Atomic Magnetometer for Human Magnetoencephalography

Sandia National Laboratories

Peter D. D. Schwindt, Cort Johnson, Michael Weisend*

* The Mind Research Network, Albuquerque, NM 87101

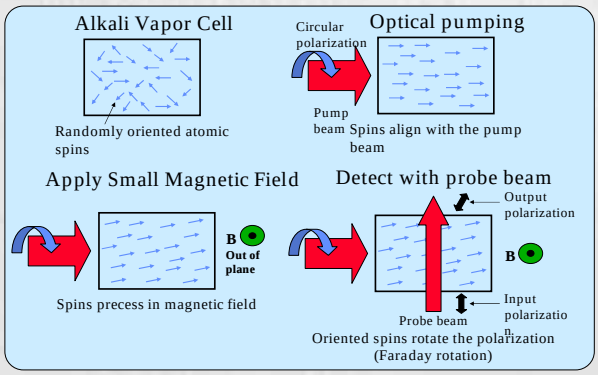
Problem

Magnetoencephalography (MEG) has traditionally been performed with highly sensitive superconducting quantum interference devices (SQUIDs). Traditional SQUID systems require large capital expenditure and high maintenance costs because they must be maintained at liquid helium temperatures. Atomic magnetometers (AMs) are a potential noncryogenic alternative to SQUIDs and have recently demonstrated subfemtotesla sensitivities [1]. In AMs, a vapor cell of alkali metal is heated to 200 ºC producing a high-density atomic cloud. Circularly polarized laser light aligns the electron spins of the cloud to create a collective magnetic moment. The interaction of this moment with an external magnetic field changes the optical properties of the vapor. A probe laser beam monitors this change to produce an output signal proportional to the magnetic field. Although MEG with atomic magnetometers has been demonstrated [2], little effort has been invested to develop AMs that could be packaged in a whole -head MEG system. With this goal in mind, we have designed a small-profile, rubidium-based AM that operates inside a fiberglass vacuum vessel.

Approach

Low-field Atomic Magnetometers

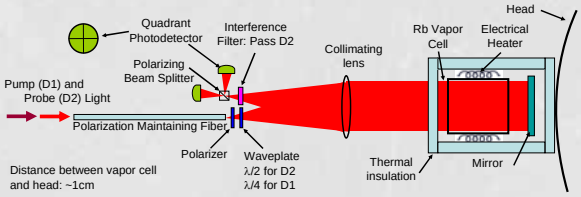
Electron spins in an atomic alkali vapor are aligned via optical pumping. Atomic magnetic moments precess around the magnetic field vector resulting in a field-dependent rotation of the probe beam plane of polarization. Polarization analysis therefore measures the strength of the magnetic field.

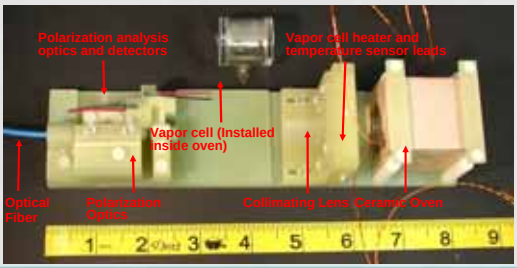


Two-Color Single Optical Axis Magnetometer

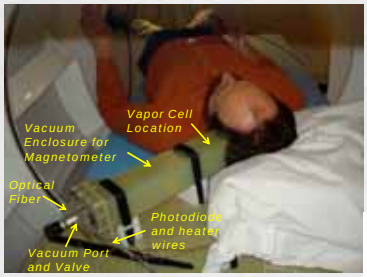
High Scalability

- Fiber optic coupling: one laser for multiple sensors
- Co-linear pump/probe beams: simple construction
- Small footprint on head: enables whole-head coverage



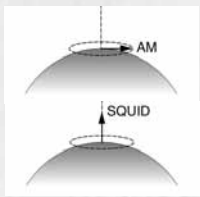


Results



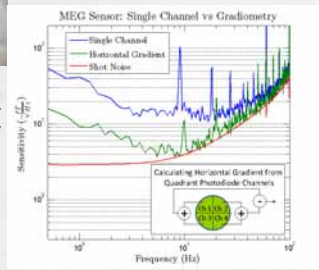
Atomic Magnetometer installed in the magnetically shielded room at MRN

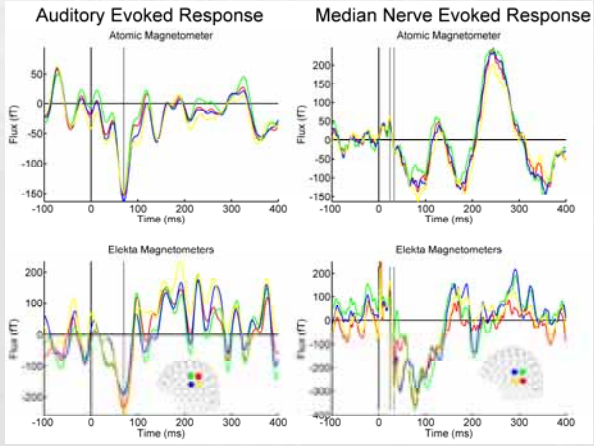
- Conventional magnetically shielded room is insufficient.
- Ambient field cancellation coils are necessary.
- Magnetically shielded room could be abandoned in favor of human-sized shield.
- Magnetometer enclosed in vacuum vessel to protect human subject from 200 ºC cell.



Atomic Magnetometer Sensitivity

Component of the Magnetic Field Measured by the Atomic and SQUID Magnetometers





Replication of left hemisphere response to auditory stimulation with 1000 Hz tones comparing the atomic magnetometer and Elekta Instrument.

Atomic Magnetometer Data: Trials: 320; Filters: 1 to 40 Hz; Baseline correction: -100 to 0 ms; Sampling Rate: 1000/s.
Elekta Magnetometer Data: Trials: 110; Filters: 1 to 40 Hz; Baseline correction:-100 to 0 ms; Sampling Rate: 1200/s

Replication of left hemisphere response to right median nerve stimulation with atomic magnetometer and Elekta Instrument.

Atomic Magnetometer Data: Trials: 368; Filters: 1 to 150 Hz; Baseline correction: -100 to 0 ms; Sampling Rate: 1000/s.
Elekta Magnetometer Data: Trials: 313; Filters: 1 to 150 Hz; Baseline correction:-100 to 0 ms; Sampling Rate: 1200/s

Significance

- Comparisons of brain activity recorded with the atomic magnetometer and magnetometers in the Elekta-Neuromag magnetoencephalography instrument are quite favorable.
  - In recordings of activity elicited with median nerve stimulation, the M20 (postcentral gyrus response), M30 (precentral gyrus response), and M90 (secondary somatosensory cortex response) are visible and comparable to independent recordings from the Elekta instrument.
  - In recordings of activity elicited with 1000-Hz tones, the 100-ms response (Heschl's gyrus) is comparable in independent recordings from the atomic magnetometer and the Elekta Instrument.
  - Differences in the waveforms are likely due to the differences in the measurement of field components.
- Additional work will scale up the atomic magnetometer to record simultaneously from multiple locations on the head and increase the sensitivity and bandwidth of the of the instrument.
- Atomic magnetometer–based MEG could provide a forward deployable functional neuroimaging capability for diagnosis of traumatic brain injury and post traumatic stress disorder or determine fitness for duty.

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