Anatomical imaging with a portable non-cryogenic ultra-low-field MRI system and atomic magnetometers

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Ultra-low field (ULF) MRI methods became feasible for anatomical imaging thanks to the method of switched prepolarization and the sensitive magnetic field detection of nuclear spins with low-T_c SQUIDs in a mu-metal shielded room, needed to compensate for extremely low levels of the NMR signal. ULF MRI has many potential advantages such as low cost, portability, convenience, enhanced contrast, open design, absence of susceptibility artifacts, and some others. However, the use of SQUIDs and a shielded room is a significant drawback. For example, a SQUID-based system is not cheap and has to be attended frequently, thus being less convenient compared to conventional MRI scanners based on superconducting magnets, which require minimal maintenance related to the liquid helium.

At Los Alamos, to make ULF MRI applications commercially viable, we have worked on developing alternative non-cryogenic detection methods. In our preliminary experiments, we found that with a resistive flux transformer, an atomic magnetometer can be easily substituted for SQUIDs in ULF MRI [1]. However, the resistance of the flux transformer, which was made of copper wire and operated at room temperature not to rely on the use of cryogens, introduces significant Johnson noise deteriorating the magnetic field sensitivity below that of low-Tc SQUIDs. From the analysis, it follows that the sensitivity can be much improved by increasing NMR frequency. Actually, by changing the frequency from 3 kHz to 60-120 kHz (still keeping most of the advantages of the ULF regime) and by increasing the prepolarization field strength from 400 G to 1 kG, we were able to improve sensitivity by more than an order of magnitude. As a result, we obtained MRIs with a resolution of 1.5-3 mm in 5-20 minutes of acquisition time, with longer times required for better visibility of anatomical features. A typical MRI obtained with our system is shown in Fig. 1. In addition to removal of cryogenic requirement, we were also able to achieve high sensitivity and good-quality of MRI without a shielded room or any large-size structure, thus making our system cost-effective, convenient, compact, and portable. We used only one detection channel for obtaining ULF MRI – a coil resonated by a capacitor and an amplifier. However, a one-channel operation is not optimal in terms of sensitivity, field of view, and scan time. Using atomic magnetometers, it will be possible to implement a high-sensitivity multi-channel non-resonant MRI detection system. This would make our ULF MRI scanner on par in terms of image quality with other scanners used for anatomical imaging. More importantly, the multi-channel system would allow us to move from small-size imaging such as that of a hand demonstrated in Fig.1 to large-size imaging of head, spine, or even whole body by covering the imaging area with an array of flux transformers connected to atomic magnetometers, each operating independently due to the absence of resonating currents in the coils. The hand image is only the first step showing feasibility of the non-cryogenic ULF method of anatomical imaging. Work on the development of a ULF MRI non-cryogenic scanner for the human brain is in progress. Acknowledgement: this work is supported by NIH grant R01EB009355.

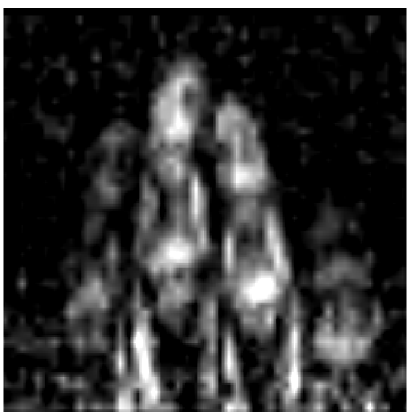

Fig. 1. Hand 2-mm resolution image: one most informative slice is shown.11 slices are acquired in 6.7 min [2]

Literature:

1.I.M. Savukov, et al., JMR 199, 188-191 (2009).
2. I. M. Savukov, et al., Non-cryogenic anatomical imaging in ultra-low field regime: Hand MRI demonstration, JMR 211, 101-108 (2011).