Autotuning Electronics for Varactor Tuned, Flexible Interventional RF Coils

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Interventional coils can detune substantially due to differences in patient loading and positioning. This is especially true for flexible interventional coils, which absolutely require re-tuning after implantation. We have developed and tested a method for asynchronous re-tuning of varactor-diode tunable coils. We use a micro-controller to orchestrate a reference oscillator, a phase comparator, a DAC for the varactor tuning, TR switches, and a simple tuning algorithm. Before-and-after measurement of the tuned coil impedance reveals successful retuning in under 300 milliseconds.

Introduction: Recent work with flexible, interventional coils has resulted in very high local SNR.[1] However, by increasing the coupling between the RF receiver and the patient, the differences in loading conditions have a stronger effect on the coil tuning, and detuning can hamper performance. This has led to work in varactor-tuned coils. [2,3] Here we develop an electronic method for automatically tuning such a coil for optimum SNR: to center its tuned impedance curve at the frequency of interest.

Principle of Operation: The impedance of a parallel resonant circuit is purely resistive on resonance, and is capacitive and inductive if resonant at frequencies below and above the target Larmor frequency, respectively. If a signal is applied at the Larmor frequency to a resonant circuit in series with a reference capacitor, their voltages will have a difference in phase of 90 degrees under tuned conditions.

Multiplication of the voltages across the tuned circuit and the reference capacitor results in a DC term of $|v_1||v_2|\cos(\phi_1\text{-}\phi_2)$, where $v_{1,2}$ are amplitudes, and $\phi_{1,2}$ are absolute phases of the signals. On resonance there is a DC null, and we tune the circuit to find this null.

Methods: We chose an Atmel 90S8515 μ-controller with an SPI interface and an analog comparator to perform the simple tuning algorithm. It controls the PLL synthesizer, composed of a MC145170-2 PLL, a mini-circuits POS-100 VCO, and a LT1227 tri-stateable current feedback amplifier. This block produces and drives a 63.9MHz signal during tuning, and switches to 90MHz and high-Z to avoid interfering with the coil during receive mode. The PIN diode TR switches provide 40dB of isolation, and, along with a classic $\lambda/4$ impedance transformation, enable appropriate impedance isolation for both tuning and receiving modes.

To perform the phase comparison we use an AD835 high-speed multiplier with an RC lowpass filter at the output, and AD96685 ultra-fast voltage comparators to eliminate amplitude sensitivity. The varactor-diode bias voltage is generated by an LTC1257 12-bit serial DAC, which the μ-controller steps through the tuning range while comparing the multiplier output to ground.

Results and Discussion: Figure 1 shows the impedance curves for the tuneable receiver coil through a progression of conditions. The coil is designed to present 50Ω while loaded, which it does: however, loading also shifts the center frequency by as much as 2.8MHz (figure 1a). The automatic retuning circuit (at the press of a button) then re-tunes the impedance curve to center on 63.8MHz, well within the 600kHz 3dB bandwidth of the MR signal. Total tuning time is under 300ms.

New diagnostic modalities will rely upon the increased SNR that shapable, smaller receiver coils offer. Cardiac catheter coils, and intra-articular coils are prime examples of this. The strong and diverse loading conditions present during these procedures necessitate automatic tuning.

References:

[1] GOLD, G. *et al.*, Proc. ISMRM, 84, 2001.
[2] SCOTT, G. *et al.*, Proc. ISMRM, 20, 2001.
[3] BOSKAMP, E., Radiology, 157:449, 1985.

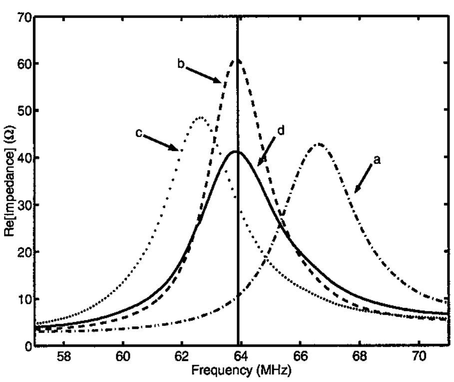

Figure 1: Impedance curves. a) Coil loaded by human fist, detuned to 66.6MHz. b) Same loading, automatically tuned to 63.8MHz. c) Different human fist loading, detuned to 62.55MHz. d) Automatically tuned to 63.8MHz.

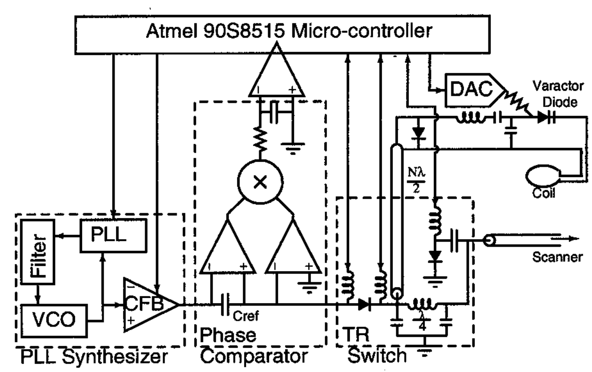

Figure 2: Autotuning receiver circuit diagram.