Current noise in one-dimensional electron systems

Björn Trauzettel[1], Fabrizio Dolcini[1], Reinhold Egger [2], Hermann Grabert[1], and Ines Safi[3]

[1] *Physikalisches Institut, Albert-Ludwigs-Universität, 79104 Freiburg, Germany*
[2] *Institut für Theoretische Physik, Heinrich-Heine-Universität, 40225 Düsseldorf, Germany*
[3] *Laboratoire de Physique des Solides, Université Paris-Sud, 91405 Orsay, France*

tzettel@physik.uni-freiburg.de

Current noise, in particular shot noise, has found increased interest in the past view years, because the noise power spectrum of the current, defined by

$$P(\omega) = \int dt e^{i\omega t} \left\langle \{\Delta I(t), \Delta I(0)\}_+ \right\rangle \ , \tag{1}$$

can provide information that goes beyond the current-voltage characteristics alone. However, one has to distinguish between the noise of different physical situations: (i) In thermal equilibrium at finite temperature, the current noise can be directly related to the a.c. conductance of the system under consideration via the fluctuation-dissipation theorem. Therefore, in that case, it does not contain more information than the average current. (ii) In presence of a non-vanishing average current, the non-equilibrium part of the noise power spectrum, Eq. (1), at zero frequency and zero temperature is totally absent in clean (impurity-free) conductors, but arises if a backscatterer enables partitioning of the incoming particle beam. This kind of noise, commonly called shot noise, is due to the quantization of charge of the backscattered particles. Consequently, shot noise should allow us to investigate the interesting issue of fractional charge in strongly correlated electron systems.

It is well known that the transport properties of fractional quantum Hall (FQH) edge states at filling factor $\nu = 1/m$, where m is an odd integer, can be described by the chiral Luttinger liquid model. In such systems, the fractional charge $e^* = \nu e$ of the Laughlin quasiparticles has been observed through shot noise experiments on quantum point contacts in semiconductor heterostructure devices. In contrast, the two-terminal shot noise of non-chiral Luttinger liquid systems, such as e.g. cleaved edge overgrowth quantum wires and carbon nanotubes, with an impurity is due to backscattered quasiparticles constructed out of the zero modes and the plasmons of the bosonized Luttinger liquid model. Similar to the Laughlin quasiparticles in FQH fluids, the backscattered quasiparticles in non-chiral Luttinger liquids carry a fractional charge $e^* = ge$, where $0 < g \leq 1$ is the Luttinger liquid interaction parameter. One might then naively expect that a shot noise experiment on a non-chiral Luttinger liquid system with an impurity should reveal the fractional charge $e^* = ge$, similar to the chiral situation. We show that this is not the case, which is a consequence of the presence of external leads. Instead, the zero-frequency shot noise of a non-chiral Luttinger liquid system coincides with the noise of a non-interacting quantum wire. This result seems unexpected but can be understood in a simple picture. If a non-chiral Luttinger liquid of finite length L is coupled to Fermi liquid reservoirs then the zero frequency shot noise probes current correlations on a length scale much longer than L, because $\omega < v_F/L$, where v_F is the Fermi velocity of the electrons. Such an experiment probes the current correlations of the leads and accounts the compound, made up of the quantum wire and the impurity, as a point-like scatterer.

For $\omega \sim v_F/L$ the situation is different. Then, the noise consists of a mix of white (ω-independent) and frequency-dependent contributions. It turns out that the white contributions of the finite frequency current noise indeed depend on the fractional charge $e^* = ge$.