Dynamical oscillator-cavity model for quantum memories

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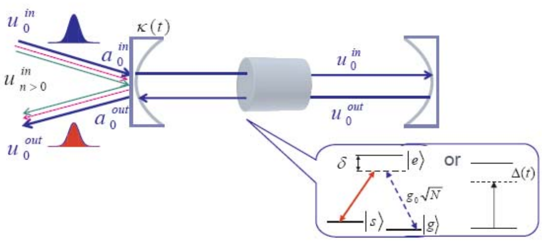
We propose a dynamical approach to quantum memories using an oscillator-cavity model. This overcomes the known difficulties of achieving high quantum input-output fidelity with storage times long compared to the input signal duration.



We use a generic model of the memory response [1], which is applicable to any linear storage medium ranging from a superconducting device to an atomic medium. The temporal switching or gating of the device may either be through a control field changing the coupling, or through a variable detuning approach, as in more recent quantum memory experiments. An exact calculation of the temporal memory response to an external input is carried out. This shows that there is a mode-matching criterion which determines the optimum input and output pulse time-evolution.

This optimum pulse shape can be modified by changing the gate characteristics. In addition, there is a critical coupling between the atoms and the cavity that allows high fidelity in the presence of long storage times. The quantum fidelity is calculated both for the coherent state protocol, and for a completely arbitrary input state with a bounded total photon number. We show how a dynamical quantum memory can surpass the relevant classical memory bound, while retaining long storage times.

Quantum memories are devices that can capture, store, and then replay a quantum state on demand. In principle, storage is not a problem for time-scales even as long as seconds or more, since there are atomic transitions with very long lifetimes that could be used to store quantum states. A quantum memory must store quantum superpositions. These cannot be stored in a classical memory in which a measurement is made on a quantum state prior to storage. The fundamental interest of this type of device is that one can decide at any time to read out the state and perform a measurement. In this way, the collapse of a wave-packet is able to be indefinitely delayed, allowing new tests of decoherence in quantum mechanics.

Such devices also have a fascinating potential for extending the reach of quantum technologies. Here, the main interest is in converting a photonic traveling-wave state - useful in communication - to a static form. Although atomic transitions are normally considered, actually any type of static mode can be used as a quantum memory. For the implementation of quantum networks, quantum cryptography and quantum computing, it is essential to have efficient, long-lived quantum memories. These should be able to output the relevant state on demand at a much later time, with a high fidelity over a required set of input states. The benchmark for a quantum memory is that the average fidelity $\bar{F}$ must be higher than any possible classical memory when averaged over the input states: $\bar{F} > \bar{F}_C$.

References

[1] Q. Y. He, M. D. Reid, E. Giacobino, J. Cviklinski, P. D Drummond, arXiv:0808.2010.