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# Experimental Validation of Superconducting Quantum Interference Device Sensors for Electromagnetic Scattering in Geologic Structures

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**Los Alamos**
NATIONAL LABORATORY

# Experimental Validation of Superconducting Quantum Interference Device Sensors for Electromagnetic Scattering in Geologic Structures

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## Abstract

This is the final report of a one-year, Laboratory Directed Research and Development (LDRD) project at Los Alamos National Laboratory (LANL). This project has supported the collaborative development with Sandia National Laboratories (SNL) and the University of New Mexico (UNM) of two critical components for a hand-held low-field magnetic sensor based on superconducting quantum interference device (SQUID) sensor technology. The two components are a digital signal processing (DSP) algorithm for background noise rejection and a small hand-held dewar cooled by a cryocooler. A hand-held sensor has been designed and fabricated for detection of extremely weak magnetic fields in unshielded environments. The sensor is capable of measuring weak magnetic fields in unshielded environments and has multiple applications. We have chosen to pursue battlefield medicine as the highest probability near-term application because of stated needs of several agencies.

## Background and Research Objectives

This effort was undertaken to develop, on a short time scale, a small hand-held sensor based on superconducting quantum interference device (SQUID) sensor technology developed in the biophysics group at the Los Alamos National Laboratory (LANL) over the past few years. The purpose of this small sensor was originally to detect scattered electromagnetic (EM) waves from underground structures as a method to locate and characterize those structures. As a result of ending the Underground Structures (UGS) program in NN-20 of DOE and increasing interest within the battlefield medicine community for sensors capable of diagnosis and monitoring certain battlefield conditions, the focus of the effort was redirected. The focus was redefined to utilize these hand-held

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SQUID sensors to demonstrate the capability of detecting biomagnetic signals, primarily from the heart and brain, in unshielded environments. The information can be used to diagnose numerous conditions of the heart and possibly detect trauma in the brain quickly and noninvasively. This effort is the primary focus of a collaborative effort between Los Alamos and Sandia National Laboratories (SNL) and the University of New Mexico (UNM).

## Importance to LANL's Science and Technology Base and National R&D Needs

The immediate focus of this effort is the biosciences through the detection of biomagnetic signals from the human heart and brain. The benefits of developing such a sensor that can be used in unshielded environments are numerous, although the current focus is for application in the battlefield. The information gained can speed and improve existing techniques for battlefield triage, monitoring, and detection of various conditions as well as diagnose conditions not currently detectable in the battlefield setting. Biomagnetic sensors can be used completely noninvasively and in situations (such as in the presence of significant bodily fluids) when existing techniques, EKG and EEG for example, could not be used. Furthermore, there is the potential for a tremendous benefit to the larger civilian emergency medical community as well as medical office diagnosis and monitoring. The SQUID sensor technology has numerous non-bioscience applications as well. These include not only UGS detection but also nondestructive testing of corrosion and material flaws in materials such as missile housings, weapons components, and aircraft structures.

## Scientific Approach and Accomplishments

This project has supported the collaborative development with SNL and UNM of two critical components for a hand-held low-field magnetic sensor based on SQUID sensor technology. The two components are a digital signal processing (DSP) algorithm for background noise rejection and a small hand-held dewar cooled by a cryocooler.

The results of the DSP algorithm implementation were reported at the 10th International Conference on Biomagnetism. Traditionally SQUIDs have been operated in magnetically shielded rooms costing approximately $500,000 or more to reduce background fields sufficiently that they will not overwhelm the dynamic range of the SQUID. The novel approach developed as part of this LDRD effort was implemented in a prototype system that enables cancellation of more than 99% of the background magnetic field at the SQUID using the principle of superposition of magnetic fields. Using state-of-the-art electronics and digital circuits, we anticipate being able to cancel at least 80 dB (99.99%) of the background signal. This level of background cancellation at the SQUID makes applications such as monitoring head trauma or cardiac function in the field a realistic prospect and one that we will develop.

We have designed dewar systems capable of supporting SQUID sensors in very small (hand-held) containers, which require holding small sensor chips at a very constant temperature near 77 K and having electrical connections to the "outside world." Two approaches were taken. The first, led by SNL and UNM, was a heavy (1 cm thick) aluminum-walled dewar. This thickness of aluminum prevents all high-frequency signals (the 3 dB cut-off frequency is approximately 20 Hz). This would passively filter out EM noise common in our environment, for example 60 Hz line frequency, high-frequency RF and radar. The one drawback to this design is the high-frequency detail in the QRS complex of the heart and similarly higher frequency signals and components of signals from the brain (delta waves).

The second approach, led by LANL, was to design a non-metallic dewar that would filter out none of the electromagnetic spectrum. A variable thickness aluminum sleeve inside the dewar would be added for RF shielding and could be changed as needed by the experimental conditions. This configuration would not interfere with the detection of signals at frequencies of interest for biomagnetic applications, but with a moderately thick shield (0.5-1 mm) would filter out much of the RF spectrum. The drawback is the significant background of line frequency (60 Hz) that is anticipated in the general environment and was experienced in field experiments at Sandia.

To date, the dewars have been designed and parts have been fabricated. Due to functional problems with the cryocooler (insufficient cooling power at $10^{-6}$ torr) obtained for this project, we have had to redesign the cooling scheme. The dewars have been redesigned to include a small liquid nitrogen reservoir and a wicking material to hold the cryogen at the sensors regardless of sensor orientation.

A continuing effort is being supported at a low level by a DOE grant at LANL and through LDRD funds at SNL. Collaborators at UNM continue to consult with the effort. The hand-held SQUID sensor system is nearing completion as of the writing of this report.