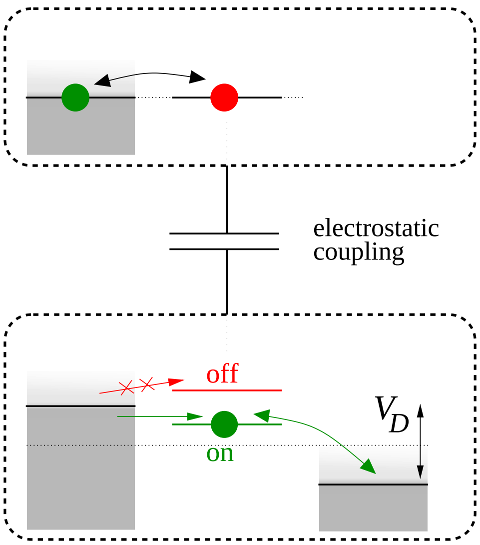
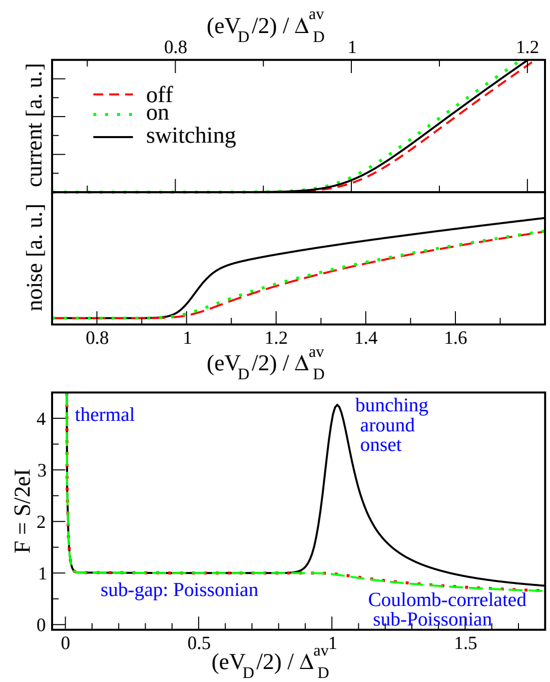
Super-Poissonian current noise in coupled single-electron transistors

Introduction: Several metallic islands can be coupled, capacitatively or by tunnel junctions, to form different networks of single-electron transistors. These complex devices show a rich variety of physics and are of interest both from a theoretical points of view, e.g., for investigating the measurement process and backaction effects, as for applications, for instance realizing electron pumps or turnstiles. Recently we developed a real-time diagrammatic method algorithmic approach to calculate (zero-frequency) current-current noise and current crosscorrelations in networks of metallic SETs. In capacitatively coupled SETs novel correlation effects appear. For instance, as shown in Fig. 1, bunching of electrons, similarly also investigated in semiconductor systems [1] is found. We identify a number of different mechanisms causing super-Poissonian noise, which could be experimentally investigated in coupled SETs. Experimental work of the group of Prof. Per Delsing recently opened the possibility to measure the intrinsic low frequency noise in gated metallic SETs [2].



(a) Tunneling in the upper SET opens and closes the transport channel in the lower SET.



(b) Switching between off and on state results in bunched transport of electrons, associated with super-Poissonian noise and positive cross-correlations between two output leads of the lower SET.

Figure 1: Electron bunching as transport channel is switched on and off.

Purpose of visit: The visit at Chalmers University, Göteborg aimed at, firstly, pushing forward the theoretical analysis of the super-Poissonian noise features. Secondly, we wanted to explore connections to the experimental investigations on noise in metallic SETs performed at Chalmers. Moreover, possible new directions or extensions of the theoretical work, were to be discussed.

Description of visit: The current status of our theoretical work on super-Poissonian current noise in coupled single-electron transistors were presented to the theoretical group and members of the experimental group of P. Delsing working on this subject. Serguei Kafanov presented the experimental results he obtained in the group of P. Delsing as part of his PhD work. In the following, Göran Johansson and I, discussed implications of the experimental progress on our work, the further progress of our theoretical work, and finally, we explored possible explanations for some features of unpublished experimental data, which are not completely understood. Preliminary ideas and results were discussed, in particular with Per Delsing, throughout the visit.

Results of visit and outlook: The experimental progress of Per Delsing's group confirmed, that our theoretical explorations are within reach of experimental exploration. They managed to extract from their measurements the intrinsic low frequency noise of a gated single-electron transistor. Using the radio-frequency single-electron transistor (rf-SET) technique, low frequency noise of the reflected voltage from the rf-SET in the range of a few hertz up to tens of MHz was measured overcoming limitations due to the amplifier noise. The extension to noise measurements of coupled SETs is straightforward; some limitations have to be considered, however, when exploring sub-threshold (i.e. rather weak) noise in SETs. An extraction of intrinsic noise from the amplifier background can become unattainable in that situation.

During my stay in Göteborg Göran Johansson and I finalized outlining of a publication on our work on super-Poissonian current noise in coupled single-electron transistors (see below). We expect to finish writing a manuscript during the summer break and submit in a few months.

Unpublished experimental data from the Chalmers group on low frequency current noise of an SET with high conductance (other experimental data of the same sample can be found in Ref. [2]) show surprising features at high transport voltage. Orthodox (sequential tunneling) theory predicts a Fano factor going down to $1/2$ with increasing transport voltage [3], as is indeed found for low conductance samples. Cotunneling, the leading correction to sequential tunneling in the Coulomb blockade regime, yields a Fano factor of 1 [4]. The experimental data, however, show a Fano factor decreasing with rather constant slope to values below $1/2$, when the transport voltage is increased. This somewhat counterintuitive result of a Fano factor below $1/2$ in a regime, where sequential tunneling (with $F = 1/2$) and cotunneling processes (with $F = 1$) contribute caught our interest. Unfortunately, we cannot directly explore the experiment with our diagrammatic real-time technique, as convergence of the perturbative approach is not guaranteed for such high conductance samples. Unphysical artefacts of perturabtion theory will show up around the opening of new transport channels, i.e., whenever an additional charging-energy level enters the voltage window. However, we believe, that we achieved some physical understanding of the origin of the $F < 1/2$ Fano factor in open SETs. We will try to establish more quantitative statements, which may result in a further publication, possibly in collaboration with the experimental group.

Projected publications

(1) *Super-Poissonian current noise in coupled single-electron transistors*
Björn Kubala, Göran Johansson, and Jürgen König, in preparation.

References

[1] S.S. Safonov, A.K. Savchenko, D.A. Bagrets, O.N. Jouravlev, Yu.V. Nazarov, E.H. Linfield, and D.A. Ritchie, Phys. Rev. Lett. **91**, 136801 (2003); A. Cottet, W. Belzig, and C. Bruder, Phys. Rev. B **70**, 115315 (2004).

[2] S. Kafanov, H. Brenning, T. Duty, P. Delsing, arXiv:0807.2751 (unpublished).

[3] A.N. Korotkov, Phys. Rev. B **49**, 10381 (1994).

[4] D.V. Averin, cond-mat/0010052 (unpublished).