

**Project 1**  
**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/or coil already mounted to your beam. Part 1 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 circuits you can build to produce a signal proportional to the acceleration of the beam using the strain gauge or the coil. Part 4 discusses what will be expected of you in the project write up. Part 5 the practical skills that will be tested during the practical questions. The purpose of this experiment is to compare the measurement for acceleration you have taken using the accelerometer chip to the measurement of acceleration derived from the signals from the strain gauge and/or the coil.

Minimum Requirements: Find the actual acceleration using the accelerometer. Build a circuit or derive a signal that is proportional to the acceleration of the beam using the strain gauge or the coil. Compare the two results.

*The strain gauge output is proportional to beam position, while the pickup coil output is proportional to beam velocity. Decide how you will use these two signals to determine the most accurate value for acceleration. There are at least two ways to do this. It is possible to use the signals directly to determine acceleration. It is also possible to record the signals and then process them offline to determine acceleration. The former is better for practical application, since it can be done more simply and in real time. However, the latter is generally easier since it does not require any additional circuitry to be built. It is recommended that you follow the latter approach, but you can base your design on either technique. You must discuss both approaches in your report.*

Basic Steps:

- 1) Build the accelerometer circuit
- 2) Mount it to the beam
- 3) Calibrate the position and velocity sensors.
- 4) (Build differentiator(s) -- optional)
- 5) Take your measurements and record results in Excel. It is important that you use the same beam and take measurements of signals you want to compare at the same time. Use both channels of the scope. If you wish to compare the strain gauge and the coil to the accelerometer, you will have to take two sets of measurements (gauge + acceleration AND coil + acceleration), as we have only two channels. ***Also remember that the accelerometer chip adds mass to the beam. Any measurements taken without it in place or with it in a different place will not be comparable.***
- 6) Do the calculations. The acceleration can be found directly using the OUTPUT SCALE FACTOR of the accelerometer chip. Note that g is the acceleration due to gravity. To derive the acceleration from the strain gauge and/or coil signals, you will have to work harder. You can either use the differentiator circuits, fit a decaying sinusoid to the signal and take the derivative(s) mathematically, or use the slope function in Excel.

Part 1 --Building an AD Accelerometer

The basic circuit is found in the figure below. Details can be found on the specification sheet for the accelerometer <http://products.analog.com/products/info.asp?product=ADXL250>. We do not have the op-amp indicated, but we have an equivalent (actually better) op-amp from Maxim. The Maxim op-amp is a MAX473 (see [http://dbserv.maxim-ic.com/quick\\_view2.cfm?qv\\_pk=1109](http://dbserv.maxim-ic.com/quick_view2.cfm?qv_pk=1109) for the datasheet). We must 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 a negative voltage in our circuit; rather we connect it to ground and 5 volts. The pinouts are the same as in the circuit shown in figure 15 from the ADXL250 spec sheet.

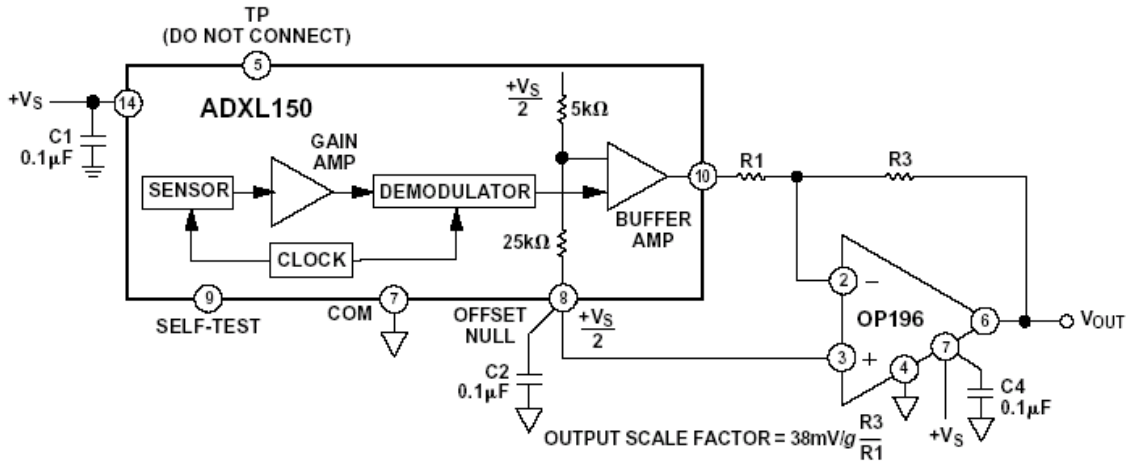
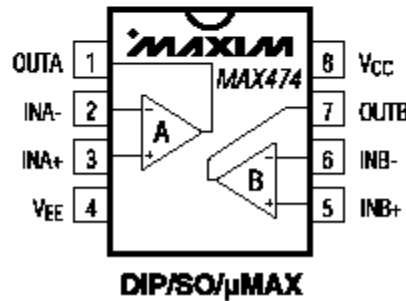
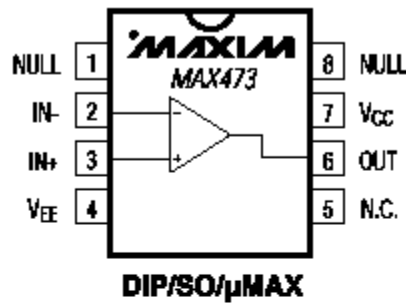


Figure 15. Using an External Op Amp to Increase Output Scale Factor



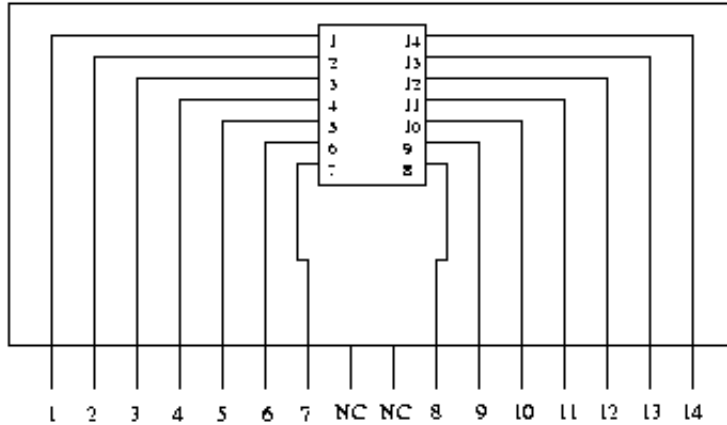
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A second complication in using the accelerometer is that it is surface mounted and, thus, cannot be plugged into a protoboard. We have mounted the chips on what is called a surfboard for this purpose. You will have to be careful that you connect things 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

Obtain an accelerometer from a TA or instructor. Build the circuit, mount it to the cantilever beam and test all three sensors to be sure they are working. *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. 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.*

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

First, you should adjust the gain of the amplifier you built previously for the strain gauge bridge. Adjust the amplification of the strain gauge until the amplitude of both signals is about the same. How much did you have to amplify the signal?

The output from the magnetic pickup coil should be proportional to the velocity of the beam. To verify this, we simultaneously record the amplified strain gauge and coil signals after we pluck the beam. The coil measurement is transient by definition because the coil only produces a voltage when the beam is oscillating. One of the best ways to show that the two signals (the amplified strain gauge bridge output and the pickup coil output) are comparable is to produce a Lissajous pattern that is close to a circle. Do this and describe how you set things up. *You must use the same scale factor for both scope channels to demonstrate that the signals are the same amplitude. Changing the scale factors on the 'scope does not change the signal.*

The strain gauge signal should be proportional to the change in position of the end of the beam. First we assure ourselves that the strain gauge output does indeed give a signal proportional to position by calibrating the output of the differential op-amp configuration vs. beam position (measured as an offset from its zero position). We check to see if the relationship is linear by plotting the position vs. voltage. If it is not, we can still use the signal as long as we recall the calibration. When you do this you should see a reasonably linear relationship because you should not cause the beam to deflect very much. Calibrate the amplified strain gauge signal level vs. beam deflection using a simple ruler. This is to establish the base signal level. Note the gain of the amplifier configuration you are using so you will also know how the unamplified signal relates to beam deflection.

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Simultaneously record the signals from the amplified strain gauge output and the pickup coil. Using the resulting plot (print it out using Agilent Intuilink), show that the pickup coil output (which we assume is proportional to velocity) and the strain gauge output (which we assume is proportional to position) are roughly consistent.

Now we can confirm that the coil output is proportional to velocity by taking the time derivative of the strain gauge signal and showing that the result is similar (proportional) to the velocity. The most accurate way to make this comparison is to capture the two signals using the Waveform option in Agilent Intuilink. When you use this option, you are transferring the actual voltages and times from the scope to the computer. There are two ways to take the derivative of the signal:

1) Mathematical: Since the signal you measure is probably a decaying sinusoid, you can find the decaying sinusoid that most closely resembles the signal without the noise (fit the curve to the data) and then, take the derivative of this function.

2) Excel: To calculate the derivative in Excel, use the SLOPE function (details can be found at the end of this hand out). If you use only two points for your regression in the SLOPE function, you may find that the signal looks like a derivative of the noise, not the signal. Try experimenting with the number of points in the regression to smooth out the noise. Note that very noisy signals, or those with many secondary oscillations may not give you good results in Excel.

*Note – The signals observed may not look exactly like a decaying sinusoid because some of the beams do not oscillate at just one frequency and the sensors may also affect the signal observed. You can ignore such irregularities in the signal. However, many of these irregularities are caused by secondary oscillations and can be avoided if you oscillate the beam gently.*

When you have completed this analysis, you should have found that the coil signal is proportional to velocity. Having confirmed that the strain gauge and coil signals are proportional to position and velocity, respectively, it is now possible to find acceleration. This can be done by taking the time derivative of the velocity signal or the second time derivative of the position signal. *Because of the noise on the signal, it is always safer to take one derivative rather than two.* Thus, it is recommended to take the derivative of the velocity to get acceleration. Note that if you have the time and the inclination, you can do both and compare the accuracy of each method.

Don't forget to take into account in your calculations that the signals you are dealing with are voltages proportional to displacement and change in displacement. Use the calibration you performed earlier and the relationship between the strain gauge and coil signals to find an appropriate constant to map this voltage to the displacement for the strain gauge or change in displacement for the coil. When you have found a measurement for acceleration, you should determine whether the numbers you come up with make any sense at all. Do you expect to find an acceleration much less than or much greater than 1g, for example?

Using the strain gauge or coil to gather data and a microprocessor (like the one used in LITEC) to perform the derivative of that data is a viable method of building an accelerometer. However, you can also build a circuit to take the derivative of your velocity signal (or two derivatives of the displacement signal) in real time. The next section discusses how to do this.

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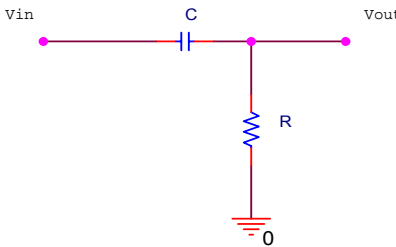
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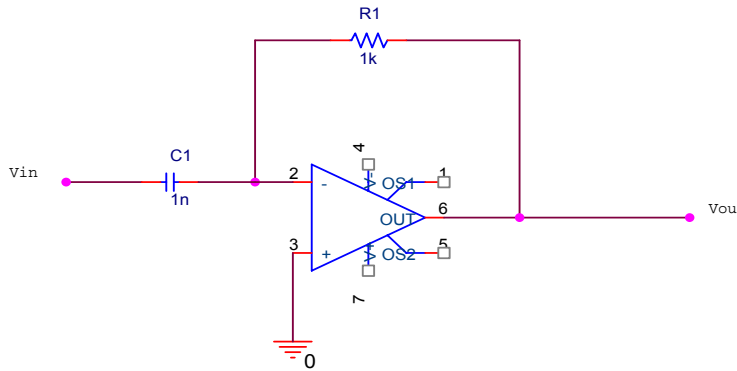
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## Part 3 – Real Time Measurement

The derivative of the velocity can be taken in real time using an analog differentiator circuit, like the ones shown below:



The first version is passive and requires only a resistor and a capacitor. The second version (next figure) also requires an op-amp. Because of the noise on the signal, it takes some time to get either one of these simple circuits to work well. Also note, that if you wish to use the strain gauge output, you must use two differentiators. *Less than 10% of the groups working on this project in the past were able to get this approach to work. If you choose this approach, begin by writing down the relationship between  $V_{out}$  and  $V_{in}$ .*



## Part 4 – Project Write Up

*Note: In this project write up, you will find the general questions found in all projects and also questions and information specific to this project. Be sure that you address everything you have been asked to do. There is a place in each section for you to add your personal comments and clarifications of the tasks to be performed. Also, this project does not require much original design. Rather, it is the first activity of this term in which several different experimental systems must be made to work together.*

1. Introduction -- Introduce and describe the goals of your project. (2 pts)

*Application Goal: Using the strain gauge and/or magnetic pickup coil output, develop and implement an approach that gives a reasonably accurate measurement of the cantilever beam acceleration. Compare the performance of your acceleration measurement with the output of a commercial accelerometer from Analog Devices.*

*Educational Goals: Find the amplification needed to make the level of the strain gauge output comparable to that seen with the magnetic pickup coil. Find a signal proportional to acceleration, even though we have no sensor whose output is directly sensitive to acceleration. Use a differential amplifier and a bridge circuit in a practical application. Identify key issues and problems, particularly those associated with combining two electrical systems such as a strain gauge bridge and an amplifier. (For example, problems can include noise, power dissipation, load impedance.) List at least two topics from this course that play a significant role in this project.*

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Comments:

2. Design -- Describe your project design, how it works, how you came up with this particular design, and discuss potential problems. This last item is very important. You should not expect your initial design to be a complete success. Remember that you will have the opportunity to make changes while you build and test your project. (4 pts)

*Be sure that you include information (in the appendices if you wish) necessary to describe the components you are using in your design. For example, you should have data on the frequency and amplitude of the output from the strain gauge bridge and the pickup coil. You should also find some information on the properties of strain gauges such as the one we are using.*

*Draw a circuit diagram that you can use to build your design. Explain how to build it and how it will be operated once it is built.*

*How will you know if it is working properly? Develop a detailed plan for testing your design. The key step in your testing plan should be a comparison with the commercial accelerometer.*

*Once you have a complete design and a plan for testing it, have your work checked by a TA or instructor and have them indicate that they have done so on the last page of this write up. You need to be sure that you are on the right track so you don't waste time needlessly.*

Comments:

3. Analysis – Discuss why your project should work. Support your discussion with calculations, graphs, PSpice simulations, and common sense reasoning. (3 pts)

*Do a PSpice simulation of your combination of a strain gauge bridge differential amp. You did a simulation like this in Experiment 4, but now you need to use the exact components (or as close as you can get) that you plan to use in your design. Use the PSpice output to show that your design should give a reasonable signal level, if it works correctly. Check to be sure that your output has little or no DC offset. If you have set up your amplifier correctly, this should be the case. You will eventually want to compare the actual signal levels measured with your simulation as part of your testing procedure.*

*A PSpice simulation is not always the best kind of analysis to perform. For example, there are some simple calculations that can be done by hand. Simplify the strain gauge bridge circuit so that you can better understand what gain to expect. For example, you can either find the Thevenin equivalent of the entire bridge circuit or the equivalent of each leg of the bridge, whichever makes it easier for you to see what the gain will be. Then, from your understanding of how the differential amplifier works, estimate the output signal level you expect to see with your design. You should get the same answer as you did with the PSpice simulation. Again, you will want to compare signal levels which actual measurements as part of your testing procedure.*

*Calibrate the amplified strain gauge signal level vs. beam deflection using a simple ruler. Simultaneously record the signals from the amplified strain gauge output and the pickup coil. Using the resulting plot (print it out using Agilent Intuilink), show that the pickup coil output (which we assume is proportional to velocity) and the strain gauge output (which we assume is proportional to position) are roughly consistent.*

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Comments:

4. Implementation (3 pts) -- Discuss what problems were encountered during the implementation of your project and how you solved them. Include advice you would offer to someone who wished to avoid these problems in the future.

*This might be the most important part of any project. If you are sure that nothing went wrong, think things through again. Provide at least two clear lessons you learned from this project.*

5. Final Design and Testing (4 pts)-- Describe your final design, what needed to be changed and why. Show that the new design works with experimental data from your hardware and PSpice simulations. Include your PSpice schematics. Have your experimental data signed by a TA or instructor.

*One of the best ways to show that the two signals (the amplified strain gauge bridge output and the pickup coil output) are comparable is to produce a Lissajous pattern that is close to a circle. Do this and describe how you set things up. You must use the same scale factor for both scope channels to demonstrate that the signals are the same amplitude. Changing the scale factors on the 'scope does not change the signal.*

*Using your testing plan, demonstrate that acceleration is measured.*

6. Discussion (2 pts) – Based on your experience with this measurement, address a few general questions.

*Discuss the ranges of cantilever beam acceleration amplitude and frequency that your approach is capable of sensing with some accuracy. Your purpose here is to establish a reasonable range of application for using your approach rather than using the commercial accelerometer. Can you make beam acceleration measurements that cannot be made with the AD accelerometer?*

*How would you use some of the accelerometer signals in a car to enhance the driving experience?*

*If there are so many accelerometers in present day cars, why is acceleration not displayed for the driver? (If you find a car with one, let us know.)*

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

Comments:

6. Personal Responsibilities – Describe what each group member contributed to the project design. (1pt).

*When doing this and other projects, you must break down the tasks to be performed and assign each of them to specific members of your group. For example, one person should be responsible for developing the testing procedures that you use to show that your design works. At some point during class time, explain the breakdown in tasks to a TA or instructor and have them indicate that you have done so on the last page.*

Comments:

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7. Appendices -- Include any background materials, such as materials from in-class experiments, that you used in preparation of your design. (1 pt)

*You probably have some data from Experiments 2 and 3 that show the output from the strain gauge bridge and the pickup coil. If your data is not that great, you should confer with other groups to see what kind of signals they saw. You are asked to retake this data, but it is useful to look at other cases to be sure you have done this correctly.*

Web Resources on Accelerometers:

*List here any web sites you found useful for this project. You will find some examples in the Helpful Info section of the course web site under Project Information. Be sure you look over all of these sites, especially the Lecture notes for lectures 4 and 5 from the Stanford course on sensors. Information on the Analog Devices accelerometer is also available there or directly at <http://products.analog.com/products/info.asp?product=ADXL250>.*

*Do not include materials just to pad your report. Any materials you choose to include should be useful.*

## Part 5 – Practical Questions and Participation

*In a lab-based course like this, it is essential that all students learn and be able to demonstrate some basic practical skills. If you have been sharing the experimental tasks (using the instruments, analyzing circuits with PSpice, etc.), you should be well prepared to show your capabilities. During the class time dedicated to all four projects, one third to one half of the students in each section will be asked to perform simple practical tasks related to the projects. During the semester, each student can be expected to answer at least two questions of this type. The instructor will assign the points based on your ability to perform the tasks in a timely fashion. The points for this section (5 pts) will be assigned based on the answers to the practical questions or attendance for those students who are not asked questions on a particular project. Attendance will be taken for all students.*

***Please notice that the practical questions are meant to be answered individually. You are not allowed to collaborate with your group mates. Below are examples of practical skills that will be examined.***

1. You should be able to describe the goal and the methodology of the project.
2. You should be able to identify components and parts of each circuit.
3. You should be able to explain what do the circuits do.
4. You should be able to debug the circuit (for example if a component is removed or misplaced, you should be able to replace it.)
5. You should be able to connect the circuits to the power supply and to the ‘scope. You should know how to set up the scope without using the “Auto Scale” button.
6. You should be able to set the power supply and operate the scope to get the desired signal.
7. You should be able to capture the scope signal both as a picture and data, using Agilent Intuilink software.
8. You should be able to calibrate the strain gauge signal with regard to the position of the beam.
9. You should be able to explain the process of obtaining acceleration from an electrical signal, whether it is the strain gauge signal, pick up coil signal or from the AD accelerometer.
10. You should be able to set up a simple circuit in PSpice.
11. You should be able to set up and run a PSpice analysis (Transient, AC sweep or DC sweep).
12. You should be able to plot the results and measure specific points on the plots, using the cursors.



**How to take a Derivative in Excel**

When you grab the data from the 'scope, you get two sets of points. X is the time axis and is in the A column and Y is the voltage axis and is in the B column. You can use the SLOPE function to get another column of data, the points of which represent the derivative of Y with respect to X. Here is some background on the SLOPE function from the EXCEL documentation:

**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 equation for the regression line gives a value for the slope at each point in the derivative of a function based on at least two points in the function. You can use any number of points to determine the slope at each point. It is best to start with 3-5 points in (X,Y) for each point in (X,Y'). Increase the number of points to smooth out the noise

**Procedure:**

1. Determine the value of the first point, C1, using = SLOPE(B1:B4,A1:A4).  
This should give you a value for C1.
2. Copy the equation into the clipboard.
3. Highlight *all* the points in C from C1 to Cn, where n is the number of points.
4. Paste from the clipboard.
5. Excel will place the equation in each cell, adjusting the values from which it determines the point based on the index.
  - ie. C2 will have = SLOPE(B2:B5,A2:A5)
  - C3 will have = SLOPE(B3:B6,A3:A6)....
  - Cn-1 will have = SLOPE(Bn:Bn+3,An:An+3)
6. Now you can graph the data.