Journal Club by Oleg Chalaev

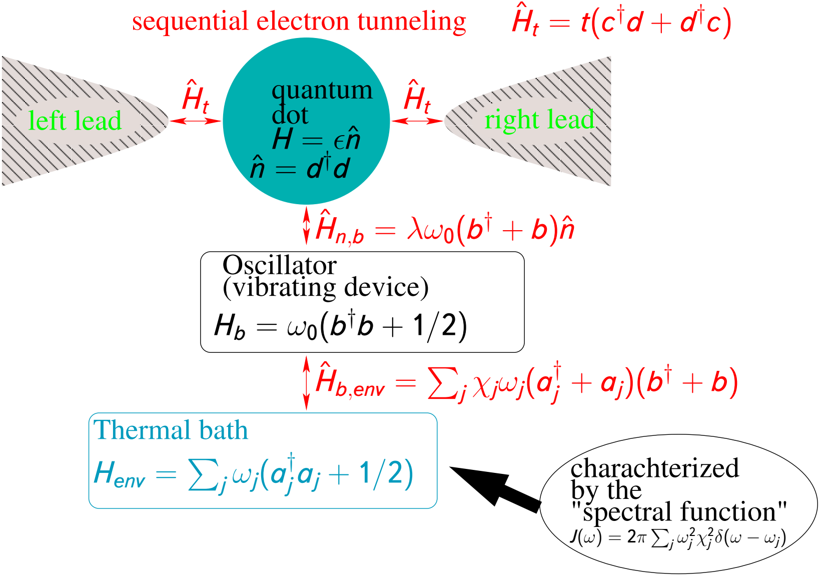
Anomalous suppression of the shot noise in a nanoelectromechanical system

F. Haupt, F. Cavaliere, R. Fazio,
M. Sassetti

08.08.2006

cond-mat/0607080

The system and its Hamiltonian



Task: calculate Fano factor: $F = \frac{S(\omega=0)}{2e\langle I \rangle}$.

Rate equation

occupation numbers: $|n, l\rangle$, $n =$electrons in the dot, $l =$phonons in the oscillator.

Considering "diabatic" regime:

$\omega_0 \gg \Gamma^{(0)} = 2\pi\nu t_0^2 =$tunneling rate.

$\Longrightarrow$ignoring off-diagonal elements of the density matrix:

$\langle n, l|\hat{\rho}|n', l'\rangle \propto \delta_{n,n'}\delta_{l,l'}$.

$i\frac{\partial\hat{\rho}}{\partial t} = [\hat{H}, \hat{\rho}] \Longrightarrow$ equation of motion:

$$\frac{d}{dt}P_{nl} = \sum_{n' \neq n}\sum_{l',\alpha}[P_{n'l'}\Gamma_{\alpha}{}^{n'\to n}_{l'\to l} - P_{nl}\Gamma_{\alpha}{}^{n\to n'}_{l\to l'}] + \sum_{l'}[P_{nl'}\Gamma^{rel}_{l'\to l} - P_{nl}\Gamma^{rel}_{l\to l'}].$$

$\longleftarrow$ relaxation rates $\Gamma^{rel}_{l'\to l}$ are considered separately.

$\longleftarrow$ reminds quasiclassical kinetic equation for the distribution function.

Now let us evaluate the "collision term" on the rhs (i.e., the rates Γ)

Expressions for the rates Γ

The transition rates are evaluated using Fermi golden rule approximation. Now let us evaluate the “collision term” on the rhs (i.e., the rates Γ).

- Relaxation rates:

$$\Gamma^{rel}_{l\to(l-1)} = e^{\beta\omega_0}\Gamma^{rel}_{(l-1)\to l} = l\frac{\mathcal{J}(\omega_0)}{1-e^{-\beta\omega_0}},$$

–equilibrium expression!

- Charge transfer rates:

$$\begin{aligned}
\Gamma_{\alpha\, l\to l'}^{\,0\to 1} &= \Gamma^{(0)} X_{l'l} f_\alpha(\omega_0(l'-l)),\\
\Gamma_{\alpha\, l\to l'}^{\,1\to 0} &= \Gamma^{(0)} X_{l'l}[1-f_\alpha(\omega_0(l-l'))],\\
X_{ll'} &= e^{-\lambda^2}\lambda^{2|l-l'|}\frac{l_<!}{l_>!}\left|L_{l_<}^{|l-l'|}(\lambda^2)\right|^2,
\end{aligned}$$

Using these (known before) expressions, the authors numerically solve the rate equation.

Limiting cases

- $\lambda \to 0$ sequential tunneling, minimal Fano-factor$= 1/2$.
- $\lambda \gg 1$

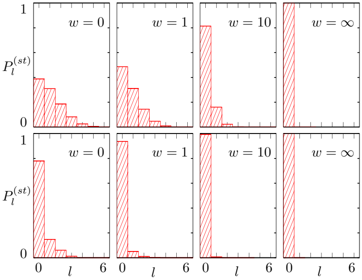


Figure: Stationary phonon probability distribution $P_l^{(st)}$ for different values of w. Upper panels: $\lambda^2 = 0.4$, lower: $\lambda^2 = 7$.

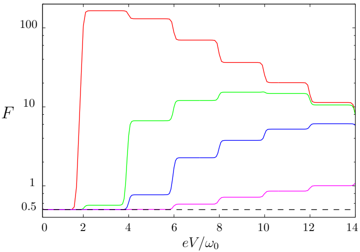


Figure: Fano factor as a function of voltage for $\lambda^2 = 16$ and for different values of the relaxation strength w; red $w = 0$, green $w = 0.1$, blue $w = 1$, magenta $w = 10$.

What happens for $\lambda^2 \sim 1$?

Interpolation between two limiting cases?

No! Finite relaxation rate can induce unexpected features!

Moderate coupling

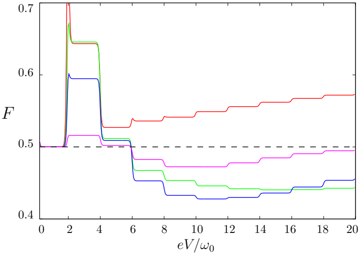


Figure: Fano factor as a function of voltage at $\lambda^2 = 3$ and for different values of the relaxation strength w; red $w = 0$, green $w = 5$, blue $w = 12$, magenta $w = 100$. Dashed line, $F = 1/2$. Other parameters: $\bar{\varepsilon} = 0$ and $k_B T = 0.02\,\omega_0$.

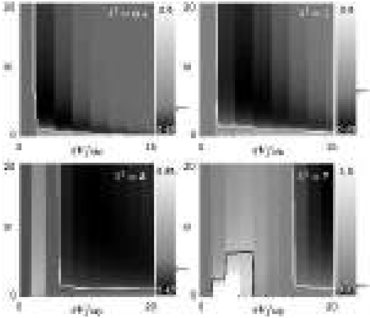


Figure: Fano factor as a function of bias V and relaxation w for different values of λ. In all the panels: dark gray $F < 1/2$, medium gray $F = 1/2$ (indicated by the arrow in the color map) and light gray $F > 1/2$. The white line corresponds to $F = 1/2$. The black line in the 4th panel delimits the region where noise is superpoissonian, $F > 1$. Other parameters: $\bar{\varepsilon} = 0$ and $k_B T = 0.02\,\omega_0$.