In-Vivo High Resolution Rat Brain using a Temperature-Stable High-Temperature Superconducting Cryostat at 3 Tesla

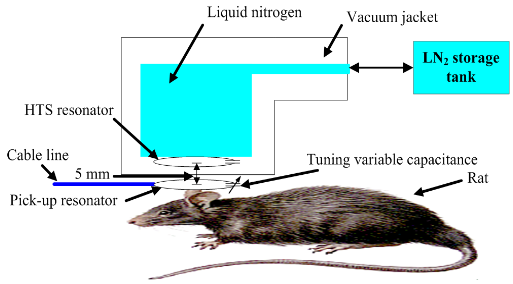
In-Tsang Lin[1], Hong-Chang Yang[2], and Jyh-Horng Chen[1]

[1]*Interdisciplinary MRI/MRS Lab, Department of Electrical Engineering, National Taiwan University, Taipei, Taiwan,* [2]*Department of Physics, National Taiwan University, Taipei, Taiwan*

Abstract In this work, a compact temperature-stable high temperature superconducting (HTS) cryo-system, keeping animal rectal temperature at 37.4 ºC for more than 3 hours, was successfully implemented. The proton resonant frequency (PRF) method was used to monitor rat temperature changes due to liquid nitrogen. The signal-to-noise ratio (SNR) of the HTS surface coil at 77 K is higher than that of a professionally-made copper coil at 300 K with the same geometry by a 3.79 folds SNR gain.

Introduction The cryogenic HTSC system should be designed carefully due to its complexity of system setups[1] in that HTS RF coils were usually placed closely to the ROI in vivo. Here we presented a new method to design the dewar that can hold temperature stable about 3 hours and to obtain high-resolution (39x 109 um) rat brain images in 71 minutes.

Materials and Methods To reduce the coil resistance, a HTS tape material, Bi2223 tinned tape (Innova Superconductor Technology Co., Ltd., Beijing, China), was used to fabricate the coils. Single-loop HTS surface coil of diameter 40 mm was used as the receive coil and a copper surface coil with the same size was used for comparison. For RF signal transmission and reception, as illustrated in Figure 1, inductive coupling method was applied by using a pick-up coil (copper).[2] All the coils were tuned to 125.3 MHz and the frequency response was measured on a vector network analyzer (HP8751A, USA). For maintaining the temperature at 77 K, LN_2 was filled in a thermal insulated dewar to cool the HTS coil. The temperature-stable cryogenic system is difficult to design because it needs good thermal insulation.[3] The LN_2 container with a vacuum layer was designed at the middle layer to provide a good thermal insulation. The pressure of vacuum was kept lower than 10^{-7} torr to keep the thermal insulation well.



Figture 1 The 3T system setup of the rat

Results First the phantom experiment was performed without a external air blowing circulation system. This blowing circulation system blew fresh air through the gradient coil and exchanged the fresh air from the other side. MR experiments were performed on the Bruker Biospec 3 T system. Conventional gradient echo sequence with spoiled gradient was employed to acquire the phase data and the scanning frequency was 1 scan per two minutes. Repetition time (TR)/echo time (TE) = 21.7/7 msec was set to provide enough temporal resolution, the matrix = 128 x 128, and the temporal resolution = 2 sec/scan. A total of 90 scans were acquired to reconstruct the temporal temperature change. Phase images were reconstructed to map the temperature change using the MR PRF method. The phase image acquired at the beginning serves as the reference phase and the phase difference (ΔP) at each interval thereafter can be derived by subtracting the phase with the reference. The capacity of MR thermometry in HTS experiments was evaluated by correlating with those from independent fiber-optic sensor temperature measurements.[3] Fitting the correlation between temperature difference (ΔT) and ΔP, PRF thermal coefficient can be derived. The temperature on the surface of the phantom decreased from 22ºC to 19ºC during a 3 hours measurement. The linear fitting curve was $\Delta P = \gamma\Delta T - 0.0013$, and the PRF thermal coefficient γ was then determined as $\gamma = 0.03$ rad/ºC, as shown in Figure 2 (Black line). And these were derived from the measured data of ΔP and ΔT. With this relationship, temperature variation can be derived by measuring the phase difference during the HTS experiment. Then, the second experiment was performed with the blowing circulation system. The temperature on the surface of the sample was kept at 22ºC during the 3 hour measurement, as shown in Figure 2 (Red line). The result reveals the stability of the cryo-system with the air blowing circulation system. Images of rat brain were acquired by using the fast spin echo sequence with TR/TE = 3506/62 ms. The in-plane resolution was 234 um and the slice thickness was 1.24 mm. The scan time is 1 minute and 36 seconds. The comparison of rat brain images from HTS tape and copper coils were shown in Figure 3. Figure 3(a) represents the image acquired from HTS tape coil in 77 K and Figure 3(b) represents the image acquired from the copper coil in the room temperature. The SNR of using the HTS tape coil was 46, 3.79 folds higher than that of using the copper coil, which is 13 at 300 K. The difference of SNR, as shown in Figure 3 (c), which is mainly contributed from the noise reduction, while there is almost no increase in signal intensity. Further experiment to test the capacity of HTS platform, the high resolution *in-vivo* rat brain experiment was demonstrated in 71 minutes. The in-plane resolution was 39 x 109 um and the slice thickness was 1.24 mm. The results were presented in Figure 4 (a), where the organized cerebral cortex structures, corpus callosum and the hippocampus were shown.

Conclusions The capability of this temperature-stable HTS cryo-system for in-vivo rat brain applications was demonstrated and higher resolution rat brain image can be achieved. With the high-quality HTS coil, the signal-to-noise ratio can be improved, suggesting that HTS RF coil is a potentially helpful diagnostic tool for MRI imaging in various applications. Further applications of a functional MRI and dynamic contrast enhanced (DCE) MRI are under investigation to test the applicability of this HTS cryo-system in a 3T system.

References [1] L. Darrasse and J. Ginefri, *Biochimie,* vol. 85, pp. 915-937, 2003. [2] D. Hoult and B. Tomanek, Concepts in Magnetic Resonance, vol. 15, pp. 262-285, 2002. [3] I.-T. Lin, H.-C.Yang, J.-H. Chen, "Diffusion tensor imaging using a High-Temperature Superconducting Resonator in a 3 Tesla Magnetic Resonance Imaging for a spontaneous rat brain tumor," APL, 2013(Selected as the Cover Image, Under published) [4] B. Quesson, *et al.*, *Journal of Magnetic Resonance Imaging,* vol. 12, pp. 525-533, 2000.

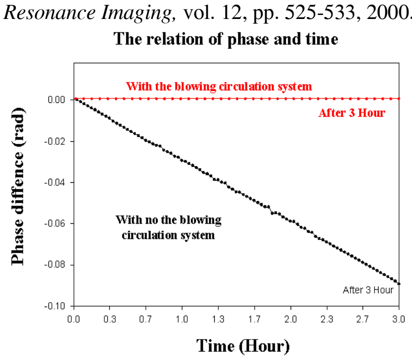


Figure 2 The difference of time-to-phase curve under different condition

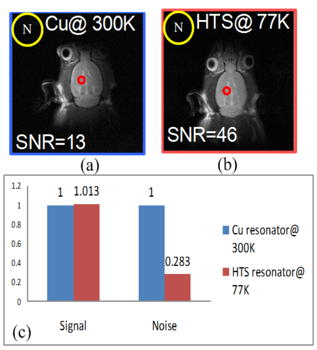


Figure 3 (a) The image acquired from HTS tape surface coil at 77 K and (b) the image acquired from the copper surface coil at 300 K. (c) The SNR of using the HTS tape surface coil was 46, 3.79 folds higher than that of using the copper surface coil, which is 13 at 300 K.

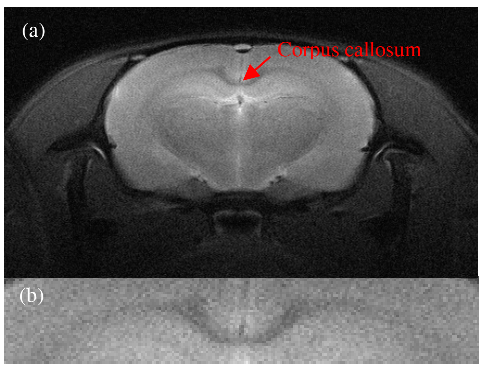


Figure 4 (a)High resolution (39 x 109 um) In-vivo rat brain (b) Enlarged rat brain image.