JOHNSON NOISE THEORY

Reference: Text: *Melissinos and Napolitano (M&N)* Chapter 3.6.

Charge is quantized because electrons are quantized. Johnson noise comes from the thermal fluctuations of electrons in matter. As the motion of electrons in matter change as a function of temperature, they induce currents, since $I = \frac{dq}{dt}$. If the temperature of a resistor is changed, the electrons in the resistor will cause a fluctuation in current and produce a voltage difference across the resistor. In this lab you will measure these fluctuations of voltage across a resistor at a fixed temperature (Room Temperature) in order to determine the Boltzmann constant, k. Derivation of k is possible because electrons are quantized, therefore a system of electrons, say electrons in a resistor, is described through statistical mechanics. In the resistor there are N particles which is constant. There is entropy σ in the resistor, which changes with temperature since $\sigma = ln(g)$ where g describes the number of energy states, or degeneracy, of the electrons in the resistor, which we know increases as temperature increases.

The average value of voltage across a resistor, $\langle V \rangle$, is zero, meaning all fluctuations in the thermal noise occur in all directions and sum to zero. That being said, because there are fluctuations over defined periods of time, the variance of the voltage is non zero:

$$\sigma_V^2 = \langle (V - \langle V \rangle)^2 \rangle = \langle V^2 \rangle - \langle V \rangle^2 = \langle V^2 \rangle \neq 0$$

Equation 1

This value is the Johnson Noise voltage for a resistor with resistance R, also described in terms of a time frame for the random walks of electrons, t_0. Refer to the text (M&N), chapter 3.6.1. for a detailed derivation.

$$< V^2 > = \frac{4kTR}{t_0}$$

Equation 2

From Equation 2, the following expression including g(ν) (the gain as a function of frequency, ν) follows, as shown in the text:

$$< V^2 > = 4kTR \int_0^\infty g^2(v)dv$$

Equation 3

ANALYSIS

- Using **matplotlib** and the data from the first measurement (Section III.1 from the Johnson Noise Lab Instructions manual), determine the numerical value of this integral and its error
- For each input resistance, determine $\langle V^2 \rangle$

- Plot the variance as a function of *R* and determine the slope and its error assuming a linear behavior with a non-zero intercept
- Using equation 3, find a value for the Boltzmann constant