ABSORPTIVE AND DISPERSIVE BISTABILITY FOR A DOPPLER-BROADENED MEDIUM IN A FABRY-PEROT: STEADY-STATE DESCRIPTION*

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Abstract: We present a steady-state theory for absorptive and dispersive bistability using a Doppler-broadened two-level medium in a Fabry-Perot. Details in the saturating Doppler line reflect the mode structure of the standing-wave cavity. However the qualitative effects of Doppler-broadening on transmission characteristics are understood in general terms which apply also to non-Doppler inhomogeneous broadening in a Fabry-Perot and inhomogeneous broadening in a ring cavity. The approximate treatment of Doppler-broadening using a truncated Bloch hierarchy is compared with our theory which treats the Bloch hierarchy to all orders.

I. INTRODUCTION

The first proposals for optical bistability exploited the absorptive nonlinearity in a saturable medium. Optical bistability is now recognised as a more general phenomenon which may be engineered around a variety of optical nonlinearities. Following the experimental realization of dispersive bistability by Gibbs et al this *Work supported in part by a grant from the Robert A. Welch foundation.
diversification has proceeded apace. With the potential for device applications as a primary stimulus numerous schemes have now been proposed\textsuperscript{7-16}. This paper is concerned with both absorptive and dispersive bistability in a saturable two-level medium. More particularly, we consider a Doppler-broadened medium set within a Fabry-Perot.

McCall\textsuperscript{5} gave the first detailed analysis of absorptive bistability using a homogeneously broadened two-level medium in a Fabry-Perot. In conjunction with the experiments of Gibbs et al\textsuperscript{6} this description was subsequently extended to include dispersive effects. Much theoretical work has been conducted since using this saturable two-level model. In its simplest formulation\textsuperscript{17-21} a cubic state equation characterises bistable steady states. Bonifacio and Lugiato\textsuperscript{17} initiated interest in this simplified approach with their discussion of the fluorescent spectrum for absorptive bistability. It has now been employed extensively for theoretical studies of quantum-statistical\textsuperscript{22-26}, stochastic\textsuperscript{27-30}, and transient\textsuperscript{31-34} features in optical bistability. Cubic state equations arise with the spatial averaging of cavity fields, and at appropriate levels of approximation, essentially equivalent\textsuperscript{35} models may be built around either a ring cavity\textsuperscript{8,19,21} or a Fabry-Perot\textsuperscript{17,20}. However, more correctly, the standing-wave mode structure in a Fabry-Perot distinguishes these geometries. If a uniform assumption of weak absorption and high cavity Q (mean-field approximation, MFA) is applied to both, only the ring-cavity model yields a cubic state equation\textsuperscript{36-42}. For a dispersive bistability well below saturation (Kerr medium limit) the cubic form is of course regained in a Fabry-Perot after expansion of the nonlinear susceptibility to first order.

The mode structure in a Fabry-Perot also carries direct consequences for the treatment of Doppler-broadening; the subject of special interest in this paper. In a ring-cavity model Doppler and non-Doppler inhomogeneous broadening are included in a single formulation. The nonlinear susceptibility is now defined by integrating contributions over a distributed atomic detuning. Both gaussian\textsuperscript{19} and lorentzian\textsuperscript{18,43} distributions have been discussed in the recent literature. Non-Doppler inhomogeneous broadening in a Fabry-Perot follows a similar prescription\textsuperscript{38}. However a Doppler-broadened medium meets with added complexity due to atomic motion through the standing-wave field. Each atom sees frequency shifts associated with both forward and backward waves. In the linear regime this merely gives rise to two tuned populations contributing forward and backward polarizations respectively. However, nonlinearities couple the counter-propagating fields. At this level features are introduced which have no counterpart in a ring cavity. Treatments have been given by Stenholm and Lamb\textsuperscript{44} and Feldman and Feld\textsuperscript{45} in theories of the high intensity gas laser. Lax\textsuperscript{46} also discusses this problem in the context of laser theory. His analysis includes nonlinearities