SAND2016-4251C

Signal Processing

for a Multi-channel Analog Data Acquisition Instrumentation System for an MEG Atomic Magnetometer

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Description

- Sandia National Labs is developing an atomic magnetometer (AM) for use with human magnetoencephalography.
- Developing the AM requires unique signal processing.

Sandia National Laboratories

History

- ☑ **Sandia started the project in 2008 with the charter to develop a low-cost scalable atomic magnetometer for use in magnetoencephalography (MEG).**
  - ✓ Demonstrated the feasibility of a laser based, optically pumped atomic magnetometer.
  - ✓ Demonstrated basic MEG measurements
- ☑ **Phase 2 of the project has the goals of:**
  - ✓ Developing a multi-channel atomic magnetometer that can be configured for head size and position.
  - ✓ Developing a human sized magnetic shield
  - ✓ Demonstrating equal or better performance to prevailing SQUID (superconducting quantum interference device) magnetometers on human subjects using auditory and somatosensory stimuli.

Definitions

Magnetometer

- ✓ An instrument used for measuring magnetic forces.

Atomic Magnetometer

- ✓ A magnetometer where the magnetic field is sensed by measuring the interaction between a magnetic field and the electronic spins of a vapor of alkali atoms.

MEG

- ✓ MEG is the acronym for magnetoencephalography
- ✓ Magnetic field corollary to electroencephalography (EEG)

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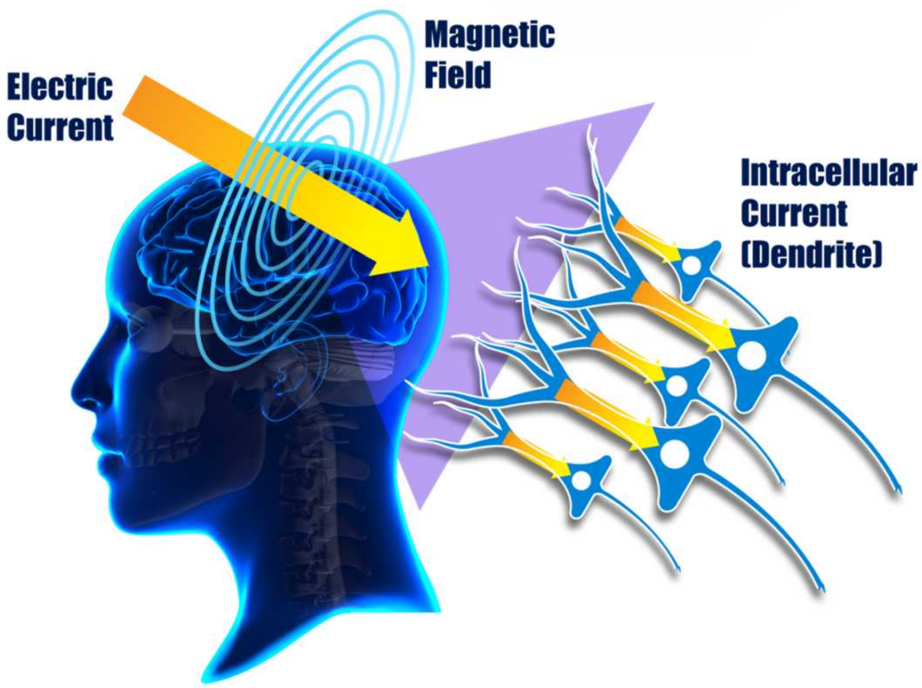
What is MEG

- ✓ Detects magnetic fields produced by neural currents.
- ✓ > 10,000 neurons
- ✓ < 10-13 T or 100 fT
- ✓ Measures noninvasively.
- ✓ Signal frequencies < 100 Hz
- ✓ Signal strength ~100 fT (Earth's field ~50 μT)

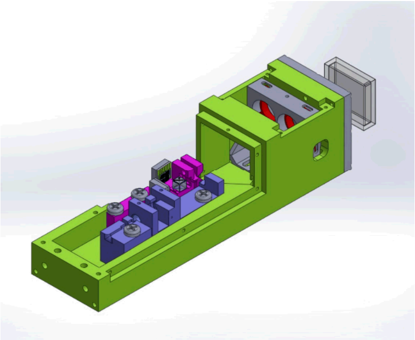


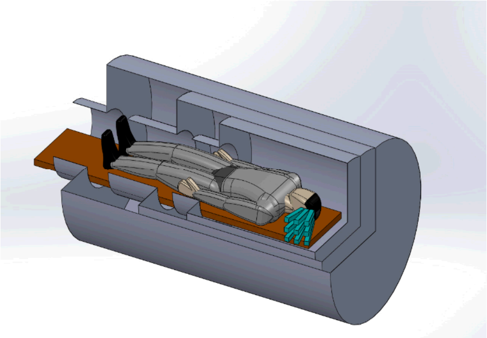
Why MEG…

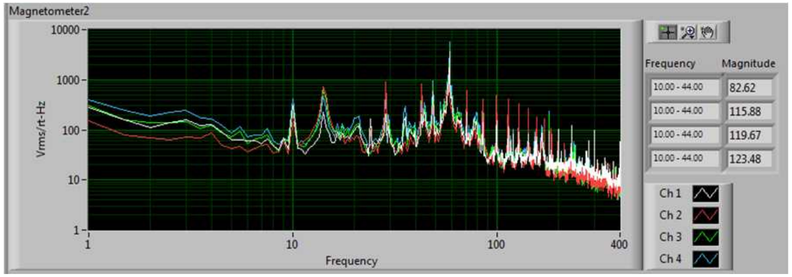
	EEG	MEG	fMRI
Spatial Resolution	**Poor** (~cm)	**Great** (~mm)	**Great** (~mm)
Temporal Resolution	**Great** (~ms)	**Great** (~ms)	**Poor** (~s)

MEG Challenges

- ✓ Ultra-sensitive magnetometers
- ✓ Magnetic shielding
- ✓ Signals must be extracted from the ambient noise floor

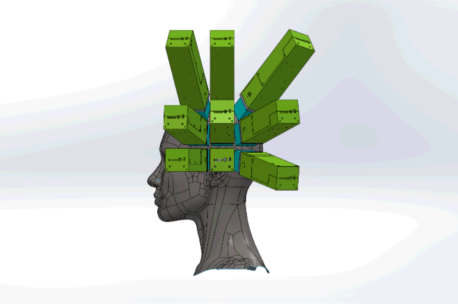


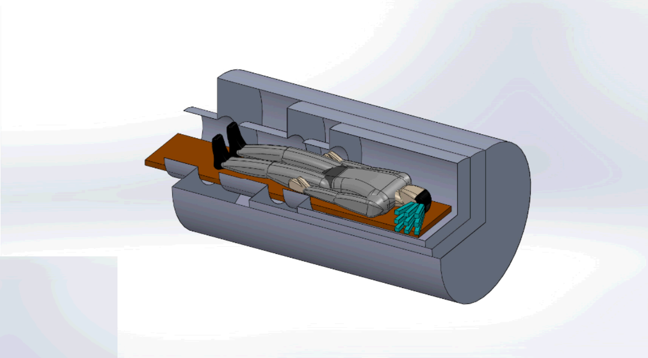




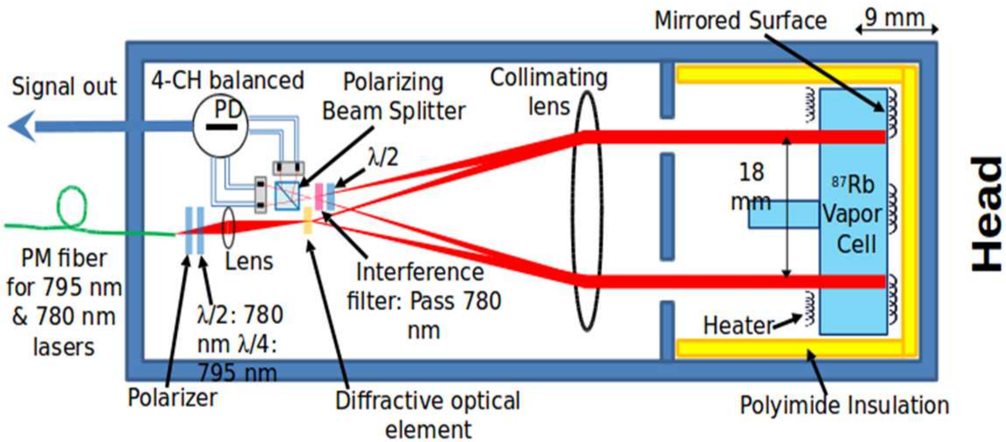
System Description

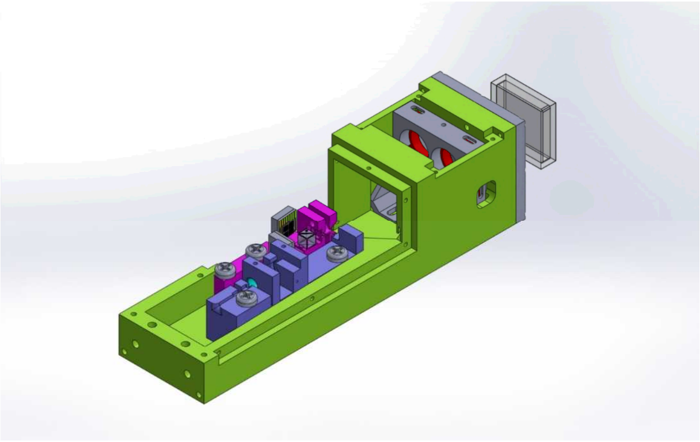
- ✓ 9 magnetometers
- ✓ 4 channels per magnetometer
- ✓ 36 total channels of analog inputs for data acquisitions

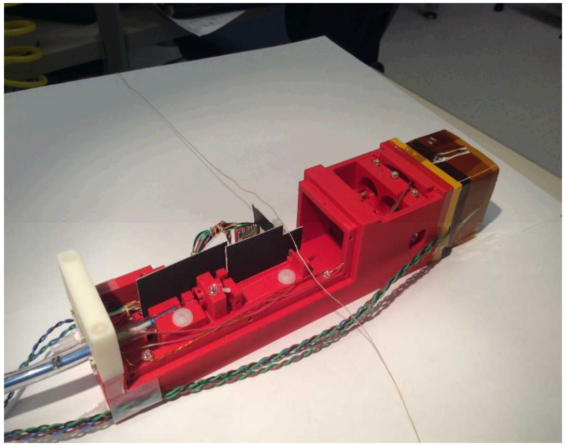




2nd Generation Magnetometer







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Signal Processing Requirements

- **Magnetic Field is on the order of 100 fT (10-13 T).**
  - ✓ By comparison, the earth's magnetic field is on the order of 50 μT (50 X 10-6 T)
  - ✓ For human applications, the magnetic shield must be open at each end
- **Must extract the signal from the ambient noise floor.**
  - ✓ Signal lock-in algorithm
  - ✓ Conversion of raw signal data from the time domain to frequency domain
  - ✓ Conversion of frequency domain levels to Power Spectral Density
  - ✓ Use gradiometery to subtract inter-channel noise

Signal Processing Requirements

- **Stream Lock-in data to disk for future data analysis.**
- **Real-time Visualization of:**
  - ✓ Raw Data
  - ✓ Lock-in Data
  - ✓ Power Spectral Density
  - ✓ Gradiometry
- **Ultimately replace the need for many measurement instruments with a single, self-contained instrument package.**

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Lock-in Detection

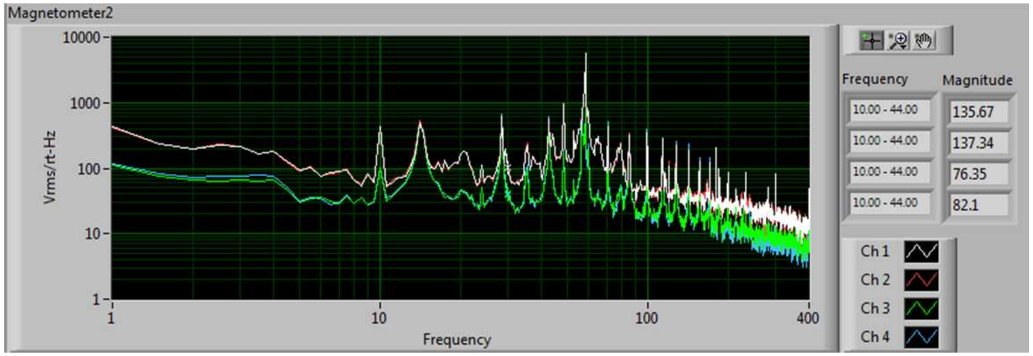
- **Raw signal capture from the magnetometer**
- **Capture a lock-in signal using a lock-in amplifier**
  - ✓ Modulation-demodulation of a fixed frequency
  - ✓ Signals of interest are on the order of 100 Hz
  - ✓ Use of a 1 KHz modulation frequency with a 400 Hz low-pass filter
- **Phase shift between the channels is critical. Cannot have any phase shift between the reference frequency and the modulated signal channel from the magnetometer**

Power Spectral Density

- **To detect the frequency of interest**
  - ✓ Frequency Domain of the locked signal is derived from a FFT (fast-fourier transform) of the locked time domain signal
  - ✓ Frequency domain is converted to Power Spectral Density providing power vs. frequency of the locked-in signal

Gradiometery

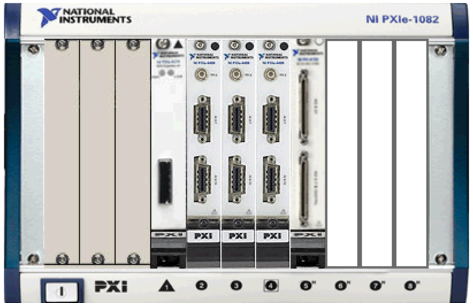
- **Remove self induced noise**
  - ✓ Subtract the power spectrum of two channels from a magnetometer and display the resultant gradient
  - ✓ Gains can be added to the power spectrum on any magnetometer channel
- **Gains and gradients are used to remove the noise generated by the sensors**



Hardware Implementation

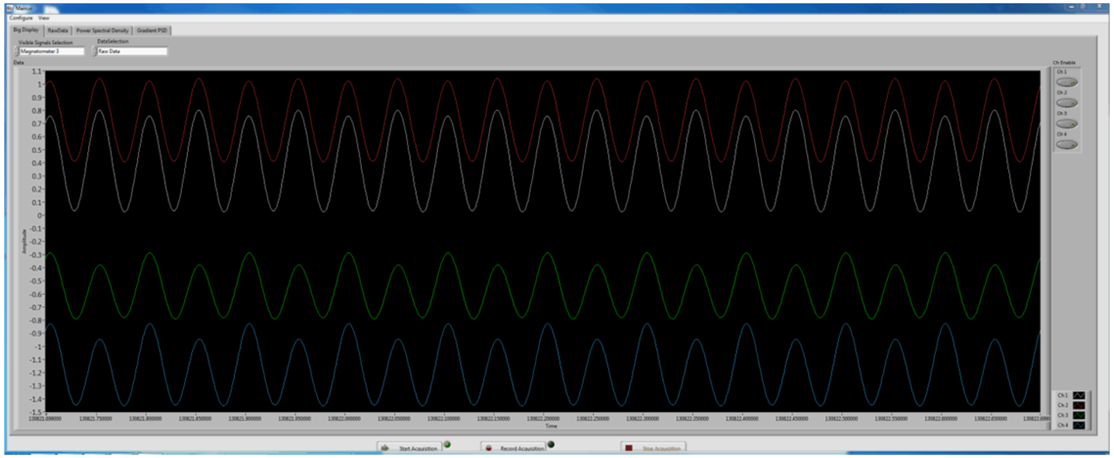
- **National Instruments PXIe-4499 16 channel Dynamic Signal Analyzer**
- **Three PXIe-4499's for a total of 48 possible channels**
- **The PXIe-4499s are synchronized together in a PXIe Chassis**

Phase drift will significantly affect the acquired data



Software Implementation

- **LabVIEW 2014 was utilized for data acquisition and analysis.**
- **A LabVIEW lock-in detection algorithm was developed and optimized for a 36-channel system.**
- **HDF5 file format was utilized for steaming data to a storage disk**
  - ✓ HDF5 was selected for compatibility with Matlab



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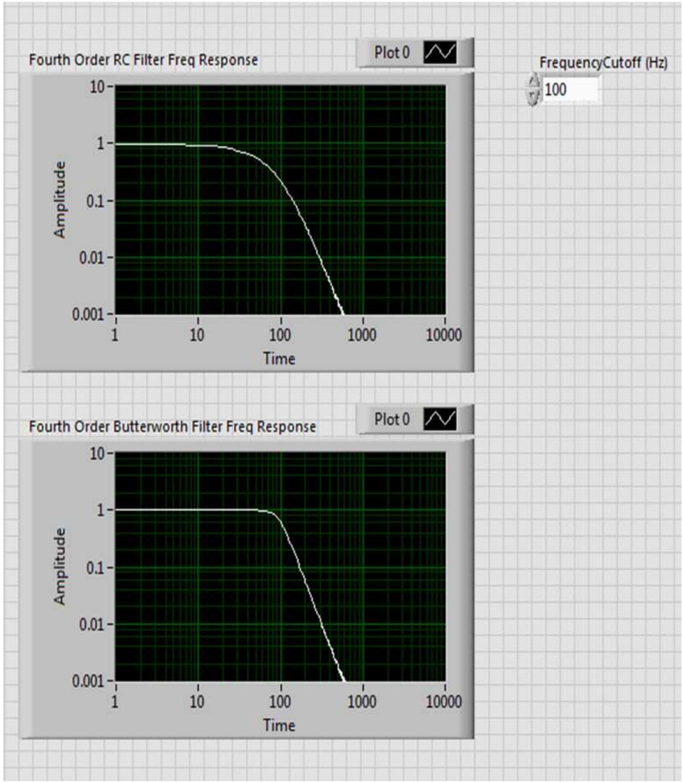
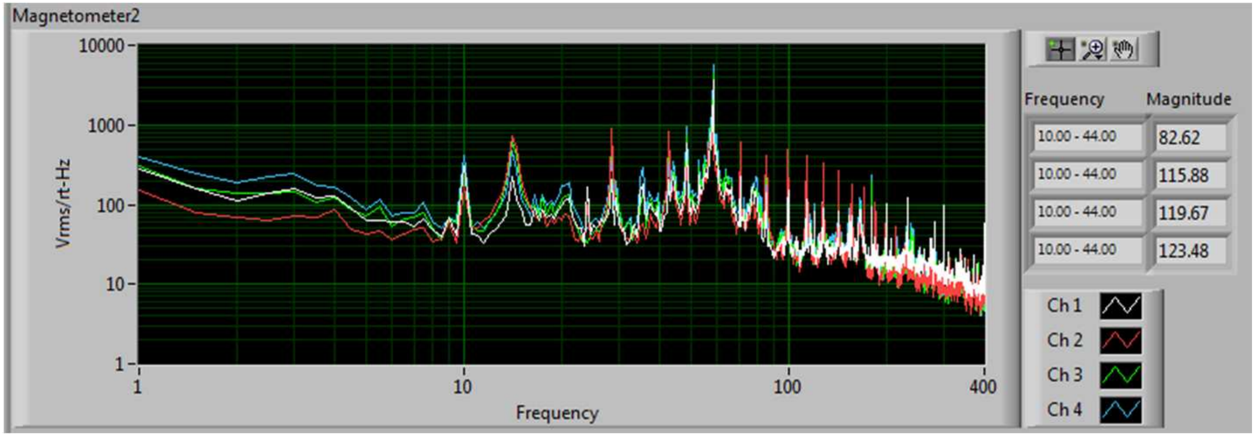
Lock-in Detection

- **LabVIEW lock-in detection algorithm was optimized for a 36-channel system.**
- **Different filtering methods were added including an RC low pass and Butterworth low pass filters.**
- **Optimization was developed for performing the lock-in algorithm on 36 channels in parallel.**
- **Lock-in data is streamed to a data storage disk and to the user interface for real-time feedback.**

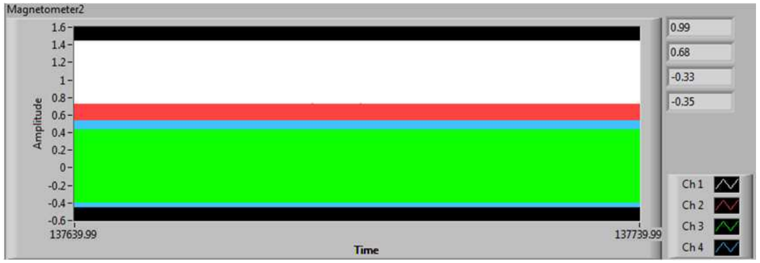


Power Spectral Density

- **Power Spectral Density is a function built into LabVIEW.**
  - ✓ The ability to dynamically change the resolution bandwidth of the measurement was added.
  - ✓ Buffered the data before the Power Spectral Density calculation.
  - ✓ Down-sampled the data.

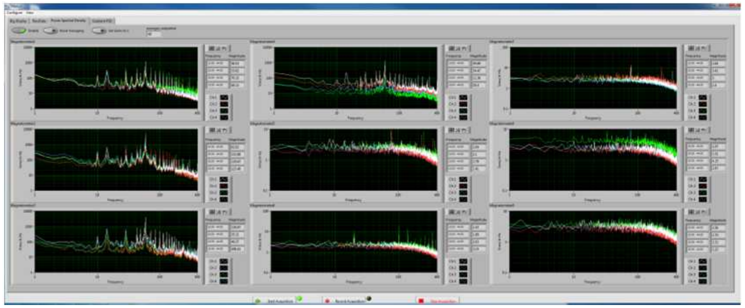


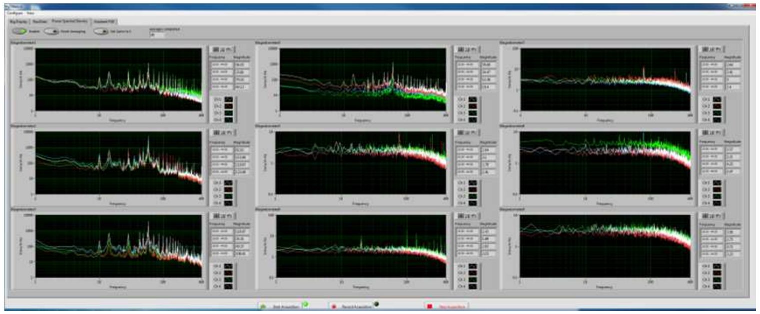
Achieved Results



Real-Time visualization of Raw Data, Lock-in Data, Power Spectral Density, and Gradiometer

Power Spectral Density Software Display for all 9 Magnetometers

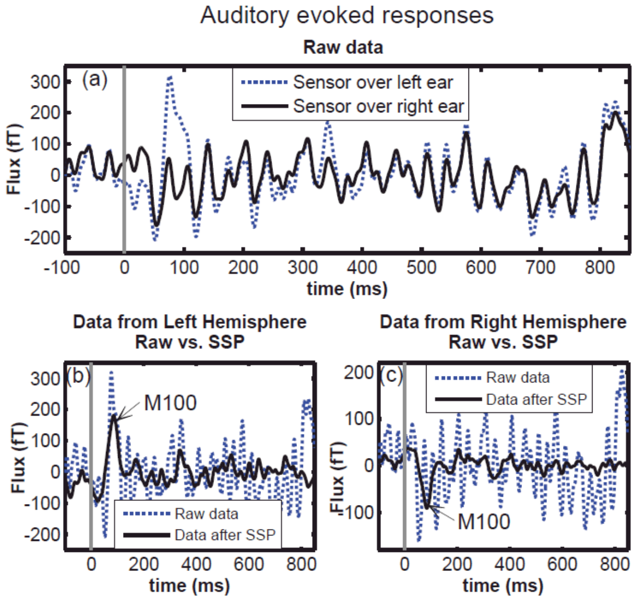




Gradiometery Software Display for all 9 Magnetometers

Next Steps (Phase 3)

- **Develop calibration routines to create a zero field within the enclosure (active noise cancellation from PSD).**
- **Goal is to have zero magnetic fields in the enclosure over the spectrum of interest.**
- **Be able to detect M100 responses after signal processing.**



At this point the system will be ready for initial human trials.