Magnetic Capacitance

1. What is Magnetic capacitance?

Solving magnetic problems dynamically by considering a magnetic system to behave somewhat like an electrical circuit, having discrete component values connected by magnetic conductors, is an art that is not generally taught. Simple (closed) magnetic circuits such as transformer cores are partially solved where the dimensions of a limb plus the known core permeability yield the magnetic reluctance of that limb. Reluctance is equivalent to resistance in an electric circuit so already we have the concept of a magnetic component. However, the solutions for transformer cores generally goes no further than an assembly of reluctance values for each limb used to apportion magnetic flux between the limbs. Dynamic performance in the magnetic circuit domain [1] is not generally performed, instead an electric circuit is used containing coupled primary and secondary coils that magically transform voltage and current without any magnetism. Around this impossible component are mounted other electrical components (resistors and inductors) to account for the imperfections in a practical transformer, such as coil and core losses, the need for magnetic flux, and any flux leakage. Although this serves electrical engineers' needs well it hides some aspects of transformers that some people find surprising. A good example is the application of Lenz's Law with regard to the magnetic field created by the secondary current where, in good transformers designed to have zero flux leakage, the secondary current surprisingly does not create any flux. The secondary current creates a mmf that counters the mmf from the primary *load-current* component, hence the only current that creates flux is the *magnetizing* component of the primary current. This complete cancellation of two mmfs is due to the entire core material responding en masse and virtually instantaneously to the time-changing external influences of the coils. In effect the core forces that situation, at any instant in time the magnetic flux everywhere along the core has the same value. That symmetry is broken when the frequency is high enough to create magnetization waves that travel along the core.

Solving in the magnetic domain, where mmf (ampere-turns) is treated as magnetic "voltage" and flux is treated as magnetic "current", opens one's eyes to the dynamic magnetic world, a world where we need dynamic components like "magnetic inductance" or "magnetic capacitance". Unfortunately, apart from "reluctance", we do not have recognised names or symbols for these magnetic components, so we must invent our own. In this paper we use the classical electrical symbols (R, L, C) with the subscript m to denote these are magnetic circuit components. For names other than the existing Reluctance, and for brevity in writing, we use electrical terms with an M for the first letter to get Minductance, Mapacitance and Meactance. This also helps keep our minds on track; we are so brainwashed with electrical circuitry that we need these new terms to prevent out minds from inadvertently jumping to the electrical world.

In that magnetic world it has been shown [1] that a secondary coil of N turns (around a magnetic core) connected to a load resistor R appears in the magnetic circuit as a series Minductor L_m obeying $U=-L_m.d\Phi/dt$, where U is the induced mmf from the load-current in the coil and Φ is the flux provided by the magnetizing component of the primary current. The value of L_m is N^2/R.

Since Minductance represents an energy *sink*, it is pertinent to ask the question, what would be the effect of having a series Mapacitance C_m in the magnetic circuit, obeying $\Phi=C_m.dU/dt$? The answer is it would act as an energy *source* feeding power into the circuit. (Note that in the classical transformer the phase between flux Φ and mmf U of the primary load current component is exactly that which would occur from a series Mapacitance.) If the Meactance of an additional series Mapacitance ($1/\omega C_m$) is equal to the Meactance of L_m (ωL_m), a magnetic resonance that is at the present time unknown, then only the reluctance of the core remains. In that case the input to the primary coil would appear as a pure inductance and there would be no continual power drain from the electrical source, but power would continue to be dissipated in the load resistor across the secondary. In this search for such an internal energy source the possibility of extracting energy from Larmor precessions of Nuclear Magnetic Resonance (NMR) and Electron Spin Resonance (ESR) has been likened to a magnetic capacitance [2]. In this present paper a new possibility is discussed where magnetic delay along a core might also produce Mapacitance.

2. Aspects of the math imaginary *j* (or *i*) notation

In electric circuits used solely for alternating voltages or currents it is common practice to represent the reactance of inductors or capacitors using the math symbol *j* having a value of the square root of minus 1, using so-called imaginary numbers. When real numbers are plotted as x values on a graph and imaginary numbers plotted as y values, we get a vector representation of reactance values that can be summed graphically. When multiplied by an alternating current these vectors can correctly show phase, e.g. between voltage and current. In this perspective the voltage and current vectors rotate CCW at the AC frequency hence we can also take account of additional effects that are phase advanced, or phase retarded. In the math world a multiplication by *j* produces a 90-degree CCW rotation, hence introduces a phase advance, while a multiplication by *-j* produces a 90-degree CW rotation, a phase lag. A time delay along a circuit causes a phase delay that is represented by a CW rotation of a vector. A phase delay of 90 degrees is equivalent to a multiplication by *-j,* hence has the ability to turn a resistance value into a capacitive reactance value or an inductive reactance into a resistance value. This is well known in electrical transmission lines but to the author's knowledge has never been applied to magnetic transmission lines (magnetic cores) to turn a Reluctance value into a Meactance, more specifically a Mapacitive Meactance, or to turn a Minductance into a Reluctance. This paper explores those possibilities.

3. Electrical Transmission Line

Figure 1 shows an electrical transmission line of length x and characteristic impedance Z_0, here assumed to be resistive R_0. There is a deliberate mismatch at the far end with a load resistance of R_L.

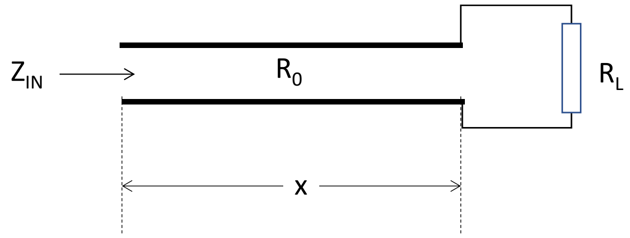

Figure 1.

When multiplied by the phase constant β the line length x becomes an electrical (phase) length θ in radians. If attenuation is small enough to be neglected the input impedance Z_{IN} is given by

$$\frac{Z_{IN}}{R_0} = \frac{\frac{R_L}{R_0} + j\tan\theta}{1 + j\frac{R_L}{R_0}\tan\theta} \qquad (1)$$

Putting $\frac{R_L}{R_0} = K$ and θ = 45° ($\tan\theta$=1) then (1) becomes

$$Z_{IN} = R_0 \frac{2K - j(K-1)}{1+K^2} \qquad (2)$$

For large K (as R_L approaches an open circuit) this becomes

$$Z_{IN} \approx \frac{2R_0}{K} - jR_0 \qquad (3)$$

For this 45° line the input impedance has become predominantly capacitive with reactance of value R_0, i.e. a capacitor of value

$$C = \frac{1}{\omega R_0} \qquad (4)$$

Thus, in the electrical world we have the ability of using transmission lines to create reactive component values. Can we also do this with magnetic transmission lines?

4. Magnetic Transmission Line

The manner in which magnetic wavefronts travel along magnetic cores is quite complex, involving the energies needed to flip atomic dipoles, the movement of domain walls etc. The author has access to some work on transmission delay through Ferroxcube 3F4 ferrite in the form of a large ring core, Figure 2.

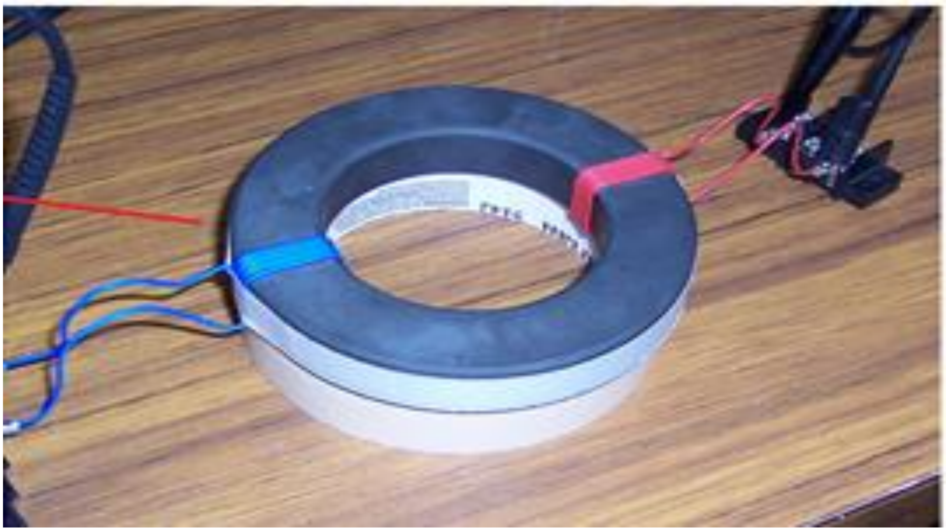

Figure 2. Magnetic delay transformer

This had small coils at diametrically opposite positions. Measurements were performed over frequencies from 1KHz to 20MHz with the secondary loaded with various resistance and parallel capacitance values. Figure 3 shows the phase delay from input voltage to output voltage.

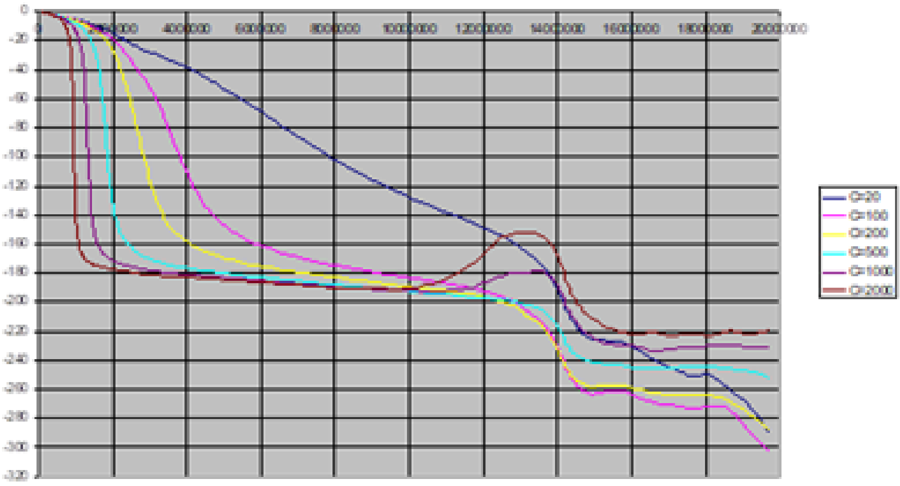

Figure 3. Phase delay primary to secondary

Of significance is the dark-blue line for the 20pF measurement where the phase is almost linear with frequency up to 13MHz where the 20pF begins to have an effect. This represents a fixed time delay of 34.8nS over the core length of 0.135m from primary to secondary, yielding the wave velocity as 3.88×10^6 m/S. Figure 4 shows the ferrite characteristics where core losses peak at 8MHz and are significant at the 4.5MHz point needed for a 45° phase delay. This indicates the ferrite material is probably MnZn only suitable for frequencies below 5Mhz.

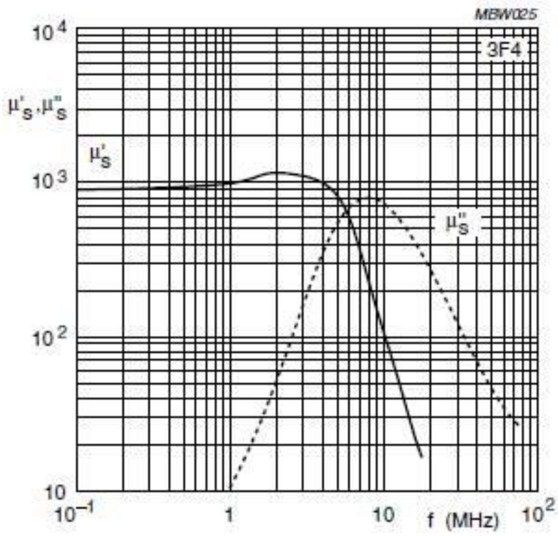

Figure 4. 3F4 ferrite characteristic

NiZn ferrite is used for frequencies up to GHz, hence if a NiZn ring core of similar size were used, and had the same wavefront velocity, then this would be suitable for experimenting with the possibility of obtaining a Mapacitive Meactance within a transformer, although the wider BH loop hence greater losses of that ferrite might hide the effect. Figure 5 shows such a possibility where an air-gap creates a large value Reluctance separated by distance from the transformer section where primary and secondary coils are wound over each other.

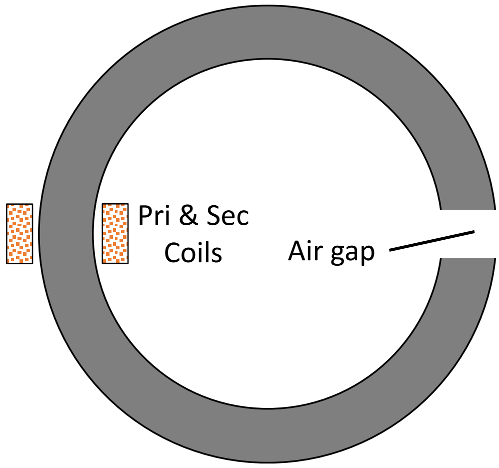

Figure 5. Transformer with time-delayed gap

A much larger air gap hence higher end reluctance could be obtained by using a ferrite rod to create a linear transformer as shown in Figure 6 where the pole faces are widely separated. Also shown is a conductive sheath around the rod that has a slot along its length so as to not be a shorted turn. At the high frequencies needed for this experiment induced eddy currents cause the conductive sheath to act like a diamagnetic material so flux lines do not cross it. This prevents flux from escaping along the length of the rod hence concentrates the delayed effect of the distant air gap. NiZn ferrite rods for HF antenna use are readily available.

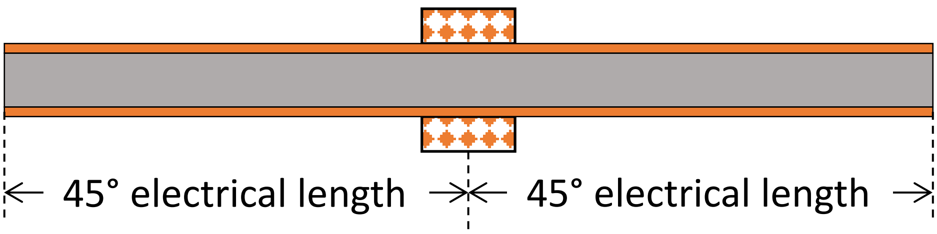

Figure 6. Linear version with ferrite rod

As this version is axisymmetric along the centre of the ferrite rod this version can be modelled by FEMM in 3D to create a static image of field lines, shown in Figure 7 where the FEMM image and its mirror have been joined together. Unfortunately, the manner in which FEMM creates flux lines in the axisymmetric mode does not show flux along or close to the centreline, hence in this image there appears to be zero flux there. This is not the case and examinations show the B field there to be about 1/5 of the value along the inside surface of the rod. The effect of the conducting sheath has been modelled by using the FEMM facility to model diamagnetic materials that have μ_0 less than 1, here using $\mu_0 = 0.001$. The flux can only escape via the flat ends of the rod, hence this models a true magnetic dipole where the ends are almost perfect separated N and S monopoles. Apart from the possibilities offered by the phase delay along the rods, this would be an interesting form of antenna to study.

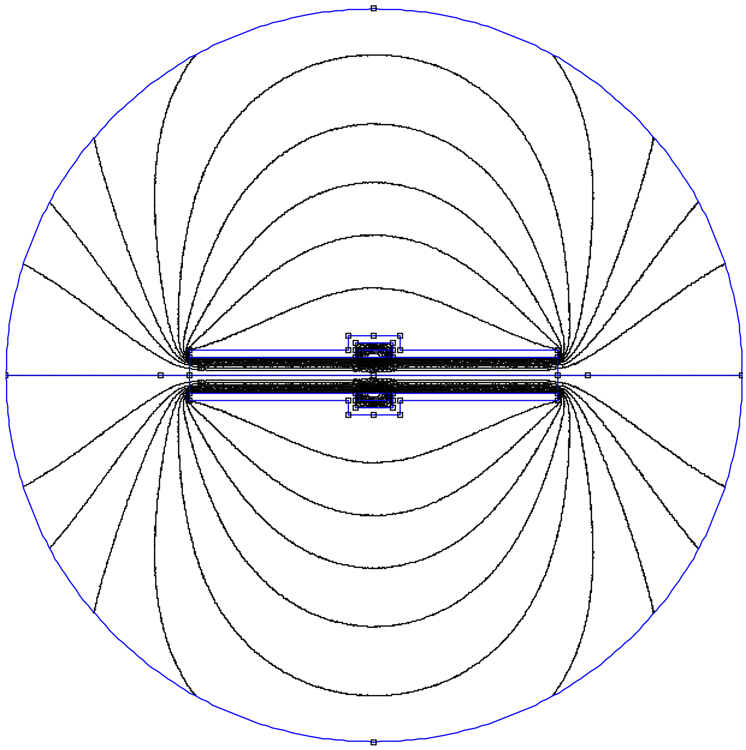

Figure 7. Flux pattern

The reluctance of this air gap between widely separated poles may not be high enough, but there is another method for obtaining even higher reluctance and that is by creating an air gap between poles of the same polarity. Figure 8 shows a magnetic circuit with two air gaps (it could be done with two C cores) that has two drive coils at opposite positions. As before a conductive sheath around the core prevents RF flux from escaping and the sheath extends over the air gaps.

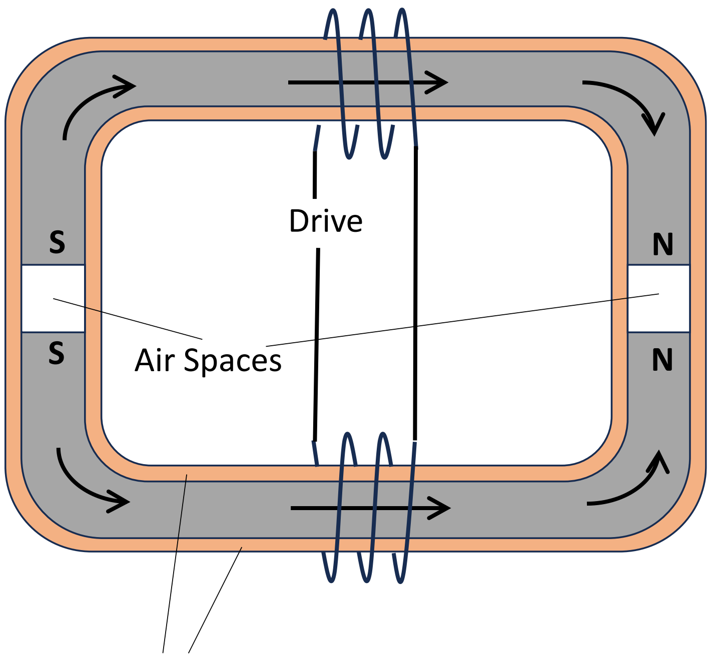

Figure 8

A FEMM plot using diamagnetic material for the sheath is shown in Figure 9. The sheath ensures that very little flux passes along the core in this static simulation using a diamagnetic sheath, hence demonstrating the effective very low reluctance of the repelling poles air gaps. In the proposed RF system the forward and backward magnetic waves along the core would of course still see the high core permeability; FEMM cannot model this.

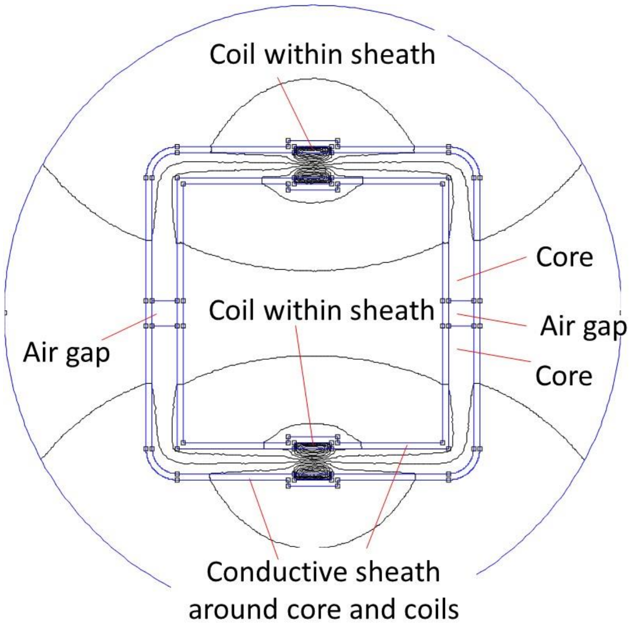

Figure 9

The two centre coils can be connected in series and their magnification Q observed over a frequency range where we expect to see an anomalous high value at the frequency where the delay is 45°. If we are lucky the system will self-oscillate at that frequency. Alternatively we could have primary and secondary coils at the mid positions to create a transformer that has anomalous gain.

5. Discussion

It is by no means certain that reflection from the pole faces will behave in a similar manner to that of electrical lines, but if they do then with primary and secondary coils wound on that centre section the transformer should tend to exhibit over unity characteristic. Should this be the case the question must be asked, where does the excess energy come from? The answer could well be the phase relationship between the standing waves of flux Φ and mmf U at various stations along the core.

Under normal operating conditions, at frequencies where time delay along the core is negligible, there is no phase difference between magnetization M and the mmf gradient H as they are tied together by the characteristics of the core material $M=\chi H$, where χ is the material magnetic susceptibility. Also, since $B \approx \mu_0(H+M)$ and flux Φ is the integral of B across the core then Φ and H are everywhere in phase. And with H arriving from the primary magnetizing current component so also Φ and that U are everywhere in phase (the load current mmf component does not create flux as it is cancelled by the secondary mmf). However, at high frequencies with M being a standing wave from waves travelling forward and backwards it is possible to arrive at the condition where M is not in phase with mmf U from current at strategically placed positions on the core. Then the atomic dipoles (electron spins) that create M can give up energy. The input Meactance of the 45° magnetic delay line above has that desired phase.

Although the current scientific census is that extracting energy directly from their electron spins is impossible because atomic dipoles obey quantum rules, it has been shown [3] that when that inter-atomic space is taken into consideration there is a considerable interchange of energy between the spins and the magnetic field within that inter-atomic space. It is strange that science accepts the presence of fields within inter-atomic space, in magnetized material fields that have stored energy far in excess of the input energy supplied to create the magnetization, yet ignores that glaringly obvious difference. When will it finally be accepted that electron dipoles, be they orbital motion or electron spins, act like small current loops that can have induced emf that attempts to change their motion, and Nature's quantum rules that keep them spinning is the source of their perpetual motion hence is the source of energy extracted from these spins? Perhaps experiments performed as a result of this paper will answer that question.

6. Conclusion

It has been shown that a magnetic capacitance (herein called a Mapacitance), if it were to exist, would be an energy source. The inclusion of a Mapacitance in the magnetic circuit of a transformer would enable the construction of an over unity transformer. It has been shown that magnetic delay along a ferromagnetic core might create a standing magnetic wave from reflection, and with appropriate line length and far end mismatch this could produce a Mapacitive input. Should this be possible the phase between the flux at that input point and the magnetization mmf there is such that energy can be drawn from the atomic electron circulations there that are responsible for the magnetization and that create the mmf. In view of the need for alternative sources of energy it would seem sensible to do experiments to explore this possibility.

Annex A

To achieve the wanted 45° phase delay between coil and airgap at much lower frequencies where core losses are less it is possible to make the core appear as a lumped constant delay line by adding further coils and capacitors over those paths. The author has demonstrated this many years ago in a crude experiment using a ring core having primary and secondary coils at diametrically opposite positions. Between these are a series of additional coils that are each shorted by capacitors. Figure 10 shows the experiment with the primary coil driven by a pulse, showing the non-delayed secondary pulse when all the capacitors are disconnected.

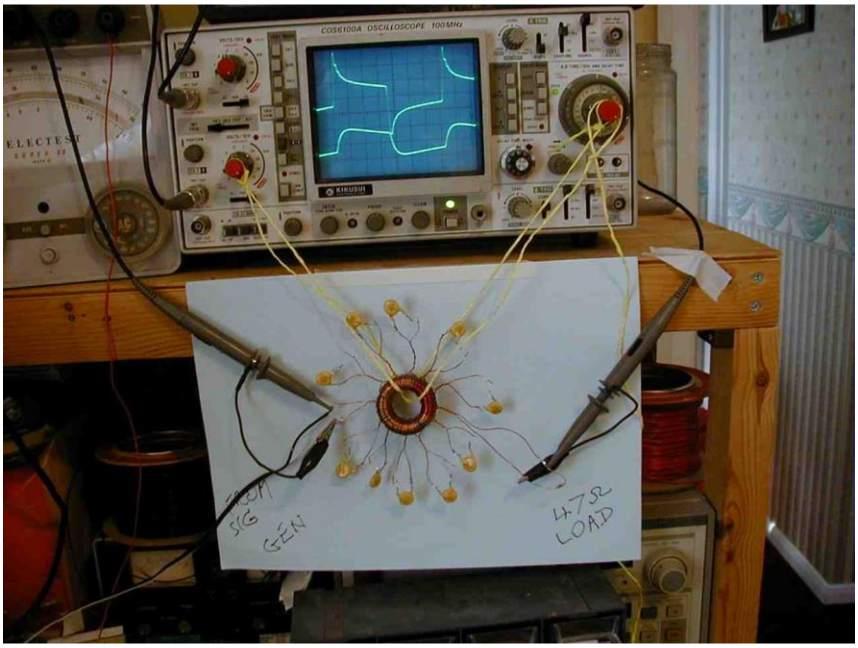

Figure 10

Figure 11 clearly shows the time delay introduced by having all the intermediate coils connected to their capacitors.

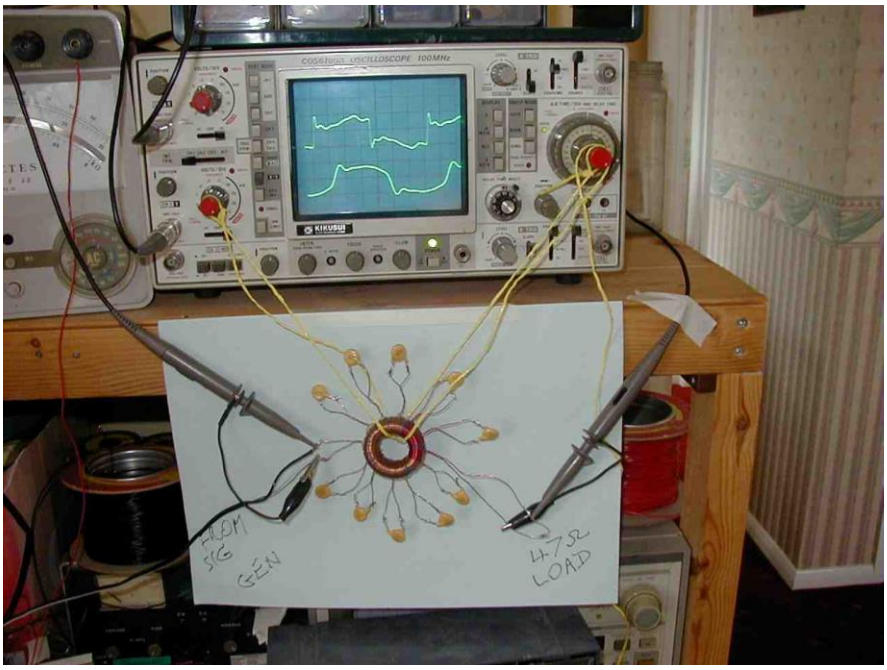

Figure 11

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[3] Magnetic Energy in Ferromagnetic Material
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