JOHNSON NOISE - TEACHSPIN APPROACH

Reference: Text: *Melissinos and Napolitano (M&N)* Chapter 3.6, *Noise Fundamentals (TEACHSPIN Manual) Pages 1-1 to 1-13*

Objective: To determine Boltzmann constant by amplifying signals from thermally dependent electron movements in a resistor.
In this experiment, the voltage variance across several resistors that generate Johnson Noise will be measured as a function of resistance at room temperature using the TEACHSPIN hardware (labelled "Noise Fundamentals" on two interface wooden boxes). From this curve, one will be able to calculate the Boltzmann constant. Note that this setup will be more understable to you after you have gone through the process of designing and fabricating of the electronic circuit that will achieve the same purpose on a breadboard. The difference of course is that the TEACHSPIN will have superior noise suppression due to its compact circuitry.

Experimental Setup:

The connections and settings for the experimental hardware have been set up for you to expedite the process of data collection. Details of the setup can be obtained from the second reference cited at the beginning of this section.

Figure 1 below is essentially the Pre-Amplifier Stage similar to the one you built. This has a low gain of 6 through a non-inverting amplifier. Make sure the hardware is setup according to the image you see in the figure.

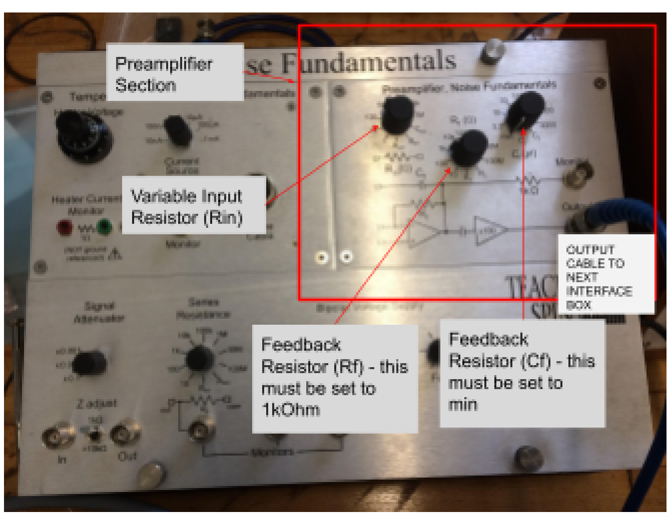

Figure 1: Noise Fundamentals Interface Box showing preamplifier section used for this measurement. Make sure the settings are the same as shown in the figure: $R_f = 1k\Omega$, C_f = min. You will choose various values for R_{in} to perform the measurement of the Boltzmann Constant.

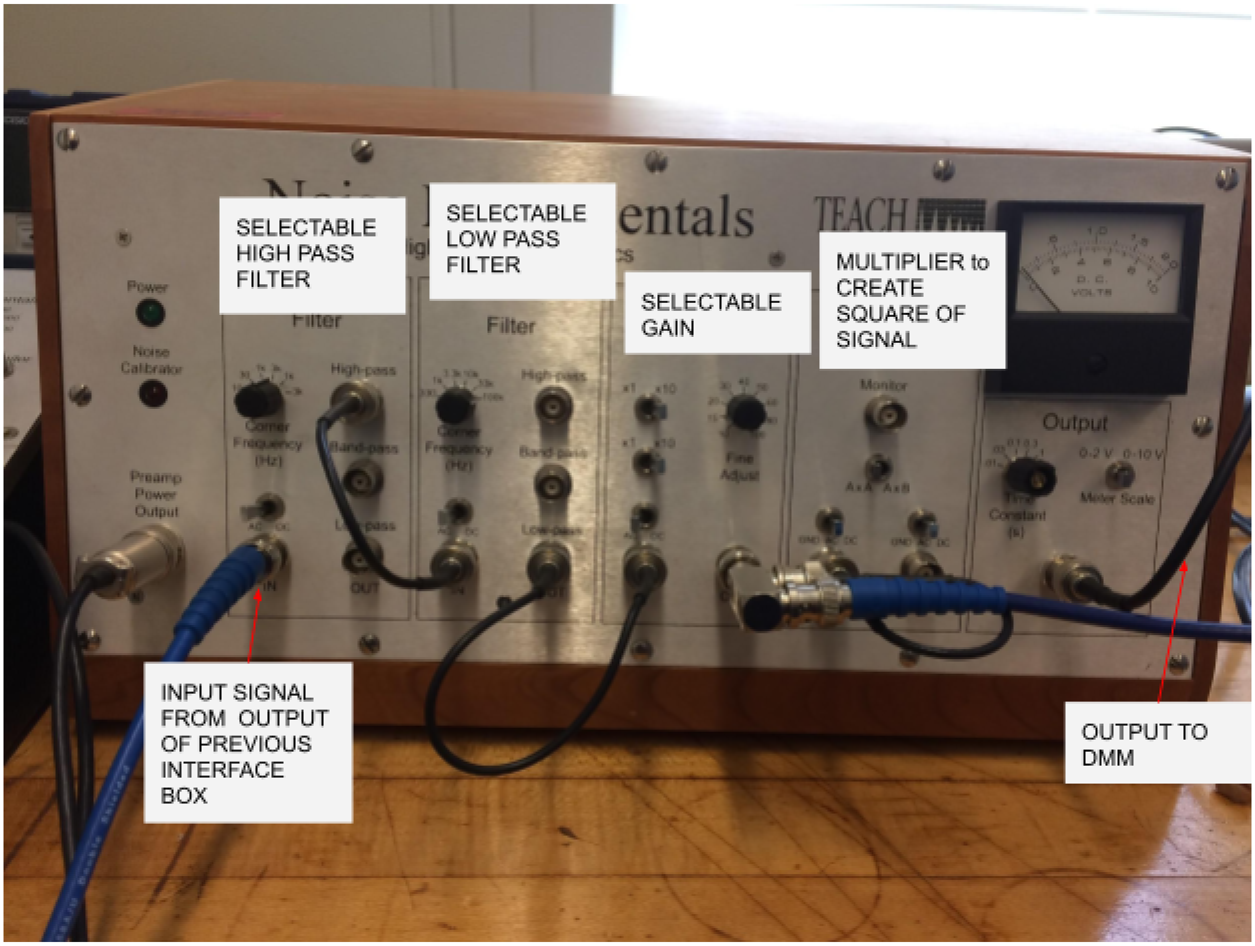

Figure 2: Second Noise Fundamentals Interface Box that generates the amplified Johnson Noise signals we will measure to compute the Boltzmann Constant.

Settings for the Second Interface Box:

- HIGH PASS FILTER (allows frequencies higher than the chosen corner frequency):
  - Corner Frequency : 0.3kHz
  - Toggle set to AC (for AC Coupling)
  - Cable connection from High Pass (output) to input of next section (LOW PASS FILTER)
- LOW PASS FILTER (allows frequencies lower than the chosen corner frequency):
  - Corner Frequency: 100kHz
  - Toggle set to AC (for AC Coupling)
  - Cable connection from Low Pass (output) to input of next section (GAIN)
- GAIN (adjustable gain for final amplified signal from the Bandpass Filter created by using the Low Pass/High Pass filter sections):
  - Gain: Choice of Toggle between 1-10
  - Gain: Choice of Toggle between 1-10

    - Gain: “Fine Adjust” between 10-100
    - Toggle set to AC (for AC Coupling)
    - Final Gain from this section is the multiplication of all three adjustable gains
    - Cable connection from Gain (output) to input (IN A) of next section (MULTIPLIER)
- MULTIPLIER (multiplies two specified inputs: either AxA or AxB. The former “squares” the input signal at IN A and the latter multiplies the signals at IN A and IN B). The output of the multiplication is sent internally to the MONITOR section
    - Toggle between GND, AC and DC - Set Toggle to AC
- OUTPUT (generates the final amplified Johnson Noise)
    - Set Time Constant to 3s
    - Change the gain (on the GAIN section) so that the output voltage is always < 2V

Johnson Noise Measurement

The background information on this measurement is provided in the “Noise Fundamentals” in Section 1.3, part (b). Part of this section is reproduced here.

The (final) output voltage measured is given by:

$$V_{out}(t) = G\,[V_J(t) + V_N(t)] \qquad (1)$$

where V_{out} is the measured output voltage, G is the final gain, V_j is the Johnson Noise and V_N is the intrinsic noise in the system

When the mean square of this value is taken, the following result is obtained:

$$\langle V_{out}^2(t)\rangle = G^2 \{ \langle V_j^2(t)\rangle + \langle V_N^2(t)\rangle \} \qquad (2)$$

If the source resistance i.e. R_{IN} in Fig 1.1a from the cited TEACHSPIN manual (labelled as “Johnson Noise preamplifier schematic”) were to be set to “0”, we would expect to measure V_N because $V_J = 0$. This is not possible nor necessary. It will be sufficient to use small values of $R_N = 1$ or 10Ω or use the intercept of the curve of $\langle V_{out}^2(t)\rangle$ versus R_{IN}. This inferred value of V_N is then assumed to not change with changes in the source resistance.

Using the Digital Multimeter, set to DC V (i.e. measurement of DC voltages), measure the output voltages for a variety of sources resistances (do not include the 1MΩ resistor) available on the interface box. Note the Gain (G2) that you used to perform the measurement - this is the final combined gain from the second interface box (Figure 2). For example, if one toggle switch is at 10, the other at 1 and the Fine Adjust is at 50, then G2 = 10 x 1 x 50 = 500.

The gain from the PreAmplifier stage (Figure 1), G1, is 600. Make sure you understand how this value was computed. Ask the Instructor if you are not sure.

The cited TEACHSPIN manual (pg. 1-11) shows that the final value, $\langle V_{sq}\rangle$ that is measured with the Digital MultiMeter is given by:

$$\langle V_{sq} \rangle = \{(G_1\, G_2)^2 / 10V\} \langle V_J^2 + V_N^2 \rangle \qquad (3)$$

Using the data you collected for the various resistance values, compute the value of $\langle V_J^2 \rangle$ (as shown on page 1-11), using the lowest source resistance to estimate $\langle V_N^2 \rangle$, or the intercept of the graph of $\langle V_J^2 + V_N^2 \rangle$ versus R_{IN}, and subtract this to obtain the Johnson Noise.

Page 1-13 shows the final equation you need to compute the Boltzmann Constant, k_B. The equation is:

$$\langle V_J^2(t) \rangle = (4\, k_B\, T\, \Delta f)\, .R_{IN} \qquad (4)$$

Plot the computed Johnson Noise ($\langle V_J^2(t) \rangle$) as a function of R_{IN} and use the slope to compute the Boltzmann Constant using equation (4). The frequency bandwidth is obtained by subtracting the High Pass Filter corner frequency from the Low Pass Filter corner frequency.