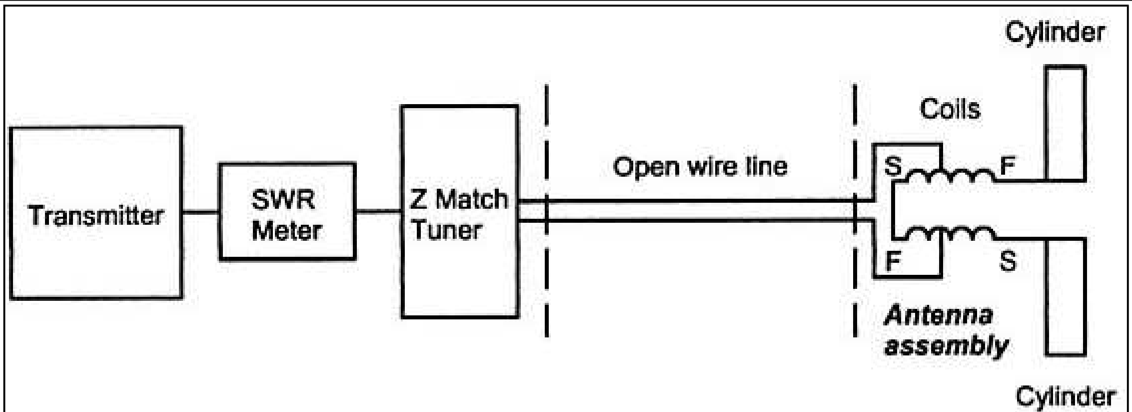

Figure 5 - VK5BR_X3 Antenna Tuning & Matching System

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, further down track I discovered other reasons for that rise in resistance. Firstly I was getting additional loss resistance because of poor insulating material separating the plates and secondly (particularly on the lower frequency bands) there was direct induction into earth and surrounding objects.

At this point I started to question whether the crossed field theory was valid at all and I went looking for other explanations to explain the operation of the EH and X2/X3 antennas.

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. In fact measurements showed that current flowing in the inner conductor of the coax transmission line was double that of the outer braid conductor.

Why is the outer of balance current so high? This is essentially due to out of balance coupling to earth and return current via earth. The voltage across the dipole is very high as it is multiplied by the factor Q of the resonant circuit between the dipole capacitance and the shunt inductance across it. This multiplied voltage increases the return earth current by that factor Q.

I was able to eliminate this common mode component 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. Further observation, by the inventor himself, showed that the EH antenna was not effective if the antenna circuit was properly balanced.

It is interesting that the VK5BR -X2/X3 antennas started off as balanced crossed field antennas. The fact is that I designed them balanced to get rid of the current imbalance in the feed lines and the resultant common mode or longitudinal component. But like the EH antenna, I eventually found that the signal level of the X3 improved by about two S points when the antenna was connected up in an unbalanced mode to become the X3U. (Refer to figure 6).

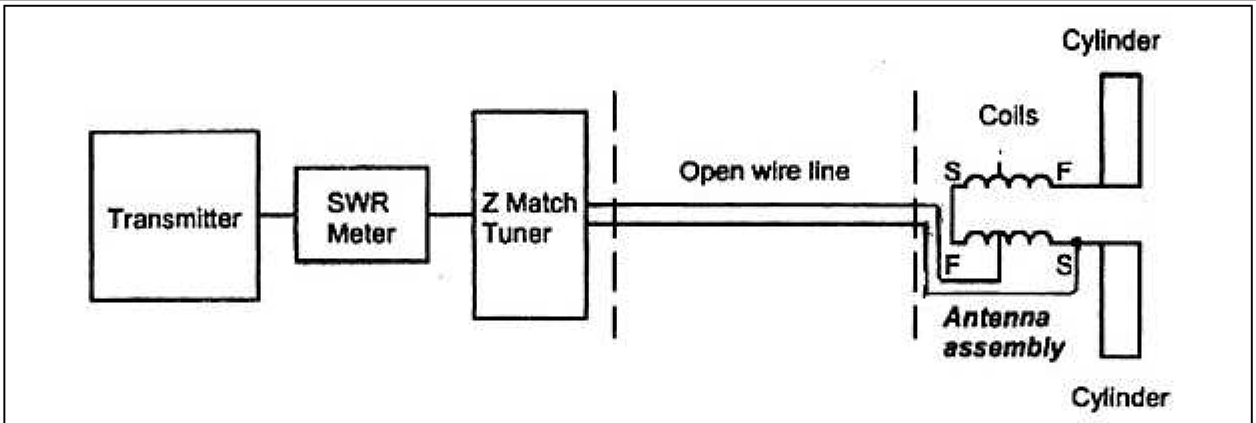

Figure 6
X3 Antenna Tuning & Matching System with antenna circuit unbalanced (the X3U)

All in all, it does appear that the successful performance of the EH and X2/X3 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.

In the EH antenna, the common mode current component can be tracked down the full length of the coaxial transmission line. However, it can be blocked by a coaxial balun or tuned longitudinal 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 so that there is a small coax tail, it can be quite effective in increasing radiation resistance to improve radiation efficiency.

Theory on Short Coax Tail

So how does the short coax tail work so well?

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 7 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. Radiation resistance increases with the square of the radiating element length and hence 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 and certainly high compared to the series loss resistance, mainly in the coil. Efficiency is therefore very much higher than that achievable for the simple 0.5 metre dipole operating when the antenna circuit is balanced with no longitudinal or common mode current flowing.

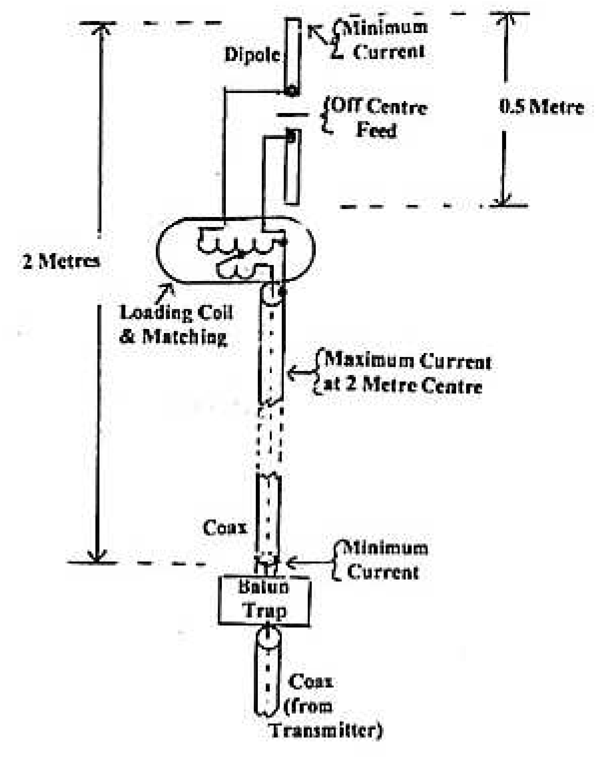

Figure 7 - The 20 Metre EH Antenna with a Short Coax Tail

Single Coil X3U

A final conclusion for the X3 antenna is that if it doesn't work in a crossed field using the coil magnetic fields, we don't need the two coils mounted in a specific orientation and the antenna can be tuned by a single coil mounted in any orientation. Hence I constructed the simplified antenna for 40 metres shown in figure 8 and figure 9. Fed with open wire pair and adjusted by the Z Match controls in the radio shack, it works like a charm to enable high antenna current at the top of the antenna where that current is well placed for effective radiation. One might consider it as a very effective top loading system.

There is no need for critical adjustment of the antenna itself, as in the EH antenna. Just provide series inductance aiming somewhere near resonance with the small dipole capacitance. Required matching is achieved by reflecting reactance and resistance up the open line from the Z Match output.

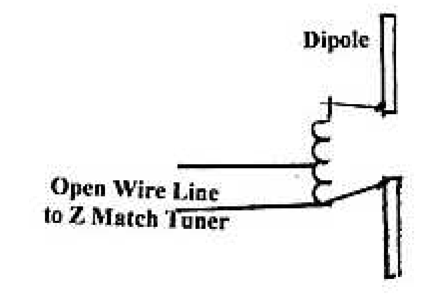

Figure 8
Single Coil X3U Connection
(A very simple arrangement)

Figure 9 The 40 metre X3U antenna using a Single Coil

If you wish to experiment with this simple antenna arrangement, here are some guidelines:

To make an antenna for any frequency band, select some form of large metal tubing, round or square. Cross section dimensions are not really critical. Cut two lengths of around 1% of a wavelength to form the two dipole elements which are fixed apart physically and electrically with some form of insulated assembly.

Provide, at the dipole centre, a coil of heavy insulted wire of such inductance that it resonates with the capacitance between the dipole elements at a frequency somewhere within the frequency band. The precise frequency is not critical as this can be controlled by reactance fed up the line from the Z Match. The coil can be orientated as desired. Precise resonant frequency of the antenna can be easily checked using a dip meter with the feedline disconnected from the coil. Provide a coil tap at about one third of the turns to connect one leg of the open wire or ladder line.

For the system diagram, refer again to figure 6 but replace the two coils with the single coil.

In Conclusion a few brief words

These small antennas work very well but I conclude that their operation is more to do with the effects of unbalancing the antenna connection than due to crossed fields. High Q multiplied voltage across the dipole elements multiplies the out-of-balance of currents in the two line legs feeding the antenna. This difference current, or common mode condition, extends a longitudinal radiating element back down the line. It could be considered as a very effective top loading system.

You might like to look at my single coil X3U idea. It looks very much like the star EH antenna circuit but with tuning and matching controlled using the Z Match tuner from within the radio shack.

References

For more detail on the experimentation and testing of EH and X2/X3 antennas, refer to my web site:
http://www4.tpgi.com.au/users/ldbutler/
In particular look at:
http://www.qsl.net/vk5br/NewX2_X3.htm
http://www.qsl.net/vk5br/X3UExperiment.htm
' http://www.qsl.net/vk5br/EHAntennaFurtherTests.htm

A series of articles have also been published in "Amateur Radio".