Optically pumped vector magnetometer for geomagnetic applications

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We present a novel approach which enables an optically pumped magnetometer (OPM) to be operated within the Earth's magnetic field as a vector magnetometer whose sensitive axis can be freely defined. Thus, the measurement of any component of the Earth magnetic field vector, also orthogonal to it, is enabled with high sensitivity. The OPM uses a microfabricated cesium vapor cell with nitrogen buffer gas (≈180 mbar), which is immersed into a homogeneous bias field of about 700 µT. The bias field, which is more than an order of magnitude stronger than Earth's magnetic field, determines the sensitive axis of the OPM. The bias field is generated by solid-state magnets and was designed to exhibit a very low inhomogeneity ($<10^{-4}$ in relative units) within the vapor cell and features a point of vanishing temperature dependence at around 40°C. The OPM uses the light-narrowing effect, which allows for an effective suppression of the spin-exchange relaxation even in such a strong magnetic field [1,2]. By that, we demonstrate a white noise floor of $<100\ \mathrm{fT}/\sqrt{\mathrm{Hz}}$ above 100 Hz and a sensor bandwidth of >2 kHz. The sensor concept presented herein is intended to be used in the field of transient electromagnetics (TEM) for the exploration of ore deposits, where up to now SQUID sensors are the gold standard. However, the approach enables unshielded ultrasensitive vectorial measurement capabilities, also relevant in other important applications such as biomagnetism.

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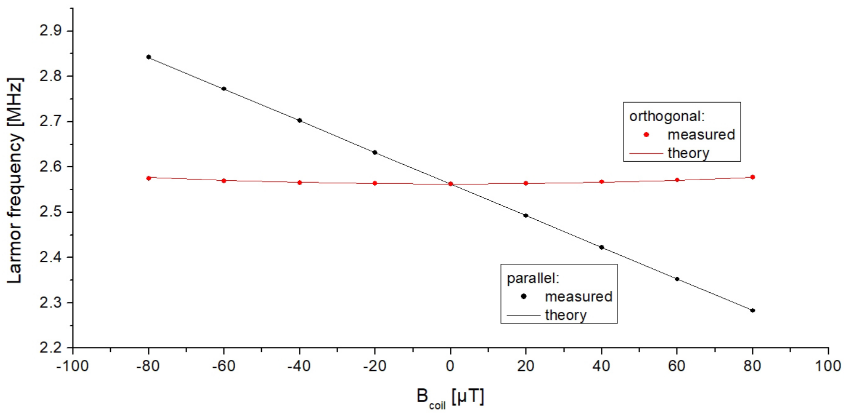

Figure 1. Proof of vectorial sensitivity: If a magnetic field is applied parallel to the bias field, it has a linear impact on the measured Larmor frequency. Orthogonally applied magnetic fields, in contrast, are strongly suppressed, exhibiting a very weak quadratic characteristic.

[1] T. Scholtes, V. Schultze, R. IJsselsteijn, S. Woetzel, and H.-G. Meyer, Light-narrowed optically pumped Mx magnetometer with a miniaturized Cs cell, Phys. Rev. A **84**, 043416 (2011).
[2] V. Schultze, B. Schilling, R. IJsselsteijn, T. Scholtes, S. Woetzel, and R. Stolz, An Optically Pumped Magnetometer Working in the Light-Shift Dispersed Mz Mode. Sensors 2017,**17**, 561.