Superconducting Receive-only 7 Tesla Coil for High Resolution Rat Brain DTI

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Introduction

It has been well recognized that, in the case of a sufficiently small coil, thermal noise of the system is dominated by coil noise and that cooling of receiver coils, made of either Cu or HTS materials, can provide a very significant SNR improvement [1]. Cryogenic coils and coil arrays have become a subject of significant interest, which has resulted in several development studies on both single coil and array designs [2-3] leading to recent commercialization of such coils [4]. For small animal imaging such coil set-up should be size compatible with standard scanner transmit coils and for both cold copper and/or superconductors a low-loss matching/tuning/decoupling electronic circuit is required. In this work we present Rx only, small and practical cryogenic coil system, which can work at 300 MHz either with 77 K copper or high-critical-temperature superconducting surface coil and which is compatible with a standard Bruker Tx coil (Fig. 1a). Boiling-off liquid nitrogen time is ~4 hours.

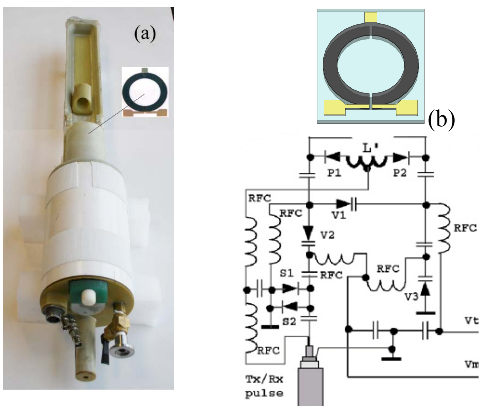

Figure 1. A picture of the liquid nitrogen 77 K G-10 cryostat with an animal bed attached (inset shows a picture of HTS coil) (a) and a sketch of the HS coil design connected to a high Q matching and tuning circuit (b) are shown. CC, P, and V denote coupling capacitors, PIN diodes, and varactor diodes (details are not shown).

Method and Results

Double-sided copper high frequency laminate with a dielectric constant ε=2.2 and thickness of 0.38 mm was used for the copper coil fabrication. The coil and electronic circuit layout was patterned using LPKF PhotoMat C100. YBCO films on both sides of a 0.33 mm thick Al_2O_3 (ε=10.4) wafer were patterned using optical lithography and wet etching into a split quasi ring shape (Fig. 1b). The gaps in each quasi ring were rotated 180° from each other. The matching/tuning and detuning circuit with GaAs varactor diodes was integrated with the coil inside the cryostat. Calculations of the potential SNR gain from cooling included cryostat and electronic losses ($1/Q_{total}=1/Q_{cryostat}+1/Q_{coil}+1/Q_{body}+1/Q_{electronics}$), in addition to the coil and body resistances. Measured unloaded Q_{coil}'s have the following values: 330 (Cu 295 K), 850 (Cu 77 K), and 50,000 (HTS at 77 K). $Q_{electronics}$ depends on the voltage applied to the tuning/matching varactors and was in the range of 1000-13000. The following SNR gain equation for estimation of the SNR gain of cryogenic over 295 K coils was used: $SNR\_gain = \sqrt{(1+\delta+\gamma)/1+(\alpha\beta\delta+\alpha_1\gamma)}$, where α and α_1 are the ratio of coil to body and electronics to body temperatures ($\alpha=T_{Coil}/T_{Body}$ and $\alpha_1=T_{Electronics}/T_{Body}$). β is the coil resistance ratio at T_{Coil} and 295 K, b is the coil resistance reduction coefficient, and $\gamma=R_{electronics}/R_{body}$. In such approach a figure of merit for the SNR gain, $\delta=R_{coil}/R_{body}$, is equal to $\delta=(1-Q_L^{295K}/Q_L^{77K})/(Q_L^{295K}/Q_L^{77K}-Q_0^{295K}/Q_0^{77K})$ [5-6]. Measured Q's allowed to estimate that a coil of 17-18 mm diameter should provide 100 % gain for 77 K Cu and 150% for 77 K HTS coils for rat brain load. The built set-up was tested for coil detuning, tuning and matching, both for copper and the HTS coils. An example of high SNR of the coils was confirmed by comparison of phantom images acquired (Fig. 2) using MSME sequence [7]. Recent SNR gains obtained for cooled Cu and HTS coil over room temperature copper, tested on phantoms at 300 MHz in a few cryogenic configurations, were 80-100% (~6 dB) and 150-170% (~8 dB), respectively.

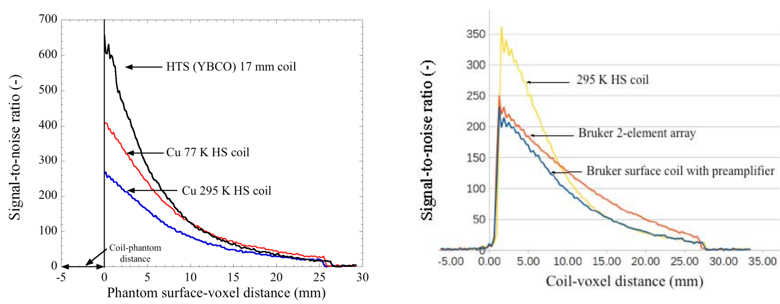

Figure 2. Comparison of the SNR of Cu and HTS 300 MHz coils *vs.* voxel distance from the phantom surface. Both copper and HTS were cooled to liquid nitrogen temperatures . Note that for reference purposes the SNR data for Bruker surface coil and array are also included in the plot (b). It provides performance comparison of the homemade.

Discussion and conclusions

Maximum of Q and hence the SNR gain of the system is limited here either by rat body losses, for *in-vivo* rat imaging, or by electronics losses, for *in-vitro* microscopy imaging. Further increase of the SNR gain for microscopy will require use of a cryogenic preamplifier and also further reduction of the tuning/matching circuit losses. SNR/resolution limits of the HTS coil are currently tested for 3 D imaging of sciatic mouse nerve and also for DTI of rat brain (Fig. 3).

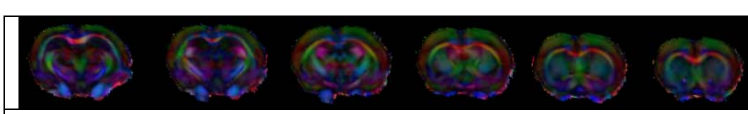

Fig. 3. RGB FA maps of a rat brain (1mm slice, 0.273 by 2.73 mm in plane spatial resolution). They display FA maps of a normal brain. DTI was recorded with a four shot EPI sequence, TR 5000 ms, TE 36 ms, b value 800 ms/s^2.

References

[1] P. Styles and N. F. Soffe, *J. Magn. Res.*, 60, pp. 397–404, 1984.
[6]. J. Wosik et. al, *Applied Physics Letters* 91, 183503 (2007)
[7]. M. Kamel et al., Proc. ISMRM. 15 (2007) p. 327
[2]. R. S. Withers et. al, *IEEE TAS*, 1, pp. 2450–2455, 1992.
[3] for review: L. Darrasse et al., *Biochimie*, **85**, p. 915, 2003.
[4]. www.bruker-biospin.com/mricp-tech.html
[5] L. Xue et. al, Proc. ISMRM 16 (2006), p. 2616.
[6]. J. Wosik et. al, *Applied Physics Letters* 91, 183503 (2007)
[7]. M. Kamel et al., Proc. ISMRM. 15 (2007) p. 327.