Modeling of EIT-based Quantum memories using phase-space methods

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One of the milestones towards the realization of quantum computation is a device that allows the coherent storage of quantum information. The Heisenberg Uncertainty Principle sets a limit on the quality of stored quantum information that depends on direct measurement and subsequent reconstruction [1]. Experimental and theoretical research are therefore directed towards using Electromagnetically Induced Transparency (EIT) as a mechanism to facilitate quantum information storage in a manner that allows the circumvention of the HUP limit [3]. Two optical fields, a weak probe and a strong control beam, driving two transitions of a Lambda structure will set up quantum interference that leads to a extremely narrow transparency window. The associated steep dispersion profile will result in significant slowing of the group velocity of the probe light. By adiabatically switching off the control field, information encoded in the probe field can be mapped onto the coherent superposition of the two atomic ground states, thus allowing storage of quantum information. This information can then be retrieved at a later time by the switching on of the control field. By encoding amplitude and phase modulations onto the sideband of a propagation light pulse, and taking into account atomic noise and decoherence of a realistic experiment, we construct a model to quantify the efficacy of quantum information storage via EIT.

Figure 1: Storage of Amplitude (b) and phase (c) quadratures of a light pulse when adiabatically switching off and on the coupling beam (a)

Our recent work has shown that theoretically both quadratures can be delayed with no added noise. These calculations were made by solving the Maxwell-Bloch equations with Langevin terms in a weak probe approximation regime [2]. We are now using an analytical as well as a numerical model to calculate the degradation of the signal to noise ratio when the coupling beam is switched off and on. Our analysis takes into account the adiabatic switching process of the control beam without making a weak probe approximation. A set of stochastic differential equations in the positive-P representation is developed. The solution of these equations in time and space is obtained using the XMDS package. Initial results suggest that the memory produces no excess noise but has a non-negligible absorption due to the finite width of the transparency window [Fig. (1)].

We plan to use the quantum information benchmarks for quantifying storage protocols efficacies. Signal transfer coefficients, conditional variances [4] and average fidelities will be calculated to examine the advantages of the EIT process in an analogous way to quantum teleportation. These results will tell us the experimental parameters required to implement EIT-based memories in the quantum regime.

References