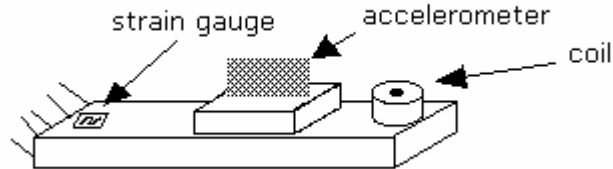


Project 2
Acceleration Measurement

For this project, each group will investigate the acceleration of the cantilever beam by comparing the signal from a commercial grade accelerometer chip to a waveform for acceleration that you will find using the strain gauge and coil already mounted to your beam.

In this project you will be comparing the acceleration of the beam found using three different devices.



When you connect each of these devices to the scope, you get a voltage signal. The strain gauge output is proportional to beam position, while the pickup coil output is proportional to beam velocity. The accelerometer gives a signal proportional to the acceleration. We know that the unit of displacement is meters, m; the unit of velocity is m/s; and the units of acceleration is m/s^2 . We also know that all of these signals are time dependant functions that look like decaying sinusoids. In this project, we will take data from all three devices, calibrate them, convert all three to acceleration, and compare the results.

Part 1 of this handout discusses how to use the accelerometer chip (available from your instructor) to find the acceleration of the beam directly. Part 2 discusses methods of using measurements taken by the strain gauge (which is proportional to the displacement of the beam) and measurements taken by the coil (which is proportional to the velocity) to derive a signal equivalent to the acceleration of the beam. Part 3 discusses comparing the acceleration signals. Part 4 discusses some ideas for extra credit. Appendix I contains a task list for the project. Please note that the handout for the project (parts 1-4) contains background information that you need, but the task list provides the order in which the tasks should be performed. Appendix II contains what your appendix for the project report should contain. Appendix III outlines the project report. For additional background information consult the links and spec sheets on the course links page: <http://hibp.ecse.rpi.edu/~connor/education/EILinks.html#Proj2> .

Note: Many groups end up taking their data more than once for this experiment. It is a good idea simply to practice the first time. Get your circuits working. Take practice calibration measurements. Make sure you are absolutely sure you know all the data you need to take. Then, when you are ready, all the data can be taken in about 15 minutes under the same conditions.

Part 1 --Building an AD Accelerometer

This section discusses how to build and calibrate an accelerometer circuit that you can use to find the acceleration of the cantilever beam directly.

The Circuit

The following circuit can be used to create a signal proportional to the acceleration of the beam using a commercial accelerometer.

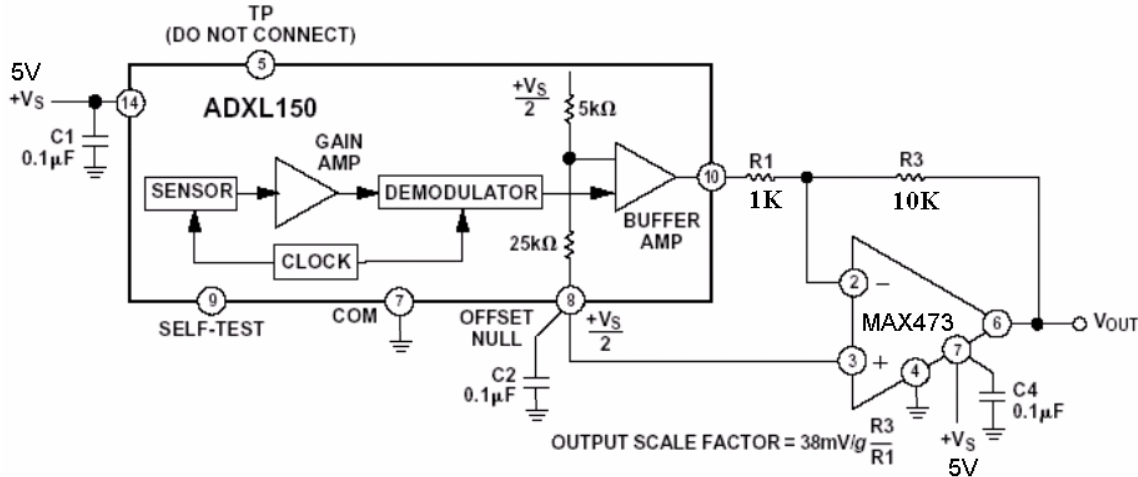
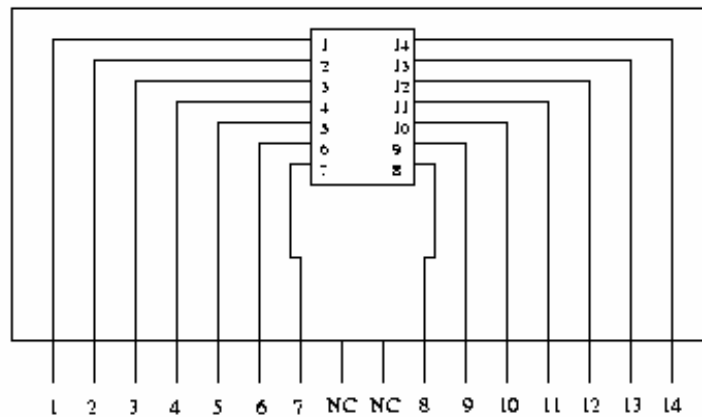


Figure 15. Using an External Op Amp to Increase Output Scale Factor

The accelerometer is surface mounted and, thus, cannot be plugged into a protoboard. It also needs to be oriented vertically in order to record the acceleration of the beam. Therefore, we have mounted the chip on what is called a surfboard. You will have to be careful that you connect things correctly, since the surfboard has 16 pins and the accelerometer has only 14. (We do not use the two in the center). The pin numbering is given in the figure below.



NC: Not Connected

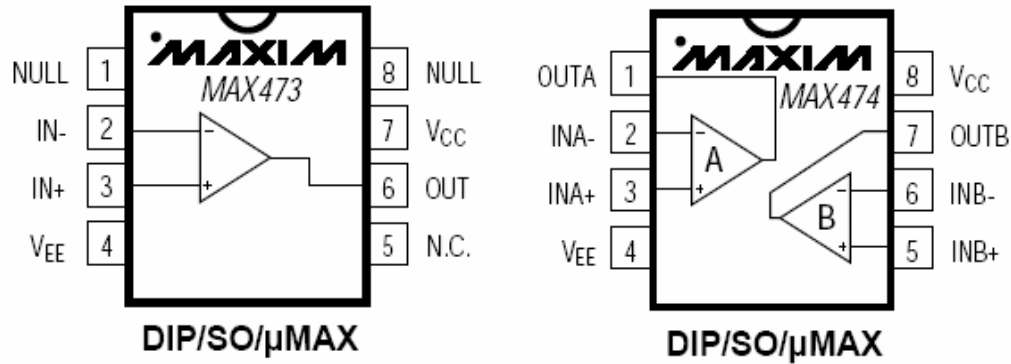
Instead of the 741 op amp from your kit, we will provide you with an op-amp from Maxim, the MAX473. We need to use this much more expensive op-amp because we need the output voltage to be able to cover the entire range from the negative to the positive power supply voltages. We call this a rail-to-rail op-amp. We do not use an equal negative and positive voltage to provide the power source for this op-amp. We connect it to ground and 5 volts. As shown in the following figure, the pinout for the single op-amp chip, the MAX473, are the same as in the circuit shown in figure 15 from the ADXL150 spec sheet. The pinout for the double op-amp chip, the MAX474, are also shown below. If you have a MAX474 chip, be careful to use the correct pins. (The circuit will still somewhat work if it is wired incorrectly, but it will not amplify.) The spec sheets for the ADXL150 and the MAX473 can be found in the spec sheets for these chips located on the links page.

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Obtain an accelerometer from a TA or instructor. Build the circuit. Be very careful with the accelerometer. It is mechanically robust, but the surfboard is not. Also it is electrically sensitive. If you apply the wrong voltages, you may damage it. (Circuit components cannot be repaired). *Please have a TA or instructor check your circuit before applying power.* Mount your small protoboard to the end of the beam and test to see if your circuit is working. The accelerometer signal will have a DC offset and it will be fairly noisy. Where is the noise coming from?

Important Note: This experiment does not work unless all your measurements are taken when the ‘effective mass’ at the end of the beam is the same. You may recall from experiment 4 that adding additional mass to the end of the beam slows down the frequency. This means that you need to have the accelerometer mounted to the beam when you take all your measurements or else your frequencies (and data) will be off. The wires attached to the accelerometer circuit also contribute to the effective mass at the end of the beam. Heavy connectors tend to add extra weight and make the damping excessive. Supporting the wires by hand (every time you take data) can help alleviate this problem. A better method is to take long wires (cut from the spool at the front of class) and use them to make connections to the accelerometer. Make sure these wires can move freely to minimize their influence on the data.

We do not have enough accelerometer chips for all three sections. Carefully mark your protoboard with the location of the surf board and return the accelerometer at the end of each class. **You must return the accelerometer at the end of each class period. If you do not do so, you will lose 5 points on this project.**

Calibration

The signal you get from the accelerometer circuit is not acceleration in m/s^2 . It is a voltage proportional to the actual acceleration. In order to find the actual acceleration, you must calibrate the measurement. If you look closely at the circuit diagram, you will see an output scale factor. This gives the relationship between the voltage you read at the output of the circuit and the actual acceleration the chip is experiencing.

According to the given output scale factor, $V_a[t] = \frac{38}{g} \frac{R3}{R1} a_b[t]$. In this equation, g is the acceleration

due to gravity, $9.8 m/s^2$, and the voltage from the accelerometer circuit, V_a , must be expressed in millivolts. The expression $R3/R1$ represents the gain of the MAXIM op-amp circuit. Note that the circuit contains an inverting amplifier. Since phase shift is important to us in this experiment, we need to multiply by -1 , to get the actual effect of the inverting amplifier on the output of the accelerometer chip. Thus, we

get: $a_b[t] = -V_a[t] \frac{9.8}{0.038 \left(\frac{R3}{R1} \right)}$. Using this scale factor, you can calculate $a_b[t]$ in m/s^2 using the

ratio of the two resistors and the voltage from your circuit in volts. You will need to include this calibration constant and how you found it in the appendix of your report. See appendix II of this handout for details.

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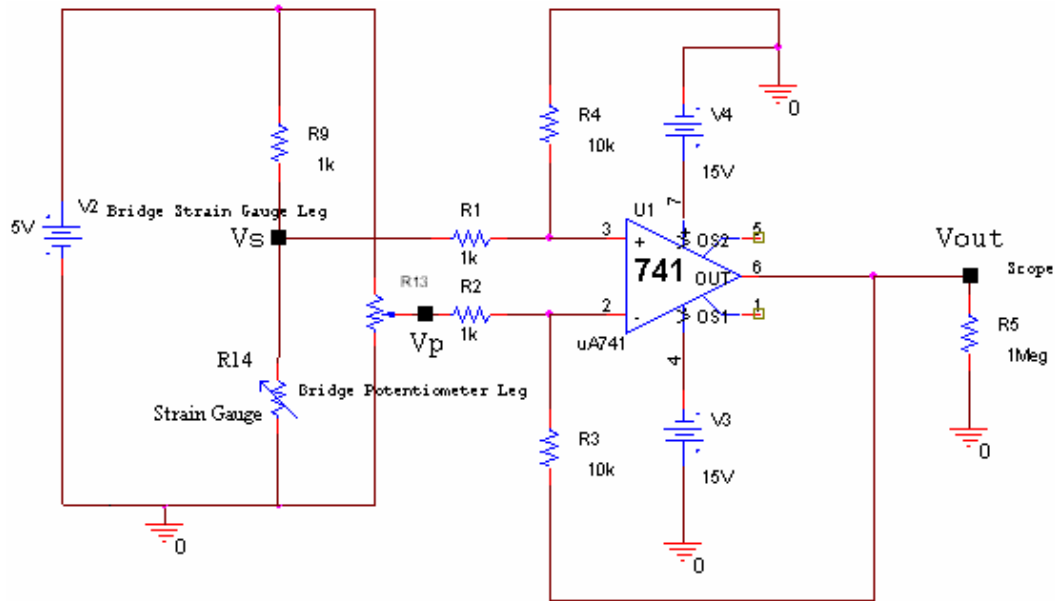
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Part 2 – Finding Acceleration using the Strain Gauge and Coil Outputs

This section discusses how to determine acceleration using the strain gauge and coil sensors you have used already in experiments 4 and 5.

Circuits

You have already built a bridge to measure the output from the strain gauge. For this project, we will add a differential amplifier to the bridge. It will subtract the two input signals to the op-amp. This means you will be able to read the difference between the two legs of the bridge with only one scope channel attached to the output of the op-amp circuit. It will also make the signal larger. The amplified strain gauge bridge circuit is pictured below. In this section, you will also use the coil sensor that you used in experiment 5. This sensor can be hooked directly to the scope.



Comparing the strain gauge and coil signals

Build the amplified strain gauge circuit. Balance the bridge. (It is very important that you balance the bridge before you take any measurements. Don't use AC coupling. Since your bridge is now hooked to a difference amplifier, balancing the bridge is much easier. You only need to adjust the pot until the output signal has no DC offset.) Look at the output at points Vs, Vp and Vout. According to the equation for the differential amplifier, the output at Vout should be

$$V_{out} = \frac{10k}{1k}(V_s - V_p)$$

Is the output your circuit creates consistent with this equation? Your circuit will probably have some losses because the frequency of the cantilever beam is so low. What is the actual gain of the circuit? Leave the output signal, Vout, hooked to channel 1 of the scope.

Now hook the coil sensor directly to channel 2 of the scope and observe the strain gauge and coil signals simultaneously. What do you notice about the relative amplitudes of the two signals? What is the phase difference between them? The strain gauge signal should be proportional to the change in position at the end of the beam. The coil measurement is transient by definition because the coil only produces a voltage when the beam is oscillating. Therefore, the output from the magnetic pickup coil should be proportional to the velocity of the beam. What should the phase difference be if the two signals are proportional to position and velocity, respectively?

It is important that you get the phase difference correct. Since the velocity of the beam (coil) is the derivative of the displacement of the beam (strain gauge), the signals should look like a cosine (coil) and a

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sine (strain gauge). If the coil signal looks like a negative cosine relative to the strain gauge signal, reverse the coil leads to the scope. [These are wired somewhat arbitrarily and do not necessarily conform to the standard color conventions.]

Finding the Amplitude Ratio

Calculate the ratio of the amplitude (or V_{p-p}) of the amplified strain gauge signal to the coil signal. We will call this value the amplitude ratio and denote it by R_A for the rest of this project handout.

$$R_A = \frac{A_{\text{strain-gauge-signal}}}{A_{\text{coil-signal}}} = \frac{A_{sg}}{A_c}$$

This ratio will need to be around 1 to successfully complete the experiment. If the amplitudes are not about the same, alter the value of the resistors in your differential amplifier. Do not forget that you must alter these resistors in pairs. Note that getting an exact ratio of 1 to 1 is extremely difficult because every time the frequency of the beam varies even a little, the ratio will change. It is best to get it close to one and then, calculate the exact ratio of the two, R_A , right before you take your final data.

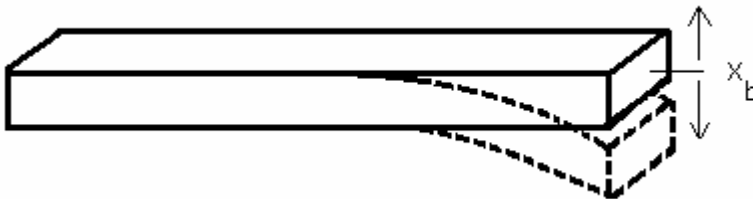
You will need an image of the data you use to find the amplitude ratio. Make sure this image contains the peak to peak voltage of both signals. Since the signals will vary depending upon how the beam is hooked up physically, you will want to take your final version of this image at the same time that you take your final data. For now, produce a Lissajous pattern that shows one amplitude on the vertical axis and the other on the horizontal axis. If the amplitude ratio is reasonably close to one, this should look like a circle. Since your beam is moving very slowly, you will have to use the AUTOSTORE feature on the scope to get a picture of the complete signal.

It is very important to hook up the strain gauge and the coil, mount the accelerometer, balance the bridge, take a picture of the transient signal using the Agilent software (for verification), and recalculate the amplitude ratio each time you take data using the three sensors. Any changes to the physical beam system (see **Important Note** in part 1 on page 3) can alter this ratio substantially and throw off your data. You will need a *verifiable* number (with a picture to back it up) for this ratio to do the calibration of the three signals and complete the project.

You will need to include a picture of the two signals with matched amplitudes and the Lissajous figure in the appendix of your report. See appendix II of this handout for details.

Calibration of the Strain Gauge Signal

We are given that the strain gauge signal is proportional to the displacement at the end of the beam, $x_b[t]$:



We also know (from physics) that: $v_b[t] = \frac{dx_b[t]}{dt}$ $a_b[t] = \frac{dv_b[t]}{dt} = \frac{d^2x_b[t]}{dt^2}$

We can measure the displacement of the strain gauge directly using a ruler. If we place the ruler at the end of the beam, move it up and down, and record both the distance and the voltage, we can use the data to find a direct relationship between the signal from the strain gauge and the actual displacement at the end of the beam. If we plot these two quantities and find the slope of the line, m , in meters/Volt. We can use it to convert the strain gauge signal to meters and use two derivatives to find the acceleration.

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$$x_b[t] = mV_{sg}[t] \quad v_b[t] = m \frac{dV_{sg}[t]}{dt} \quad a_b[t] = m \frac{d^2V_{sg}[t]}{dt^2}$$

Calibration of the Coil Signal

Unfortunately, we cannot measure the velocity of the beam directly, so we cannot use the same method as we did for the strain gauge to relate coil voltage to the velocity at the end of the beam. We need another way to map the voltage to velocity in m/s. If we use our amplitude ratio, R_A , to relate the amplitude of the coil and strain gauge signals, we can derive a calibration constant for the coil.

If we assume that we can ignore the decay, we can express the two signals as follows:

$$V_{sg}[t] = A_{sg} \sin(\omega t) \quad \text{and} \quad V_c[t] = A_c \cos(\omega t)$$

We know that the coil signal, V_c , is a cosine wave because the derivative of the displacement (sine) is the velocity (cosine). We don't know the amplitudes of either of the two signals, but we know that they have the same frequency.

We also know from physics that $v_b[t] = \frac{dx_b[t]}{dt}$ and from the previous section that $x_b[t] = mV_{sg}[t]$.

$$\text{Therefore, } v_b[t] = \frac{dx_b[t]}{dt} = m \frac{dV_{sg}[t]}{dt} = mA_{sg} \frac{d \sin(\omega t)}{dt} = mA_{sg} \omega \cos(\omega t)$$

We can determine the amplitude ratio from our experimental data. This allows gives us the relationship between the two amplitudes: $A_{sg} = R_A A_c$. We also know that the coil signal is a cosine wave, so $V_c[t] = A_c \cos(\omega t)$. If we substitute, we get $v_b[t] = mR_A A_c \omega \cos(\omega t) = mR_A \omega V_c[t]$.

To find acceleration using the coil, we must multiply the coil signal by the calibration constant, $mR_A \omega$, to convert it to meters/sec and take a single derivative. $a_b[t] = \frac{dv_b[t]}{dt} = mR_A \omega \frac{dV_c[t]}{dt}$. (Remember that ω is $2\pi f$.)

Finding Calibration Constants

Once the amplitude ratio has been determined, we can find the actual calibration constants for the strain gauge and coil. First, mount the accelerometer circuit to the beam and attach the wires. Since the coil calibration constant depends upon frequency and the frequency changes when the mass at the end of the beam changes, it is important to mount the accelerometer before the calibration information is taken. (See **Important Note** in part 1 on page 3) Take data relating the voltage of the amplified bridge circuit to the displacement at the end of the beam. You can use the scope or DMM to measure the voltage and a ruler to measure the change in height of the end of the beam. In order to ensure a linear relationship, be careful not to over-deflect the beam. Plot the data, verify that the relationship is linear, and determine the slope, m . Include this information in your report.

Now you can calibrate the coil. Hook up the coil and the strain gauge, balance the bridge, and determine the amplitude ratio, R_A . The only additional information you need to find the calibration constant of the coil is the frequency of your signals. Use your output to find the frequency in Hertz. Calculate ω and determine the calibration constant for the coil.

You will need to include the calibration constants and how you found them in the appendix of your report. See appendix II of this handout for details.

Part 3 – Comparing the Signals

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This section describes how to take and analyze your data using Excel. Your final comparison of the data will be in units of acceleration, m/s^2 .

Taking the Data

Once you have everything working and you know your calibration constants, you can take your data in Excel and compare the two signals. Since we have only two channels on the scope, you will need to take two sets of data: one comparing the strain gauge signal to the accelerometer signal and one comparing the coil signal to the accelerometer signal.

You are taking the derivative of a sinusoid, so you want to have data as close to a sinusoid as possible. You may notice that the coil sometimes generates a signal that is almost triangular. This is caused by secondary oscillations. Move the beam gently in order to avoid this shape. (If your coil is giving a signal that is not symmetric, then your magnet is not positioned far down enough in the coil. Try adjusting it. If the problem still does not go away, try another beam.) The signal from the strain gauge and the accelerometer are generally sinusoidal. The accelerometer signal will be noisy because of the internal cantilevers. If it is too noisy, change the resistors in the MAXIM op-amp circuit to decrease the gain.

Before you take your data, you should verify that the phases are as expected. The displacement should be 180 degrees offset in phase from the acceleration because of the double derivative. Therefore, the strain gauge signal and the accelerometer signal (which is inverted) should be in phase. [Two derivatives causes a 180 degree phase shift, which is equivalent to the inversion.] The acceleration wave should be a cosine relative to a velocity sine wave because of the single derivative. Because of the inversion, however, the signal from the accelerometer should appear like a negative cosine relative to the coil signal.

In order to get Excel to take a decent derivative, you need to give it enough information. When you take data from the two sets of signals, try to capture the sinusoidal nature of the signals, and not the decay. Capture between 3 and 6 cycles of the signals at a point when they have a decent amplitude and look sinusoidal. Remember that if your wave does not look like a sinusoid, its derivative will not be a sinusoid and you will have trouble getting the data to work out. Also, you will need to have enough data points per cycle to take a decent derivative.

To take data in Excel, run the special toolbar version of Excel located in the applications folder on the desktop. When the toolbar loads, hit the button with the small green sinusoidal signal on it. A window will pop up asking for a number of data points. More points is safer than less. Your data will be placed automatically into a spreadsheet and a graph showing the two signals will be automatically created. The accelerometer signal will have a DC offset.

When you have successfully taken the raw data, you should have two spreadsheets: 1) data from the strain gauge and the accelerometer versus time, and 2) data from the coil and the accelerometer versus time. You will need to include an Excel plot of each of these sets of raw data in the appendix of your report. See appendix II of this handout for details.

Applying Calibration Constants

Once you have taken the data, you need to calibrate all three devices. First, you will have to subtract any DC offsets that exist on the signals. Then you can multiply each signal by its appropriate calibration constant. You will have a different constant for the signal from the strain gauge, the coil, and the accelerometer. Part 1 of this handout describes how to find the correct constant for the accelerometer. Part 2 describes how to find the calibration constant for the strain gauge and the coil. Make sure that your constants convert the signals correctly to meters, meter/sec, and meters/sec², respectively. When you have successfully applied the constants, you should have two sets of data.: 1) the calibrated strain gauge signal in meters and the calibrated accelerometer signal in meters/sec² and 2) the calibrated coil signal in meters/sec and the calibrated accelerometer signal in meters/sec². Note that there must be two different sets of data because you can only read two signals at a time with the scope. The next step is to take one derivative of the coil signal and two derivatives of the strain gauge signal. This will enable you to compare them to the calibrated acceleration signals.

Taking the Derivatives using Excel

Because we need to preserve the phase information, taking our derivatives with excel involves two steps: using the SLOPE function to take the derivative of a signal and using the AVERAGE function to adjust the phase of the signal we are comparing the derivative to. This means that each time you use the SLOPE function on the strain gauge or coil signal, you will need to apply the AVERAGE function to the accelerometer signal. You will need to apply the SLOPE function twice to the strain gauge signal and once to the coil signal to get acceleration.

The Slope Function

The slope function in Excel (described in detail on the following page) can be used to take a derivative. It has the form “=SLOPE(B1:Bn, A1:An)”, where the A column is the x coordinate of the signal (time), the B column is the y coordinate, and n is the number of points to use for each slope calculation.

SLOPE

Returns the slope of the linear regression line through data points in known_y's and known_x's. The slope is the vertical distance divided by the horizontal distance between any two points on the line, which is the rate of change along the regression line.

Syntax

SLOPE(known_y's,known_x's)

Known_y's is an array or cell range of numeric dependent data points.

Known_x's is the set of independent data points.

Remarks

- The arguments must be either numbers or names, arrays, or references that contain numbers.
- If an array or reference argument contains text, logical values, or empty cells, those values are ignored; however, cells with the value zero are included.
- If known_y's and known_x's are empty or have a different number of data points, SLOPE returns the #N/A error value.
- The equation for the slope of the regression line is:

$$b = \frac{n \sum xy - (\sum x)(\sum y)}{n \sum x^2 - (\sum x)^2}$$

Note that the function uses a regression to determine a value for the slope at each point in the derivative based on at least two points in the function. If you use successive points, “=SLOPE(B1:B2,A1:A2)”, then the output will be a set of points corresponding to the slope of each pair of points in the data. Since your data contains noise, the slope between two successive points will not be representative of the shape of the curve as a whole. To get a good derivative in spite of the noise, you can use any number of points to determine the slope at each point. It is best to start with about 10 points in (X,Y) for each point in (X,Y'). Adjust the number of points to smooth out the noise and get a good derivative. Depending upon how many cycles you have and how many data points you used, this value can get very high (more than 50).

Determine the value of the first point, C2, using = SLOPE(B2:B11,A2:A11). (Note: We are using ten points as an example. You may need a different number depending upon your data.) Copy the equation

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from C2 into all additional columns in C. Excel will place the equation in each cell, adjusting the values from which it determines the point based on the index. [C3 will have = SLOPE(B3:B12,A3:A12), Cn will have = SLOPE(Bn:Bn+9,An:An+9).] Graph the data. Adjust the value of n until your derivative looks fairly smooth. Note: The second derivative of the strain gauge signal may not require as many points, since the noise has already been smoothed out.

The Average Function

When you take derivatives using Excel, the regression tends to shift the phase of the derivative signal. We have no need to take the derivative of the acceleration signal, so it ends up without the phase shift introduced by the derivative. We can use the AVERAGE function in Excel to add a comparable phase shift to the acceleration signal. This function will also (conveniently) help smooth over the noise in the (usually very noisy) acceleration signal. Take the calibrated acceleration data and average it over the *same number of points* you used to take the derivative of the other signal. For example, if you used ten points to take your derivative and your calibrated acceleration data is stored in column E, you would use the equation “=AVERAGE(E2:E11)” to create a column of the smoothed and averaged acceleration.

Taking the Derivatives

For the coil data, you will have to take one derivative. Take the derivative of the calibrated coil signal using the SLOPE function to get acceleration. Adjust the number of points until it looks like a decent sinusoidal signal. Apply the AVERAGE function to the calibrated accelerometer signal using the *same number of points* you used for the SLOPE function. If you do this correctly, the two signals should be at least comparable in amplitude and roughly the same phase. If you have a large discrepancy, check your units.

For the strain gauge data, you will have to take two derivatives. Take the first derivative of the strain gauge signal using the SLOPE function to get velocity. Adjust the number of points until it looks like a decent sinusoidal signal. Create a plot of this signal and include it in your report. (It is important to look at this signal to verify that the first differentiation is good before you apply the second one.) Apply the AVERAGE function to the accelerometer signal using the *same number of points* you used for the SLOPE function. Take the second derivative of the differentiated strain gauge signal using the SLOPE function to get acceleration. Adjust the number of points until it looks like a decent sinusoidal signal. Apply the AVERAGE function a second time to the accelerometer signal using the *same number of points* you used for the second application of the SLOPE function. If you do this correctly, the final two signals should be at least comparable in amplitude and roughly the same phase. If you have a large discrepancy, check your units.

You should now have two plots: 1) the calibrated accelerometer signal (averaged once) together with the calibrated coil (differentiated once), and 2) the calibrated accelerometer signal (averaged twice) together with the calibrated strain gauge (differentiated twice). You should also have a plot of the calibrated strain gauge signal differentiated once.

Data Comparison

When you have successfully calibrated your signals, taken the correct derivatives, and adjusted the acceleration signal, you should have two sets of signals that represent the acceleration at the end of the beam in m/s^2 . Do the numbers you came up with make any sense at all? Do you expect to find an acceleration much less than or much greater than $1g$ (9.8m/s^2), for example? Are the phases consistent?

You may not get perfect data. If the amplitude match is within a factor of 10, it is acceptable, as long as you applied the correct procedure. Often it is because of factors that are out of your control (like the particular accelerometer you used) that interfere with the quality of your data. We want to see honest data and a good discussion of possible error sources in your report. Don't forget to compare both the amplitude and phase of your signals.

Additional Questions

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In the conclusion of your report, we want you to consider the following:

Accelerometers are used extensively these days in cars. How would you use accelerometer signals in a car to enhance the driving experience? If there are so many accelerometers in present day cars, why is acceleration typically not displayed for the driver?

If you had a portable accelerometer, what would you do with it?

Details about the report conclusion are contained in appendix III of this handout. You will need to include an Excel (or Maple) plot of your final data in the appendix of your report. See appendix II of this handout for details.

Part 4 – Extra Credit

The following discussion is offered for those who would like to go beyond the minimum requirements for the project and receive extra credit.

Really Good Data

If your data is especially consistent you are eligible for extra credit. Take time in the extra credit section of the report to show that your calibration constants were found correctly and that they actually gave rise to the good data. Do not come up with mysterious factors to make the data look good. This will not get you any extra credit and will likely count against you on the remainder of the report.

Compare all three signals on the same plot

This is more complicated than it seems. It would be nice to see all three signals (from the strain gauge, from the accelerometer, and from the coil) on the same plot in order to do a real comparison. We cannot, however, do this directly because we only have two scope channels. You can use Excel to get the three signals on the same plot if you can determine a way to match the accelerometer signals from the two data samples. If you can find a location where the amplitudes of both accelerometer signals are the same, you know that you have found a point in time at which the two signals can be matched. By translating the time data from one set of signals so that the accelerometer signal amplitudes match in both sets, you can obtain a plot with all three signals on it. Provide a plot with all four signals showing how well you were able to match the two accelerometer signals.

Compare Velocities

You must calculate acceleration of the end of the strain gauge, but what about velocity? If you take the signals from the strain gauge and the coil simultaneously, you can calibrate them, take the derivative of the strain gauge signal, and determine the velocity in m/s of the end of the beam.

Build a Circuit to take the Derivative(s)

The derivative of a signal can be taken in real time using either an op-amp differentiator (active differentiator) or a simple high pass filter (passive differentiator). Both will modify the amplitude of the signal. The active differentiator also introduces an inversion. You can add one of these two devices to your circuit(s) to take the derivative electronically. It is possible to make three different comparisons using these circuits.

- Take one derivative of the strain gauge signal and compare it to the coil signal.
- Take one derivative of the coil and compare it to the accelerometer.
- Take two derivatives of the strain gauge and compare it to the accelerometer.

You can simply demonstrate that the signals are proportional (display correct phase) using an Agilent picture. If you'd like, you can go into more detail and determine the calibration constant for each signal. Then you can use Excel to convert the data to m/s or m/s². (Don't forget that the differentiation circuits introduce an additional change in amplitude.) The more you do, the more extra credit you are eligible for.

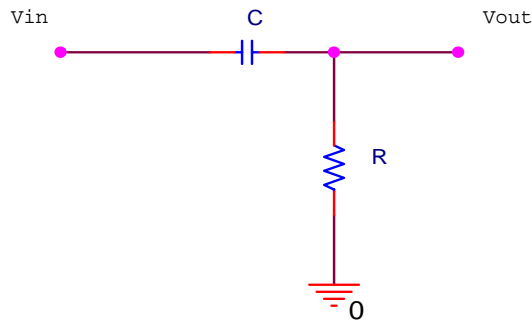
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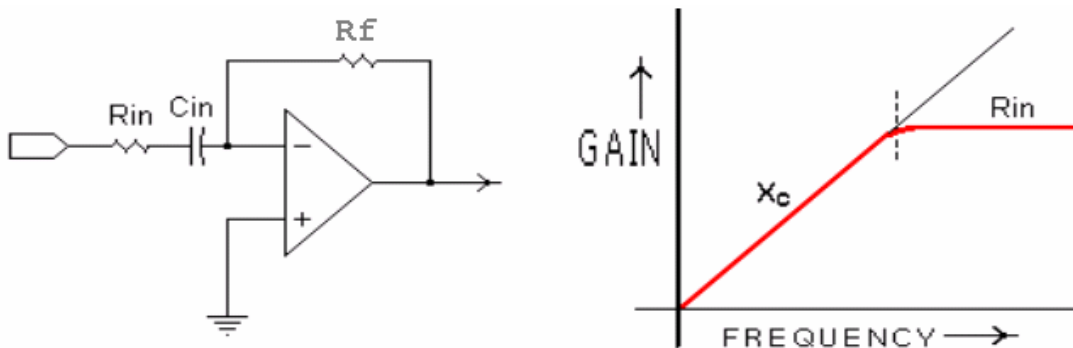
The circuit pictured below can be used as an approximate differentiator



The transfer function for this circuit is given by: $H(j\omega) = \frac{j\omega RC}{1 + j\omega RC}$. You know from experiment 2

that the transfer function will have a magnitude of 1 at high frequencies, but it will be governed by the following equation at low frequencies: $H_{LO}(j\omega) = j\omega RC$. This is equivalent to the equation of an ideal differentiator without the inversion. Since your signal has a frequency of only around 20 hertz, this simple circuit may give you an adequate differentiation. Note that this circuit will differentiate the signal and also multiply it by RC. If you want to mathematically remove the amplitude change contributed by the circuit, but preserve the differentiation, you must divide your result by RC.

The following circuit is the active differentiator we covered in experiment 5.



The transfer function for this circuit is given by: $H(j\omega) = -j\omega RfCin$ at frequencies substantially below $1/(2\pi RinCin)$. Note that this signal will differentiate the signal and also multiply it by $-RfCin$. If you want to mathematically remove the effect of the gain, but preserve the differentiation of the circuit, you must divide your result by $-RfCin$.

You know from experiment 5, that the differentiator does not differentiate at all frequencies. The same is true of the approximate differentiator. (It is even more sensitive to frequency.) In order to avoid wasting your time randomly swapping out components, it is best to build a simple test circuit in PSpice to find a good choice for the values of your components. Build either one, the approximate or the active differentiation circuit, in PSpice using a sinusoidal source with the approximate amplitude and frequency of the signal you want to differentiate. Put a 1Meg ohm resistor between the output of the circuit and ground to represent the load on the circuit from the scope. Pick some values for R and C or Rin, Cin, and Rf using components you have in your kit. Run a transient. Are the input and output signals out of phase by about 90 degrees? If the absolute value of the phase change is not near 90 degrees, the signal is not being differentiated. Does the output have a reasonably high amplitude? If the amplitude is too small, the signal will be lost in the noise. You can now adjust the components experimentally to find a circuit that gives a reasonable differentiation of the signal at the input frequency.

Calibrate the Accelerometer Chip

In the spec sheet for the ADXL150 on page 12, there is a procedure that describes how to calibrate the accelerometer chip. You will get better results if your chip has been calibrated, however, it is not necessary for this project. We just accept that there will be errors due to the fact that the chips are not well calibrated. You are free to calibrate your chip and you will receive extra credit for the attempt. Note that this procedure involves building a more complicated circuit for the accelerometer.

Other Extra Credit Ideas

If you have something else you would like to try for extra credit, ask your professor.

Part 5 – Appendices

The following appendices summarize what you need to do, what the appendix of your report should contain, and what should be included in your report. Appendix I of this handout gives you a task list of things you need to do. Appendix II of this handout gives you a list of things to include in the appendix of your report. Appendix III of this handout summarizes the parts of the report.

Appendix I: Task List

- A. Build the accelerometer circuit
 - 1. Build the circuit on the small white protoboard.
 - 2. Have your circuit checked by a staff member. This is important because the accelerometer chips are expensive and easily damaged if wired incorrectly.
 - 3. Mount the surfboard to the end of your beam.
 - 4. Test your circuit to make sure that it functions.

- B. Match the amplitudes of your coil and strain gauge signals
 - 1. Build the amplified strain gauge bridge circuit
 - 2. Mount the accelerometer circuit to the beam and hook it up. (Remember different masses on the end of the beam result in different frequencies.)
 - 3. Put the signal from the amplified strain gauge (from experiment 5) on channel 1 and the signal from the coil on channel 2.
 - 4. Balance the strain gauge bridge.
 - 5. Compare the two signals when the voltage scales are the same. Adjust the resistors on the differential amplifier of the strain gauge circuit until the amplitudes of the two signals is about the same.
 - 6. Take a picture of the two signals. Make sure the amplitude or peak-to-peak voltages are indicated on the plot. Include in Appendix A. [You will need to take this picture right before you take your final data.]
 - 7. Create a Lissajous figure of the two signals and include it in Appendix A.
 - 8. Determine the frequency of your signal and write it on your plot.
 - 9. Have the plot signed.

- C. Determine your calibration constants
 - 1. Balance the strain gauge bridge.
 - 2. Use a ruler to measure the displacement at the end of the beam and the DMM or scope to measure the corresponding voltage from your strain gauge bridge. Record the voltage for at least three displacements of the end of the beam.
 - 3. Plot the relationship between output voltage and beam displacement. Find the slope of the plot. The slope relates the displacement at the end of the beam to the voltage from the strain gauge. Express this constant in meters/volt. Include in Appendix B.

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4. Use the frequency of your circuit, the amplitude ratio of the two signals, and the slope you found in 3 to relate the velocity at the end of the beam to the voltage signal from the coil. Express this constant in meters/volt-sec. Include in Appendix B.
5. Calculate the output scale factor of your accelerometer circuit. This constant relates the voltage signal from the accelerometer to the acceleration at the end of the beam. Express this constant in meters/volt-sec². Include in Appendix B.

D. Take your data

1. Using exactly the same circuits and beam that you used to determine the scale factors, attach the amplified strain gauge signal to channel 1 and the amplified accelerometer signal to channel 2. Take data with Excel.
2. Using exactly the same circuits and beam that you used to determine the scale factors, attach the coil signal to channel 1 and the amplified accelerometer signal to channel 2. Take data with Excel.

E. Analyze your data

1. Compare strain gauge and accelerometer data
 - a. Multiply your strain gauge signal by its calibration constant. This gives you the displacement at the end of the beam in meters. Take one derivative using the SLOPE function. Adjust the number of points until the derivative looks good. Plot the first derivative. Take a second derivative using the SLOPE function in Excel to find the acceleration in m/s². If the signal does not look smooth enough, increase the number of points you use in the SLOPE function.
 - b. Subtract DC offset from accelerometer voltage signal. Multiply your accelerometer signal by its calibration constant. This gives you the acceleration in m/s². Use the AVERAGE function to smooth out the acceleration signal. Do this twice and use the SAME number of points you used to take each derivative in part a.
 - c. Plot the two signals together.
2. Compare coil and accelerometer data
 - a. Multiply your coil signal by its calibration constant. This gives you the velocity at the end of the beam in m/s. Take one derivative using the SLOPE function in Excel to find the acceleration in m/s². If the signal does not look smooth enough, increase the number of points you use in the SLOPE function.
 - b. Subtract DC offset from accelerometer voltage signal. Multiply your accelerometer signal by its calibration constant. This gives you the acceleration in m/s². Use the AVERAGE function to smooth out the acceleration signal. Use the SAME number of points you used to take the derivative in part a.
 - c. Plot the two signals together.

E. Assemble the appendix (as described in appendix II).

F. Write your group report (as described in appendix III).

Appendix II: The Appendix of Your Report

The following list of items must be included in the appendix of your report, numbered and ordered as listed. This will help make sure that everyone includes everything that is required. In your report you should refer to each appendix specifically as needed to help illustrate your descriptions and conclusions. If you would like, you can include a second copy of what is in the appendix in order to better illustrate what you are trying to say, however, this is not necessary and cannot be used as a replacement for the contents of the appendix.

Appendix A: Matched Amplitudes

1. Agilent plot of coil and strain gauge signals with amplitude ratio clearly indicated
 - * plot title
 - * peak-to-peak voltage of each signal included on the plot
 - * frequency written on plot
 - * signature
2. Agilent plot of Lissajous figure of the two signals
 - * plot title

Appendix B: Calibration Constants

1. Strain Gauge
 - * plot of displacement vs. voltage for strain gauge circuit
 - * determination of slope
 - * calculation of calibration constant in meters/volt
2. Coil
 - * formula for finding calibration constant
 - * calculation of constant in meters/volt-sec
3. Accelerometer
 - * formula for finding calibration constant
 - * calculation of constant in meters/volt-sec²

Appendix C: Raw Data

1. Excel plot of amplified strain gauge voltage and accelerometer voltage
 - * plot title
2. Excel plot of coil voltage and accelerometer voltage
 - * plot title

Appendix D: Final Data

1. Excel plot of first derivative of strain gauge showing a reasonable sinusoidal signal.
 - * plot title
2. Excel plot of acceleration found using strain gauge signal and accelerometer signal in m/s²
 - * plot title
3. Excel plot of acceleration found using coil signal and accelerometer signal in m/s²
 - * plot title

Appendix E: References (Must be included.)

- * Names of websites referenced
- * Title, author, etc. of any books used.
- * Any additional references

Appendix F: Extra Credit

- * Any additional materials you would like to include for extra credit

Appendix III: Your Group Report (80 points)

Introduction (5 pts)

- * State the purpose of the project.
- * Also include at least 2 topics you studied in this course that helped you understand the project.

Theory (14 pts)

- * Describe the basic theory. What is the relationship between displacement, velocity, and acceleration? How does the accelerometer measure acceleration? How does the strain gauge measure strain? Why is the coil signal proportional to velocity?
- * Describe how the circuits work. What are the basic elements of your strain gauge circuit? What do they do? How does the accelerometer circuit work?
- * Describe the calibration process. Why are calibration constants needed? Where do the constants come from?
- * Use your own words and be sure to cite any resources you used in appendix E.
- * Demonstrate to the grader that you understand what is happening.

Initial Design (11 pts)

1. Accelerometer circuit
 - * How did you build the accelerometer circuit?
 - * Why is the signal from your circuit so noisy?
 - * What is the calibration constant for the accelerometer circuit?
 - * Include references to relevant material in the appendix.
2. Strain gauge and coil circuits
 - * How did you build the amplified strain gauge circuit?
 - * What was the initial difference in the amplitudes of the two voltages?
 - * Did you have to adjust the amplitudes? How much? What are the values of the new resistors?
 - * Why are the two signals out of phase? What is the phase difference?
 - * What is the frequency of the signals?
 - * What is the calibration constant for the strain gauge circuit?
 - * What is the calibration constant for the coil circuit?
 - * Include references to relevant material in the appendix.
3. Initial Data Discussion
 - * Does the raw data in appendix C make sense? Are the phases as expected? Are the DC offsets and amplitudes about what you would expect given the circuits that the signals came from?

Final Design and Analysis (10 pts)

1. Compare strain gauge and accelerometer signals
 - * How did you determine your final signals?
 - * Given the initial signal for the strain gauge, do your results look reasonable based on your knowledge of the relationship between position, velocity, and acceleration? Are they close in phase and amplitude?
 - * What is the maximum acceleration in m/s^2 of each signal?
 - * Include references to relevant material in the appendix.
2. Compare coil and accelerometer signals
 - * How did you determine your final signals?
 - * Given the initial signal for the coil, do your results look reasonable based on your knowledge of the relationship between velocity and acceleration? Are they close in phase and amplitude?
 - * What is the maximum acceleration in m/s^2 of each signal?
 - * Include references to relevant material in the appendix.

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Conclusions (10 pts)

1. Summarize basic conclusions
 - * Compare the acceleration found using the strain gauge to the acceleration found using the accelerometer. How close are they in phase and amplitude?
 - * Compare the acceleration found using the coil to the acceleration found using the accelerometer. How close are they in phase and amplitude?
 - * Which sensor, the strain gauge or the coil, gave a signal closer to the acceleration found using the accelerometer?
2. Address sources of error
 - * Why did the signals not match exactly?
 - * What were the sources of error in your experiment?
 - * How could you improve your process or the experiment itself to get closer results?
3. Answer the questions
 - * Use of accelerometers in cars
 - * What would you do with an accelerometer?
4. Discuss any extra credit activities you did and why.

Personal Responsibilities (4 pts)

- * How were the tasks divided between group members?

Appendices (16 pts)

- * Many of the sections contain points for things included in the appendix
- * See appendix II of this handout

Extra Credit (0-10 pts)

- * Include any details that you would like to include about anything you tried above and beyond the basics of the project.

Your grade will also include a general assessment of project understanding and quality worth up to 10 points. You do not need to write a general assessment.

Total: 70 points for project report
+ 10 points general assessment
+ 20 points attendance
= 100 points

Attendance (20 possible points)

3 classes (20 points) 2 classes (10 points) 1 class (0 points)
Minus 5 for each late
No attendance at all = no grade for project