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Automotive Rollover Detection and Early Warning Device

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Abstract

One of the most dangerous driving scenarios is a vehicle rollover, yet there is little in the way of preventing them. The goal of this project is to analyze the cause of these rollovers and create a device that can be attached to all cars aftermarket and alerts the driver that they are in danger. Using knowledge of the accelerations under which cars roll over and an accelerometer which relates acceleration to electrical characteristics, we designed a device to alert the driver of danger before the car rolls over by lighting warning LEDs, Green, Yellow, and Red, and sounding a buzzer; these being controlled by a comparator network with thresholds set at the tipping point of cars. Tests show that this device, when subjected to lateral acceleration, lights all warning LEDs and the buzzer in order. We concluded that this device will successfully alert a driver that they are in danger of a rollover however it does not auto-correct the problem nor will it prevent reckless driving. Further additions can be made to this device, including a charging circuit for the batteries and a digital interface to control the LEDs.

Acknowledgments

We would like to extend our thanks to everyone who participated in helping us complete our Major Qualifying Project.

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Executive Summary

Vehicular safety is one of the foremost concerns in the growing automobile industry. The general safety of a vehicle is commonly one of its top selling points, and oftentimes can be one of the most important factors in choosing which automobile to buy. Unfortunately, even with our advancements in the design and components of a vehicle, it is still very possible to get into an accident while driving recklessly. One of the most common types of these accidents is a rollover, brought on by turning too sharply at too great a speed. Once a vehicle begins to tip, there is very little that the driver can do to prevent it from rolling over altogether, and once it begins to roll it becomes a danger to the passengers of the car and everyone around them. Every year there are hundreds of thousands of rollover accidents, many of which result in fatality. As the number of cars on the road increases, the likelihood of these accidents occurring increases as well. This will no doubt result in more driving fatalities, the problem which our group has sought to remedy.

In order to help promote safe driving and reduce this staggering number of dangerous accidents, we have worked to develop a device that should aid the driver in understanding the bounds of safety while driving. Our design was based off specific customer requirements gathered from surveys distributed to drivers with varying vehicle experience and driving habits. This allowed us to obtain a broader perspective on the needs and concerns of drivers as a whole. Our goal was to provide a warning for drivers that are driving too recklessly and turning too sharply, so as to give them the opportunity to correct their behavior before their vehicle would roll over, resulting in injury or even death. Road tests of our device at higher sensitivities has proven that it responds correctly and accurately to turns at varying speeds and properly alarms the

driver if dangerous thresholds are reached. Based on this testing, we can conclude that our product can serve as an effective and affordable safety tool in the prevention of rollover accidents in motor vehicles.

1.0 Introduction

The purpose of this project is to give ourselves a chance to become fully immersed in the design process from start to finish for a particular design. The design process involves many steps. The first step is to identify a problem. We decided to take on the problem of vehicle rollovers. After performing background and market research, including customer surveys, we decided to focus on rollover detection and forewarning. Our device is aimed to be used in a variety of vehicles and give the driver a visual indication of the lateral acceleration forces present on a moving vehicle. It will also provide a visual and audio warning when the vehicle is experiencing lateral forces that are close to the threshold for rolling over. We derived a set of criteria that we felt would give us a framework for our design. These design criteria included: affordability, portability, versatility, ease-of-use, and to have an appropriately effective warning system. We went through several phases of designing and testing, making corrections and improvements after each design. Finally, we developed a final prototype for presentation and demonstration of our concept. There remains much potential for further development of this project into other implementations.

1.1 Problem Statement

One of the biggest concerns in a time when millions of people drive to work every day is safety. In our research we have found that over 280,000 rollover accidents occur each year, over 10,000 of which result in fatalities (NHTSA Rollover Ratings). In order to help prevent these accidents, we sought to develop a device that would warn the driver when they are at risk for tipping or an outright rollover, allowing them to correct the problem. Our hope is that in providing these drivers with early warning, it will allow them to drive more safely and therefore allow for fewer accidents.

2.0 Methodology

The goal of our project is to design and create a device that would detect and inform drivers when they are at risk of a rollover, so as to give them time to adjust their driving accordingly. To accomplish this we:

- Researched existing devices that fit similar roles, and compared them to our market-driven design specifications.
- Surveyed drivers to learn about driving habits and familiarity with similar devices.
- Designed a prototype based on requirements collected from surveys, and adjusted based on results of extensive testing.
- Developed a final working design.

2. 1 Surveyed Customers

Our first objective was to assess the need for our device. To do this, we created a survey which we distributed to a number of drivers. The survey included questions asking what kind of car they drive, knowledge about the frequency of rollover accidents and systems already in place to prevent them, as well as their driving habits. We also asked which qualities were most important in buying a device that would detect rollover detection early in order to help us define specific market-driven requirements.

2.2 Market Research

We next researched the existing prior art, to determine what could be improved and which of the market specifications that the devices currently on the market are not meeting. This involved research into both on-board and discrete devices in cars that essentially detected the forces capable of causing a car to rollover and either warned the driver or self-corrected the vehicle without any need for the driver to self-adjust. This research and a description of the devices we found are discussed earlier in Chapter 2.

2.3 Designing and Testing a Prototype

To design our first prototype we took into account the quantified product requirements gathered from our market research (see Appendix D). The concept of our device is that it will detect that lateral acceleration of a vehicle as it turns to the left or right and, based on the selected size of the car and the pre-determined thresholds for various levels of danger, will alert the driver as to their level of risk of a rollover. Our basic specifications were that it would be a small, lightweight device (under 2 pounds) which would detect the g-forces that the car is subject to and display the level on a series of LED's. This was chosen to provide a simple and intuitive output that could be easily seen by the driver without providing a significant distraction. For the sake of ease of use, we also decided to include a buzzer which sounds when the driver is approaching the critical acceleration threshold, warning them when they are very close to rolling over.

We were able to simulate basic tests in the lab by building the circuit on a breadboard and tilting it to simulate the turning and eventual tilt of a vehicle. These tests acted as a proof of concept of our design and allowed us to make adjustment to create a more accessible device. For the sake of helping the user adjust their driving we changed the array of LED's to be bidirectional, indicating whether the vehicle was tilting to the left or the right instead of just the severity of the acceleration.

Once we had adjusted the design so that it responded properly to our testing in the laboratory, we had to confirm that it work in its intended application. To accomplish this, we adjusted the values of the components in the device to linearly reduce the required thresholds to set off the different LED's, which allowed us to test the device at much lower thresholds than would be dangerous and potentially put us at risk to roll over. We then took the device into a 2004 Mercury Mountaineer and performed a series of turns at various speeds to test how the device responded. Our testing showed promising results, responding as intended for all different speeds and setting off the alarm when a critical acceleration is achieved.

2.4 Developing a Final Design

After testing our device on the road, we were able to finalize our design for the device. The schematic for the finished design can be seen in Appendix A. Using a board development environment, we were able to create a printed circuit board with this design, and build a working model of our finished product in the approximate size that our market specifications suggested. Once again testing this in a vehicle for consistency confirmed its correct operation, incorporating all of the intended features of our device.

3.0 Background Research

Before any project building and design work can happen, research must first be done. The foundation of any good design work is the research that gives the ideas and understanding to design a fully functional product. Our research includes finding prior art similar to our desired product, finding out how and why cars roll over and how it can be measured and calculated. We also researched how accelerometers function and what is used to make one. Finally, we surveyed our customers in order to understand what requirements they had for our final design. All of our findings within these topics are shown in the following sections.

3.1 Rollover Statistics

According to the National Highway Traffic Safety Administration (NHTSA), over 280,000 rollover accidents are reported every year (NHTSA Rollover Ratings). In 2004, 31,693 passenger vehicle occupants were fatally injured in vehicle crashes, and of those 10,553 were caused by rollovers (Stashny, 2007). These numbers make the study of rollover prevention and safety a high concern in today's world.

This topic is not totally unvisited, and there are a few devices and systems to lessen the probability of going into a rollover, as well as systems to ensure safety of the occupants when a rollover accident does occur. Some of the most popular systems are Electronic Stability Control (ESC), Rollover Prevention and Mitigation, and Rollover Preparation Systems. These systems are detailed more fully in the sections to follow. The first two systems aim to stabilize the vehicle by taking control of certain aspects of the vehicle to make a rollover less likely given dangerous circumstances. ESC attempts to take control of the vehicle during a dangerous skid by adjusting steering, breaking, and engine speed. The Rollover Mitigation systems work in conjunction with ESC to further adjust the vehicle's course to prevent a rollover. The last of these systems, Rollover Preparation, takes action when a rollover is occurring to ensure the safety of the passengers within the vehicle. These actions may include slowing the engine speed and preparing roll-bar systems. These topics are revisited and elaborated in the Prior Art section of this report.

The figure below shows the number of rollovers per 100 crashes by vehicle type for the year 1999 (SUV and Car Safety). From the figure it is easier to grasp how frequently these dangerous accidents occur. The National Automotive Sampling System General Estimates System (GES) database holds data on vehicle crashes, and according to the NHTSA, the GES obtains its data from a sample selected from the estimated 6.2 million police-reported crashes that occur every year (Stashny, 2007).

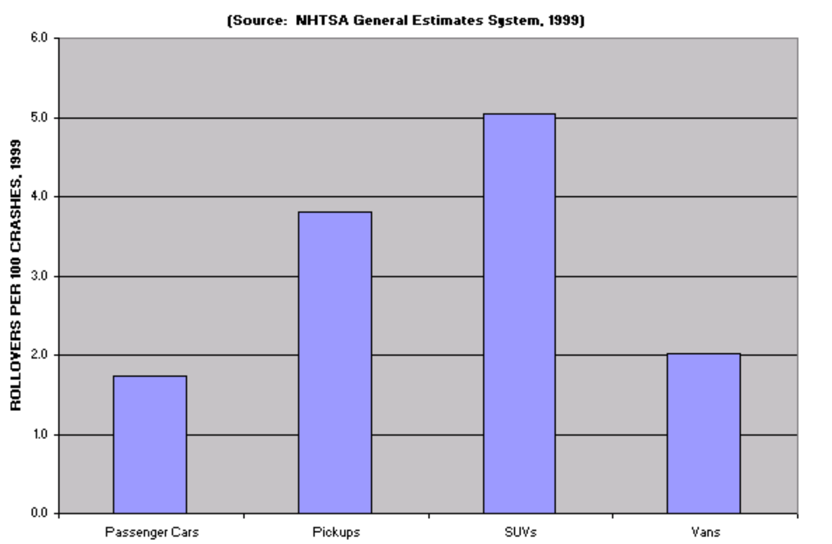

Figure 1 Rollover rate by vehicle type (SUV and Car Safety)

Figure 1 above helps display which vehicles are the highest candidates for having a rollover. Larger vehicles such as SUV's and Pickups have a higher incidence of rollover because of their higher center of gravity. This translates into a smaller lateral force being necessary to force the vehicle into a roll. Vans and passenger cars make up a smaller percentage though even a one-in-a-hundred chance of rolling a vehicle is quite dangerous considering that these types of crashes tend to produce a high fatality rate. The graph below further illustrates this point by comparing fatality rates of different SUV classes and non-SUV vehicles in rollovers and in non-rollover accidents. As can be seen from the graph, SUV fatalities occur most often in rollover accidents.

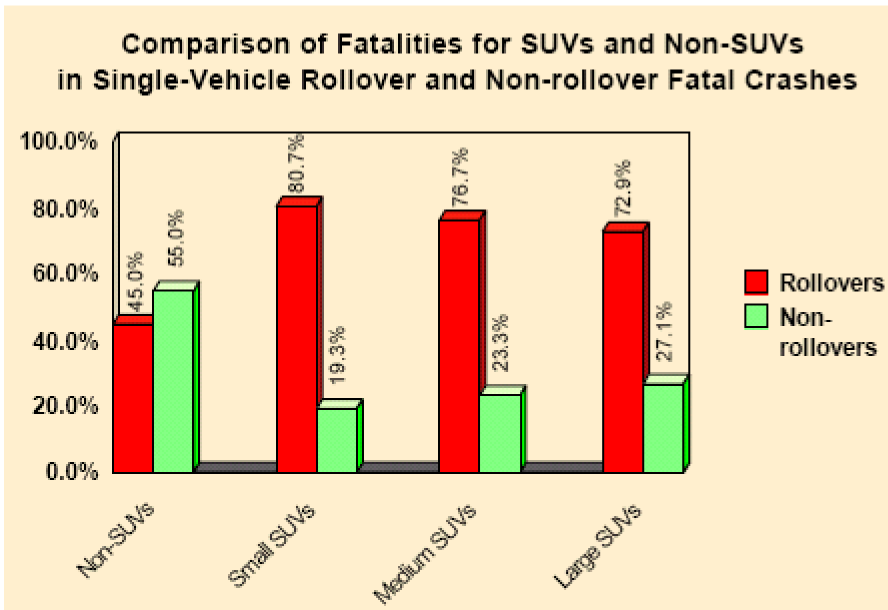

Figure 2 SUV and Car Safety

These numbers make it apparent that while the problem of rollovers has been visited and explored, there is still a high amount of fatalities regardless of the improvements. The NHTSA has been taking steps to reduce these numbers. One of the main features used to reduce this risk is ESC. Research conducted in 2004 confirms that ESC reduces the risk of single-vehicle crashes by 56 percent (IIHS Status Report, 2006). Further research suggests that ESC reduces the risk of a fatal single-vehicle rollover by 69 percent for all vehicles and 72 percent for SUV's (IIHS Status Report, 2008). These numbers are encouraging, however, our surveys of consumers suggests that some are wary of such systems taking control from the driver. Also, some share a concern that such auto-correction systems can promote bad driving skills by leaving the driver unaware of their actions that caused the rollover. The results of our customer survey research are discussed more in depth later in the report.

3.2 Rollover Ratings

Rollover resistance ratings, developed by the NHTSA, are a way of assessing the rollover risk of a certain vehicle. Vehicles are given a rating between one and five stars to determine the risk. The number of stars indicates a percentage of risk associated with the vehicle's tendency to rollover. Figure 3 below shows what each rating means (NHTSA Rollover Ratings).

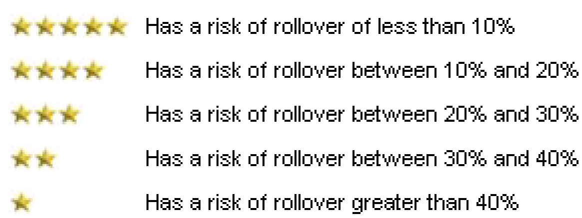

Figure 3 NHTSA Rollover Ratings

The figure below shows average ratings for vehicles tested under the NHTSA's 2001-2003 rollover resistance ratings system (NHTSA Rollover Ratings). These ratings reflect the data of over 86,000 real single-vehicle crashes. As can be seen in the graph, SUV's, pickups, and vans tend to have lower ratings than cars. SUV's and pickups have the most variability in their range of ratings and also holding the worst ratings. This data suggests that these problem vehicles are those that need the most improvement. To ensure the safety of the operators and passengers of these vehicles a supplementary system such as ESC or our proposed design could aid the driver in being safer on the road.

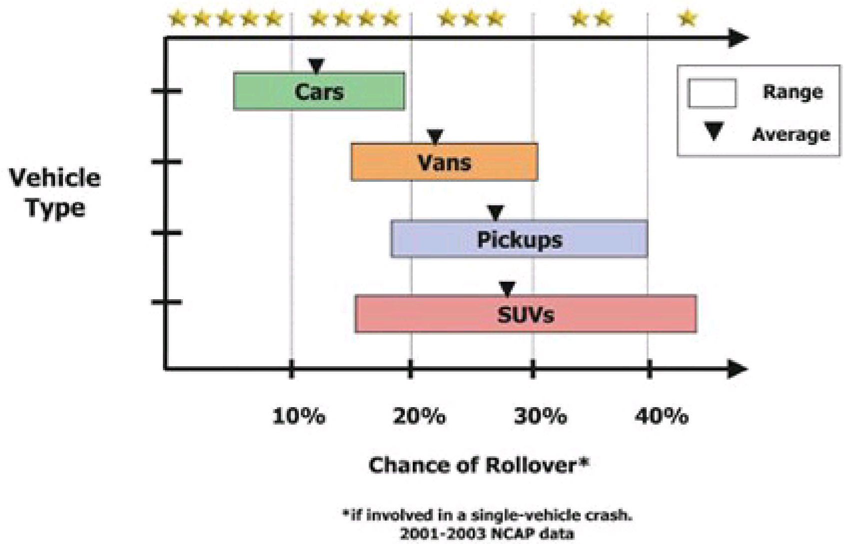

Figure 4 NHTSA Rollover Rating Categories

3.3. Prior Art

The problem of detecting and preventing vehicle rollovers is not unvisited. There are a few solutions already available on the market as well as devices that can function somewhat similarly to our system design.

3.3.1. ESC

Electronic Stability Control, or ESC, is a feature built on top of an anti-lock brake, or ABS, system available in modern day vehicles. It is a computerized system integrated into the vehicle's own system that detects skids, and in the event of one, attempts to stabilize the vehicle. The components of ESC include a yaw rate sensor that measures angular velocity around a vertical axis, a lateral acceleration sensor, a steering wheel sensor, and a control unit (ESC Wiki).

The device detects a skid by comparing the direction in which the vehicle is going to the direction it should be going (by means of the steering wheel sensor) and if these do not match up, the vehicle is engaged in a skid. In the event of a skid, the system predicts the direction the vehicle will go, the control system applies the breaks to individual wheels asymmetrically to create a torque that opposes the skid and also aids in pointing the vehicle in the desired direction. The system also may reduce engine power to slow the vehicle down (ESC Wiki).

The estimated price of fitting a vehicle with ESC is $300 to $800 dollars (IIHS Status Report, 2006). However, ESC is not often available as a stand-alone option, and is not easily available for aftermarket installation. A package containing ESC can cost several thousand dollars (IIHS Status Report, 2006).

Our design aims to avoid auto-corrective features. Our reasoning is that it promotes poor driving. The driver might not even be aware of the corrections being made, and thus cannot improve their own driving skills to make them safer drivers. Also, the problem with relying on auto-correction is that they don't always function correctly. If there is an error in the system it can be costly to repair and in the case of the next potential hazard it won't perform the correction and puts the driver in a dangerous situation.

ESC is primarily designed to correct in the condition of a skid, not in a rollover. However, it does significantly reduce the chances of a rollover. As mentioned previously it is estimated to reduce rollover accidents in vehicles by over 50% (IIHS Status Report, 2008).

StabiliTrak is General Motor's version of the Electronic Stability Control that was introduced in 1997 (ESC Wiki). The earliest forms of ESC were first introduced in 1987 by Mercedes-Benz, BMW, and Toyota. The first models did not however, aid in the corrective steering of the vehicle. ESC is unavailable in vehicles produced before this time, and it is rarely available for aftermarket to install into older vehicles.

With this solution already available on the market as a competitor our design offers a way to detect rollover conditions and not just skidding. Also, our product could go into market for under $50 dollars with no installation necessary. Our product does not implement auto-corrective features that force the driver to rely upon them for safety. Our product aims more to serve as a warning when dangerous lateral accelerations are present to allow the driver ample time to self-correct their course before entering a dangerous state.

3.3.2. Personal G-Force Meter

There are numerous sources available with instructions on how to create a G-Force meter that could be used in a vehicle. There is also an application available for the iPhone to measure acceleration. These two options have a low cost as the first requires the user to build it from scratch using parts. The second is an application that can be downloaded onto an iPhone for between $4.99 and $12.99. These two are the lowest cost available g-force meters around. However, neither is designed to warn the driver of dangerous acceleration forces.

One such model, called the G-TECH Pro Competition Performance Meter, can output a variety of different measurements including the lateral G-Force. This product is intended for professional drivers and is advertised to cost $199.95. There are also others on the market that range from $30 to over $300 dollars. These products can offer an accurate measurement of the G-forces in a vehicle. However, many cannot be easily incorporated easily into a vehicle. Also, what these products do not offer is an indication as to what level of lateral G-forces could be dangerous. To use these products in the context of how we wish our product to be used, the driver must possess the knowledge of their vehicles tipping thresholds and continually refer to the meter to determine how close they are.

Our product offers an easy to interpret string of LED's. Yellow lit LED's indicate that the driver is approaching a dangerous condition. Red LED's in conjunction with a buzzer sound indicate to the driver that they are close to potentially flipping their vehicle. These warnings are easily interpreted with a glance or by listening for the buzzer alarm as opposed to a digital LCD display that displays a number that may or may not be any use to the driver.

3.3.3. Rollover Prevention and Mitigation

There are also rollover prevention and mitigation systems available on the market. These systems will apply the brakes and lower the engine speed to help maintain control. They have several names, including Electronic Roll Mitigation, Roll Avoidance, Active Roll Mitigation, Roll-Over Protection System, depending on which of the various companies (DaimlerChrysler, Ford, Range Rover, and Volvo respectively) made the particular system for use in their vehicle.

These systems often built upon the functionalities of Electronic Stability Control, and are designed to take corrective action when the user is in a dangerous situation. These systems are not readily available for installation after market. To obtain one, the system is often included in a package when the vehicle is purchased. The running cost of such a system exceeds that of Electronic Stability Control. These systems are typically not present in older vehicles and can cost (in a package) up to several thousand dollars.

3.3.4. Rollover Preparation Systems, and Vehicle Stabilizing Systems

Delphi developed a system that in the instance of a rollover it would implement several safety features including roll bars, seat belt pretensions, window airbags and/or head airbags. Vehicle Stabilizing Systems work similarly, aiming to take action to reduce damage to the vehicle occupants in the instance of a crash or rollover.

These systems, while useful in the case of an accident do nothing to prevent the accident or rollover itself. Our design aims to alert the driver before a rollover occurs so that they can take corrective action. However, these safety systems are useful in reducing injury when an accident cannot be avoided. The systems described could potentially be used in conjunction with our rollover-warning system in the case where the driver fails to correct their driving after the warning is given.

3.3.5. Patents

There are a variety of patents already available on the subject of vehicle rollover detection. Essentially, many patents for devices like our own rely on a combination of accelerometers, roll rate detector, roll angle detector, yaw-rate, side-slip angle, vehicle speed, and a matter of reading the status of the steering wheel. These devices offer an accuracy that is greater than our design because of the precision of using many different types of sensors.

We make the argument that these extra sensors are not necessary for our purpose. The aim of like designs is often to output a control signal that will activate some sort of roll-safety-unit. This can be roll bars, air bags, or any safety device. Our design aims to provide a very cost effective solution that gives the driver a feel for how dangerous their driving maneuvers are at any particular time. Since our thresholds are set a fraction below the tipping point of each class of vehicle, we only need to utilize a lateral acceleration force to determine if the vehicle will roll over. The physics of this are shown in the next section.

3.4 Physical Principles of Rollovers

One of the primary factors in causing a vehicle to roll over is the lateral acceleration, that is, the side-to-side acceleration of the vehicle. When a person is driving along a straight route, they are accelerating and decelerating in a linear, forward-and-backward direction. When that same person makes a turn, however, they are accelerating in the direction that they are turning. This acceleration gives rise to a lateral force on the vehicle, called the "centripetal force."

The centripetal force is created by the traction of the tires gripping the road. Because this effect occurs at a different point than the center of the gravity of the vehicle, as the car travels around a turn there is a twisting motion as the inertia of the center of gravity causes it to trend forward while the tires are following the course of the turn. It is this twisting motion that can cause a vehicle to rollover in extreme situations.

The likelihood of such a rollover can be predicted based on a fairly simple model. The key characteristics of the vehicle include its center of gravity, located at approximately 1/3 of the total height of the vehicle, and its track width, or the distance between two wheels diagonally across from each other. With this information, we are able to fairly easily calculate the lateral acceleration required to initiate a rollover for that particular vehicle. The formula for such a calculation is as follows:

$$Acceleration = 0.0310809502 * \frac{(16 * Track\ Width)}{(0.38 * Height\ of\ Vehicle)}$$

This formula can be applied to all manner of vehicles, as the concepts of center of gravity and track apply to sedans, SUVs, and vans alike. This allows us to factor in individual makes and models of cars into our calculations and compare them objectively to create "averages" for a certain class of vehicle. This allowed us to have various settings for our device to apply to different sizes of vehicles.

3.5 Accelerometers

In order to relate the rotational forces experienced by a car during a rollover to electrical data, a sensor is needed. This sensor is known as an accelerometer. There are many variations of accelerometers: piezoelectric, piezoresistive, thermal, capacitive, etc. Despite these differences, each of these accelerometers has the same basic function; to withstand a force and output a corresponding voltage. In our application, an accelerometer is used to detect the forces withstood by the car and use the output voltage of the accelerometer to power an indicator letting the driver know the level of danger that they are in.

3.5.1. Accelerometer Functionality

Accelerometers are designed for many different levels of functionality as well. The first of these functionalities is the number of axes. The most common of these is a 2-axis accelerometer which can measure forces along the X and Y axes; however there can also be accelerometers that can detect forces along just one axis, or along all three axes. The second functionality of accelerometers is the "g-rating." An accelerometer detects the level of acceleration that an object withstands. This acceleration is analyzed in terms of "g-force" which interprets it as a ratio to the acceleration due to gravity. The acceleration due to gravity has a rating of 1g, and an acceleration of twice this will have a value of 2g, etc. The "g-rating" of an accelerometer tells how much acceleration it can withstand. This can range anywhere from +/-1g to +/-18g. For our application, we will use an accelerometer that is rated for +/-2g.

One of the wonderful aspects of an accelerometer is that the output voltage will be based on the supply voltage. This means that the supply voltage can be varied and it will not affect the voltage ratio experienced at the output. Despite this allowance for variation in the supply voltage, accelerometers are still rated for a supply voltage range. Determining this range means allowing enough room in the supply voltage to allow for the full acceleration that the accelerometer can withstand. To know what this maximum voltage swing will be, accelerometers are also rated for sensitivity. The units of this sensitivity are given in V/g, meaning the amount of voltage that the output will change for every interval of 1g acceleration. For example, an accelerometer with a sensitivity of 200mV/g will swing 200mV at the output at 1g, 400mV at 2g, etc.

Accelerometers can be used with either a single supply voltage or a dual supply voltage. In order to allow for the maximum output voltage swing of the accelerometer, determined from the sensitivity and "g-rating," the accelerometer will have an offset at the center of the supply range. In the instance of a dual supply, this is very simple as the center voltage is just 0V or ground. In the case of a single supply, this voltage offset will be half of the supply voltage. For example, if the supply voltage is 3V, the accelerometer offset will be 1.5V. Because accelerometers can be used in both the single and dual supply configuration, some adjustment is needed. When switching between the dual and single supply, in order to keep the output voltage swing intact, the voltage difference between supply rails must remain the same. If the dual supply has voltage rails set at +/-1V, then the single supply voltage must be +2V in order to keep the same difference between the rails.

3.5.2. Accelerometer Types

All of these functionality properties of accelerometers must be taken into account when selecting which device to use. However, these are not the only factors to consider.

The type of accelerometer can affect the conditions under which it can be used and how well it will perform. The following section gives a brief overview of several different options of accelerometer types.

3.5.2.1. Capacitive

A capacitive accelerometer is a mechanical device that relies on a silicon cantilever that is forced to move under the stresses of acceleration. The acceleration is measured as a change in capacitance of the capacitors that are located above and below this cantilever. Since this device is symmetric the effects of temperature on the output are reduced. The output of this type is a varying voltage that has a linear relationship to the acceleration. (PCB Piezotronics INC.)

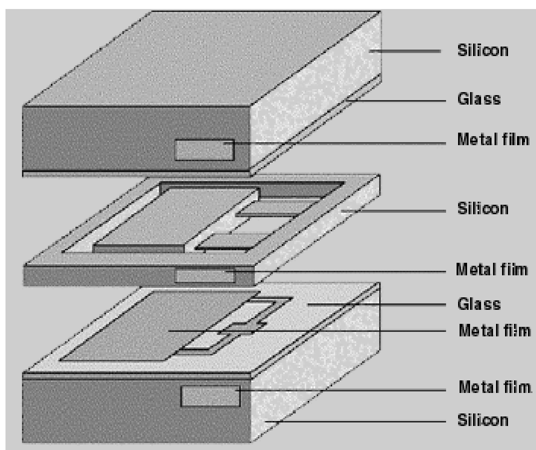

Figure 5 Capacitive Accelerometer (Vierinen, K)

3.5.2.2. Piezoelectric

Piezoelectric accelerometers also called 'compression type' are another mechanical type of accelerometer where the sensing element is a crystal that emits a charge when it is compressed (Kulwanosky). A mass and a spring, when subject to the forces of acceleration, provide pressure onto the crystal which then emits a voltage that can be converted via a linear relationship to a corresponding g-force. This acts upon the principle of Newton's Second Law (F = M*A).

The output of such a device can be described by the following equations (Kulwanosky, 2004):

$$\frac{a_o}{a_b} \approx \frac{1}{\sqrt{\left[1-\left(\frac{f}{f_n}\right)^2\right]^2+\left(\frac{1}{Q^2}\right)\left(\frac{f}{f_n}\right)^2}} \quad \text{phase lag } (^\circ) \approx \frac{60}{Q}\left(\frac{f}{f_n}\right) \text{ for } \frac{f}{f_n} \leq \frac{2}{5}$$

f_n	=	undamped natural (resonant) frequency (Hz)
f	=	frequency at any given point of the curve (Hz)
a_o	=	output acceleration
a_b	=	mounting base or reference acceleration ($f/f_n = 1$)
Q	=	factor of amplitude increase at resonance

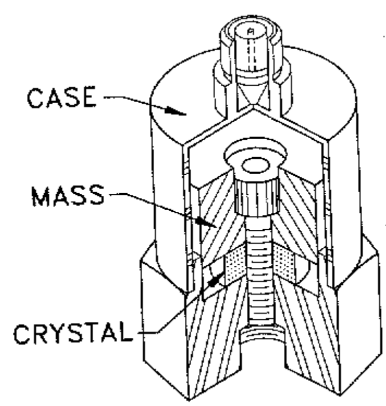

Figure 6 Commercial Piezoelectric Accelerometer (Lecture #10)

3.5.2.3. Piezoresistive

A piezoresistive accelerometer works similarly to a piezoelectric accelerometer. Instead of having a crystal that emits a signal when it is squished between a mass and the base, it features a piezoresistive substrate that when squeezed will vary the resistance of the etched bridge network which is detected by a Wheatstone bridge network. One interesting thing about piezoresistive accelerometers is that they can measure accelerations down to zero Hertz while a piezoelectric sensor cannot.

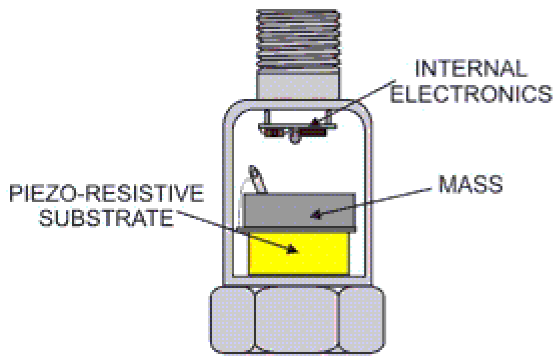

Figure 7 Commercial Piezoresistive Accelerometer

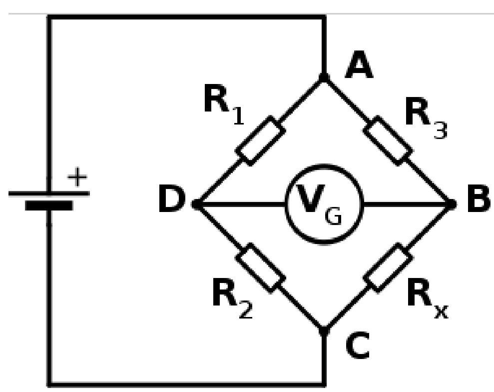

Figure 8 Wheatstone Bridge to measure resistance (Wheatstone Bridge Wiki)

3.5.2.4. Hall Effect

A hall-effect accelerometer is another mechanical sensor. The Hall element is attached to a spring with a moveable mass. The movement is the result of the forces due to acceleration. The element moves in a non-uniform magnetic field. The generated Hall voltage is proportional to the measured acceleration. The motion is converted into energy by the sensing changing magnetic fields.

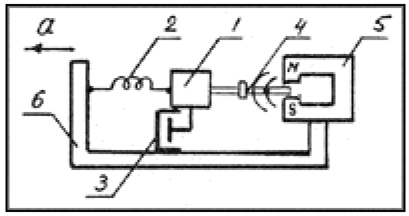

Figure 9 Hall Effect

a = acceleration,
1 = seismic mass,
2 = spring,
3 = damper,
4 = Hall element,
5 = source of non-uniform magnetic field,
6 = case (Hall Effect)

3.5.2.5. Magneto-resistive

The magneto-resistive accelerometer works in much the same way as the Hall Effect sensor except that it derives its output by measuring the resistive changes in a material brought on by a changing magnetic field.

3.5.2.6. Heat Transfer

This type of accelerometer uses a heated gas bubble with thermal sensors and function much like a construction level. When the accelerometer is tilted or accelerated the sensors pick up the location of the gas bubble and this is proportional to the acceleration or tilt of the device.

3.5.2.7. MEMS-Based (Micro-Electro Mechanical System)

This type of accelerometer is manufactured and designed to be small, on a micrometer scale. They can take on the characteristics of other accelerometer sensor types, just on a reduced scale to keep up with our technology growing ever smaller and more efficient. Some iterations of MEMS-Based accelerometers include those which use a seismic mass and the deflection is measured to determine the acceleration. Another less common type features a dome filled with air, the air is heated, and where the heated air reaches within the dome determines the acceleration (Practical Guide to Accelerometers).

3.5.2.8. Spring-Mass

A spring mass system, or mechanical system, is able to detect acceleration. It consists of a spring attached to a base and a seismic mass attached to the other side. The displacing of the mass (measured as a varying resistance) is a measurement of the accelerative force (How Accelerometers Work). This varying resistance is converted to a current or a voltage. However, in this type of accelerometer it is important to keep the mass from oscillating at the spring's natural frequency.

3.5.2.9. Pendulum

This type of accelerometer uses a pendulum. The acceleration is a result of the angle of the pendulum with a seismic mass attached to the free end. This angle corresponds to the acceleration.

3.6 Customer Survey

It is important to take into consideration the wants and needs of the customer. After researching our problem and conducting market research on the subject we set to survey potential customers that would have an interest in our product. We asked questions to assess the perceived need for this design and the specific wants of the consumer who would purchase it if it were available. The survey, which we distributed to twenty-seven different people, can be seen in Appendix B. The results of the survey are tallied below and discussed in the following sections.

3.6.1. The Results

The results of the survey are shown in the chart below. The survey was administered to 27 people throughout New Hampshire, Connecticut and Massachusetts. The results below are a tally of the most important questions asked and the most encouraging answers received.

Though trucks, vans, and SUV's have the highest instance of rollover, fewer people drive them. Our survey showed that over half of our participants chose a sedan. Using these results we decided to tailor to three types of vehicles: sedans, SUV's and vans.

As can be seen from the chart many people have bad feelings about auto corrective technologies. To tailor to this, we decided to create a device that employs no auto-corrective features; it just delivers a warning. Many of the surveyed subjects expressed their concern about a system failure and their unease toward having an automated system take control of their vehicle.

Questions six and eight showed us that many people aren't concerned about a getting into a rollover accident; furthermore, many drivers do not obey the speed limit on ramps. This, we determined, could be a cause of these accidents. Questions nine and ten showed us that many of our survey participants didn't know the scope of rollover accidents/year and the great number of fatalities as a result. Also, many drivers did feel that research into the problem was necessary after reading how many accidents and fatalities there were per year.

The final question asked the participants to reveal what they would want in a rollover-detection system. We found that the most important factors were ease-of-use and cost. The least important factors were aesthetics and portability.

Table 1 Customer Survey Results

Question	Responses	Tally of Responses
1	***What type of car do you drive? Sedan, SUV, Truck, etc.?***	
	Sedan	15
	SUV	7
	Truck	3

	Van	2
4	***How do you feel about auto-correct features in cars?***	
	Good	12
	Bad	10
6	***How concerned are you about getting into a rollover accident? 1-10 scale***	
	Indifferent	5
	Low (1-3)	15
	Moderate (4-7)	9
	High (8-10)	2
8	***How fast would you say on average you drive on an on-ramp?***	
	Below 30 MPH	7
	30-39 MPH	12
	40+ MPH	6
9	***Did you know that there are over 280,000 rollover accidents in the US each year, and that over 10,000 of them result in fatality?***	
	Yes	5
	No	22
11	***What features would you like in a rollover early warning detection system?***	
	Aesthetics	4
	Cost	10
	Functionality	11
	Portability	5
	Easy-to-Use	14
	Aesthetics	4

4.0 Design Criteria

We derived our product specifications after performing market research and surveying potential consumers. From our research we came up with six design criteria to help shape our design in the design process. These six criteria we listed as affordability, ease-of-use, versatility, portability, effective notification, and aesthetics. Each of these specifications is discussed in the following sections along with how our design meets these criteria.

4.1 Affordability

Our most important criterion was to make the design affordable. As previously mentioned in our Market Research, many of the options already available are costly to the consumer. The prices range from $100 for small personal acceleration measurement devices (which are not tailored to be used as a rollover detection system) to upwards of thousands of dollars for an electronic stability control system. We expected our device to have a retail price no greater than $100 dollars. However, we aimed for a loftier goal of under $50.

Our final list of parts comes out to a total of $72.51, with an expected retail price of $90. This price is found using the parts list from our prototype design. With mass production our device would become even more cost effective, as the price per unit of the parts required would go down significantly. This pricing is discussed in further detail in the Cost Analysis Section.

4.2 Ease-Of-Use

One of the things we learned from our market research was that customers want the product to be easy to use. They do not want to be required to press buttons while driving, nor have to constantly be staring at the device for it to be helpful. To make this device 'easy to use' we came up with a set of qualitative rules.

- The driver should not have to adjust the device while driving.
- The device should be easy to see.

- The driver should not have to look at it constantly, and thus we would need to include an audio alarm.
- The device should be mountable in a location that is easy to see and doesn't block other important driving features of their own personal vehicle.
- The device should have some sort of battery life indication.

Our device tailors to this criterion by passing each of the rules. The device only needs to be placed, then turned on, and set to the right vehicle type before driving. There are no adjustments needed in travel to the device. We implemented a string of LED's as a visual indicator; these can be processed by the brain in a short glance as there is no need for the driver to analyze a numerical result that one would get from a personal G-force meter. The device we designed would be mountable in such a way that a GPS is mountable. Finally, we included a battery life indicator. The center LED of the device remains on during use. If the light is dim or off, then the battery is low or dead and needs to be replaced.

4.3 Versatility

We determined from our research that our device should be versatile. Because of the nature of rollovers, different vehicles have different thresholds for lateral accelerative forces that would cause the vehicle to tip. We wanted to make our design applicable to all types of vehicles. This feature is included so that if a family has multiple vehicles, the devices can be easily moved between them rather than buying a specialized device for each car model. We decided to group vehicles into three classes: sedans, SUV's, and vans. This covers a broad spectrum of vehicles. The device we designed would have a setting for each that could be easily switched before starting the vehicle.

Our concept achieves this design criterion. We designed our product to be able to switch between vehicle types while our prototype only features one type. In our design, we needed to be able to change the value of two resistors proportional to each other (one going up, and one going down). One proposed solution was to use photo-resistors. This criterion could also be implemented using a digital solution.

4.4 Portability

We also aimed to have our device be portable. This criterion is more or less a group of smaller criteria. To be portable the device needs to be small and not permanently attached to the vehicle. Quantitatively, we decided that the size of the device should be no larger than 5′′ by 4′′ by 2′′. This is about the size of a GPS system. Also, in order to be portable the device needs to be able to run off battery power. We also hoped to implement a charging element.

Our final prototype fits in an enclosure that is 5′′ x 2.75″ x 1.275″, which fits within our size specification. We did not, however, implement a charging element to our design. As a suggestion to future groups who wish to take on this project, it is another element that would be nice to include. We did however include a battery indicator. The center LED on the device is always on, indicating that the device is working. If the center LED is not lit, the batteries must be replaced. We decided to run our design on two AA batteries, an easy standard and widely available.

4.5 Effective Notification

Our device needed to alert the driver of dangerous lateral forces that may cause a rollover if exceeded. This criterion is harder to quantify however we determined that we would need both a visual indication and an audio indication when the top threshold is crossed.

We satisfied this criterion by having a string of LED's. There are three green LED's, two yellow LED's and two red LED's that provide an easy to understand reference. Upon turning left abruptly, the lights would light up in order in the left direction from green, to yellow, to red; this also applies when swinging to the right. Red indicates a dangerous lateral acceleration. This device requires nothing more than a quick glance and there is no need to interpret numbers, just a simple visual gauge in a color scheme that is easy to comprehend. Upon one of the Red LED's lighting up, our design also deploys an audio warning in the form of a buzzer while that light is lit. This design criterion was successfully fulfilled in full.

4.6 Aesthetics

Aesthetics is an important consideration of any design. A fully functional design can fail if it is not pleasing to the eyes. Our design criteria included a few constraints that ultimately affect the aesthetics of our design. One such criterion limited the size of the device. Another criterion stressed 'simplicity' in the device's user interface. This criterion specified that there should not be any unnecessary "bells and whistles" attached to our device and that the device should be a 'set-and-forget' type. Essentially, this means that the user could set the device before driving and have no need to make adjustments during travel.

One of our design criteria involved limiting the size of our design to fit within a 5″x 4″x 2″ space. As we mentioned before, our final prototype fits in an enclosure that is 5″x 2.75″x 1.275″, which is well within our criteria. We also sought to have a fairly simple interface. There is a switch that adjusts the device to correspond to sedans, vans or SUV's, and a button to turn the device on. A string of LED's is the only other visible component to the device. The middle LED illuminates to indicate that the device is powered on.

This simple interface allows the user to assess their risk without having to take up a large amount of space. This feature is inherent in almost all devices as technology grows smaller. Our device also offers a simple warning system. A quick glance is all the user needs to obtain information about their risk under certain driving maneuvers. Figure 10 below is an artist's rendition of our prototype in its final form.

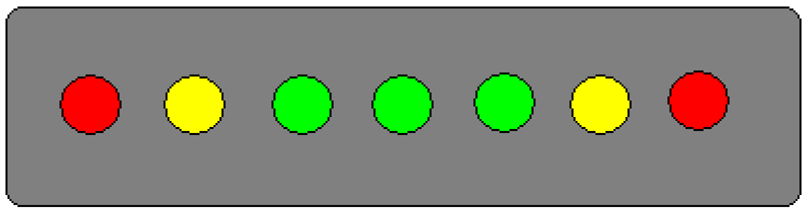

Figure 10 Artists Rendition of LED Output Array

5.0 Implementation

The concept of this device was to have a string of output LEDs with different colors representing the different levels of danger that the driver is in. The lowest warning level has a color of green, the middle level of warning has a color of yellow and the highest level of warning has a level of red. These LEDs will light once the acceleration of the car reaches the predetermined thresholds mentioned earlier in the background section. In addition to the warning LEDs there is a buzzer that sounds simultaneously with the turn-on of the red LED. This concept was inspired by sound recording clipping monitors. These monitors have a string of LEDs which flash from green to red based on the volume level of the sound being recorded. If this sound level is too high the red LED will light indicating that the volume must be lowered. The following section discusses the stages of implementation used in trying to realize this concept.

5.1 Initial Design

The concept behind the initial design was to have multiple transistors that would be turned on at different voltage levels. As the voltage increased, the Base to Emitter voltage of each transistor would increase until it eventually reached its turn-on value at which point the transistor would allow current flow and would light up the LED. This section describes the circuit of this implementation and discusses the successes and failures associated with it.

5.1.1 Circuit Description

This circuit has five parallel branches that are made up of the same components. Each of these branches includes a Current Limiting Resistor, LED, and BJT all connected in series. The Resistor and LED are connected in series between the positive terminals of the battery and the collector terminal of the BJT. The Emitter of the BJT is connected to ground. This configuration is repeated for all five LED branches. The difference between these branches comes in the Base connection of each BJT. Each Base terminal is connected to a voltage divider. The Resistor values of these voltage dividers were determined such that as the voltage supplying each voltage divider increases, the BJTs in each branch will turn-on at different voltage levels. A schematic of this circuit can be seen below in Figure 11.

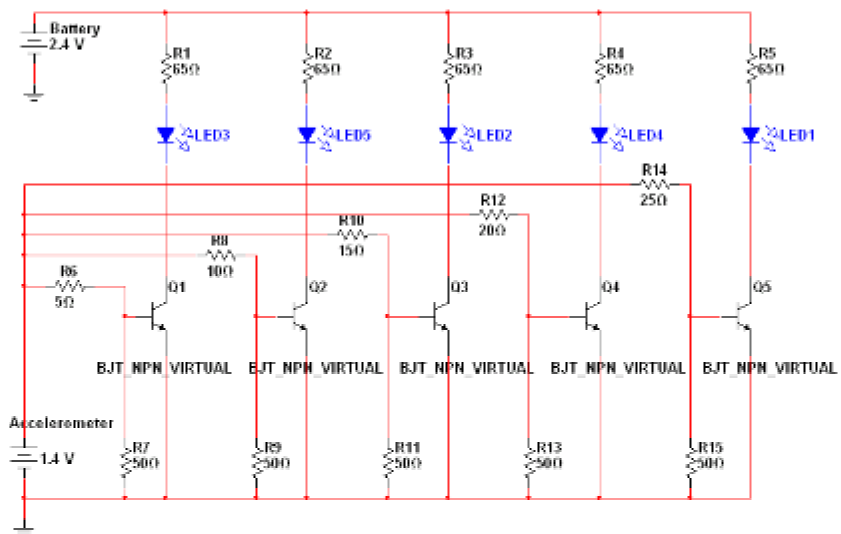

Figure 11 Initial Output Design Circuit

5.1.2 Discussion

This initial design would not work in simulation and as such never made it to the build and test phase. The circuit did work in the respect that the voltage divider did allow the BJTs to turn on at varying levels. Once these BJTs turned on the circuit worked as expected, with the LEDs turning on and staying on until the BJT turned off. The problem with this circuit was with the inconsistencies in BJT design. Since each BJT is different, their turn-on voltages will all be slightly different. This difference in turn-on voltage makes it impossible to design the voltage dividers for a generic case. If the turn-on voltage is too low, the LEDs will light up too early and conversely if the turn-on voltage is too, the LED will light up too late. For the next design, the Resistor, LED, BJT branches will be kept and changes will be made to better control the turn-on points of the BJTs.

5.2 Second Design

From the first design, it was determined that using a BJT to control when the LED lights works well but something more is needed to control the turn-on point of each BJT. This second design addresses this issue by using comparators. When the threshold of the comparator is crossed, the full voltage of the battery will supply the Base of each BJT, eliminating any problems with varying turn-on voltages in the BJTs. This design also addresses the issue of varying the turn-on voltages for different types of cars and includes the buzzer which sounds when the red LED is lit. This section describes the circuit of this implementation and discusses the successes and failures associated with it.

5.2.1 Circuit Description

The circuit for this design has the same Resistor, LED, BJT parallel branches as the initial design. Different than the initial design, the Base of each BJT is connected to the output of a Comparator. The positive input of each comparator is connected to the output of the accelerometer. The negative terminals of the Comparators are connected to different points on a voltage divider supplied by the battery. Each of these points corresponds to a different voltage level which will remain constant. There is a multi-positional switch which is connected to the voltage divider. In each position of the switch there is a different resistor whose value will change the levels of the voltage divider, increasing or decreasing the threshold values for a given type of car. As the accelerometer output voltage increases past the voltage of the negative input voltage, the output of the comparator goes to a “high state” at a voltage equal to the battery voltage. This voltage will turn on the BJT and subsequently the LED will light up. A schematic for this circuit can be seen below in Figure 12.

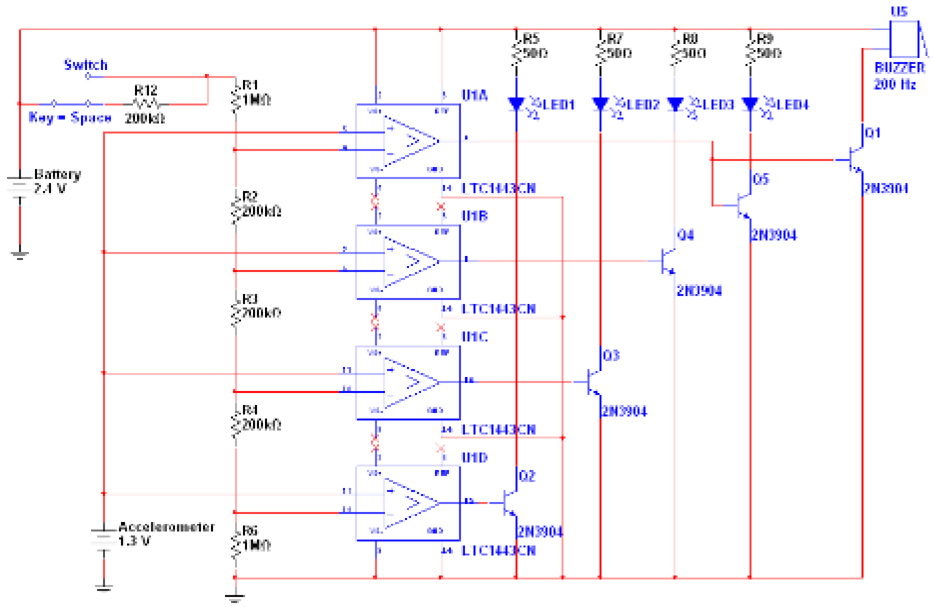

Figure 12 Second Output Design Circuit

5.2.2 Discussion

Unlike the initial design, this design did work in simulation. As a result, the circuit was built and tested in the lab using a function generator to simulate the varying input of the accelerometer. This circuit worked when tested in the lab as well. The problem with this circuit is that it was designed with false assumptions. It was thought that the accelerometer would have an output of 0V when withstanding no acceleration. In the Dual Supply scenario this is true but in the Single Supply case the accelerometer has an output offset of half of the supply voltage. As mentioned in the Background section of this report, the accelerometer output will swing from 0V to the supply voltage to account for the negative and positive accelerations. Because of this the design must be modified to allow for the negative as well as the positive. In its current design this circuit will only allow for the positive. Other observations about the circuit showed that the accelerometers can produce enough current and voltage at the output to drive the

LEDs directly without needing the BJT. The next design will keep the comparators and will alter the voltage divider and comparator output stages to account for the problems mentioned.

5.3 Final Design

While the second design was a success, it was not correct for the proper requirements of accelerometers. Based on the new information, this design includes two separate comparator networks, one for the positive acceleration and one for the negative. The positive configuration will be connected in the same manner as the second design with adjustments to the voltage divider network to account for the new thresholds. The negative configuration will have the same concept as the positive except that it must be designed so that the comparator output will enter the "high state" when the accelerometer output goes lower than a certain threshold. This can be done using the same components as the positive configuration just connected in a different fashion. This section describes the circuit of this implementation and discusses the successes and failures associated with it.

5.3.1 Circuit Description

This circuit uses the Comparator concept from the second design with a few differences. In this circuit there are two parts, one for positive acceleration and one for negative acceleration. Each consists of a voltage divider, three comparators and three LEDs, one each of green, yellow, and red. In the positive section, the voltage divider is used to give the voltage levels for the negative inputs of the comparators. The positive inputs of these comparators are supplied by the output of the accelerometer. In the negative acceleration section, a voltage divider is used to give the voltage levels for the positive inputs of the comparators. The negative inputs will be supplied by the output of the accelerometer. Each comparator in both the positive and negative acceleration sections will have a series resistor and LED connected to ground. Also added in this circuit is the buzzer which is connected to the a node of two diodes, each going to the output of a Red LED comparator, one for the positive acceleration and one for the negative acceleration. There is also a Green LED which is connected directly from the battery through a resistor to ground. This LED will remain on at all times and will dual serve as a power indicator and a centering point for the output LEDs. The last part of this circuit is a Sensitivity Modulation circuit. This consists of an Op-Amp configured with negative feedback and a varying inverting gain. The Positive input of the Op-Amp is connected to a voltage divider to give the output the same bias as the accelerometer. The output of the accelerometer is connected to the positive input of the Op-Amp through a 1MΩ resistor. Using a 3-Position Switch, the feedback resistance is changed, varying the gain. This varying gain allows the device to be used in SUVs, Vans, and Sedans without needing a separate device for each. A schematic for this circuit can be seen below in Figure 13.

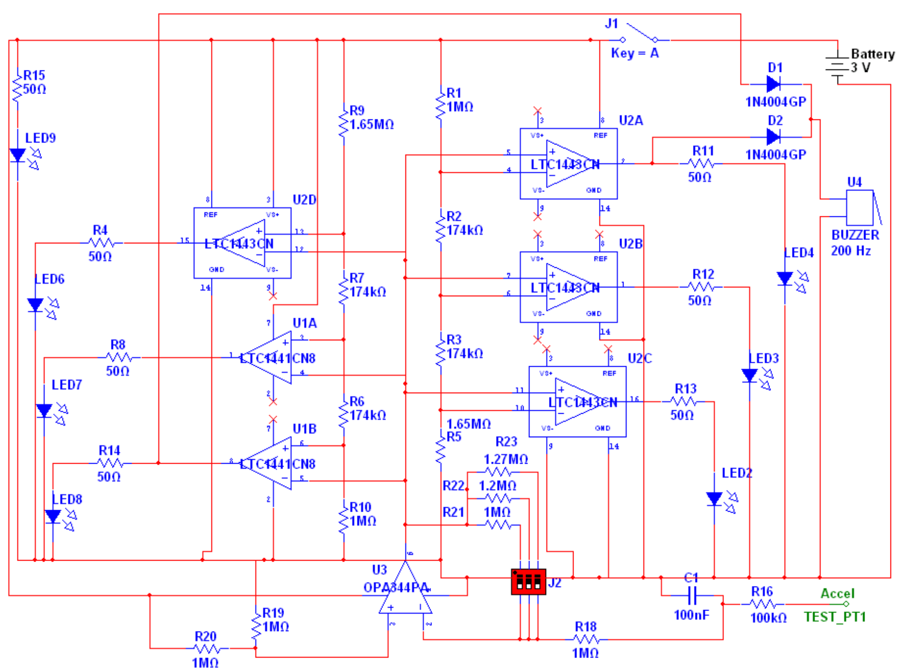

Figure 13 Final Design Output Schematic

5.3.2 Discussion

This circuit worked well in simulation and was built and tested in lab. The functionality of this circuit was confirmed through testing in the lab using a Function Generator to replicate the changing accelerometer output. With all the changes made to the circuit, almost all of the problems were solved. However with these solutions came one new problem. Because there are now two voltage divider networks, the threshold levels cannot be changed as they were in the second design with a simple multi-positional switch and a resistor. In order to change the thresholds there would need to be two switches or some other implementation. After many ideas, a final solution was chosen to be a Sensitivity Modulator as described above. By changing the amount that the accelerometer output swings per g, the thresholds do not need to be changed. This Sensitivity Modulator circuit was added to the breadboard and tested. By increasing the gain of the Op-Amp, the LEDs turned on under less intensive conditions. The next step was to test this circuit using the accelerometer and battery together. The Battery and accelerometer were added to the circuit and by tilting the device along its axis, and increasing the acceleration, the LEDs shown as expected. Having proved that the circuit works, the next step was to design a Printed Circuit Board (PCB) for this circuit.

5.4 Prototype

It was a project objective to have a working prototype by the end. Required for this were the design of a PCB and the soldering of the components onto this PCB. Next, an enclosure was modified to make room for the switches and LEDs. After soldering components to the PCB and mounting it inside the box, the device was given final testing and debugging to ensure functionality.

5.4.1 Printed Circuit Board

The Printed Circuit was created using the program Ultiboard. This is a sister program to Multisim and allows for easy crossover from a Multisim Schematic to an Ultiboard board layout. The desire of this board was to make it as small as possible and after many attempts to put components closer together, the board was shrunk to a size of 4″x 3″. This was considered an acceptable size however a box to contain this size PCB was hard to come by.

A new approach was taken to find a box first and then design the PCB to fit the box. After much searching, a box was found with dimensions 5″x 2.75″. Subsequently the PCB was redesigned to fit the board requirements of the box of 4.65″x 2.36″. The boards were then order through Advanced Circuits. After they were delivered, the parts were soldered to the PCB and the prototype was put together and debugged. A picture of the PCB with components can be seen below in Figure 14.

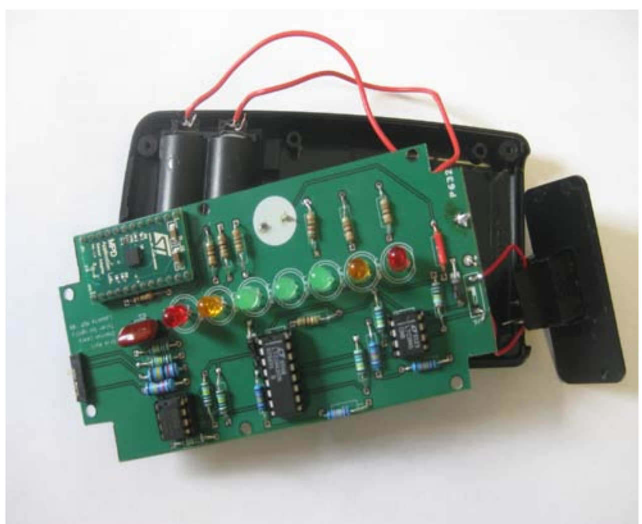

Figure 14 Printed Circuit Board with Components

5.4.2 Testing and Debugging

The prototype was tested in the same fashion as the breadboarded circuit. It was tilted on its axis and given increased acceleration. From these tests, we found that two of the LEDs were not lighting up as expected. Initially it was thought that the Comparator IC controlling these LEDs was not functioning correctly. After switching out the IC, the problem continued. Next, a test circuit was made on a breadboard to prove the functionality of the comparators. The comparators again were not working, even though they were brand new. After much time deliberating and looking at the test circuit, a solution was found. The comparator IC has a built-in reference. This reference when not used is desired to be left unconnected. In our circuit, this reference was connected to the positive power rail. After disconnecting this pin in the test circuit, the circuit worked as expected. The same was then done to the prototype and both LEDs which were previously unlit, lighted up when expected. After disconnecting the reference pin on the IC, the prototype worked as expected with the LEDs lighting in order Green-Yellow-Red with the buzzer sounding simultaneously. This prototype was then tested in a car with the same results; however the Red light was never lit due to safe driving. A picture of the final prototype can be seen below in Figure 15.

Figure 15 Final Prototype while Testing Functionality

6.0 Analysis and Results

After building the device, the first step of testing was to simulate the accelerometer output. Since this is a voltage that will be changing due to acceleration we chose to use the Function Generator to simulate this changing wave pattern. The wave pattern chosen was a triangle wave of 3V peak-peak with an offset of 1.5V. This gives a triangle wave that oscillates from 0-3V, the supply range of the batteries. At first the circuit seemed to be working as predicted. As the triangle wave went above the offset, the LEDs lit up in order Green-Yellow-Red and then unlit in the reverse order. The same happened when the triangle wave went below the offset. This function is what was desired. Also operating as desired was the buzzer, which sounded simultaneously with the lighting of the Red LEDs. The results of these tests prove that this circuit will perform as desired and that the concept holds true.

The Function Generator was initially used because the accelerometer could not be mounted on the breadboard being used. After searching on electrical component provider Digikey, an evaluation board was found which had through-hole pins which allowed the accelerometer to be mounted to the breadboard. Now that the accelerometer could be mounted, the Function Generator was no longer needed. By moving the board left and right at different speeds, the output of the accelerometer changes and therefore changes the input to the comparators.

At first glance the circuit seemed to be working but problems arose when the Red LED and Buzzer turned on. It was noticed that the negative acceleration Red LED would not come on fully nor would it stay on and the opposite was happening for the positive acceleration. The comparators for each side were swapped and the problem still occurred suggesting that the problem was with something other than components. The oscilloscope was connected to the output of the accelerometer and the threshold of the Red LED on the positive acceleration side. The oscilloscope of this can be seen below in Figure 16.

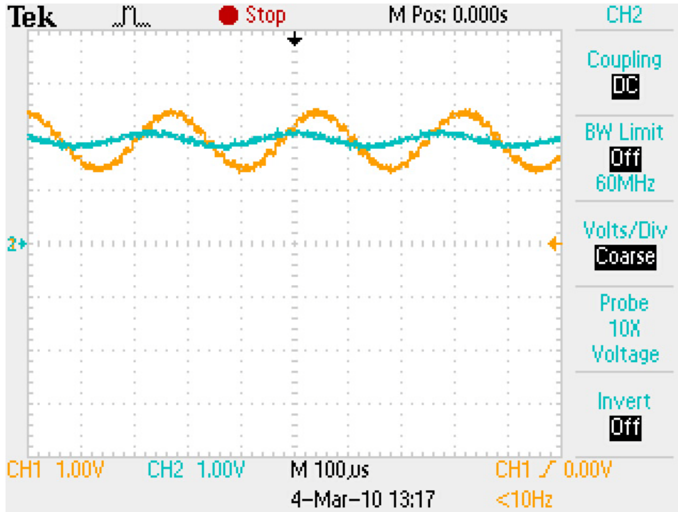

Figure 16 Oscilloscope Graph of Accelerometer Output and Threshold with Oscillation

Although the oscillation seen above only occurred when the highest threshold was crossed, the affect upon the accelerometer output was such that a solution was necessary to prevent change in all thresholds. Based on this data it was determined that the oscillation of the buzzer sound was creating an oscillation in the accelerometer output. Taking the buzzer out of the circuit made the circuit work as it did with the Function Generator, proving that it was indeed the buzzer that was creating the errors. What is believed to have happened has to do with the physics of the accelerometer. Since the output voltage is proportional to the supply voltage, when the output oscillates the supply will oscillate as well. With this oscillation in the supply voltage, the threshold levels also oscillate. This oscillation in the thresholds was causing the accelerometer to jump back and forth across the thresholds, giving skewed lighting on the Red LEDs.

One solution was to filter out the oscillation caused by the buzzer. The idea is that filtering out this oscillation will only allow the DC value of the accelerometer output to get through, keeping the output constant and eliminating the oscillation in the supply voltage and the thresholds. This solution was added to the circuit in the form of an RC Filter. After adding this filter, the oscillation was no longer causing problems and the accelerometer output remained unaffected. After solving this issue, testing was carried out on the final breadboard in an SUV using higher gain to ensure safety of the driver and passengers. Going around a sharp bend at approximately 30 MPH, the Red LED was triggered and the buzzer sounded. Because these tests were performed using a higher sensitivity, they do not prove what driving with the device will be like under actual conditions, but rather proves that the concept works. The final prototype was tested using actual sensitivity and also worked as expected without the Red LED lighting and buzzer sounded because the tipping point of the car was never reached due to safety concerns of those in the car.

6.1 Cost Analysis

One of our most important criteria was to make our product inexpensive. The figure below shows our list of parts we used for our final prototype as well as the Digikey manufacturer number and the name of the manufacturer of each part.

Table 2 Final Parts List

Description	Manufacturer No.	Manufacturer
On/Off Switch	GRS-4011-1600	CW Industries
3-Position Switch	CSS-1310MC	Copal Electronics
1.65M Ohm Resistor	SFR2500001654FR500	Vishay/BC Components
174k Ohm Resistor	HVR2500001743FR500	Vishay/BC Components
1M Ohm Resistor	SFR2500001004FR500	Vishay/BC Components
Project Box	H-67 AA BLACK	Serpac
Rail-Rail Op-Amp IC	OPA344PA	Texas Instruments
1.2M Ohm Resistor	HVR3700001204FR500	Vishay/BC Components
1.27M Ohm Resistor	HVR3700001274FR500	Vishay/BC Components
LED Mount	HLMP-0103	Avago Technologies
Quad Comparator IC	LTC1443CN	Linear Technologies
Dual Comparator IC	LTC1441CN8	Linear Technologies
1N4004GP Diode	1N4004GP-E3/54	Vishay/General Semiconductor
2.3 kHz Buzzer	PB-12N23P-03Q	Mallory Sonalert Products
2g Accelerometer	LIS244ALHTR	STMicroelectronics
100k Ohm Resistor	HVR3700001003FR500	Vishay/BC Components
100µF Capacitor	FK20Y5V0J107Z	TDK Corporation
50 Ohm Resistor	PAC100005009FAC000	Vishay/BC Components
Green LED	LN31GPH	Panasonic-SSG
Red LED	LN21RPH	Panasonic-SSG
Yellow LED	OVLGY0C9B9	TT Electronics/Optek Technology
PCB		Advanced Circuits

First, we set to calculate how much it cost us to create one of our prototypes with the above parts. The table below shows the itemized cost of each part of the design. We were able to produce our prototype for $72.51. This, however, does not reflect the production cost. The analysis was completed again for the cost per unit if we were to create 1,000,000 units. The cost of each part goes down significantly if purchased in bulk. The price of our PCB was purely an estimate. We presumed that if we were to make a million of this device the cost of each PCB would drop by about two-thirds. With the new itemized cost, also depicted in the table below, we determined that if we produced a million of these devices the production cost per unit would be $34.53. Our product criteria called for having a retail cost of under $50. With each device costing $34.53, if we were to sell the device for $39.99 we would receive $5.46 for each unit as profit. This amounts to over $5,000,000 dollars in profit after each was sold. If we sold the device for $49.99 we would have a profit of over $15,000,000.

Table 3 Quantified Cost Analysis

Description	Qty	Price/Unit For 1 unit	Total Unit Price For 1 unit	Price/Unit For 1M units	Total Unit Price For 1M units
On/Off Switch	1	0.99	$0.99	0.45875	$0.45875
3-Position Switch	1	0.68	$0.68	0.27	$0.27
1.65M Ohm Resistor	2	0.19	$0.38	0.0096	$0.0192
174k Ohm Resistor	4	0.636	$2.54	0.636	$2.544
1M Ohm Resistor	6	0.19	$1.14	0.047	$0.282
Project Box	1	6.8	$6.80	2.7	$2.70
Rail-Rail Op-Amp IC	1	1.71	$1.71	0.6875	$0.6875
1.2M Ohm Resistor	1	0.78	$0.78	0.059	$0.059
1.27M Ohm Resistor	1	0.798	$0.80	0.061	$0.061
LED Mount	7	0.335	$2.35	0.12	$0.84
Quad Comparator IC	1	2.5	$2.50	2.5	$2.50
Dual Comparator IC	1	1.85	$1.85	1.85	$1.85
1N4004GP Diode	2	0.048	$0.10	0.048	$0.096
2.3 kHz Buzzer	1	6.06	$6.06	2.9125	$2.9125
2g Accelerometer	1	3.978	$3.98	3.825	$3.825
100k Ohm Resistor	1	0.78	$0.78	0.059	$0.059
100µF Capacitor	1	1.775	$1.78	1.775	$1.775
50 Ohm Resistor	7	0.42	$2.94	0.42	$2.94
Green LED	3	0.215	$0.65	0.09534	$0.28602
Red LED	2	0.168	$0.34	0.09129	$0.18258
Yellow LED	2	0.19	$0.38	0.09	$0.18
PCB	1	33	$33.00	33	10
		Total Cost/Unit	$72.51	**Total Cost/Unit**	$34.53

Through this cost analysis we determined that our design could be developed and sold for under $40 for a moderate profit or for just under $50 for considerably more profit.

6.2 Reliability

A very important factor to consider while designing our product was that it needed to be reliable over a long period of time. Our device was designed to be usable out-of-the-box with minimal need for user input before being ready for use. Additionally, because the adjustment for different vehicles was implemented as an external switch, the user should never need to adjust, manipulate or replace any of the components of the device. Therefore, the discussion on the reliability of the device can be separated into two general sections, Battery Life and Component Reliability.

6.2.1 Battery Life

The first characteristic that many consumers are concerned about in a portable electronic device is its battery life. Replacing depleted batteries can account for a sizable amount of additional cost in the upkeep of a product, and can render an otherwise inexpensive device to cost considerably more over its lifetime.

Our device runs on 2 AA batteries, widely available at most stores. It was designed with ultra-low powered comparators and relatively high resistances in order to limit the current drawn from the batteries, even if all of the LED's on a side are lit. Under this worst-case scenario, our device can be expected to draw about 90mA of current from the power supply. The 2 AA batteries we use can be expected to provide an approximate total of 2500 mAh, allowing our device to run in the most power-intensive scenario for upwards of 25 hours before needing to replace the cells. Certainly, this value is only an average and varies based on the brand and composition of the battery as well as the actual rate of discharging. A conservative estimate of a battery life of 25 hours, however, is characteristic of a low-power device, as we intended. For a driver with a 25-minute commute, this corresponds to needing to replace the batteries approximately once a month, or 24 AA batteries a year. We deem this to be well within an acceptable range, as the device can and should be used every time the user is driving.

6.2.2 Component Reliability

Since our device is comprised of a single printed circuit board enclosed within the outer casing and is not intended to be removed, we must be sure that our product can operate for extended periods of time and the lifetime of many battery replacements before failing. The best way to ensure this is to use much lower currents, and to limit the speed at which the device will switch on and off.

As mentioned in the previous section, our device uses ultra-low powered comparators that have relatively insignificant draw on the power supply. Our 7 LED's are rated at approximately 20mA each, with a maximum of 4 LED's lighting at any given time (the central "power" LED and 3 tilt LED's on either the left or right sides) for a maximum of 80mA drawn by the LED's. Additionally, the buzzer that sounds when the device reaches the tipping point draws about 10mA, for a grand total of 90mA. As this is relatively low power and because no particular component or resistor must handle more than 20mA, our device is in very little danger of exceeding the recommended ratings for any component.

7.0 Conclusions and Recommendations

Our design meets nearly all of the criteria we had outlined at the start of the project. We have determined that it is affordable, easy-to-use, versatile, portable, gives effective notification, and is reasonably aesthetic. As previously discussed, the only criterion that we were unable to meet was the inclusion of a battery charging element that would increase its portability.

While we have completed our MQP for graduation there are, however, improvements and recommendations that we have thought about for anyone who may continue development of our concept. Our MQP advisors have also made suggestions that are included in this section. Our design is fairly simple in concept, however could be made to be integrated into a larger more complicated system.

Our first suggestion would be to meet the minimum requirements fully set out by our group by designing a charging element for the circuit. People often charge things such as phone and GPS in their cars, and ideally if this charging circuit was designed they would rarely have to change the batteries, and rarely have to remove the device form their vehicle. This would make our product easier to use.

One suggestion that was popular among the group members of this project and our advisors was to integrate our system into an existing GPS system. This might entail digital design to have it display on the GPS screen, or our analog solution could be incorporated and the GPS could feature a string of lights in the outer frame. This approach could potentially raise the appeal of a GPS system by adding features that a user might like without having to purchase separate devices. Our design, if put into a digital design would be simple to implement and cost effective if consumers really enjoyed the feature.

Another suggestion was given to us by one of our advisors. Professor Labonté suggested that we implement a sound alarm that was similar to the likes of the sonar alarms already available in vehicles to help drivers determine the distance between the back of their vehicle and an obstacle. This could involve a beeping feature, where the greater the force, the less time between beeps. Another option would be to vary the volume with increasing hazardous accelerative forces. Potential problems with trying to implement such a feature is that under driving conditions lateral acceleration can have a tendency to increase very rapidly making it hard for the driver to associate volume (or frequency of beeps) with increasing danger.

Our solution to prevent rollovers is essentially very simple, in line with our main goal of making this device affordable and versatile. There are already auto-corrective systems available for drivers who are willing to pay the price. One suggestion our group could make is to further research the principals of rollovers and take into account other factors that could lead to a rollover. Our system is not entirely accurate as it does not incorporate two axes to measure the acceleration. It also doesn't take into account the effects of suspension and road conditions to make predicting rollovers more accurate. Our system aims lower than the forces required to tip a vehicle for the sake of safety, though having a more accurate system could open up possibilities for this device to be used in other applications.

One such application to consider is implementing the device in race cars to reduce serious accidents. This same principle could also be applied to emergency response vehicles, as often they have to take risky driving procedures to arrive at the scene of an emergency. This device could help them better determine the risk of their maneuvers to reduce accidents.

This design also has potential in driver education. If the devices was made more accurate and included a second accelerometer to measure the acceleration forward and braking, students could receive instant feedback on their driving skills. This could help students grow accustomed to making smooth starts and stops in their vehicle with qualitative feedback.

Another potential use of this system would involve sampling the output of the accelerometer and logging it. This change to the design could make it appealing to insurance companies or agencies with company vehicles. This could be used by employers or even rental car facilities to ensure that consumers or employees are not abusing their vehicles.

In short, this concept has a lot of potential to be improved and implemented in other scenarios other than an aftermarket solution for those who can't afford or do not want Electronic Stability Control, or Rollover Mitigation Systems. However, our market research suggested that people would be interested in this system as a substitute for ESC or Rollover Mitigation Systems. There is marketing potential for this device on its own, however it might have more appeal if it was implemented with additional features such as logging, or included into a system such as GPS. This design is a step in the direction of making rollover prevention applicable to all classes and vehicles at an affordable price.

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Appendix B: Customer Survey

Rollover Early-Warning Detection Survey

1. What type of car do you drive? Sedan, SUV, Truck, etc.?________________________

2. Make ____________________Model____________________Year______________

3. Have you ever heard of or do you know about Electronic Stability Control or Rollover Stability Control?
   (circle one) Yes/No

4. How do you feel about auto-correct features in cars?

5. Have you ever been in or do you know anyone who has ever been in a rollover accident?
   (circle one) Yes/No

6. How concerned are you about getting into a rollover accident? 1-10 scale_______________

7. Do you obey the standard on-ramp speed limit of 25MPH?
   (circle one) Yes/No

8. If not, how fast would you say on average you drive on an on-ramp?_________________

9. Did you know that there are over 280,000 rollover accidents in the United States each year, and that over 10,000 of them result in fatality?
   (circle one) Yes/No

10. Knowing these statistics and knowing that there are no federal rollover regulations, do you feel that rollover prevention is an area that should be researched?
    (circle one) Yes/No

11. What features would you like in a device designed for rollover early warning detection? Aesthetics, Cost, Functionality, portability, Ease of use, etc.?

Appendix C: Weekly Updates

November 11, 2009

The task for this past week was for our group to finalize the block diagram and start designing each block. This is the beginning of our design stage where we will use brainstorming and simulation to choose the best solution that fits our product specifications. Our plan is to start designing the output block first so that we know how much power will need to be supplied. At the same time we are researching accelerometers and their I/O characteristics. The tasks for the next few weeks will likely be the same; continue designing blocks of the block diagram. As these blocks are realized, we will determine specific components that will be used and generate a parts list.

Completed this week, we have designed our entire output corresponding to the warning system. This output contains a parallel branch of LEDs that will light up at certain voltage levels in a linear fashion. The circuit also includes a buzzer that buzzes with simultaneously when the last red LED lights. This week we have also changed our block diagram to include more specific blocks. Before, the block diagram had generic blocks such as Input and Output. Now, the block diagram specifically tells that the Input will be an accelerometer, the output will have both LEDs and a Buzzer, and the entire system will be powered by a rechargeable battery, as well as other blocks that will control voltage signals and current flow.

We have met our expectations for this week's schedule and feel that as of this time we are on schedule. Our design process will take place over the next few weeks with our next big deadline coming in December when we hope to have our parts list in place and can start ordering. There was one problem that occurred this week which we have not yet found a solution for. To get specific rollover values for cars, we need data with the height of the car's center of gravity. Owner's manuals of cars, at least not the ones which we have looked at, do not seem to give this specification and without it we cannot calculate the g-force needed to roll over a vehicle. We found data that tells a range of rollover thresholds in g-force but we cannot confirm their accuracy or validity. For now, we are going to continue searching for this data in the hopes that we might find it on the internet or from car manufacturers themselves. This problem has had no immediate effect on our simulation and design. For the time being our design process is going smoothly and we still hope to meet our December deadline for ordering parts.

November 18, 2009

This task for this past week was for our group to continue the design of the blocks on our block diagram. Also it was given as a task by Labonte last week for us to familiarize ourselves with the workings of accelerometers and to explore the various options we had in terms of this choice. Last week we had designed an output block that would take an input either directly from an accelerometer or from the output of a microprocessor that would process the output from the accelerometer according to the type of vehicle and produce an output voltage that would be appropriate to the tipping g-force threshold of a vehicle. Labonte also supplied an article to read that detailed the solution to create a g-force detector. This article raised several points that we have become more aware of since studying how accelerometers work. The task for the next week is to continue working on the block diagram and to build a working model to test its functionality and also determine how much power we will need to supply to this device.

Completed this week we have made revisions to the output block accordingly, fixing a mistake in our placement of the buzzer. We have also searched for parts that would be compatible with this schematic. One problem we had encountered when using a BJT to drive the buzzer was that the current was limited. In turn we managed to find a 3kHz piezoelectric buzzer that could run off a 3V supply and only required 9mA of current to drive it. This find is reflected in our schematic and the circuit now functions correctly. We have also researched accelerometers to find that there is a vast variety of different types to consider. One interesting thing found was the difference between digital and analog accelerometers. There are also many types of accelerometers including but not limited to: capacitive, piezoelectric, piezoresistive, hall effect, magnetoresistive, and heat transfer. Also upon examining the presented article we have also come to recognize special needs of an accelerometer who's output can vary with temperature or the tilt of the accelerometer. Solutions to this may include some kind of temperature compensation to ensure the accuracy and using a 3-axis accelerometer so as to calculate a full vector sum of the force exerted on the vehicle around a term for accuracy's sake again. It is also noted that this device must be securely attached to the vehicle in order to avoid interference from tipping the device itself. Also another thing to consider is noise in our signal that could be generated by the vibrations of the vehicle itself.

We have met our expectations for this week's schedule and have also conducted the research requested of our professor and examined the article which was presented to us. Our design process will continue over the next 4 weeks with the ultimate goal of having a parts list assembled and put out to order by the end of the term with the hopes of fully testing our design throughout C-Term. The presented article also showed that the g-force rating of a vehicle is indeed documented somewhere and these values we wish to find and determine the variance in different classes of vehicles so we can decide if to base the output values on specific models of cars or if general classes of vehicles can be safely generalized to make the device incredibly easy to set (ie choosing a class of vehicle such as Sedan, SUV, etc as opposed to a specific model). We also wish to have a working model by the next meeting for demonstration purposes of our design.

November 24, 2009

This task for this past week was for our group to implement the design of our output circuit on a breadboard to confirm proper operation. We also sought to qualitatively analyze different accelerometers and choose one or two that best fits our needs.

Earlier in the week we attempted to construct our original output circuit design on a breadboard using an LM741 Op Amp and several LEDs. Unfortunately, the op camp was unable to source the amount of current that our design required, and were thus unable to create a working configuration using that design. This prompted us to seek out a number of alternative solutions in order to implement our idea. Upon speaking with Prof. Bitar about possible designs, he suggested two that should be more effective. The first of these utilizes transistors and resistor networks in order to drive the LED's without needing to utilize an operational amplifier. This is advantageous because our previous design was greatly limited by the specifications of amplifiers, providing us with a viable workaround. The second design that was discussed using a quad-pack of comparators to compare the output voltage of the accelerometer to a constant source that is stepped down in stages through several large resistors in order to limit the current at the input of the comparators. Based on the values at each of these steps, the LED's at their output will be switched on or off in succession at specific, discrete points. Luckily, neither of these circuits requires sources of larger than about 2.4V to properly implement, which makes powering our device much easier.

Also this week, we have developed a value analysis for various models of accelerometers for use in our device. We began by selecting a number of capacitive accelerometers, as we determined that these would best suit our needs based on their ease of use as well as their resistance to change in values based on temperature, as temperatures in vehicles can vary by large amounts based on the season and the cars internal climate control. So far, the most promising choices are the ADXL322JCP-REEL-ND and the ADXL322JCP-ND, from Analog Devices.

We have met most of our expectations for this week's schedule, in researching viable accelerometers as well as testing and reimagining our output block. We maintain that our goal for the end of the term is to have a parts list assembled and ordered and begin testing our prototype by C-Term. At this point we feel that we are on pace to meet this goal. We will continue our research on potential accelerometers, and we intend to call the representative from Analog Devices after the holiday in order to inquire about our options.

December 4, 2009

This past week did not see as much work done as it could have. With the Thanksgiving holiday and mini break from school, our group did not meet a lot. With this lack of meeting time however, we were able to cross off a large section of our projec t in the LED Output. We were able to finialize our design and simulate it with real components, and then we were able to put that design on a breadboard and make it work for real. The LED Output is a set of four LEDs, two green, one yellow, and one red. Based on the output voltage from the Accelerometer, the LEDs will light up at different voltage levels corresponding to different levels of rollover danger. This section of the design is the largest and most involved part of the design and with it out of the way it is a huge burden lifted from the group's shoulders. Other tasks that we had set out to complete this week were to try and find rollover threshold statistics and data from the library resources and to call Ms. Barbeau at Analog Devices and try to get a sample Accelerometer or two. Of these, we were partially successful on one. When we went to the library, all of the research librarians were either out or in meetings. The person at the research desk told us to fill out a research consultation form. This form allows us to ask for research in a specific area and then schedules us for a sit down meeting with one of the research librarians. In this meeting, the librarian will provide us with a list of sources for research and will help us eliminate the unnecessary ones. This will allow us to narrow our search and find results with ease. The meeting has not yet been scheduled but we gave a deadline for the research for the end of the term and we are hopeful that we will be able to meet next week. The third task we intended to complete was to get in touch with Ms. Barbeau at Analog Devices. This has not yet been accomplished and the lack of completing this task has resulted in the group falling slightly behind schedule.

Our goal for the end of the term was to have all our parts ordered and hopefully to have received them by the Winter Break. At this time we have yet to order our Accelerometer which is the main component of the design. RCL components, transistors, and ICs for the Output block and charging circuit can be found either in our lab kits or at the ECE shop and most have already been obtained. The Accelerometer has been chosen but not obtained. The hope is that Ms. Barbeau at Analog Devices will be able to provide us with a sample of this Accelerometer, but if she can't then we will have to order it. The longer we put this off, the less likely it will be that we have all our components ready by the end of the term. There is still time left in the term and we can still call Ms. Barbeau at Analog Devices but it must be done no later than the beginning of next week.

For next week, we plan to have picked a battery to use and designed a charging circuit for that battery based around the 12V supply of a car battery. We will also have called Ms. Barbeau at Analog Devices, and with her aide or not we will have ordered an Accelerometer. If these tasks do not take a large amount of time then we will start the selection process for the LEDs we wish to use. If we work hard for the remaining two weeks of the term we believe we will be right on schedule and ready for building and testing in C term.

December 9, 2009

The tasks for the previous week included gathering more information critical to our project, make an important call regarding our accelerometer, and begin designing the next block of our design. For this week we had promised to get in contact with Ms. Barbeau to see if we were able to get some samples of our desired accelerometer or a like one. Also, as we have yet to effectively determine a rollover threshold, we needed to going through with our Research consultation to find more information. Finally we needed to begin design of our power block.

Firstly, we contacted Ms. Barbeau at Analog Devices, she informed us that we should try getting our samples from the website. So the next step regarding the choice of our accelerometer is to attain these samples from the website or if this isn't a possibility we can order the ones we need deducting the amount from our MQP account.

Secondly, we went to the library for our research consultation. We were directed toward ScienceDirect, SAE (Society of Automotive Engineers), and Engineering Village. We were also directed to www.carfolio.com for a list of car specifications. We performed more research within the parameters of these scientific collections and came across a method to estimate the height of the center of gravity for a vehicle with typically less than 5% error from the actual measured value. This can be used in conjunction with the carfolio specifications and a formula we had located earlier in A-Term to derive values for rollover thresholds. We intend to collect data from a sample of cars from each class and take an average of this value (leaning toward the low side for safety) to determine our thresholds for each class of vehicle.

We also began designing the battery charging circuit and battery life indication circuit for our design. We have a preliminary design and over the next week plan to improve this model and test our results.

For next week we plan to have a parts list that contains all of the necessary parts to complete our design and have it ready to be built and tested upon the start of C-Term. To do this we also need to have our output design finalized (resistor changes depending on the thresholds we calculate), our thresholds determined, and our battery circuit finalized. As of now we are still safely on schedule if we complete these tasks by the end of next week.

January 28, 2010

We have made some substantial progress in the time we have had since our last meeting. Over break we each used www.carfolio.com to research and record the specs of several different sedans, SUV's and vans. These specifications were then entered into the formula we discovered in A term that allowed us to calculate the tipping point of a specific vehicle based on its track width and height. These values were recorded in a spreadsheet, and the data used to find the first quartile value in each category to be used as the benchmark for that particular set of vehicles. We chose this value to err on the side of caution so as to be safest for the largest number of possible vehicles.

Earlier, we chose accelerometers that suit our needs quite well, and have since received them from Digikey and plan to test them shortly. To that end, we have revised our test circuit based on both the specifications of the accelerometer and to suit our new tipping thresholds so as to be as accurate as possible. We designed it in such a way that the majority of the parts are easily acquirable from the ECE shop, therefore circumventing the need for a lengthy delay before we can begin testing large portions of our design. We have already placed an order for the comparators, which should be in within the next few days and allow us to completely test our full output circuit, since the resistors we need can be found in the shop.

In the next week we plan to test our output circuit, as we should have all the components necessary by then to test the majority of its parts. This will allow us to make any further changes we find necessary as we near a final design for the output. Additionally, we will continue researching and designing our battery circuit, which is the other major component we must finish before a total working prototype can be tested. We intend to have a rough design by the end of next week that should suit our needs for the time being. We have barely depleted our budget and already have most of the more expensive parts we will be needed for this design, so we appear to be able to finish under budget if no unforeseen issues arise. At this point we feel that we are on schedule, as there are still several weeks left in the term, more than enough time to test and revise our circuit at the rate we are progressing.

February 11, 2010

This week, the main issue of concern was power. We wanted to analyze exactly what our circuit needed for volage and current, what batteries we can get that will supply that, and what we can get as an output from the power jack in a car. The way the circuit is designed now, when the system is on and nothing is happening, there is very little current being drawn. It is when the LEDs are on and the buzzer is sounding that there is draw. With all four LEDs lit and the buzzer going, the circuit draws 50mA, four LEDs with 10mA draw and a buzzer with 9mA draw.. This is a fairly large amount of current but at the same time it is not a situation that will occur a lot. We have also designed the circuit so that it can be run off of 2 AA batteries. These batteries can range anywhere from 400-3000mAH. Even if the circuit is drawing at the maximum, this will still give almost 10 hours of run time on a single set of batteries with the low capacity. We have also decided that due to the availability of AA batteries, the circuit does not need to be used with rechargeable batteries. We have also decided that when in the car, the batteries can be made secondary by the power jack in the car itself. We want to design a circuit so that when the device is plugged in, it can run off of the power supplied by the jack, while disconnecting the batteries so that they are not being drawn from. We researched these power jacks and found that there are two main types, Size A and B, A mostly is found in American cars and B is mostly found in European cars. These jacks output 12V from the car battery but depending on the type of connecting wire used, they can output anywhere from 1.5V to 12V DC and even in some cases they can provide 120V AC. With these large varieties, we can find something that will be able to supply the correct voltage and current levels for our device.

This past week was mainly a research week dealing exclusively with power. Next week we intend on getting some of these power options and testing them out in the circuit. As always, we are continuing to build our circuit and through simulation and testing, we are finding different areas to improve. By next week we intend to have all the components to completely build our output block and attach the accelerometer and batteries to it. With this circuit we will be able to test the functionality of the power supplied by the batteries, ie: is it enough, and we also hope to be able to test the accelerometer. Overall, there was not much done this week but given the level we are at with the project as a whole, we feel that is has not put us behind schedule at all. Next week is an important building and testing week which, depending on how it goes, could mean we end up either further ahead of schedule or behind schedule. As of right now, we still feel that we will meet the deadline of having the device built and debugged by the end of C term so that we can spend most of D term preparing for presentations and writing reports.

February 19, 2010

There were a few things we set to accomplish over the past week. Our first objective was to test our revised output circuit. The thresholds for each of the LED's have been determined and were simulated in Multisim. This week, we set out to have a working test model of this design element so that the next step would be to incorporate the accelerometers. Another goal we had for the week was to chose the LED's that would be driven by our output system. Lastly, we needed to continue work on the battery charging circuit and power elements of our design.

Over the last week we have created a working model of our design and have tested it in the lab. The resistances chosen need revision to match the thresholds we calculated for the final LED to light up. The prior lights are lit up in a linear fashion before the 'tipping threshold' voltage is reached. For the LED array we have decided to use white LED's with color caps for the different colors we wished to implement into this system (two green, one yellow, and one red). By using the colored LED caps we do not need to make adjustments to our output driving circuit to accommodate the varying current draws and luminosity equality issues between the different colored LED's. We have determined for our power system that we wish to run this device using two double A batteries for a source voltage of 3V. This voltage is sufficient to power the elements in our circuit. We have taken a look at already implemented battery charging circuitry that is already available in chip form and hope to have one chosen by the end of next week. We have a preliminary design in place, but are looking into these already designed systems to improve our own.

Over the next week we are going to finalize resistor values in our output circuit and incorporate the accelerometer into the testing process. To accomplish this we need to mount the surface mount accelerometers onto a testing board and test it in the lab. Another thing that needs resolving is that we need to locate a car cigarette lighter adapter to use in our design.

With two weeks left in the term we are hard pressed to finish our design, build, and test it. The gaps that we need to fill in the next to week include finalizing our power circuitry, finalizing our battery charging circuit, and build a working model of our project and subject it to testing. This may require that we work into D term, which we had originally delegated time to just writing the report. Despite this, we are confident that we will have ample time to finish our design, build and test our circuit in these next few weeks and into D term while also having time to write sections of our MQP report.

February 26, 2010

Objectives for the past week:

- Redesign and Re-breadboard our output circuit to match specifications from datasheet to our design specifications
- Research a solution to attach our accelerometers to our circuit or find an alternative solution

In the last week we have taken our original circuit design and modified it to operate at the ½ Voltage bias (1.2V) that the accelerometers are designed to center at. This allows us to measure and output the acceleration in both left and right directions on the same scale. This leads to a more intuitive output, showing the user which way they are tipping and by how much, allowing them to correct it. This new design has been breadboarded and appears to function as intended. The next step is to directly implement the accelerometer into the circuit as a proof of concept of our design.

We have thus far been unable to find a board to properly mount the surface-mount accelerometers to streamline their use in our design. We were, however, able to find nearly identical accelerometers that came on a through-pin test board which, while a bit more expensive, will allow us to test and implement our circuit. Pending further research and a check of the remaining timeline, we plan to order one or more of these devices so as to fully breadboard our output circuit. By successfully implementing the accelerometer board, we should have a working device that will allow us to test it.

Objectives for next week:

- Research, and if possible order the new accelerometers
- Continue designing Ni-Cd recharging circuit
- Ideally, basic tests of our design

March 19, 2010

Minutes from last meeting

The meeting last term we discussed:

- Discussed observed oscillations in thresholds when buzzer sounded and discussed potential causes and solutions.
  - One potential cause for this observations could be due to noise from the buzzer oscillating transferring through the circuit.
  - Another potential cause could have been interference due to messy wiring scheme.
  - The last cause we discussed was having a lack of a common ground could be pulling the thresholds.
- We brought up a problem in our new design. If we wished to be able to have the feature to switch between vehicle classes (SUV, Van, and Sedan), we would have to modify two resistances in the circuit by the same amount.
  - This could be accomplished by two three way switches.
  - Discussed using photoresister solution.
- We made some progress on the report and discussed how to proceed.
  - We proposed having 'section leaders' for different sections of the report who would be accountable for that section (however we are all working on various parts each section, and all of us take part in revision of each section)

Agenda

Last week, over vacation, we continued working on the report and strove to have a single document with appropriate sections filled in. What we have produced is a document containing problem statement, background information, physics of rollovers, methodology, implementation of our design, and analysis/results. These sections are currently in a draft form and require revision, though they provide a good outline of topics to be discussed in further detail.

Improvements have been made to the circuit design to solve the oscillations problem we had observed. This was done by adding a lowpass first order RC filter to filter out the oscillations of the buzzer. The circuit is functional with one vehicle class (sedans). We are still working to solve the problem of varying the resistors for different car classes simultaneously without the use of two switches.

We were asked to develop a timeline for the rest of the term. There are three main tasks that need to be completed at this point. Developing a working prototype and working on our presentation are two tasks that need to be completed by Project Presentation Day (April 22nd). Lastly, we need to finish the final report by the end of the term. The first two tasks take presentence.

For the prototype we need to conclude our design phase by finalizing the charging circuit for our design. After this is built and tested we can integrate into our already working design. Our design also needs to undergo field tests in a vehicle to determine if there are any other possible issues that could come up from using our design in a vehicle (issues such as noise for example). We can then finalize our develop our final PCB board as the final prototype.

For the presentation we need to assemble the key points of our report-in-progress and create a Power Point presentation slide. To prepare for the actual presentation on April 22nd we need to set aside time to practice the presentation itself.

The report we have already started working on. The sections that have already been written need revision and polishing and the remaining sections left to be written need to be written.

To complete all of these tasks we have a little under five weeks to complete our prototype and our presentation. We have one additional week after that to finish the report. Prototype finalization and presentation development are high priority and will take the front seat in the next weeks to come. The report will also be done in conjunction with these tasks. We have attached a schedule with tasks delegated for each week and major deadlines.

March 26, 2010

Minutes from last meeting

The meeting last term we discussed:

- Discussed the feasibility of implementing a charging circuit as well as adjustable threshold levels in our circuit.
  - The first major concern being the time constraint, as it would extend our development time
  - Increasing the complexity of the circuit could create potential problems in proper operation that we previously did not account for
- We developed a timeline and determined some of the major milestones in our project.
- We discussed the report and ways to improve it, including research into the devices utilized in GPS systems such as powersupplies.

- We proposed having ‘section leaders’ for different sections of the report who would be accountable for that section (however we are all working on various parts each section, and all of us take part in revision of each section)

Agenda

We continued to improve our device, including an amplifier circuit that allows us to lower the thresholds of the LED’s to account for the lower tipping points of vans and SUV’s. This essentially solved the design problem of a simple and intuitive way to have adjustable thresholds for different classes of vehicles.

We adjusted our circuit slightly, increasing the gain substantially to lower the thresholds to the point that we could easily test the basic functionality of the device without needed to drive in the dangerous conditions that would normally be at risk of a rollover. We then drove around, observing the operation of the circuit as we turned increasingly more intensely.

We have continued to work on our report, much of which has included extensive work on further background research and relevant prior art.

April 2, 2010

Minutes from Last Meeting and Weekly Accomplishments

- Discussed Designing a PCB and Ordering it
    - The final circuit was designed and we wanted to put it on a PCB and have it ordered by this Friday.
    - PCB is designed, but due to enclosure constrictions, a redesign is needed. Hopefully it can be finished and be ready for ordering by Monday.

- Started putting together a final parts list including all resistors, capacitors, ICs, switches, etc.

- Discussed Breaking up the report into Section Leaders
  - Continued working on Citations and References for Final Report.
  - Continued Editing previously written sections
- Discussed Having a Presentation
  - Started putting together a basic outline of topics that we want to talk about in our presentation

Agenda for Next Week

- Have the final PCB layout designed and ready to be ordered for Monday.
  - Ordered by Monday April 5, so that it can be received the following week and built in time for Project Presentation Day (April 22)
  - Have a Final Parts List that can be ordered simultaneously with the PCB so that once the PCB arrives, the final product can be built.
- Have a rough draft of the missing sections written for the Final Report
  - Included: Executive Summary, Conclusions and Recommendations, Introduction
- Have a set of basic Power Point slides put together that can be edited and finalized for Project Presentation Day
  - Slides finalized by Friday April 16 so that they can be practiced for the presentation

Appendix D: LIS244AL Accelerometer Datasheet

(On Next Page)

LIS244AL

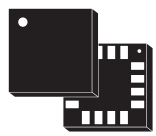
MEMS motion sensor:
2-axis - ±2g ultracompact linear accelerometer

Features

- Single voltage supply operation
- ±2g full-scale
- Output voltage, offset and sensitivity are ratiometric to the supply voltage
- Factory trimmed device sensitivity and offset
- Embedded self test
- ECOPACK lead-free compliant
- High shock survivability (10000g)

Description

The LIS244AL is an ultra compact consumer low-power two-axis linear accelerometer that includes a sensing element and an IC interface able to take the information from the sensing element and to provide an analog signal to the external world. The sensing element, capable of detecting the acceleration, is manufactured using a dedicated process developed by ST to produce inertial sensors and actuators in silicon. The IC interface is manufactured using a CMOS process that allows high level of integration to design a dedicated circuit which is trimmed to better match the sensing element characteristics.



LGA 16 (4x4x1.5mm)

The LIS244AL is capable of measuring accelerations over a maximum bandwidth of 2.0kHz. The device bandwidth may be reduced by using external capacitances. A self-test capability allows the user to check the functioning of the system.

The LIS244AL is available in Land Grid Array package (LGA) and it is guarantee to operate over an extended temperature range of -40°C to +85°C.

The LIS244AL belongs to a family of products suitable for a variety of applications:
- Mobile terminals
- Gaming and Virtual Reality input devices
- Antitheft systems and Inertial Navigation
- Appliance and Robotics.

Table 1. Device summary

Order codes	Temp range, °C	Package	Packing
LIS244AL	-40°C to +85°C	LGA-16	Tray
LIS244ALTR	-40°C to +85°C	LGA-16	Tape & Reel

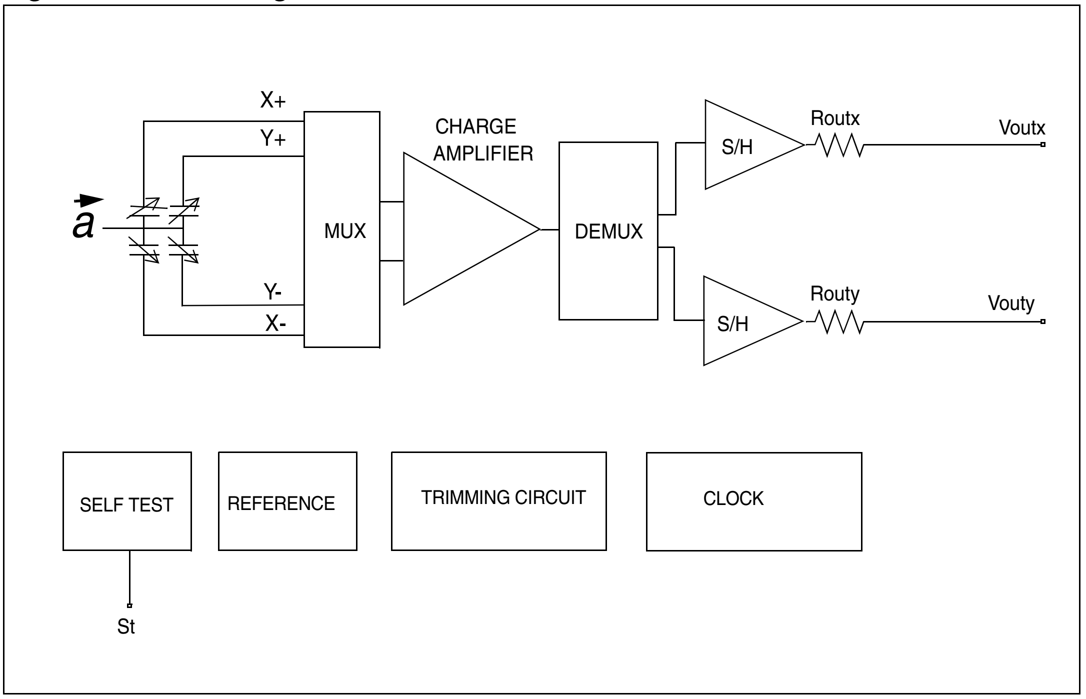
Note: Tape & Reel parts are compliant to International Standard EIA-481.

Contents

1 Block diagram & pins description

1.1 Block diagram

Figure 1. Block diagram



1.2 Pin Description

Figure 2. Pin Connection

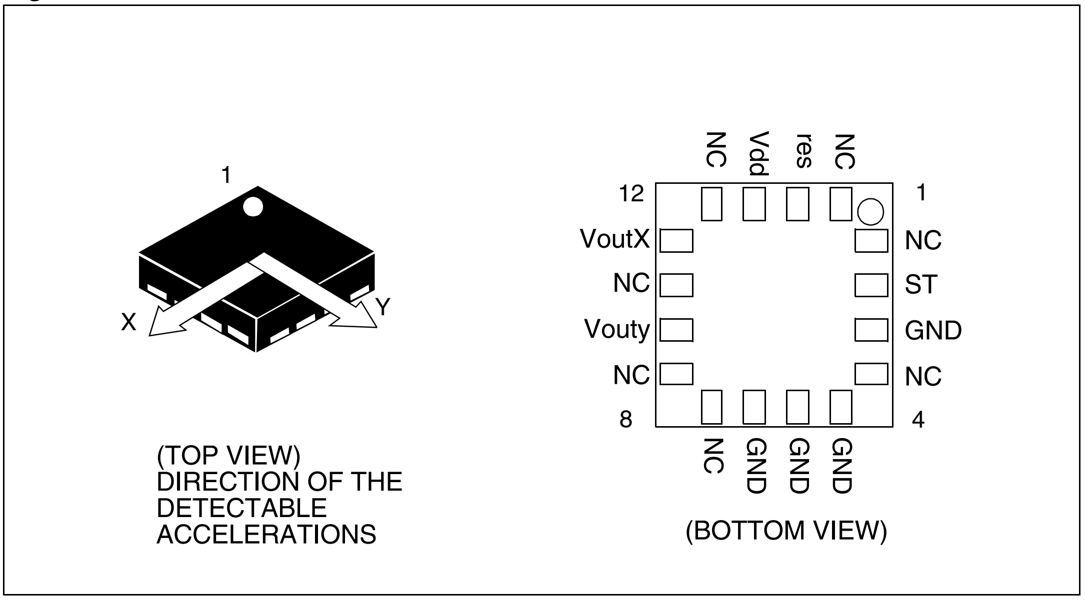


Table 2. Pin description

Pin #	Pin name	Function
1	NC	Not to be connected
2	ST	Self test (logic 0: normal mode; logic 1: self-test mode)
3	GND	0V supply
4	NC	Not to be connected
5	GND	0V supply
6	GND	0V supply
7	GND	0V supply
8	NC	Not to be connected
9	NC	Not to be connected
10	Vouty	Output voltage Y channel
11	NC	Not to be connected
12	Voutx	Output voltage X channel
13	NC	Not to be connected
14	Vdd	Power supply
15	Res	Connect to Vdd
16	NC	Not to be connected

2 Mechanical and electrical specifications

2.1 Mechanical characteristics

(Temperature range -40°C to +85°C). All the parameters are specified @ Vdd =3.0V, T = 25°C unless otherwise noted

Table 3. Mechanical characteristics(1)

Symbol	Parameter	Test condition	Min.	Typ.(2)	Max.	Unit
Ar	Acceleration range(3)			±2		g
So	Sensitivity(5)		0.140*Vdd - 10%	0.140*Vdd	0.140*Vdd+ 10%	V/g
SoDr	Sensitivity change vs temperature	Delta from +25°C		0.01		%/°C
Voff	Zero-g level(4)	T = 25°C	Vdd/2-15%	Vdd/2	Vdd/2+15%	V
OffDr	Zero-g level change vs temperature	Delta from +25°C		1		mg/°C
NL	Non linearity(5)	Best fit straight line		±0.5		% FS
CrossAx	Cross-axis(6)			±2		%
An	Acceleration noise density	Vdd=3.0V		220		$\mu g/\sqrt{Hz}$
Vt	Self test output voltage change(7),	T = 25°C Vdd=3.0V X axis		105		mV
		T = 25°C Vdd=3.0V Y axis		105		mV
Fres	Sensing element resonant frequency(8)	X,Yaxis	4.0			kHz
Top	Operating temperature range		-40		+85	°C
Wh	Product weight			0.040		gram

1. The product is factory calibrated at 3.0V. The operational power supply range is from 2.4V to 3.6V. Voff, So and Vt parameters will vary with supply voltage
2. Typical specifications are not guaranteed
3. Guaranteed by wafer level test and measurement of initial offset and sensitivity
4. Zero-g level and sensitivity are essentially ratiometric to supply voltage at the calibration level ±8%
5. Guaranteed by design
6. Contribution to the measuring output of an inclination/acceleration along any perpendicular axis
7. “Self test output voltage change” is defined as $Vout_{(Vst=Logic1)}$-$Vout_{(Vst=Logic0)}$
8. Minimum resonance frequency Fres=4.0kHz. Sensor bandwidth=1/(2*π*32kΩ*Cload)

2.2 Electrical characteristics

(Temperature range -40°C to +85°C) All the parameters are specified @ Vdd =3.0V, T=25°C unless otherwise noted

Table 4. Electrical characteristics[1]

Symbol	Parameter	Test condition	Min.	Typ.[2]	Max.	Unit
Vdd	Supply voltage		2.4	3.0	3.6	V
Idd	Supply current			0.65		mA
Vst	Self test input	Logic 0 level	0		0.8	V
		Logic 1 level	2.0		Vdd	V
Rout	Output impedance of Voutx, Vouty			32		kΩ

1. The product is factory calibrated at 3.0V
2. Typical specifications are not guaranteed

*Note: Minimum resonance frequency Fres=4.0kHz. Device bandwidth=1/(2*π*32kΩ*Cload)*

2.3 Absolute maximum ratings

Stresses above those listed as "absolute maximum ratings" may cause permanent damage to the device. This is a stress rating only and functional operation of the device under these conditions is not implied. Exposure to maximum rating conditions for extended periods may affect device reliability.

Table 5. Absolute maximum ratings

Symbol	Ratings	Maximum value	Unit
Vdd	Supply voltage	-0.3 to 6	V
Vin	Input voltage on any control pin (ST)	-0.3 to Vdd +0.3	V
A_{POW}	Acceleration (any axis, powered, Vdd=3.0V)	3000g for 0.5 ms	
		10000g for 0.1 ms	
A_{UNP}	Acceleration (any axis, not powered)	3000g for 0.5 ms	
		10000g for 0.1 ms	
T_{STG}	Storage temperature range	-40 to +125	°C

	This is a Mechanical Shock sensitive device, improper handling can cause permanent damages to the part
	This is an ESD sensitive device, improper handling can cause permanent damages to the part

2.4 Terminology

Sensitivity describes the gain of the sensor and can be determined by applying 1g acceleration to it. As the sensor can measure DC accelerations this can be done easily by pointing the axis of interest towards the center of the earth, note the output value, rotate the sensor by 180 degrees (point to the sky) and note the output value again thus applying ±1g acceleration to the sensor. Subtracting the larger output value from the smaller one and dividing the result by 2 will give the actual sensitivity of the sensor. This value changes very little over temperature (see sensitivity change vs. temperature) and also very little over time. The sensitivity tolerance describes the range of sensitivities of a large population of sensors.

Zero-g level describes the actual output signal if there is no acceleration present. A sensor in a steady state on a horizontal surface will measure 0g in X axis and 0g in Y axis. The output is ideally for a 3.0V powered sensor Vdd/2 = 1500mV. A deviation from ideal 0-g level (1500mV in this case) is called Zero-g offset. Offset of precise MEMS sensors is to some extend a result of stress to the sensor and therefore the offset can slightly change after mounting the sensor onto a printed circuit board or exposing it to extensive mechanical stress. Offset changes little over temperature - see "Zero-g level change vs. temperature" - the Zero-g level of an individual sensor is very stable over lifetime. The Zero-g level tolerance describes the range of Zero-g levels of a population of sensors.

Self Test allows to test the mechanical and electric part of the sensor, allowing the seismic mass to be moved by means of an electrostatic test-force. The Self Test function is off when the ST pin is connected to GND. When the ST pin is tied at Vdd an actuation force is applied to the sensor, simulating a definite input acceleration. In this case the sensor outputs will exhibit a voltage change in their DC levels which is depending on the supply voltage through the device sensitivity. When ST is activated, the device output level is given by the algebraic sum of the signals produced by the acceleration acting on the sensor and by the electrostatic test-force. If the output signals change within the amplitude specified inside *Table 3*, than the sensor is working properly and the parameters of the interface chip are within the defined specification.

Output impedance describes the resistor inside the output stage of each channel. This resistor is part of a filter consisting of an external capacitor of at least 2.5nF and the internal resistor. Due to the resistor level, only small inexpensive external capacitors are needed to generate low corner frequencies. When interfacing with an ADC it is important to use high input impedance input circuitries to avoid measurement errors. Note that the minimum load capacitance forms a corner frequency close to the resonance frequency of the sensor. In general the smallest possible bandwidth for a particular application should be chosen to get the best results.

3 Functionality

The LIS244AL is an ultra compact low-power, analog output two-axis linear accelerometer packaged in a LGA package. The complete device includes a sensing element and an IC interface able to take the information from the sensing element and to provide an analog signal to the external world.

3.1 Sensing element

A proprietary process is used to create a surface micro-machined accelerometer. The technology allows to carry out suspended silicon structures which are attached to the substrate in a few points called anchors and are free to move in the direction of the sensed acceleration. To be compatible with the traditional packaging techniques a cap is placed on top of the sensing element to avoid blocking the moving parts during the moulding phase of the plastic encapsulation.

When an acceleration is applied to the sensor the proof mass displaces from its nominal position, causing an imbalance in the capacitive half-bridge. This imbalance is measured using charge integration in response to a voltage pulse applied to the sense capacitor.

At steady state the nominal value of the capacitors are few pF and when an acceleration is applied the maximum variation of the capacitive load is in pF range.

3.2 IC Interface

The complete signal processing uses a fully differential structure, while the final stage converts the differential signal into a single-ended one to be compatible with the external world.

The first stage is a low-noise capacitive amplifier that implements a Correlated Double Sampling (CDS) at its output to cancel the offset and the 1/f noise. The produced signal is then sent to two different S&Hs, one for each channel, and made available to the outside.

All the analog parameters (output offset voltage and sensitivity) are ratiometric to the voltage supply. Increasing or decreasing the voltage supply, the sensitivity and the offset will increase or decrease linearly. The feature provides the cancellation of the error related to the voltage supply along an analog to digital conversion chain.

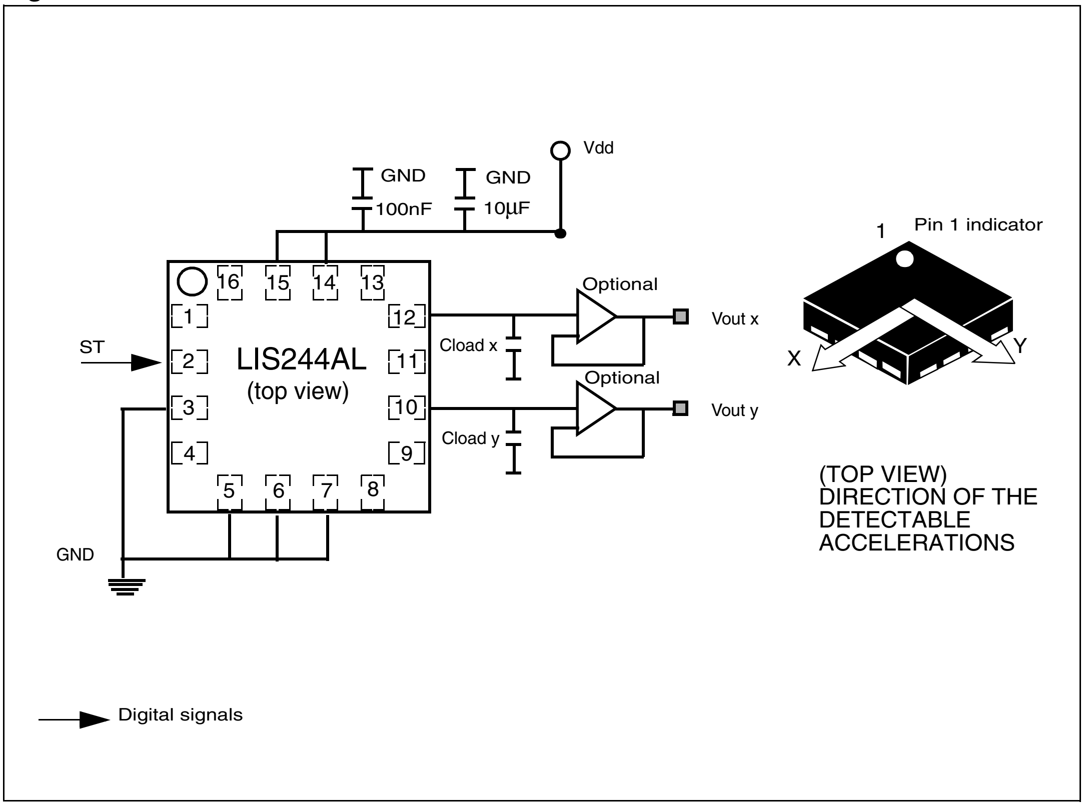
3.3 Factory calibration

The IC interface is factory calibrated for sensitivity (So) and Zero-g level (Voff).

The trimming values are stored inside the device by a non volatile structure. Any time the device is turned on, the trimming parameters are downloaded into the registers to be employed during the normal operation. This allows the user to employ the device without further calibration.

4 Application hints

Figure 3. LIS244AL Electrical connection



Power supply decoupling capacitors (100nF ceramic or polyester + 10µF Aluminum) should be placed as near as possible to the device (common design practice).

The LIS244AL allows to band limit Voutx, Vouty through the use of external capacitors. The recommended frequency range spans from DC up to 2.0kHz. In particular, capacitors are added at output Voutx, Vouty pins to implement low-pass filtering for antialiasing and noise reduction. The equation for the cut-off frequency (f_t) of the external filters is in this case:

Equation 1

$$f_t = \frac{1}{2\pi \cdot R_{out} \cdot C_{load}(x, y)}$$

Taking into account that the internal filtering resistor (R_{out}) has a nominal value equal to 32kΩ, the equation for the external filter cut-off frequency may be simplified as follows:

Equation 2

$$f_t = \frac{5\mu F}{C_{load}x, y}[Hz]$$

The tolerance of the internal resistor can vary typically of ±20% within its nominal value of 32kΩ; thus the cut-off frequency will vary accordingly. A minimum capacitance of 2.5nF for C_{load}(x, y) is required.

Table 6. Filter Capacitor Selection, C_{load} (x,y),

Cut-off frequency	Capacitor value
1 Hz	5 µF
10 Hz	0.5µF
20 Hz	250nF
50 Hz	100nF
100 Hz	50nF
200 Hz	25nF
500 Hz	10nF

4.1 Soldering information

The LGA package is compliant with the ECOPACK, RoHs and "Green" standard.

Pin1 indicator is electrically connected to pin 1. Leave pin 1 indicator unconnected during soldering.

4.2 Output Response vs. orientation

Figure 4. Output response vs. orientation

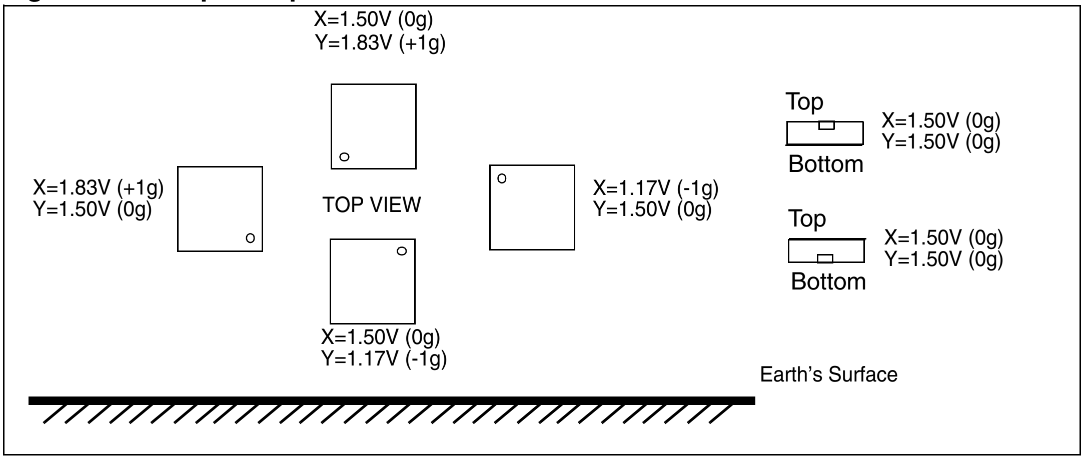


Figure 4 refers to LIS244AL powered at 3.0V.

5 Package information

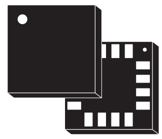
In order to meet environmental requirements, ST offers these devices in ECOPACK® packages. These packages have a Lead-free second level interconnect. The category of second Level Interconnect is marked on the package and on the inner box label, in compliance with JEDEC Standard JESD97. The maximum ratings related to soldering conditions are also marked on the inner box label. ECOPACK is an ST trademark.

ECOPACK specifications are available at: www.st.com.

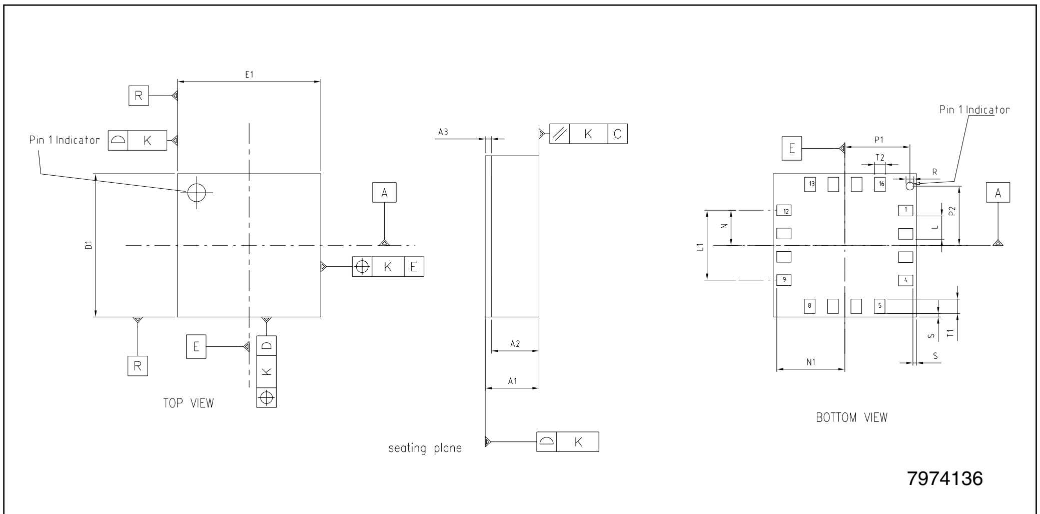
Figure 5. LGA 16: mechanical data & package dimensions

Dimensions						
Ref.	mm			inch		
	Min.	Typ.	Max.	Min.	Typ.	Max.
A1		1	1.60		0.039	0.063
A2			1.33			0.052
A3	0.160	0.20	0.24	0.006	0.008	0.009
D1	3.850	4.0	4.150	0.152	0.157	0.163
E1	3.850	4.0	4.150	0.152	0.157	0.163
L		0.65			0.026	
L1		1.95			0.077	
N		0.98			0.039	
N1		1.90			0.075	
T1		0.40			0.016	
T2		0.30			0.012	
P1		1.750			0.069	
P2		1.525			0.060	
R		0.30			0.012	
S		0.10			0.004	
k		0.05			0.0019	

Outline and mechanical data



LGA 16 (4x4x1.5mm)



6 Revision history

Table 7. Document revision history

Date	Revision	Changes
29-Jun-2007	1	Initial release