Development of an RF coil tuning system to enable Nuclear Quadrupole Double Resonance in Fast Field-Cycling MRI

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Fast Field-Cycling Magnetic Resonance Imaging (FFC-MRI) differs from conventional MRI techniques in the ability to vary the magnetic field strength of the scanner. This additional functionality is exploited to access contrast originating from the dependence of relaxation rate on the Larmor frequency[1]. Importantly, at magnetic field strengths where the proton Larmor frequency is equal to a Nuclear Quadrupole Resonance (NQR) frequency of a coupled quadrupole spin system an increased proton relaxation rate is observed[2]. At these field strengths the quadrupole system can affect effective proton spin-lattice relaxation times; this is a form of Nuclear Quadrupole Double Resonance (NQDR).

Other NQDR methods, developed in solid-state NMR, potentially allow more sensitive detection, thus enabling relaxation effects to be seen in samples with a lower concentration of quadrupole nuclei[3]. These techniques involve the addition of RF irradiation at one or more frequencies and as such it is necessary to develop an RF coil capable of being tuned and matched during a pulse sequence.

By utilising SVC236 varactor diodes, which act as voltage-controlled capacitors, in place of conventional tuning and matching capacitors, a system was developed where commands from the scanner's commercial console (MR Solutions Ltd., U.K.) could select any tuning frequency within the coil's attainable range. The intermediary control circuit consisted of four cascaded serial-to-parallel 74HC595 shift registers which passed data to two 16-bit DAC715 Digital-to-Analogue Converters (DAC). This allowed the process to be controlled using just three of the console's limited number of TTL lines. The output of each DAC provided the reserve bias voltage across an array of varactors used for either tuning or matching. For maximum tuning flexibility, a calibration procedure was designed to allow MATLAB (The MathWorks Inc., U.S., version 2013a) to calculate the critical variables used in the pulse sequence code.

The method of control benefitted from full integration with the existing FFC-MRI scanner, allowing tuning instructions to be conveniently inserted within the pulse sequence code. It was found that memory-efficient code could tune the coil every 1.2 milliseconds. With a carefully-selected RF coil inductance and additional levels of fixed capacitance, the system was made tuneable between 2 MHz – 3 MHz, covering the two highest NQR frequencies of Nitrogen-14 in biological samples. Future work is now aimed at exploring the effects of applied irradiation to quadrupole containing samples in FFC-MRI.

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References

[1] D.J. Lurie *et al*. *Comptes Rendus Phys*. **2010**, 11, 136–148.
[2] R. Kimmich, E. Anoardo *Prog. Nucl. Mag. Res. Sp.* **2004**, 44, 257-320.
[3] D.T. Edmonds *Phys. Rep*. **1977**, 29, 233-290.