Low-Frequency Shot-Noise Thermometry
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Motivation
- Accurate measurement of temperature by common methods, such as traditional thermometers and thermocouples, become challenging due to complications associated with the small size of nanoscale devices.
- Shot-Noise thermometry is a primary temperature measurement technique, and thus does not require calibration.
- Devices utilizing electrical noise are capable of providing a relatively low-cost, non-intrusive method of obtaining highly accurate temperature measurements.
- The low frequency regime of the noise signal has been avoided in the past due to the presence of 1/f noise; however, for devices such as carbon nanotubes, this additional noise source can encompass a significant portion of the frequency spectrum.

Governing Theory
- Johnson Noise is present in any conductor and is the result of random fluctuations of the electron gas, also referred to as Brownian motion. These fluctuations are due to thermal vibrations within the material and obey the following relation for current spectral density:
\[ S_{1/f} = \frac{4kT}{R} \]  
(1)
- Shot-Noise is the result of charge carriers crossing a barrier under an applied bias. Due to their discrete nature of the electrons crossing the junction, an electrical noise is introduced into the system of the following spectral density:
\[ S_{s} = 2eI \]  
(2)
- Temperature dependence, shot-noise initially appears to be of little use in thermometry; however, when measured in conjunction with Johnson noise, the current spectral density obeys the following non-linear relation, where \( F \) is the Fano factor:
\[ S_f = 2eIF \cosh \left( \frac{eV}{2kT} \right) \left( 1 - F \right) \frac{4kT}{R} \]  
(3)
- Fano factor and temperature was evaluated while modifying several different parameters.

Experimental Setup

Numerical Simulations
- A signal was first generated at three voltage levels that contained all three noise sources discussed above (Johnson, Shot, 1/f) having a certain value for temperature, Fano factor, and 1/f noise parameters \( A \) and \( \beta \).
- Noise was generated by a normal distribution for Johnson and Shot noise. For 1/f noise, the phase was varied uniformly in frequency space, after which the inverse Fourier transform was taken.
- This signal was then transferred to the frequency domain via fast Fourier transform (FFT) and averaged using Bartlett's method.
- To the parameters utilized to generate the signal, the low-frequency range was fitted to Eq. (4).
- Based on the fit, the 1/f noise was accounted for and the remaining portion was fitted to Eq. (3) to determine the temperature and Fano factor.
- The actual values for Fano-factor and temperature used for signal generation were compared to the calculated values determined by fitting with Eq. (3).
- Accuracy of this method for determining the Fano factor and temperature was evaluated while modifying several different parameters.

Results

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Based on Results in: