USE AND ABUSE OF QUANTUM NOISE

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In this talk I will review prominent results for quantum noise in thermal equilibrium and in stationary non-equilibrium. I start out by discussing exact treatments. Moreover, I will point out several pitfalls that show up when one attempts to model quantum noise and quantum corrections without resource to its full quantum operator nature. Various recent schemes of treating quantum noise and quantum stochastic processes are examined and critically commented on -- wherever appropriate.

Quantum noise is a salient random source in many nano-scale and biological systems. For example, the tunneling and the transfer of electrons, quasiparticles, and alike, is assisted by noise for which the quantum nature cannot be neglected. The features of this noise change drastically as a function of temperature: At sufficient high temperatures a crossover does occur to classical Johnson-Nyquist noise [1,2].

In this talk I will present various methods and schemes of modeling thermal quantum noise from first principles. In particular, the thermal noise must at all times obey the quantum version of the fluctuation-dissipation theorem (a la Callen-Welton [3]). This latter property is necessary in order to be consistent with the second law of thermodynamics and the principle of (quantum) detailed balance. We elaborate on several alternative but equivalent methods to describe quantum noise: These are the functional integral method for thermal quantum systems and as well for time-dependent driven quantum systems [5], the quantum Langevin (operator) approach [6] and a stochastic Schrödinger equation scheme [7]. Then, we point out a series of delicate pitfalls which must be obeyed when making even naive looking approximations. Such pitfalls involve the rotating wave approximation, the use of quasiclassical Langevin forces, the quantum regression hypothesis and/or the Markov approximation [8]. In particular, such approximation schemes can simulate a quantum-Maxwell-demon behavior, which, however, must consistently be ruled out by virtue of the validity of the second law in thermal equilibrium. Put differently, such anomalies should *not* be interpreted as a physical reality, but rather are the signature that something went wrong with the inherent fundamental physical symmetries by having invoked the corresponding approximation scheme *per se*.

In a second part we consider quantum noise phenomena in quantum systems far away from thermal equilibrium. An important situation is given for quantum systems that do exhibit quantum-noise-directed transport such as quantum Brownian motors [9,10], quantum pumps and quantum shuttles, as well as quantum rectifiers.

As an explicit example we discuss the current fluctuations in strongly ac-driven transport through molecular wires and quantum dots. By use of a generalized, non-Hermitian Floquet theory we derive novel explicit expressions for the time-averaged zero-frequency component of the power spectrum and the corresponding Fano factor. As a main result we find that the relative noise level of transport noise can selectively be manipulated near regions of dynamically induced current suppressions.

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References

[1] J. B. Johnson, *Thermal agitation of electricity in conductors*, Phys. Rev. **32** (1928) 97–109.
[2] H. Nyquist, *Thermal agitation of electric charge in conductors*, Phys. Rev. **32** (1928) 110–113.
[3] H. B. Callen and T. A. Welton, *Irreversibility and generalized noise*, Phys. Rev. **83** (1951) 32–40.
[4] H. Grabert, P. Schramm, G.-L. Ingold, *Quantum Brownian motion*, Physics Reports **168** (1988) 115–207; see also in the book: T. Dittrich, P. Hänggi. G.-L. Ingold, B. Kramer, G. Schön, and W. Zwerger, *Quantum* Transport *and Dissipation*, Wiley-VCH, Weinheim-Berlin-New York-Brisbane-Singapore-Toronto (1998); ISBN 3-527-29261-6.
[5] M. Grifoni and P. Hänggi, *Driven Quantum Tunneling,* Physics Reports **45** (1998) 229–358.
[6] V. B. Magalinskii, *Dynamical model in the theory of the Brownian motion*, Sov. Phys. JETP **9** (1959) 1381–1382 [J. Exptl. Theoret. Phys. (U.S.S.R.) **36** (1959) 1942–1944]; see also: G. W. Ford and M. Kac, *On the quantum Langevin equation*, J. Stat. Phys. **46** (1987) 803–810.
[7] J. T. Stockburger and H. Grabert, *Non-Markovian quantum state diffusion*, Chemical Physics **268** (2001) 249–256.
[8] P. Talkner, *The failure of the quantum regression hypothesis*, Ann. Phys. (New York) **167** (1986) 390–436.
[9] P. Reimann and P. Hänggi, *Quantum features of Brownian* Motors *and Stochastic Resonance*, Chaos **8** (1998) 629–642.
[10] R. D. Astumian and P. Hänggi, *Brownian Motors*, Physics Today **55** (11) (2002) 33–39.
[11] S. Camalet, J. Lehmann, S. Kohler and P. Hänggi, *Current noise in ac-driven nanoscsale conductors*, Phys. Rev. Lett. 90, 210602 (2003); arXiv: **cond-mat/0212247** (2002) 1–4.