Questioning the validity of the Two Level Approximation

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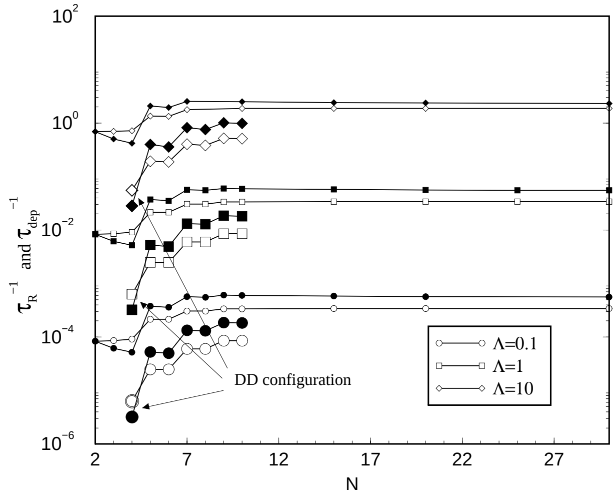
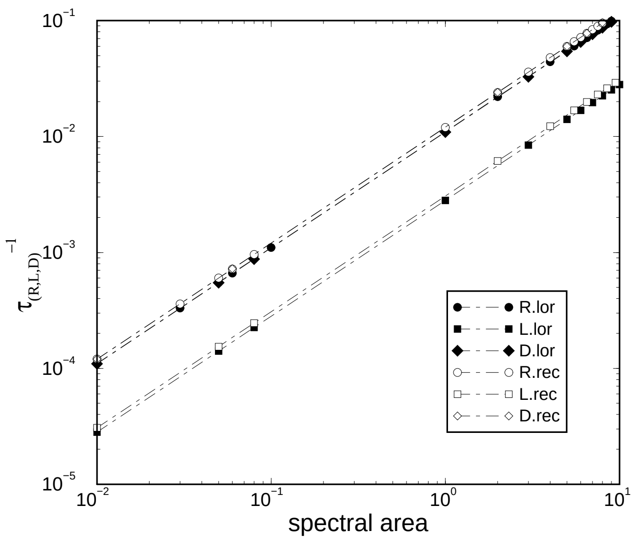
We examine the effect of multilevels on decoherence and dephasing properties of a quantum system consisting of a non-ideal two level subspace, identified as the qubit and a finite set of higher energy levels above this qubit subspace. The whole system is under interaction with an environmental bath through a Caldeira-Leggett type coupling. The model that we use is an rf-SQUID in the macroscopic quantum coherence regime and coupled inductively to a flux noise characterized by an environmental spectrum. The model interaction can generate dipole couplings between the qubit subspace and a high number of excitation levels. The decoherence properties of the qubit subspace is examined numerically using the master equation formalism of the system's reduced density matrix. We numerically examine the relaxation and dephasing times as the environmental frequency spectrum, the environmental temperature, and the multilevel system parameters are varied. We observe that, these time scales receive contribution from all available energies in the noise spectrum (even well above the system's energy scales) stressing the dominant role played by the non-resonant (virtual) transitions. The relaxation and dephasing times calculated, strongly depend on the number of active levels. Under the influence of these effects, the validity of the two level approximation is restricted not by the temperature but by the dipole couplings as well as the availability of the environmental modes at low temperatures.

To stress the importance of the non-resonant transitions, we use other model spectral profiles and study the effect of the central frequency, the width and the total spectral area on the decoherence times. We find that, due to the strong influence of the non-resonant transitions, the spectral parameters affect the decoherence times only through the dependence on the spectral area. In this regard the weight of the resonant contributions is negligible as compared to that of the entire noise spectrum.

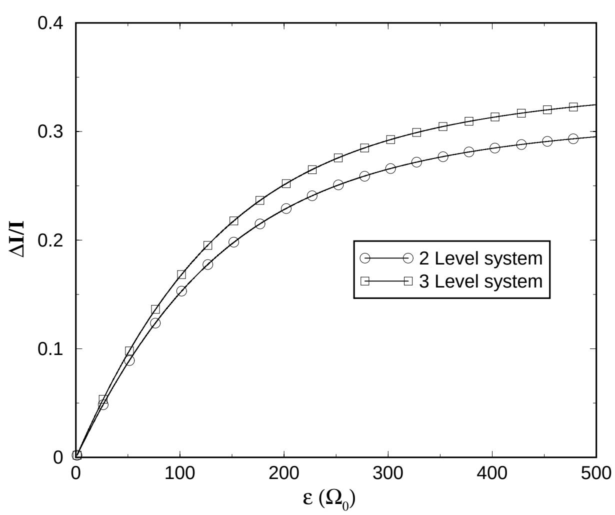
The credibility of our results depends on the accuracy of the Born approximation in the short time evolution. In this regard, it is crucial that the approximation holds in the range of the numerical data. This has been also confirmed by checking the renormalization of the noise spectrum at the RPA level.



<u>Figure 1.</u> Relaxation and dephasing rates against the number of levels for different spectral widths at T=0. The open and solid symbols refer to dephasing and relaxation times respectively.



<u>Figure 2</u>. Decoherence times for rectangular and Lorentzian spectra



<u>Figure 3.</u> Renormalization of the noise spectrum at the RPA level

References:

[1] A.O. Caldeira, A.J.Leggett, Phys.Rev. Lett. **,** 46, 211 (1981)

[2] T. Hakioğlu, K. Savran, *Decoherence and dephasing in multilevel systems interacting with thermal environment* cond-mat/0311136 (2003)