Noise characterization and SNR benefit of cryogenic RF coil

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Introduction: Magnetic resonance microscopy such as mouse imaging requires high spatial resolution. Signal-to-noise ratio (SNR) is the most significant limitation to achieve higher resolution. Sample loss, coil loss and preamplifier loss are the main sources of noise in MRI. As the coil size decreases, the coil noise begins to dominate. In this study, the sample and coil losses at 7 T for various sizes of surface coils were studied. The objective was to better understand noise characterization and potential SNR gain of cryogenic RF coil compared to room temperature coil.

Methods: Three surface coils with diameters of 1.87 cm, 3.83 cm and 7.59 cm were constructed with 28 gauge (0.32 mm diameter), 22 gauge (0.64 mm diameter), 16 gauge (1.29 mm diameter) copper wires (Belden Electronics Division, Richmond, IN), respectively. Each coil was tuned to 300 MHz and accurately matched to 50 Ω (S_{11}<-30dB) in a balanced fashion. The theoretical sample resistance of a semi-infinite sample was $R_{sample} = \mu_0^2\omega_0^2 r^3/(3\rho)\cdot(2/\pi\cdot\tan^{-1}(\pi r/8d))$ [1], where μ_0 is the permeability of air, ω_0 the Larmor frequency, ρ the sample resistivity, r the radius of the surface coil and d the distance between coil and sample. The term in the last bracket was used to correct the sample loss between the coil and phantom. The coil resistance was estimated as $R_{coil}=r\rho_{Cu}/(r_{wire}\delta)$ where r is the coil radius, ρ_{Cu} is the copper resistivity, r_{wire} is the wire radius and δ the skin depth. A styrofoam block was machined into a reservoir for liquid nitrogen, surface coils were attached to the inner wall, a large container of 50 mM NaCl was positioned against the outer wall at 9 mm distance from the coil. The experimental quality factor Q of the unloaded and loaded coil was determined by measuring the reflection (S_{11}) of the matched coil on a network analyzer (Agilent 4395A, Palo Alto, CA). Each measurement was done three times for uncertainty estimation. The experimental sample-to-coil resistance ratio was calculated as $R_s/R_c=Q_U/Q_L-1$, where Q_U and Q_L are the unloaded and loaded Q. The theoretical SNR ratio is $SNR_{LT}/SNR_{RT}=[(T_{RT}R_{coil}+T_{RT}R_{sample})/(T_{LT}R_{coil}+T_{RT}R_{sample})]^{1/2}$ between cryogenic coil to room temperature coil, where T_{RT} and T_{LT} are room temperature (293 K) and liquid nitrogen temperature (77 K). The experimental SNR is determined using a 90° excitation experiment on a 7 T MRI scanner (Varian NMR System, Palo Alto, CA).

Results and Discussions: Fig 1 is the logarithmic plot of sample-to-coil resistance ratio versus coil size, the data were linearly fitted to y=2.96x+4.90 (R^2=0.98) where x and y are logarithms of coil radius and sample-to-coil resistance ratio respectively. The resistance ratio was dependent on the 2.96 power of coil size, this is similar to the theoretical value of 3 for solenoid coils [2]. Since for small coils, the Q value does not change much from unloaded to loaded case, the error in Q measurements results in larger R_s/R_c relative errors. The crossover coil size for equivalent sample and coil resistance is r=2.1 cm. Fig 2 illustrated the theoretical SNR on a few common field strengths and experimental SNR gain at 7 T by cooling the coil to LN_2 temperature. The difference between theoretical and experimental SNR gain obtained are possibly due to preamplifier noise which is not accounted for the theoretical model. This analytical model and experimental approach in this study can be extended to other coil configurations such as solenoid and phased-array coils to estimate SNR benefit by cooling the coil before actually building such coils.

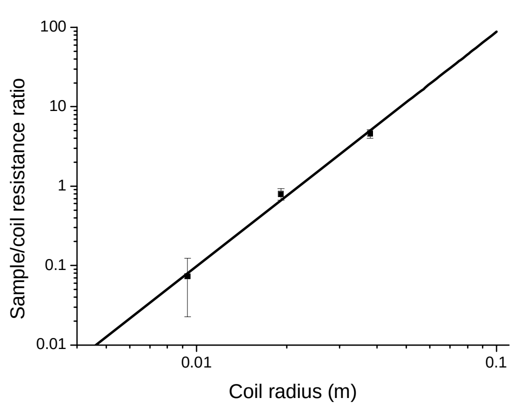

Fig. 1: Sample-to-coil resistance ratio of surface coil at 7 T.

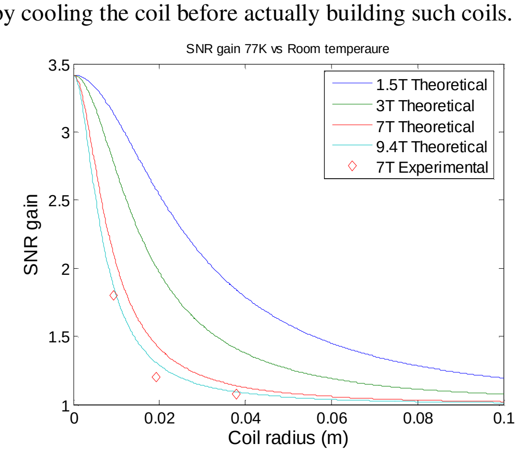

Fig. 2: SNR ratio of LN_2 cooled coil to room temperature coil as a function of field strength and coil size.

References: 1. A.C. Wright et al., MRM 43(2):163-169; 2. D.I. Hoult et al., JMR, 34(2):425-433