HOW TO MEASURE EXTREMELY LOW CURRENT NOISE IN SINGLE BARRIER TUNNELING DEVICES

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Abstract

The aim of this poster is to present the method for very low-level electronic transport measurements, which enables to measure the fluctuations of very low tunneling currents in mesoscopic systems.

Why to measure the noise?

Time dependent fluctuations of a tunneling current reflects the temporal correlations between charge transfer events through a conductor. For mesoscopic systems where Pauli priciple and Coulomb interactions play important role, the deviations from the classical Poissonian full shot noise power density $2eI$ can provide additional information about interactions between electrons inside the tunneling barrier and the mechanism of the transport (e.g. existence and number of localized states which participate in transport).

The system

• Single-barrier resonant tunneling GaAs/AlAs/GaAs structure with Si δ-doping ($3*10^9$ cm^{-2}) in the center of the 10 nm thick AlAs barrier. The diameter of the mesa structure varies between 50-150 μm.

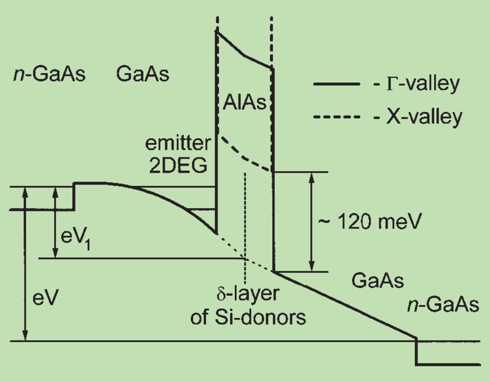


Figure (left): A schematic conduction-band diagram of a single barrier tunneling device under an applied voltage V. Figure from I. E. Itskevich, L. Eaves, P. C. Main, M. Henini, and G. Hill, *Phys. Rev.* B 57, 7214-7218 (1998)

I-V Characteristic

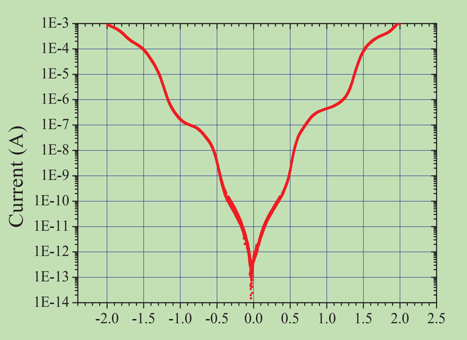


Figure (left): Typical I-V characteristics of the single barrier resonant tunneling heterostructures. We expect that for different bias voltages i.e. for various transport mechanisms the temporal fluctuations of the tunneling current will be different.

The measure for current fluctuations are:

• the Power Spectral Density of the signal

$$S_I(f) = \frac{\langle (\delta I(f, \Delta f))^2 \rangle}{\Delta f}$$

• the Fano factor

$$F = \frac{S_{I,real}}{2eI}$$

which indicates if the signal is super- ($F>1$) or subpoissonian ($F<1$).

We are searching for the interesting physics related to the resonant tunneling transport through small amount of impurities in the barrier. Currents in such a transport are on the level of 10^{-13}-10^{-9} A. Therefore we develope the technique which shall enable the noise measurement at the level at least of 1 fA/√Hz.

How to measure noise-signal (temporal fluctuations of current)?

Crosscorrelation method

What is the Idea:

• to have two independent amplifiers in two independent signal-carrying channels
• to correlate these signals at higher level (i.e. after amplification)
• the uncorrelated noise of amplifiers will not appear in crosscorrelation spectra
• the sample-related correlated noise will be measured

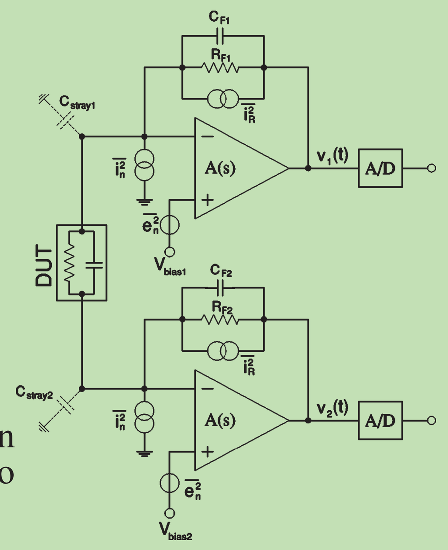


Figure (right): Basic scheme for current measurements using the correlation spectrum analyzer. The signal from the DUT (Device Under Test) is fed to two distinct and independent input amplifiers operated in parallel. Figure from [1].

How is it Implemented:

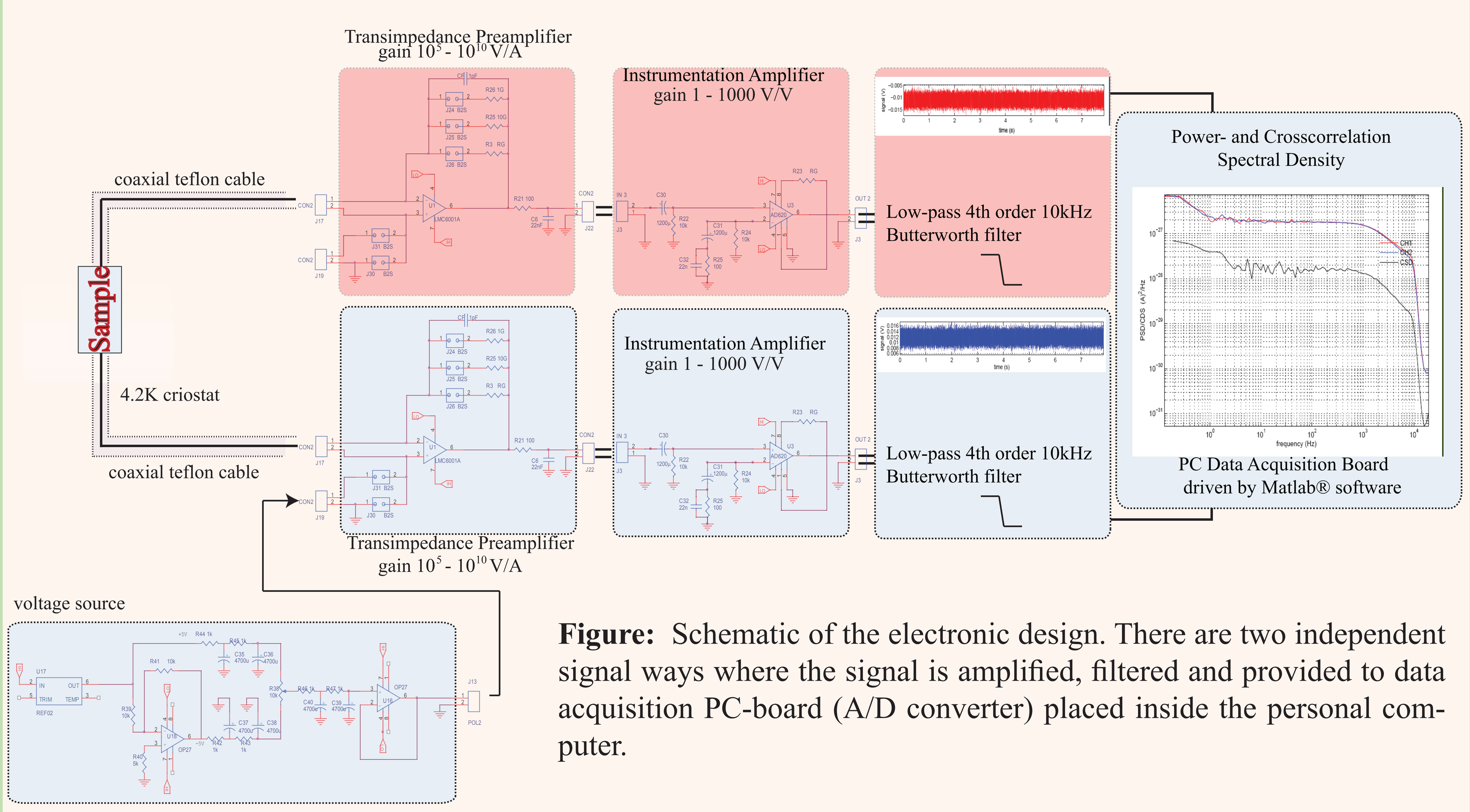


Figure: Schematic of the electronic design. There are two independent signal ways where the signal is amplified, filtered and provided to data acquisition PC-board (A/D converter) placed inside the personal computer.

How it looks like:

Figure (up) The sample holder is immersed directry into the liquid helium container which is placed in the box with sand standing on the cartire in order to amortize vibrations.

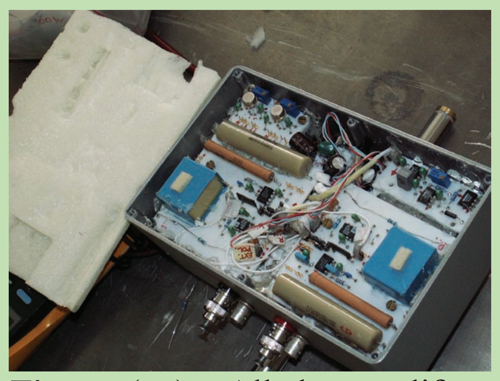
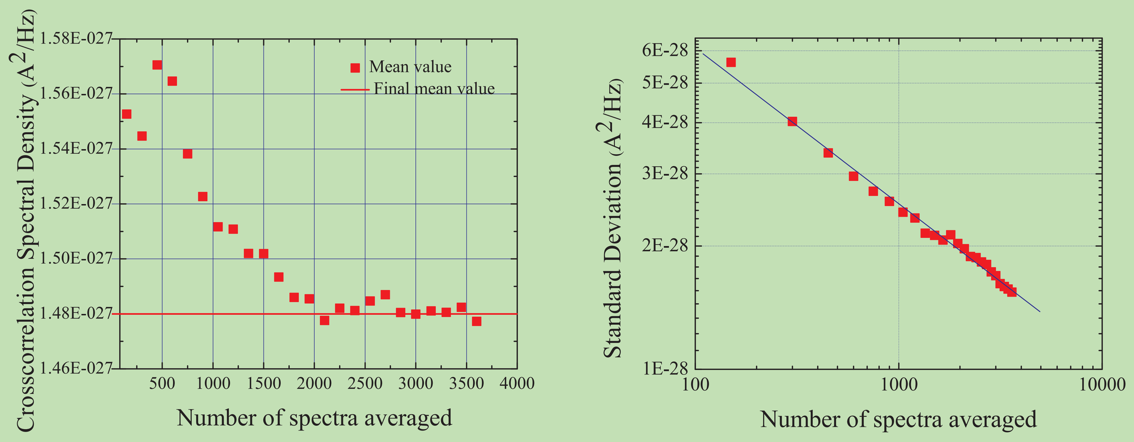


Figure (up). All the amplifiers and the voltage source are closed tightly inside the metalic box. The free space inside is filled up with foamed polystyrene to avoid acoustic resonances which feed the triboelectric effect on the teflon circuit board.

How it works:



Figures (up): After more than 2000 averages of the collected spectra the mean value starts to converge to the final mean value of the crosscorrelated spectral density (left) and standard deviation of this mean value tends to zero when $N \rightarrow \infty$, where N-number of spectra averaged.

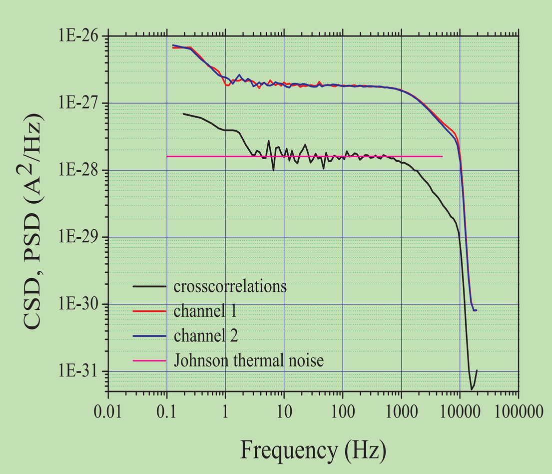


Figure (left): Typical example of the current noise spectrum for 100 MΩ nonpolarized resistor. After already ca 50 averages the mean value converged to the $4kT/R = 1.6 \cdot 10^{-28}$ A^2/Hz which is the value of the thermal current noise of this resistor at room temperature. The origin of the low frequency rise-up of the PSD remains unclear. Maybe it comes from the single operational amplifier on board of the multiplexed multichannel A/D converter. Low frequency noise of this single amplifier is seen in both channels and probably contributes with correlated, low-frequency noise to signal in both channels.

What is important:

• material for cable (teflon has huge triboelectric effect, one can minimize it by lubricating the dielectric-metal contacts with graphite lubricant)
• capacitance of cables limits the bandwidth of the transimpedance amplifier, one has to make cables as short as possible or put the preamplifier as close to the sample as possible
• mechanical vibrations coming from outside will generate the correlated signal in both channels, one has to avoid it by damping them by means of damper (e.g. tire) and a box with sand (nonelastic!)
• filtering of the signal by means of low-pass filter eliminates higher-frequency components of the signal which otherwise aliases to frequences below Nyguist limit $f_s/2$, where f_s - sampling frequency

Conclusions:

Known problems - solved

• External vibrations of the experimental setup
• Triboelectric / microphonic effect
• Unsufficent stability of the reference +5V voltage
• Unsufficient stability of commercially available voltage regulators

Known problems - to be solved

• DAQ board inside the framework of the PC-computer catches MHz electromagnetic interferences which aliases to lower frequency range (up to 100 kHz) of the A/D converter.
• DAQ board has few multiplexed analog input channels and only one amlifier which probably gives rise to the observed low-frequency noise below 1Hz.
• Capacitance of teflon cables influences indirectly the bandwidth of the transimpedance amplifiers

References

[1] G. Ferrari and M. Sampietro, *Correlation spectrum analyzer for direct measurement of device current noise*, *Rev. of Sci. Instr.*, 73, 2717 (2002)
[2] Yuanzhen Chen and Richard A. Webb, *Full shot noise in mesoscopic tunnel barriers Phys. Rev. B* 73, 035424 (2006)