Wireless Control of an Implantable Coil System for MRI/S

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Introduction

Of the total U.S. population, 7% have diabetes, and 5-10% fall under the category of Type-I diabetes, a pancreatic disorder in which insulin production is hindered, resulting in an unbalanced content of glucose in the bloodstream [1]. Although daily insulin injections give people a near normal life, they are still greatly affected by a changed lifestyle and can only delay the major health consequences induced by diabetes [2,3]. An alternative solution to alleviate the burden of the current treatment is the development of tissue engineered pancreatic constructs with a surface coil as an RF antenna at 4.7T [4-5]. Although these experiments demonstrated excellent potential, they faced limited sensitivity which hindered 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. Multiple-resonant coils require additional components or create degenerate modes that add loss to the coil circuit and limit the Signal-to-Noise Ratio (SNR) of *in vivo* tests.

Here we propose a multiple-frequency solution involving a "single resonant" approach, where an array of varactors and capacitors can be remotely switched, via a microcontroller embedded within a microchip, to resonate with the inherent inductance of the coil. The user can set any desired frequency by communicating with this microcontroller. This coil would then essentially behave as a single-frequency resonant coil, significantly improving the SNR. Such a system is shown in Figure 1. The focus of this work was to build a proof-of-concept prototype before developing the entire micro fabricated integrated chip system.

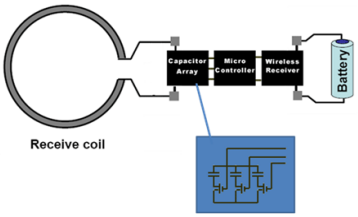


Figure 1. Conceptual diagram of the implantable,wireless microchip and MR coil.

Methods

The prototype design was built to mimic 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). A block diagram of the prototype is shown in Figure 2. 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 variable tuning of 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 (ATmega168) to control the array and a wireless receiver (consisting of a small antenna, bandpass filters, and envelope detectors) to detect the user's desired frequency of operation as input. 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 digital voltage for FETs to select the appropriate array branch to be activated. To select an MR frequency, the user simply sends an rf signal at the MR frequency of interest, which is detected by the small antenna and input in to the prototype circuitry.

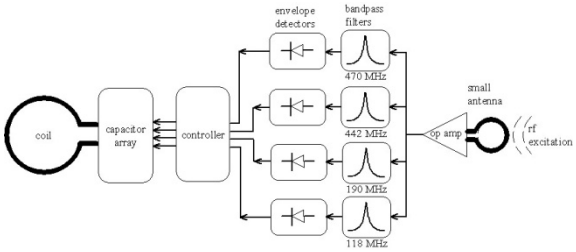
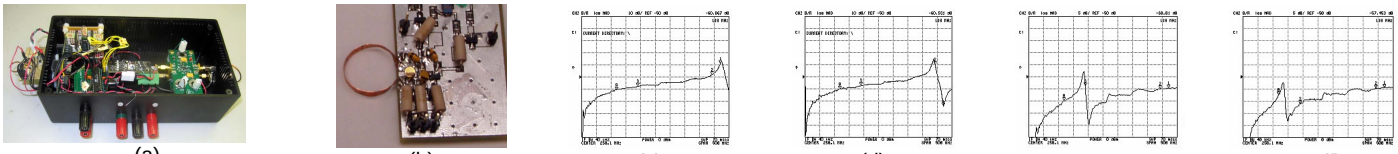


Figure 2. Block diagram of prototype

Results

The assembled working prototype, with all of the modular components described above, is shown in Figure 3 (a), along with a close-up of the capacitor array in Figure 3 (b). Figure 3 (c)-(f) displays plots taken from the network analyzer measured response of the prototype when each of the 4 frequencies is requested wirelessly. This proves successful frequency selection. The overall capacitor array displayed an equivalent-series-resistance of ~1.0 across all frequencies.



(a) (b) (c) (d) (e) (f)

Figure 3. (a) working prototype, (b) close-up of the capacitor array and MR coil, and (c)-(f) Network analyzer measurements of the MR coil switched to four frequencies available at 11.1 T; (c) 470 MHz (^{1}H), (d) 442 MHz (^{19}F), (e) 190 MHz (^{31}P), and (f) 118 MHz(^{13}C).

Conclusion

Use of the varactor array enables tuning to any frequency. Therefore given any user-specified input frequency through pulses within the MR console, the controller can automatically tune the coil to this desired frequency by supplying the appropriate voltages to the varactor array. For example, our project was designed to demonstrate function at 11.1 Tesla for 4 frequencies 470 MHz (hydrogen), 442 MHz (flourine), 190 MHz (phosphorus) and 118 MHz (carbon). 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 FR4 circuit board. The end product of this project will be a microfabricated chip which should circumvent these losses. However, the prototype presented herein shows promise in allowing a flexible design that can be adapted to the targeted MR frequencies.

References

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