Mixed electromagnetically and self-induced transparency

M. O. Scully

Department of Physics, Institute for Quantum Studies, Texas A&M University, College Station, Texas 77843-4242; Max-Plank-Institut für Quantenoptik, Garching, D-85748, Germany

G. S. Agarwal

Physical Research Laboratory, Navrangpura, Ahmedabad-380 009, India

O. Kocharovskaya

Department of Physics, Texas A&M University, College Station, Texas 77843-4242; Institute of Applied Physics, RAS, Nizhny Novgorod, 603 600, Russia

V. V. Kozlov

Department of Quantum Physics, University of Ulm, Ulm D-89081, Germany

A. B. Matsko

Department of Physics, Texas A&M University, College Station, Texas 77843-4242

mats@atlatic.tamu.edu

Abstract: We show that application of self-induced transparency (SIT) solitons as a driving field in V-type electromagnetically induced transparency (EIT) leads to “mixed induced transparency” (MIT) that nicely combines the best features of both SIT and EIT.

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References and links

1 Introduction

Among the most important milestones concerning propagation of coherent optical pulses through multilevel absorbers are self-induced transparency in two-level systems by McCall and Hahn [1, 2], simultons by Konopnicki and Eberly [3], counterintuitive pulse sequences by Oreg, Hioe and Eberly [4, 5], matched pulses via electromagnetically induced transparency (EIT) by Harris [6, 7], and the dressed-state pulses by Eberly, Pons, and Haq [8]. The phenomena of matched and dressed-state pulses are linked to electromagnetically induced transparency (EIT), which is particularly interesting because it offers a wide variety of applications ranging from lasers without population inversion (for the earliest papers on EIT/LWI see [9, 10, 11, 12, 13], for reviews on EIT/LWI see [14, 15, 16, 17, 18, 19]) to new trends in nonlinear optics [20, 21, 22, 23, 24, 25].

The EIT of a weak probe pulse relies on a two-photon coherence which is induced by the joint action of the probe field and a strong driving field in a three-level system. In order to make an optically thick medium transparent, the driving field must preserve its intensity all along the path. This condition appears rather demanding, especially for \( V \)-type systems, because the driving field couples fully populated state and empty excited state of the system. This is the main drawback of \( V \) EIT. The strong drive field provides the transparency for the probe field, but itself remains subject to resonant absorption and dispersion. In order to fix this we appeal to SIT [1, 2, 26, 27, 28, 29, 30] and apply the effect to achieve transparency for the driving transition in \( V \) EIT experiments. Then, both transitions appear to be transparent, one — in the sense of SIT, the other — in the sense of EIT. Such “mixed-induced transparency” (MIT) constitutes the subject of our study.

Previous related studies are associated with lossless propagation of simultons in three-level systems [3, 31, 32, 33] and \( N \)-type systems [34], Raman amplification of ultrashort pulses [35] in \( V \) configuration, theoretical and experimental studies on transparency enhancement for an ultrashort weak-pulse propagation in an inhomogeneously-broadened \( V \)-type medium [36, 37], and propagation of ultrashort pulses in phaseonium [38].

Equivalent durations of involved pulses is common feature of the above studies. In contrast, our interest here will be in suppression of absorption for both weak and long probe pulse when a sequence of short \( 2\pi \)-pulses drives the adjacent transition of the \( V \)-type atom, as shown in Fig. 1. We will demonstrate that the application of a sequence of \( 2\pi \)-pulses as the drive field in \( V \)-type configuration results in suppression of population transfer produced by a weak long pulse, thereby creating conditions of transparency for the weak field. During propagation, the population transfer on the probe transition is continuously minimized by a coherent \( 2\pi \)-pulse-induced rearrangement of energy (reshaping) inside the probe pulse.

2 Motivation

Let us consider a \( V \)-type three-level system with the ground state \( |b\rangle \) and excited states \( |a\rangle \) and \( |c\rangle \), as shown in Fig. 1. Transition \( |b\rangle \leftrightarrow |c\rangle \) of frequency \( \omega_{bc} \) is driven by a field \( E_{\Omega}(z,t) = \mathcal{E}_{\Omega}(z,t) \exp(ik_{\Omega}z - i\Omega t) \). A probe field \( E_{\alpha}(z,t) = \mathcal{E}_{\alpha}(z,t) \exp(ik_{\alpha}z - i\nu_{\alpha}t) \) is applied to the transition \( |b\rangle \leftrightarrow |a\rangle \) of frequency \( \omega_{ab} \). Here \( \mathcal{E}_{\Omega}(z,t) \) and \( \mathcal{E}_{\alpha}(z,t) \) are the slowly varying envelopes of the electric field. They are related to the Rabi frequencies \( \Omega \) and \( \alpha \) according to \( \mathcal{E}_{\Omega} = h\Omega/\varphi_{cb} \) and \( \mathcal{E}_{\alpha} = h\alpha/\varphi_{ab} \), where \( \varphi_{cb} \) and \( \varphi_{ab} \) are dipole matrix elements of the transitions \( |c\rangle \leftrightarrow |b\rangle \) and \( |a\rangle \leftrightarrow |b\rangle \). The carrier waves have wave numbers \( k_{\Omega} \) and \( k_{\alpha} \), and frequencies \( \nu_{\Omega} \) and \( \nu_{\alpha} \).

We start from a simple example which discloses advantages arising from the combination of SIT with EIT: a single atom of \( V \)-type with a weak long probe pulse applied