Could this work?

1. Discussion on hidden magnetic field energy.

The historical manner in which magnetism developed has created a science which has some serious disconnects in its formulation, never more so than in the physics of ferromagnetic materials. Even though modern scientists know that the magnetization comes from arrays of discrete atomic dipoles, where in that micro-universe the separation between atoms is huge compared to their size, that inter-atomic space and the magnetic fields therein are generally ignored. Scientists use a term called *magnetization* (usually denoted **M**), which is a volume-density of a "substance" called *dipole-moment*, and proceed as though that "substance" is smoothly spread through all space within the material. They know that dipole-moment is a characteristic of a discrete dipole, and that **M** should really be a discrete number-density, but because that number-density is so very high (like 10^{28} atomic dipoles per cubic meter) it has been found more convenient to imagine **M** as a volume-density smooth function. That inconsistency, the filling of inter-atomic space with that imaginary "substance", prohibits the calculation of the actual magnetic fields there and so continues to hide the magnetic energy stored in that space and its vital connection to the atomic dipoles. For permanent magnets those inter-atomic fields are not trivial, and the stored energy has a density significantly greater than the magnet's maximum BH energy product.

Again for permanent magnets that inconsistency has lead to the nonsense of a negative **H** residing within the magnet, i.e. **H** opposing the **B** field. And it has hidden the true meaning of the reluctance of the *air space* occupied by the magnet, something that is used when calculating the load line. This calculation is usually performed by rote with little thought as to why it works, yet the answer is very simple. The magnetic domain equivalent circuit for a permanent magnet is an mmf source (i.e. the combined effect of all the aligned atomic dipoles) in series with that air-space reluctance, and the load-line procedure is simply a graphical method of calculating the mmf drop across that reluctance. Another clue to the inconsistency is the known feature of permanent magnets having an incremental permeability of unity, i.e. they act like air to alternating fields (eddy currents excluded).

The same arguments apply to soft ferromagnetic material, when magnetized there is within the inter-atomic space magnetic energy that is far in excess of that used to create the magnetization. That excess energy is supplied by Nature, it comes from the quantum domain, from the quantum forces driving each atomic dipole. If each atomic dipole were modelled as a small loop driven by a constant current generator, each current generator would supply that excess energy during the magnetic field build-up (and retrieve that excess energy during magnetic field decay). This comes about because the time-changing field induces voltage into each loop so as to oppose or enhance the currents, and it is easily shown that this energy exchange with the generators exactly accounts for the excess energy within that inter-atomic space. In the case of alternating excitation this store of hidden energy is cyclic, which opens the door to methods of extracting a portion on each cycle, with that "loss" (which is our gain) being replenished from the quantum forces driving each dipole.

We are taught that the material stores the quantity of energy we input as given by $\frac{1}{2}Li^2$, where L is the inductance of the coil wound around the material and i is supplied current. That input energy value translates into an *apparent* magnetic energy density of value $\frac{1}{2}B^2/\mu$ within the material where the material obeys $B=\mu H$ having a permeability $\mu=\mu_r\mu_0$. But that discounts the vast inter-atomic space where the magnetic energy is really stored. In reality the energy density stored there is $\frac{1}{2}B^2/\mu_0$, which is μ_r time greater than we are led to believe, and this comes about because the H within that inter atomic space is increased from that just supplied by the coil current. The increase in H comes from the aligned atomic dipoles, which create an H value of χ times the coil's H where χ is the magnetic susceptibility. The sum of the coil's H and the dipole's H is then $(1+\chi)$ times the coil's H, where $(1+\chi)=\mu_r$.

So instead of imagining a *material* that has the property of increasing B for a given H input value, we should imagine *an air space of the material dimensions* where the supplied H is increased by the addition of χH. The presence of the applied H "conjures up" the additional χH. The "conjuring up" is not a magical process, it comes from an array of atomic dipoles (imagine them as tiny bar magnets) that rotate or flip in response to the applied field. At zero applied H field they have random orientations so their net effect seen from outside the material is zero. But when an externally applied H field is present they tend to align themselves with the field, hence increasing the internal H field value, and the relative permeability is simply our method of accounting for that increase.

This paper now looks into the possibility that the atomic dipoles that supply so much hidden field energy could be used to supply energy to an external circuit. This requires an understanding of how our reactive components such as inductors and capacitors behave in the magnetic domain. Few people are familiar with magnetic domain analysis, i.e. treating a magnetic circuit involving mmf and flux in the same manner as an electric circuit involving voltage and current. For anyone interested, my paper [1] "Analysing Transformers in the Magnetic Domain" provides useful information.

2. Magnetic domain circuits

We now wish to take into consideration the atomic dipoles that really supply most of the flux within high permeability cores. Thus the simple case of an inductor supplied with current will look like that shown in figure 1.

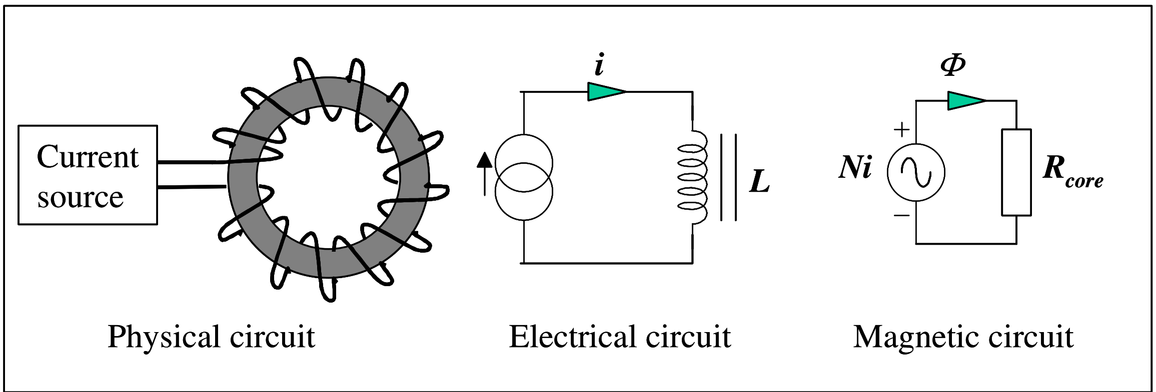

Figure 1. Inductor carrying current and equivalent magnetic circuit

Here R_{core} is the classical reluctance of the magnetic path through the core given by

$$R_{core} = \frac{l}{\mu_r \mu_0 A} \qquad (1)$$

where l is the core magnetic length, A its area and μ_r is the relative permeability. Note that here we are dealing with a core that has no air gaps. In reality the core material obtains its relative permeability by alignment of atomic magnetic dipoles providing a magnetization **M** that is given by $\chi\mathbf{H}$ such that $\mathbf{B} = \mu_0(\mathbf{H} + \mathbf{M})$ and where χ is the magnetic susceptibility. Thus the true magnetic circuit is as shown in figure 2 where the internal magnetization gives rise to an effective mmf that is χ times the applied mmf, *applied to the air space occupied by the core*.

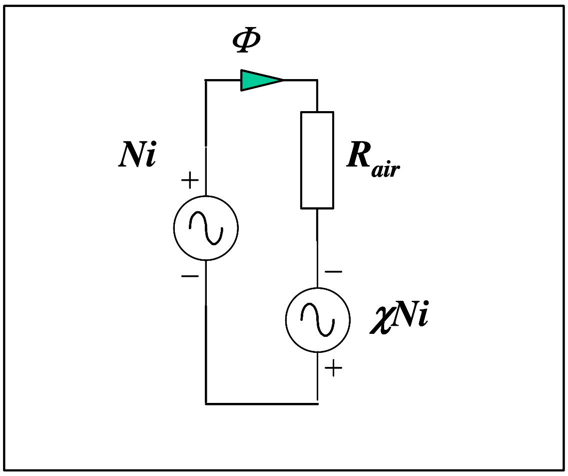

Figure 2. Magnetic circuit showing the mmf from the atomic dipoles

It is clear that the flux Φ is now given by $\Phi = \frac{(1+\chi)Ni}{R_{air}}$ and since $1+\chi = \mu_r$ we can replace R_{air} with $R_{core} = \frac{R_{air}}{\mu_r}$ yielding $\Phi = \frac{Ni}{R_{core}}$ which is the solution to the classical magnetic circuit shown in figure 1.

The use of the classical R_{core} given by (1) hides that atomic dipole contribution. The quest now is to find ways of using those dipoles to supply energy, not hidden as inter-atomic field energy, but supplied to the outside world.

3. Capacitive loading

In transformers [1] it is seen that the primary coil acts as a mmf generator driving flux Φ into the core reluctance, while the resistive-loaded secondary acts like a magnetic inductor L_m in series obeying induced mmf = $-L_m.d\Phi/dt$. It is also shown that connecting a capacitor across the secondary appears as a weird component D obeying induced mmf = $-D.d^2\Phi/dt^2$. Leaving aside the resistive load and considering only sine waves where the flux is say $\Phi\sin(\omega t)$, that second differential yields $\frac{d^2\Phi}{dt^2} = -\omega^2\Phi\sin(\omega t)$. **Hence the induced mmf appears as a positive value aiding the flux flow** given by

$$U = -D\frac{d^2\Phi}{dt^2} = +\omega^2 D\Phi\sin(\omega t) \qquad (3)$$

Dividing (3) by the flux $\Phi\sin(\omega t)$ and taking account that the mmf U has the opposite polarity to that of an mmf drop yields an effective *negative* reluctance $\omega^2 D$. **A capacitively loaded coil appears in the magnetic domain as a negative reluctance**. The value of D is N^2/C where N is the number of turns and C is the capacitance. Figure 3 shows the classical circuit where some flux exists from a previous excitation. Of course this is simply an LC resonant circuit and we would expect the AC flux to decay exponentially due to losses (not modelled here yet, we can add losses by putting a magnetic inductance L_m in series). At resonance the negative reluctance $\omega^2 N^2 C$ exactly negates the positive reluctance R_{core}.

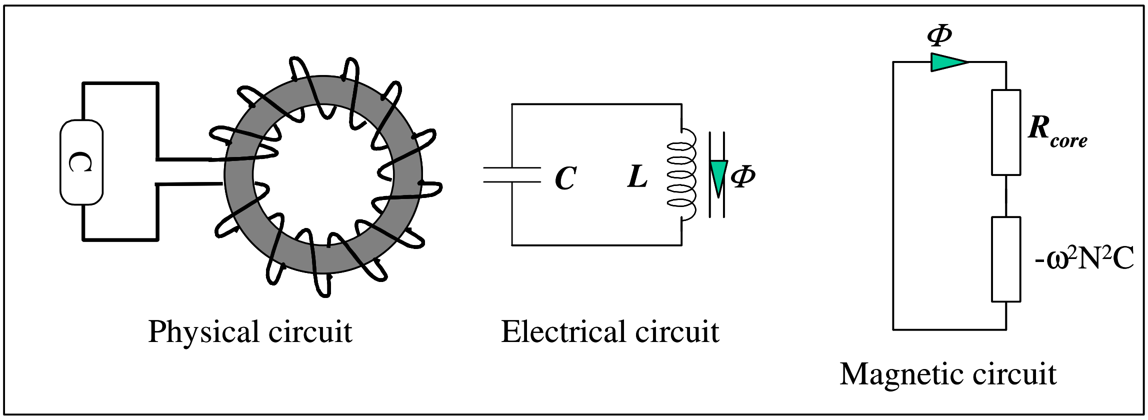

Figure 3. Capacitive connection

When we now take the non-classical view and show the atomic dipole contribution we see that atomic mmf driving flux through a positive reluctance R_{air} that is the air space occupied by the core and a negative reluctance of value $\omega^2 N^2 C$, figure 4.

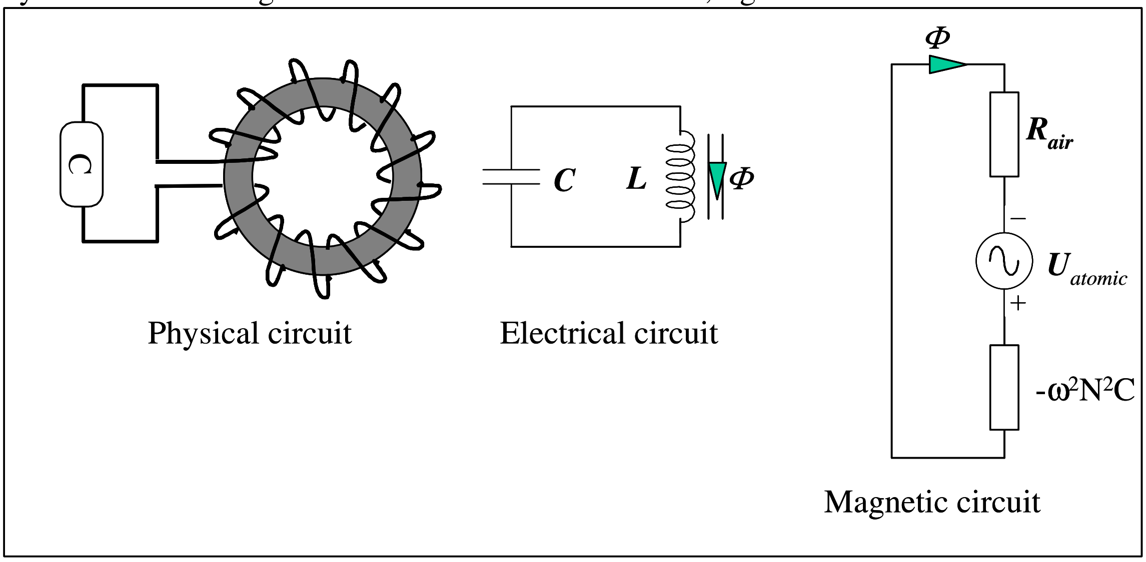

Figure 4. Capacitive connection showing atomic mmf

Clearly here is another resonant condition when the two reluctances cancel each other, given by

$$R_{air} = \omega^2 N^2 C \qquad (4)$$

This is the capacitance C resonating with the inductance L_{air} of the coil where the coil is air-cored, it is the resonant condition that would occur if the core were saturated. The interesting feature of this resonance is the atomic mmf driving into a magnetic short circuit, it requires near zero mmf to obtain magnetic flux. This suggests an unstable situation that could be triggered by thermal noise. If this is really the case it beggars the question why has it not been discovered? Well so far we have not modelled losses, all core materials are lossy and our coils have ohmic resistance and are also lossy. It could well be that these losses prevent our practical experiments from exhibiting this magnetic instability, and since this particular resonant condition has not been recognized before no one has attempted to design an experiment to prove it. For high permeability cores this new resonant condition would require either (a) many orders increase in frequency and that means increased core loss or (b) many orders increase in capacitance which means far greater circulatory current and increase in coil loss. The optimum architecture for this experiment could look completely different to the classical toroidal coil component.

4. Cook Coil Considerations

Unusual features of Cook's coils are their huge size and enormous wire length that suggests many turns. Also with the wire wound directly as a single layer onto the iron core there will be considerable capacitance involved. It is interesting to consider the resonant condition (4) and see what would be the number of turns and the frequency with *C* being the cylindrical; capacitance between core and winding. Thus taking a core of length *l* and diameter *d* (4) becomes

$$\frac{4l}{\pi\mu_0 d^2} = \omega^2 N^2 C \qquad (5)$$

A cylindrical capacitor of length *l* and diameter *d* will have a capacitance

$$C = \frac{K\varepsilon_0 \pi d l}{\delta} \qquad (6)$$

where δ is the thickness of the dielectric between the two cylinders (core and single layer winding) and *K* is the dielectric constant. Putting (6) into (5) and rearranging gives

$$\omega^2 N^2 = \frac{4\delta c^2}{\pi^2 d^3 K} \qquad (7)$$

where we have used $\mu_0\varepsilon_0 = \frac{1}{c^2}$, *c* being light velocity.

If we use $\delta = 10^{-4}$ m as a typical wire insulation thickness, and $d = 0.1$ m as a large diameter core, and say $K = 4$ then we obtain $\omega N \approx 3\times 10^7$. If *N* is 1000 turns we get a frequency of 5KHz. These numbers seem quite practical so maybe there is something to take further here.

5. References

[1] Analysing Transformers in the Magnetic Domain. Cyril Smith February 2006 http://www.overunityresearch.com/index.php?topic=2516.msg39847#msg39847