

Overview of Teaching Motion using MEMS Accelerometers

Introduction to the RET MEMS Research Project

I participated in a Research Experience for Teachers (RET) program sponsored by UC Santa Barbara and funded by the National Science Foundation. In the summer of 2002, I assisted Dr. Kimberly Turner's Mechanical Engineering graduate student (Rajshree Baskaran) test a MEMS device she designed. The following year I met regularly with the participating teachers of the RET group and we created lesson plans that would bring this research experience into the classroom. During the school year of 2003-2004, I tried the MEMS lessons on my 8th grade students and modified the lessons. Periodically the lessons will be revised as I (and hopefully you) use them and send feedback. Check for the version number at the bottom of the document. The students learned the targeted concepts and also got some first hand experience with some state of the art technology. I think they enjoyed learning on devices that weren't designed for kids.

Learning Objectives

Students will learn what MEMS are, how they work, and what they are used for. As a basis for learning about MEMS, students should be familiar with the concepts of speed, velocity and acceleration. Students should be able to quantify each readily given data they generate. Students should have a working knowledge of the metric system and scientific notation so they will be able to interpret measurements in nanometers and micrometers.

How to Introduce Your Students to MEMS

Physical Science teachers usually have students do a variety of activities to find the speed of objects such as running students, rolling cars, and building boats that are propelled by fans. The MEMS device used in these lessons is a detector of changes in velocity along the X and Y axes and can be used to determine the speed of objects. It takes an ordinary ruler and stopwatch lab up a notch by having students use technology that is used in industry for important things like deploying airbags in cars. You may want to "gee-whiz" your students with some of the applications of MEMS before starting any of the activities. Here are some ideas.

Step 1

Introduce your students to MEMS by showing them the Introduction to MEMS PowerPoint. It's a fun presentation and begins by discussing some applications of MEMS and then focuses on the accelerometer they will use in the activities. Have the students visit the Sandia Labs website and have them search for MEMS images and they'll be able to see a gallery of images of tiny bugs walking around on tiny machines. It's a great way to introduce them to the smallness of MEMS.

GPS

Bring in a handheld Global Positioning System (GPS). There is a learning curve for these! In any case, you/student can walk around the room and it will show you how fast you are going. The obvious next step is to run! Question: How does it know how fast you are going? Well by golly there's a MEMS accelerometer inside!

Color Gameboy

A good way to introduce MEMS is a color Gameboy with the "Kirby Tilt 'n Tumble" game. To play the game, you actually jerk the Gameboy around to move the character (Kirby). The accelerometer senses the angle and hence the acceleration of Kirby by the degree of tilting.

Table of Contents for "MEMS in the Classroom" Documents

1. This document, "*Overview of Teaching MEMS*"
2. Teacher website guide which includes background information about MEMS, updated versions of the lessons, with links to companies that build MEMS and new technologies using MEMS.
3. PowerPoint Presentation "*What are MEMS?*" to use as an information background for teachers and to introduce students to MEMS.
4. Questions for students "*pptquest*" to answer about MEMS after viewing the PowerPoint Presentation.
5. Teacher notes for equipment set up of MEMS and student activity "*Intro to MEMS Accelerometer*"
6. Student Activity "*Intro to MEMS Accelerometer*".
7. Teacher notes for student activity, "*Building a MEMS Accelerometer*".
8. Student Activity "*Building a MEMS Accelerometer*".

PowerPoint Presentation (screen shots) of “What are MEMS?”

The following table summarizes the content of each slide shown in the image:

Slide Number	Slide Title	Key Content
1	MEMS	• What are they? • What are they good for? What are MEMS?
2	MEMS	• Micro - very small device (less than 1 mm) • ElectroMechanical - turns mechanical energy into electrical energy or vice versa • Systems - used with other electrical products, mostly as sensors
3	MEMS	• Extremely small machines with levers, gears, torsion bars. • All fabricated using Nanotechnology. • Visit Texas National Labs website image gallery.
4	Small Measurement	• A nanometer is a billionth of a meter, 10^{-9} • A micrometer is a millionth of a meter, 10^{-6} • Link to Powers of 10 site
5	A MEMS device on a human hair	A MEMS device 30 μ m across Human hair 100 μ m across
6	Think of the possibilities...	You could have multiple MEMS devices installed on your hair! Worbar
7	MEMS	• What are they? • What are they good for? • How are they made?
8	MEMS Saving Lives!	MEMS are used as sensors to deploy air bags!!
9	MEMS Saving Lives!	
10	MEMS Saving Lives!	
11	MEMS Saving Lives!	• The C-Leg is fitted with microprocessors and sensors that mimic the stability and step of a natural leg. The C-Leg
12	MEMS Saving Lives!	• Curtis Grimsley fitted with the C-Leg was able to walk down 70 flights of stairs at the same speed of most others fleeing the World Trade Center during Sept. 11's terrorist attacks.
13	What else are MEMS good for?	MEMS GAMES! 1998000000 23 146
14	Inside the Kirby Tilt 'n' Tumble Game	• A MEMS device and electrical circuits needed to operate the device. • Let's examine the MEMS device inside the game.
15	The ADXL202 MEMS Device	• Moveable Mass • Capacitors - "combs" • Folded Springs
16	How does the MEMS accelerometer work?	• How does the MEMS accelerometer work? • When the device is tilted. • The mass moves • The springs expand/compress • The capacitor combs "sense" a change in voltage. • The integrated circuit processes the information.
17	Close up of folded springs	
18	A close up of the capacitor "comb"	 Figure 1. Mean Dimensions for a Single Finger.
19	Movement	 Figure 2. Mean Dimensions for a Single Finger.
20	How does the MEMS accelerometer work?	• How does the MEMS accelerometer work? • When the device is tilted. • The mass moves • The springs expand/compress • The capacitor combs "sense" a change in voltage. • The integrated circuit processes the information.
21	Materials used to understand the MEMS accelerometer.	• ADXL202 Evaluation Board from Analog Devices • Computer • Crossbow software (comes with eval. Board)
22	Using the MEMS ADXL202 Evaluation Board	 Evaluation Board located in COM port. Evaluation Board
23	Using the Crossbow software with the evaluation board.	 The image on the right is when the evaluation board is tilted.
24	Using the Crossbow software with the evaluation board.	 Attach the board to a toy car and drive it over a bump and you'll see this graph! Lab: speedbumps.

INTRO TO MEMS ACCELEROMETER ADXL202

Background Activity: View an introduction to MEMS PowerPoint and answer the following questions.

Please answer these questions after viewing the PowerPoint.

1. What are MEMS?
2. What units are MEMS devices measured in?
3. Give an example that shows you understand just how small they are.
4. What are MEMS used for? (give at least 2 examples)

RET II Summer Presentation “MEMS”

Kim Doubleday RET II Project: MEMS in the classroom

INTRO TO MEMS ACCELEROMETER ADXL202 *Teacher Notes*

Purpose: Learn how to use the ADXL202-232 MEMS evaluation board.

I Background information

Students view PowerPoint and answer questions demonstrating they have some idea of what a MEMS device is. Teachers should view this site:

<http://www.kdoubleday.com/Science/sciteachers.html> in order to get background information on MEMS for teaching. The PowerPoint for students is found at: <http://www.kdoubleday.com/Science/RET/MEMSintro.ppt>

Student Lab Questions

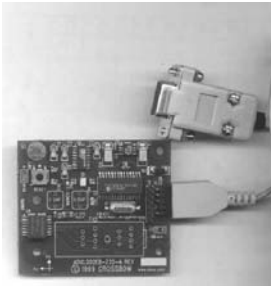
Please answer these questions after viewing the PowerPoint.

5. What are MEMS?
6. What units are MEMS measured in?
7. Give an example that shows you understand just how small they are.
8. What are MEMS used for? (give at least 2 examples)

II Intro to MEMS lab

Equipment set up. The devices are extremely sensitive and can be a little feisty to set up. Plug the circuit board into the cable and attach the cable to your computer’s COM port. If you have a newer laptop, it may not have these ports. Install the software from Analog Devices and reboot the machine. Pictures below may help.

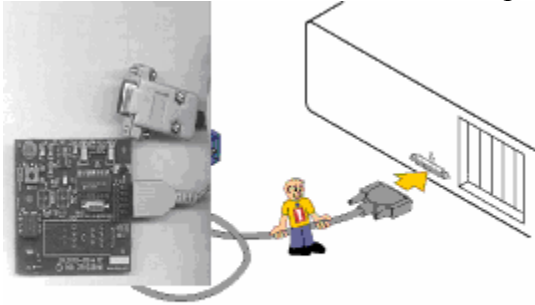
1. “The Device” MEMS accelerometer evaluation board ADXL202EB-232A



2. Close up of the RS-232 connection that goes into the computer’s COM Port



3. Attach the device to the back of the computer



9. Install the software from the disk and reboot.

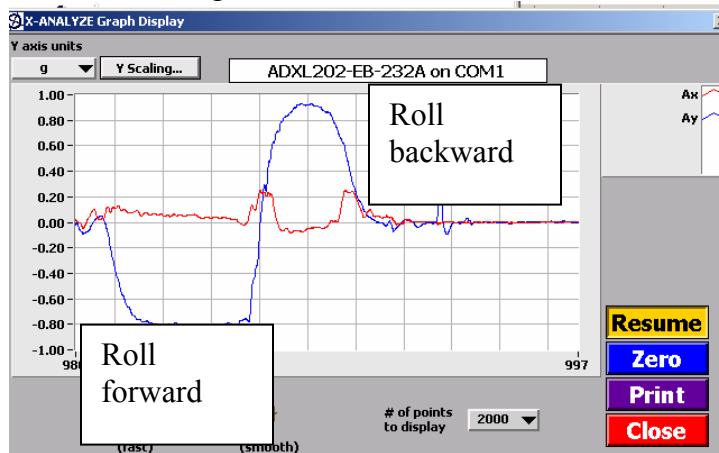
Set up

1. Sit the accelerometer on a flat surface near the computer.
2. Use the connecting cable to attach it to the computer's serial port. Carefully make sure that the plugs are pushed in firmly.
3. Click on "Add a connection".
4. In the dialogue box, click on ADXL202-EB-232A on COM1 and click on "select".
5. You should see a green light and the word "connected". If you see a red light, try again. You may have to close out the program and reopen it.
6. Find "Select a display" and click on the box to the left showing a red and blue line graph.
7. You will see a new screen "Graph Display" and be making a few adjustments. The goal is to get flat lines for the x and y axes on the zero of the graph.
 - a. Find "# of points to display" and choose 200.
 - b. Find "filtering" and slide the bar to the right at 20 (smooth)
 - c. Click on "Y Scaling". Change the Y Maximum to 1.00 and the Y Minimum to -1.00. Click on "set scale".
8. Set the accelerometer flat on the table and click on zero. If you get *relatively* flat (horizontal) red and blue lines on the zero, GOOD! Note, the device is picking up some vibrations from the computer and other noise in the room so the lines will probably not be totally flat.
 - a. If the lines are wiggly, (sometimes this works) click on "g" under "y axis units" and choose PWM% and then click on "g" again. Click on zero.
9. Hmm... if things do not seem to be working, reboot, reinstall, unplug, and go have coffee. You can go to the Analog Devices website and try to troubleshoot with them. These devices change so fast as well as the software for testing that you might need to contact them with your particular needs.

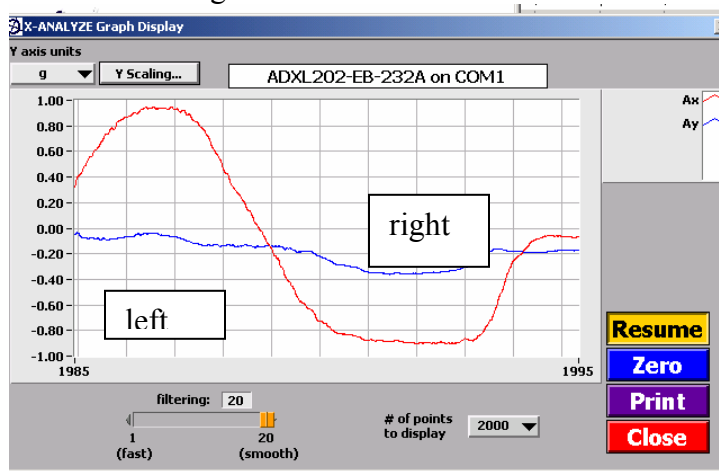
Understanding the graphs.

Students will be rolling and pitching the device to understand what the device does. See the images below to check their work.

Movement along the Y axis



Movement along the X axis



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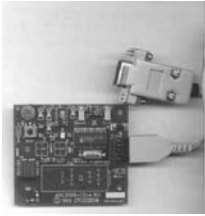
INTRO TO MEMS ACCELEROMETER ADXL202

Name:

Purpose: Learn how to use the ADXL202-232 MEMS evaluation board. You should have already viewed the PowerPoint Presentation on MEMS and answered the questions.

Materials: These materials are extremely sensitive!!!! Please be careful using them.

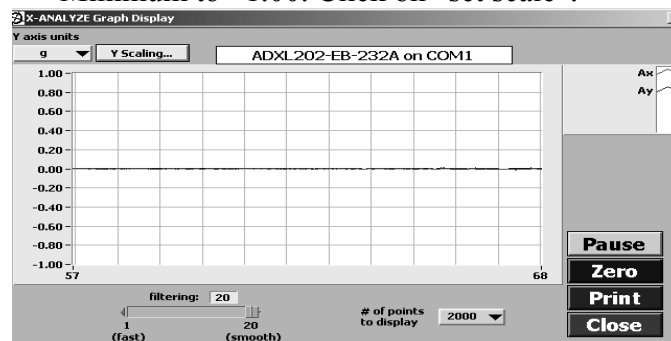
- Analog Devices MEMS accelerometer evaluation board ADXL202EB-232A
- Computer with Com ports RS-232 and Crossbow software “X-analyze”.
- Red and blue colored pencils, this lab.



MEMS evaluation board

Set up

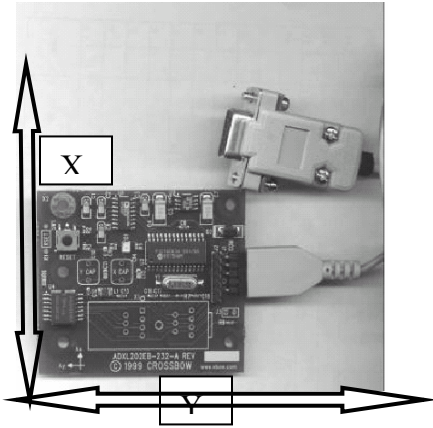
9. Open the X-analyze program.
10. Click on “Add a connection”. In the dialogue box, click on ADXL202-EB-232A on COM1 and click on “select”
11. You should see a green light and the word “connected”. If you see a red light, try again. You may have to close out the program and reopen it.
12. Find “Select a display” and click on the box to the left showing a tiny red and blue line graph.
13. You will see a new screen “Graph Display” and be making a few adjustments. The goal is to get flat lines for the x and y axes on the zero of the graph.
 - a. Find “# of points to display” and choose 200.
 - b. Find “filtering” and slide the bar to the right at 20 (smooth)
 - c. Click on “Y Scaling”. Change the Y Maximum to 1.00 and the Y Minimum to -1.00. Click on “set scale”.



The red and blue lines are on the 0.00 line.

14. Set the accelerometer flat on the table and click on zero. If you get *relatively* flat (horizontal) red and blue lines on the zero, GOOD!

15. The axes for the device are shown below.



Understanding the graphs.

Now that you're connected, let's figure out what it does!!

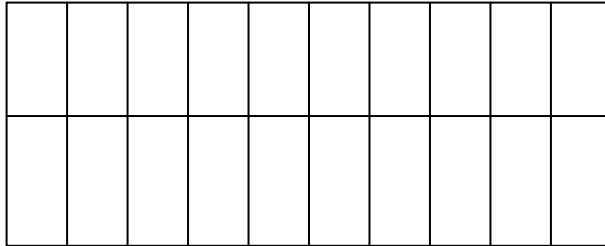
1. Lay the board down completely flat and don't bump the table.
2. Click on zero and the red and blue lines should be in the middle of the graph.
3. Look up on the right hand corner to find out the color codes for each axis and record it below.

Axis: Color:	↕	Axis: Color:
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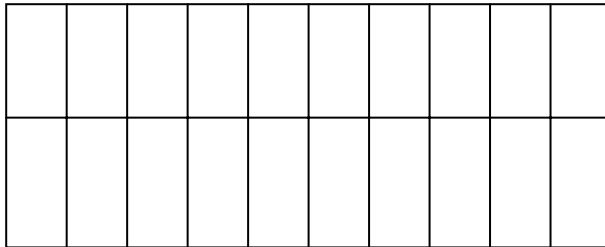
4. **Slowly** roll the board down (point the board to the ground) but not side-to-side. Sketch the graph in color below. Record the start and end time located on the bottom corners of the graph.

5. **Slowly** roll the board back (point the front to the ceiling) but not side-to-side. Sketch the graph in color below. Record the start and end time located on the bottom corners of the graph.

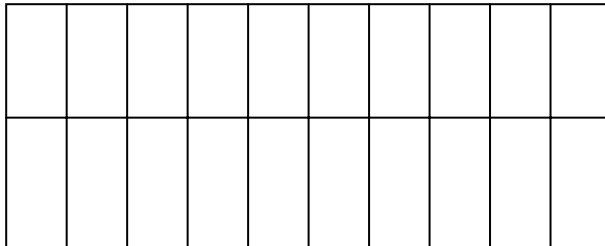
6. **Slowly** tip the board to the right (point the right side to the ground) but not forward or back. Sketch the graph in color below. Record the start and end time located on the bottom corners of the graph.



7. **Slowly** tip the board to the left (point the left side to the ground) but not forward or back. Sketch the graph in color below. Record the start and end time located on the bottom corners of the graph.



8. Lay the board flat on the table, zero the unit again and hit the table really hard with your fist to cause a vibration. Record what you see below:

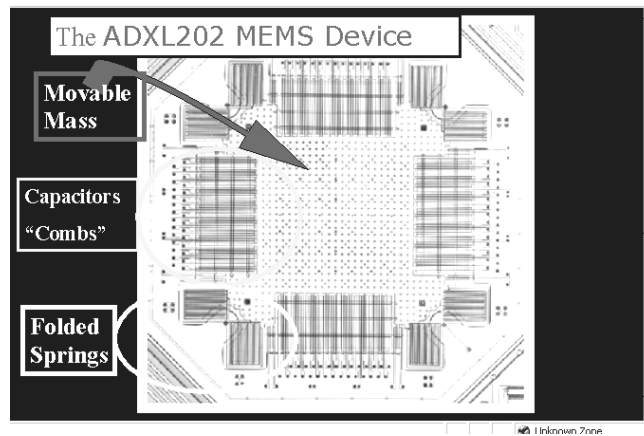


9. **Application:** Now that you have a sense of what this device can do, brainstorm with your group about what it might be used for. First, list its unique qualities. Then describe what it can do. Then come up with a minimum of three uses that you think might be possible.

BUILDING A MEMS ACCELEROMETER Teacher Notes

Purpose: To build a model of an Analog Devices ADXL202 and be able to explain how a MEMS accelerometer works. (Please see the MEMS intro PowerPoint for an overview). This activity is meant to accompany some activities where students have a MEMS accelerometer mounted on an evaluation board (circuit board) attached to a computer.

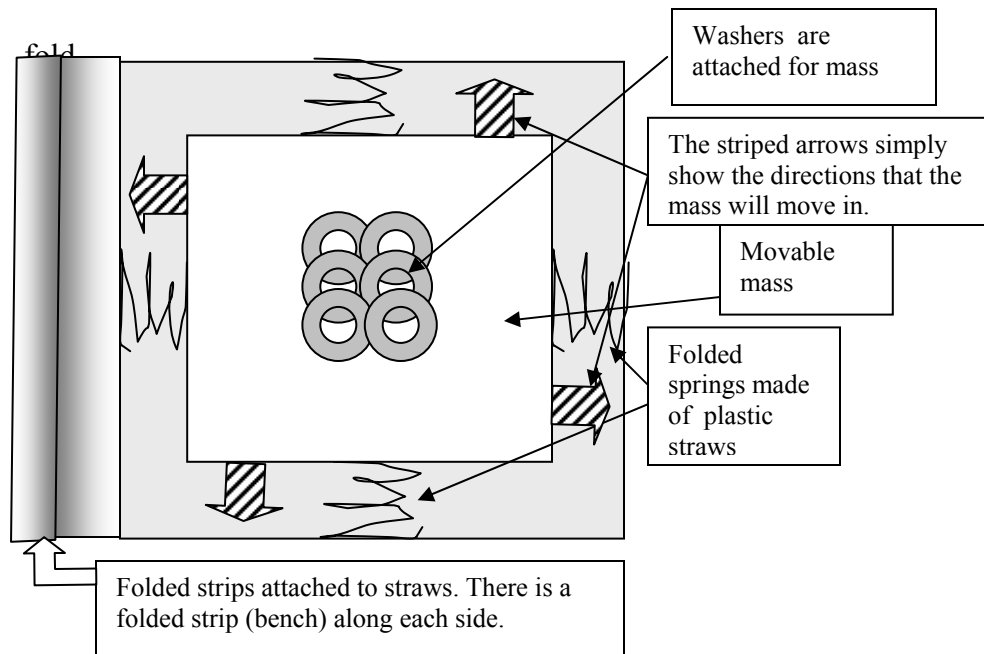
Below is a picture of the real MEMS accelerometer. The device is intended to detect acceleration in 2 directions (dual axis) and has many uses such as air bag deployment. The device has a mass in the center and this mass is attached to the base by tiny folded springs so that it can move. I don't think the actual MEMS mass moves, it sends signals indicating a voltage change. As the device is moved and suddenly stops, the mass slides along one of the axes. The mass also moves if tilted.



The student MEMS is simplified in shape. The mass can be created using cardboard and any thing that can be taped to the mass so that it slides.

Materials: Cardboard, straws, masking tape, washers or any objects with enough mass to make the mass move. After the students create the MEMS, have them do some practice "accelerometer" tasks with it. See ideas below.

Design of Cardboard Model of an Analog Devices MEMS Accelerometer



Directions for Building Cardboard MEMS

1. Cut a square of cardboard with length approximately 8 inches.
2. Cut a square of cardboard with length approximately 4 inches.
3. Draw a 7 inch square onto the 8 inch cardboard square.
4. Cut 4 2 inch by 7 inch strips of cardboard and bend them in half lengthwise.
5. Tape the strips of bended cardboard around the border of the 7 inch square that you drew. Arrange them like little benches and the seats are facing away from the center.
6. Put the 4 inch square in the center of the benches and tape something to it to give it some mass. You can use washers, old batteries, etc. Then test out the Cardboard MEMS by sliding it on a flat surface and making sure the mass (4" square) doesn't go over the benches.
7. Now to make some folded springs out of ordinary drinking straws. Cut each straw in half and fold them back and forth so they look like little slinky springs. One end of the straw is attached to the mass and the other to the back of the bench. Do this on all sides.
8. Test out the Cardboard MEMS by sliding it on a flat surface and see that the springs compress on one side and stretch out on the other.
9. Outside of the benches, label one side as the X Axis and nearest side perpendicular to it as the Y Axis.
10. Draw a simple number line along the outside of the benches, have it go from -4 to positive 4. Do this for both axes.

Activity Ideas for Using the Cardboard MEMS

1. Have the Intro to MEMS Lab paper handy.
2. When you tilted the MEMS device you generated some graphs with red and blue lines. Tilt your Cardboard MEMS towards the negative numbers on the Y Axis.
3. Describe what the graph looked like on the computer when you tilted the MEMS Device towards the floor.
4. Inside the MEMS device is a movable mass just like (almost) your Cardboard MEMS. Using the graph you made on the computer, and your Cardboard MEMS, try to figure out which way the mass moves for the positive number direction and the negative number direction for each axis.
5. Describe the relationship between which way the mass moves (positive or negative) and the Y axis of the computer graphs you generated.

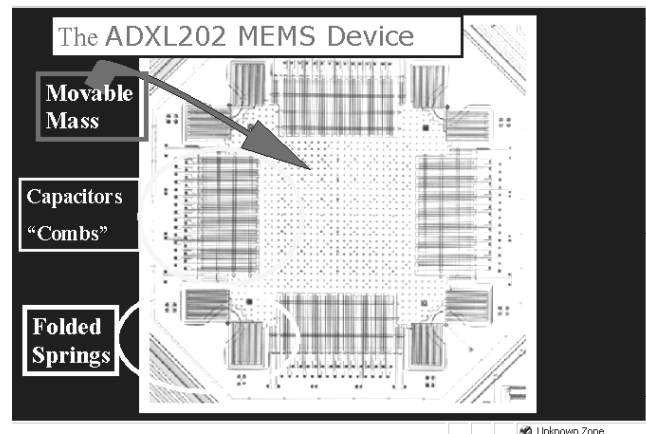
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BUILDING A MEMS ACCELEROMETER

Name:

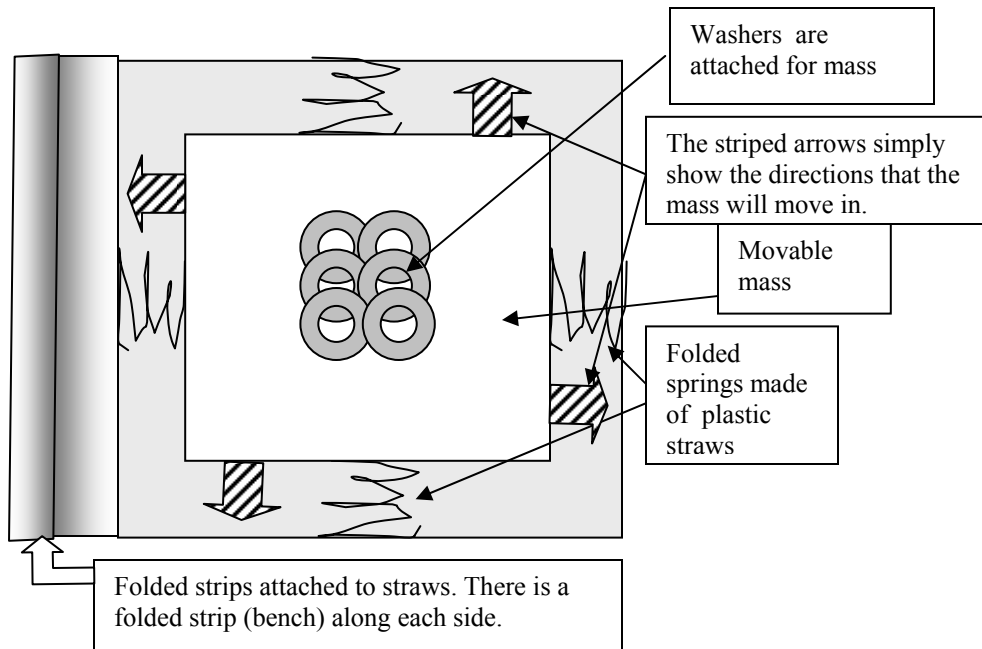
Purpose: To build a model of an Analog Devices ADXL202 and be able to explain how a MEMS accelerometer works.

Below is a picture of the real MEMS accelerometer. The device is intended to detect acceleration in 2 directions (dual axis) and has many uses such as air bag deployment. The device has a mass in the center and this mass is attached to the base by tiny folded springs so that it can move. I don't think the actual MEMS mass moves, it sends signals indicating a voltage change. As the device is moved and suddenly stops, the mass slides along one of the axes. The mass also moves if tilted.



Materials: Cardboard, straws, masking tape, washers or any objects with enough mass to make the mass move.

Design of Cardboard Model of an Analog Devices MEMS Accelerometer



Directions for Building Cardboard MEMS

1. Cut a square of cardboard with length approximately 8 inches.
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4. Cut 4 2 inch by 7 inch strips of cardboard and bend them in half lengthwise.
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6. Put the 4 inch square in the center of the benches and tape something to it to give it some mass. You can use washers, old batteries, etc. Then test out the Cardboard MEMS by sliding it on a flat surface and making sure the mass (4" square) doesn't go over the benches.
7. Now to make some folded springs out of ordinary drinking straws. Cut each straw in half and fold them back and forth so they look like little slinky springs. One end of the straw is attached to the mass and the other to the back of the bench. Do this on all sides.
8. Test out the Cardboard MEMS by sliding it on a flat surface and see that the springs compress on one side and stretch out on the other.
9. Outside of the benches, label one side as the X Axis and nearest side perpendicular to it as the Y Axis.
10. Draw a simple number line along the outside of the benches, have it go from -4 to positive 4. Do this for both axes.

Questions to Check for Understanding Using the Cardboard MEMS and the Intro to MEMS Activity

1. Have the Intro to MEMS Lab paper handy.
2. When you tilted the MEMS device you generated some graphs with red and blue lines. Tilt your Cardboard MEMS towards the negative numbers on the Y Axis.
3. Describe what the graph looked like on the computer when you tilted the MEMS Device towards the floor.
4. Inside the MEMS device is a movable mass just like (almost) your Cardboard MEMS. Using the graph you made on the computer, and your Cardboard MEMS, try to figure out which way the mass moves for the positive number direction and the negative number direction for each axis.
5. Describe the relationship between which way the mass moves (positive or negative) and the Y axis of the computer graphs you generated

Name: _____

Finding the Speed of Cars Using MEMS ACCELEROMETER ADXL202

Prior to this lab: Students know how to calculate the speed of moving objects. View an introduction to MEMS PowerPoint, build the Cardboard MEMS and complete the “Intro to MEMS” Lab.

Purpose: To find the speed of battery powered cars using two methods. First find the speed using stopwatches and rulers, then using a MEMS accelerometer.

Hypothesis: (Write a testable statement in If-> then format about which method you think will be most accurate)

Materials:

Part I
Stopwatch
Ruler
Car with battery

Part II
MEMS Accelerometer ADXL202EB-232
Computer with X-Analyze software and Printer
Speedbump made from plastic straw, paper and tape

Procedure for Part I:

1. Find the speed of your battery-powered car and record your results below.

SPEED OF CARS

Trial	Distance in cm	Time in sec	Speed in cm/sec
1			
2			
3			
4			
5			

2. Calculate the Average Speed for your car below: _____ cm/sec

Procedure for Part II:

3. Set up the computer as you did in the Intro Lab (see the very bottom of this lab for the set up procedure in case you forgot).
4. Create a Speedbump on your desk near the computer. Take a straw and tape it down to the table, then cover it with a piece of paper to smooth out the bump so the car will go over it easier.



5. Practice running the car over the speedbump and have your partner click on “Pause”. Try to pause the program so that you get a nice graph with 2 “bumps” on it, one above and one below the zero line.
6. Start the car and roll over the bump.
7. Take a screen shot of the graph and repeat this step 5 times.

To take a screen shot, press “print scrn” on the keyboard, open up Word and paste into the document.

8. Print out your graphs and number them 1 – 5.
9. To determine the speed, calculate the time between “peaks” on the graph. The distance is the wheelbase (length between axles). Record your results below.

SPEED OF CARS USING MEMS

Trial/Graph	Distance in cm	End Time in sec	Start Time in sec	Total Time in sec	Speed in cm/sec
1					
2					
3					
4					
5					

10. Find the average speed of the cars using MEMS _____ cm/sec

Questions

1. Is there any difference in the average speeds between Part I and Part II? If so, calculate the difference.
2. Why do we use the wheelbase as our distance in part II instead of the distance the car traveled?
3. Explain which method you feel is most accurate and why.
4. Compare your results with other teams. Which team had the greatest difference in speeds (answer to question 1) record their difference.
5. Which team had the least difference in speeds (answer to question 1) record their difference.
6. Which method do you feel is most accurate and why?
7. What makes one method more accurate than another?

Set up

16. Sit the accelerometer on a flat surface near the computer.
17. Use the connecting cable to attach it to the computer’s serial port. Carefully make sure that the plugs are pushed in firmly.
18. Click on “Add a connection”.
19. In the dialogue box, click on ADXL202-EB-232A on COM1 and click on “select”
20. You should see a green light and the word “connected”. If you see a red light, try again. You may have to close out the program and reopen it.
21. Find “Select a display” and click on the box to the left showing a red and blue line graph.
22. You will see a new screen “Graph Display” and be making a few adjustments. The goal is to get flat lines for the x and y axes on the zero of the graph.
 - a. Find “# of points to display” and choose 200.
 - b. Find “filtering” and slide the bar to the right at 20 (smooth)
 - c. Click on “Y Scaling”. Change the Y Maximum to 1.00 and the Y Minimum to –1.00. Click on “set scale”.