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Magnetometry with stroboscopic probe light

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Atomic-optical magnetometers have reached sensitivities where quantum noise becomes a limiting factor. One fundamental quantum noise source is back-action noise, which arises from the coupling between quantum fluctuations in the probe light's polarization and the atomic spin ensemble being measured. This back-action can be circumvented by stroboscopically modulating the probe intensity at twice the Larmor frequency, effectively decoupling the light's quantum fluctuations from the observed atomic-spin system [1]. Beyond reducing measurement noise, this technique opens the door to generating spin-squeezed states, offering further sensitivity enhancement.

Previous studies have demonstrated the effectiveness of stroboscopic probing under conditions where the second-rank tensor polarizability —a Hamiltonian term associated with atomic alignment effects—is negligible. This regime arises in the presence of buffer gas or when the probe light is detuned far from resonance, rendering the excited-state hyperfine structure unresolved. In contrast, when this tensor contribution is significant, it has been shown to enable both spin and light squeezing, offering additional avenues to enhance magnetometric sensitivity [2, 3]. Notably, these effects have been observed using continuous, unmodulated probe light, and their effectiveness relied on the use of two oppositely oriented spin ensembles.

In this work, we investigate stroboscopic probing of a single ensemble in a regime where the second-rank tensor polarizability cannot be ignored. We observe distinctive features in the spin noise spectrum and explore the conditions under which polarization-squeezed light is generated via the interaction of stroboscopically modulated light with the atomic ensemble. The resulting squeezing, centered near the Larmor frequency, offers a promising path for improving the performance of atomic magnetometers.

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