SQUID-DETECTED MAGNETIC RESONANCE IMAGING IN MICROTESLA FIELDS: A NEW CLINICAL MODALITY?

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The principles of the Superconducting QUantum Interference Device (SQUID) and of nuclear magnetic resonance (NMR) are briefly reviewed. We describe the use of a SQUID, coupled to an untuned gradiometer, to detect magnetic resonance imaging (MRI) in microtesla magnetic fields. The nuclei are prepolarized in a much higher magnetic field, and the oscillating signal produced by the precessing spins is detected after the polarizing field is removed. This technique enables us to perform NMR spectroscopy of protons in liquids with a high signal-to-noise ratio and a 1-Hz spectral resolution at frequencies as low as 80 Hz. Our MRI system operates at 5.6 kHz, corresponding to a magnetic field of 132 μT. The magnetic field noise, referred to the lowest loop of the second-derivative gradiometer coupled to the SQUID, is below 1 fT $Hz^{-1/2}$ at the imaging frequency. Two-dimensional images of phantoms containing water demonstrate an in-plane resolution of better than 1 mm, and three-dimensional *in vivo* images of a human forearm have an in-plane resolution of about 2 mm. We have measured the longitudinal relaxation time T_1 of different concentrations of agarose gel in water, and find much greater T_1-contrast in low fields (below 1 mT) than in high fields. This enhanced contrast has potential medical applications, for example imaging tumors. In preliminary experiments we have measured T_1 in specimens of normal and malignant prostate tissue removed surgically. The T_1-values in normal tissue are typically 60% higher than in malignant tissue; by comparison, there is no significant difference in high-field MRI. The potential integration of microtesla-field MRI with whole-head systems for magnetoencephalography is discussed, and estimates of achievable spatial resolution are presented. This work was supported by the U.S. Department of Energy.