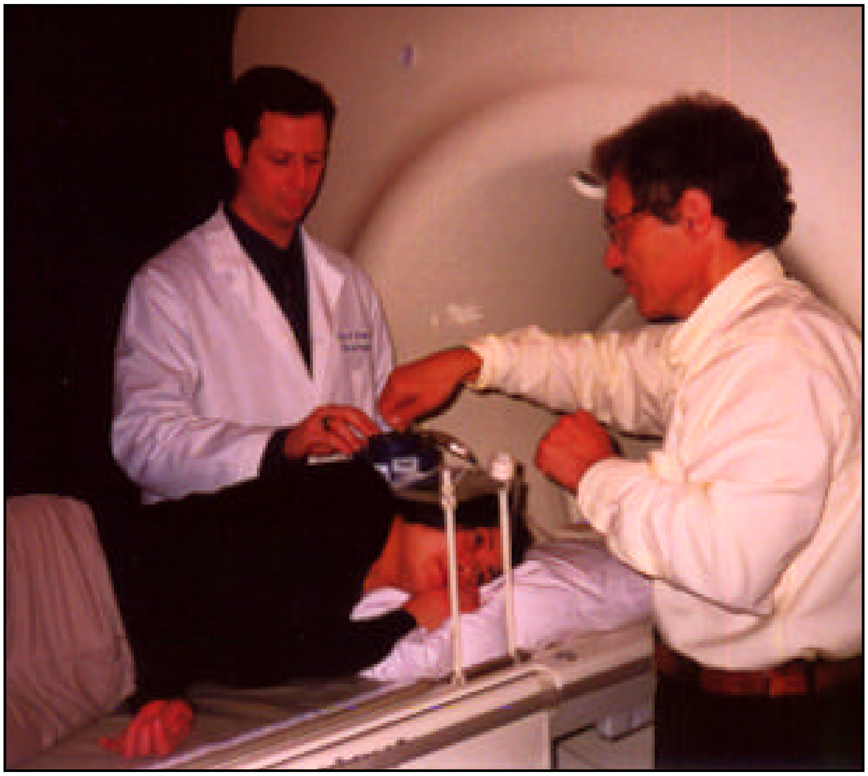
Magnetic Resonance Imaging (MRI) of Human Organs Using HTS Surface Coils

Abstract— MRI techniques have revolutionized modern medicine at the nation's health facilities by affording a non-invasive methodology for determining disease or malformations in the soft tissue of the body. High temperature superconductors (HTS) are clearly superior to standard copper probes. The relatively new field of high-temperature superconductivity (HTS) makes it possible to design and construct a small MRI receiver probe system for imaging, utilizing a 1.5 Tesla scanner. The system, operating at 77 K, needs only 10-15 minutes to be fully operational. At present, the technology has been applied to small animals.



MRI in SPACE—Equipment in space flight must be smaller than equipment on Earth because of strictures in housing and encasement on board space vehicles. Dr. Jarek Wosik (*r.*) research associate professor in electrical and computer engineering, and Dr. Jim Bankson (*l.*) of the Department of Imaging Physics, University of Texas M. D. Anderson Cancer Center, conduct their investigation with Lian Xue (*c.*), on the gurney as the test patient in a carotid scan. The test utilizes an HTS coil in the GE scanner located at the M. D. Anderson Hospital. This test is designed for the development of HTS coils specialized for space-oriented small MRI systems.

RECENT POSITIVE REPORTS REGARDING APPLICATIONS OF HIGH temperature superconductors (HTS) provide clear demonstration of the superiority of HTS receiver probes over standard copper probes in selected Magnetic Resonance Imaging (MRI) areas. MRI is an extensively used clinical and research tool with exceptional capability of imaging soft tissues. It is based on the phenomenon of nuclear magnetic resonance (NMR) where the excitation and relaxation of nuclei (most frequently protons) in a dc magnetic field take place within living tissues. An excitation rf pulse at the Larmor frequency n, which is the precession frequency of protons in the dc magnetic field (ν = 21.3 MHz for 0.5 Tesla), disturbs the equilibrium state of the nuclei. After the rf pulse, the nuclei relax to the equilibrium state with two different relaxation times (T_1 and T_2) and produce a weak decaying rf signal. In an MRI set-up such a signal is detected by a receiver probe. For medical diagnostics, the signal has to be much larger than the noise level so that the signal-to-noise ratio (SNR) of the receiver probe is high. In addition, SNR causes fundamental restrictions in achieving fast scans and high resolution required for future MRI systems.

In the case of small-volume imaging, the noise of the probe's coil and/or preamplifier set the system noise floor, therefore affecting the MRI performance; body noise no longer dominates the SNR of the system.[1] Thus, it is desirable to reduce thermal noise of the coil to improve the image resolution and reduce the image acquisition time. Since the Johnson noise is a function of the product of resistance and temperature, reduction of either or both of these parameters will enhance the SNR values.

Several demonstrations have been provided of feasible applications for superconducting coils from the MRI microscopy to low-field MRI.[2,3] Black and co-workers from GE showed the promise of HTS probe coils for high resolution MRI microscopy at 300 MHz;[1] this research was followed by the development of low-field MRI (5-20 MHz) by Conductus NMR spectroscopy coils.[2] In recent years, several other impressive demonstrations of HTS

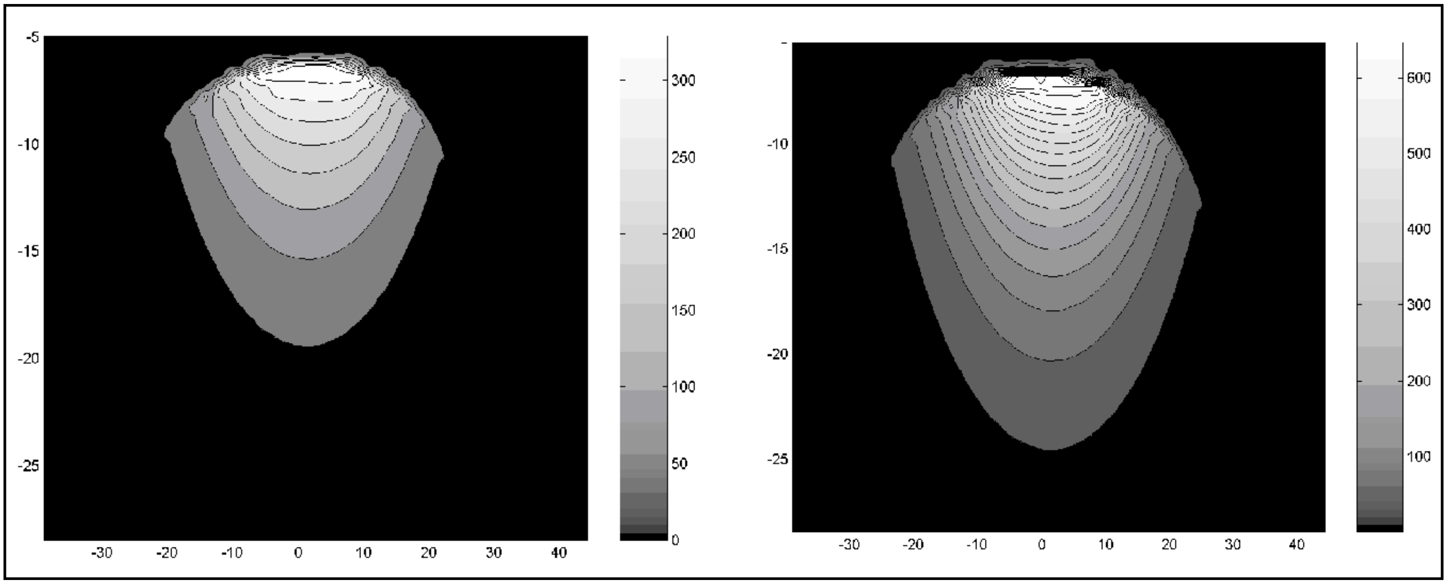


Figure 1. Maps of SNR are plotted for the normal metal coil at 295 K (a) and 77 K (b).

probes used to improve SNR were reported.[3] However, much work remains to be done in replacing presently used copper coils with superconducting probes for selected applications.

Methods

This project was executed in collaboration with Dr. Willerson's group at the Texas Heart Institute and Dr. J. D. Hazle's group at the M. D. Anderson Cancer Center. The main goal of this project, which is closely related to our current work on applications of superconductors in MRI, was to implement and integrate our setup developed previously for small animals with the 1.5 Tesla GE clinical scanner. This program provided a proof of concept that by using HTS coils for imaging human organs and parts such as a knee, wrist, elbow, or neck, significant gains in SNR can be achieved in clinical MRI.

We have designed and fabricated a 63.7 MHz probe consisting of patterned, double-sided metal or superconducting layers deposited on two-inch $LaAlO_3$ substrates. Measurements of the unloaded Q of a normal metal probe at room temperature and 77 K resulted in Q = 400 and 1000, respectively. The superconducting coil at 77 K has an unloaded Q of 20,000. The use of distributed capacitance in the coil design keeps the electric field away from the sample, thus minimizing the body dielectric losses.

We have also redesigned a complete system which consists of: (a) a small plastic liquid nitrogen cryostat, (b) 2 inches in diameter normal metal or HTS (84.4 MHz) coil integrated with this cryostat, (c) a fine frequency tuning paddle matching to 50 Ω coaxial line circuitry integrated with the cryostat cover, and (d) a normal metal transmit coil, which is also integrated with the cryostat cover. The system is fully operational after 10-15 minutes of preparation. The cryostat can sustain liquid nitrogen temperature without refilling up to 1.5 hours, which is sufficiently long to conduct MRI experiments.[4]

Results

We compare the signal-to-noise ratio (SNR) maps of the 1.5 Tesla coils operating at different temperatures. The images shown in Fig. 1 represent the SNR map for the same normal metal coil measured at two different temperatures using cylindrical phantoms. The coil is placed above the phantom at distance of about 10 mm as it is shown in Fig. 1. At low temperature, the coil sees deep into the phantom; i.e., the field of view increases as represented by a larger bright area compared with the RT picture. The black area indicate SNR values below one. More significant improvement is seen in the values of contrast, plotted here as dark lines corresponding to various SNR levels, which show 100 percent increase from its maximum value of 300 at RT to 600 at 77 K.

These maps are confirmed by Fig. 2 where the relative SNR, plotted as a function of distance from the coil at 77 K, has clearly 100 percent larger values than those obtained at room temperature. Furthermore, sensitivity at high measurements may be obtained from a significantly larger distance than for RT.

Confirmation of these findings comes also from MRI of human wrists obtained using the coils operating at RT and at 77 K. Imaging axial slices show differences in resolution depending on the operation temperature. Details visible from the cooled down probes (the right hand side columns of MRI micrographs) due to improved SNR are not attainable from the RT MRI coils.

Conclusion

We have designed and constructed a small MRI receiver probe system for imaging using a 1.5 Tesla scanner. The system, operating at 77 K, consists of a modified 2 in. twin-horseshoe coil fabricated of either normal metal or superconducting double-sided films deposited on $LaAlO_3$ dielectric, a plastic cryostat integrated with the coil, and tuning/matching mechanisms. The system needs only 10-15 minutes to be fully operational.

We observe significant SNR improvement over that of normal metal probes operating at room temperature. Cooled metal probes were superior to its normal temperature equivalent probes providing about two times gain in the SNR value. The gain in SNR is expected to be almost three times for superconducting coils.

References

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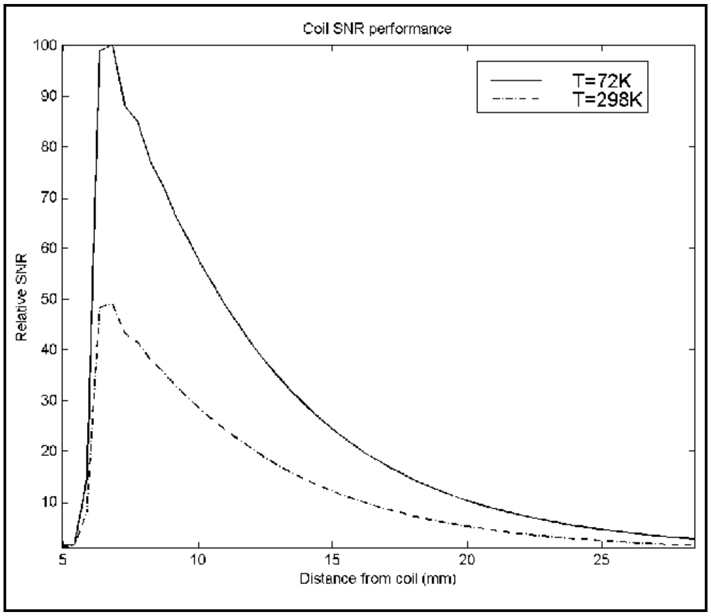

Figure 2. SNR versus axial distance from the coil plotted for data from Fig. 1.

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Investigative Team

Jarek Wosik, Ph.D., Research Associate Professor, Department of Electrical and Computer Engineering and the Texas Center for Superconductivity at the University of Houston

Student Assistants
Maged Kamel, graduate research assistant, Dept. of Electrical and Computer Engineering
Liping Ji, graduate research assistant, Dept. of Electrical and Computer Engineering
Lian Xue, graduate research assistant, Dept. of Electrical and Computer Engineering
Haiyan Teng, graduate research assistant, Dept. of Computer Science

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Funding and proposals

“Cryogenically Cooled Surface Coils for Parallel Processing.” Co-PI: S. Wright, Texas A&M; ATP Texas Coordinating High Education Board, 2001, $210,000; *not funded*.

“Spine Injuries and Brain Reorganization (Functional MRI).” PI: P. A. Narayana, UT- Houston Health Sciences Center, Radiology Department; University of Houston, $120,000, and NIH; *under review*.

“Superconducting MRI Phased Array Coils for High Sensitivity Rapid Imaging Using SENSE and SMASH Techniques.” Co-PI: S. Wright, Texas A&M, and M. Naghavi, MD, Division of Cardiology, Univ. of Texas Houston Medical School; NIH R21/R33 Program, $300,000; *in preparation*.

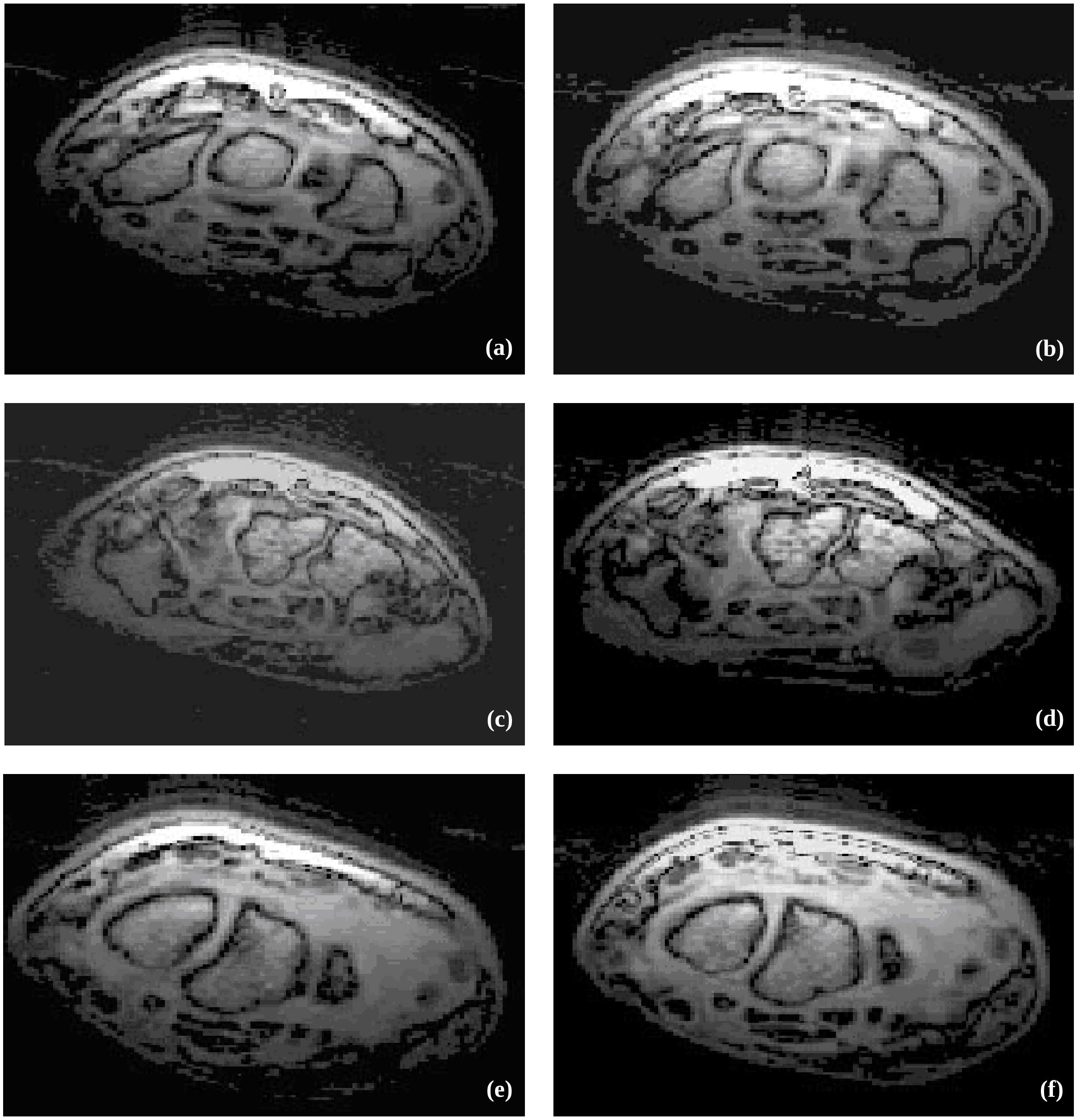

Figure 3. Two sets of three slices (1 mm apart) of human wrist images. On the left are presented images acquired at room temperature; at the right, images at 77 K.