A quantum-noise-limited pulsed gradiometer at Earth's field

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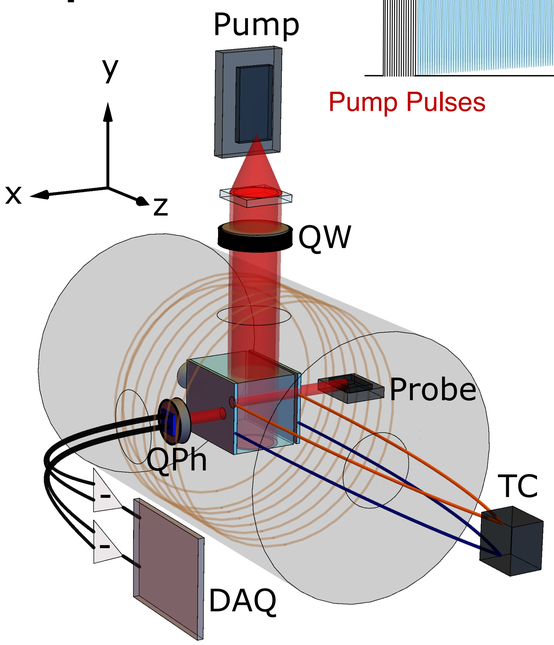
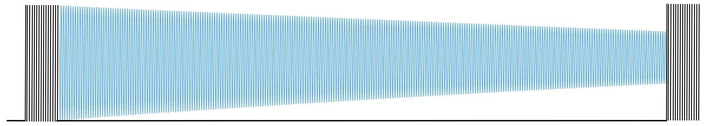
Experiment





·An optically heated ^{87}Rb cell at 100 C sits in μ-metal shielding, with gradient and DC coil sets

·^{87}Rb is pumped with D1 σ_+ light using <1 µs pulses perpendicular to a bias field B_z, giving

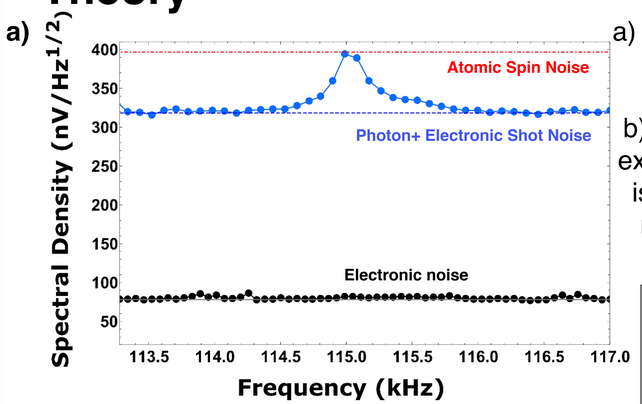
·Initial ^{87}Rb polarization near unity

·Pulsed laser capable of producing 4 W in 1 µs

·Off-resonant probe laser monitors free spin precession, with two balanced polarimeters measure top/bottom of cell

·All-optical gradiometer with 0.2 cm baseline

Theory



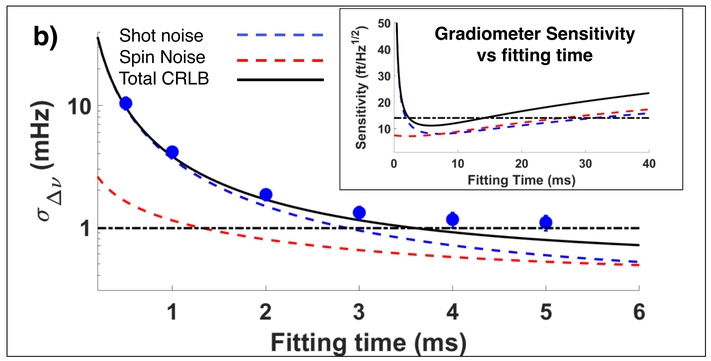
White Noise Non-white Noise

$$\sigma_\nu^2 \geq \frac{12(\rho_w^2 + \rho_{nw}^2 C_{nw})C}{(2\pi)^2 A^2 T^3}$$

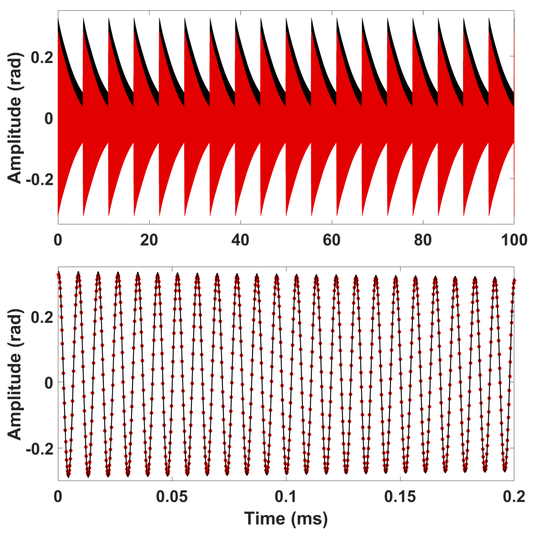
Generalized Cramer-Rao lower bound (CLRB) for damping sine wave in the presence of white-noise and non-white spin noise including diffusion

a) Spin noise spectrum for unpolarized spin ensemble at B_z = 16 μT, along with electronic and photon noise.

b) Varying fitting times, we show good agreement between experimental standard deviation and total CRLB. Sensitivity is quantum-noise-limited over the entire investigated field range, including B_z = 50 µT. (Inset) Optimal gradiometer sensitivity occurs for 5.7 ms fit times.

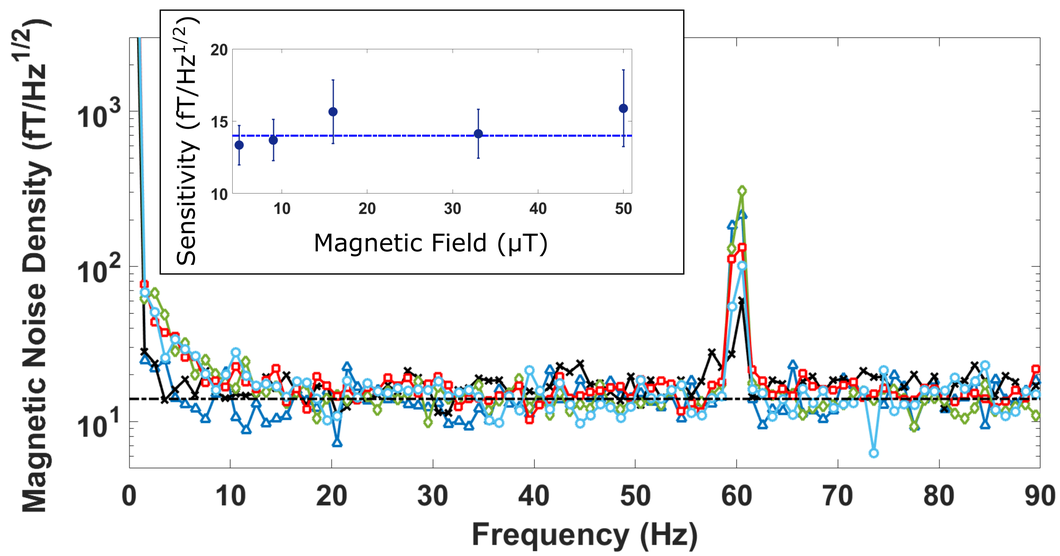


Results



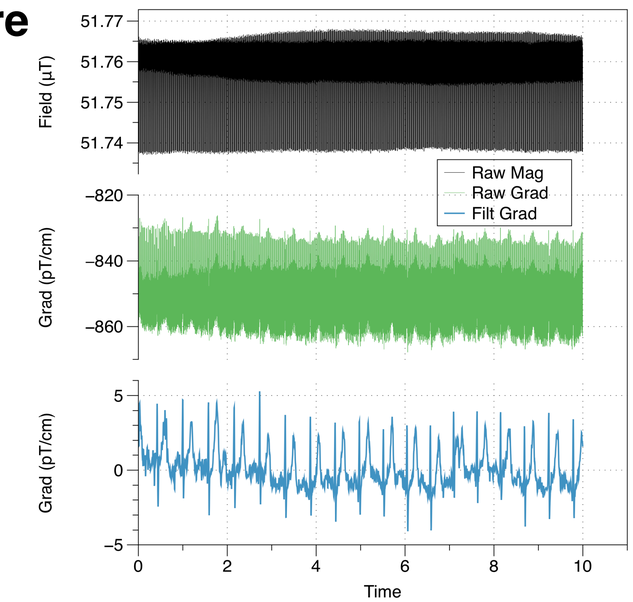
Pumping and detection is repeated at 180 Hz. Each free precession data is fit to

$$V_0 \sin(2\pi\nu_L t + \delta)e^{-t/T_2}$$



Subtracting two magnetometer frequencies and using fitting times of 5 ms, we find a differential field sensitivity of 14.7 ΔfT/Hz$^{1/2}$. The all-optical gradiometer shows no loss of sensitivity with bias fields outside the SERF regime, due to spin-exchange relaxation suppression from high Rb polarization. We also find a common mode rejection ratio of 10^4.

Future



This work informed a next-gen gradiometer with a 3 cm baseline. USB powered and ran from a laptop, we detect heartbeats in a noisy environment in Earth's field.

For novel heading error correction, see Poster S1:36 (Thurs.) W. Lee, et al., "Heading error analysis of a pulsed ^{87}Rb magnetometer at geomagnetic fields"

1.) V. G. Lucivero, W. Lee, M. V. Romalis, M. E. Limes, E. L. Foley, T. W. Kornack (2019) arXiv:
2.) V. G. Lucivero, N.D. McDonough, N. Dural, and M. V. Romalis, Phys. Rev. A 96, 062702 (2017)
3.) D. Sheng, S. Li, N. Dural, and M. V. Romalis, Phys Rev. Lett. 110 160802 (2013)