Wireless Control of an Implantable Coil System for Magnetic Resonance Imaging and Spectroscopy

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Introduction: About 7% of the U.S. population has diabetes, with 5-10% of these having Type-1 diabetes; a pancreatic disorder in which insulin production is hindered [1]. Although daily insulin injections give people a near normal life, they are still greatly affected by this lifestyle and this therapy can only delay the major health consequences of diabetes [2,3]. An alternative therapy is implantable tissue-engineered pancreatic-constructs for insulin production, which have been monitored with NMR [4-5]. However, these NMR measurements are sensitivity-limited and therefore hinder the evaluation of the construct functions and performances. In addition, the detection of multiple important biological nuclei, including $^{1}H$, $^{19}F$, $^{31}P$, and $^{13}C$ is necessary for a complete characterization of the pancreatic substitute’s function, but multiple-resonant coils require additional components, or create degenerate modes, that add loss to the coil circuit and limit the sensitivity.

To overcome the sensitivity limitations, we developed a multiple-frequency solution involving a “single resonant” approach (see Figure 1), where an array of varactors and capacitors are remotely switched, via a microcontroller embedded within a microchip, to resonate with the inherent coil inductance. Then the resonance frequency can be controlled by communication with this microcontroller. In this way, the coil essentially behaves like a single-frequency resonant coil, significantly improving the sensitivity. Here we report on a proof-of-concept prototype of this microchip system.

Experimental: The prototype (see Figure 2) mimics the function of the above concept at 11.1T for the detection of 4 MRI/S nuclei: $^{1}H$ (470 MHz), $^{19}F$ (442 MHz), $^{31}P$ (190 MHz), and $^{13}C$ (118 MHz). The MR coil is directly connected to a capacitor array, which determines the frequency at which the MR coil resonates. The capacitor array consists of three parallel branches, each containing a varactor for tuning the MR coil. The first branch contains only a varactor. The second and third branches each contain a varactor and PIN diode switch controlled by a FET. The supporting circuitry consists of a controller for the capacitor array and a wireless receiver (consisting of a small antenna, bandpass filters, and envelope detectors) to detect the input desired frequency of operation. The overall digital system level design consists of 3 main-functional components: (1) buffering and amplification of filter input to the microcontroller; (2) automated control of varactors via DAC converters; (3) automated control of the FET switches. Based on the input selected, the controller generates 2 outputs: (1) the appropriate data stream to the multiple-output DAC to generate an analog voltage for the varactors, and (2) a DC voltage for FETs to select the appropriate array branch to be activated. In this fashion, the small antenna detects the input MR frequency-of-interest then the supporting circuit sets the prototype capacitor array.

Results and Discussion: The prototype, with all of the modular components described above, was used to select the 4 MRI/S frequencies, then the performance was measured with a network analyzer. The prototype successfully selected each frequency and the overall capacitor array displayed an equivalent-series-resistance of ~1.0 Ohm for all frequencies.

Conclusions: The use of the varactor-array design enables coil tuning to the input-specified frequency, since the controller provides automatic coil tuning by supplying the appropriate voltages to the varactor array. The overall capacitor array displayed a higher equivalent-series-resistance (~1.0) than expected, which was probably due to losses in the PIN diode switches and perhaps the circuit board. However, a microfabricated chip should circumvent these losses. This prototype study shows the flexibility of the design and illustrates that this design can be adapted to a range of targeted MR frequencies.

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References