

MEASUREMENT OF THE CORRELATION COEFFICIENT OF TEMPERATURE  
FLUCTUATIONS AT DIFFERENT POSITIONS IN THE ROOM

### EQUIPMENT

Thermistor  
Transformer  
Lock-in Amplifier

### INTRODUCTION

In this lab you will set up a resistance bridge to monitor variations in the resistance of a thermistor as the temperature of the room varies. You will use the lock-in amplifier to optimize the signal to noise ratio of the bridge output. Temperature fluctuations as a function of time will be recorded from two different locations simultaneously by combining your data with that of another group. The cross correlation coefficient of the two data series as a function of the distance between the thermistors will be used to determine the characteristic distance over which the temperature fluctuations are correlated. The concept of a "correlation length" has proved to be a powerful tool in areas of science such as stellar diameters, elementary particle diameters and the size of laser pulses.

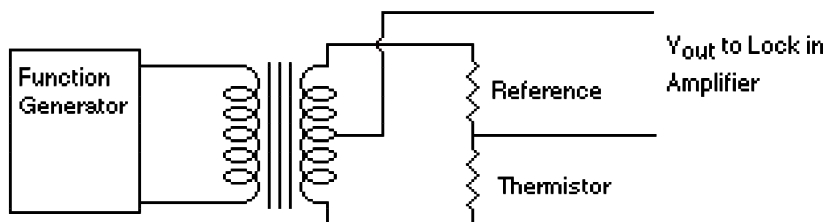
The correlation coefficient does not take account of a possible time lag between the two records. Thus if a traveling wave of temperature variation swept across your two locations it could lead to a very small correlation coefficient even though there is a strong relationship between the two signals. This would be clear if you computed the cross correlation *function* and the cross spectrum. There are a number of alternatives for performing the computations required in this lab. If you are familiar with the *Excel* spreadsheet, it will require the least effort on your part. You can also use built-in functions in *TestPoint* or in *Origin*. If you prefer to write your own code, Basic and Fortran are both available on the PC's in the lab. In order to perform the analysis with *Excel*, *Origin*, or your own code, you will need to transfer your data from *TestPoint*. This can be done to *Origin* by selecting the graph of your data in *TestPoint*, switching to a worksheet in *Origin* and then using either the Paste or Paste Link command. If you use your own code, you will need to save the data to a disk file in ASCII format. This can be done by dragging the disk icon from the *TestPoint* "stock" into the action list and providing an appropriate name for the file. If you have difficulty setting up the data analysis consult with the instructor or a TA. You can use **noise.tst** to acquire the data, adding any modifications that are required by your method of data analysis.

### PROCEDURE

#### Set up the resistance bridge

Use the small transformer, the thermistor, and a decade resistance box to connect a bridge as shown.  $R_T$  is meant to be the thermistor. For the "drive" voltage ( $V_{in}$ ) use a sine wave from your signal generator at a frequency of a few hundred Hz. Use a coax "T" to connect the same signal to the reference signal input of the lock-in *or*, if you use a generator that also has a fixed amplitude square

wave output, connect it to the lock-in reference input. Connect the output terminals ( $V_{\text{out}}$ ) to the signal input of the lock-in. Is there any reason to select one side or the other to connect to the lock-in ground?



### Adjust the lock-in phase

Make certain that the bridge is *not* nulled so that there is a finite signal on the lock-in. Increase the sensitivity of the lock-in until the meter shows an easily readable deflection. Then adjust the phase to maximize the signal. Push the button to change the phase by 90, increase the sensitivity, and fine adjust the phase to null the signal. Release the 90 phase shift button and the phase will be precisely set for maximum signal.

### Adjust the drive amplitude

In order to obtain the highest possible sensitivity, the bridge drive voltage should be set as high as it can be without heating the thermistor. You can test for heating by finding whether there is some drive voltage level at which the bridge balance point depends on the level. If no such voltage is found, use the maximum voltage available from the generator. (You can double the voltage by connecting the generator to only half of the transformer primary so that you will get a 2:1 step up of the drive voltage.)

### Calibrate the thermistor

Although we are primarily interested in the variations of the temperature and not its mean value, it will be useful to have at least an approximate calibration of the thermistor. You can do this by measuring its resistance at room temperature and at your body temperature. Assume that the room is at approximately 20C to 24C, that your body temperature is 37C (fingers are cooler, say 34C), and that the thermistor is linear in this range.

### Select sensitivity range

In order to obtain the largest possible voltage swing from the lock-in output, you will want to set the lock-in sensitivity such that the variations in room temperature will correspond to a sizable fraction of the full scale output range. However, if the sensitivity is set too high, the output will go off scale and you will not collect data. Place the thermistor bridge on the work bench where you intend to make measurements and watch the meter. If it is biased to one side of null, adjust the decade resistor to bring it near center. If the voltage swings are then very small, increase the sensitivity. If the meter is

swinging off scale at times, reduce the sensitivity. It may be necessary to watch the output for a minute or more to be certain of the size of the variations. The system can be sensitive enough to detect whether you are standing next to it; this means that the null also depends on where you are. An improper null will show up as a DC contribution to the signal, which in turn limits the dynamic range of the data.

#### Select filter time constant

From your observations above, you should have some idea of the rate of change of the room temperature variations. Any fluctuations at periods shorter than a few seconds are probably due to either the inherent noise in the electronics or a stray 60 Hz signal. There will be a substantial separation in frequency between these "noise" signals and the true room temperature variations so that you can further enhance your signal to noise ratio by selecting the longest appropriate time constant for the lock-in filter. State the time constant which you used and give your criterion for selecting it.

#### Record the temperature

Now you should be ready to use *TestPoint* to record the temperature as a function of time. Select the A/D icon and set it to record at least 4096 points. In order to avoid "aliasing" you must sample at least two times per filter time constant. This may not be a sufficiently long record to include the longest period fluctuations in temperature. If so, you will need to use a longer filter time constant and a slower sampling rate. Before spending the time to collect a long time series of data, you should test your procedures on some shorter records. Notice that the time variation is sufficiently slow that you would need to record data for more than 15 minutes to include all possible periodicities. (The largest periodic term will be at a period of 24 hours and there will likely be an annual term as well.) However, in order to complete the experiments below before the end of the laboratory period (before the end of the year) you will be forced to use shorter records. If you are certain that your technique is working properly, records of 15 to 30 minutes will be the longest you can obtain. Note that the apparatus is sensitive enough to detect the temperature rise from the proximity of your body. Don't move around while taking data!

#### Plot the data; examine the spectrum

If there are any large peaks in the spectrum make a note of their frequencies.

#### Record simultaneous records and find cross correlation coefficients

Join with another group to record their lock-in output and yours at the same time with the two thermistors at locations about 1 meter apart. The recording times would be guaranteed to be "simultaneous" if both data series were recorded on the same computer. However, if both records are started at the same time, this should be more than accurate enough for the slow variations that you will be recording. With the two records you can now compute the cross correlation coefficient,  $\rho$ . The algebraic expression for  $\rho$  is,

$$\rho = \frac{C_{xy}}{\sigma_x \sigma_y}$$

$$C_{xy} = \frac{1}{n} \sum_{i=1}^n (x_i - \bar{x})(y_i - \bar{y})$$

$$\sigma_x = \sqrt{\sum_{i=1}^n (x_i - \bar{x})^2}$$

$C_{xy}$  is called the “covariance” of the two data series by analogy with the “variance” of each,  $\sigma_x^2$  and  $\sigma_y^2$ . You could use a series of math icons to perform this computation directly in *TestPoint*. If you import the data directly into *Excel*, select “Tools” from the main menu, then “Data Analysis” and finally correlation. With the correlation dialog box showing, you can use the mouse and our keyboard commands to select the appropriate columns for input and output of the computation. If you use *Origin*, you will need to combine the covariance computation for the two data series with the sum of squares (*ss*) computation to determine the  $\sigma$  for each data series individually. Then use the algebraic operations icon to subtract the mean from the data series. With the means subtracted from both data series you can now compute the correlation coefficient, .

Repeat the measurements and calculations at increasing separations between the two. You might find that  $\rho$  changes sign with distance. What could this mean (other than that your data is bad)? Finally, plot  $\ln(\rho)$  vs. distance to see if it is approximately exponential. What is the minimum number of points required? If it is exponential, then determine the approximate "correlation length" by using the "curve fit" icon to perform a linear fit.