MULTI-MODE ARRAY FILTERING OF RESONANCE FLUORESCENCE

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Fluorescence and correlation filtering is a field that has long been studied [1, 2]. In this work we develop a theoretical approach to better filter fluorescence from a resonantly driven atom. We start with a simplest example by looking at a two-level atom driven on resonance coupled as a cascaded system to an array of tunable single-mode cavities, with Hamiltonian [3]:

$$H = \hbar \frac{\Omega}{2} \left(\sigma_{+} + \sigma_{-} \right) + \hbar \sum_{j=-N}^{N} \omega_{j} a_{j}^{\dagger} a_{j} + \frac{i\hbar}{2} \sqrt{\frac{\gamma\kappa}{2N+1}} \sum_{j=-N}^{N} \left(e^{-ij\pi/N} a_{j} \sigma_{+} - e^{ij\pi/N} a_{j}^{\dagger} \sigma_{-} \right), \tag{1}$$

where Ω is the driving field Rabi frequency, $\omega_j = \omega_0 + \delta\omega$ is the frequency of the j^{th} mode of the cavity with central mode frequency ω_0 and mode frequency spacing $\delta\omega$, $2N+1$ is the total number of filter modes, γ is the atomic decay rate, κ is the decay rate for each cavity mode, σ_+ (σ_-) is the atomic raising (lowering) operator, and a_j $(a_j^\dagger)$ is the photon annihilation (creation) operator for the j^{th} mode. The Lindblad master equation for this system is

$$\frac{\mathrm{d}\rho}{\mathrm{d}t} = -i[H, \rho] + \frac{1}{2} \sum_{j=-N}^{N} \left(2C_{j} \rho C_{j}^{\dagger} - C_{j}^{\dagger} C_{j} \rho - \rho C_{j}^{\dagger} C_{j} \right) + \frac{\kappa}{2} \sum_{j=-N}^{N} \left(2a_{j} \rho a_{j}^{\dagger} - a_{j}^{\dagger} a_{j} \rho - \rho a_{j}^{\dagger} a_{j} \right), \tag{2}$$

with cascaded decay operator for the j^{th} mode:

$$C_{j} = e^{ij\pi/N} \sqrt{\frac{\gamma}{2N+1}} \sigma_{-} + \sqrt{\kappa} a_{j}. \tag{3}$$

For a single cavity mode, the filtering profile is a Lorentzian, which, having long tails, possibly passes non-target frequency photons. With the proposed model, we can realise a better approximation to a bandpass filter, allowing for a much sharper frequency cut-off while still capturing all the dynamics from the target transition. We calculate filtered first- and second-order correlation functions of the centre and side peaks of the Mollow triplet, comparing them to approximate correlation functions in the dressed state picture.

References

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