An Automatic Impedance Matching System for Multiple Frequency Coils

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Introduction

It is estimated that over 250 million people worldwide have diabetes, with juvenile diabetes occurring at epidemic levels. Type-I diabetes is a pancreatic disorder in which insulin production is hindered, requiring daily insulin injections, with severe long term health consequences. An alternative therapy is implantable tissue-engineered pancreatic-constructs for insulin production, which have been monitored with NMR (1,2,4). 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 construct, but losses in multiple-resonant coil designs hinder the ability to assess construct viability and function. To overcome these sensitivity limitations, we are developing a "single resonant" approach in which an array of capacitors is remotely switched, via a microcontroller embedded within a microchip, to resonate with the inherent coil inductance. These concepts are being incorporated into an inductively-coupled, implanted coil system, where an external coil and an implanted coil are coupled to allow measurement of the NMR biological nuclei of interest. Previous results reported the ability to switch the operating frequency of a small coil under microprocessor control (3). Such a broad frequency approach requires system impedance match at every frequency. This work reports on an Automatic Impedance Matching (AIM) system developed for this multiple-frequency system. A companion work (see Conference abstract index) reports on initial testing of a microchip capacitor array for the implanted coil.

Methods

The AIM system is designed for the 11.1 Tesla NMR scanner to detect multiple nuclei including ^{13}C (118MHz), ^{31}P (190MHz), ^{19}F (442MHz), ^{1}H (470MHz). Figure 1 shows the high-level block diagram of the AIM system and provides details of its three Modules: 1) Tuning and matching microprocessor, 2) Impedance sensing circuit, which measures the relative magnitude and phase of the reflected RF signal at the frequency of interest, and 3) A varactor tune and match network. Initially, the microcontroller receives a special RF control sequence from NMR console to select the frequency of interest. Then, the microprocessor controls the impedance sensing circuit to obtain the S11 information of the coil. In particular, the microprocessor (ADCu7020) sets the sensing RF signal at the frequency of interest in the impedance sensing circuit. This signal goes through a bidirectional coupler that attaches to the varactor tune and match network. The bidirectional coupler provides both a reference signal at the forward coupled port, as well as the reflected signal at reverse coupled port. Moreover, both signals are sent to a gain-and-phase detector to obtain their magnitude ratio and phase difference in terms of DC voltage. The microprocessor uses its built-in analog-to-digital converters to read the information provided by the impedance sensing circuit, then implements an algorithm that tunes the coil to different predetermined load models and finds the overall minimum S11. Once the model is identified, the microprocessor fine tunes the coil by repeatedly adjusting the voltage on the tuning and matching varactors for the best result (smallest S11).

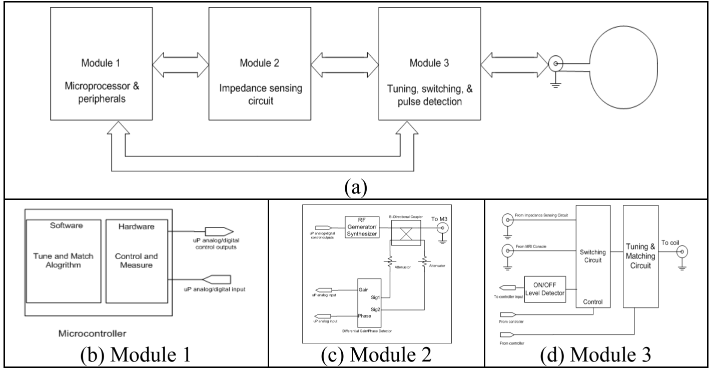

Figure 1. (a) AIM system high level block diagram and (b-d) Module details.

Results

The prototype of all three parts for the AIM system is shown in Figure 4 (a-c). Module 3 is simplified to work at ^{19}F (442MHz) and ^{1}H (470MHz) in order to test the AIM system under varying load conditions. The last four figures are the S11 results obtained from a network analyzer. These results show that the AIM system can tune and match the coil at the two desired frequencies in either the unloaded coil condition or the loaded coil condition with an average brain phantom (ε_r=48.8, σ=0.62 S/m).. The S11 was greater than -20 dB for all loading and frequency states. The unloaded Q was ~35 and loaded Q ~19 for both frequencies.

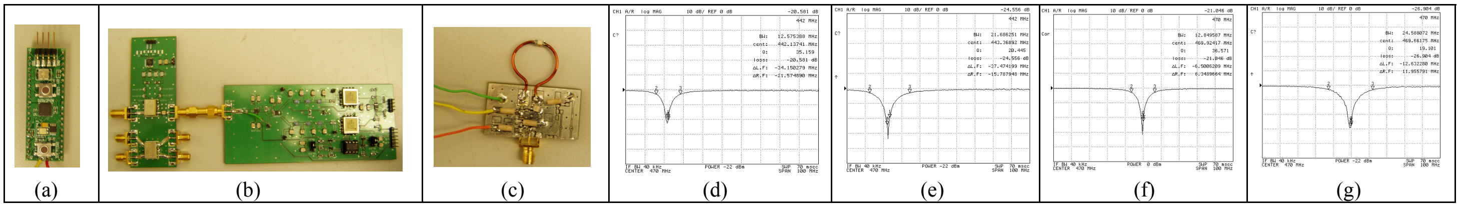

Figure. 4 (a) Module 1, microcontroller, (b) Module 2, prototype of impedance sensing circuit directional coupler (left) and voltage controlled oscillators (right), (c) Module 3, a simplified tune and match network (442MHz and 470MHz only) with coil, (d-g) S11 and Q measurement of the AIM system from the network analyzer, (d) 442MHz without a load, S11= -20.6 dB, Q=35, (e) 442MHz with average brain phantom, S11= -24.6 dB, Q=20, (f) 470MHz without a load, S11= -21.0 dB, Q=37,(g) 470MHz with average brain phantom, S11= -26.0 dB, Q=19.

Conclusion

These results validate the concept design of the Automatic Impedance Matching system. The design can be extended to tune and match for ^{13}C (118MHz) and ^{31}P (190MHz) easily by replacing the varactors in the tune and match network with ones having a wider range of capacitance, since the impedance sensing circuit will work from 100MHz to 500MHz. While the concept is validated, the overall performance of the AIM system still needs to be improved. For example, optimum signal strength is needed to reduce unwanted capacitance modulation of the varactor while keeping the reflected signal detectable. Moreover, a better algorithm is needed to decrease the tune and match time (presently ~ 20 s). Nevertheless, this prototype validates the fundamental design concepts of the AIM system.

References

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