Time-dependent theory of nonlinear electrical conductance

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The theory of linear response (formalized by R. Kubo in 1956) allows one to express the variations of physical observables (the "response") when a system is displaced slightly out-of-equilibrium by a "foreign perturbation". It is analogous, for physics, to the first order Taylor expansion for a mathematical function with, in addition, dynamical aspects: the system response usually lags after the perturbation that caused it. A well-known example of linear response function is the impedance of an electrical circuit, which gives the response of the current in an electrical circuit to a change in the voltage. The real part of impedance measures the dissipative response, which is fundamentally connected to voltage fluctuations in the unperturbed system by the fluctuation-dissipation theorem (FDT). This theorem is a crucial consequence of the Kubo formula and is encountered in all areas of science.
Despite its universality and its huge success, the linear response theory cannot handle many physical systems that are intrinsically nonlinear. This is the case, for instance, of nanostructures where the Coulomb repulsion between electrons plays a crucial role. Several approaches were used to address the response of such systems, but, being specific to each problem, they have a limited scope However, we have shown that there is a rigorous generalization of the Kubo formula giving the response of such physical systems to an arbitrary excitation. This generalization is valid with virtually no restrictions on the system (it may be out of equilibrium, time-dependent, interacting...) and respects conservation laws by construction. This formalism is therefore suited to address the response of nonlinear systems. In particular, for the stationary regime, it has allowed us to offer a microscopic expression for the generalized out of equilibrium finite frequency admittance $G(\upsilon,V)$, which has been investigated theoretically since then in strongly correlated systems [Safi, 2008; Zamoum, 2012; Moca, 2012; Chu, 2012]]
Consequently, and to illustrate the power of this generalization, we have established a new non equilibrium and time-dependent FDT-type relation for correlations between the currents measured at two different times in an arbitrary conductor connected to multiple terminals.

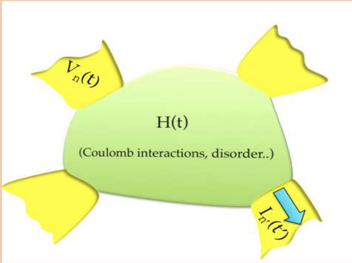

Figure: A conductor described by a Hamiltonian (potentially time-dependent) connected to several terminals connected to time-dependent voltages sources Vn(t) where n is the index of the terminal. In a manner similar to the Kubo formula, we can express the conductance $G_{nn'}(t, t')$, which gives the variation of the average electric current $I_{n'}(t')$ in a terminal n' in response to a variation of $V_n(t)$ while keeping all voltages finite. The result is a new FDT-type theorem relating the correlations between the currents measured in n and n': $\langle I_n(t)\ I_{n'}(t')\rangle$, and the conductance $G_{nn'}(t, t')$.

Time dependent theory of non-linear response and current, I. Safi, P. Joyez, Phys. Rev. B ***84****, 205129 (2011).*