

Signal Processing

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

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AEgis
TECHNOLOGIES

Description

- ✓ **Sandia National Labs is developing an atomic magnetometer (AM) aka. optically pumped magnetometer (OPM) 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.

Optically Pumped Magnetometer (OPM)

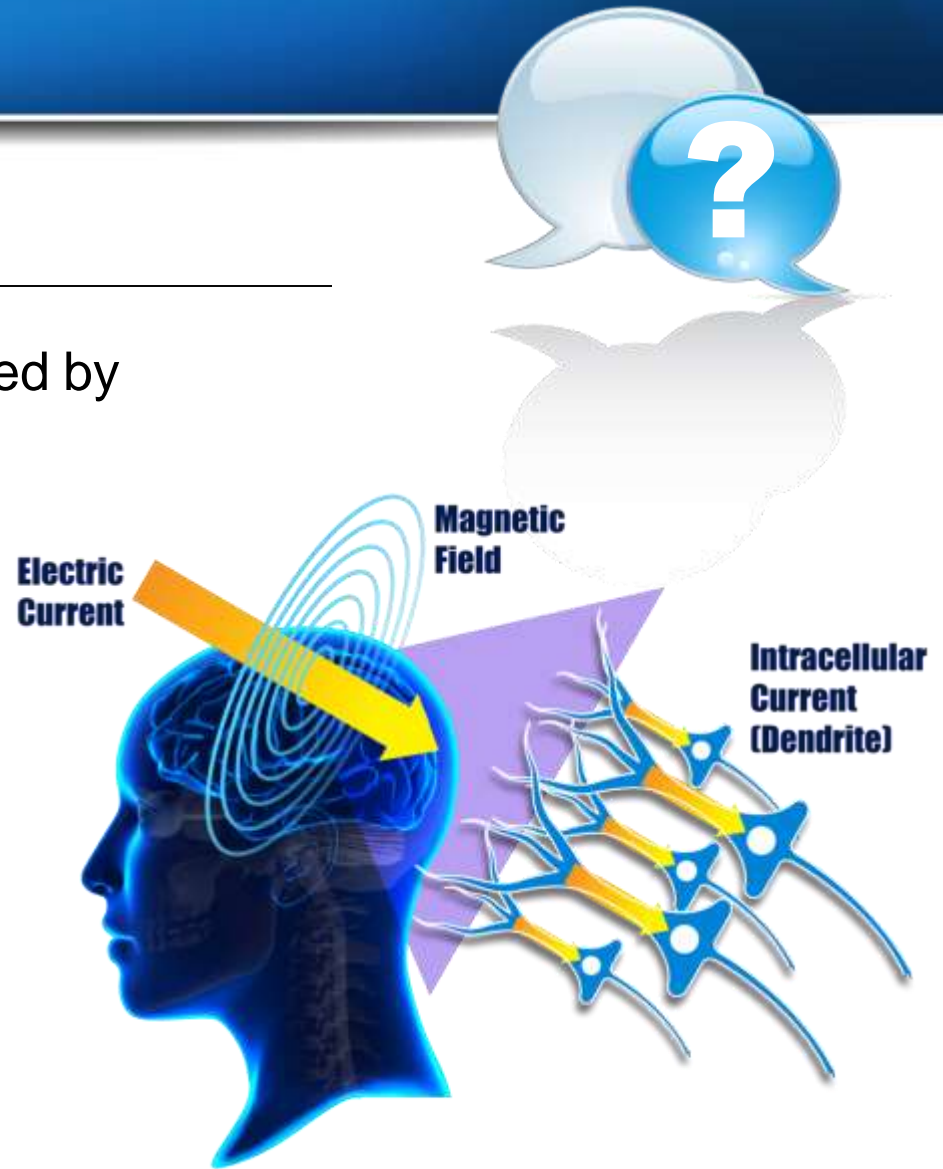
- ✓ Also known as Atomic Magnetometer. The electronic spins of alkali atoms are aligned using a process called optical pumping.

MEG

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

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 μ T)

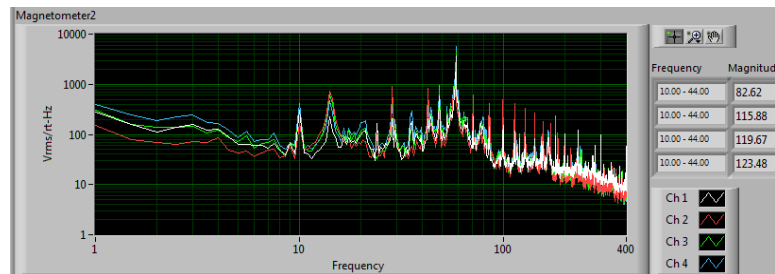
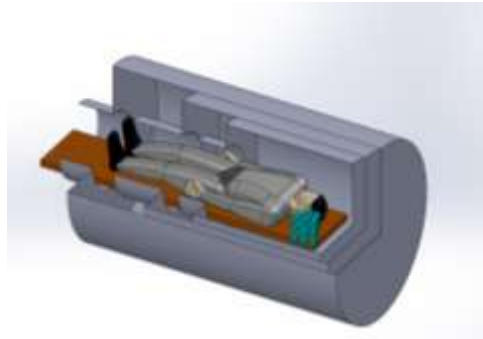
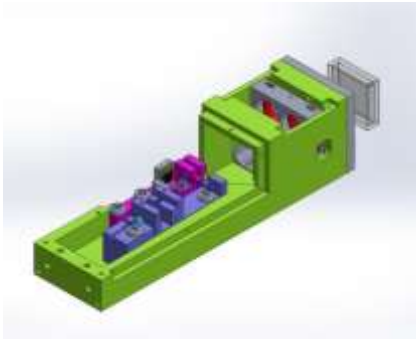


Why MEG...

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

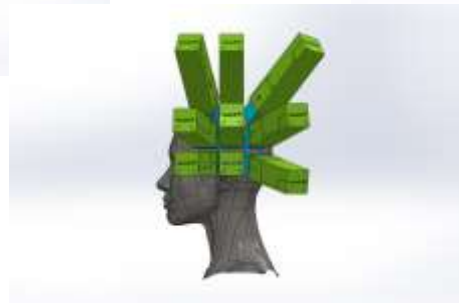
MEG Challenges

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

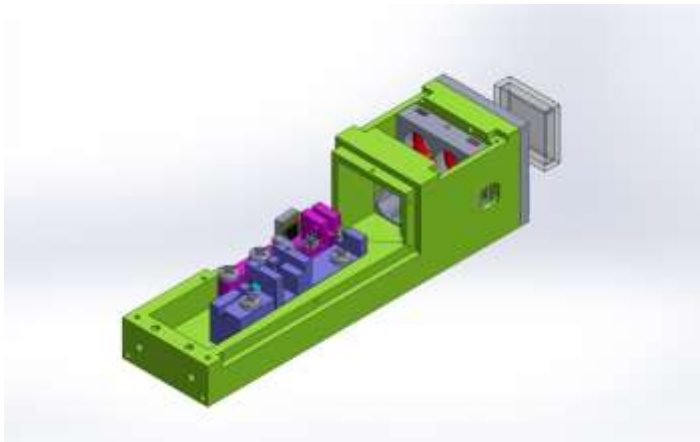
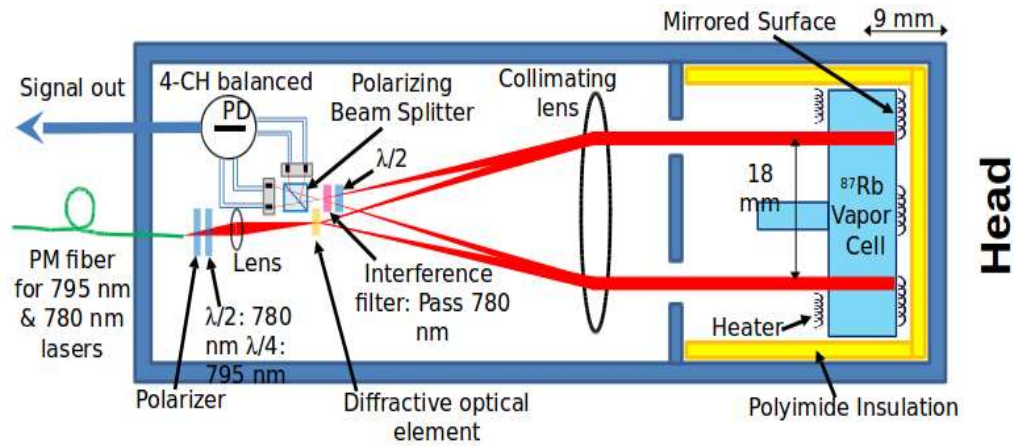


System Description

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



2nd Generation Magnetometer



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 μ T (50×10^{-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 gradiometry 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.**

Lock-in Detection

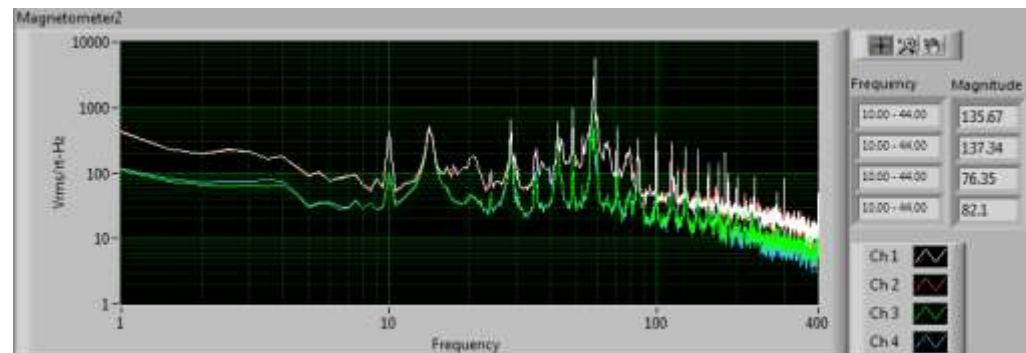
- **Raw signal capture from the magnetometer**
- **Capture a lock-in signal using a lock-in amplifier**
 - ✓ Modulation-demodulation of a fixed frequency
 - ✓ Signals of interest are on the order of 100 Hz
 - ✓ Use of a 1 KHz modulation frequency with a 400 Hz low-pass filter
- **Phase shift between 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

Gradiometry

- **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

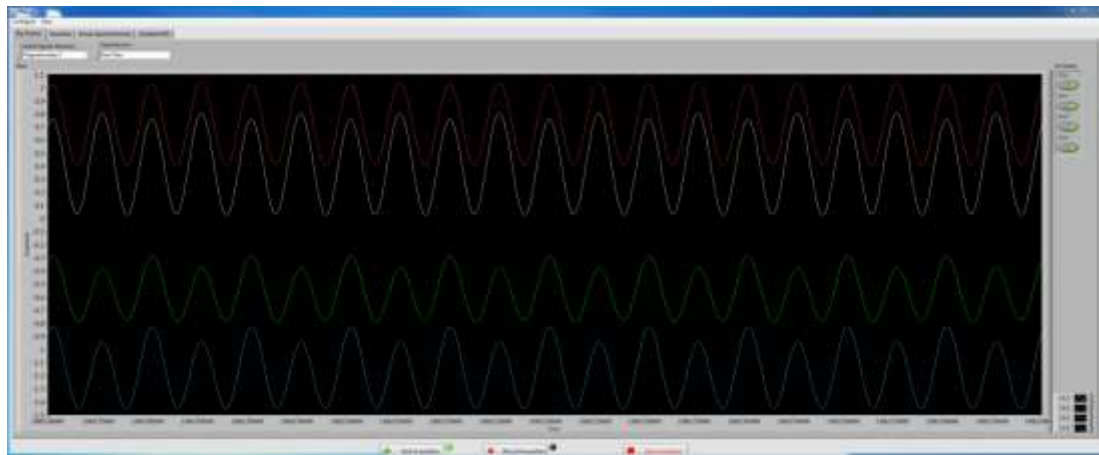
- **National Instruments PXIe-4499 16 channel Dynamic Signal Analyzer**
- **Three PXIe-4499's for a total of 48 possible channels**
- **The PXIe-4499s are synchronized together in a PXIe Chassis**

Phase drift will significantly affect the acquired data



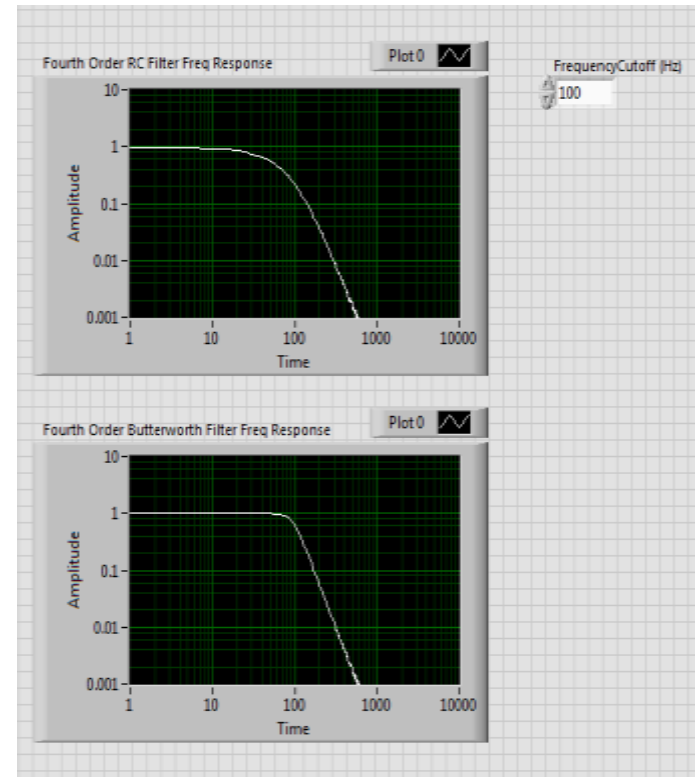
Software Implementation

- **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 **streaming data to a storage disk**
 - ✓ HDF5 was selected for compatibility with Matlab



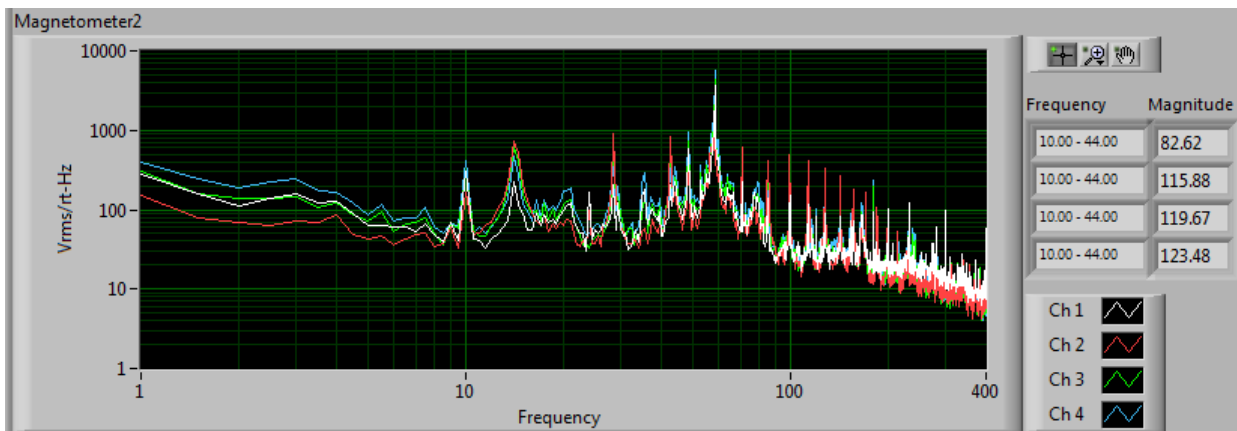
Lock-in Detection

- **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.**

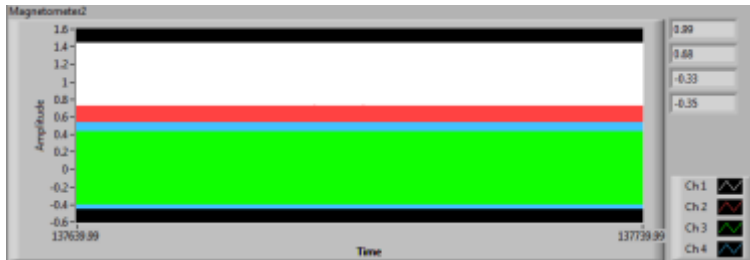


Power Spectral Density

- **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.

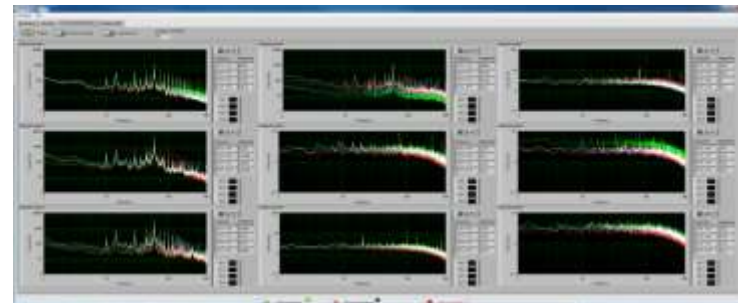


Achieved Results

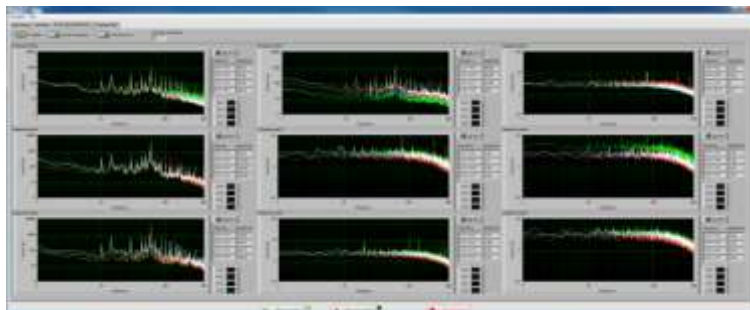


Real-Time visualization of Raw Data, Lock-in Data, Power Spectral Density, and Gradiometer

Power Spectral Density
Software Display for all 9
Magnetometers



Gradiometry 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.

