ROLE OF THE CIRCUIT
IN MESOSCOPIC NOISE MEASUREMENT

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Theories of mesoscopic noise are typically based on one of three approaches:

1. Invocation of a quantum mechanical operator, without explicit concern about its relation to measurement.

2. Counting the rate at which electrons cross a specified mathematical surface, unconnected to the measurement apparatus.

3. Concern with the location of the image charge of the moving carrier, as in Secs. III and IV of Ref.[1].

It seems likely that in the case of completely coherent quantum mechanical transmission, where the electron traverses the sample in *one gulp*, that the three approaches yield the same result. The purpose of this note: To expand on approach 3. Let us, at first, assume that the electron density in the sample is low; electron correlation within the sample can be neglected. We will, subsequently, discuss the case of densely populated samples.

Experiments do not measure the rate at which electrons cross a mathematically specified surface. Rather, as in Ref. [2], the experiment is likely to measure the voltage fluctuations across a small series resistor. (Alternatively we can feed a relatively fixed current to the sample through a large resistor, and measure voltage fluctuations across the sample. The two alternative methods can be related by circuit theory and we will not do that here.)

Figure 1 shows a sample connected to two reservoirs. Reservoir 1 is connected via an external circuit to ground. Reservoir 2 is connected via a measuring resistor to a voltage source. There are no other nearby electrodes. A carrier traversing the sample has its image charge distributed among the two reservoirs. Thus, the charge will be distributed in a way which depends on the geometry; the image charge on Res. 2 will grow to the full (negative) equivalent of the carrier charge, as the carrier approaches Reservoir 2. During this buildup, and not when the carrier finally reaches Res. 2, a corresponding current will flow in R_M. Of course, the fluctuating current will only flow through R_M if $R_M C$, where C is the capacitance across the sample, is small compared to the reciprocal of the measurement frequency.

If the sample traversal is a single coherent quantum mechanical event then the widely discussed $\sum_i T_i(1-T_i)$ results apply. The detailed time–dependent shape of the current waveform through R_M does not matter as long as this is fast compared to the measurement frequency. The measurement of charge flow through R_M is essentially an electron counting operation; how many electrons in a given time interval were transmitted. The measurement is unrelated to a carrier momentum determination. On the other hand if the carrier traversal consists of a sequence of successive independent statistical events, then the elementary charge pulse through R_M, measured by the spectral decomposition of the voltage across it, consists of a change in the image charge at Res. 2 produced by one of these independent events. That was the approach of Sections III and IV of Ref. [1], except that in that case the image charge at the ends was assumed to form on plane parallel electrodes.

Now consider Fig. 2 where a capacitive electrode couples to the sample, and screens it from the reservoirs. During most of the carrier's trip the image charge is on that electrode. Only at the end of the trip does the image charge form on Reservoir 2, and only then is there a corresponding charge pulse through R_M. In this case we do, in fact, approximate method 2 of the introductory paragraph. Figure 3, where the gate is tied to a different voltage, leads to the same situation as in Fig. 2. Consider, instead the situation of Ref. [3] where a number of reservoirs are tied to the sample, producing incoherence during the traversal. These are floating; now it is the image charge of the charged reservoir that matters. If we assume that the reservoirs are close to the sample, then the electrostatics will not differ greatly from that discussed in connection with Fig. 1.

Finally, let us consider more densely populated systems. We invoke an approach discussed in Ref. [4], which was an informal response to suggestions in the early 1980's that the fractional charge carried by solitons in polyacetylene could be measured through the shot effect. Consider motion of a charge in such a system from point A to point B, perhaps two points along the path designating incoherent events. The disappearance of a charge at A and its reappearance at B is equivalent to the formation of a dipole. A field is associated with this, and will decay through conductive processes. If we were dealing with classical macroscopic phenomena it would decay with an ϵ/σ time constant. A mesoscopic system is more complex, but similar. The key point: Capacitive effects determine the time scale, but the actual charge transfer is conductive. How much of the annihilated (and created) charge is compensated through flow from one electrode, how much through the other? In Ref. [4] it was shown, using macroscopic circuit theory, that the charge transfer through the actual circuit was equal to the carrier charge multiplied by the fraction of the total voltage drop that occurs between A and B. (This result sounds like a simple consequence of conservation of energy, but it is not.) The simple result just cited may apply to the mesoscopic case only in a suggestive and qualitative way. Low frequency plasma oscillations, related to *backflow*, are likely to be involved in a transient way, but would not relate to long range charge flow to the electrodes.

When a carrier is displaced from A to B, in an event incoherent with earlier and subsequent motion, first changes in the image charges on terminating electrodes take place. Subsequently, the conductive redistribution of charges discussed in the preceding paragraph takes place. If we are dealing with a spatially uniform medium, and we can neglect fringing capacitances, then the slower conductive redistribution does not result in further external current flow. That simplicity, however, is unlikely to be found in a mesoscopic sample.

Obviously this is only the motivation for a theory, to be elaborated and confirmed. And some of the physical effects, e.g., the relation to the Coulomb blockade, are still hazy.

This informal discussion, which is not a preprint, is a result of the recent Rencontres de Moriond Conference, *Workshop on Coulomb and Interference Effects in Small Electronic Structures*, Villars-sur-Ollon, Switzerland, January 22-29, 1994; particularly of discussions with M. De Jong and G. Bergmann, amplified later by interaction with M. Büttiker. These notes, however, express my prejudices, not theirs.

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