Ultrasensitive all-optical Rydberg microwave receiver

Sebastian Borówka[1], Mateusz Mazelanik[1], Wojciech Wasilewski[1], Michał Parniak[1]

[1] Centre for Quantum Optical Technologies, University of Warsaw, Poland

The transitions between Rydberg energy levels of alkali atoms provide a versatile medium for the sensitive detection of microwave (MW) electric fields. Various detection schemes have been proposed, including solutions in room-temperature atomic vapours, where the simple setups employed point to immediate applications. Using atoms as radio frequency sensors has many advantages over conventional antennas, including stealthy, weakly disruptive measurements due to the sensors containing very little metal and the readout being fully optical. However, the greatest sensitivities have been presented with the use of MW local oscillator in a superheterodyne detection, where the measurement is no longer all-optical.

Here we propose a solution to achieve the sensitivity comparable with state-of-art superheterodyne measurements, while remaining all-optical. For this approach we propose the use of a loop-type part of the energy level structure of rubidium, presented in the Fig. 1**A**. In this kind of detection the collective laser phase noise is transferred to the readout of our sensor. Instead of using extremely stable lasers, we propose to register the noise in a separate wave-mixing process in a nonlinear crystal, Fig. 1**B**, and compensate the noise in post-processing. We report the sensitivity of measurement down to 176 nV/cm/$\sqrt{\text{Hz}}$ and a relaible operation up to 3.5 mV/cm of received MW field.

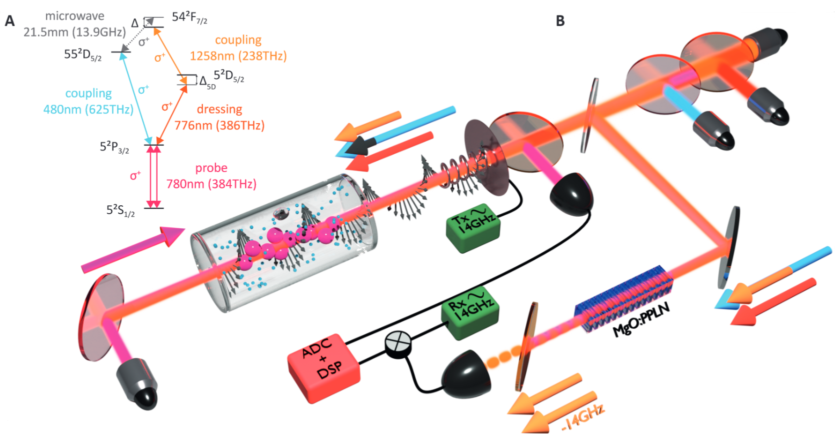

Figure 1. A, A loop-type energy level structure of rubidium employed in this work. **B**, The experimental setup of the all-optical receiver. Optical fields are combined inside the rubidium vapour cell. Separate propagation path allows for the measurement of collective phase noise of the laser fields, obtained via wave-mixing in a nonlinear crystal. Analog-to-digital conversion (ADC) of both signals then enables digital signal processing (DSP) to obtain phase-compensated received signal.

[1] S. Borówka, M. Mazelanik, W. Wasilewski and M. Parniak, Optically-biased Rydberg microwave receiver enabled by hybrid nonlinear interferometry, preprint at arXiV:2403.05310 (2024).