

## Time-resolved laser saturation spectroscopy. Theory of the free induction decay of two-level saturation resonances\*

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**Abstract.** We give the theory of the free induction decay of two-level saturation resonances in the time-resolved laser saturation spectroscopy. The saturating and probe fields may be either co- or counter-propagating. The change-signal line-shape is analysed in detail in two cases of practical importance, namely when the saturating field is either strong or weak. The time evolution of the change-signal exhibits many interesting features which include Ramsey-type fringes, oscillatory decay, narrow resonances, line-narrowing etc. It is shown that by analysing the decay of the change-signal in time one can distinguish (i) various laser interaction processes such as population effects, coherence effects, three-photon Raman-type process, dynamic Stark splitting, power-broadening etc., and (ii) various relaxation mechanisms such as phase-changing collisions, etc.

**Keywords.** Laser saturation spectroscopy; time-resolved spectroscopy; two-level systems; free induction decay; counter-propagating fields; co-propagating fields; population effects; coherence effects; three-photon process; Stark splitting; power broadening; atom-field interaction; oscillatory decay; narrow resonances; line-narrowing.

### 1. Introduction

Laser saturation spectroscopy is one of the many new branches of science and technology opened by the invention of laser. (For a general review of laser saturation spectroscopy and its applications, see Letokhov 1976). The steady-state line-widths measured by the techniques of laser saturation spectroscopy are the sum of the contributions due to various physical processes and relaxation mechanisms. To separate out these processes and mechanisms, one must observe the decay of steady-state line-shapes in time using the methods of coherent transients (namely optical nutation, free induction decay and photon echo). This is done in time-resolved laser saturation spectroscopy (TRLSS) which combines the techniques of saturation spectroscopy and coherent transients (Ducloy and Feld 1977). The techniques of TRLSS allow one to study (i) various physical processes contributing to the interaction of the laser field and the atomic (or molecular) system (e.g. population effects, Raman-type processes, dynamic Stark splitting, etc.), (ii) various relaxation mechanisms of the system (e.g. level lifetimes, phase-changing collisions, velocity-changing collisions, etc.) (Ducloy 1979).

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