# The EH Analyzed
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T his report is my recent analysis of the EH antenna using the *Pspice* program and considering the antenna as a set of circuit elements. The antenna can be considered as a set of circuit elements because it is electrically small-meaning that the phase delay that occurs as a wave travels the maximum length of the antenna is a small fraction of an RF cycle. This means that all voltages and currents set up in the circuit can be considered the same anywhere on a particular wire in the antenna that one might test with a voltmeter or ammeter. If it were electrically large, one would need a Smith Chart to calculate the voltages and currents on its wires.

The analysis below generates and uses many curves. These curves are full of data, but the real INFORMATION is contained in the changes in the curves as some parameter in the antenna is changed. I often use a sort of "differential analysis" where I hold everything in a system constant except one parameter, which I then tweak about while watching the system response. This is a natural way of learning about something—just watch how a 2 year old approaches a mysterious new object in his/her world: the object is tweaked, wiggled, tasted, etc., until its properties are understood. So, I recommend the reader sort of defocus, stand back a bit and try to watch the movement of the curves as circuit element properties are changed. The EH's basic component, the Isotron, is simply a large inductor and small capacitor with a long physical spacing between plates wired as a series-tuned circuit. Energy stored in the inductor as 1/2*inductance*(current)squared is stored in the capacitor as 1/2*capacitance*(voltage)squared a quarter of an RF cycle later. The voltage is very high, which is why these devices might be called "Tesla coil antennas".

EH DEFINED

Essentially, the EH antenna consists of two "Isotron" style antennas in parallel across the transmission line. The radiation comes from the capacitors, which are in the form of two cylinders separated by the cylinder diameter and pasted on a 4inch PVC pipe ([click for metrics conversion](#)). The length of each cylinder is 1.5 x pipe diameter. The spacing between the cylinders is equal to the pipe diameter. The coils are wound near each other below the cylinders on the pipe. The tuning capacitor for 40 meters (7.0 MHz) is given as 63 pF. This information was taken from Ted Hart's "almost book" about the EH antenna.

This analysis starts with the characteristics of a single Isotron-type series tuned circuit. It then shows how the characteristics change when the second Isotron circuit is added. Finally, the effect of capacitive coupling and resistance between the radiating capacitors is shown. It is then noted that the coils are near each other with a common axis, so they must inductively couple. The independent coils of the first part of the analysis are exchanged for a transformer of the same inductance and variable coupling and the
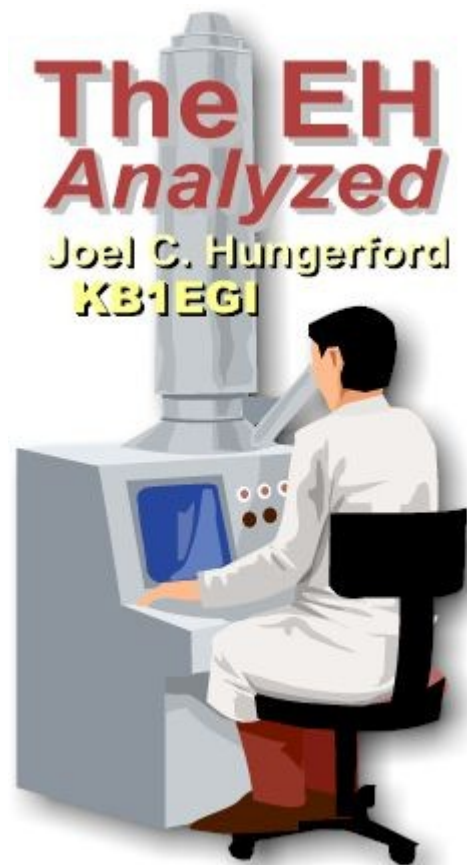
analysis repeated. The coupled coil configuration is the same as the "DLA" antenna that has been written up previously-the variable coupling curves are similar to the DLA data and it is hoped that the changes in the series of tuning curves versus coupling throws some light on the DLA operation.

This modeling shows that increasing the mutual coupling between the two Isotrons changes the tuning by making the lower frequency Isotron tuning drop in frequency and lower in Q while the upper frequency Isotron tuning rises in frequency and the Q increases. This makes sense since mutual coupling increases the voltage in the one and decreases the voltage in the other, as the Isotrons and coils are connected in opposite directions across the cable. Very small values of coupling cause large changes in the behavior of the combined Isotron system.

The analysis also shows there are three regions of importance for the phase of the voltage between the radiating capacitors. The frequency range below and above both resonant frequencies shows 180 degrees between ends…. The frequency range between the resonant frequencies shows a phase of zero degrees between ends of the antenna. The phase shifts rapidly between the two values at the circuit resonance (not the combined resonance, which moves around. The voltage on the end connected to the higher frequency Isotron is in phase with the drive in all regions. This rapid change at the resonant frequency and constant value at all other frequencies was a surprise to me, as I had been expecting the gradual phase change seen in the single Isotron.
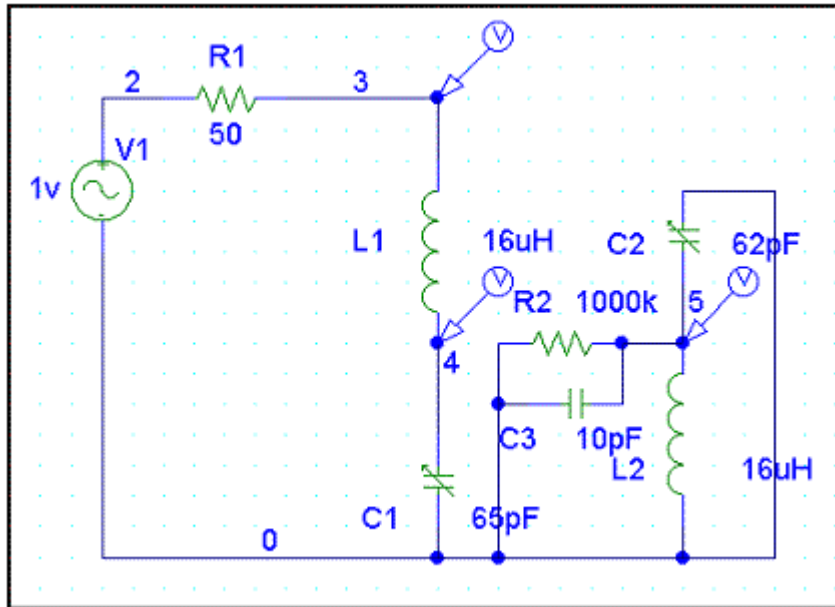
The Isotron itself is a series-tuned circuit and is a low impedance load on the cable, near resonance. Two isotrons in parallel are a high impedance in the frequency region between individual resonant frequencies. In that frequency region, one Isotron is operating above its resonant frequency and is inductive. The other Isotron is operating below its resonant frequency, and appears capacitive. The net result is a parallel tuned circuit of an inductor and a capacitor-a high impedance load to the cable.

Since the EH antenna is electrically small, there cannot be any directivity due to the effects of aperture. The point source may vary in power in different directions because of variation in the projected E and H fields in a plane perpendicular to the direction. In the EH antenna, the E fields are either from end to end, or both ends in phase to ground. Small spacing changes between the end cylinders may adjust the capacitance, capacitive coupling, and the resultant tuning caused by the coupling between isotrons, but the changes will not vary the directivity.

A SINGLE ISOTRON

The Figure 1 group shows a single series-tuned circuit or "Isotron". The circuit is in Figure 1a: L1 and C1 are the Isotron. Point 3 is the cable and R1 is the cable impedance of 50 ohms. Ignore the other circuit elements in the Figure 1 group—they are all grounded groups of elements such as the other Isotron and the coupling between the two antennas. It was easier to place the elements in the schematic and ground them for experiments that didn't use them than to redraw the schematic each time a condition changed.

Figure 1a: The Isotron - a series tuned circuit (L1,C1)
connected to a 50 ohm cable and 1 volt source (at 3)

Figure 1b: The Isotron is tuned to 7 MHz
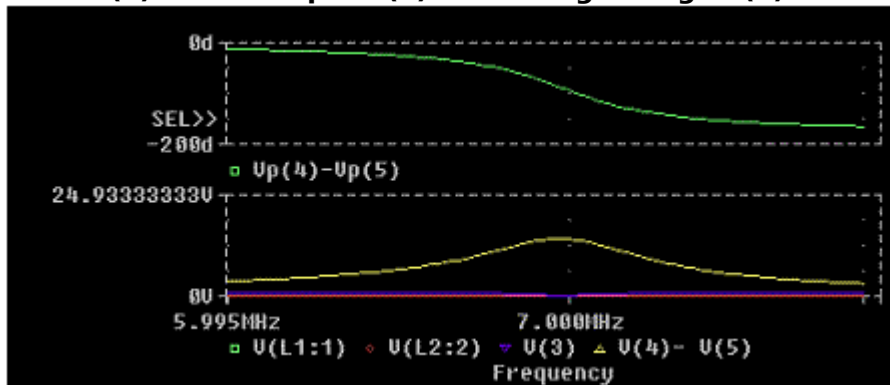**V(3) = cable input V(4) =radiating voltage V(5)=0**

Figure 1b shows the essential characteristics of the Isotron series-tuned circuit. The lower part of the Figure shows the various voltages in the circuit vs frequency. The cable voltage (V3) shows a low-impedance load at resonance at 7 MHz. The capacitor voltage (V4) shows a peak at this frequency. The other Isotron capacitor is grounded and its voltage, (V5) or V(L2:2) is zero. The upper part of figure 1b shows the phase of the radiating capacitor voltage V4. At resonance, the phase is -90 degrees.

Figure 1c: Shows where input impedance = 50 ohms (v(3)=0.5
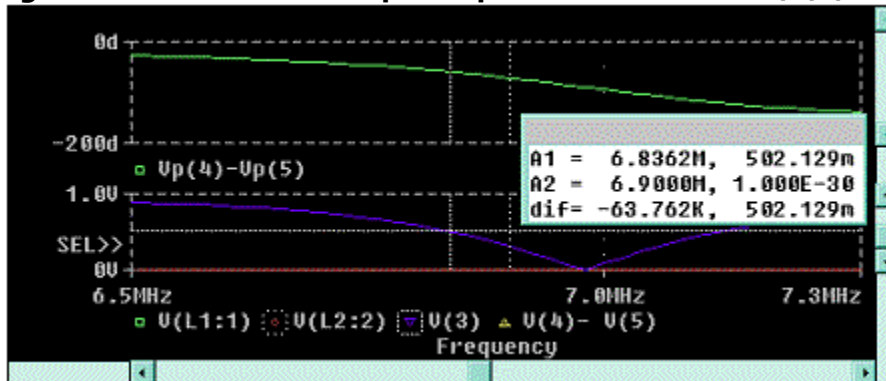
Figure 1c changes the scale of the voltage plots to 1 volt full scale from the value of 24.93 volts in figure

1b. This clearly shows the loaded cable voltage, (V3) and the null at resonance. The cable is closest to being matched when the voltage V3 == 0.5 volts. There, the load resistance is equal to the source resistance of 50 ohms. The cursor table in the figure shows that the voltage A1 is 0.502 volts at 6.832 MHz. The vertical finely dotted line is the A1 cursor. The sparsely dotted line is the A2 cursor. It is showing V(l2:2) or V5, the capacitor voltage on the other grounded Isotron that equals zero. This cursor is set at 6.9 MHz. The Isotron has two possible matched points, above and below resonance, where V3 (the blue line) crosses 0.5 volts. The dotted cursor lines surround their associated colored identifier symbols across the bottom of the figure.

ADD A SECOND ISOTRON

Figure 2a shows the schematic for the two isotrons in parallel. L1 -C1 is the lower frequency Isotron. L2-C2 is the higher frequency Isotron. The coupling between the two is still grounded and out of play.

Figure 2a: Two Isotrons wired to make an EH antenna
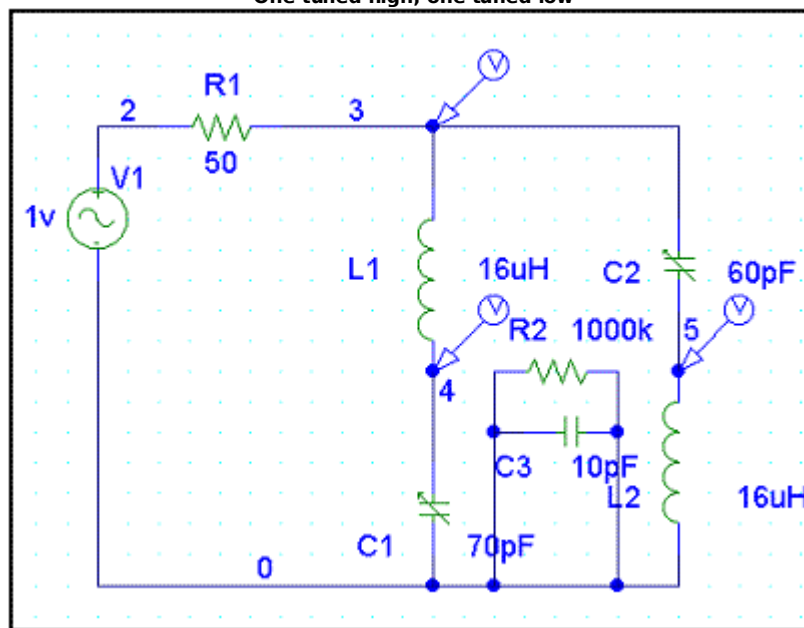One tuned high, one tuned low

Figure 2b: The two Isotrons combine to load the cable with
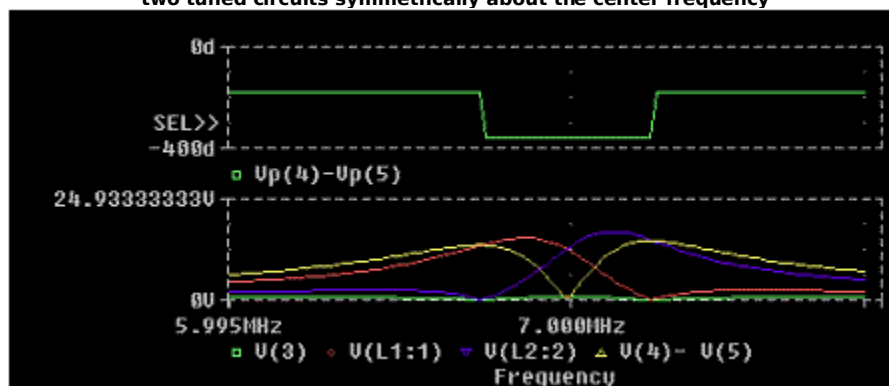two tuned circuits symmetrically about the center frequency

Figure 2b shows the voltage plots. The cable voltage V3 is green and it shows the expected two nulls at the resonant frequency of the two isotrons. The capacitor voltages are red and blue and show a peak between the center frequency of the system of two Isotrons and the respective individual resonant

frequencies. Note that the phase between the voltage at the antenna ends is quite different from that in Figure 1. It abruptly changes from -180 degrees above and below the two resonant frequencies of the system to -360 degrees == zero degrees between the two nulls in V3. No more gradual change in phase with frequency! This change happens at the real resonant frequencies of each Isotron. Note also the perfect symmetry about the center frequency of the system. The yellow curve shows the voltage difference between the ends of the antenna. At the center frequency of the system, the voltage at the two ends is in phase and is equal-the difference is zero (strictly speaking, the difference == the drive voltage V3).

**Figure 2c: At center frequency the combination is a high impedance
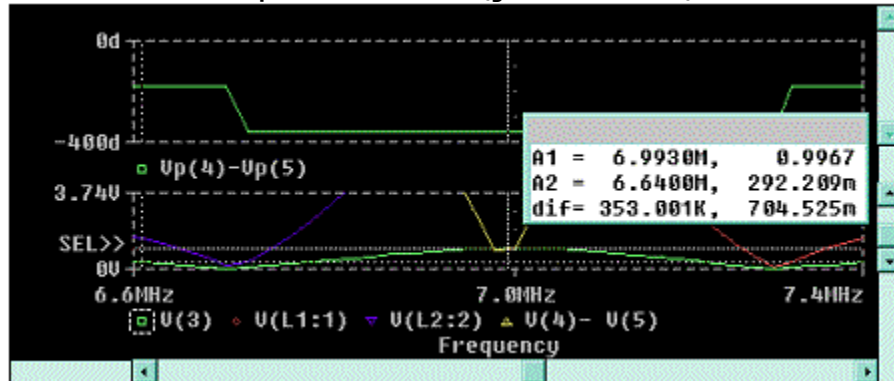-- a parallel-tuned circuit (green = cable load)**

Figure 2c is the voltage plot showing the bottom 3.74-volt range. Note the two nulls in the cable load voltage V3. The cursor is at the center frequency of the system. Now, note the voltage at the cable: 0.996 volts from a 1-volt source! This is a high impedance point—*the current is 80 uA and the load is 12.5k ohms to drop the voltage only .004 volts coming from a 50-ohm source!* Each Isotron tuning null is a zero drive point for the other Isotron as well as a maximum voltage point for its own capacitor, since the two Isotrons are in connected parallel across the cable.

ADD ONLY 10 pF END TO END COUPLING

The Figure 3 group show what just 10 pF coupling between the two cylinders does. Figure 3a shows the circuit. The coupling is C3 and there is a megohm of resistance to simulate a small amount of radiation in place. V4 and V5 are the two capacitor or cylinder voltages for the two Isotrons.

**Figure 3a: Stray coupling between ends (the C1, C2)
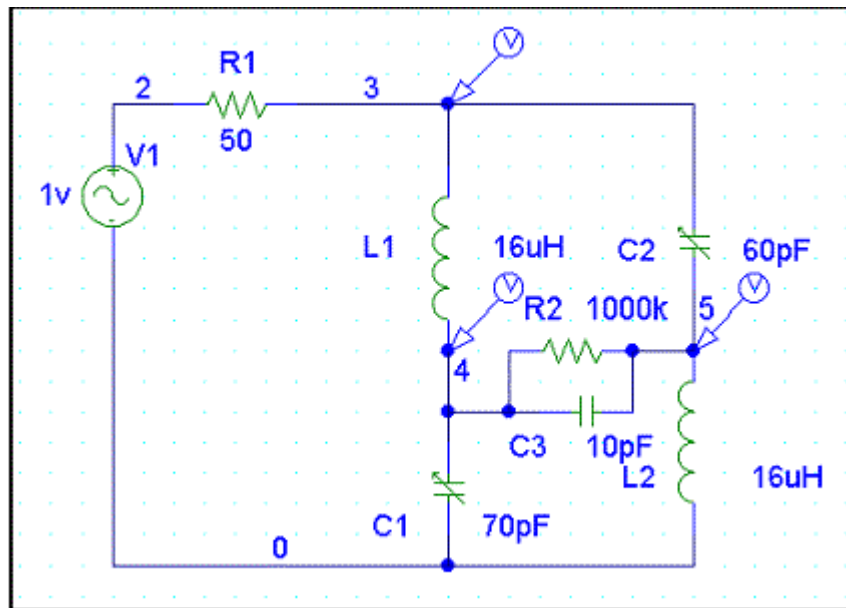and low radiation destroys the symmetry of tuning**

Figure 3b: The phase between the ends remains at
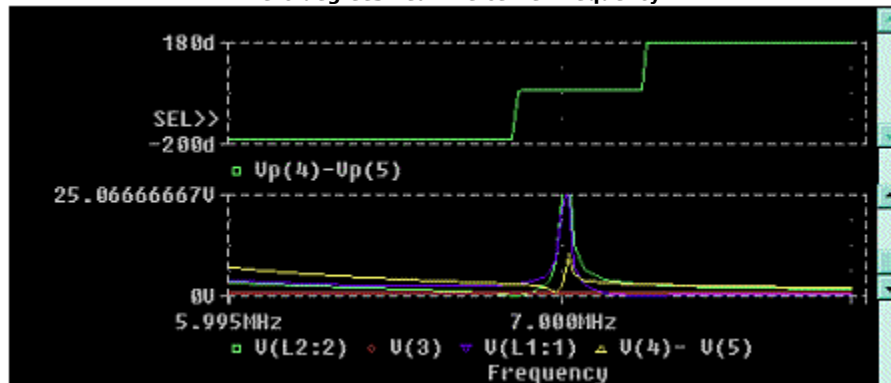zero degrees near the center frequency

Figure 3b shows that the low frequency resonance has moved off the screen to the left. The high frequency Isotron resonance is much narrower in bandwidth and has moved a small amount to the left. Note that the phase changes in V4-V5 (the cylinder to cylinder voltage) are only slightly moved in position. *They still are near the real resonance of each Isotron!!*

Figure 3c: The combination is no longer matched -- Coupling hurts!
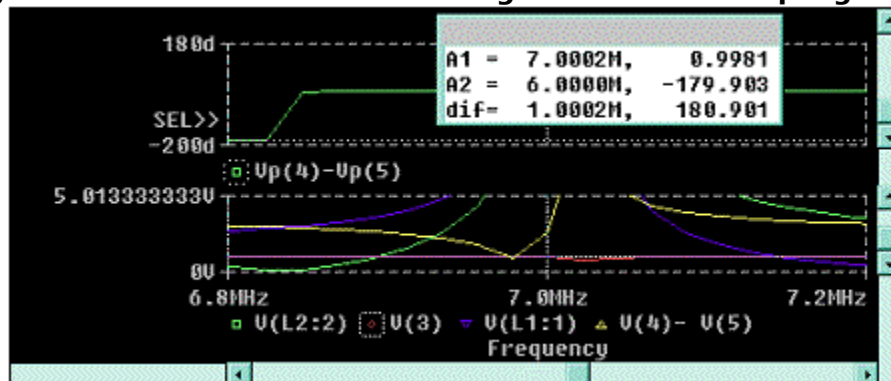
Figure 3c is a magnified version of the frequency region around the higher frequency Isotron. Note the whole screen is only 400 kHz wide. The cursor shows that loaded cable voltage is 0.9981 volts-down 38

uV from the source voltage. The load is 26k ohms. A little coupling changes things drastically.

LOWER THE RESISTOR REPRESENTING RADIATION LOAD TO 2k

The Figure 4 group show what might happen if the system were to have a radiation resistance of 2000 ohms. This is where the load would be if the voltage from cylinder to cylinder were out of phase. But, the voltages on the cylinders are in phase; so all fields are outward from the two cylinders to the cable ground. The load on the cable is still a high impedance load.

Figure 4a: A low radiation resistance loads the circuit, destroys the symmetry, but does not help the matching
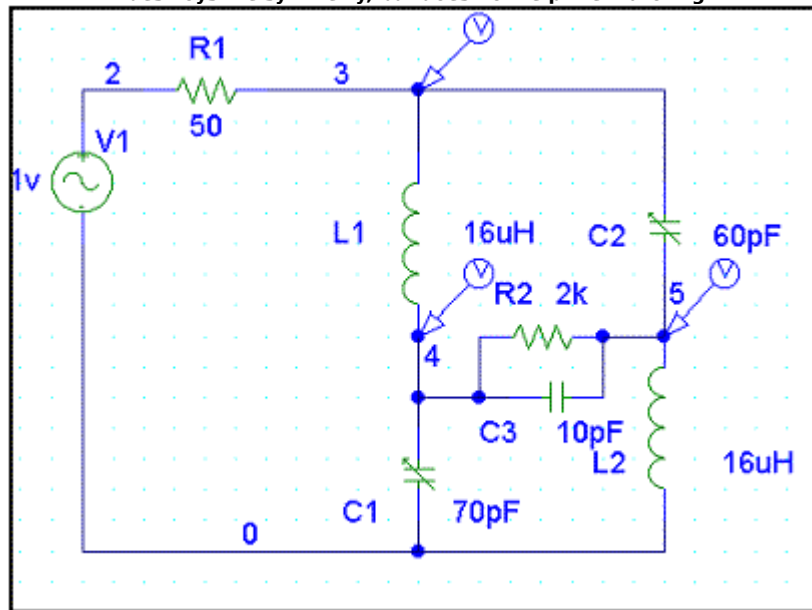
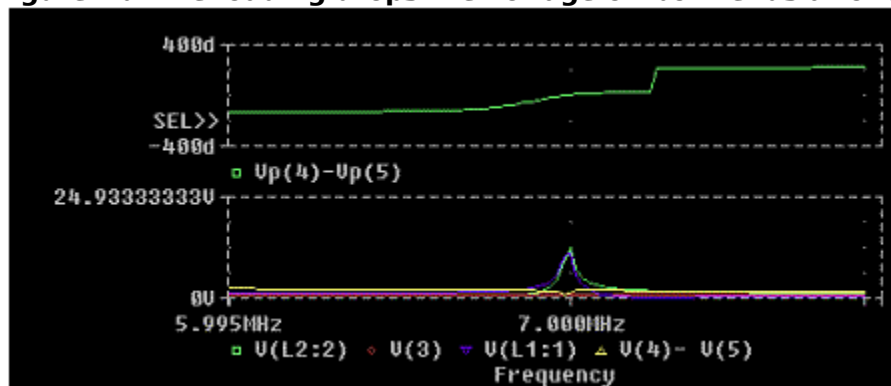Figure 4b: The loading drops the voltage on both ends at once

Figure 4a shows the circuit. Figure 4b shows the tuning curves. The effect of the 2k resistor is to load down the lower frequency Isotron and to smooth out the phase change at the real resonant frequency of this component. Note that the phase change related to the upper frequency Isotron is still near the real resonant frequency. Also, note that the maximum capacitor voltage is less than half of what it was without the 2k load that was represented in the Figure 3 group.

The two inductors are wound on the pipe below the cylinders, along the axis of the pipe. They must have some inductive coupling. All of the curves discussed so far are for the condition where the coils are independent and not coupled. The next series of curves show what happens when there is inductive coupling between the inductors.

REPRESENT THE COILS WITH A TRANSFORMER WITH THE SAME INDUCTANCE AS L1 AND L2

Figure 5a shows the circuit with only inductive coupling. The coupling transfers some of the energy from one Isotron to the other.

Figure 5a: Inductive coupling between the coils (=K) is inherent in the structure
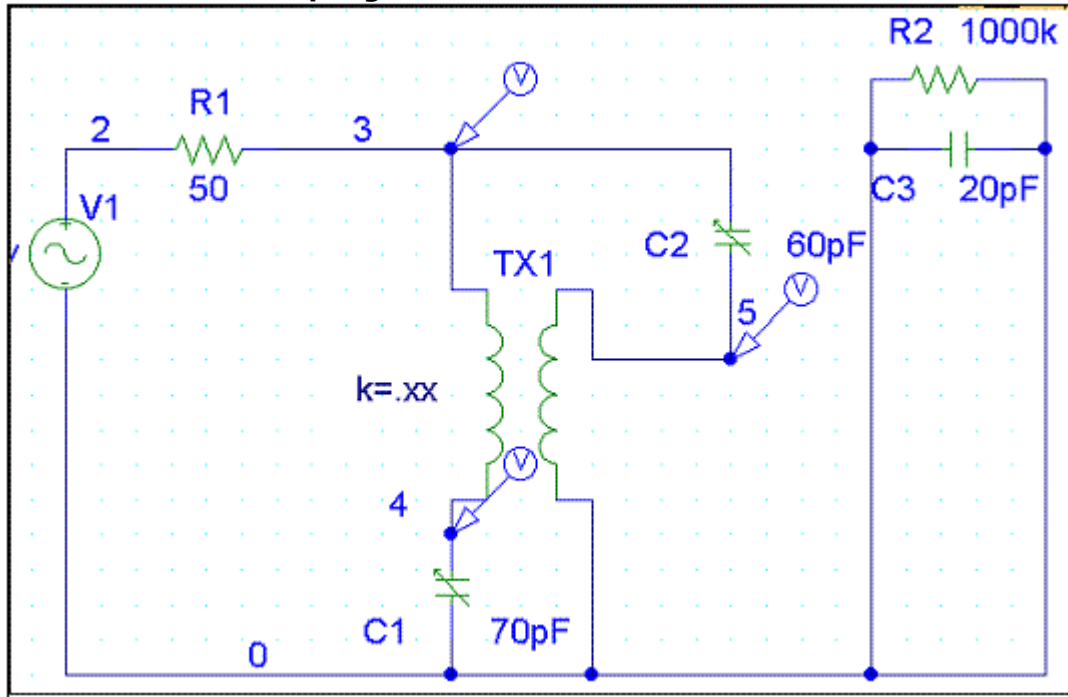
The Figure 5b group is a series of frequency scans at different coupling coefficients, k, from 0.001 to 0.2. The lowest coupling gives curves that look like Figure 2-symmetrical about the center frequency of the system. As k increases, two things happen. First, the lower frequency Isotron moves lower in frequency and the width of the pattern increases. The Q of this Isotron is lowered. The higher frequency Isotron moves upward in frequency and its pattern narrows. Its Q increases. Second, the abrupt phase shifts between the cylinders accompany the pattern of the higher frequency Isotron in its movement. At higher k values, the cylinder voltages are out of phase (180 degrees) over the whole pattern of the lower frequency Isotron.

**Figure 5b: Increasing coupling spreads the resonances apart,
lowers the Q of one and raises the Q of the other**
Click for Figure 5b Group

Figure 5c shows the lowest 1-volt range of the figure 5b curves. The loaded cable voltage crosses the 0.5-volt value twice for each Isotron, except at the highest coupling, where the upper frequency Isotron just gets down to 50 ohms at the bottom of its null. For k > 0.2, it would never be a matched load. The inductive coupling between Isotrons gives 3 or 4 chances to be matched, with different voltages between the cylinders or from the cylinders to ground.

Figure 5c: The system is matched at 3 frequencies (v3=.5)
Click for Figure 5c Group

I should observe here that I first found this strange double resonance with a DLA that had a k of 0.82 and no radiating capacitors-just radiating coils. The spacing between high and low resonant frequencies was

enough that I tried to make a dual band 40- and 20-meter version! I didn't recognize the coupling association until this study.

## ADD THE CAPACITIVE COUPLING BETWEENTHE CYLINDERS

Figure 6a shows the capacitive coupling between Isotrons. Figure 7a is the same except the coupling is increased to 20pF. The inductive coupling was set at 0.02 for these curves.

Figure 6a & 7a: Coupling between the ends does the same kind of thing
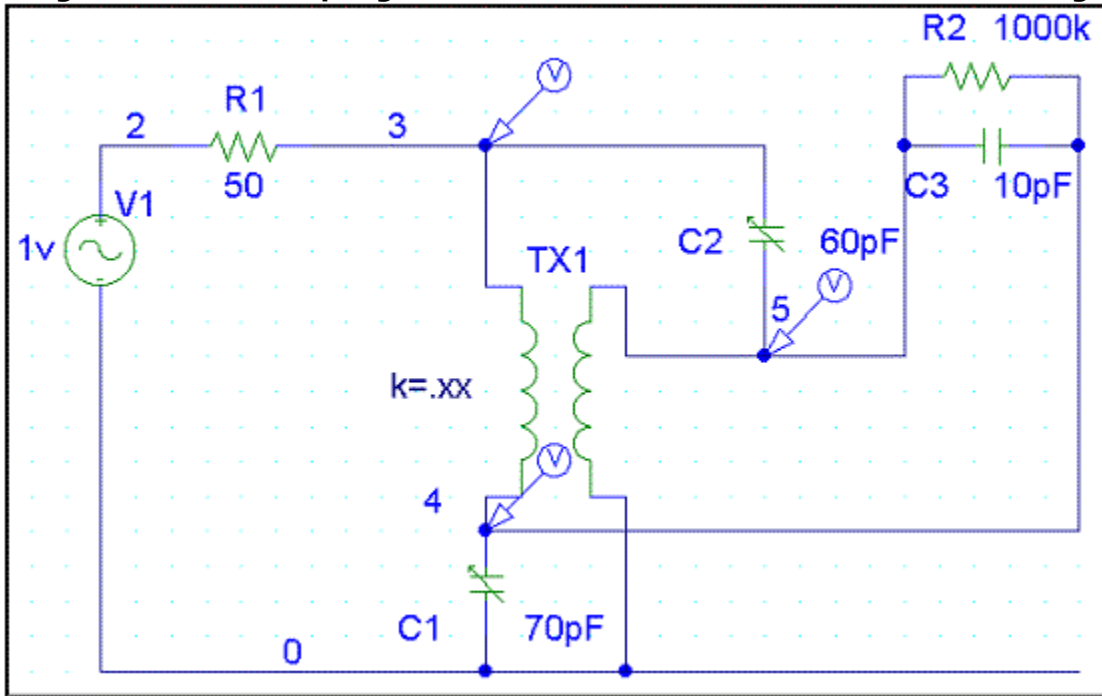
The Figure 6b group shows the patterns for three values of coupling capacitor: 1pF, 4pF and 10 pF. The highest value has about the same amount of effect as the inductive k of 0.2, and all the effects are the same for either kind of coupling.

Figure 6b: The tuning spreads but the phase between ends is still zero or 180 degrees
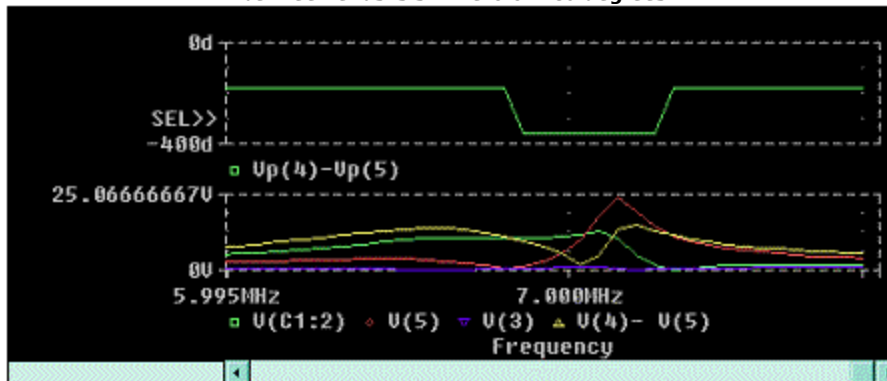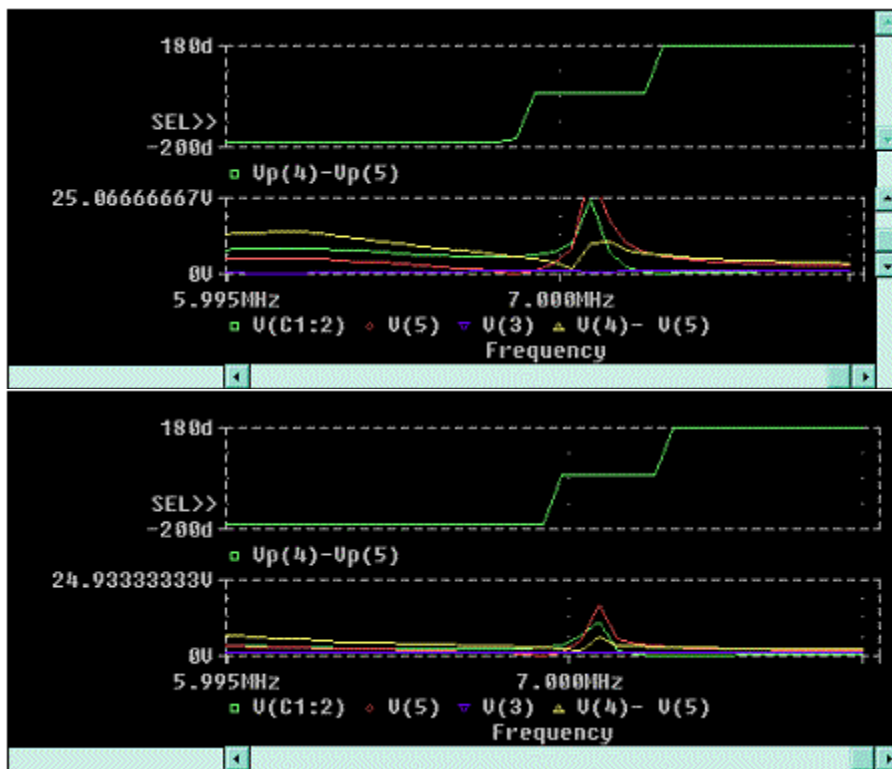
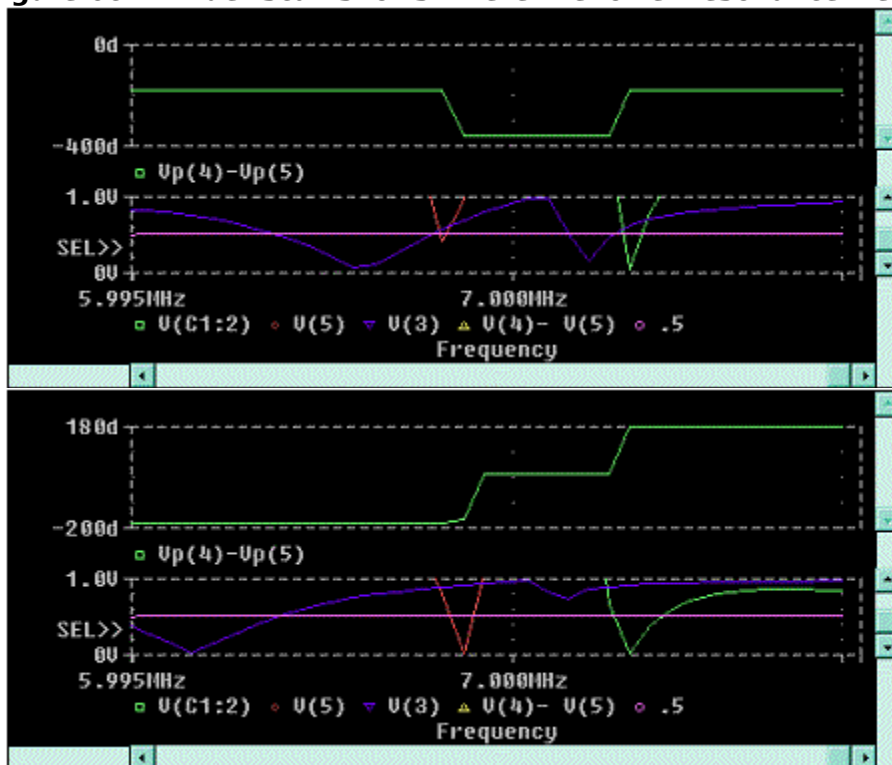**Figure 6c: A wider scan shows where the lower resonance went**

Figure 6c shows the bottom 1-volt range for the two lowest couplings. Note that just 4pF coupling is enough to raise the impedance at the highest resonant frequency to a value greater than 50 ohms, while the resonant pattern has the usual two matched frequencies. For the 10pF coupling, the frequency scan was widened to completely show the lower frequency pattern. Figure 6d shows the bottom 1 volt of the

patterns. The yellow line in figure 6d shows the 0.5-volt level where the cable voltage V3 is matched.

Figure 6d: There are still only two matched points
**It looks like only one isotron!**
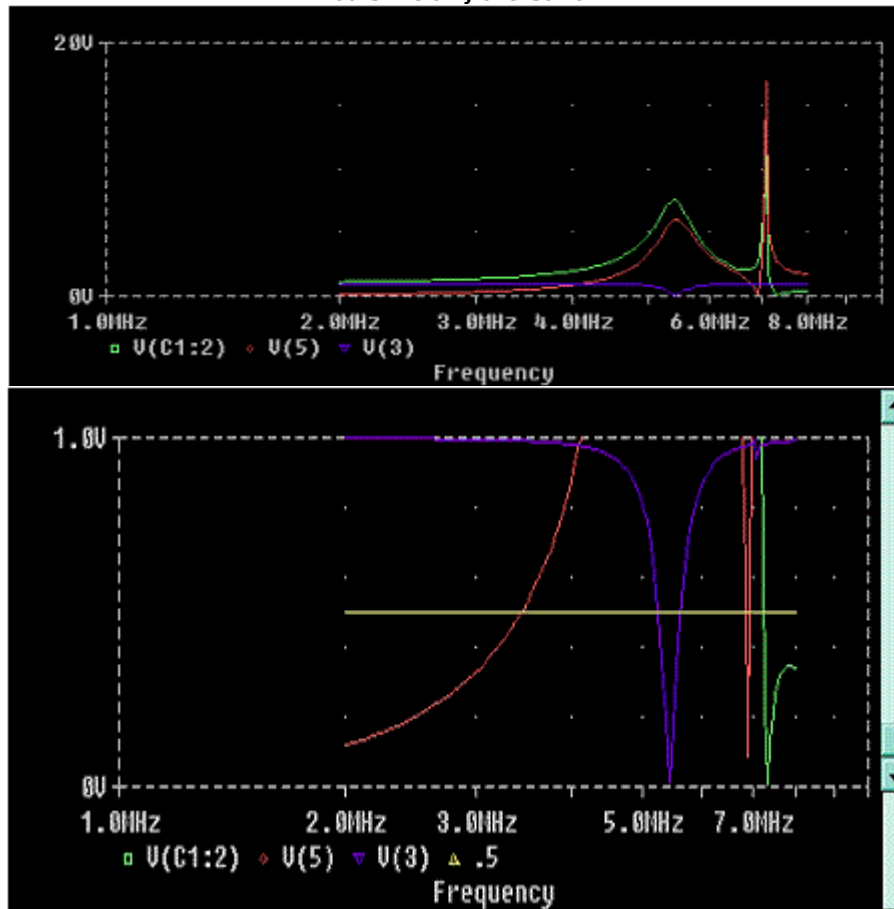
INCREASE THE CAPACITIVE COUPLING TO 20 pF

Figure 7b shows the effect of 20pF and k=0.02. The lower frequency resonant point is moved from around 7 MHz to about 4.6 MHz while the higher resonant point is under 8 MHz. Figure 7c shows the bottom 1-volt range to help locate the matched points.

Figure 7b: Increasing the capacitive coupling
between ends moves the resonances further apart
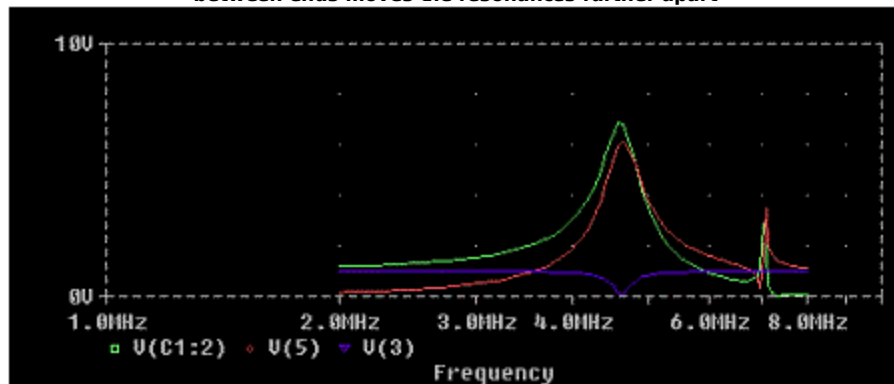
Figure 7c: Still only matched at 2 places
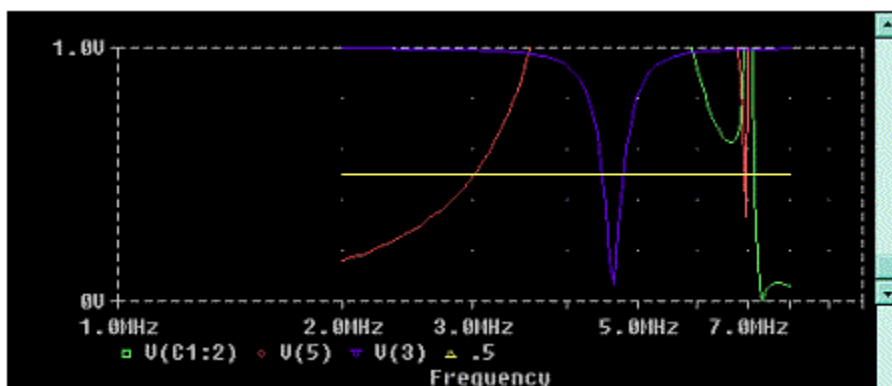
Figures 8a and 8b show that increasing the k ten times, to 0.2, only moves the lower frequency resonant point from 4.6 to about 4.3 MHz. Both types of coupling work together in the same directions.

Figure 8a: 10x inductor coupling doesn't change things too much with high end coupling
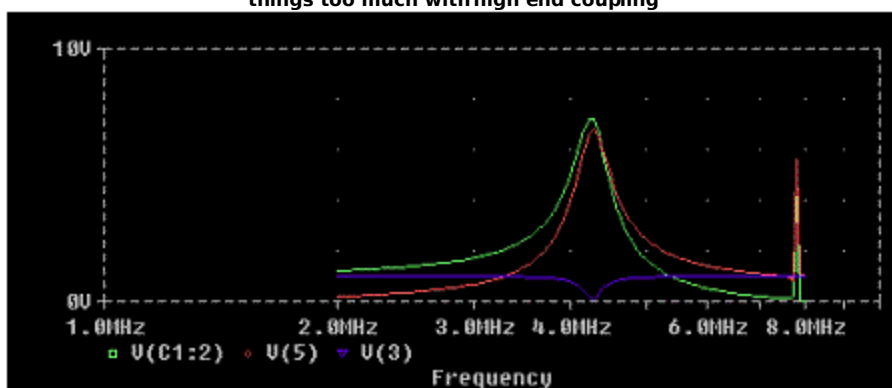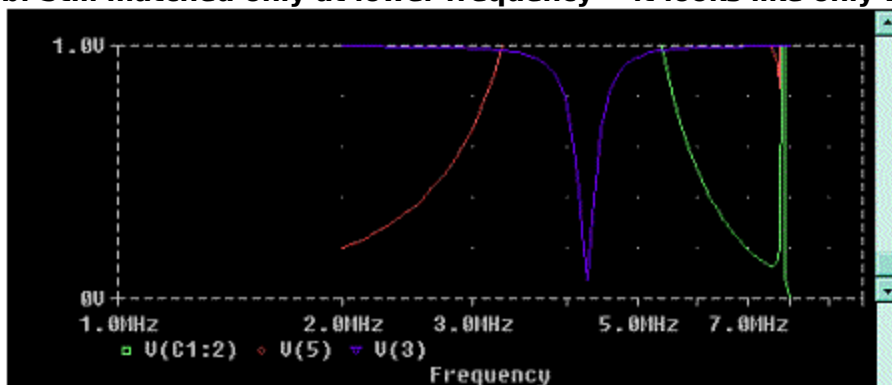

Figure 8b: Still matched only at lower frequency -- it looks like only 1 isotron!

MY CONCLUSIONS

The EH antenna appears to be simply two Isotrons combined to give the effect of a single, much lower frequency Isotron. As such, I would expect it to radiate numbers that seem to average about an S unit (-20 db) down from a dipole.

The EH antenna is a member of the class of antennas where coupling between two radiating tuned circuits, a factor poorly controlled in most designs, can produce great tuning changes. This factor works against any possible meaningful merits worth comparing the other various EH constructions.

The abrupt phase transitions and broad regions of unchanging phase over many different tuning and coupling conditions suggest that trying to tweak the phase to produce CFA-like conditions ***is doomed to***

failure. I think any variations in performance observed are due more to the movement of the resonance patterns in frequency than to any field interactions. **-30-**

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