# A Dual-Tuned Half Volume Coil for $^{13}C\{^{1}H\}$ MRS: Two Open Coils in One

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**Introduction:** $^{13}C\{^{1}H\}$ double resonance experiments require a radiofrequency, RF, coil system that produces RF fields at both the carbon and proton frequencies and does so over the same field of view. A coil design which has found significant applications in $^{13}C\{^{1}H\}$ leg or brain studies is one based on the half volume coil developed by Adriany and Gruetter [1] consisting of two surface coils operating in quadrature at the $^{1}H$ decoupling frequency and a single surface coil for both transmission and reception at the $^{13}C$ observe frequency. While a reasonably homogeneous RF field is produced at the proton frequency, the field produced by the single surface coil at the $^{13}C$ frequency is much less homogeneous. Moreover, this coil is not efficient at detecting signal from the deeper structures of the brain which may be of greater interest in, for example, the study of neurological disorders. A further challenge is that the three coils need to be meticulously positioned with respect to each other in order to maximize the isolation between them. As a less challenging alternative, we present here a double-tuned, single unit $^{13}C\{^{1}H\}$ half volume coil based on the open coil (half birdcage) design [2,3] that is able to produce adequate RF homogeneity at both frequencies. The half-birdcage coil has the advantage of also providing a more uniform field at depths that are of greater neurologoical interest. In order to make the open coil tuned at two frequencies, it was constructed as a low-pass network with eleven legs, each alternate leg contributing to the RF field at one or other of the two frequencies. Isolation of the two frequencies was achieved by placing a trap circuit in every leg, such that the trap resonated at the unwanted frequency in that leg.

**Rationale and Methods:** *Theory:* A schematic diagram of the coil layout showing six of the eleven legs (made from copper strips) is shown in figure 1. The six alternate legs consisting of the capacitors $C_1$ and the $L_1^*C_1^*$ trap circuits provide a resonance at the proton frequency at 3 T, i.e. 128 MHz (the lowest resonating mode in a low-pass open coil). The capacitors $C_1$ tune the proton legs of the coil and $L_1^*C_1^*$ form parallel resonating LC circuits at the carbon frequency, 32 MHz, thus blocking any current flow at that frequency in the proton legs. Similarly, the capacitors $C_2$ tune the resonance created by the remaining five legs to that of the carbon frequency, while $L_2^*C_2^*$ form parallel resonating LC circuits at the proton frequency thus blocking any proton currents in the carbon legs. The trap circuits essentially decouple the two frequencies from each other thereby ensuring that the composite coil consist of two independent open coils (one for each frequency) fabricated together. As shown in figure 1, the coil was matched and fed at each frequency at the end legs [3]. Variable capacitors were placed parallel to the tuning capacitors at the opposite end legs for fine tuning at each frequency.

*Experimental methods:* All experiments were carried out using an 80 cm bore, 3 T magnet (Magnex Scientific PLC, Abingdon, UK) in conjunction with a SMIS console. All preliminary experiments were conducted on human legs. To illustrate the homogeneity of the coil at the proton frequency, images of a leg were obtained using a spin echo imaging sequence with the following parameters: TE = 15 ms, TR = 3 s, FOV = 200 mm, slice thickness = 7 mm, 128 phase encode points, and 256 frequency encode points.

**Results:** The trap circuits provided a desirable isolation (i.e. greater than 15 dB) between the two coil ports, namely, -18 dB at the $^{13}C$ frequency and -26 dB at the $^{1}H$ frequency without reducing the efficiency of the coil below acceptable standards. Employing a 1 litre saline phantom that produces a load on the coil equivalent to a human leg, the ratio of the unloaded to loaded coil quality factors was found to be 2.5 at both the $^{1}H$ and $^{13}C$ frequency modes (an efficiency of 60%). The proton RF homogeneity of the half-birdcage coil was compared to that of a quadrature surface coil by mapping the RF fields in a uniform oil phantom (13.7 cm diameter) using the double angle method [4]. It was found that along the central vertical line of an axial image obtained with the half birdcage coil that the fractional standard deviation (standard deviation/mean) of the field values was about 80% of that of a quadrature surface coil indicating that the half birdcage coil produces a more homogeneous field. To verify the efficacy of the coil *in vivo*, experiments were conducted on the human calf. Figure 2 shows the axial proton image obtained from a human calf with the dual-tuned half-birdcage coil. Figure 3(a) displays a $^{13}C$ fat spectrum obtained from a leg by a $^{13}C$ excitation pulse in the absence of any proton decoupling, while figure 3(b) shows the result of applying a WALTZ-16 proton RF decoupling sequence during the acquisition period. It is clear that the coil was effective in irradiating the protons coupled to the $^{13}C$ nuclei observed in figure 3(a) causing the multiplets to collapse into the singlets seen in figure 3(b). The SAR due to proton decoupling was within the 4 W/kg FDA guidelines for NMR of extremities. A potential application of this coil is in the study of muscle glycogen. Figure 3(c) shows a natural abundance glycogen spectrum obtained with the half-birdcage coil from a calf muscle.

**Conclusion:** We have described in this work a single-unit coil design that can be employed in $^{13}C\{^{1}H\}$ studies as an alternative to the three coil Adriany-Gruetter design [1]. We demonstrated that a half-birdcage coil can be made to resonate at two frequencies by arranging for each alternate leg to tune to one or other of the two frequencies and by placing a trap circuit in every leg that blocks current at the other frequency. The main advantage of this coil is that it provides a more uniform field than a surface coil at depths that may be of greater interest. Although the coil concept was designed and tested on a human calf, the same concept can be employed in either $^{13}C\{^{1}H\}$ or $^{1}H\{^{13}C\}$ studies of the human brain, and should prove to be valuable in studying regions of the brain that are deeper than the occipital lobe.

**Figures**

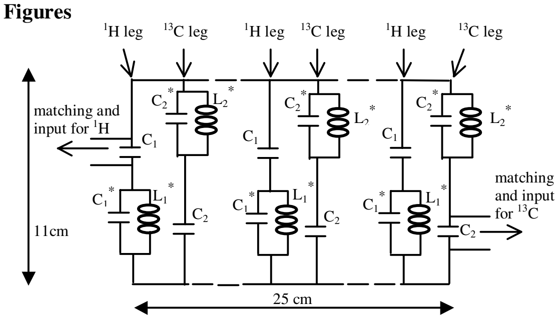


Figure 1: Schematic diagram of the coil. The legs termed "$^{13}C$ leg" refer to those legs forming the resonance at the $^{13}C$ frequency and similarly the "$^{1}H$ legs" are those creating resonance at the $^{1}H$ frequency.

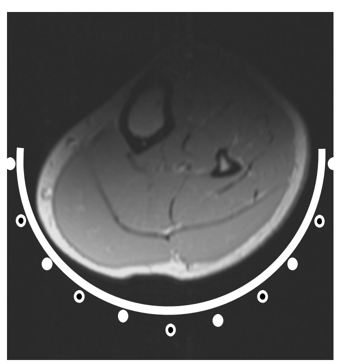

Figure 2: An axial proton image of a human calf obtained with the constructed coil. The white curve represents the outline of the RF coil while the circles represent the eleven legs of the coil. The circles filled in with white indicate the $^{1}H$ legs while the black ones indicate the $^{13}C$ legs. The depth of the coil is 8 cm.

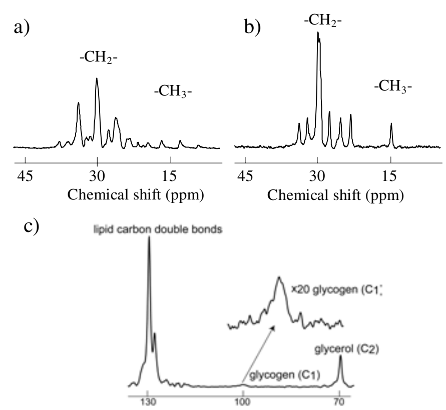


Figure 3: a) An undecoupled $^{13}C$ fat spectrum of a human calf. b) The spectrum acquired under the same conditions as (a) but proton decoupled. Both spectra were acquired in 32 averages. c) A proton decoupled spectrum showing natural abundance $C_1$ glycogen, acquired in 1500 averages, tr = 1.5 s.

**References**

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