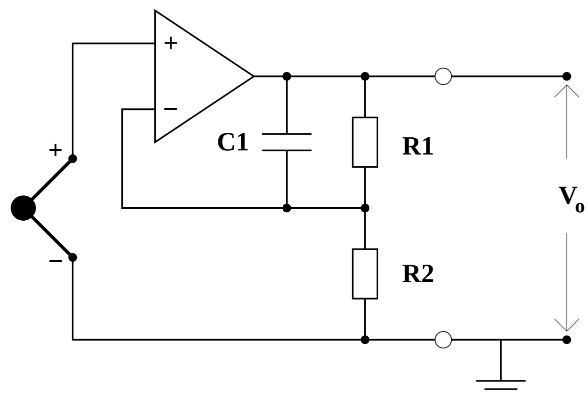
EE 521 Measurement and Instrumentation

Fall 2006 - Dr. Anders M. Jorgensen

Thermocouple Sensor Characterization

In this project you will characterize a thermocouple sensor used in a system to measure so-called microthermal atmospheric turbulence. Microthermal measurement systems measure the very rapid variation in air temperature associated with atmospheric turbulence. Knowledge of atmospheric turbulence is of interest in a wide array of applications ranging from astronomical observations through to laser propagation for communications purposes.

The sensor is connected to a low-noise operational amplifier which conditions the output from the microthermal sensor and outputs a voltage. The operational amplifier is supplied with -6V and +6V power. R1=220KΩ, R2=22Ω, C=0.047μF.



You will be given a data set consisting of measurements recorded at the rate of 300 samples/sec with an Analog to Digital Converter (ADC). Your job is to determine the sensor response function. First derive a reasonable expression for the differential equation describing the sensor response. Then use that information to derive the power spectrum of the sensor response when you know that the power spectrum of temperature variations is a Kolmogorov function and that there is an additional component of white noise which may be a combination of digitization noise in the ADC and electronic noise in the measurement system.

Assignment:
Your analysis should consider the following questions.

1. Explain what this sensor really measures. Refer to Northrop Section 6.4.1. Why is this measurement reasonable considering that we are only interested in rapid atmospheric temperature variations? Why are there not two thermocouples with one at a fixed reference temperature?

2. Derive the differential equation describing the response of the thermocouple sensor itself. Make appropriate assumptions and explain your assumptions.

3. Derive the differential equation describing the response of the sensor system and amplifier circuit.

4. What are the time-constants involved? What is the time-constant of the combined circuit?

5. Measure the time-constant by computing the power spectrum of the input data and comparing it with the input power spectrum which we assume to be a Kolmogorov spectrum.

6. How does the measured time-constant compare with the time-constant of the amplifier circuit? What part of the circuit determines the effective time-constant? What is the purpose of the rest of the circuit? How does the measured time-constant compare with information from the data sheet? What could be the source of any discrepancy?

7. How many bits were digitized assuming that all of the noise is due to digitization error? Assume that full ADC range is -5V to +5V. Determine the number of bits in the ADC in another way and compare your answers.

8. Derive any formulas that you use, or otherwise convince me that you understand them.

9. Estimate uncertainties where appropriate.

Data:
The data are stored in a single binary file as a sequence of 4-byte floating point numbers in Intel processors format. The values in the data file are the output of the ADC converted to voltages, and should therefore fall in the range -5V to +5V.
References:
The following documents may be of use to you. Please convince me that you understand formulas that you take from the literature, for example by deriving them.

- Short et al., The Astrophysical Journal, Volume 599, pages 1469-1477, 2003.

- Specifications sheet for Omega Engineering CO-2K Style 2 thermocouple.

This assignment is given to you on September 11, 2006, and your response is due October 2, 2006.

Tips:

1. When you Fourier transform the data set I suggest you transform shorter lengths of data and average those instead of transforming the entire data set together. You probably only need to consider frequencies above approximately 10^{-3} or 10^{-2} Hz.

2. You will need to derive Equation 1 in Short et al. (2003).

3. In deriving the differential equation for the sensor response you may wish to consult Northrop Section 1.2.1, as well as consult the sensor specification sheet and consider describing the basic physics of the sensor.