RF coil design with automatic tuning and matching

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Introduction

RF coils with transmission line elements are commonly used for high-field MRI, as both transmitter and transceiver elements. The RF coil element is typically terminated at the variable trimmer capacitors commonly called matching capacitor (C_m) and tuning capacitor (C_t) at one end, and a fixed value capacitor (C_f) at the other to form a capacitively tuned, matched, and shortened half-wave resonator. These resonant coil elements usually have a high quality factor (Q). High transmit efficiency and receiver signal-to-noise (SNR) are dependent on a well tuned (to Larmor frequency) and matched (to load) resonance for the element. Conversely, variable body loading of these coil elements can adversely impact both tuning and matching, and therefore efficiency and SNR of the coil. This study demonstrates a high-speed, electronically actuated, automatic impedance matching and tuning technique to assure optimal coil efficiency and SNR over a range of patient-coil loading conditions.

Purpose

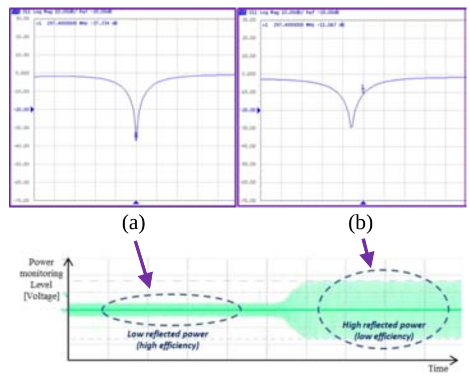
The figure 1 (a) shows the reflection coefficient (S_{11}) when the input impedance (Z_{in}) of RF coils is initially tuned in to 50Ω to obtain the maximum power efficiency. However, it is vulnerable to the surrounding conditions. The changing of biological loads results in the reduction of the resonance frequency from the Larmor frequency and a drop of Q as shown in figure 1(b). And figure 1 (c) shows the power monitoring level according with both matched and mismatched conditions that have high power efficiency and low power efficiency respectively. Consequently, this situation makes it impossible to take MR images with good quality in MRI applications. To avoid it, following an initial tuning of trimmer capacitors, re-tuning procedure is needed after human body is loaded into the MRI scanner and completed within a minute to match the impedance of RF coil coupled with anatomy at the Larmor frequency. The purpose of this study is to replace manual tuning procedure with automatic tuning and matching. This method provides the real time and stand-alone RF coil tuning and matching to maintain the impedance matching condition under various human anatomies and experimental conditions.

Methods

A stand-alone system for automatic tuning and matching of RF coil is implemented in figure 2. This system consists of RF coupler, RF switch and power detector, capacitor array bank with PIN diodes and FPGA as well as RF coil based on TEM. There are two steps; the first step is automatic tune/match procedure with moderate power level, less than 20dBm, and the second step is similar with normal MRI scanner operation with high power to take MR images. In the first step, the output of RF power detector represents the reflective power level through RF coupler for power monitoring. From this information, the system decides the optimum impedance matching condition depending on the load (patients) conditions. Capacitor-array banks with PIN diodes are built in Π-matching network to search the optimum matching condition and FPGA installed the main algorithm drives PIN diodes electrically to turn on or off through PIN diode driver circuits during searching the optimum impedance matching condition. Once the final results are kept in FPGA, RF switch turn off circuits except necessary part for driving PIN diodes to protect the circuitry operated with low power domain. Eventually, manual re-tuning/matching by hands are not required and this concept sharply reduce the time-consuming step.

Results

Figure 4 shows the automatic tuning and matching results from experimental setup of 7T MRI scanner (f=297.2MHz, Siemens Magnetom 7T) with a cylindrical phantom filled 8 liter sucrose/saline (ε_r=58.1 and σ=0.539 S/m). A portable network analyzer that was used check the impedance matching inside the EM shielded room shows that the proposed system returns the reflection coefficient (S_{11}) to the initial tuned/matched condition to avoid loading (body) effect after running automatic tune and match procedure. From these preliminary results, SNR (Signal-to-Noise Ratio) is enhanced about 20% (combined transmitting and receiving) in the top side and 24% in the bottom side, respectively, in figure 5 (a) and (b) and penetration depth is also increased in B_1^+ map(μT/sqrtW) of figure 5 (c) to (d). For stand-alone system operation, the RF un-blank signal from the MR console is used to trigger off the automatic tune/match function and the entire operation has done less than 1 second to get the optimal impedance matching condition returned.



(a) (b) (c)

Fig 1. Reflection coefficient (S_{11}); (a) matched condition and (b) mismatched condition due to loading effect. And (c) Measured power monitoring level [voltage] corresponding with (a) and (b).

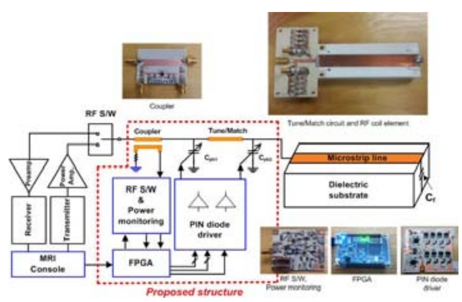


Fig 2. System block diagram for single RF coil element.

Conclusions

An automatic, electronic tuning and matching system interfaced to a TEM element (coil) has been developed and demonstrated thus far on a phantom at 7T. The prototype auto-tuning and matching system includes an adaptive tune/match control algorithm, a high power PIN diode driver and a power monitoring feedback circuit all integrated into a stand-alone device interfaced to and RF coil element in the 7T magnet bore. The results of this study demonstrate that the performance of high-speed, electronic, automatic tuning and matching can be made to perform well in an ultra-high field magnet as measured by improved B1 efficiency, field profile, and SNR, taking less than 1 second to complete a tune-match cycle. Application of these methods may improve current clinical coil performance and may help to make multi-channel coils practical.

Acknowledge

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References

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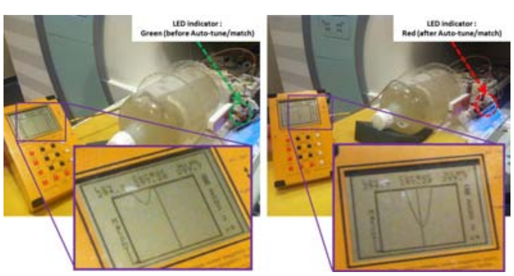
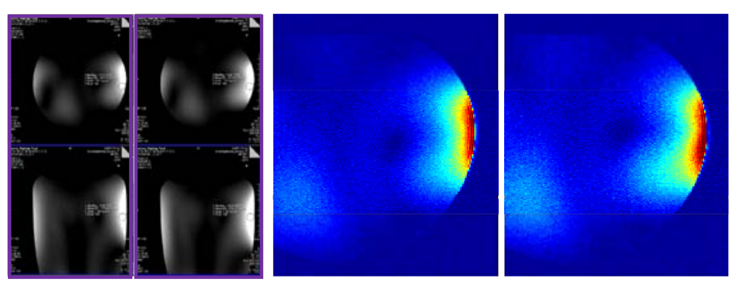


(a) (b)

Fig 4. Experimental set-up with single RF coil element in 7T and the results; (a) before auto-tune/match (b) after auto-tune/match.



(a) (b) (c) (d)

Fig 5. Experimental MR image results of the slices in the central region of with a cylindrical phantom; (a) and (c) are before auto-tune/match and (b) and (d) are after auto-tune/match.