Some Thoughts on NMR
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1. **Introduction**

Back in 1995 Bertil Werjefelt put forward an eloquent case for using coupled spin systems for extracting energy from magnetic materials. This was based on early NMR work that had been recognized as exhibiting negative (effective) temperatures. He referenced Purcell and Pound's 1951 paper[1] and Ramsey's 1956 paper[2] that both referred to such negative temperature systems. He then went on to propose and patent some structures using rotating permanent magnets that he thought would work as a "Magnetic Battery" but which anyone trained in magnetic analyses could show were nothing of the sort. Clearly he did not appreciate just what *negative temperature* means or how the "coupled spin systems" (his words) in NMR gave rise to such effective temperatures. He is not alone in this lack of appreciation, I myself, although being familiar with NMR techniques and having worked on NQR (which uses similar techniques), did not fully realize what negative temperature systems really were.

Now having educated myself in that area I am able to offer my thoughts on how it may be possible to create a "NMR Battery", a system that extracts energy from the persistent Larmor precessions of nuclei. I use the word persistent because in atomic physics such precession is the only allowable state for individual nuclei in the presence of a magnetic field. However it is not possible to distinguish individual nuclei in any practical material sample, we only see the overall magnetization vector. The precessional rotation of that magnetization vector, coming from an enormous number of such nuclei, is not normally persistent, and NMR deals with how and why that measurable precession comes and goes. It should be noted that when that overall magnetization precession is absent it does *not* mean that the individual precessions have vanished, indeed they are still there but arranged with so much disorder that their overall precessional effect is zero. The NMR Battery aims to use the persistent nuclei precessions as a permanent RF generator delivering electrical power to a load. The source of that power is whatever keeps the nuclei in their persistent precessing state.

2. **Negative Temperatures**

The first thing to realize is that *negative temperature* is not the actual temperature of the material. The ability of a material to absorb from, or emit energy into, its surroundings can be treated thermodynamically where energy always flows from the "hotter" material to the "colder" material. A transmitting antenna that is radiating RF into space can be given an "effective temperature" that determines its ability to radiate power, and clearly that will be "hot". This is not its actual temperature. It is simply treating non-temperature related movement of energy as though it obeyed thermodynamic rules. So we must not think of *negative (effective) temperature* as being a real temperature below ambient, or below absolute zero. By its definition *negative temperature* means *able to radiate energy whatever the temperature of its surroundings*, so in effect it is really hot, indeed hotter than hot! In a system that exhibits negative temperature you can liken a non-linear relationship between heat and temperature as something like the trigonometric tangent function, where the angular degrees represent heat and the tangent represents temperature (It is unfortunate that this analogy uses the word "degrees" as having two different meanings, on the one hand it is a measure of temperature and on the other hand it is a measure of geometric angle. But people are familiar with the non-linear tangent function that goes through infinity so it is used here merely as an illustration of such a function). Starting at zero angular degrees (representing heat) and zero temperature (tan=0) both heat and temperature rise until at 90° (of heat) the temperature is infinite. At that 90° the temperature is both positive and negative infinity (tan90=±∞). Above 90° the temperature is negative (tan<0) and rises from negative infinity, so we still have positive slope. Clearly that negative temperature region (>90°) is "hotter" than the positive temperature region

(<90°). Obviously real energy flow via heat transfer cannot exhibit such a temperature v. heat relationship, but other forms of energy flow (such as RF radiation from antenna arrays) *when treated thermodynamically* can have such weird *effective* temperature v. *effective* heat characteristics.

In thermodynamics, temperature (and *effective* temperature) is related to entropy, which is a measure of disorder in the system. To quote Ramsey, "the only requirement for the existence of a negative temperature is that the entropy S should not be restricted to a monotonically increasing function of internal energy U. At any point for which the slope of the entropy as a function of U becomes negative, the temperature is negative". Thermodynamically, internal energy U is heat capacity. To put this into context, consider the following figure taken from John Denker's on-line tutorial[3].   This shows an array of spins that all start at the bottom in the spin-down position. Clearly there is no disorder, and being spin-down the spins cannot deliver energy. This represents a very cold system. As we move up the chart some of the spins change orientations, they flip, and to do this we have to add energy to the system. At the centre we have maximum disorder, that is maximum possible temperature at infinity. As we continue to add energy more and more spins flip to the spin-up position, and the disorder decreases while the stored energy increases. This is the negative temperature region. Finally at the top of the chart we again have zero disorder, corresponding to a very small negative temperature, and maximum stored energy. (In this chart T is temperature and Decker's β is simply inverse temperature $1/T$.)
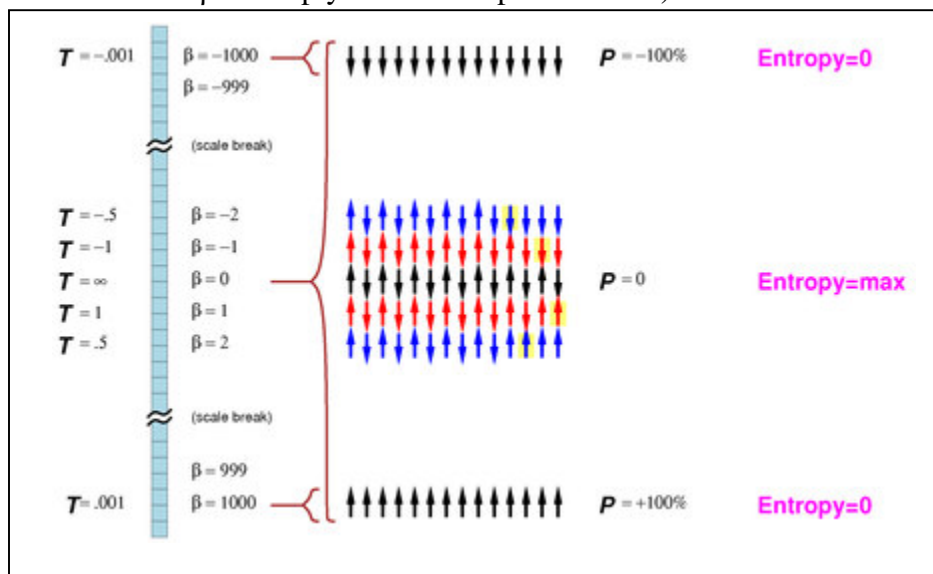

Figure 1. Spin System

The spin system in Figure 1 is exactly what you get in a ferromagnetic core that is magnetically biased, say by a DC current in a coil or a permanent magnet. The magnetic bias saturating the core causes all the spins to align in one direction. That represents the very cold condition at the bottom of the chart. By putting on another coil and supplying current in the reverse direction the bias is gradually reduced bringing the spins into disorder, the centre portion of the chart. More current takes the spins to their ordered state to reach saturation at the top of the chart. All the energy put in, which is simply charge of an inductor, can be recovered to get back to the bottom of the chart. Treating that energy like heat stored in a material leads to the top part of the chart being hotter than the bottom half. Now it may be thought that such a simple inductor will automatically achieve the goal of overunity, but not so. Here we have a reciprocal system where the energy available has to be put in, the system doesn't get "hot" on its own. What we need is a system that stays "hot" as we take out energy, a system that has its own internal supply of energy to keep it "hot". It is possible that a system of precessing spins can do just that if something keeps those precessions going while we take out energy, and that leads us to magnetic resonance systems like NMR. That this might be possible is enhanced by Ramsey's comments "It was found for example that, when a negative

temperature spin system was subjected to resonance radiation, more radiant energy was given off by the spin system than was absorbed". It is the objective of this exercise to create such a spin system using protons that are readily available in water and other materials, to subject them to resonant "radiation" in the form of a RF magnetic field and to collect the RF energy given off from them via their magnetic field.

3. Nuclear Magnetic Resonance

NMR uses the fact that some nuclei have both a magnetic moment and angular momentum from their spin. Thus in the presence of a static magnetic field they precess like miniature gyroscopes do in the presence of gravity. Whereas gyroscopes precess about the gravity vector, nuclei precess about the static magnetic field vector, the precession rate (Larmor frequency) being determined by the gyro-magnetic ratio of the nucleus and the strength of the static field. Without any stimulus the net external effect of many nuclei precessing is zero because of their disorder, the magnetization vector is static and simply points along the applied field direction. But the precessions can be temporarily ordered by several different means.

One simple means is used in some magnetometers that measure the earth's magnetic field by measuring the precession frequency. A strong "static" field is applied at right angles to that of the earth to get the protons generally aligned in that sideways direction. This may take several minutes! Of course the protons precess about that field but having random phases the net magnetization vector is static pointing in that sideways direction. The sideways field is then removed suddenly, but the magnetization vector doesn't suddenly jump to the earth's field direction. It precesses about the earth's field producing a decaying sideways magnetic field at the Larmor frequency. That frequency is measured to get the earth's field value. Koehler[4] has a good paper describing such a home-made device. A disadvantage of this scheme is the large amount of power wasted in the coil that supplies the sideways field.

Another means for creating a precessing magnetization is by applying an RF pulse of suitable amplitude and width (a so-called 90° pulse), and this has the advantage of having less power loss. This is the basis of most NMR experiments. The RF is at the precession frequency and has the effect of cohering the otherwise random phases of the persistent precessions. That cohered set of precessions is seen as a precessing magnetization that can detected as an oscillation beyond the end of the exciting pulse, that oscillation decaying away with time. This is known as a free-induction-decay (FID). The decay is caused by two different effects, the first of these being spin-spin interactions. This is the local magnetic field from one nucleus (note that field is precessing) interacting with a nearby nucleus via its magnetic dipole moment (note that moment is also precessing). This is a mechanism for creating disorder in the phasing so the precessions lose coherence and the overall magnetization vector precession reduces with time. The time-constant for this decay is designated the relaxation time T_2, and to quote Ramsey again "T_2 is of the order of 10^{-5} seconds. It is this process that brings the spin system into thermodynamic equilibrium with itself in a similar way to that in which molecular collisions bring about the thermodynamic equilibrium of a gas". Now we know that heat flow through a gas comes about via those molecular collisions, so here we see the NMR dephasing being likened to an outflow of heat and the spin system changing temperature as a result. But of course this is not real temperature, it is just the *effective* temperature in this thermodynamic treatment.

It may be noted that with molecular collisions bringing about thermodynamic equilibrium, we have no means for "undoing" those collisions, we can't reverse the process. But with NMR dephasing we do have means for "undoing" the effect. A short time after the magnetization precession has decayed to zero the dephased nuclear precessions can be brought back into phase by the application of another RF pulse excitation of suitable amplitude and width (a so-called 180° pulse). The magnetization vector precession builds up during this pulse, then decays away again. That build-up

and decay is known as a spin-echo, and it is possible to have a train of excitation pulses with spin echoes, but generally the peak amplitude of these echoes gradually reduces with a relaxation time T_1 that is much longer than T_2; T_1 times of several minutes have been reported. Ramsey likens this to the leakage through the thermos bottle walls in ordinary heat experiments. That "leakage" comes from the nuclear precessions interacting with the crystal lattice and is dependent on the lattice vibrations that eventually destroy any form of coherence. Because T_1 is so much greater than T_2 the NMR spin system can be considered to be two independent thermodynamic systems each having its own effective temperature. We can treat the cohered nuclear precessions as an isolated spin system having negative effective temperature that is "hotter than hot" with the capability of losing energy to its surroundings.

Note that the above explanation uses RF pulses to create the measurable effect. Normally the train of spin echoes has reducing amplitudes following the time constant T_1 but, with appropriate applied RF pulses, it is possible to maintain a train of spin echoes at constant amplitude indefinitely.

A third form of NMR experiment uses a continuous wave (CW) excitation. When this is applied in the form of a CW magnetic field at the Larmor frequency the proton rich sample absorbs some energy and the previously static magnetization vector starts precessing. Usually either the applied frequency is swept through the Larmor value, or the Larmor frequency is swept (by altering the applied B field magnitude) through the fixed applied value, so that the absorption peak can be found. Alternatively it is possible to observe the precession of the magnetization as an emission peak. It is this emission peak that we are wish to explore to see whether it can deliver power in excess of that absorbed.

4. **CW or Pulsed?**

The earliest NMR experiments used CW excitation that looked for a peak in the absorption spectrum. With advances in NMR spectroscopy, and particularly in MRI, CW excitation has fallen out of fashion. Hence all the NMR text-books devote much to the different types of excitation pulse and pulse sequences. In addition to this the imaging aspect requires static magnetic bias fields that vary in amplitude throughout the sample so that each image pixel is recognized by its unique precession frequency. This deliberate drive over a wide frequency range would not produce a sharp absorption or emission peak. However we are not interested in imaging, we just want maximum NMR signal from a reasonably large material sample. If we can produce a static bias field that is uniform over the sample, then CW excitation is the easiest to perform and yields maximum continuous CW output. What is more we can easily decouple the output from the input by the use of coils at right angles. Then we are not looking for absorption, but looking for output that can only come from a precessing magnetization vector.

The system acts very much like a high Q tuned circuit. The bandwidth, hence Q, is determined by the uniformity across the material sample of the applied static field. With a high degree of uniformity you get a high Q, i.e. a high magnification factor. Now in a LC tuned circuit the Q is current or voltage magnification, it is not a power magnification. If Ramsey is correct in his statement that NMR spin systems can emit more radiation than they absorb, then the high Q resonance peak seen in CW excitation could offer power magnification. When it is realized that the precessing spins, acting like an array of rotating magnets, are persistent, and that the CW excitation merely keeps them in phase, then this power magnification seems eminently possible. The anomalous energy gained comes from the quantum forces that keep those persistent precessions going.

Critics will observe that NMR experiments have been carried out world wide for nearly 70 years, if there were any possibility that these could yield OU then surely this would have been discovered. My answer to that is that the scientists are taught the impossibility of such action, it borders on

perpetual motion that is (of course!!) impossible. Hence there has been no serious attempt to look into this. And the chance of inadvertently finding OU in laboratory experiments is slim because, to my knowledge' there has never been experiments where the magnetic coupling from the sample ensures that *all* the emitted energy is captured. The scientists use "filling factor" to take account of the volume of the sample relative to the volume of the output coil, and treat a 100% value (where the coil is wound directly onto the sample) as denoting maximum possible coupling. Few experiments actually use 100% filling, but even if they did for typical solenoidal coils wound onto proton rich sample "cores" significant fields exist outside the coil volumes and at the radio frequencies involved some power is radiated. More significantly driving a RF magnetic field into air involves high RF current that creates significant coil losses, hence any overunity is hidden behind those losses. In the search for Ramsey's elusive "more radiant energy given off than absorbed" we cannot allow energy loss to dominate the results. Thus the proposed experiment, where the water is contained within a closed ring of plastic tubing, represents the best possible approach to get 100% *coupling*, as opposed to 100% *filling*.

5. **What material?**

It seems all NMR experiments looking for OU use ferromagnetic material, presumably on the basis that such material will yield the largest magnetic output. This inevitably creates problems with uniformity of the static magnetic bias because of the shape dependent depolarising field. Large samples of bulk material are therefore difficult to use, which is why conventional NMR experiments on ferromagnetic materials use thin sheet samples where there is uniform demagnetisation. There seem to be no OU work done using proton spin, despite the ready availability of protons in the form of water.

A proton spin magnetometer that uses proton precession to measure the earth's magnetic field can be easily constructed by the experimenter: there the NMR frequency is about 2KHz. The NMR signal amplitude, being proportional to the applied static field, is very weak in the small earth's field. However we can get increased signal by applying a higher static field using a permanent magnet. Most OU experimenters have NdFeB magnets that can produce 1T fields where the proton frequency would be about 42.5MHz, so at first sight that looks like a good frequency to use. However NdFeB magnets, with their necessary nickel protective coating, are electrically conductive and at that frequency would create significant eddy current loss. Ferrite magnets could be a better option where a field in the region of 0.1T will give a frequency of 4.25MHz.

6. **Proposed System.**

With the CW system, if there is any hope of getting more energy emitted than is absorbed, the resonance line width must be as small as possible yielding high Q, which means having the static applied B field as uniform as possible throughout the water sample. This suggests a small cross section area for the material, which goes against the requirement for large cross section to maximise the signal output. Clearly there has to be a compromise here. Another factor to be considered is the geometric demagnetisation factor that depends upon sample shape, this factor determines the ability of the sample's magnetization to produce a measurable RF B field. If the water sample is in the form of a closed magnetic ring, like the core in toroidal coils, there is no demagnetisation of the RF signal hence yielding maximum signal amplitude. We have chosen to use this ring-core approach where that field improvement offsets the effect of small cross section area. Thus the water is held in a ring shaped plastic tube, having means for filling at the top and for draining at the bottom, as shown in Figure 2.
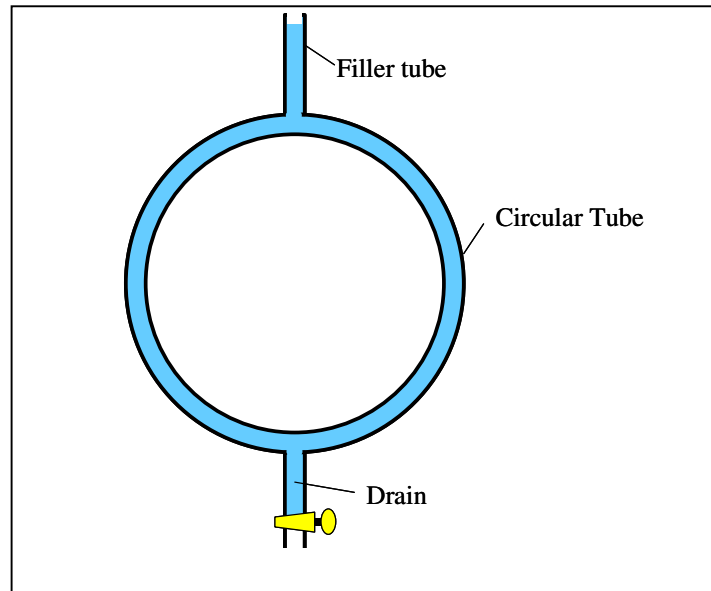
Figure 2. Ring-shaped tube containing water.

Note: At some time it may be necessary to consider other liquids as a source of protons, such as methanol or kerosene. This would require the tube to be resistant to such materials, and the construction of the tube could be an interesting exercise in glass!!

A toroidal coil is wound onto this ring, Figure 3: this is the output coil.
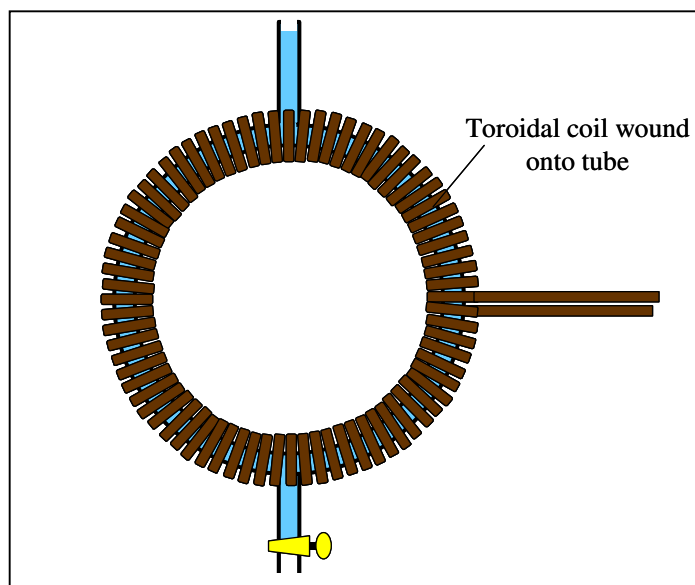

Figure 3. Output coil wound onto tube

To have the proton precessions driving RF magnetization around this ring, the static magnetic field around which the magnetization vector precesses must be everywhere lying across the tube diameter. This is achieved by using a pair of disc magnets applying a magnetic field parallel to the axis of the ring, Figure 4.
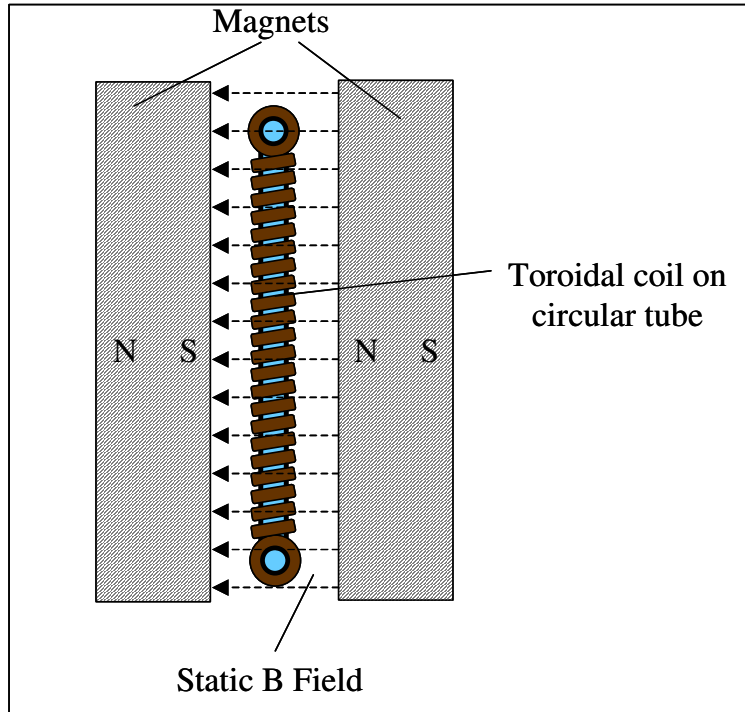
Figure 4. Ferrite magnets supply the static field

The driving magnetic field now has to be radial to the ring axis, and this is obtained by the use of two pancake coils set each side of the ring. Each pancake coil needs to be mounted on a supporting disc, Figure 5.
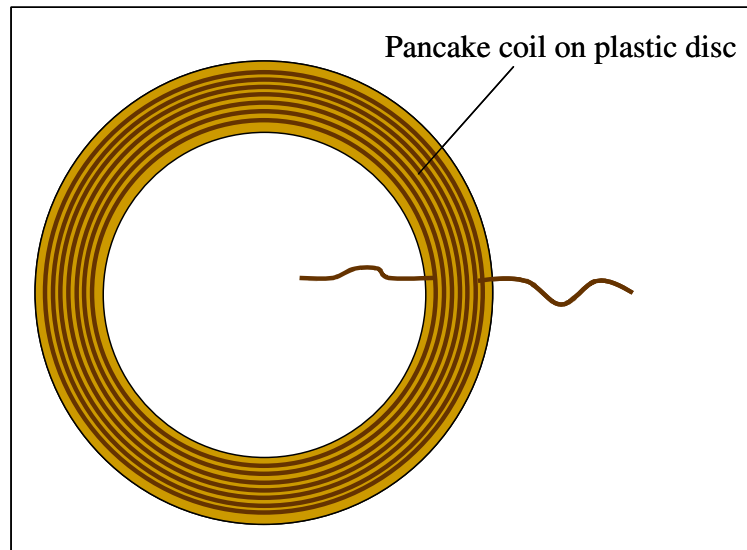

Figure 5. Pancake coil wound onto plastic disc

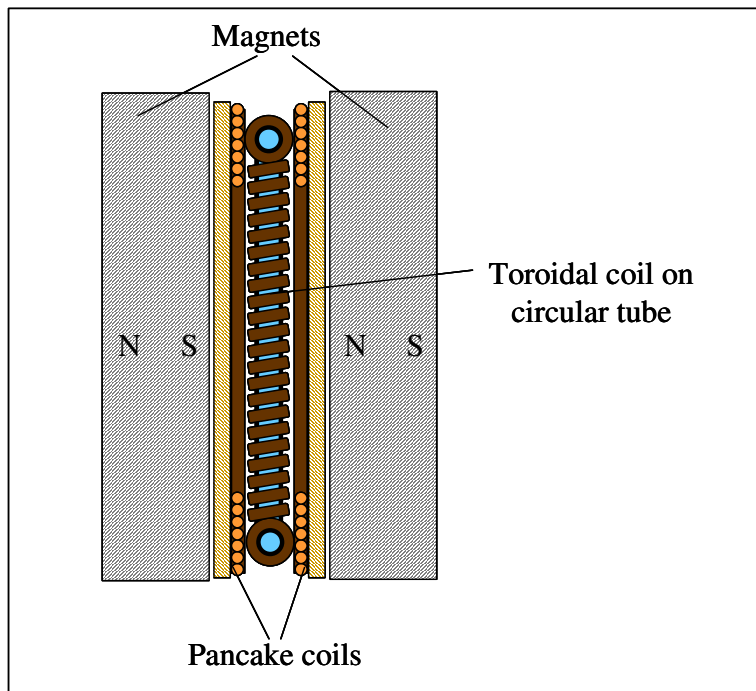Figure 6 shows the completed assembly.

Figure 6. Cross section of complete assembly

Because the water cross section is small compared to the size of the magnets, and with the circular symmetry, this approach should offer uniformity of B field throughout the water sample. However it should be noted that the manufacturing process for the disc magnets does not necessarily guarantee that symmetry, so it may be necessary to use additional large coils carrying DC current that can be manoeuvred to improve the field linearity. It should also be noted that the local earth's field in the laboratory may not be uniform, and this will add to the field from the magnet. Some trial and error adjustments of position and orientation may be required in order to achieve the narrowest absorption or emission peak.

7. Calculations

To establish the NMR signal magnitude it is necessary to determine the number of protons in the material, then derive an expression for the material magnetization from the dipole moments of the protons, that magnetization being a vector that precesses about the static magnetic field applied to the material. The atomic weight of the water molecule is 18.016 (two hydrogen atoms at 1.008 and one oxygen atom at 16). Thus 1 kilomole weighs 18.016Kg. Avagrado's number is 6.0225×10^{26} molecules per kilomole hence there are $6.0225 \times 10^{26}/18.016 = 3.3429 \times 10^{25}$ molecules per kilogram. 1000Kg occupies 1 cubic meter hence the number density of molecules is 3.3429×10^{28} per m^3. As there are two hydrogen atoms per molecule the number density N_p of protons is $N_p = 6.6857 \times 10^{28}$ per m^3. Only a small number of these contribute to the magnetization signal, Koehler[4] uses the fraction $\dfrac{\mu B}{kT}$ where μ is the proton magnetic dipole moment (1.41×10^{-26} Am^2), B is the applied static field, k is Boltzmann's constant (1.3805×10^{-23} Joules/°K) and T is the absolute temperature. Hence the magnetization M is given by

$$|M| = N_p \mu \left(\frac{\mu B}{kT} \right). \qquad (1)$$

My work on NQR, which also used precessing nuclei as a signal source, led me to obtain an expression for M involving the precession frequency ω as

$$|M| = \frac{3^{1/2}\,\omega h^2 \gamma N}{4KT} \tag{2}$$

where h is Planck's constant (hbar) (1.0545×10^{-34}) and γ is the gyromagnetic ratio (2.6752×10^8 rad·s^{-1}·$\underline{T}^{-1}$ for protons). The magnetic moment μ of the nucleus is implicit in this expression because $\mu = h\gamma/2$ for the proton. In NMR the precession frequency $\omega = B\gamma$ so (2) becomes

$$|M|_{max} = \frac{3^{1/2}\,B\mu^2 N_P}{kT} \tag{3}$$

which is almost twice Koehler's value. At 290°K this gives us $M = 5.755 \times 10^{-3} B$.

In magnetism a well-known relationship between M and B is obtained from $M = \chi H$ where χ is the magnetic susceptibility and H the applied field. Since our applied H is $\dfrac{B}{\mu_0}$ we obtain $M = \chi\dfrac{B}{\mu_0}$.

The susceptibility χ has been measured for water, which is diamagnetic, having a negative susceptibility of -9.035×10^{-6}. This then gives us a value $M = -7.1898B$ whose magnitude is much greater that derived above and is negative. The reason for the polarity change is the diamagnetic nature of water that comes from two paired electrons in the molecular bond, and it is *their* magnetic moment that creates the negative value. Hence the static B field actually creates a negative magnetization that could be made to precess at the *electron* resonant frequency. What this tells us is that if we chose to investigate ESR (electron spin resonance) instead of NMR we would gain a factor of 1200 in magnetization magnitude but would have to work at a frequency that is much greater, i.e. 17.6GHz instead of 4.25MHz. Perhaps we will stick to that 4.25MHz, the resonant frequency of the smaller positive magnetization from the aligned protons.

Note that Koehler[4] quotes the measured susceptibility of water, taken from the Handbook of Physics and Chemistry, as 4.26×10^{-9} after his conversion to SI units, and uses this value to support his formula. Schenk[5] gives a useful review of magnetic susceptibility and the different units used. His Table VIII, reproduced here without permission, shows the different contributions to the measured values. The nuclear contribution there is 3.9×10^{-9}.

TABLE VIII. Estimates of the magnetic susceptibility component for water and copper (25 °C). Data from Refs. 158, 165, and 302.

Water		Copper	
Susceptibility mechanism	Calculated value	Susceptibility mechanism	Calculated value
Langevin diamagnetism	-10.12×10^{-6}	Langevin diamagnetism	-25.1×10^{-6}
Van Vleck paramagnetism	$+1.10 \times 10^{-6}$	(core electrons)	
Nuclear paramagnetism	$+0.0039 \times 10^{-6}$	Landau and Pauli paramagnetism	$+15.6 \times 10^{-6}$
		(conduction electrons)	
Total	-9.02×10^{-6}	Total	-9.5×10^{-6}

With a known value for M, which precessing at a known rate creates RF flux into our output coil, it is a simple matter to establish flux $\Phi_{RF} = B_{RF}A$ and $B_{RF} = \mu_0 M_{RF}$ where A is the core cross section area. With our closed loop of water there is no demagnetisation factor hence we know that output voltage $V_{RF} = \omega N \Phi_{RF}$ where N is the number of turns leading to

$$V_{RF} = \omega\mu_0 M_{RF} A N \tag{4}$$

With our tube having say an internal diameter of 10mm and say a toroidal coil of 100 turns we obtain an output voltage of 1.5194×10^{-4}. This can be increased by tuning the output coil to the NMR frequency with a shunt capacitor, yielding a resonant circuit with a Q factor. We then get Q times this voltage value, i.e. a Q of 100 will yield a signal of 15.2 mV. Although small this is readily measurable. The inductance of the toroidal coil is given by

$$L = \frac{\mu_0 N^2 A}{l} \qquad\qquad\qquad (5)$$

where A is the area and l the circumferential length. For our coil of 100 turns on a 12 mm OD plastic tube having a length around the ring of 100π mm we obtain an inductance of $4.52\mu H$. That requires about 300pF to resonate at 4.25MHz.

I do not know what value of CW RF magnetic field is needed to drive the magnetization precession to it maximum value. From my NQR work I do have the requirements for the RF pulse needed to get the proton precessions to cohere. This is an RF pulse of certain magnitude and width, the greater the amplitude the lower the width. Then the magnetization $|M| \propto \sin\varepsilon$ where ε is the spin flip angle given by

$$\varepsilon = 3^{1/2} \gamma B_{RF} t_p \qquad\qquad\qquad (6)$$

where B_{RF} is the driving RF magnetic field and t_p is the pulse width. For maximum M we need the spin flip angle ε to be $\pi/2$ (the so called 90º pulse) hence $B_{RF} t_p = \frac{\pi}{3.464\gamma}$, and this yields the M we derived above, equation (3). [For those who wish to follow the pulsed RF route equation (6) with ε set to the value π gives you the 180º pulse required for spin echoes.] Also my NQR work looked at nuclei precessing at about 5MHz, which is near the frequency we will be using, and there a typical pulse width in use was 100μS. Using that pulse width the magnitude of the RF B field comes out at 3.39×10^{-4}T (3.39 Gauss), which is quite small and easily provided. It can be assumed that CW operation could require less than this order of drive signal.

Because our pancake coils occupy an annulus where the inner diameter is a large fraction of the outer diameter we can calculate the magnetic field as though adjacent to long thin sheets of current. This is treated in Boast[6] for a point near a single current sheet or strip, and using that treatment we can derive the field for a pair of current strips carrying opposite current. We then have the situation shown in Figure 7, where our point P is central and the relative permeability μ_r in Boast's equations is unity.
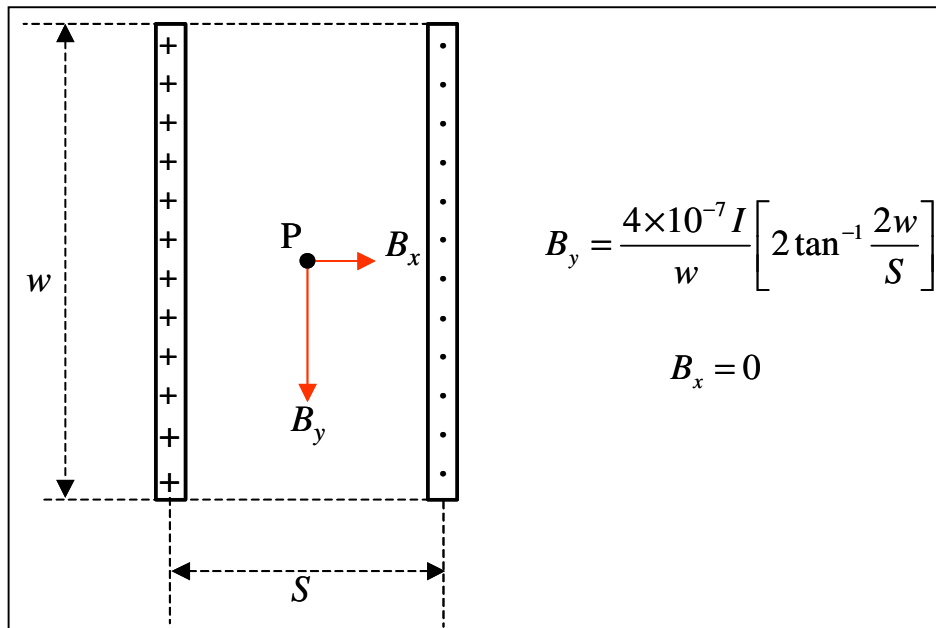

$$B_y = \frac{4\times10^{-7} I}{w} \left[2\tan^{-1}\frac{2w}{S} \right]$$

$$B_x = 0$$

Figure 7. Field at the centre of a pair of current sheets

Our initial design has the coil separation S of 15mm, the width w is 30mm and this leads to the current I in each strip being 11 amps to get the required 3.39×10^{-4} T drive field. A FEMM simulation with these dimensions yielded 3.25×10^{-4} T. FEMM also gives the inductance for the

long line presented as 11 closely spaced turns as 4.6×10^{-5} H/m. Since our line is in the form of a circle of mean radius 100mm having a circumference of 0.314m we can take the inductance of our pair of 11 turn pancake coils connected in series to be about 1.45×10^{-5} H. This requires a capacitor of about 100pF to resonate at our frequency. That is convenient since we will need to tune the device and moving-vane variable capacitors covering that value are readily available.

8. Design Summary

Figure 8 shows the basic design with the dimensions used in the previous calculations. It is left to the experimenter to chooses his own dimensions based around whatever components he can obtain. The formula given in section 7 should allow him to perform his own calculations. Figure 9 shows the basic circuit diagram where the input is assumed to be a low impedance signal generator that needs to be matched to the high impedance of the input resonant circuit. This is simply achieved with the capacitor network shown.
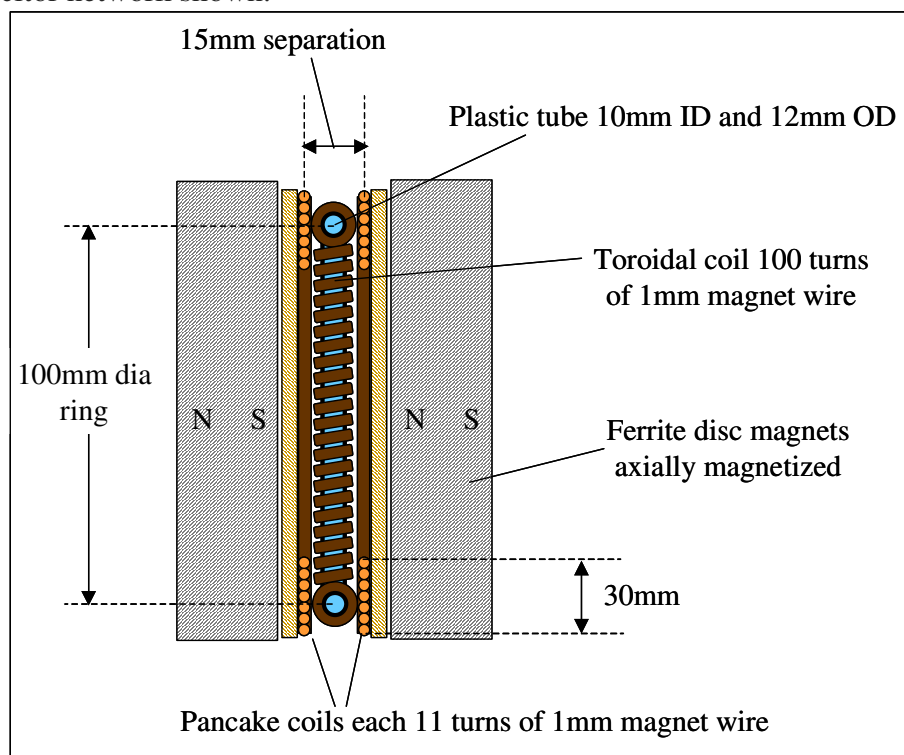

Figure 8. Basic design dimensions.

The drive coils will have RF voltage across them that is several hundred volts. Thus it is likely that stray capacitive coupling to the output coil will induce a signal there, and that needs to be nulled out, either by careful layout taking account of the "hot" end of the drive or by adding extra trimmer capacitors. This could be done with the plastic tube empty, then when water is added its NMR should show up. Note however that water has a high dielectric constant and simply adding water may change the stray capacity coupling.
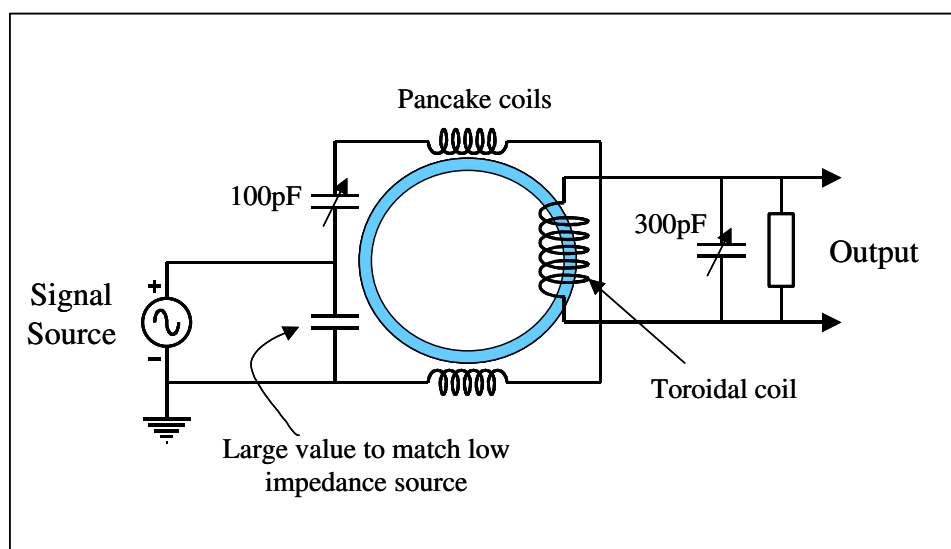
Figure 9. Basic circuit diagram

9. Extending the design

It is likely that the output power from the precessing magnetization will be smaller than the inherent losses in the circuit. It may be possible to boost the signal levels by using a liquid that has a greater number of active protons than water. Overhauser[7] manufacture proton spin magnetometers for earth's field measurements, and they claim an improvement of 5000 is feasible. Extracts from their paper are:-

> "The essence of classical proton magnetometers is to increase the magnetization of the liquid sample, i.e., to increase the difference of proton spin populations of the two energy levels by applying strong "polarizing field"…… If we add to the sensor liquid some free electrons that have "unpaired" spins and thus magnetic moments, the electrons will in general couple magnetically with the protons producing four energy level system……..Since electron resonant frequency ω_s exceeds proton frequency ω_l by about 660 times, we could theoretically end up with so much increased proton polarization, i.e., magnetization M_o……… Further improvement in Overhauser effect is achieved by free radicals where electrons exhibit strong scalar coupling with the nucleus of nitrogen (nitroxide free radicals). The effect of this interaction is that the electron dwells in a local magnetic field of about 16 gauss, i.e., its resonant frequency is not 1.4 MHz (in the Earth's magnetic field of 0.5G) but more than 60 MHz. ω_s is therefore increased and a theoretical increase of proton polarization is several thousand times instead of 660, about 5000 times being practically achievable. Further advantage of this higher resonant frequency is that the RF saturating frequency can stay constant for the whole Earth's magnetic field range. Nitroxide free radicals of interest are perfectly stable in solutions of neutral liquids such as methanol and similar."

It appears that with the electrons magnetically coupling with the nuclei you get some absorption/emission peaks at higher frequencies yielding greater signals. Clearly there is much an experimenter can do to look for these greater levels. It is worth noting another quote from Overhauser[6]

> "This setup could then result in emission of energy or so-called MASER effect. We mention it here only as a curiosity as it has no practical value."

Another line of investigation could look into the actual measured value of diamagnetic susceptibility -9.035×10^{-6}. This is due to alignment of unpaired electrons, and we could operate in a lower value of static field looking for electron spin resonance.

10. References.

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