Phase projection errors in rf-driven optically pumped magnetometers

Zoran D. Grujić[1], Marija Ćurčić[1], Aleksandra Kocić[1], Theo Scholtes[2]

[1] Institute of Physics Belgrade, University of Belgrade, Serbia
[2] Leibniz Institute of Photonic Technology, Albert-Einstein-Strasse 9, D-07745 Jena, Germany

Very prominent implementations of optically pumped magnetometers (OPM) detect the magnetic resonance in an alkali atomic vapor within a static magnetic field by the help of a small radio-frequency (rf) magnetic field [1]. Here, in the so-called $\mathrm{M_x}$ magnetometer, the amplitude and phase of modulation of light transmitted through a vapor cell is monitored in dependence on the rf field frequency. Magnetic resonance is observed when the rf frequecy coincides with the Larmor frequency of the atoms, which is given by the external magnetich field of interest. In this case the modulation amplitude is maximized, and the phase displays a dispersive and monotonic dependence on rf field frequency. This is made use of to form an active feedback circuit, in which the rf field frequency is tuned to follow changes of the (quasi-)static magnetic field by means of a phase-locked-loop (PLL).

We discuss the dependence of the phase on important experimental quantities, especially the angles between light propagation direction, rf and static magnetic field vectors. While the static dependence is considered to be well understood [2], we find a hitherto unknown dynamic phase response in the $\mathrm{M_x}$ magnetometer when subject to rotations of the static magnetic field. By solving Bloch equations we obtain analytical expressions which can explain our experimental observations using a paraffin-coated spherical Cs vapor cell [3]. We show the resulting fundamental limitations of rf-driven OPMs and highlight the importance of the findings in terms of real-world sensing applications.

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