Proton traps for multi-nuclear RF coils: design analysis and practical implementation for ^{13}C MRS in humans at 7T

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Introduction Multi-nuclear MRS (^{13}C, ^{31}P) and MRI (^{23}Na) are of particular interest at ultra high field. Trapped coil designs have been proposed which allow the operation of lower-frequency coils in the presence of a proton coil. In this work we give an analysis of useful parameter ranges for practical design of a trap circuit with two capacitors, and present first results headed towards a dual loop quadrature coil for acquisition of ^{13}C signals in humans at a 7T. The trap blocks current induced in the low-frequency coil at the ^{1}H frequency but passes RF at the second nucleus' frequency. Blocking circuits proposed consist of an inductor (L_{Tr}) either in parallel with a single capacitor [1–3] or a combination of a series and a parallel capacitor (C_{s}, C_{p}), see Fig. 1 insert [4].

Methods At higher fields, when using a single capacitor trap design, the required inductance may become impractically small. The second order trap design gives an additional degree of freedom in choosing inductance and capacitance values, opening the possibility to match the trap reactance at the low frequency to the capacitor it replaces (C_{coil}). We analytically solved the conditions for the trap capacitances and inductance (Fig. 1), yielding a pair of solutions for both C_{s} and C_{p}, for a given L_{Tr} (Fig. 2).

Results The low frequency coil has two resonances: the original of the untrapped coil at low frequency and a higher frequency "trap mode". Care must be taken to resonate the trap mode well above the proton frequency. Otherwise both coils couple strongly at the proton frequency, making the proton coil unusable. The frequency of the trap mode is controlled by choice of L_{Tr} (Fig 3). It increases with increasing L_{Tr}, when calculating C_{s} and C_{p} to fix the resonance frequency of the trap. This was experimentally verified.

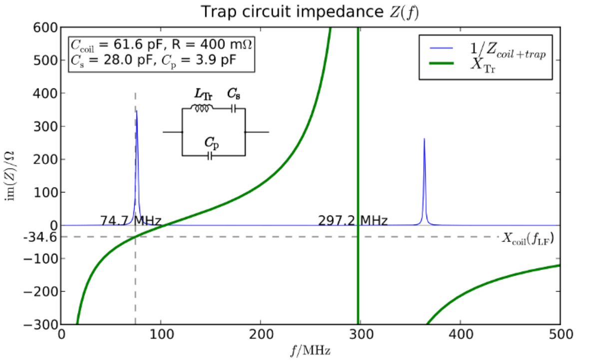

Fig. 1: Trap circuit reactance (green) and coil modes (blue) of a trapped ^{13}C coil.

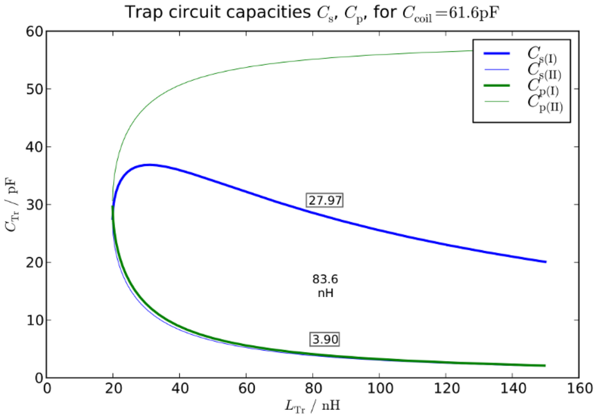

Fig. 2: Calculated solutions for trap capacitances C_{s} and C_{p} for varying trap inductance L_{Tr}.

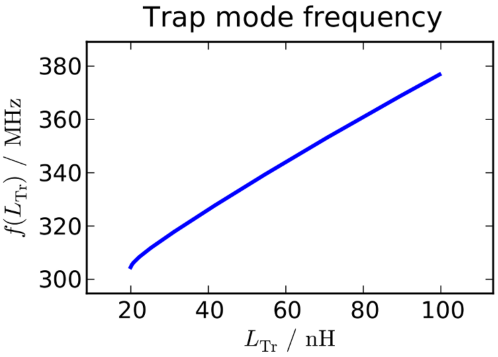

Fig. 3: Trap mode resonance frequency vs. trap inductance L_{Tr}.

For given C_{coil}, a minimum L_{Tr} exists for solving the trap conditions with any specific combination of capacitances (Fig. 2).

A 7cm loop coil with two capacitors ($C_{\text{coil}} = 62$ pF) was built, resonating at $f_{\text{LF}} = 74.7$ MHz (^{13}C at 7T). The trap was made using $L_{\text{Tr}} = 84$ nH, $C_{\text{s}}= 28$ pF, $C_{\text{p}}= 3.9$ pF, giving a trap mode resonating at $f_{\text{HF}} = 340$ MHz. The proton coil was a 12 cm loop. With this setting we achieved effective blocking while maintaining ca. 90 % of the coils' efficiency, as can be seen from a field plot (Fig. 4) acquired along the axis of the coil combinations with and without the trap.

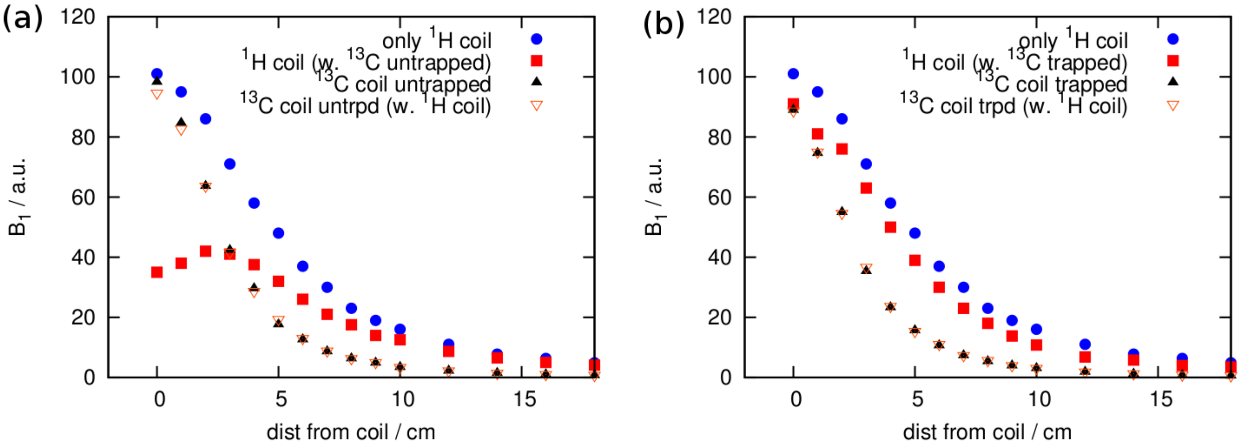

Fig. 4: Field maps for ^{1}H and (untrapped (a) and trapped (b)) ^{13}C coils along the central axis.

Discussion and Conclusion Adding a second capacitor to a trap in the non-proton RF coil allows control over the trap reactance at the low and high frequency (here ^{13}C and ^{1}H) and the frequency of the trap mode. We demonstrate the interdependence of the parameters controlled and show analytical and numerical solutions to fulfill the design constraints. Our experiments show that, using the simulations, it possible to construct an effective second order trap for ^{13}C at 7T.

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References

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