

SmartBat: A Baseball Swing Analysis  
and Training Product

by

Etan S. Trangle

Submitted to the Department of Mechanical  
Engineering in Partial Fulfillment  
of the Requirements for the Degree of

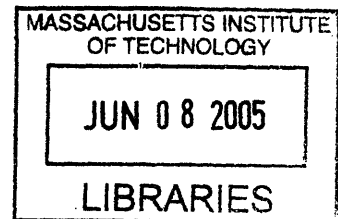
Bachelor of Science

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Massachusetts Institute of Technology

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**ARCHIVES**

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ABSTRACT

Few products exist that offer any form of feedback on a hitter's baseball swing. Since bat speed is so critical in hitting for power, a low cost device that gives information on bat speed and/or acceleration is needed. By having a visual and auditory response indicating the magnitude of acceleration, a batter can get a better idea of how much their swing is improving. That hitter could also work on maintaining control of a bat at different speeds.

The SmartBat product meets this customer need. Using an accelerometer embedded on the side of a regular wooden baseball bat, it measures acceleration and outputs the signal to an LED bar display driver. This consists of 10 LEDs in a row. The number of LEDs that light up after a swing is directly proportional to bat acceleration. In addition, whistles at the end of the bat provide auditory feedback by whistling louder at higher speeds.

The current prototype would be able to be sold for \$40, less than half of existing swing speed radars. There is also significant room for future improvements based on customer feedback, including a digital display of speed and acceleration, as well as the ability to record data onto a computer for further analysis.

Thesis Supervisor: Alexander H. Slocum

Title: Professor of Mechanical Engineering

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## **1.0 Problem**

In many sports it is difficult to learn proper technique without any instruction. Sometimes people can be practicing something the wrong way without knowing it. Some sporting activities in which proper form can make a difference include swinging a golf club, baseball bat, tennis racquet, or throwing a baseball or football. There are many instructional videos that teach the best method to do these things, but few machines that help practice these motions.

The specific action I explored was swinging a baseball bat. The best way to improve one's baseball swing is by practicing. However, practice alone without feedback can only lead to a limited amount of improvement. If someone knows how well or poorly they are swinging, they will know what areas to work on and how much room there is for improvement. A large factor in hitting a baseball far is bat speed. Power hitters are always trying to generate a maximum bat speed while maintaining control of the bat. What is needed is a device that will give them feedback on how fast they are swinging.

There already exist stand-alone radars that record bat speeds, but give no other information. The cheapest of these radars costs \$99, and is not part of the bat itself. The market has a need for a low cost product that gives feedback on the hitter's bat speed.

## **2.0 Solution**

The SmartBat provides consumers with a cheaper alternative to radars that helps batters improve their bat speed and form. Having information on the movement of a person's bat at different locations and times gives a very good evaluation of what is happening during the motion. Using an embedded accelerometer to measure acceleration, the SmartBat gives a visual and auditory feedback signal to the hitter after it is swung. Based on what customers find more helpful and enjoyable, the SmartBat technology and features are designed to give batters the best possible batting practice experience for less money than what is currently available.

## **3.0 Research**

While bat speed is not the only factor in hitting a baseball, it is a significant indicator of a hitter's power. Elementary physics states that due to conservation of momentum, a faster bat will make a ball it comes in contact with go farther. Hitters trying to hit a ball far will try to

generate as much bat speed as they can [1]. The following momentum conservation equation relates bat speed and mass before and after contact with a ball.

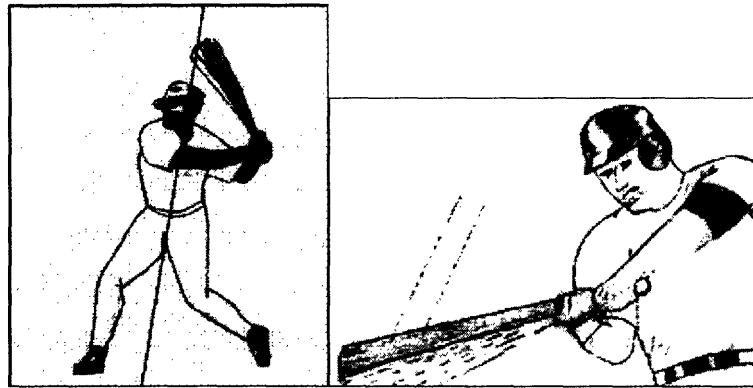
$$M_{bat} v_{bat} + M_{ball} v_{ball} = M'_{bat} v'_{bat} + M'_{ball} v'_{ball} \quad (1)$$

Ideally, a good baseball swing should reach a maximum velocity in the middle of the swing, at the time of contact with the ball. Since acceleration is the rate of change of velocity, the bat begins to decelerate at this time. By measuring the time at which the acceleration becomes negative, a hitter can know the moment at which the bat begins to slow down. Identifying the time at which the bat is at its maximum velocity can help a hitter improve the timing of their swing so they can hit the ball while the swing is at its highest velocity.

There is a trade off between heavier bats, which increase momentum, and lighter bats, which are easier to swing faster. Choosing a bat weight is a matter of personal preference. Hitters choose bats they are most comfortable swinging. However, maximum speed is not always desirable. A hitter could benefit by hitting at a fraction of his or her full power in order to gain more control, and hit a ball more easily.

The part of the bat whose speed is of concern is known as the “sweet spot”. The sweet spot can have several definitions, but is most commonly defined as the region of the bat where the batted ball speed is highest and vibrations in the batter’s hands are lowest. It is also the region where the bat’s center of percussion is located, which is where the bat translates but does not rotate, making it less painful in the hands. It is usually 5-7 inches from the end of the barrel [2]. Since hitters try to make contact with the ball at the bat’s sweet spot, it is an ideal spot to read velocity and acceleration of the bat at that point.

In addition, there are other spots on a bat where knowing the speed would give helpful information on the batter’s swing. During a swing, there are in fact 2 axis of rotation. The first axis runs down through the center of the hitter’s body and the hitter’s arms, hips, and shoulders rotate around it, as in the left picture of Figure 1. The second axis goes through the part of the bat which is being held. As a hitter swings, their inside arm pulls the bat handle toward their body while the outside arm pushes the bat barrel toward the ball, as seen in Figure 1’s right side picture.



**Figure 1:** There are two axes of rotation during a swing. One, shown on the left side, goes through the center of the hitter's body. The other axis is one around which the batter's wrists rotate [1].

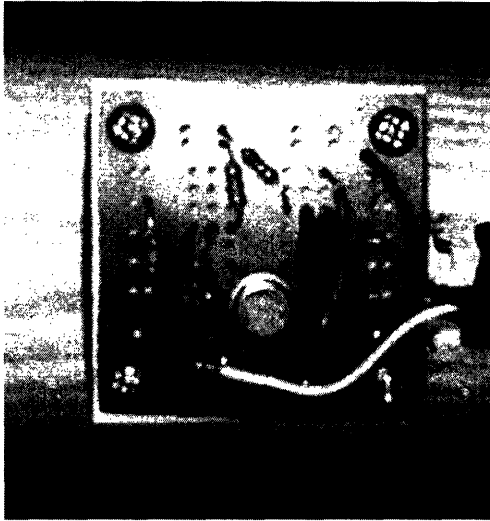
#### **4.0 Product Evolution**

Several components are needed to design a bat that can give the necessary information that indicates bat speed, including the accelerometer on the bat, and the devices that read the signal. Each component added was evaluated and tested to ensure that the final prototype would be a functioning model of the SmartBat.

##### **4.1 Accelerometer**

The most critical module of SmartBat is the accelerometer. Different variables were taken into account when designing the accelerometer component of the SmartBat. First, location was an important factor. The sweet spot of the bat was chosen for the accelerometer placement, because users would want to know how fast the part of the bat coming in contact with the ball is moving. This is located 6 inches from the end of the barrel. I attached the accelerometer with tape to different locations on the bat, and tested it using a voltmeter. The voltage readings were slightly higher near the end of the bat, because that part of the bat was traveling faster. However, for the first prototype, since only 1 accelerometer was used, it was located at the part of the bat that gave the most useful information (sweet spot).

The accelerometer model used was the ADXL50, donated by Analog Devices, Inc. It is capable of measuring up to 50 g of acceleration, which was a lot more than the acceleration in a regular baseball swing. A photograph of the ADXL50 can be viewed in Figure 2.



**Figure 2: The ADXL50 accelerometer and circuit board.**

#### 4.2 Power

Another concern for the accelerometer was powering it. The model used for the prototype required an input of +5V. The way this was tried at first was using a 9 V battery connected to an LM7905 Driver. The LM7905 takes an input voltage and gives +5V out. The battery was taped to the bat just above the accelerometer. However, this method ended up adding extra weight to the end of the bat, and it was hard to secure the battery tightly so that it did not move while swinging. In addition, since a signal wire would be coming off the bat, it would not be difficult to eliminate the battery and add another 2 thin wires (1 for power, 1 for ground) to the prototype.

#### 4.3 Signal Display

A very essential component of the SmartBat is the visual feedback seen by the batter. Different options were explored to distinguish what the most helpful and enjoyable form of feedback is.

#### 4.3.1 Voltmeter

A voltmeter was the first tool used to read the signal, shown in Figure 3 below. Using the MAX function, a maximum voltage was observed for each swing of the bat. However, this was used for experimental purposes only.



**Figure 3: A voltmeter was used as a tool for preliminary testing to read the signal.**

#### 4.3.2 Oscilloscope

Once I got the accelerometer to show a higher voltage as a result of a faster swing, I tried to find the best way to record the information in order to analyze it. Plugging the accelerometer into an oscilloscope allowed me to see the signal as it changed with a swing. The signal could also be stored, saved and analyzed on a program such as Matlab. While this method proved to be very valuable as an analysis tool, it unfortunately is not feasible for a consumer product. Due to the high cost of an oscilloscope and difficulty in transferring the data to a computer, a simpler feedback mechanism was explored.

#### 4.3.3 LED Bar Display

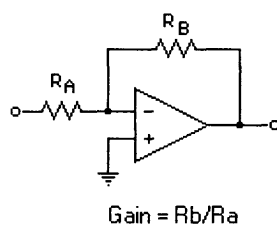
Next, I investigated the option of an LED display that lights up resulting from an increase in acceleration. For this module I acquired an LM3914 Bar/Dot Display Driver. I decided to wire it in bar mode, where all LEDs that turn on remain lit as subsequent LEDs turn on. The LM3914 takes in power of +5V for the LEDs and +15V for the driver. It's input voltage ranges



from 0V (0 LEDs lit) to 1.25V (10 LEDs lit). Of the LEDs used, the first 5 were green, the next 3 yellow, and last 2 red. The LED bar display proved to be a simple but effective way to indicate bat speed to the hitter, and was therefore selected as the feedback mechanism for the SmartBat prototype.

#### 4.3.4 Operational Amplifier

One thing observed when the accelerometer signal was being recorded was that the voltage changed only slightly when the bat was swung. This happened because the accelerometer was designed to measure up to 50 g of acceleration and a baseball swing does not accelerate beyond even 10 g. Therefore, an inverting operational amplifier (op amp) was added to the circuit to which the signal connects, in order to amplify the voltage coming from the accelerometer. The op amp used is an inexpensive LM741 op amp, whose circuit diagram appears in Figure 4.



**Figure 4: Inverting LM741 Op Amp**

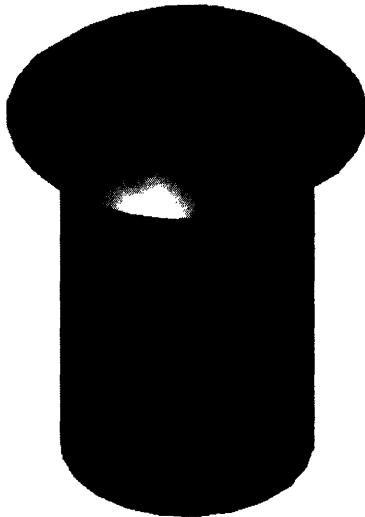
The gain on an LM741 Op Amp depends on the ratio of the two resistors ( $R_b$  to  $R_a$ ) in the circuit. Testing different ratios with the LED bar display, the ratio used in the SmartBat prototype was 36. This let the SmartBat demonstrate bat acceleration without being too sensitive to outside factors, such as noise and vibrations.

#### 4.4 Non-electronic Feedback

In addition to the accelerometer and the feedback it gives, cheaper alternatives for a type of feedback were explored in case one were to design a cheaper SmartBat without electronics, as more of a recreational toy rather than a piece of practice equipment. One option was to use a spring scale with a weight at the end. Swinging the bat would result in a centripetal force that would stretch the spring to a certain level, depending on how hard the swing was. This idea was

not practical, because it would involve either attaching a large mechanism to the bat or removing a lot of material from the bat to have a sliding weight inside.

Another suggestion for a feedback device was whistles. If small whistles could be mounted at the end of the bat and whistle as air travels across them, it would provide a simple and effective way for even young children to learn how fast they are swinging. Rubber whistles from a whistling Nerf football (0.5" in diameter and 1" long) were embedded into the bat surface at different points on the bat. The very end of the barrel, where the bat travels fastest, turned out to be the best location for whistles. The sweet spot was not an ideal place to put whistles because the whistles do not give any numerical information. A solid model of one of the whistles is in Figure 5.



**Figure 5: Three of these whistles were placed at the end of the bat barrel in the prototype**

## 5.0 SmartBat Prototype

The final design for the prototype of the bat is shown in Figure 6 in an exploded view in solid model form.



**Figure 6: The bat component of the SmartBat prototype consists of the wooden bat, whistles, and accelerometer on the circuit board.**

### 5.1 Bat

When deciding on a final design, material was an important factor in designing for function as well as manufacturing. Both aluminum and wooden bats were options. Aluminum bats are hollow on the inside, but are available in the same weights as wooden bats. Also, the collision is more elastic on aluminum bats than on wooden ones, meaning less energy is lost to rebound, so the bat stings less and balls hit with aluminum bats will travel faster and farther [2]. For this reason, professional baseball leagues only use wood, to prevent balls from going too fast and far. As far as material for this product, I chose wood because it was easier to secure the circuit of the accelerometer and the whistles to wood than aluminum. In addition, drilling holes and grooves in wood would not significantly change the bat's weight. After all the alterations, the bat's weight was 30.5 ounces, only 1.5 ounces less than its original weight. Lastly, potential customers stated they had no preference between a wooden or aluminum bat for a product such as SmartBat.

The bat I chose to modify is a Louisville Slugger MLB180. It has the properties listed in Table 1. I chose this model because it has average dimensions compared with high school, college, and even professional bats.

**Table 1: Properties of Louisville Slugger MLB180 wooden bat**

Wood	Ash
Length	33"
Barrel Diameter	2.5"
Weight (before modifications)	32 oz.
Weight (after modifications)	30.5 oz.

## 5.2 Whistles

The first modification to the original bat was adding whistles. Three whistles were placed at the end of the bat, two going into the sides about an inch from the end of the barrel, and one going in at the very end along the same axis as that of the bat. Due to the whistles' positions, the bat must be swung in a certain direction in order to produce a whistling sound.

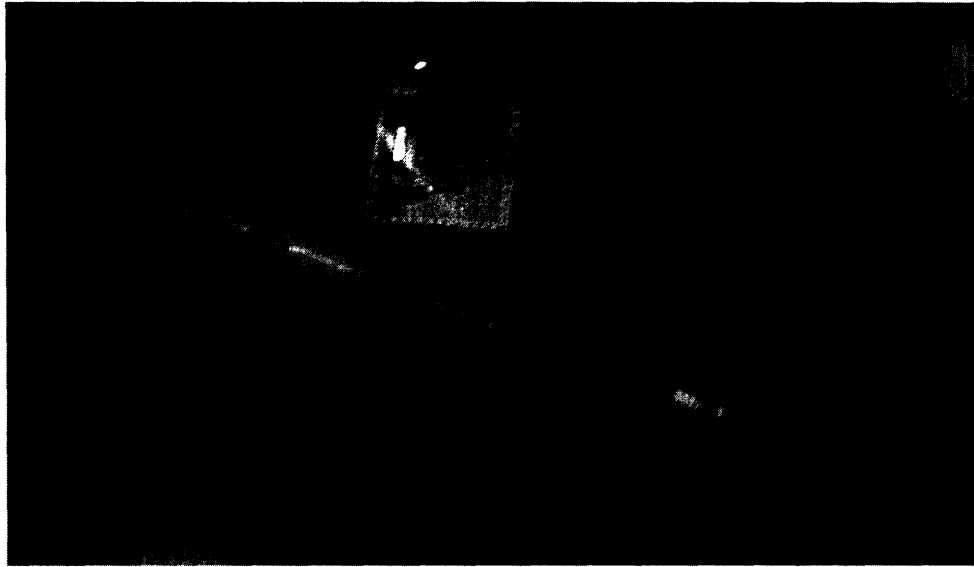
## 5.3 Accelerometer

The accelerometer used is an ADXL50 model from Analog Devices. It is capable of recording accelerations up to 50g, and it one of the cheaper models available. It takes in a +5V signal. Whenever the accelerometer is positioned with its axis vertical, it experiences an acceleration equal to gravity (g) or against gravity (-g). The voltage signal from the bat is 2.27 V at 0 g (axis horizontal), and goes up or down by .037 V every time the bat is turned so make the accelerometer's axis vertical (a change in 1 g). The accelerometer was placed 6 inches from the end of the bat's barrel, with its axis parallel to the direction of motion. This location was chosen because it is the bat's sweet spot, the spot where a ball is most likely to hit the bat.

## 5.4 Machining and Putting Together

A flat 2" x 2" square was milled onto the side of the bat. The accelerometer with its circuit board was screwed onto this surface. In order for the wire to be as little of a disturbance as possible on the hitter's bat grip, a groove was machined going from the flat square down the side of the bat. Right above the bat handle, the groove becomes a hole going through the middle

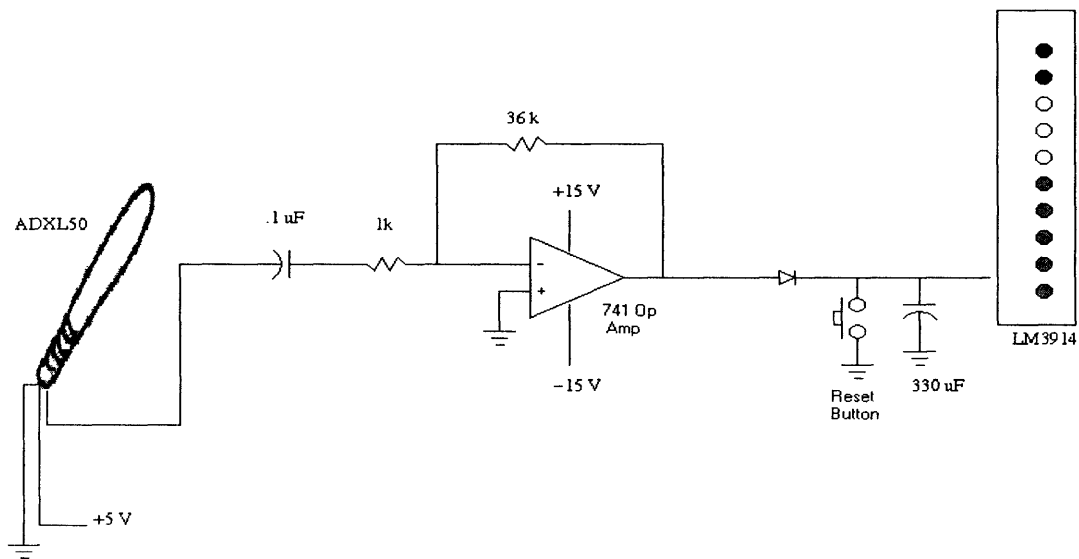
of the bat and coming out the bottom. An 8 foot wire connected to the accelerometer was placed in the groove running down the side of the bat and into the hole. It would then come out the bottom of the bat and connect to the electronic component located off the bat. This setup is shown in the photograph below (Figure 7).



**Figure 7: The SmartBat prototype, with some of the LEDs lit.**

### 5.5 Electronics

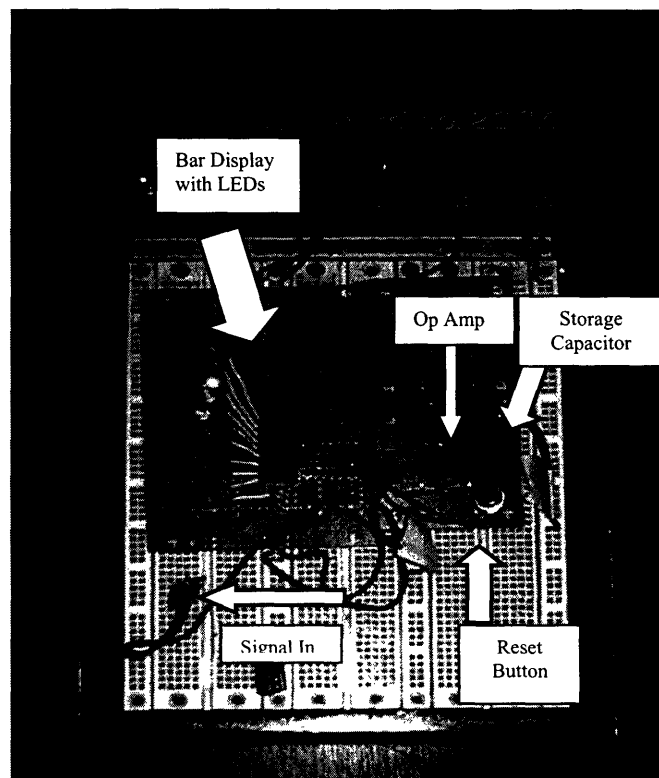
A schematic drawing of the electronics going from the bat to the LED display is in Figure 8 below.



**Figure 8. This circuit diagram shows the path of the accelerometer's signal, from the bat to the LED display. [diagram designed by Jim Bales of MIT Edgerton Center]**

There are three wires coming off the bat. One gives power (5V) to the accelerometer and another goes to ground. The third wire is the accelerometer's signal. This signal gets transmitted to a capacitor that removes the voltage offset and converts the signal to a direct current. The signal then gets amplified by an LM741 inverting operational amplifier. The gain is dependent on the ratio of the two resistor values, which are 36 k $\Omega$  and 1k $\Omega$  for the SmartBat prototype. This ratio is based on how much the accelerometer signal changes with an increase in acceleration. The resulting voltage makes one LED light up for small movements, about 5 light up for an average swing, and 10 for an extremely powerful swing. A diode and 330 $\mu$ F capacitor are located next to the op amp to store the signal, and a push button connected to ground was added to discharge the capacitor and set its signal back to 0 (turning off the LEDs).

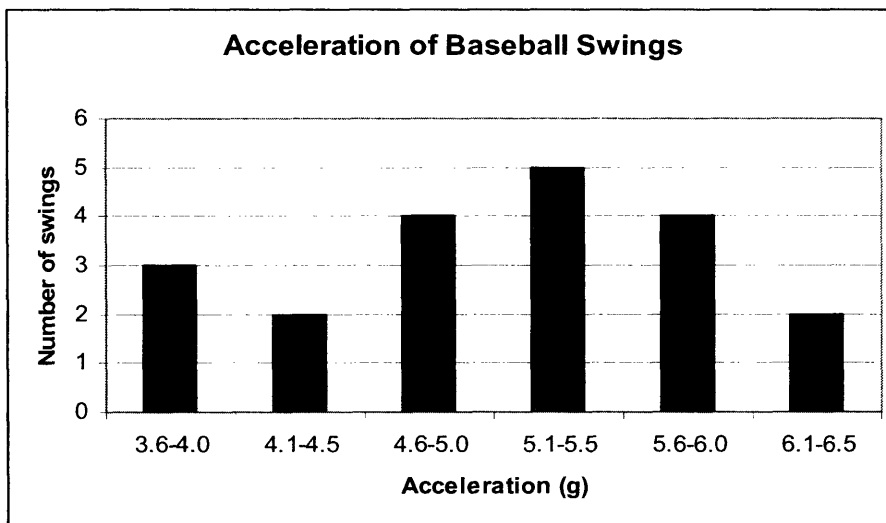
The signal coming from the capacitor gets transmitted to an LM3914 Bar Display Driver. The driver is wired to 10 LEDs (5 green, 3 yellow, 2 red). For every .125 V that go into the driver, another LED lights up. They stay lit until the reset button is pushed and the capacitor is discharged. A picture of the final circuit board is in Figure 9.



**Figure 9. Photograph of circuit outside of bat on a protoboard. It includes the capacitors, op amp, reset button, LED display, and power supply.**

## 6.0 Tests and Results

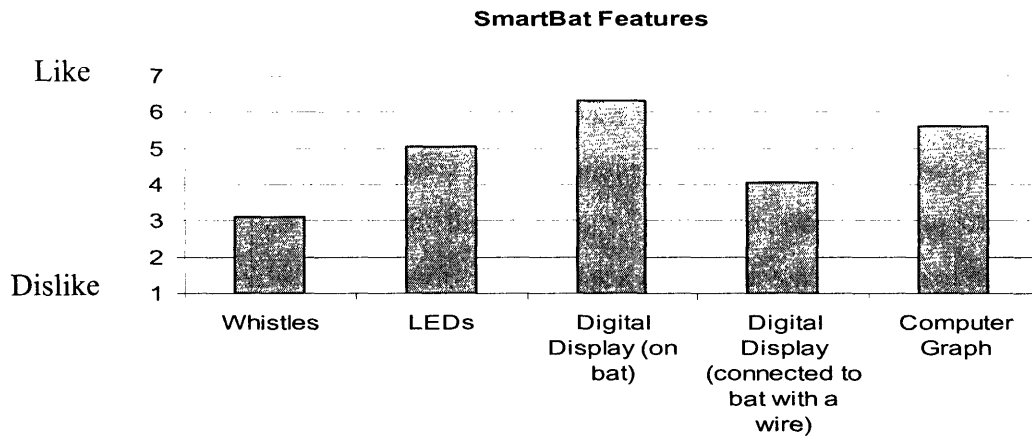
To get an idea of the best way to gather data from the bat, it would help to know approximate acceleration levels. To test this, the SmartBat was first wired to a multimeter. Using the MAX function on the multimeter, the maximum voltage reading was recorded for 20 swings, some hard and some soft. Since .037 V corresponds to 1 g acceleration, this calibration constant was used to calculate the maximum acceleration g for each of the 20 swings. Figure 10 shows a histogram of the sample accelerations with the SmartBat. This data was later used to test the proper gain required to use for the op amp.



**Figure 10: Testing the SmartBat's acceleration yielded these results. The mean acceleration was 5.03 g.**

## 7.0 Future Recommendations

There are two potential markets for a device such as SmartBat: children and serious baseball hitters. The whistles and lights component of the SmartBat prototype could be cheaply made and sold as an instructional device for children learning to play baseball. Tapping into the larger market of serious baseball hitters requires seeing what the customers want. After testing the prototype and talking to potential users (not children), including members of the MIT baseball and softball teams, information was gathered regarding what features users would find most helpful and enjoyable. Figure 11 shows a summary of this data, collected from 18 people.



**Figure 11: In a survey of 18 potential customers, mostly members of the MIT baseball and softball teams, a digital display on the bat was the most preferred feature for the SmartBat.**

### 7.1 Features

The whistles at the end of the barrel turned out to be more of a nuisance than a fun gadget. While they might attract young children buying it as a toy, a SmartBat product with accelerometers and electronics would not include whistles.

If the LED display would still be included in a future model, it would improve on the design if its sensitivity was adjustable. Obviously some serious hitters have a lot more power than children do, and by adjusting the LED scale and/or offset, the children would be able to practice the same way a professional would using the SmartBat. More so than an LED display, a digital display of peak velocity and/or acceleration on the bat appeared to be the most popular feature. This was preferred to the LED display because it gave an actual relevant number with which to compare different swings. One user said, “an LED display might not give you very detailed information about your improvements.”

From testing and survey answers, the wire coming off the bat tended to get in the way. In addition, the cord had to be made sufficiently long (about 8 feet) so that swinging the bat would not pull the wires off the circuit board. For these reasons, a future model of SmartBat would have to eliminate a wire coming off the handle. One idea is to add a wireless connection from the bat to the display device. Putting the LEDs from the current prototype or a digital display onto the bat itself (instead of a separate device) would make the SmartBat more attractive as well. Both options are worth exploring.



Removing the wire would, however, require adding a +5V power supply to the bat. A small and light battery would work well. However, if a solar cell battery could give the right power and voltage, it would be a very good feature, because the battery would not have to be recharged or replaced. Testing and market analysis would have to be done to see if the benefits of a solar cell outweigh the added cost, and if customers would be willing to pay extra for it.

The idea of plugging the bat into a computer to get a graph of acceleration and velocity vs. time was well received by some users and not by others. One person said it would give them more data than they would know what to do with. On the other hand, this feature received an average rating of 5.61 out of 7. Since a lot of data can be extracted from an accelerometer quickly, a lot of possibilities exist for swing analysis using a SmartBat. The first change to be made would be to install a memory chip in the bat in order to eliminate the wire. Once the data is recorded, the bat can then be plugged into a computer and read. Once on a computer, the acceleration and velocity vs. time can be graphed. This can be analyzed by looking at peak acceleration and velocity and seeing at what point of the swing they occur.

One change that would make users happy would be to cover the accelerometer, or even put it inside the bat (more easily done with an aluminum bat) so that a batter could hit a ball with the SmartBat without worrying about breaking one of the electronic components. Covering up the electronics also improves the aesthetic appeal of the SmartBat.

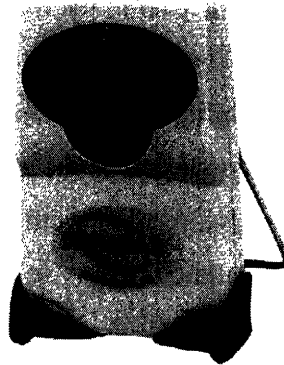
Changing the accelerometer model would also be advantageous. The ADXL50 has only one axis of acceleration, adding the possibility of errors resulting from twisting the bat. An accelerometer with 2 axes would give information on the acceleration in the direction of the swing, as well as the bat's change in height. A hitter would not have to worry about the orientation of the bat either. One axis would tell them the bat's acceleration in one direction and another axis would do the same in another direction. The magnitude of total acceleration could be calculated by summing the squares of acceleration and taking the square root of that.

The ADXL50 also records up to 50g of acceleration, while baseball swings are never above 8-10 and are usually much lower. Other accelerometer models exist (including at Analog Devices) that record in 2 axes at lower accelerations, for similar prices. Not only would this give a more precise reading of acceleration, but could eliminate the need for an op amp to amplify the signal.

The SmartBat would be an even more informative tool if more accelerometers were added. As stated in section 3.0, there are 2 axes of rotation in a baseball swing. Placing another accelerometer at the handle would allow a hitter to see the acceleration at the end of the bat compared to the handle. This would indicate how much the bat is rotating around the batter's hands relative to the rotation around his body. In addition, the user would be able to get a profile of the bat as it is swung, giving valuable information on the user's swing mechanics. Another option is to take the bat's weight into account and predict a ball's trajectory.

## 7.2 Competition

The nearest competitor product is called the "Swing Speed Radar" by Sports Sensors Inc., shown in Figure 12. It is a stand alone device that measures a baseball or golf swing's speed, storing up to 10 swings. While very similar to what the most marketable form of SmartBat would be, there are some differences. The Swing Speed Radar is a machine separate from a bat. It must be held, hung, or placed sitting on something before the swing can be measured. In addition, the price of this product, according to the Sports Sensors Inc. website is \$99.95. If SmartBat is sold for a significantly lower price than the Swing Speed Radar, it would certainly be able to compete in the market.



**Figure 12: SmartBat's nearest competitor, this swing speed radar, sells for \$99.95 [3].**

## 7.3 Price

A product with whistles and LEDs (similar to the SmartBat prototype) could be made for \$30. It could be sold wholesale for 1.5 times that (\$45), and sold in stores for 1.5 times the wholesale price (\$67.50). Individual component costs are listed in Table 2.

**Table 2: SmartBat prototype bill of materials.**

Wooden Bat	\$10.00
3 Whistles	\$0.75
ADXL50 Accelerometer	\$8.00
LM741 Op Amp	\$0.50
LM3914 Bar Display Driver	\$2.00
Resistors/Capacitors/Wire	\$0.50
10 LEDs	\$5.00
Reset Button	\$0.25
Printed Circuit Board	\$3.00
<b>Total</b>	<b>\$30.00</b>

Potential users also indicated their price preferences in the feedback survey, saying how much they would be willing to pay for a SmartBat with each of the listed features. These results are shown below in Table 3.

**Table 3: Price preferences of potential users**

<b>Price</b>	<b>\$25 or less</b>	<b>\$26-\$50</b>	<b>\$51-\$75</b>	<b>\$76-\$100</b>	<b>Over \$100</b>	<b>Would not buy</b>
Whistle	65%	18%	0%	0%	0%	18%
LED	24%	53%	0%	6%	6%	12%
Digital Display	6%	53%	18%	18%	6%	0%
Graph on computer (when plugged in)	12%	29%	35%	6%	12%	6%

Assuming the SmartBat with a digital display of speed/acceleration (the most popular feature) is manufactured and sold, it would probably be sold for \$60. Even though most people said they would be willing to pay \$26-\$50, the manufacturing price would most likely fall in that range, so the selling price would have to be higher for the product to be profitable. Alternatively, the price also must be significantly lower than the competition price of \$99.95.

#### 7.4 Next Steps

The next steps involved in developing the SmartBat would be to use the working prototype to do some more testing. This would help decide on what features work best and how helpful they are. A lot of customer feedback must also be acquired to decide on a specific feature to add and what users think about it. In addition, a patent would have to be applied for so that all the designing done afterwards is protected. The SmartBat has the potential to become a high-selling, fun, useful, and original sports product with its unique technology and design.

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- [1] “Batspeed: The Most Comprehensive Study of the Baseball Swing on the Web”, <http://www.batspeed.com>.
- [2] “WebBall”, <http://www.webball.com/skill/sweetspot.html>.
- [3] “Sports Sensors Inc.”, <http://www.swingspeedradar.com>.

## 9.0 Acknowledgements

Prof. Alexander H. Slocum, MIT, Mechanical Engineering

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Prof. Jim Bales, MIT Edgerton Center

Analog Devices Inc. donated the accelerometers used for testing and building the project

Louisville Slugger (bat)

### Problem

I plan on doing my mechanical engineering design project on a piece of equipment used as a learning and practicing device. In the seminar titled Physical Intelligence, the way the body acts as an organism is explored. The body's physical intelligence is very relevant to athletic activities and is seen in sports everyday. By better understanding how the body moves and reacts, we can learn more efficient ways of performing these activities.

In many sports it is difficult to learn proper technique without any instruction. Sometimes people can be practicing something the wrong way without knowing it. Some sporting activities in which proper form can make a difference include swinging a golf club, baseball bat, tennis racquet, or throwing a baseball or football. There are many instructional videos that teach the best method to do these things, but few machines that help practice these motions. The specific action I will be exploring is swinging a baseball bat.

Besides videos, there is an existing product that is a stand-alone radar that records bat speeds of 10 swings, but gives no other information. Having information on the movement of a person's bat at different locations gives a much better idea of what is happening during the motion.

### Functional Requirements

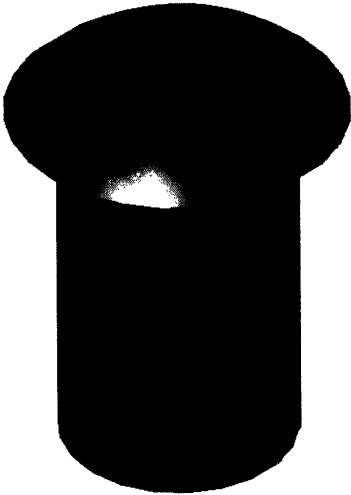
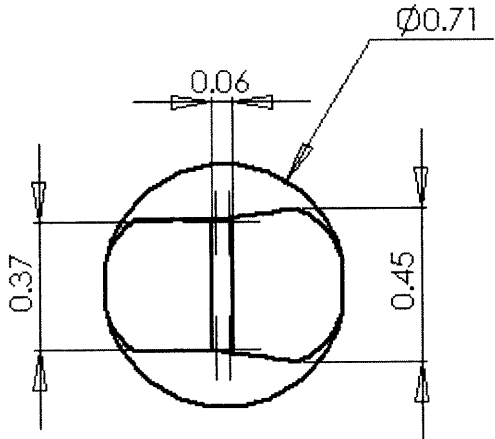
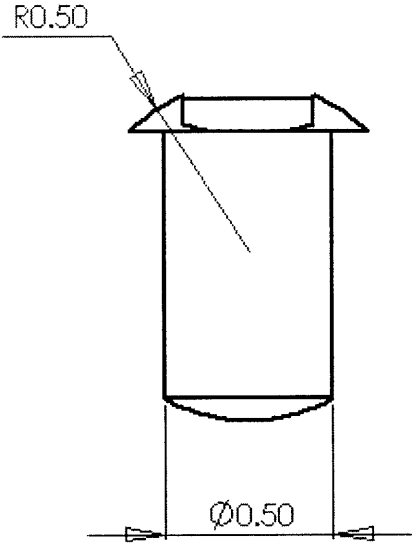
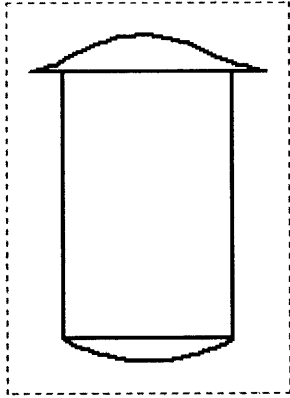
I plan on making a product that people can use to practice batting and receive feedback on their form at the same time. The product must allow a person to swing a bat. More importantly, it should also be able to tell different characteristics of that person's swing. This can be done by tracking the speed and acceleration of different parts of the bat (handle, middle, barrel). By having someone repeatedly swinging a bat and getting feedback on things such as speed, acceleration, and torque, he or she will feel more and more comfortable swinging.

### Product

Before building a final product, I will be researching the motions involved with swinging and the muscles worked and the best way to mimic these motions. The final product will be a low cost "smart" bat that records measurements such as speed, acceleration, torque, momentum, and/or

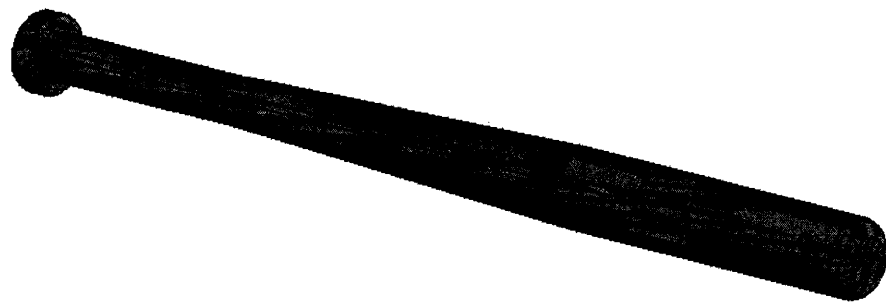
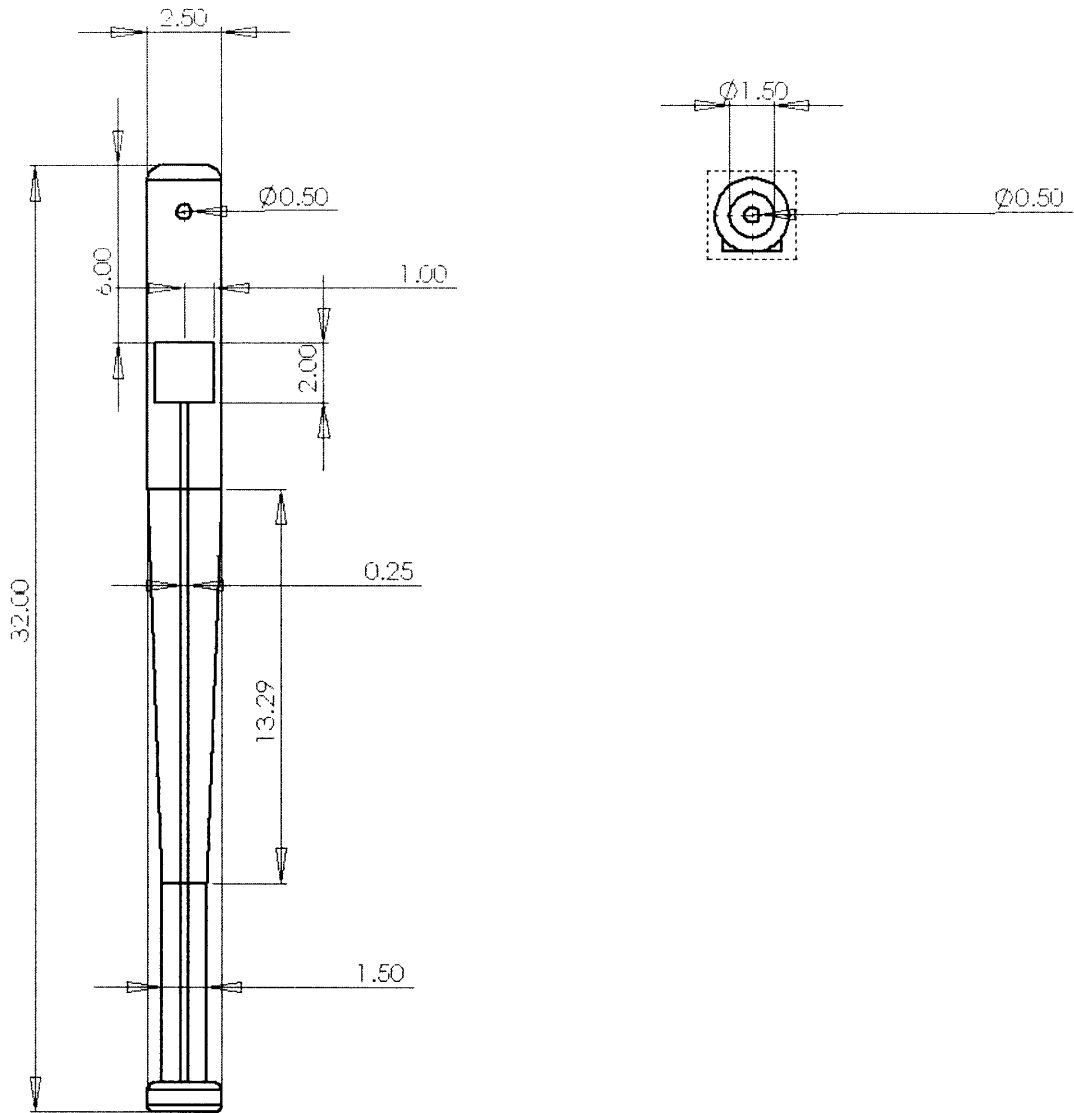
kinetic energy. Another feature that could be included is a center of percussion sensor and some sort of way to show how the energy transfers to the ball. The feedback mechanism can be a visual graph and possibly some tips to help the user improve or fix a problem.

Appendix B: Whistle Design

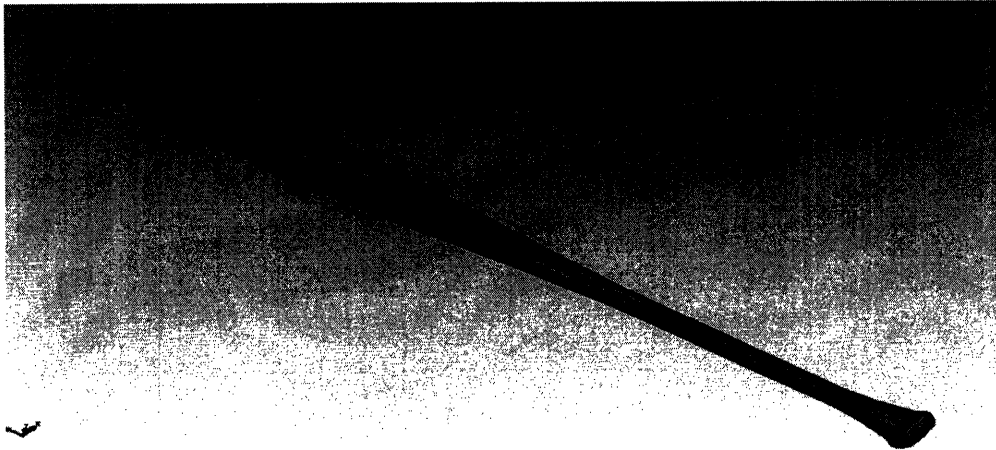
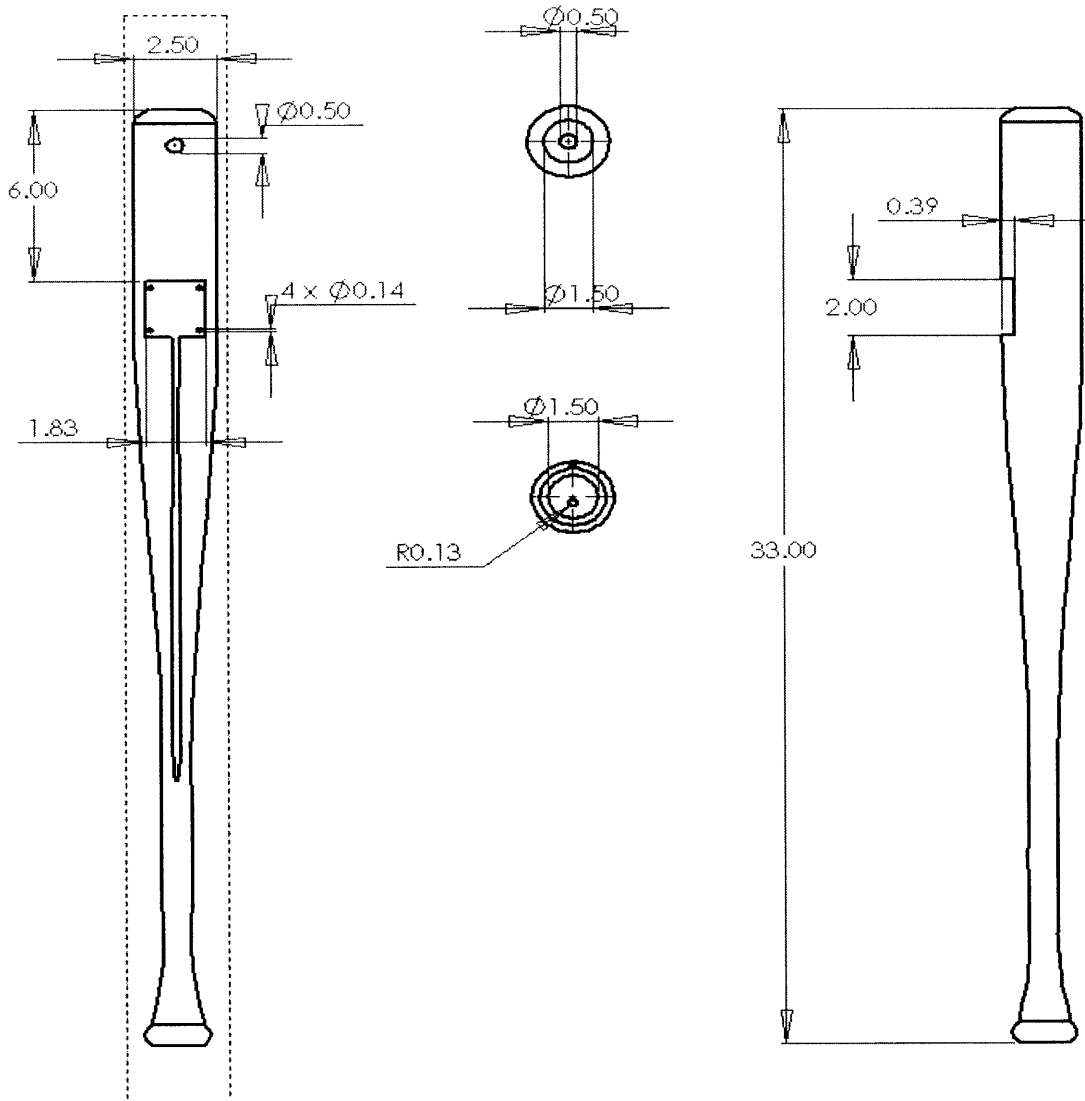




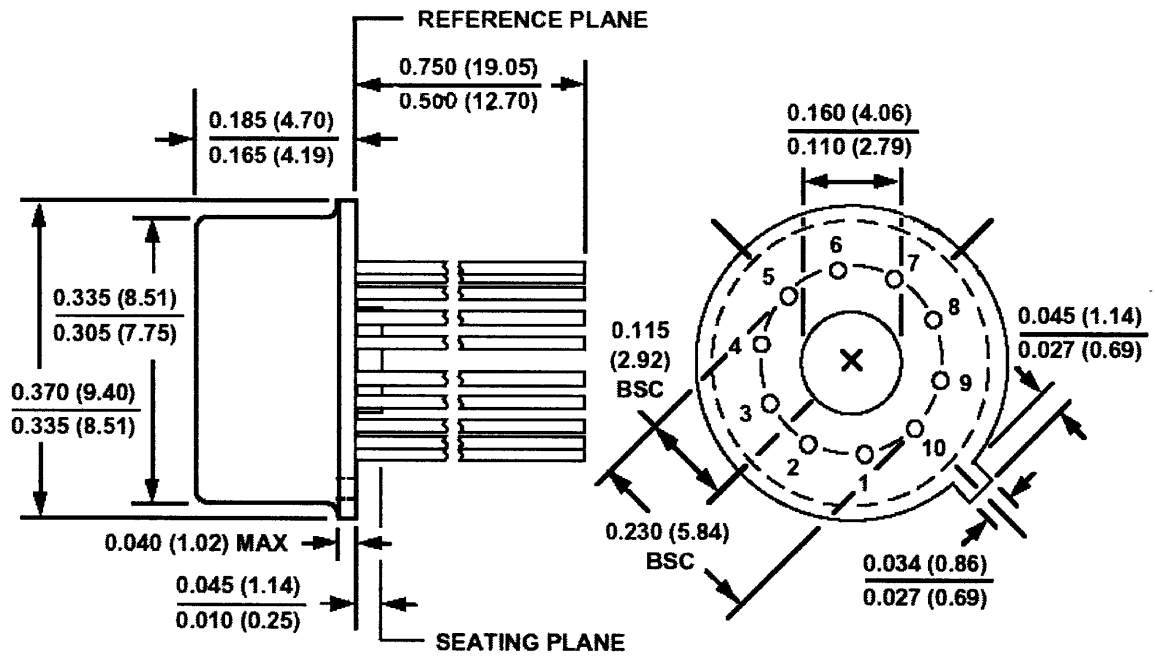
Appendix C: Preliminary Bat design



Appendix D: Final Bat Design



Appendix E: ADXL50 Accelerometer



Appendix F: Test Swings

20  
swings  
Voltage  
6  
5.9  
5.7  
4.1  
4.5  
4.9  
6.3  
5  
3.7  
4.8  
5.4  
5.5  
4.9  
5.3  
4.8  
5.1  
3.9  
4.2  
5.2  
5.4

Mean  
5.03  
Standard Deviation  
0.702702