Reducing excess quantum noise in atomic magnetometer

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Nonlinear magneto-optical rotation (NMOR) [1,2,3,4] is a sensitive technique for measuring magnetic fields. A resonant atom-light interaction is always accompanied by a polarization self-rotation (PSR) effect [5]. The PSR effect can generate squeezed light, which reduces or increases quadrature fluctuations compared with a coherent state at different quadrature phases ϕ. In a typical polarimeter, the rotation angle is measured with the maximum signal, and the corresponding noise quadrature due to the PSR effect is always above the shot noise level. We study the influence of the PSR effect on the noise and SNR of an NMOR magnetometer theoretically and experimentally. We find that the minimum and maximum noise of the NMOR light will be squeezed and anti-squeezed at specific quadrature phases due to the PSR effect in the absence of a magnetic field. In this case, the maximum SNR is achieved at $\phi \sim 0$. When a leading magnetic field is applied to the atomic vapor, the noise at all quadrature phases increases with the magnetic field, but the growth rates are different. In such circumstances, the SNR highly depends on the relative phase between the light that undergoes magneto-optical rotation and a local oscillator [5]. By introducing an optical phase shifter in the path of the light beam just before the polarimeter to controllably adjust the relative phase, the SNR can be improved by 10 dB with the optimal phase compared to the case without the phase shifter. This technique can effectively reduce the effect of excess quantum noise on the SNR when the atomic sensor is operated in a real geomagnetic environment.

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