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FPGA-Based Broadband Pumping in SERF Atomic Magnetometers

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Atomic magnetometry based on the spin-exchange relaxation-free (SERF) effect has emerged as a key technology for high-precision magnetic field measurements due to its ultrahigh sensitivity. A critical factor in enhancing the sensitivity of SERF magnetometers is achieving uniform spin polarization in high-density alkali-metal vapor. However, conventional narrow-linewidth optical pumping often leads to polarization gradients along the pump beam direction under high atomic density, due to incomplete polarization, which fundamentally limits device performance. In this work, we propose a broadband optical pumping scheme using external-cavity electro-optic phase modulation. An FPGA-controlled radiofrequency modulation system is employed to spectrally broaden the laser, and the relationship between phase noise and spectral width is quantitatively analyzed based on the Wiener-Khinchin theorem. The resulting broadband laser source exhibits strong noise suppression and significantly improves spin polarization homogeneity. Experimental results show more than 40% enhancement in spin polarization uniformity, a 4.3-fold reduction in optical frequency noise, and a 54% increase in system response compared to unmodulated pumping. A sensitivity of $0.34\ \mathrm{fT}/\sqrt{\mathrm{Hz}}$ is achieved at 30 Hz. This approach is readily extendable to other large-volume atomic ensembles requiring homogeneous spin polarization, offering a powerful solution for next-generation biomagnetic sensing applications such as magnetocardiography and magnetoencephalography.
Keywords: SERF magnetometer; broadband laser; optical pumping; spin polarization uniformity; phase modulation; noise suppression; FPGA control

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