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Quantum trajectory simulations of the fluorescence intensity from a two-level atom driven by a multichromatic field

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The quantum trajectories method is illustrated for the resonance fluorescence of a two-level atom driven by a multichromatic field. We discuss the method for the time evolution of the fluorescence intensity in the presence of bichromatic and trichromatic driving fields. We consider the special case wherein one multichromatic field component is strong and resonant with the atomic transition whereas the other components are much weaker and arbitrarily detuned from the atomic resonance. We find that the phase-dependent modulations of the Rabi oscillations, recently observed experimentally [Q. Wu, D. J. Gauthier, and T. W. Mossberg, Phys. Rev. A **49**, R1519 (1994)] for the special case when the weaker component of a bichromatic driving field is detuned from the atomic resonance by the strong-field Rabi frequency, appear also for detunings close to the subharmonics of the Rabi frequency. Furthermore, we show that for the atom initially prepared in one of the dressed states of the strong field component the modulations are not sensitive to the phase. We extend the calculations to the case of a trichromatic driving field and find that apart from the modulations of the amplitude there is a modulation of the frequency of the Rabi oscillations. Moreover, the time evolution of the fluorescence intensity depends on the phase regardless of the initial conditions and a phase-dependent suppression of the Rabi oscillations can be observed when the sideband fields are tuned to the subharmonics of the strong-field Rabi frequency. [S1050-2947(98)03501-X]

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I. INTRODUCTION

The traditional method of treating dissipative coupling between a quantum (source) system and a large reservoir employs a master equation for the system reduced density operator [1]. This describes the evolution of the density operator, having traced out the states of the reservoir and usually treating the system-reservoir coupling in the Born-Markov approximation.

Recently, new theoretical methods have been developed to describe the evolution of single quantum systems, including simulation methods of quantum trajectories [2], Monte Carlo wave functions [3], waiting time distributions [4], and quantum stochastic equations [5]. One of the methods, that has received the greatest deal of attention is the quantum trajectories method [2], which simulates the evolution of the trajectories in Hilbert space conditioned on continuous photodetection with two distinct elements. The first is a smooth evolution under the influence of a non-Hermitian Hamiltonian; the second element consists of a stochastic influence that randomly interrupts the non-Hermitian evolution by projections or quantum jumps. Carmichael has applied the method, which he described as an ''unravelling'' of the master equation, to a number of systems in quantum optics [2], including the driven Jaynes-Cummings model [6]. Wiseman and Milburn [7] have applied the method to the theory of field-quadrature measurements. Zheng and Savage [8] have analyzed the method for the specific case of optical second-harmonic generation, and Chough [9] has investigated the interference of Fock-state photons in the framework of quantum trajectory theory.

In this paper we investigate the fluorescence intensity of a two-level atom driven by a multichromatic field. We especially explore multichromatic field effects in the transient and stationary fluorescence intensity. Various aspects of the atomic response to the bichromatic excitation have been studied using standard Bloch equation approaches. For example, it has been shown that the fluorescence spectrum differs qualitatively from the characteristic triplet spectrum of an atom driven by a monochromatic field [10]. The spectrum consists of a number of sidebands whose positions depend on the frequency difference between the two driving fields [11]. The atomic inversion exhibits resonant behavior when the frequency difference is approximately equal to the Rabi frequency of the driving fields or any subharmonic of the Rabi frequency [12]. Work has also been done relating to a transient bichromatic excitation and it has been predicted that the bichromatically driven atoms exhibit a dynamical behavior that is strongly dependent on the initial relative phase of the driving-field components [13]. Wu, Gauthier, and Mossberg [14] have explored, both theoretically and experimentally, the special case wherein one bichromatic field component is resonant with the atomic transition and the other, much weaker component, is detuned from the atomic resonance by the Rabi frequency of the stronger component. They have demonstrated phase-dependent dynamics, for example, a phase-dependent slow modulation of the Rabi oscillations of the fluorescence intensity and a complete polarization of the atom–resonant-field dressed states [15]. The observed modulation represents a response characteristic to a bichromatic excitation.

The purpose of the present paper is to illustrate the quantum trajectories method for the transient and stationary ef-

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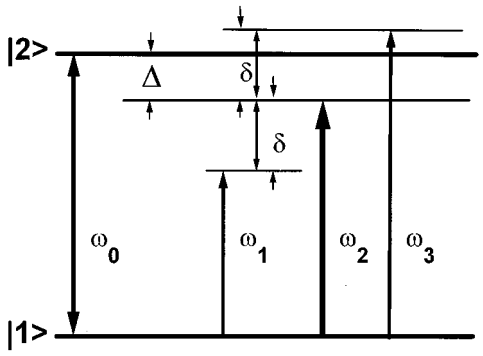

FIG. 1. Schematic diagram of a two-level atom driven by three fields of different amplitudes and frequencies.

fects in the fluorescence intensity of a driven two-level atom. In particular, we discuss the transient fluorescence intensity for bichromatic and trichromatic driving fields when one, a strong, component is resonant to the atomic transition frequency and the other component(s) is (are) arbitrarily detuned from the atomic resonance. We find that for some detunings of the weaker components the transient response of the atom shows a slow modulation superimposed on the Rabi oscillations induced by the strong field. We notice that the modulation appears for the detunings close to the subharmonics of the Rabi frequency Ω of the strong field. A small shift of the frequencies from the subharmonic resonances Ω/n is found to be proportional to $\Omega_1^2/4\delta$, where Ω_1 is the Rabi frequency of the weak components. The shift is more apparent for $n>1$ and can be identified as the generalized Bloch-Siegert shift [16]. We also find that the time modulations of the fluorescence intensity are strongly dependent on the initial state of the atom. When the atom is initially in one of the dressed states of the strong field and is driven by a bichromatic field, the time evolution of the fluorescence intensity is independent of the phase. For a trichromatic driving field the fluorescence intensity depends on the phase independent of the initial conditions and for some phases the intensity evolves in time without the Rabi oscillations.

The paper is organized as follows: In Sec. II the master equation of a two-level atom driven by a multichromatic field is presented and a method of calculating the time evolution of the fluorescence intensity is described. In Sec. III the method of quantum trajectories is applied to the system of a two-level atom driven by a multichromatic field. In Sec. IV our numerical results are given and interpreted.

II. DENSITY-MATRIX APPROACH

We consider a two-level atom with ground state $|1\rangle$, and excited state $|2\rangle$ connected by the transition dipole moment μ and separated by the transition frequency ω_0. The atom is driven by a multichromatic field (Fig. 1) with three frequency components ω_1, ω_2, and ω_3 such that $\omega_3-\omega_2=\omega_2-\omega_1=\delta$, and with the central component ω_2 detuned from the atomic resonance by $\Delta=\omega_0-\omega_2$. The atom is also coupled to all other modes of the electromagnetic field, which are assumed to be initially in their vacuum state. This coupling leads to spontaneous emission (dissipation) with a rate given by the Einstein A coefficient.

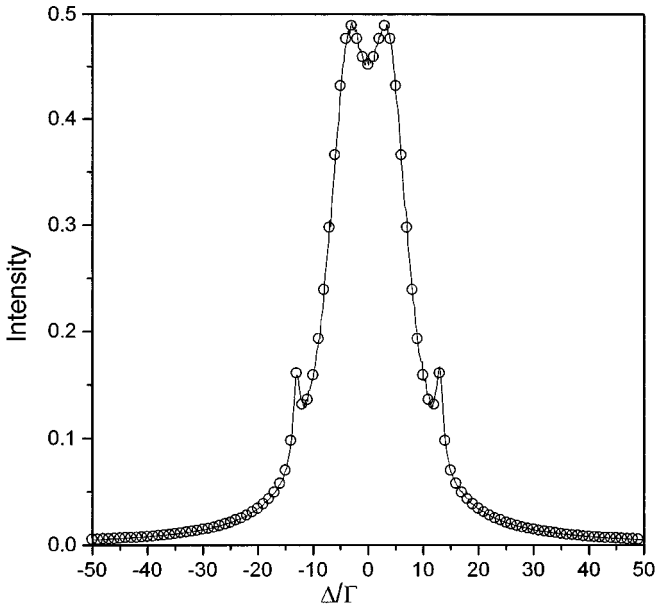

FIG. 2. The stationary fluorescence intensity as a function of the detuning Δ for a bichromatic driving field with $\alpha_1=1$, $\delta=5\Gamma$, and $\Omega=5\Gamma$. The circles present the Bloch equations results and the solid line presents the quantum trajectories results.

The time evolution of the atomic system can be described by the reduced density operator ρ, which in the interaction picture obeys the following master equation [1,11]:

$$\frac{\partial\rho}{\partial t}=-\frac{i}{\hbar}[H,\rho]-\frac{1}{2}\Gamma(S^+S^-\rho+\rho S^+S^--2S^-\rho S^+), \tag{1}$$

where S^+ and S^- are the usual raising and lowering atomic operators, which together with the inversion operator S^z satisfy the well-known commutation relations

$$[S^+,S^-]=2S^z, \quad [S^z,S^\pm]=\pm S^\pm. \tag{2}$$

In Eq. (1), Γ is the spontaneous emission rate and the Hamiltonian H is given by

$$H=\hbar\Delta S^z+\{\hbar\Omega[1+\alpha_1 e^{i(\delta t+\phi)}+\alpha_3 e^{i(-\delta t+\phi)}]S^++\text{H.c.}\}, \tag{3}$$

where Ω is the Rabi frequency of the central component of the trichromatic field, $\alpha_1=\Omega_1/\Omega$, $\alpha_3=\Omega_3/\Omega$ with Ω_1 and Ω_3 the Rabi frequencies of the detuned components of the trichromatic field, and ϕ is the relative phase between the central component and the sideband fields. The master equation (1) with the Hamiltonian (3) leads to three equations of motion for the expectation values of the atomic operators (optical Bloch equations), which can be written as

$$\begin{aligned}
\langle\dot{S}^-(t)\rangle&=-(\tfrac{1}{2}\Gamma+i\Delta)\langle S^-(t)\rangle+\Omega\omega(t)\langle S^z(t)\rangle,\\
\langle\dot{S}^+(t)\rangle&=-(\tfrac{1}{2}\Gamma-i\Delta)\langle S^+(t)\rangle+\Omega\omega^*(t)\langle S^z(t)\rangle,\\
\langle\dot{S}^z(t)\rangle&=-\tfrac{1}{2}\Gamma-\Gamma\langle S^z(t)\rangle-\tfrac{1}{2}\Omega\omega(t)\langle S^-(t)\rangle-\tfrac{1}{2}\Omega\omega^*(t)\\
&\quad\times\langle S^+(t)\rangle,
\end{aligned} \tag{4}$$

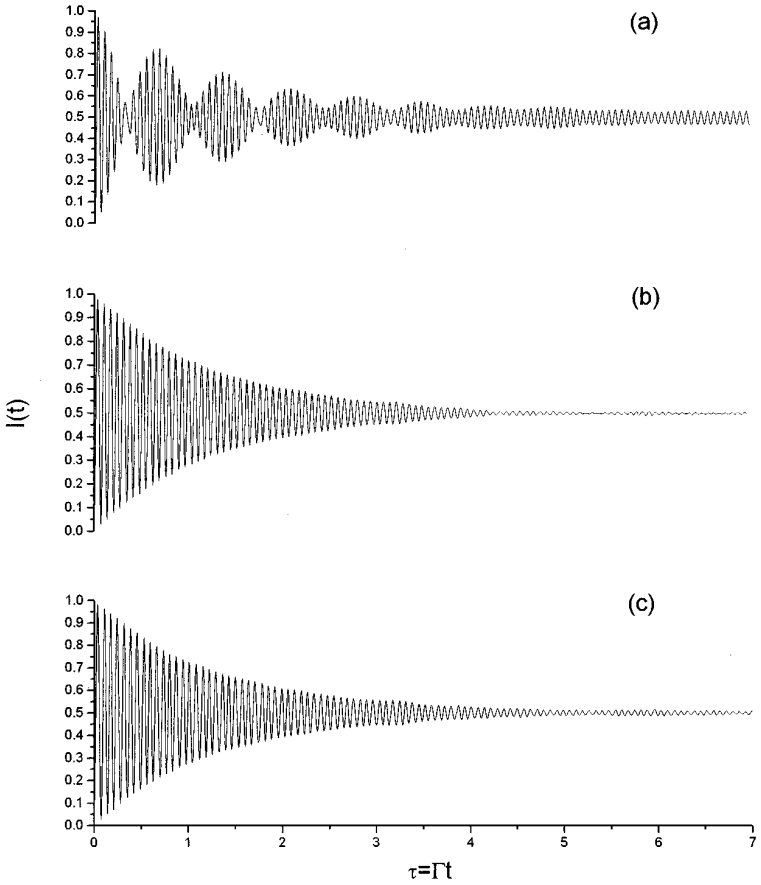

FIG. 3. Fluorescence intensity as a function of time for a bichromatic driving field with $\Delta=0$, $\Omega=90\Gamma$, $\phi=\pi/2$, $\alpha_1=0.1$, $\delta=\Omega/n$ and different n: (a) $n=1$, (b) $n=2$, (c) $n=3$. The atom was initially in its ground state.

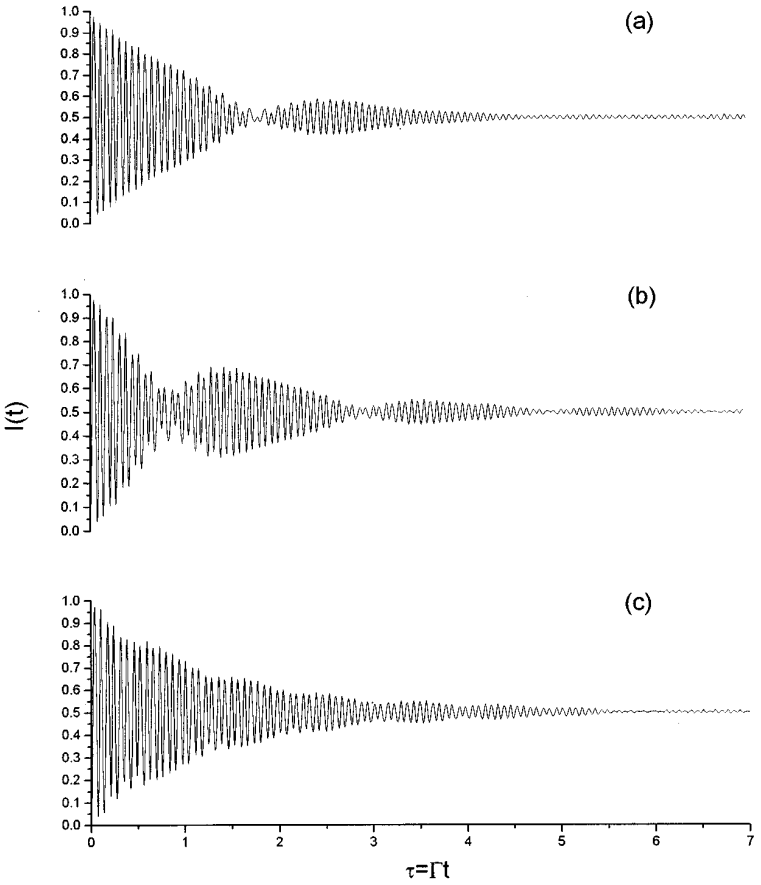

FIG. 4. Fluorescence intensity as a function of time for a bichromatic driving field with $\Delta=0$, $\Omega=90\Gamma$, $\phi=\pi/2$, $\alpha_1=0.2$, and different δ: (a) $\delta=45\Gamma$, (b) $\delta=46.8\Gamma$, (c) $\delta=49\Gamma$. The atom was initially in its ground state.

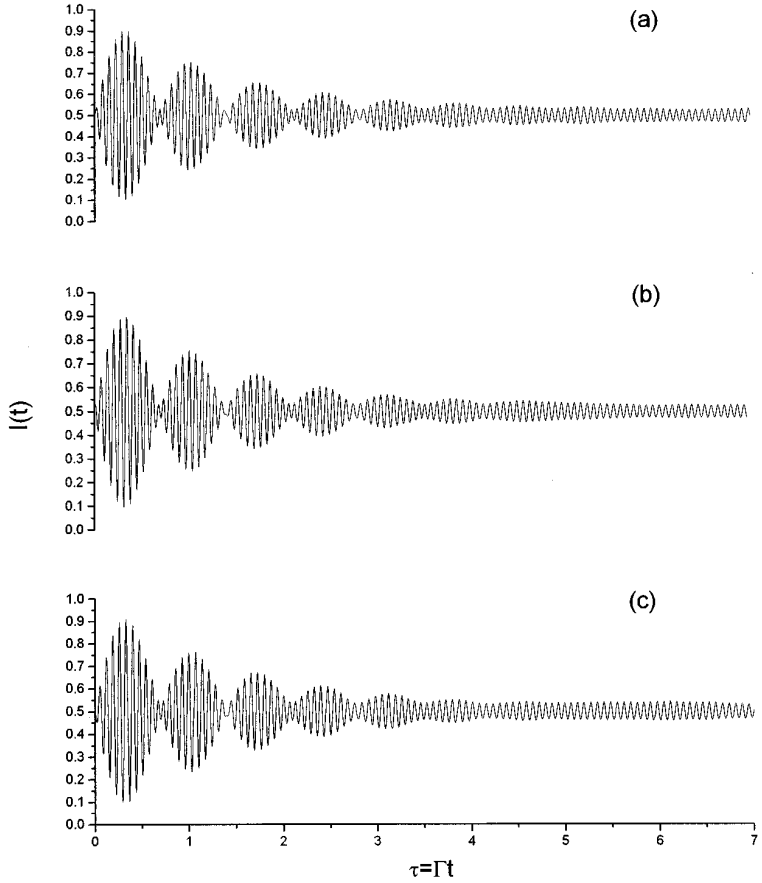

FIG. 5. The same as in Fig. 4, but the atom was initially in a superposition state with $C_1(0) = 1/\sqrt{2}$ and $C_2(0) = i/\sqrt{2}$.

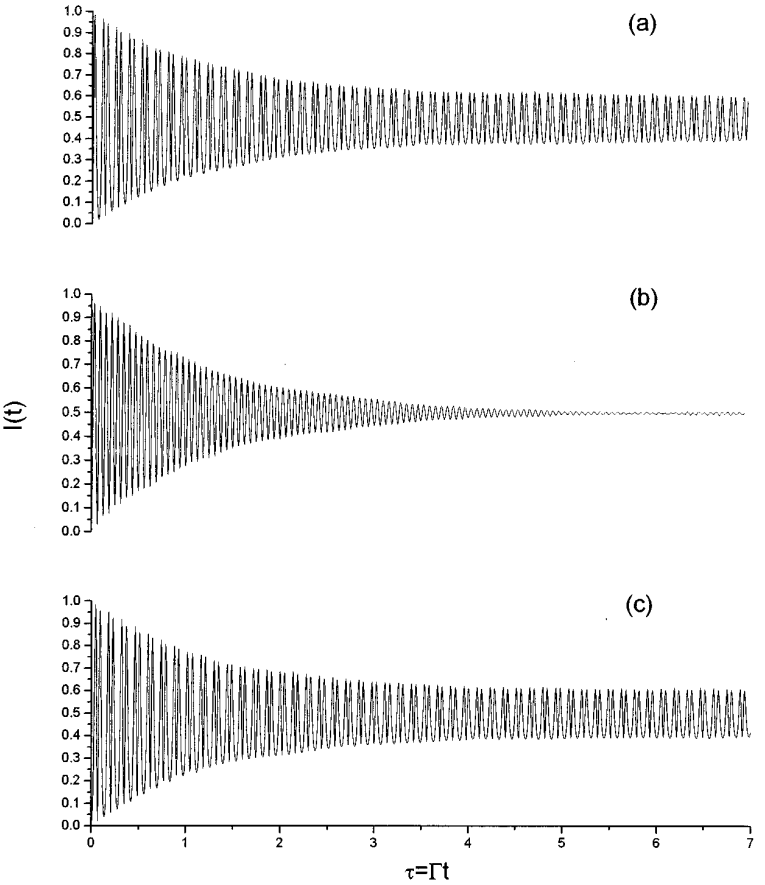

FIG. 6. Fluorescence intensity as a function of time for a trichromatic driving field with $\Delta = 0$, $\Omega = 90\Gamma$, $\alpha_1 = \alpha_3 = 0.3$, $\delta = \Omega/2$, and different ϕ: (a) $\phi = 0$, (b) $\phi = \pi/2$, (c) $\phi = \pi$. The atom was initially in its ground state.

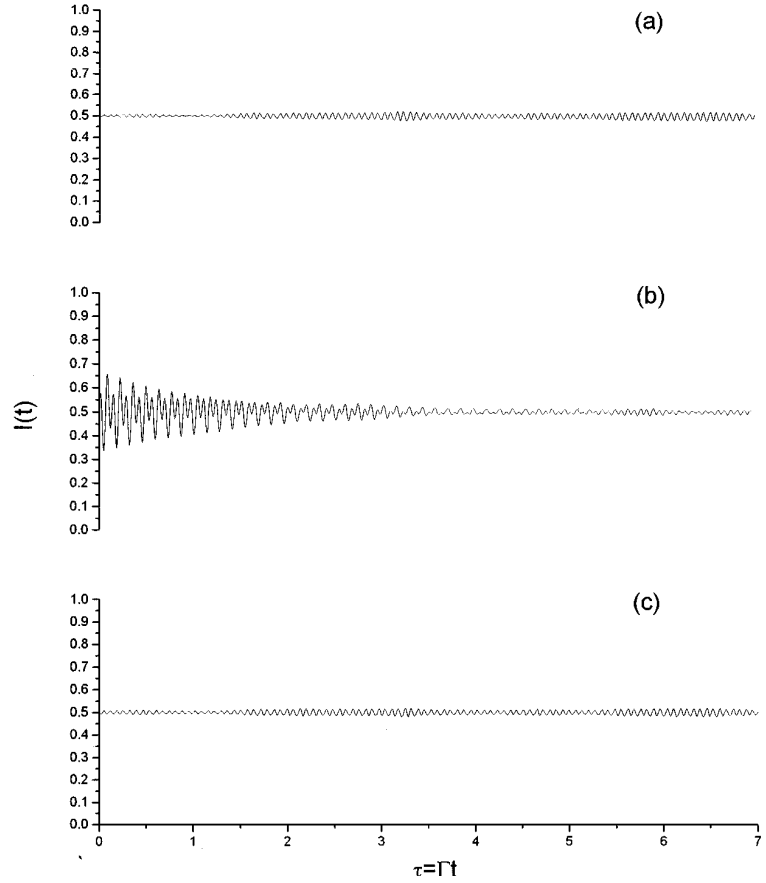

FIG. 7. Fluorescence intensity as a function of time for a trichromatic driving field with $\Delta=0$, $\Omega=90\Gamma$, $\alpha_1=\alpha_3=0.1$, $\delta=\Omega/2$, and different ϕ: (a) $\phi=0$, (b) $\phi=\pi/2$, (c) $\phi=\pi$. The atom was initially in a superposition state with $C_1(0)=1/\sqrt{2}$ and $C_2(0)=i/\sqrt{2}$.

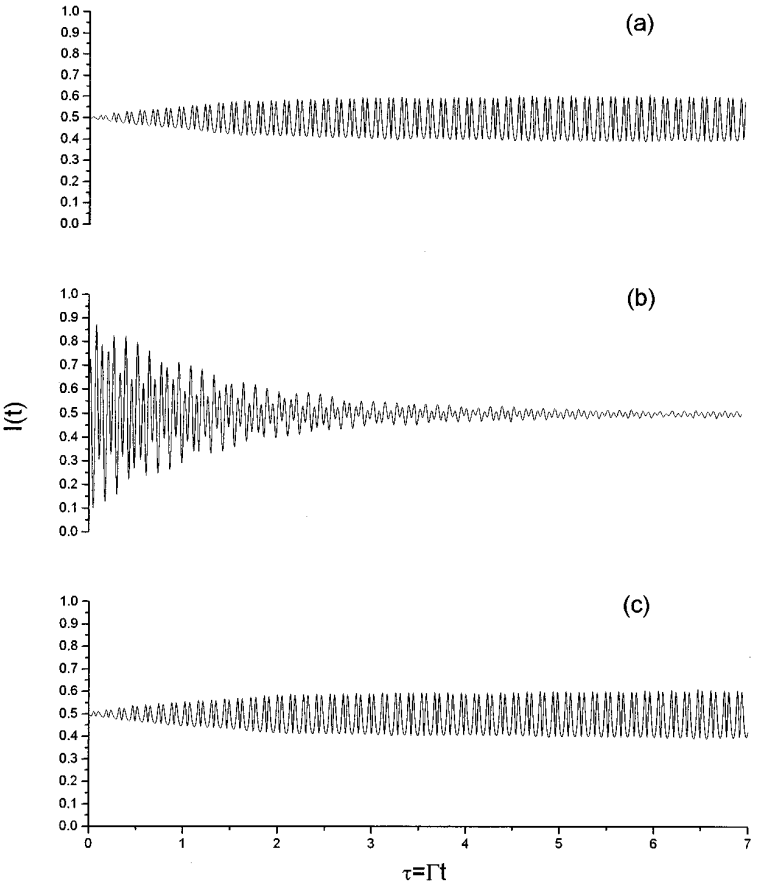

FIG. 8. The same as in Fig. 7, but larger $\alpha=0.3$.

where $\omega(t)=1+\alpha_1 e^{i(\delta t+\phi)}+\alpha_3 e^{i(-\delta t+\phi)}$.

In order to solve the system of equations (4), we decompose the expectation values of the atomic operators into amplitudes that oscillate at frequency δ and its harmonics. This decomposition is given by

$$X_i(t)=\sum_{\ell=-\infty}^{+\infty} X_i^{\ell}(t)e^{(i\ell\delta t)}, \quad i=1,2,3, \tag{5}$$

where $X_i(t)$ are the components of the vector $\vec{X}(t)=[\langle S^-(t)\rangle,\langle S^+(t)\rangle,\langle S^z(t)\rangle]$. Substituting Eq. (5) into Eq. (4), we obtain a set of equations of motion for the slowly varying amplitudes $X_i^{\ell}(t)$, which can be solved, for example, by the continuous fraction method. For general and detailed developments of this method the reader is referred to Refs. [11,16].

Here, we are interested in the time evolution of the fluorescent intensity that, in photons per second, is defined as [17,18]

$$I(t)=\Gamma\langle S^+(t)S^-(t)\rangle. \tag{6}$$

In terms of the slowly varying amplitudes $X_i^{\ell}(t)$ the intensity can be written as

$$I(t)=\Gamma\left[\frac{1}{2}+\sum_{\ell} X_3^{\ell}(t)e^{i\ell\delta t}\right]. \tag{7}$$

In Sec. IV, we will discuss the fluorescence intensity for three cases: (1) The steady-state intensity for a bichromatic driving field with $\alpha_1=1$ and $\alpha_3=0$, (2) the transient fluorescence intensity for a bichromatic driving field with $\alpha_1<1$ and $\alpha_3=0$, and (3) the transient fluorescence intensity for a trichromatic driving field with $\alpha_1=\alpha_3<1$.

III. QUANTUM TRAJECTORIES METHOD

In this section we describe the method of quantum trajectories for the specific case of a two-level atom driven by a multichromatic field. The quantum trajectories approach is built around the standard theory of photoelectric detection and the master equation theory of a photoemissive source. Here, a stochastic wave function describes the time-dependent state of the quantum-mechanical source conditioned on a history of classical stochastic signals that appear at detectors monitoring the source system. The stochastic wave-function evolution generates the measurement record, the numbers that appear in the laboratory. The parallel evolution of the stochastic wave function and accompanying measurement record is called a quantum trajectory. Such a single trajectory gives a picture of what is going on in the source in a visible form. The master equation approach does not allow this concrete visualization. Further, the connection between the conditional wave function and the master equation is that an ensemble average taken with respect to the conditioned wave function reproduces the results of a master equation calculation. Although the quantum trajectories method solves fewer equations, this advantage comes at the expense of taking an average over an ensemble of trajectories. In many cases, particularly in this paper, the average over a relatively small ensemble of trajectories is needed, which leads to a less computing time. The results here are based on ensembles of 10 000 trajectories.

Quantum trajectories are generated numerically by representing the wave function in the atomic states basis

$$|\psi\rangle=C_1(t)|1\rangle+C_2(t)|2\rangle, \tag{8}$$

where $C_1(t)$ and $C_2(t)$ are c numbers. The coefficients $C_1(t)$ and $C_2(t)$ are found from a Schrödinger equation with a non-Hermitian Hamiltonian and it is easy to show that they satisfy a system of two coupled first-order differential equations

$$\begin{aligned}\dot{C}_1(t)&=\tfrac{1}{2}i\Delta C_1(t)-\tfrac{1}{2}\Omega\omega(t)C_2(t),\\ \dot{C}_2(t)&=-\tfrac{1}{2}(\Gamma+i\Delta)C_2(t)+\tfrac{1}{2}\Omega\omega^*(t)C_1(t).\end{aligned} \tag{9}$$

The quantum trajectories method requires the integration of Eq. (9) to be repeated many times before an average is obtained to describe an ensemble of dissipative systems. The procedure involves discretizing time into finite steps Δt and at every step deciding whether or not a collapse (quantum jump) occurs. The collapses and normalization are straightforwardly implemented into this procedure, and the fluorescence intensity is calculated from

$$I(t)=\frac{1}{2}\,\Gamma\left[1+\frac{|C_2(t)|^2-|C_1(t)|^2}{|C_1(t)|^2+|C_2(t)|^2}\right]. \tag{10}$$

IV. RESULTS

In this section we discuss the time evolution of the fluorescence intensity calculated numerically using the quantum trajectories method. In order to ensure that the method is correct, we first consider two special cases, in which we compare the quantum trajectories results with that obtained from the Bloch equations. In the first case, we consider the steady-state fluorescence intensity as a function of Δ for a bichromatically driven atom, i.e., for $\alpha_3=0$. In Fig. 2, we show the steady-state fluorescence intensity as a function of Δ for $\delta=5\Gamma$, $\alpha_1=1$, and $\Omega=5\Gamma$. The solid line represents the quantum trajectories method results, whereas the circles represent the results obtained from the Bloch equations (4). In obtaining the quantum trajectories results, the average of 10 000 trajectories has been taken. It is seen that the quantum trajectories and the Bloch equations results converge accurately.

In the second case, we consider the transient fluorescence intensity for a bichromatically driven atom with one of the field components resonant to the atomic resonance and the other, much weaker, detuned from the atomic resonance by the Rabi frequency of the resonant component. This corresponds to the case used by Wu *et al.* [14] in their experiment to observe the time evolution of the fluorescence intensity and its dependence on the relative phase of the two driving fields. We find that for certain values of the phase ϕ ($\phi=\pi/2$) [19], the fluorescence intensity exhibits a slow modulation superimposed on the fast oscillations. This modulation represents a response characteristic to the bichromatic excitation and results from the splitting of the dressed states by the weaker field [11].

For certain detunings of the weaker component from the

strong component, it is possible to excite multiphoton dressed-state transitions. Therefore, we consider the time evolution of the fluorescence intensity for a bichromatic field, in which the weaker component is coupled to the subharmonics of the Rabi frequency of the strong component. Moreover, we calculate the time evolution of the fluorescence intensity for a trichromatically driven atom. In Fig. 3, we plot the fluorescence intensity for $\Omega=90\Gamma$, $\phi=\pi/2$, $\Delta=0$, $\delta=\Omega/n$, $\alpha_1=0.1$ and different n. The atom starts from its ground state. It is seen that the time evolution of the fluorescence intensity is strongly affected by the presence of the weaker field only when $\delta=\Omega$, i.e., for $n=1$. In this case the fluorescence intensity exhibits a slow modulation superimposed on the fast oscillations at the Rabi frequency Ω. It is interesting to note that the frequency of the modulation is equal to $\frac{1}{2}\Omega_2$. The factor $\frac{1}{2}$ results from the fact that the dipole moment between the two dressed states to which the weaker field is coupled is $\frac{1}{2}\mu$ [15]. When the weaker component is tuned to the subharmonic resonances of Ω, $n>1$, the time evolution of the fluorescence intensity is not affected by the weaker field and is similar to that characteristic of a monochromatically driven atom. However, a modulation can be seen for δ slightly detuned from the subharmonic resonances. This is shown in Fig. 4, where we plot the time evolution of the intensity for $\Delta=0$, $\phi=\pi/2$, $\Omega=90\Gamma$, $\alpha_1=0.2$, and different δ, but close to the first subharmonic resonance ($n=2$). It is evident from Fig. 4 that the weaker field affects the time evolution of the intensity for δ different from the subharmonic resonance $\delta=\Omega/2$. This indicates the presence of a shift of the subharmonic resonance. The same applies for the higher subharmonic resonances at $n>2$. We find that the shift of the frequencies from the subharmonic resonances is equal to $n\Omega_1^2/4\delta$, which is recognized as the generalized Bloch-Siegert shift [16]. Therefore, an experimental observation of the modulations of the time evolution of the fluorescence intensity for detunings shifted from the subharmonic resonances would provide evidence for the presence of the generalized Bloch-Siegert shift in the interaction of a two-level system with the bichromatic field.

The modulation of the time evolution of the fluorescence intensity for $n=2$ results from a two-photon coupling between the dressed states of the strongly driven atom and the weaker component of the bichromatic field. This coupling can lead to a two-photon ac Stark effect [20]. Indeed, we find from Fig. 4(b) that the frequency of the modulation is equal to $\frac{1}{6}\sqrt{13\alpha^2}\Omega$, which is recognized as the Rabi frequency associated with the two-photon resonance [20]. The multiphoton ac Stark effect in the interaction between a two-level system and the bichromatic field has recently been observed experimentally in the Autler-Townes absorption spectrum [21]. The modulation in the fluorescence intensity seen in Fig. 4(b) would be regarded as another way of testing the multiphoton ac Stark effect.

The generality of our theory allows us to investigate many different parameter regimes. So far we have considered the regime when the interaction begins with the atom in its ground state. Other interesting features may be expected with the atom initially prepared in a superposition state. Surprisingly, for a bichromatic driving field with $\delta=\Omega$ and the atom initially prepared in one of the dressed states of the strong component, $C_1(0)=1/\sqrt{2}$ and $C_2(0)=i/\sqrt{2}$, the time evolution of the fluorescence intensity is independent of the phase ϕ. This is shown in Fig. 5, where we plot the fluorescence intensity for $\Delta=0$, $\Omega=90\Gamma$, $\alpha_1=0.1$, $\delta=\Omega$, and different ϕ. The atom was initially in a linear superposition with $C_1(0)=1/\sqrt{2}$ and $C_2(0)=i/\sqrt{2}$. It is clearly seen from Fig. 5, that for the atom initially prepared in the superposition states the time evolution of the fluorescence intensity is independent of ϕ. The same conclusion applies for the case when the weaker component is coupled to the subharmonic resonances. This feature is in contrast to the monochromatic case when the phase-dependent dynamics are observed only when the interaction begins with the atom in a superposition state [22].

Finally, we apply the quantum trajectories method to calculate the time evolution of the fluorescence intensity for a trichromatic driving field. We will limit the calculations to the case when the central, strong component, is on resonance with the atomic transition ($\Delta=0$) and the two weaker sidebands have the same amplitudes $\alpha_1=\alpha_3=\alpha$ and both are equally detuned (in opposite directions) from the central component. When one of the fields is coupled to the lower frequency whereas the other is coupled to the higher frequency Rabi sideband of the strong component, the time evolution of the intensity and its phase dependence are similar to that for the bichromatic field. The effect of the sideband fields, however, is quite different if we couple the sideband fields to the first subharmonic resonance at $\delta=\Omega/2$. This is illustrated in Fig. 6, where we plot the time evolution of the intensity for $\Omega=90\Gamma$, $\alpha_1=\alpha_3=0.3$, and $\delta=\Omega/2$. In this case there is no amplitude modulation, but depending on the phase ϕ there is a modulation of the frequency of the oscillations.

On the other hand, when the atom is initially prepared in a superposition state with $C_1(0)=1/\sqrt{2}$ and $C_2(0)=i/\sqrt{2}$, the Rabi oscillations can be significantly reduced for $\phi=0$ or $\phi=\pi$. The oscillations can even be completely suppressed. This happens when the sideband fields are coupled to the first subharmonic resonance. We show this in Fig. 7, where we plot the time evolution of the intensity for $\Omega=90\Gamma$, $\delta=\Omega/2$, and $\alpha=0.1$. It is evident from Fig. 7 that for $\phi=0$ and $\phi=\pi$ the Rabi oscillations are completely suppressed and the intensity evolves in an essentially nonoscillatory manner.

The modulation of the amplitude of the Rabi oscillations for the bichromatic driving field, seen in Figs. 3 and 4, and the modulation of the frequency of the Rabi oscillations for the trichromatic driving field, seen in Figs. 6 and 8, can be explained by analyzing the Hamiltonian (3). For a bichromatic driving field with $\Delta=0$, $\alpha_3=0$, and $\phi=\pi/2$, the Hamiltonian (3) reduces to

$$H=\hbar\Omega(1+i\alpha_1 e^{i\delta t})S^+ + \text{H.c.} \tag{11}$$

In this case the sideband field acts as a modulator of the phase of the Rabi oscillations, which results in the beating Rabi oscillations seen in Fig. 3.

For a trichromatic driving field with $\Delta=0$ and $\alpha_1=\alpha_3=\alpha$ the Hamiltonian (3) takes the form

$$H=\hbar\Omega[1+2\alpha\cos(\delta t)e^{i\phi}]S^+ + \text{H.c.} \tag{12}$$

Now, depending on the phase ϕ, the sideband fields can modulate the phase or the amplitude of the Rabi oscillations. For $\phi=0$ the sideband fields modulate the amplitude of the Rabi frequency Ω, which results in the modulation of the frequency of the Rabi oscillations seen in Fig. 6. For $\phi=\pi/2$ the sideband fields modulate the phase of the Rabi frequency resulting in the modulation of the amplitude of the Rabi oscillations seen in Fig. 8(b).

The absence of the oscillations in the time evolution of the intensity, seen in Fig. 7, can be explained in the same way as for the monochromatic excitation [22]. If the atom is initially in a superposition state with $C_1(0)=1/\sqrt{2}$ and $C_2(0)=i/\sqrt{2}$, the Bloch vector and the driving field vector are initially parallel. For $t>0$ the Bloch vector $\vec{B}$ is effectively ''locked'' to the field vector $\vec{\Omega}$ (i.e., the Bloch equation is $d\vec{B}/dt=\vec{\Omega}\times\vec{B}\approx 0$) and does not precess in time. The oscillations are absent for relatively weak sideband fields ($\alpha\ll 1$). For larger α the oscillations appear again in the fluorescence intensity. This is shown in Fig. 8, where we plot the time evolution of the fluorescence intensity for the same parameters as in Fig. 7, but larger $\alpha=0.3$. The fluorescence intensity shows the modulated oscillations for all phases ϕ. For larger α the Bloch vector starts to rotate around the field vector $\vec{\Omega}$, which leads to the reappearing of the oscillations.

V. SUMMARY

We have applied the quantum trajectories method to calculate the time evolution of the fluorescence intensity of a two-level atom driven by a multichromatic field. We have found the quantum trajectories method very effective in the calculations of the time-dependent dynamics of the fluorescence field. The results show that the time evolution of the fluorescence intensity of a two-level atom driven by a multichromatic field is quite different from that arising from the atom driven by a monochromatic field. The effect of a bichromatic field, with a strong component resonant to the atomic transition frequency and the other component much weaker and resonant to the Rabi frequency of the strong field, is to produce a slow modulation of the Rabi oscillations of the strong field [14]. We have found that the modulation is sensitive to the relative phase of the two fields when the atom is initially in its ground state. When the atom is initially in the equal superposition of its states the modulation is independent of the phase. The modulation of the Rabi oscillations appears also for the frequencies of the weaker component tuned close to the subharmonic resonances of the Rabi frequency of the strong field. This effect results from the multiphoton ac Stark effect and appears only for frequencies shifted from the subharmonic resonances by the generalized Bloch-Siegert shift.

We have also calculated the time evolution of the fluorescence intensity for a trichromatic driving field with a strong component resonant to the atomic transition frequency and two weaker sideband components symmetrically located about the frequency of the central component. In this case not only the amplitude but also the frequency of the Rabi oscillations can be modulated by the sideband components. For the atom initially prepared in the equal superposition of its states the fluorescence intensity depends on the phase and a complete suppression of the Rabi oscillations can be observed.

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