Trap Design Performance for RF Coils for Dual-frequency MRI & MRS

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Introduction The growing availability of high-field whole body scanners has generated increasing interest in non-proton in vivo spectroscopy, and with it, multinuclear RF coil design. In most non-proton applications, simultaneous or sequential operation at the proton frequency is required as well; proton decoupling, scout imaging, and polarization transfer methods are cases where transmission/reception at two frequencies is required, calling for dual-tuned RF coils capable of high transmission efficiency and receive sensitivity at both frequencies. Considering the complexity of high-field proton coils (where TEM or transmit array schemes need to be applied to deal with full-wave effects), having an “insertable” second-nucleus coil which can be used with existing proton coils would be highly desirable. Dual-tuning methods used in the past include a single dual mode coil, or two separate coils, one for each frequency. Single-coil designs suffer from low performance at the higher frequency [1], while in dual coil designs, counter-rotating currents affect the resonance frequency and field pattern, requiring geometric decoupling. A recent method applied to ^{23}Na imaging [2] suggested using LC traps tuned to the proton frequency placed on the lower-frequency coil to mitigate the effects of the counter rotating currents. This work presents the application of this concept of “trapping” the second-nucleus coil in order to enable the insertion of the coil into existing proton coils. The performance of this method is studied for ^{31}P spectroscopy and imaging by comparing to the untrapped case with regard to proton coil SNR and resonance shift, and its “insertability” into existing surface, volume, and array proton coils is demonstrated.

Methods Coupling between two coils initially tuned to different frequencies affects the resonance frequencies and sensitivities, but particularly at the higher-frequency (proton) mode. Figure 1 shows the shift in resonance frequency of two coils initially tuned to ^{1}H and ^{31}P at 4.7T from their isolated state (obtained using a mutual impedance model similar to [3]). It is noted that detuning from the isolated ^{1}H frequency is significant, going beyond most standard tuning ranges. Figure 2a shows the loss in the field magnitude on axis for a circular proton coil (obtained using a static model) as a result of placing a smaller ^{31}P coil concentric and coplanar to it, presenting a significant loss especially in close proximity of the coil. Bench data (shown in Fig. 2b) obtained using a current probe and S21 measurements confirmed the expected loss. By using an LC trap on the ^{31}P coil, these two problems can be eliminated. Two concentric surface coils were built (7.1 cm diameter for ^{31}P, 12.4 cm diameter for ^{1}H), along with a proton shield to reduce radiation, in anticipation of high-field applications. A trap was designed using a 22nH inductor in parallel with a variable capacitor, and fine tuned such that inserting the ^{31}P coil did not affect the resonance frequency and field magnitude of the proton coil, as measured on the bench. Once the trap was tuned, the ^{31}P coil was removed and tested in conjunction with a birdcage proton coil (diameter=10.5cm) as well as a three-element proton surface array (total diameter=14cm). Imaging and spectroscopy tests were performed on a 4.7T/33cm magnet supported by a Varian Inova Unity system, to verify the effects of the trap on proton and phosphorus SNR. A three-chamber cylindrical phantom (mimicking the phosphorus content normally found in metabolic studies) was used for imaging and spectroscopy.

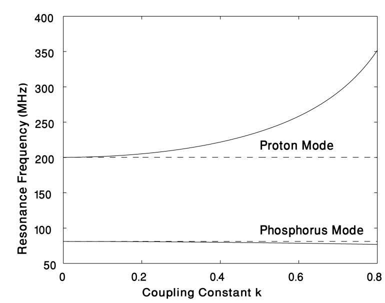

Figure 1 – Resonance mode separation as a function of coupling.

Results Figure 3 shows the images obtained from the surface and volume proton coils with no ^{31}P coil present, an untrapped ^{31}P coil present, and a trapped ^{31}P coil present (match/tune/transmit power were maintained). The introduction of the untrapped ^{31}P coil reduced the ^{1}H coil SNR significantly as compared to operation of the isolated proton coil. By adding a trap (tuned to the hydrogen frequency) on the phosphorus coil, the SNR was maintained within 7% of the isolated case. ^{31}P spectra obtained from an untrapped and trapped ^{31}P coil shows minimal (less than 5%) SNR loss (Fig. 4) due to the presence of the trap. Figure 5 shows bench data obtained from the 3-element proton coil array suggesting that the addition of the untrapped ^{31}P coil decreases the coil-to-coil isolation by providing an additional coupling mechanism. The isolation between the coils was maintained when the trap was added to the ^{31}P coil.

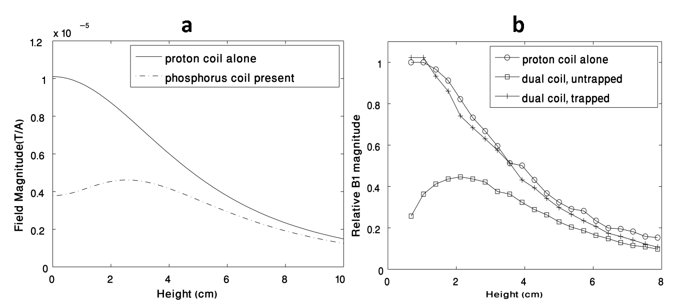

Figure 2 – Effect of ^{31}P coupling on ^{1}H field along the axis. (a): modeling results (b) bench measurements

Discussion The trapping method effectively prevented the proton coil sensitivity loss, detuning, and array coupling caused by the insertion of a ^{31}P coil. There is a small loss (less than 10% in performance) caused by the trap inductor resistance, which can be adjusted to be in favor of the lower mode (using a smaller inductor) or higher mode(using a larger inductor). Importantly, no modifications were necessary to the proton coils, enabling insertion of the trapped ^{31}P coil into existing proton coils, saving the cost of re-designing proton coils for multi-nuclear applications, with particular applicability at high fields, where spectroscopy holds great promise and proton coil design becomes more complex.

References [1] Shen G. et al. Magnetic Resonance in Medicine 1997; 38(5):717-725. [2] Alecci M. et al. Journal of Magnetic Resonance 2005;181(2):203-211. [3] Fitzsimmons J. et al. Journal of Magnetic Resonance 1993; 30(1) 107-114

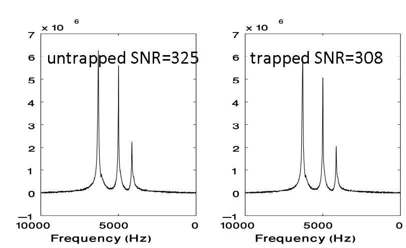

Figure 4 – Effect of the trap on phosphorus spectra

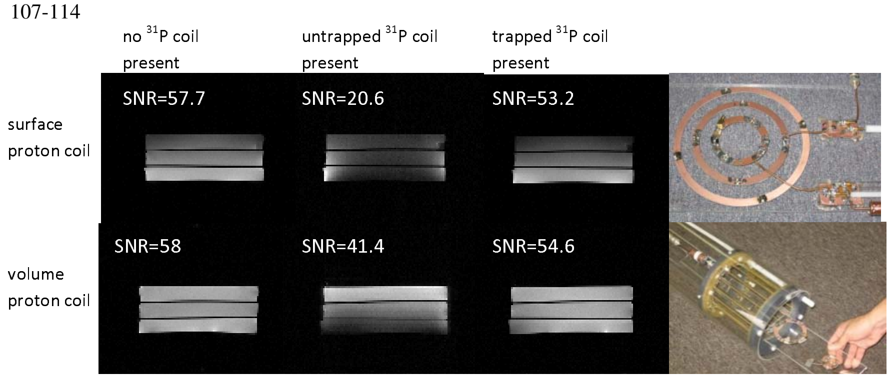

Figure 3 – Effect of the trap on proton images

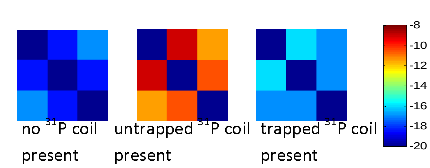

Figure 5 – Effect of the trap on proton array coil coupling (dB)