A Single Magnet Fast Field-Cycling MRI System with Detection at 0.5T

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Introduction:

In recent years there has been increased interest in the use of magnetic field cycling with MRI. In field-cycling the magnetic field is switched between three levels: the polarization field B_{0P}, the evolution field B_{0E} (often a low value) at which the spins evolve, and the detection field B_{0D} at which RF pulses and signal detection occur. B_{0P} and B_{0D} should be as high as possible in order to improve SNR. The technique is used in field-cycled proton-electron double-resonance imaging (FC-PEDRI), to image the distribution of free radicals in biological samples[1]. Here the magnetic field is reduced to B_{0E} (typically ~4 mT) at which the EPR of the free radical is irradiated for ~3×T_1, transferring polarization from electron spins to water protons via the Overhauser effect. After ramping the field up to B_{0D} in a time < T_1, signal detection occurs. A second use for field-cycled MRI is in relaxometric imaging, where field-cycling is employed to allow the acquisition of images showing the behaviour of T_1 with field strength, obtained on a single instrument. Such T_1-dispersion measurements can highlight so-called quadrupole dips in the T_1 *versus* B_{0E} plots, caused by ^{1}H-^{14}N interactions in immobilized proteins [2-4]. Relaxometric imaging can also be used in conjunction with contrast agents that are designed to have a step change in their relaxation rates as they are switched between different magnetic field strengths [5]. With relaxometric imaging the contrast due to these agents can be switched on and off at will. In our previous work we have used systems in which B_{0P} and B_{0D} have been provided by permanent or superconducting magnets to take advantage of the size, stability and homogeneity of their field, particularly for detection [6]. A co-axial offset magnet was used to reduce the field down to B_{0E}. We have recently built a field-cycled MRI system, for both of the above applications, in which B_{0E}, B_{0P} and B_{0D} (up to 0.5 T) are all provided by a single resistive magnet.

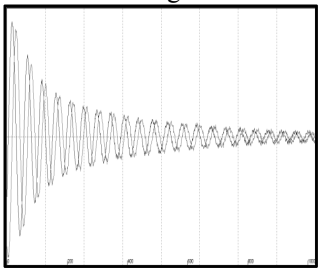
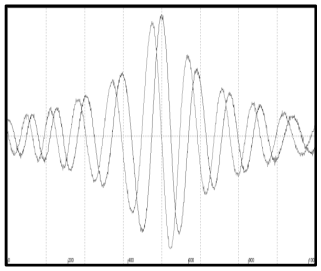
Apparatus:

***Field-Cycling Magnet Specification*:** The system is designed to cycle to any field between zero and 0.5 T, with a field switching time of under 15 ms. The maximum sample diameter is 80 mm. To avoid image artefacts the detection magnetic field must be homogeneous (shimmed to ±1 ppm over a 100 mm diameter spherical volume (DSV)), stable (±1 ppm within 10 ms of a field switch) and repeatable (±1 part in 10^8 from one acquisition to another). Relaxometric imaging measurements can tolerate relatively large spatial and temporal variations (~5%) in B_{0E} , but FC-PEDRI is less forgiving, so the specification was tailored to FC-PEDRI studies using narrow EPR-line (~50 μT) free radical contrast agents. In order to achieve uniform and efficient irradiation of the free radical's EPR, B_{0E} (typically ~4 mT) should be homogeneous (shimmed to ±10 μT over a 60 mm DSV), stable (±5 μT during the evolution period) and reproducible from cycle to cycle.

***Magnet Implementation*:** A single resistive magnet system is employed (Tesla Engineering Ltd., UK) to provide B_{0P}, B_{0E} and B_{0D}. The magnet is 679 mm long, with an external diameter of 570 mm and a bore, inside the shim and gradient assembly of 150 mm. To aid matching of the magnets impedance to the power supply it has been constructed from two co wound segments. These are driven in parallel, by a custom power supply (Copley Controls Inc., USA) with an efficiency of 833 μT A^{-1} per segment.

***Console and RF*:** The system is controlled by a commercial NMR/MRI console (Oxford Instruments Molecular Bio-tools Ltd., UK), via a standard PC. The magnetic field is set by the console via a 16-bit, high-precision DAC module whose output is fed to the magnet's power-supply amplifier. The console also provides RF at the NMR frequency (19.29 MHz). These studies made use of an eight leg birdcage RF coil tuned to 19.29 MHz for a field of 453 mT.

Results: Signals (shown below) were obtained from a 60 mm sample of 0.25 mM $CuSO_4$, using the apparatus shown on the right. On the left is a 10.24 ms FID, in the centre a spin echo.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