Electromagnetically-induced transparency in systems with multiple excited levels

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Frequency conversion and routing of quantum information carried by light is of great importance for future quantum communication networks. Here we demonstrate a protocol called Raman adiabatic transfer of optical states (RATOS), which allows the transfer and distribution of a quantum state of light between different optical modes in an adiabatic and thus robust way. The protocol is based on electromagnetically-induced transparency (EIT) in a medium with multiple excited levels (multiple-Λ system). An example of such a medium is the D1 transition in rubidium, where both the ground ($5S_{1/2}$) and the excited ($5P_{1/2}$) levels are split into hyperfine sublevels (Fig. 1)

As shown in [1], a double-Λ system coupled by two signal fields (described by annihilation operators $\hat{a}_1$ and $\hat{a}_2$) and two strong control fields (described by their Rabi frequencies Ω_1 and Ω_2) exhibits EIT for the following superposition $\hat{b}$ of the signal fields:

$$\hat{b} \propto \frac{\Omega_1}{g_1}\hat{a}_1 + \frac{\Omega_2}{g_2}\hat{a}_2, \tag{1}$$

where g_i is the vacuum Rabi frequency for the ith signal mode.

The protocol functions as follows. With only control field 1 initially present, a pulsed optical state in mode 1 is coupled into the medium. While it is propagating, control field 2 is turned on slowly, so the EIT signal mode is adiabatically converted into a superposition (1), which continues to propagate losslessly through the medium [1]. This allows the implementation of a beam splitter for the optical modes, as well as complete transfer of the quantum state of mode $\hat{a}_1$ to mode $\hat{a}_2$, with the temporal shape and intensity of the two control pulses determining the outcome of the process. This protocol resembles STIRAP but is applied to optical rather than atomic states.

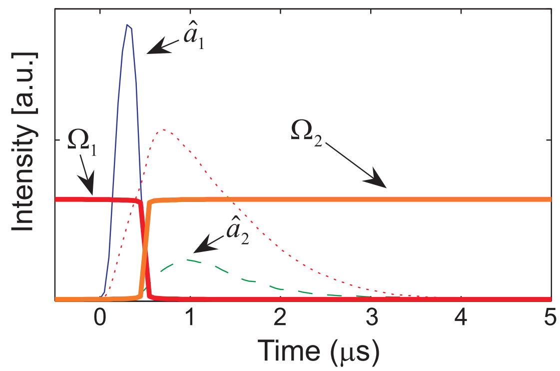

Figure 2: Implementation of RATOS. The two control pulses Ω_1 and Ω_2 are switched, respectively, off and on when the signal pulse $\hat{a}_1$ (scaled down) is inside the cell. Without switching the control fields, the signal pulse is slowed down (and partly absorbed) in the Rb cell, giving rise to the pulse shown by a dotted line. The created RATOS pulse is shown by the dashed line.

At the time of writing this abstract, the protocol has been experimentally implemented with classical fields in a ^{87}Rb vapor cell. The two control fields and the signal fields were obtained from a Ti:Sapphire laser and two diode lasers phase locked to the Ti:Sapphire. The field intensities were controlled by acousto-optical modulators. Figure 2 shows a typical experimental result.

We are now working on implementing this protocol with nonclassical optical states.

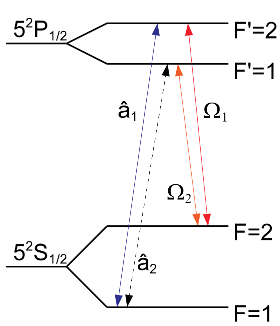

Figure 1: Energy levels of rubidium form a double-Λ scheme.

References

[1] J. Appel, K.-P. Marzlin, A. I. Lvovsky, Phys. Rev. A **73**, 013804 (2006)