BADGER BALLISTICS

Bucky's Quantum Magnetometer

Isaac Becker, John Krueger, Kaden Reybrock, Andy Rivedal, Camden Schultz

ADVISED BY:
Dr. Jennifer Choy

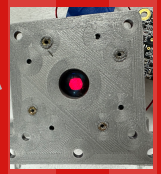
https://github.com/aiaauwmadison/2024-payload

Badger Ballistics UW-Madison

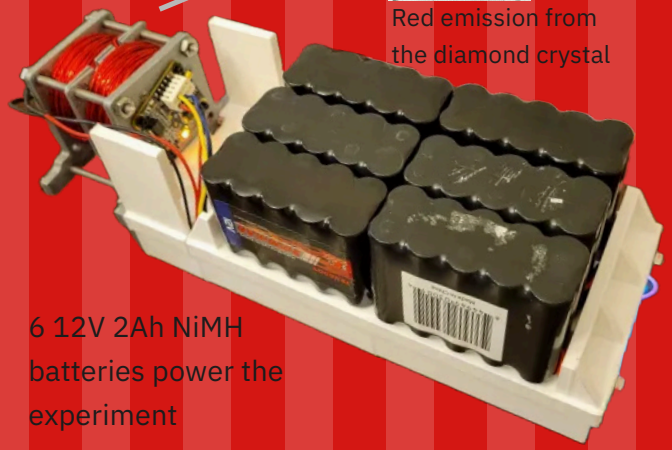
Our scientific payload: an integrated magnetic field sensor, or a magnetometer, that operates based on quantum mechanics within a 3U enclosure.

Sensor components, control electronics, and batteries are all mounted onto a removeable sled. Our sensor's core is a diamond with quantum emitters whose emission intensity varies based on the magnetic field.

Sensor head, with Helmholtz coils for magnetic field testing



Red emission from the diamond crystal



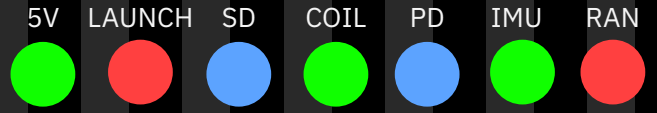
6 12V 2Ah NiMH batteries power the experiment

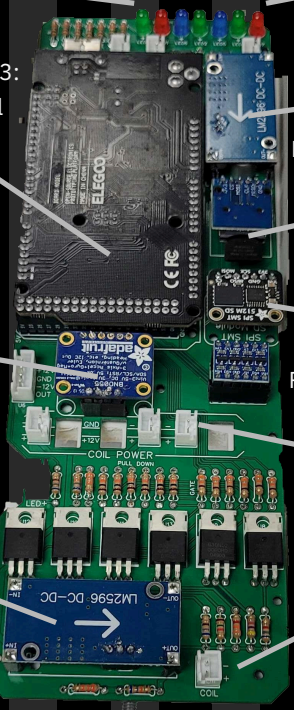
HOUSING & SLED

CUSTOM PCB

The electrical system controls the experiment through a custom-designed PCB that components are mounted to. The PCB board is designed to fit within the 3U form factor, integrates the entire electrical system, and reduces points of failure due to faulty electrical connections.

LED status indicators for key subsystems





ELEGOO Mega R3: Central Control

12V to 5V Buck Converter

Modified SD Module : Backup Data Storage

BNO055 IMU: Orientation and Launch Detection

512Mb SPI Flash: Primary Data Storage

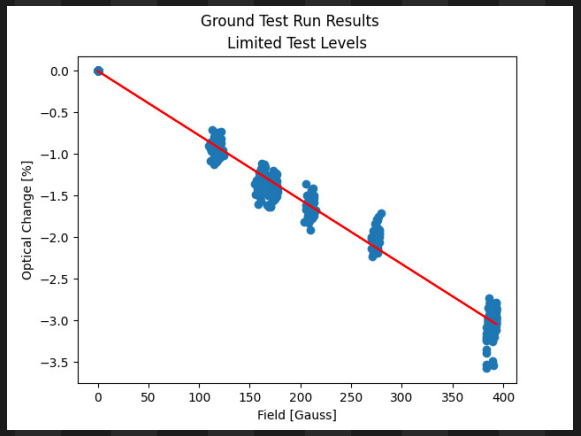
Modified Buck Converter: Coil Current and Field Control

Locking JST Battery, Sensor, and Coil Connectors

Experiment

The objective of the payload is to measure a changing magnetic field using quantum mechanics in the environment of a sounding rocket. The quantum sensor, based on color centers in a diamond, is conceived with and advised by Dr. Jennifer Choy of the University of Wisconsin-Madison's Electrical & Computer Engineering Department.

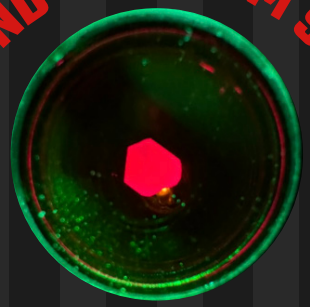
The payload functions by shining a green LED onto a diamond quantum sensor. The nitrogen-vacancy centers in the diamond are excited by the green light, and emit red light when returning to their original states. The intensity of the red light is influenced by the magnetic field. Changing the current through the Helmholtz coil alters the magnetic field around the diamond, and consequently, the red light output. The intensity of this light is recorded by a photodiode and logged to a pair of data drives, providing redundancy. Plotted below is data collected from a ground test running a limited set of magnetic field values. During the flight, a more complete range of fields will be tested.



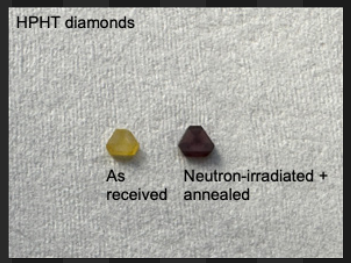
Sources:

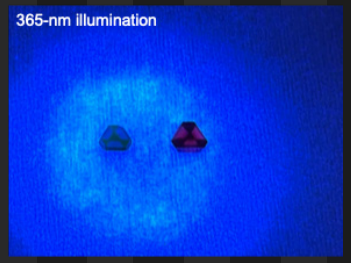
[1] Bähr, M., Jahn, M., Heinze, C., Neckermann, K., Meijer, J. and Ortlepp, T. (2023), Phys. Status Solidi A, 220: 2200338.
[2] NASA. "Magnetosphere and Ionosphere." NASA Science, https://science.nasa.gov/heliophysics/focus-areas/magnetosphere-ionosphere/. Accessed: June 17, 2024.
[3] R. Robinson, "ACCURACY OF THE VECTOR MAGNETOMETER AS AN ATTITUDE SENSING DEVICE FOR AURORAL SOUNDING ROCKETS," thesis, Rice University, Houston
[4]Kopytenko, Y.A., Petrova, A.A., Alekseev, V.F. et al. Application of Altitude Models of Earth's Magnetic Field for Solving Geophysical Problems. Cosmic Res 57, 163–168 (2019). https://doi.org/10.1134/S0010952519030067
Kyosuke Iguchi and Ayako Matsuoka 2014 Meas. Sci. Technol. 25 075803

DIAMOND QUANTUM SENSOR

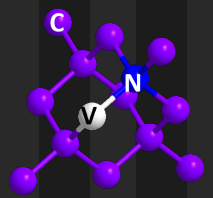


We acquired a nitrogen-rich, lab-grown diamond and made quantum color centers by irradiating the diamond with high-energy neutrons in UW's nuclear reactor. This process was followed by annealing the diamond at high temperature. This approach significantly increased the number of color centers, which improves the signal strength and sensitivity of the magnetic field sensor.

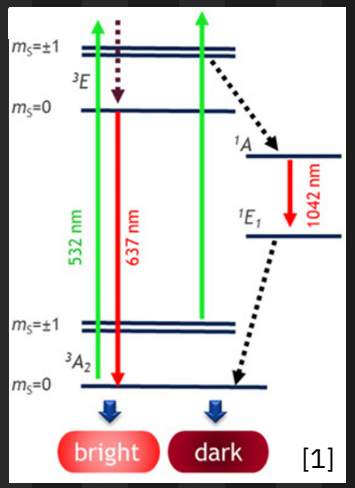




Nitrogen-vacancy (NV) centers in diamond

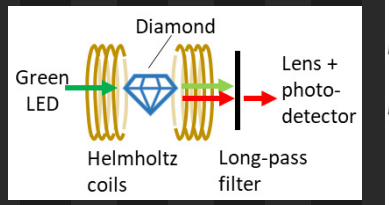


Quantum electronic transitions



[1]

Sensor schematic



Magnetic fields change whether the NV is in a bright or dark state, which changes the light intensity being measured by the photodetector.

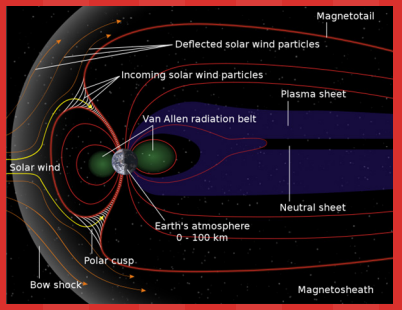
Applications

Investigating Space Plasma

Attitude Orientation Measurement

Magnetosphere Measurement

Study of Geomagnetic Field



[2]

Motivation for using a quantum magnetometer

Accuracy and Sensitivity

Potential to sense magnetic fields with sensitivity on the order of ~1 pT

All-Optical

Optical sensing reduces electrical and mechanical noise

Vector Information

Orientations can be derived from optical output

Compact Design

Potential to be miniaturized to a smaller form factor

Specifications

3U Form Factor

100-400 Gauss Field Range

0.7A-2.7A Coil Current Range

500 Turns of 20AWG Wire per Coil Side

4.81kg