Senior Design Final Report

Engineering 340

Team 8: Batteries Not Included

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Executive Summary

Tire Pressure Monitoring Systems (TPMS) enhance automobile safety by keeping drivers informed of their tire pressure. A problem with the pressure sensors is their reliance on battery-power; batteries eventually wear out. The goal of *Batteries Not Included* is to design and build an alternative energy source that provides reliable, longer-lasting power to the sensors. Magnetic induction is the proposed solution to the problem of powering the sensors. This design essentially converts the kinetic energy of the rotating wheels to electric energy by passing a coil through a magnetic field; relative motion of a coil in relation to a magnet produces current in the coil which can power the pressure sensors. Induction was used to generate power successfully; however, signal shielding issues must be resolved before a robust system can be produced.

1. Introduction

Tire Pressure Monitoring Systems are becoming more and more popular on vehicles each year. They are an important safety feature that helps to prevent accidents caused by blown tires. A TPMS offers real-time monitoring of tire pressure so that the driver can be notified if a slow leak is present. Figure 1 shows a typical TPMS [2]. Current systems use wireless sensors located inside the tires to send pressure readings to a receiver; the reading is then displayed to the driver. A downside with these sensors is their limited battery life and consequent necessary battery/sensor replacement work. Battery or sensor replacement is either a hassle for the user to carry out or an expense that the user must pay in order to further use the TPMS. The goal of this project is to develop an alternative energy source for pressure sensors that will last longer than conventional batteries. Thus, the proposed power system should significantly extend the working life of pressure sensors, perhaps to second and even third owners of vehicles. The proposed design should also alleviate the burden of system maintenance by eliminating the need for battery replacement.

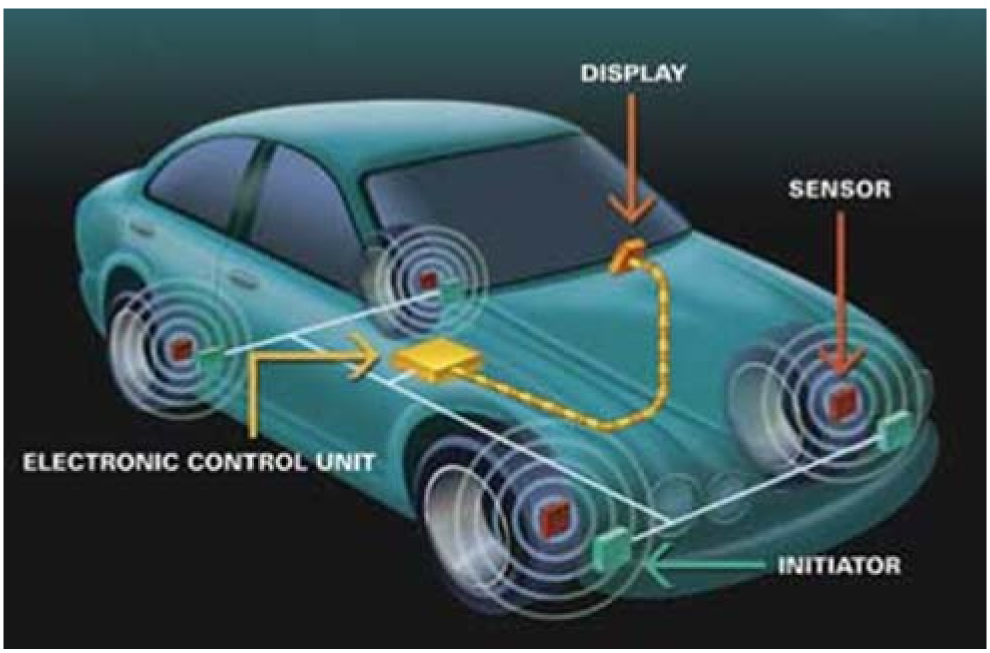

Figure 1. A Typical Tire Pressure Monitoring System [2]

2. Project Goal

The goal of this project is to eliminate the need for batteries on TPMS sensors. An alternative energy source for pressure sensors that will last longer than conventional batteries is desired. Thus, the proposed power system should significantly extend the working life of pressure sensors. The new design should also alleviate the burden of system maintenance by eliminating the need for battery replacement. Furthermore, the new power system cannot significantly increase the price of a TPMS.

The challenge in this project is to design a method to generate, use, and store enough electric power to enable the tire pressure sensor to operate continuously. Once the power system has been created, it needs to be attached to the rim inside the tire and field tested. Challenges also lie in the mechanical setup of the power system as the proposed design should not interfere with any other existing vehicle systems. The complete product could be used in a variety of tire applications in the commercial automotive market. Figure 2 shows a typical setup of the tire pressure sensor [4].

The team's Christian faith plays into the design consideration. Stewardship is a concept closely associated with the project; a battery-free system conserves resources by eliminating batteries. The design also shows care and concern for others. Prolonging the working life of tire pressure sensors increases the safety of automobiles. Finally, the project is culturally appropriate as millions of Americans drive automobiles with pressurized tires daily. The proposed technology could positively impact the average driver.

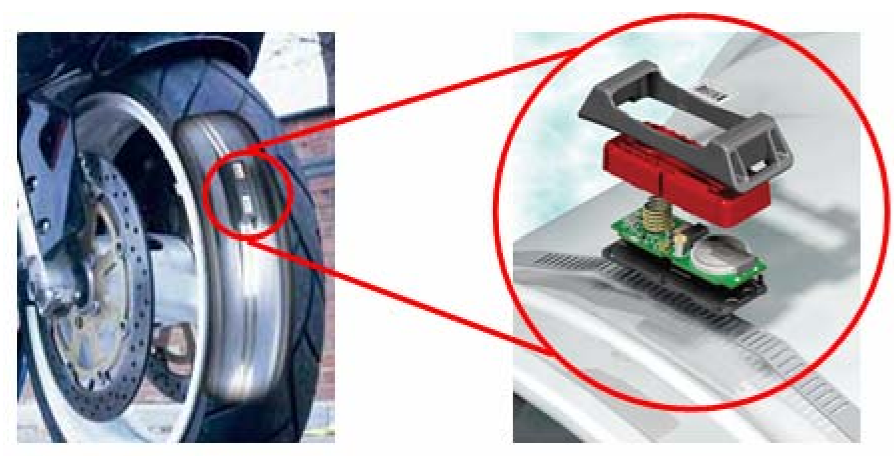

Figure 2. A TPMS Sensor [4]

3. Project Objectives

The objectives for this project are threefold. First, our main goal is to attain battery-free tire pressure sensor operation. This will hopefully extend the working life of pressure sensors significantly. Complementing the goal of battery-free sensor operation is the need for an innovative mounting solution to hold the proposed power system. The mounting implementation must be both robust and easy to replace. Finally, the power system along with its mounting apparatus must be priced competitively. A tire pressure monitoring system incorporating the proposed power system must not be significantly more expensive than current models. An explanation of design functionality and design requirements will more fully articulate our project objectives.

3.1 Design Functionality

The proposed power system's functionality must be specified. Sensors using the alternative power system must run as they are intended to when using battery power. Mounting will have great influence on the strength and rigidity of the system.

3.1.1 Increased Operating Life of Sensors

Regardless of the solution design chosen, the main purpose of the project is to increase the operating life of a tire pressure monitoring system. The working lifetime of the sensors should be extended by the realization of a new power generation system. An extended working lifetime of the tire pressure monitoring system should allow both original and successive vehicle owners to benefit from this safety feature.

3.1.2 Continuous Sensor Operation

The proposed design must implement continuous sensor operation; continuous operation includes the initial start of the vehicle. A driver should be able to know his or her tire pressure before they leave the house. Ideally, design solutions will use energy generated from the motion of the automobile (energy that is normally wasted) to power tire pressure sensors. Regardless of the solution design chosen, the system will require some type of external power storage which will allow the sensors to give an initial reading before the vehicle has moved.

3.1.3 Alternative Energy Operation

The final design must include an alternative energy source for sensor operation. The idea of a rechargeable battery is in consideration, but this design would still require an external energy source for battery charging. The power source chosen will ideally use kinetic energy associated with a moving vehicle to power the sensors, eliminating the need for a battery. The power source must be able to operate the sensor continuously. Any option chosen to power the sensor must provide for an increase in the system's working lifetime.

3.1.4 Innovative Mounting Technique

The design must provide a strong, robust solution for mounting the new power system. In addition, the power system must be easy to replace in the event that it is damaged. Furthermore, inherent pitfalls seen in current sensor designs must be avoided. For example, current sensors mounted in the valve stem are often broken when tires are being replaced. The valve stems are cracked to release pressure from the tire, which in turn damages the sensors and requires them to be replaced. The new design must include a mounting solution that allows tires to be serviced and replaced without damaging the sensors.

3.1.5 Transmission Signal Considerations

Due to the fact that the sensors transmit wireless signals, they are regulated by the Federal Communications Commission (FCC). Changes in sensor design can in no way affect the sensors' compliance with FCC regulations. Signal integrity is also important for the functionality of the tire pressure monitoring system. A power generation system creating any adverse effects on a sensor's transmission of data to the driver's display inside the vehicle is not desirable.

3.2. Design Requirements

In addition to meeting the specified design functionality criteria, successful completion of this project requires the implementation of certain requirements inherent to designing a battery-free tire pressure sensor. Market factors such as pricing, consumer need, and vehicle system interference must be considered. Federal laws must also be considered and obeyed.

3.2.1 Competitive Industry Pricing

Mass-production of the proposed design must be economically feasible. The increased safety benefits of a battery-free tire pressure sensor will only be realized in the market if the product can be produced at a cost low enough to make it economically viable for production companies. The aspect of price is extremely important to consumers and, in turn, automotive suppliers; this will be a large focus of the design.

3.2.2 Design Serviceability

Due to the fact that serviceability is a major issue with existing systems, this will be a large focus of the design work. The final design must be robust, but it must also be easily replaceable if damaged. The design must function in such a way that damage to the system components is not an issue during vehicle services such as tire replacement.

3.2.3 Vehicle Systems Effects

The final design can in no way impede vehicle performance. Research must be done to insure that introducing the new power generation design to the vehicle will not affect performance of anti-lock braking systems (ABS), normal braking systems, wheel rotation, or other important vehicle operations. Effects on the vehicle will be different for each design, so this will be a factor that helps narrow down the design alternatives to a final option.

4. Alternative Solution Designs

After several brainstorming sessions, the design team considered possible alternative solution designs. The proposed solutions below represent the most reasonable ideas generated by brainstorming sessions. All alternatives generate power for the tire pressure sensors by converting energy produced by normal automobile operation to electric power. The following power generation ideas will be expounded upon in this section: magnetic induction, piezoelectric power generation, thermal energy recovery, wind power generation, and pressure-induced power generation.

4.1 Magnetic Induction

The kinetic energy of the rotating wheel can be converted to electrical energy. Electromagnetic induction could be used for this energy conversion. If a magnetic field is moved in close proximity to a coil, a current is induced in that coil. Motion of an automobile wheel could be used to induce a current that could potentially power a pressure sensor.

The electrical aspect of this design is obvious; enough electric power must be generated in order for a tire pressure sensor to function normally. The mechanical aspect of this solution is mounting the power generation system. There is a significant challenge in the mounting of both the magnet and the coil. Our initial solution would be to mount the magnet on top of the caliper, which is stationary in relation to the spinning wheel. A coil would be mounted on the inside of the rim parallel with the magnet so that as the wheel spins, the coil passes by the magnet and induces a current. Leads off the coil would pass through the wall of the rim and connect to the sensor inside. (see Figure 3 below)

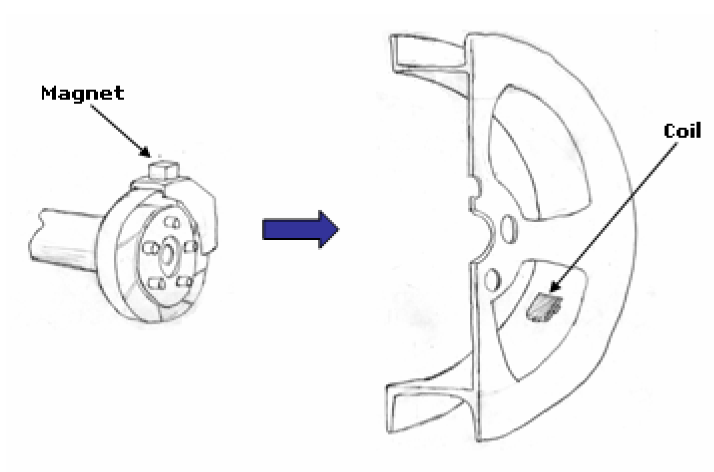

Figure 3. Magnetic Induction Design Solution

4.2 Piezoelectric Application

Another option for the conversion of kinetic energy is the conversion of wheel vibration and rotational energy to electricity. A piezoelectric device could be mounted in the suspension system or wheel of the vehicle. Piezoelectric devices produce electric energy when they are mechanically stressed. Using this technology, road vibration and wheel rotation could be used to power the pressure sensor.

For the piezoelectric option, the challenge in mounting would be to find a way to place the whole sensor inside the tire and retain proper wheel balance. Due to the nature of the energy conversion, there would be no need for wires to pass through the wall of the rim. Instead, the piezoelectric device would be mounted inside the rim, presumably mounted opposite the sensor so that the wheel could be more easily balanced. This power system would be able to take advantage of vibration of the wheel, the rotation of the wheel, and/or the air pressure inside the tire to produce electric power. (see Figure 4 on the next page)

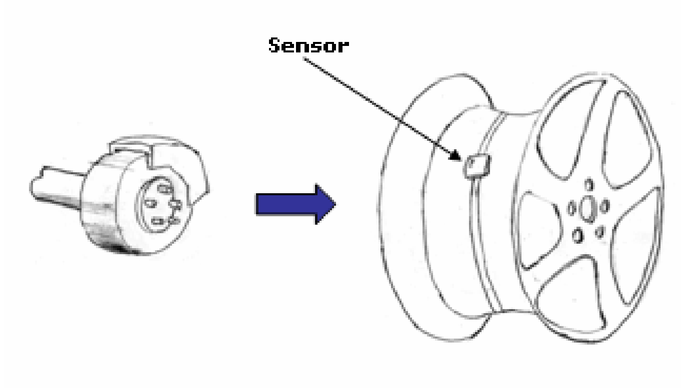

Figure 4. Piezoelectric Power Generation

4.3 Thermal Energy Recovery

Another option considered is that of converting heat energy associated with braking activity to electric energy. Thermocouples are a proposed means of accomplishing this energy conversion. A thermocouple is a pair of dissimilar metals joined together which produces a voltage when the two sides of the metal junction are exposed to different temperatures. Brake pads and rotors are hot under normal driving conditions. If one side of the thermocouple could be mounted inside or next to the brake pad, and the other side of the thermocouple could be mounted in an ambient temperature environment, perhaps enough electric energy could be produced to power the tire pressure sensor. An auxiliary system would be desirable for use when the brakes are not hot.

The mounting for the thermocouple approach would require that a wire be run through the wall of the rim. The idea behind this approach would be to mount the joint end of the thermocouple to the rotor or brake pad. The thermocouple would be run down the rotor to a contact that would join to a similar contact on the inside of the wheel. The thermocouple voltage signal will travel up a lead to a point below the sensor. A hole could be drilled through the rim, and the power signal of the thermocouple could be applied to the sensor. (see Figure 5 below)

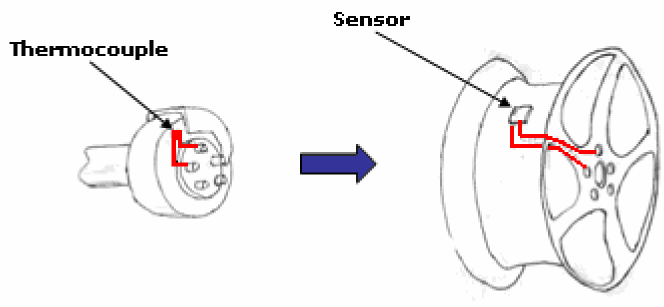

Figure 5. Thermal Energy Recovery Power System

4.4 Wind Power Conversion

Wind power generation was proposed as a solution to the problem. Brakes are often cooled by directing air from the front fascia to the brakes via air ducts. “Wind” is created in the ducts by the relative motion of the vehicle with respect to the air around it. A small turbine could be placed in a brake duct. As the wind spins the turbine, the rotational energy of the turbine could be used to power a small electric generator. This generator could potentially power a pressure sensor and charge an auxiliary power storage element. Auxiliary power will be necessary as the turbine will not rotate when the automobile is stopped.

Mounting the wind power system would be product specific. Applications would be limited to vehicles with openings in the front fascia large enough to accommodate the fan-generator unit housed in an air duct. Transmitting the power to a rotating object, such as an automobile wheel where the tire pressure sensor resides, requires some application of motor brushes. This could be done via caliper – rotor interaction. (see Figure 6 below)

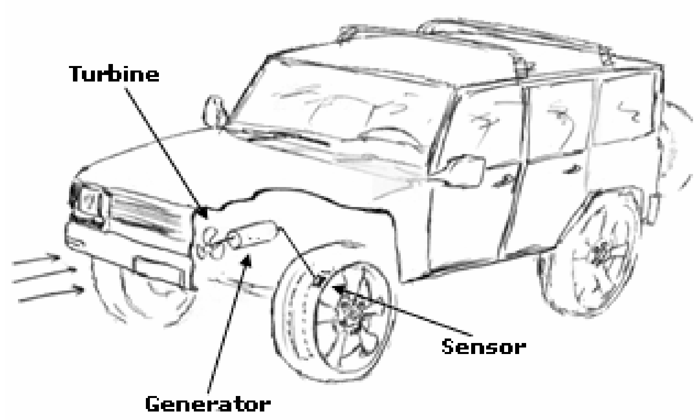

Figure 6. Wind Power Generation System

4.5 Pressure Induced Power

Another option was found in the Engineering Index research database: the abstract for a journal article mentioned a way to change a physical pressure signal directly to electric power. Not many of the details on this option are known as the Hekman Library did not have the article; it had to be ordered through inter-library loan. A guess is that this device could be a form of sensitive piezoelectric technology. When pressure is exerted on the device, a proportional voltage is produced.

The mounting solution for this approach would largely depend on the size of the device itself. If the device is very large, additional calculations would be needed to assess the forces caused by the rotation of the wheel during normal use.

4.6 Extended Battery Life

Should the aforementioned solutions prove unfeasible, a method to drastically increase battery life will be implemented. Power generation methods explained above could be used to charge a sensor's rechargeable battery.

5. Feasibility Study

The alternative solutions presented above were researched in order to gage the viability of each. Component cost and power generation capability were the most important factors in deciding whether or not a design was feasible. Design complexity was another factor considered.

5.1 Magnetic Induction

Research into the feasibility of the power induction solution proved to be fruitful. Wire used for the coil is assumed to be less than $10. Also, powerful magnets can be attained online for relatively low cost. About 10in.^{2} of magnetic material can be bought for $15.30 [1] (see Appendix 1). Thus, it seems that this option is economically feasible. The magnetic material has a rating of N40, which corresponds to a magnetic field strength of 12,600 – 12,900 Gauss. Preliminary power generation calculations indicate that this option does give adequate power generation. See Appendix 2.a for preliminary calculations and magnet specifications.

5.2 Piezoelectric Application

Research into piezoelectric devices has shown that this option is not economically feasible. Piezoelectric devices online range in price from $200 to $1000. This price is unacceptable for production purposes because one of the reasons for this project is to make a tire pressure monitoring system and the maintenance associated with it more economically accessible to the public. Furthermore, a $300 power generation system is too expensive considering that the tire pressure monitoring system itself costs only about $200. Consumers probably will not want to pay twice the price of a normal TPMS for a longer-lasting one. Finally, a piezoelectric device is economically unacceptable for this project because just about the entire allotted budget would have to be spent on a piezoelectric device. See Appendix 3 for sample piezoelectric device pricing.

5.3 Thermal Energy Recovery

There are different types of thermocouples that could be used to implement the proposed thermal energy recovery design. However, the type of thermocouple found to generate the most power only produces about 75mV. This does not meet average voltage requirements for tire pressure sensors, which is about 3V. See Appendix 4 for thermocouple specifications.

5.4 Wind Power Conversion

Turbines small enough to fit inside of a brake duct could not be found online. The smallest turbine found was the size of a small refrigerator. In addition to this setback, this option makes the power system design more complicated than necessary. A turbine would turn a generator, which would produce electricity. Essentially, this option transforms kinetic energy to electric energy using induction via a magnet and coil. This is basically the same idea as the magnetic induction alternative; however, this option is far more complicated. Furthermore, the connection between the generator and the sensor would be complex since electric power from the stationary generator would need to be taken to the rotating sensor. Research and thought has given rise to the conclusion that the wind power generation design only adds potential problems and complexity.

5.5 Pressure Induced Power

This article has not yet been received. This alternative solution is currently suspended indefinitely.

6. Preliminary Design

Based on comparison of the feasibility information compiled above, the magnetic induction design is going to be pursued as the solution to the problem of battery-powered tire pressure sensors. This option gives the best balance of performance, cost, and serviceability issues. The team also consulted with Professor Platt at the Calvin Physics Department, and he confirmed that the induction method is indeed feasible. The related power feasibility calculation is attached in Appendix 2.a. Although Professor Platt thinks that this design is feasible, he also thinks that getting this design right will require much testing. Correct placement of the magnet in relation to the coil will be essential for the proper function of the final design. Therefore, various placements of the coil and magnet should be tested extensively to ensure correct operation of the power system. Testing will be more extensively explained in the next section. The magnetic induction design is shown below.

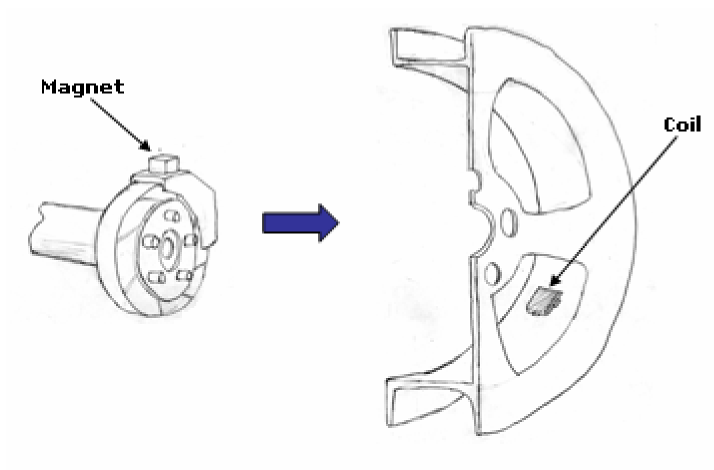

Figure 7. Magnetic Induction Design Solution

7. Preliminary Business Plan

7.1 Industry Profile and Overview

7.1.1 Industry Analysis:

Industry background and overview: There is no industry background. Our product is the first of its kind. The market right now is using battery powered sensors and has little research into further power methods. This is our market niche.

7.1.2 Major customer groups:

These customers include tier one suppliers to automotive companies and aftermarket manufacturers. Our unit will be universally applicable, and every supplier will have demand for the product.

7.1.3 Regulatory restrictions, if any:

There are no restrictions on placing magnets within the wheel well of an automobile. We have looked into the effect of our magnets on ABS sensors and have concluded that our product produces no adverse affects in ABS sensor operation.

7.1.4 Significant trends:

There are no significant trends. However, we have discovered another battery-less tire pressure sensor which has a patent. We feel the market will support our product and nurture future research and development.

7.1.5 Growth rate:

Growth would be exponential since we are the only supplier of an induction based tire pressure sensor. Our manufacturing capabilities would have to be easily increasable due to increased demand once our product gets to the market.

7.1.6 Barriers to entry:

Our first barrier to entry would be acceptance from the market share holders of current battery powered tire pressure sensors. Once suppliers are convinced to adopt the induction power generation system, the next barrier would be manufacturing costs. With our company consisting of only the four founding members, manufacturing an estimated 1 million power units would be difficult.

7.1.7 Key success factors in the industry:

Building a simple and reliable power generation system that is applicable to a wide variety of products is instrumental. Our sales force is also a key factor to success. As a new company trying to break into the industry, we will be selling our product with low margins in order to attract purchases. This in turn requires a large sales volume in order to turn a profit.

7.1.8 Outlook for the future:

There is a large market ahead due to the TREAD act of 2003 which requires all automobiles manufactured after October 1, 2006 to be equipped with a TPMS.

7.2 Product Features

Environmental responsibility, energy efficiency, and reliability are some of the main features of our product. Existing tire pressure sensors need to have battery to operate. Our product features a battery-free mechanism to give solutions to the battery problem in the sensors used in TPMS. Magnetic induction is used to provide the needed power. Utilizing the rotation of the wheels, the design passes a coil through a magnetic field and thus converts kinetic energy to electric energy. The generated electric energy is in turn used to power the TPMS sensor. Our product is designed to function without interfering with other mechanical and electrical components in the wheel, and it also functions in all environmental conditions.

7.3 Customer Benefits

Our solution to the tire pressure sensor is hassle free, and it is user-friendly. Existing tire pressure sensors have to have the battery replacement every five to seven years. The work involved with replacing the battery is normally done by mechanics, and the drivers will have lots of hassle if they decide to replace the sensors on their own; inexperienced users might accidentally damage the sensors. By making the sensor battery-independent, our product saves the auto users from having to go through the hassle of battery replacement. The product increases the lifetime of the TPMS by eliminating sensors' dependency on battery-power; thus, it offers continuous safety benefits to future users of the vehicle. Most importantly, by offering a reliable power source to the sensors, our product assures that the TPMS gives the drivers the correct information of the tire pressure.

7.4 Uniqueness

Our product gets rid of tire pressure sensors' reliance on batteries; it uses the available kinetic energy to produce electric power. Therefore, we provide an energy-efficiency solution to the current TPMS sensors. This unique feature also projects a long-term benefit on the environment. The amount of batteries thrown into landfills would be reduced when our product comes to the market.

7.5 Materials and Cost

The major raw materials for production are coils, magnets, capacitors, diodes, voltage regulators and printed circuit boards. We estimated a cost of $5.21 per unit for materials assuming the costs for raw materials are $0.38 per coil, $0.97 per magnet, $0.26 per system set of capacitors, $0.01 per printed circuit board and $0.06 per diode, and $0.62 for voltage regulators. The production would also involve labor which is needed to make the final assembly of the product. Assuming each unit takes 15 minutes (0.25 hour) to assemble and labor costs $40/hour (assuming production in U.S.), each unit will cost $10 per unit in labor.

7.6 Marketing Strategy

7.6.1 Target Market:

Existing tire pressure sensor systems use batteries, which need to be replaced. When these batteries wear out, many system owners choose not to replace them; battery replacement is expensive. Wheels must be taken off rotors, and tires must be removed from rims. Many people think the added safety of a tire pressure monitoring system is not worth the hassle or extra money associated with system replacement. A battery-free system would eliminate the need for pressure sensor system owners to disassemble their wheels (and empty their wallets) every few years.

Our company's target market consists of automobile manufacturers and tire pressure sensor manufacturers. We will focus our marketing strategy on these two groups. If we are able to convince automobile manufacturers that our product is worth having on their vehicles, the manufacturer can suggest that their sensor suppliers cooperate with us in integrating our power system with their tire pressure monitoring systems. We will also market to sensor manufacturers in hopes that they will desire the increased durability that our power system provides. This boost in sensor quality will hopefully give sensor manufacturers who integrate our system a market advantage over traditional battery-operated sensor makers. Once TPMS manufacturers are sold on our design, wheel makers will have to be brought into the integration process. If our power system is mounted on the outside of the rim (for magnetic shielding purposes), electric leads will need to be brought from the outside of the rim to the inside in order for power to reach the sensors. This will require leads to go through the rim, and wheel makers will most likely be responsible for making this happen. See Appendix 5 for a list of potential customers.

7.6.2 Customer's Motivation to Buy:

The power system of a tire pressure monitoring system will be a relatively small factor in a consumer's decision to buy a new car. Thus, an automobile manufacturer may not see our product as integral to a new vehicle's selling success. Nonetheless, our system would be a small selling point that increases the durability of a TPMS and in turn raises the standard of safety associated new vehicles that incorporate the technology.

TPMS manufacturers have seemingly more motivation to buy our design. Our power system would differentiate their sensor system from other battery-operated sensor systems on the market. A battery-free power source could perhaps be the factor that prompts an automobile maker to choose one TPMS over another.

7.6.3 Market Size and Trends:

The market for our product is uniquely poised to take off over the next few years. Whereas four years ago, no new vehicle had to incorporate tire pressure monitoring systems, at least 65% of new vehicles must be equipped with a TPMS by October 2006 due to government mandate. Over the last twenty years, new car sales have consistently been between twelve and seventeen million. If 2007 is a slow year for auto sales with roughly twelve million new vehicles sold, a 65% TPMS mandate means that 7.8 million new cars must be equipped with a TPMS. As far as we know, all sensor systems currently on the market use batteries. This indicates that a huge new market that is relatively untapped exists for our sensor power system. See Appendix 6 for new vehicle selling statistics.

7.6.4 Selling Efforts:

The company's sales department will have two divisions. One division will focus on selling to automobiles manufacturers, and the other division will focus on selling to TPMS manufacturers. Each division will consist of one salesman, and these two salesmen must be in constant communication. When one division makes a sale, that sale will most likely affect the complementary division. For example, if the automotive division sells 10,000 units to Ford, Ford's TPMS supplier will need to integrate our product into their design. Our company's TPMS division representative should be aware of this, and he should get in contact with Ford's supplier to make the proper arrangements.

An average sale should be about 10000 units. Salesmen must maintain good working relationships with existing customers as well as expand the company's customer base consistently. Ideally, 2-5% sales growth per year for the first five years of the company's existence would be desirable. In order to attract salesmen with at least five years of experience, we will compensate them with $60K per year.

7.6.5 Advertising and Promotion:

Our product will not be marketed to the general public. Our marketing strategy focuses on automobile and TPMS manufacturers. A website describing our product will be constructed; interested OEM personnel will be able to access our product information at their leisure online. However, the bulk of our advertising will be done by our salesmen in their dealings with manufacturers. Phone calls, meetings, presentations, and literature will be prepared by our sales department in order to inform our potential customers. Thus, our media costs are inherently covered in our salesmen's salaries. Overhead such as salesmen's computers and literature to distribute to customers will be accounted for in our financial forecasts.

7.6.6 Pricing:

Our cost structure takes both fixed and variable costs into account. Our fixed costs include rent for our building, utilities, and employee salaries. Variable costs include our cost of good sold (direct material and direct labor). Direct Material and Labor were mentioned earlier; this information is also noted in Appendix 7. Fixed costs are estimated in Appendix 19.

We need our product to be cheap enough that manufacturers will be willing to implement it with their sensors. However, we want our product to be known for quality. A functional, robust design is desirable. Our power system will most likely make a competitively priced sensor system more expensive to manufacture. Our hope is that the added quality associated with our power system will outweigh any excess integration costs. Obviously, our company must make a profit. The price of our system will be determined with break-even analysis. Our gross profit margin (sales – cost of goods sold) is shown in Appendix 19.

7.6.7 Distribution Strategy:

A competitive freight company will be used to distribute our product to customers. With an estimated unit package containing five products and having the following dimensions: 5”L x 3”W x 2”H, a 4’ x 4’ pallet will hold 1,728 unit packages. Assuming the pallet is not stacked any higher than 2’, this calculation is justified below:

$$\frac{48in}{5in} = 9.6 \text{ units long} \qquad \frac{48in}{3in} = 16 \text{ units wide} \qquad \frac{24in}{2in} = 12 \text{ units high}$$

$$\text{pallet:} \quad (9units\_long)\cdot(16units\_wide)\cdot(12units\_high) = 1.728 \times 10^{3} unit\_packages$$

$$\left(1.728\cdot 10^{3}\cdot package\right)\cdot\left(2\cdot\frac{pounds}{package}\right) = 3.456 \times 10^{3}\cdot\frac{pounds}{pallet}$$

$$\left(1.728\cdot 10^{3}\cdot package\right)\cdot\left(5\cdot\frac{products}{package}\right) = 8.64\cdot 10^{3}\cdot\frac{products}{pallet}$$

The calculations above show that 3500 pounds is a good estimate for shipment of one pallet of product. A sample quote for standard and 3-day rush freight is attached in Appendix 8.

7.6.8 Test Market Results:

Continuous communication between our customers and our sales representatives will take place as long as a business relationship exists between the two companies. If our customers have a problem, we want to know about it as soon as the problem comes to light. We are committed to quality.

7.7 Location and Labor

The location of our company would be in Michigan. In this way it would be easier to make communications with some of the major auto manufacturers such as Ford and GM. Having the company located in Michigan would also help us coordinate with these auto manufactures and obtain customer feedback. The location of the company would be adjusted accordingly based on the needs of the customers and contracts made with different auto manufacturers. The wage for labor is estimated at $30/hour. If the production is of considerable size, outsourcing might be considered to reduce the labor cost.

7.8 Competitor Analysis

7.8.1 Existing Competitors:

We have found one other product in the battery-less sensor market but have yet to find any information about them trying to market this product. They could possibly become a competitor, but we believe our product is further along in development than their RF signal sensor.

7.8.2 Strengths:

Our ingenious design is efficient and compact. It also uses a minimal number of components which decreases total cost. Our manufacturing is also easily outsourced to foreign regions where labor is inexpensive. However, it could also be easily transformed into an automated process and done here in MI close to the prospective market.

7.8.3 Impact on the business if competitors enter:

Since our product would be first to market, we would have contracts and a customer base before other businesses would enter. It would be very difficult for another company to enter the market and compete with us.

8. Test Method

The nature of our project mandates that a large part of the design process be dedicated to testing. As noted previously, Professor Platt believes that extensive testing will be necessary in order to determine proper placement of the magnet in relation to the coil.

Variation in the application for tire pressure monitoring systems is quite significant. Systems could be applied to a wide range of vehicles with tires including the following: semi-trucks, light trucks, cars, motorcycles, trailers etc. This range of applicable vehicles has a wide variety of wheel sizes and brake setups.

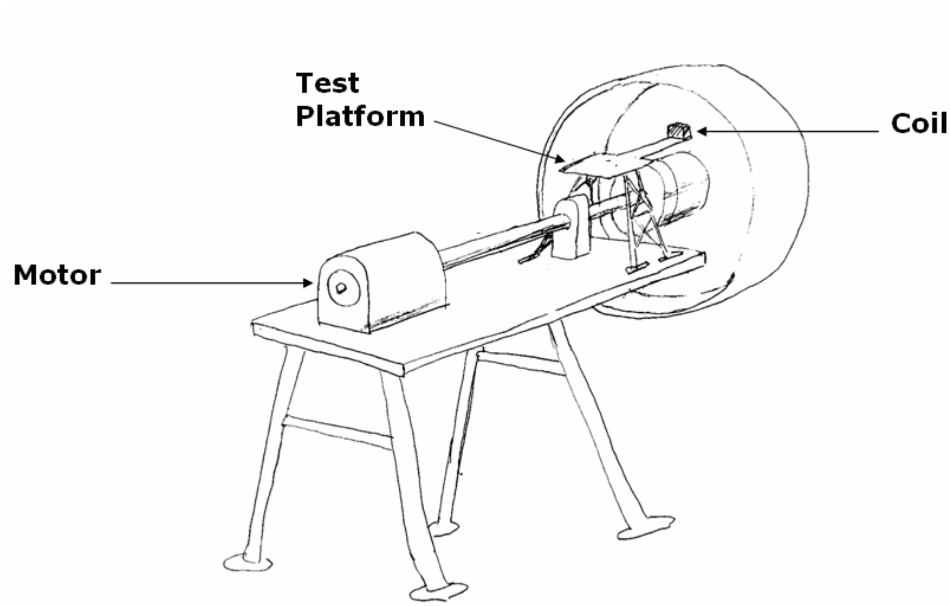

Figure 8. Test Apparatus

8.1 Test Apparatus Construction

The test apparatus allows variation of the position of the coil by using an adjustable platform shown in Figure 9 below. The coil is attached to the adjustable platform, and two sets of magnets are affixed to the inside of a rim.

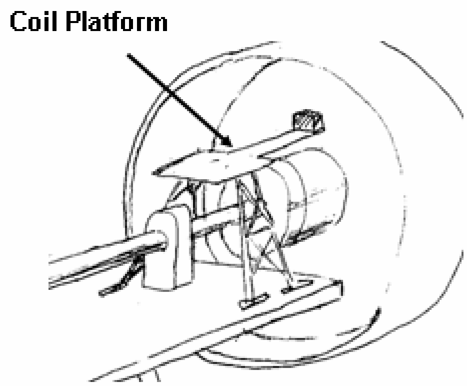

Figure 9. Adjustable Test Platform

A motor is an integral part of the test apparatus. Due to the wide variety of vehicle applications, it is necessary to test the magnetic induction design at various wheel speeds. The motor obtained for testing is a 1/8 horsepower electric motor with variable speed. The variable speed motor runs over a range from 0 to 1750 rotations per minute (RPM). For a 25.6 inch diameter tire, this variable motor speed is analogous to vehicle speeds of 0 to 135 miles per hour. A plot of the conversion from RPMs to MPH is shown below. Complete motor specifications can be found at the end of this section.

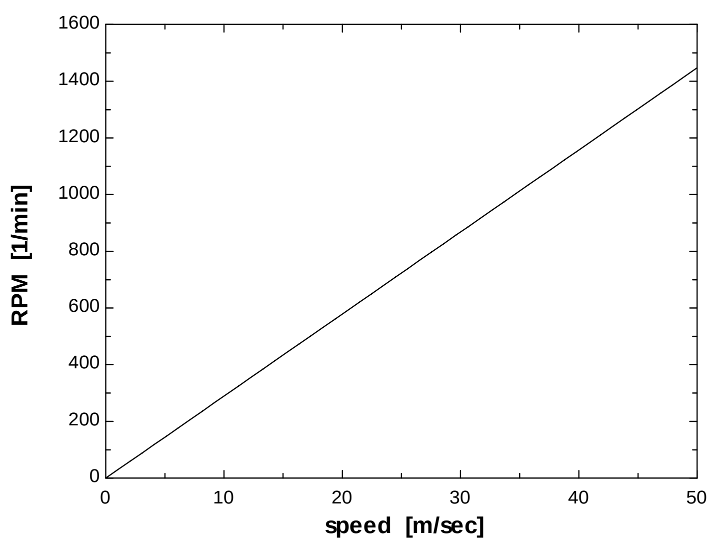

Figure 10. Speed vs. RPM Relationship

The final part of the test apparatus is the wheel attachment. Three rims were procured for testing purposes. A hub was built and attached directly to the motor using a long shaft, a coupling joint, and two support bearings. The coupling was secured to the shaft using woodruff keys and set screws. The hub was welded to the end of the steel shaft.

8.2 Test Procedure

A large number of variables mandated an accurate and easily repeatable testing procedure. A list of test parameters was compiled. These parameters were broken down into two main categories: coil parameters and magnetic parameters.

There are four major coil parameters. First, the coil diameter was varied. Coil diameter refers to the diameter of the windings of the coil. The second parameter was to vary the number of turns in the coil. Again, more turns in the coil correlates to more magnetic flux and consequently more current. The relationship between magnetic field strength and the number of turns in the coil is shown in Appendix 2.b. A consideration was also made for wire thickness. It is unsure as to how wire thickness affects the current generated in the coil. However, thickness of the wire has a direct influence on the overall size of the coil. Another consideration concerning the coil is what type of protective coating to use. There are a variety of options including the use of a coated wire, a corrosion resistant wire, or an epoxy resin potted coil. It is unsure as to how differences in wire coating will affect the induction of the coil; however, these alternatives were tested. Finally, one of the largest difficulties concerning the coil was the connection between the coil and the sensor. Different connection methods were tested for their strength, durability, and functionality.

Magnet parameters were also varied during testing. The distance between the magnet and coil was an obvious testing point. The use of multiple magnets to increase field strength is something that has been considered, but Calvin College Physics professors have stated that magnetic fields do not combine proportionally. This adds another dimension of complexity to the testing as multiple magnets do not give predictable fields.

Finally, all previously mentioned test parameters will be examined using a reasonable motor speed range. Variable speed motor specifications for the test apparatus are shown below.

Model	Power	Voltage	Current	Misc.
Century Motors DN EMI 9-208222-01 DC Motor	1/8 Hp	115 Volt	1.12 Amp	1750 RPM Max
Boston Gear R12 DC Control Box	1/8 Hp	115 Volt	20 Amp Max	

9. Design Implementation

When test apparatus construction was complete, the team began testing different magnet and coil configurations to produce electric power. Once the proper voltage level was produced by the magnet and coil, power regulation was necessary for proper sensor function. A power regulation circuit was designed and implemented. Fine coil adjustments were then made to ensure proper power would reach the sensor at the predetermined speed of 15 mph.

9.1 Magnet/Coil Configuration

The strength of the magnetic field and the cross-sectional area of the coil are the key factors that determine the performance of the power system. The plate magnets are magnetized through the thickness; therefore, the magnetic field lines pass through the thickness of the magnets as shown below:

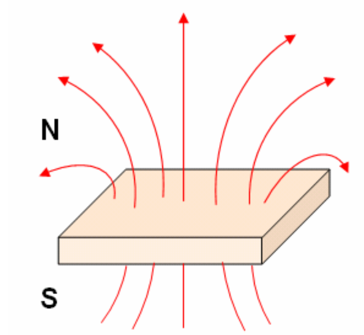

Figure 11. Magnetic Field Lines of Magnets Used

In the early stages of the testing, it was assumed that more magnets would give a stronger magnetic field. In general, this is true; however, the field critically depends on how the magnets are positioned in relation to each other. The power generated by a magnet and coil is proportional to the change in magnetic flux over the area of the coil. The first test utilized two magnets which were positioned side by side. The coil was fixed at a stationary platform, and the magnets were passed by the coil as illustrated below:

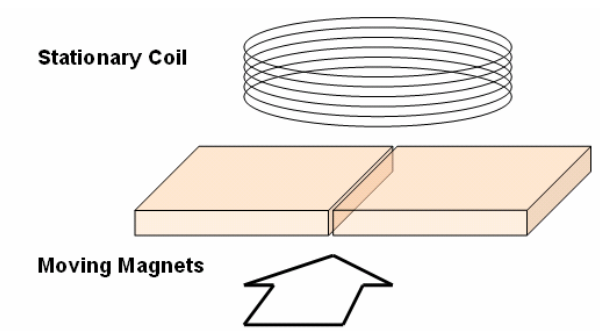

Figure 12. Magnet Orientation - Two Magnets

The test revealed that the voltage generated by the magnet configuration above was in fact smaller than the voltage generated by only one magnet. This went against the team's expectation. It was assumed that more magnets would increase the magnetic field strength, which in turn would increase the induced power in the coil. In order to further investigate the relationship between the number of magnets and the generated potential, a second test was conducted. This time four magnets were used; the setup is shown below:

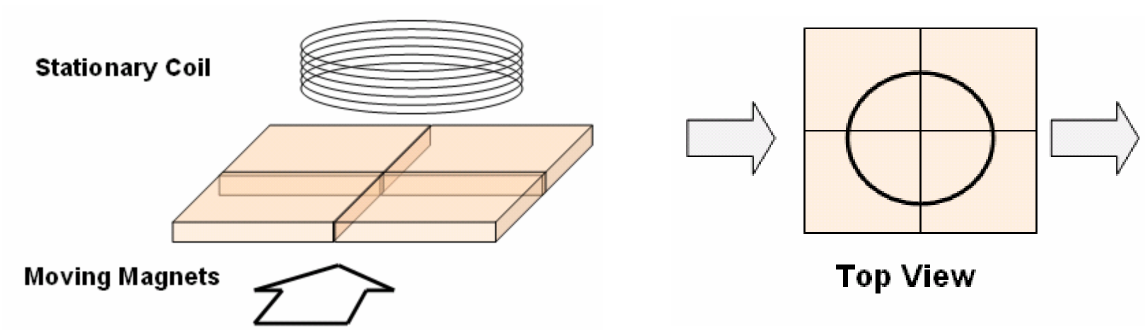

Figure 13. Magnet Orientation - Four Magnets

The results showed that the generated potential was not the same as that of the setup utilizing only one magnet. Ironically, the peak power generated was even less than the peak power generated by only using one magnet. The tests revealed that multiple magnets positioned next to each other do not necessarily provide a stronger magnetic field. The tests also revealed another fact: the position and orientation of each magnet significantly affects the overall strength of the collective magnetic field. Professor Platt of the Calvin physics department helped the team to understand that magnetic fields could actually cancel between magnets positioned next to one another. This can potentially reduce the amount of change in flux over the coil and in turn decrease the generated potential. The reason that fields are canceled is that the combined magnets have opposite polarity. Combined magnets tend to stick to each other because their polarities are different; the field strength would increase if the magnets had the same polarity; however, in that case, the magnets would repel each other. The figure below illustrates how polarity difference affects the magnetic field of the combined magnets.

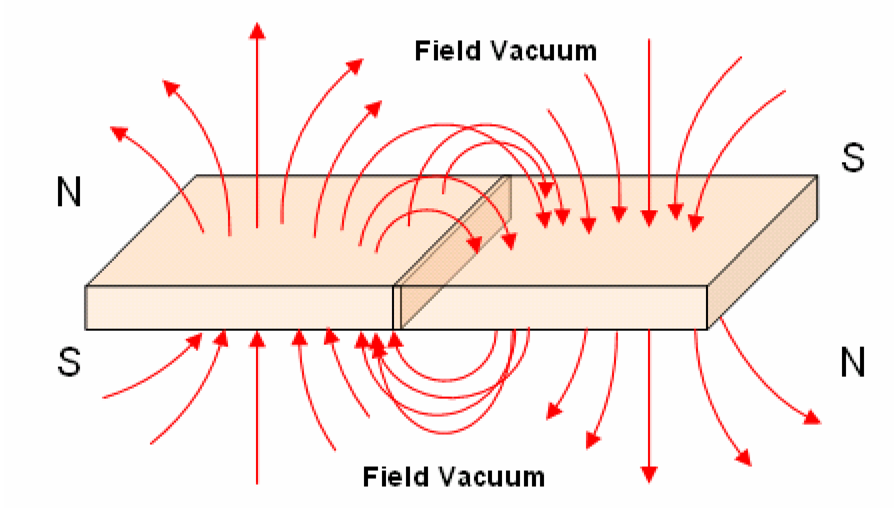

Figure 14. Magnetic Field Cancellation

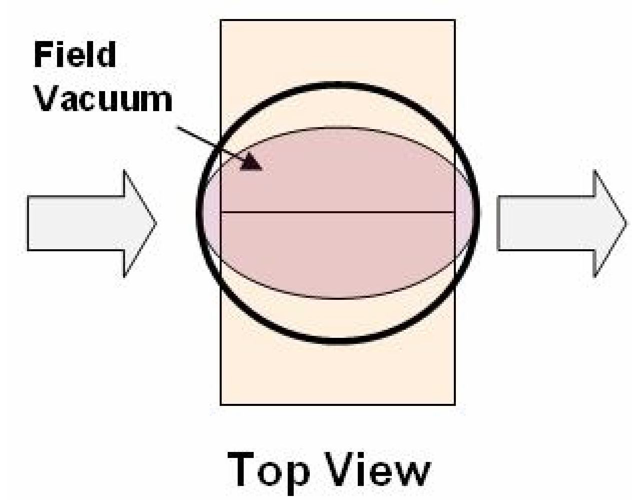

Figure 15. Magnetic Field Cancellation - Top View

This explains how the field strength is actually reduced. The new magnetic field gets weaker in the middle of the magnet configuration due to the cancellation of the fields at the boundary area. This significantly affects the generated potential because the coil passes right by the shaded region shown above, which is where the fields get canceled.

The final setup utilized only one magnet. The coil passes right by the surface of the magnet where the field lines cut through it. A single magnet ensures that there is no cancellation of magnetic fields. The setup is shown below:

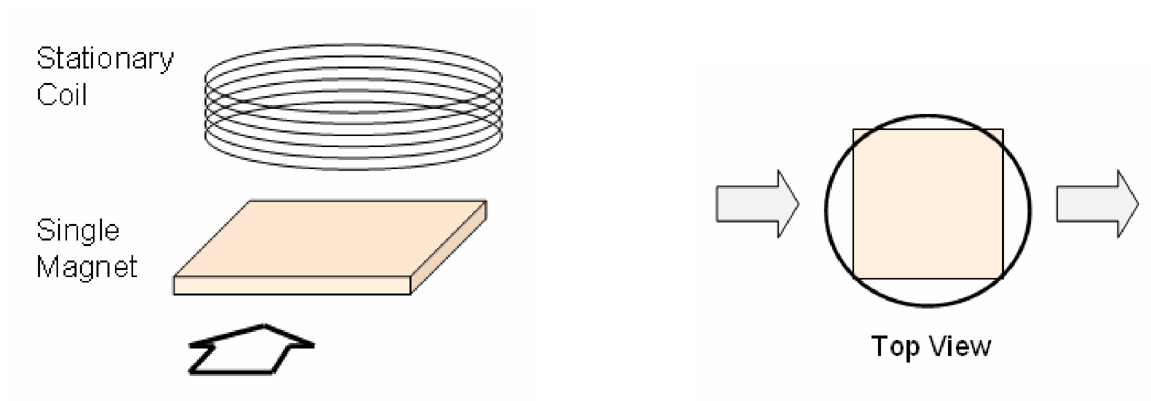

Figure 16. Magnet Orientation - One Magnet

The size of the coil also affects the generated potential. Determining the optimal cross-sectional area of the coil is key to optimizing the overall performance of the power generation system. The generated potential in the coil is proportional to both the area of the coil and the change in flux over the area of the coil. The equation below describes the aforementioned relationship:

$$emf = N \cdot A \cdot \frac{dB}{dt}$$

where emf is the electromotive force (voltage), N is the number of turns of the coil, A is the cross-sectional area of the coil, B is the magnetic field density, and t is time.

Different sizes of coils were tested, and it became apparent that in order to maintain the maximum rate of change of the magnetic field, the area of the coil should be kept very close to the surface area of the magnet. A cross-sectional coil area larger or smaller than the area of the magnet would reduce the rate of change in magnetic flux over the coil and in turn reduce the generated potential. The figure below demonstrates this idea.

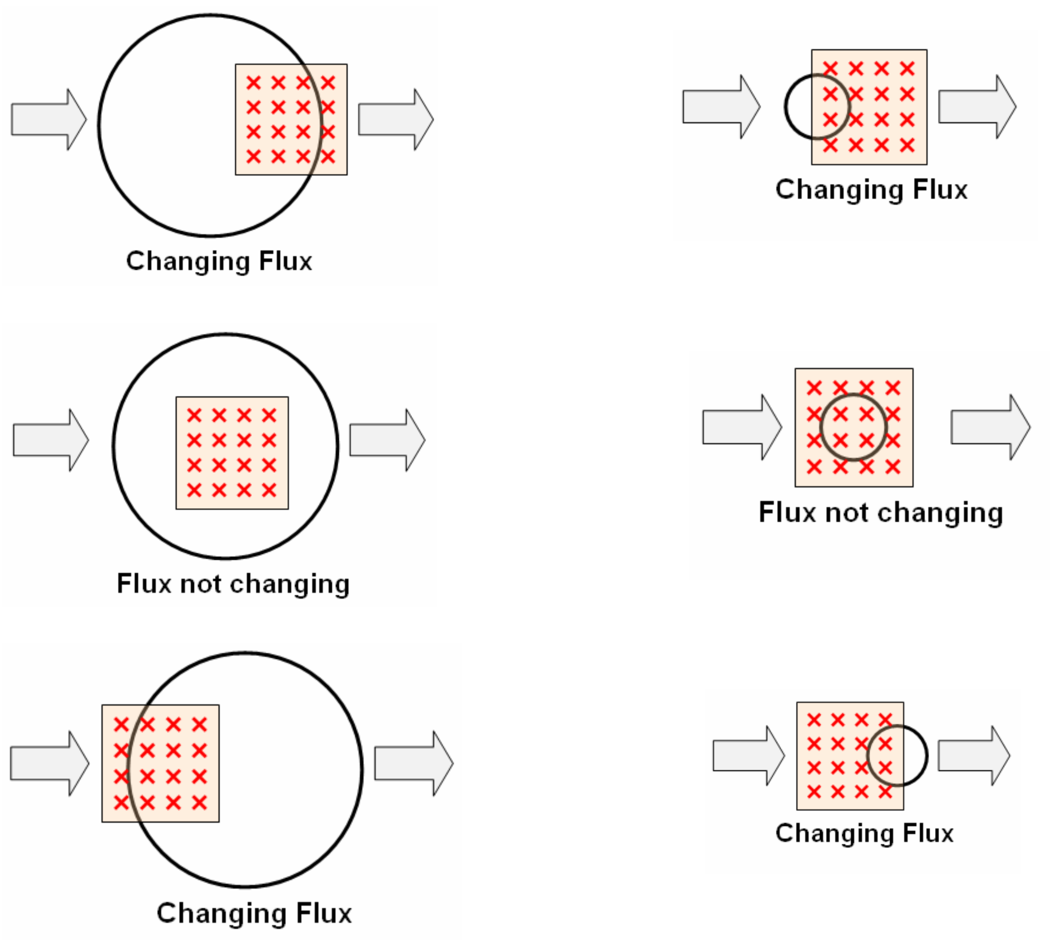

Figure 17. Inadequate Flux Change Due to Large Coil Size (Left) and Small Coil Size (Right)

As shown above, if the coil is either larger or smaller than the magnet's area, there is a period of time when the coil does not "cut" the magnetic field lines. The flux does not change during this period of time; thus, no electric potential is generated. For the best result, the coil area was matched to the magnet surface area as closely as possible. The figure below illustrates the sequence of coil passing by the magnet. The coil and magnet have comparable cross-sectional areas; this causes magnetic flux to continually change as the coil passes by the magnet.

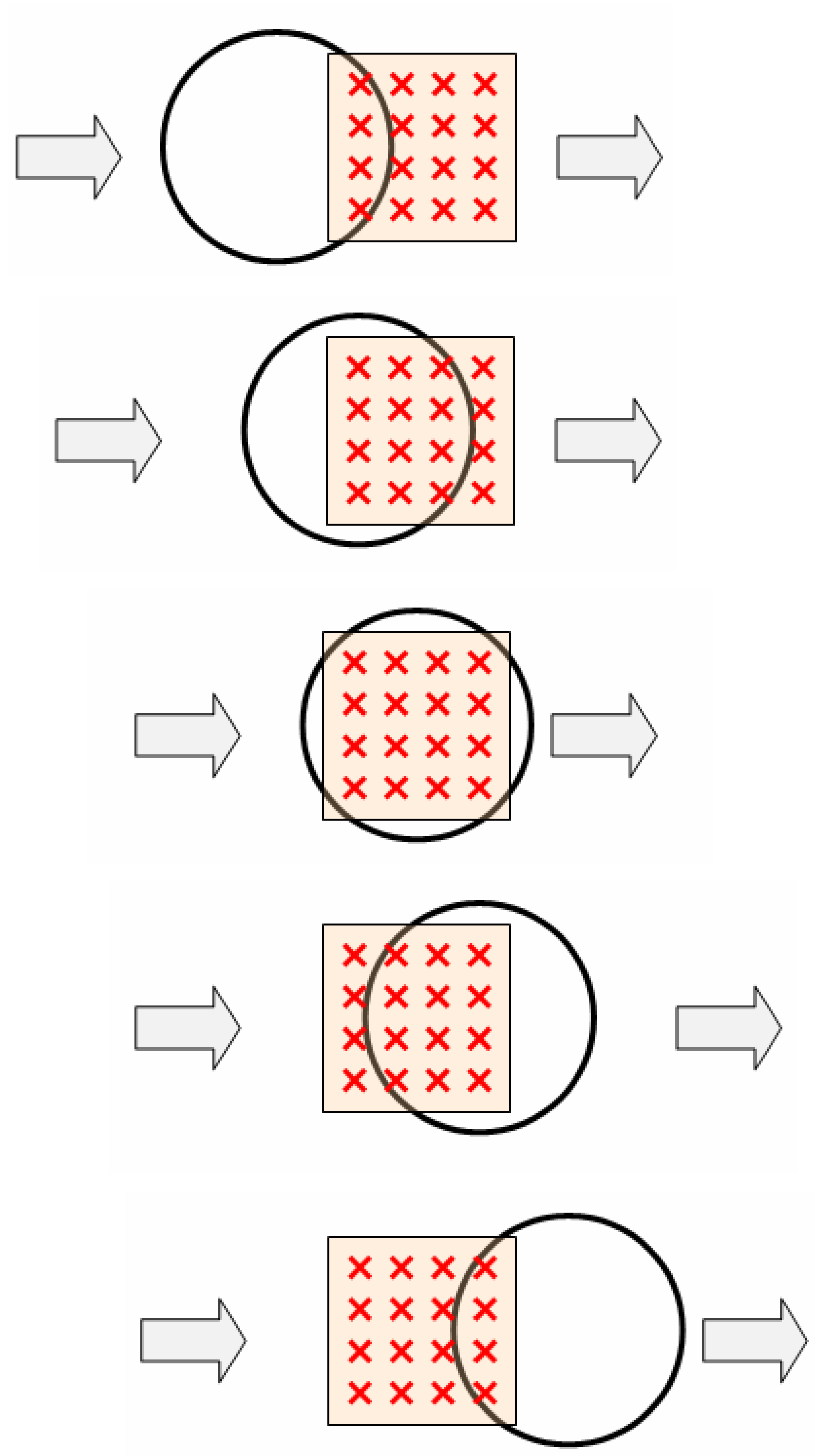

Figure 18. Optimal Coil Size for Flux Change

9.1 Coil Design

During preliminary feasibility studies, a graph of coil size vs. magnet strength was made that correlated to the required 3 volts necessary to operate the sensors. The graph, located in Appendix 2.b, shows the need for more coil turns when using weaker magnets. Using small plate magnets, (PN: Q125F from www.amazingmagnets.com) the final coil contains 1000 turns of wire. Coils constructed for testing were wound on an aluminum rod with 0.5 inch diameter. Final coil construction can be done using existing methods for mass coil production. After testing and prototype building was completed, it was discovered that using a ferromagnetic substance as a coil core would enhance the coils performance. The placement of a steel core in the coil has the effect of focusing the magnetic field creating a denser magnetic field gradient. This in turn would produce more flux and thus more induced EMF. A 1000 turn coil would theoretically produce more voltage with a ferromagnetic core than it currently does without. Using a steel core in the coil would lower the operating speed of the system due to the increased voltage production. An alternate option to using the steel core is reducing the amount of turns in the coil; this would maintain the current operating speed of the system but reduce the amount of material needed to produce the coil. Since this discovery was made after testing had concluded, these findings have not been quantified. They are listed here for future use and/or testing.

9.2 Coil Placement and Potting

The final placement of the coil is dependent on the type of wheel the system is being used on. Steel wheels shield magnetic fields; the coil would need to be mounted on the inside of the wheel for these applications. Mounting the coil on the inside of the wheel allows for a closer proximity to the magnets which benefits voltage production. The leads from the coil could either pass through a hole drilled in the wheel and seal with a pressure fitting or be run around the outside of the rim underneath the tire bead. Aluminum wheels provide two modes of mounting. The coil could be mounted on the inside of the wheel as is the case with steel wheels, or the coil could be mounted next to the sensor within the tire. Placing the coil within the tire leads to the option of creating one self contained sensor box instead of having the coil be a separate entity from the sensor. The coil is also protected from the wheel well environment which would affect the style of potting used. During prototype testing, the coil was potted with epoxy and secured to the inside of the rim using high temperature RTV compound. The coil leads were run over the surface of the wheel underneath the tire and to the sensor. RTV compound was again used to secure the wire leads on the wheel from the coil to the sensor.

9.3 Coil Testing

In order to fully understand the functionality of the procured TPMS, a pressure tube was constructed which enabled quick access to a pressurized environment without the need to mount and dismount tires frequently. Once functionality of the TPMS system was understood, the battery from a sensor was removed and wires were soldered to the battery terminals. The wires passed through the end cap of the pressure tube where they were connected to a proto-board. Using the pressure tube to vary pressure, the sensor functionality was tested with varying circuit components. Once a final circuit was built, the entire sensor/circuit assembly was placed in the pressure tube to test effectiveness.

The initial goal when designing coils was to produce 3 volts with the given magnet strength. As understanding of magnetism increased magnet configuration, coil size and shape were revised. Initial coils where very large and long made from heavy gauge wire. After research, coils were then made with large diameters and very thin wire. Further research led to coils roughly the size of the magnet, or approximately 0.75 inch in diameter. Testing with these smaller coils and revised magnet arrangement produced the required 3 volts of energy. Power was produced at a very high speed so it was necessary to further refine the coil size. Initial small coils were produced with 500 turns of wire. Increasing the number of turns to 800 effectively lowered the speed required to produce 3 volts from 40 to 20 mph. After a discussion on safety, it was decided that the system should operate at 15 mph instead of 20. 15 mph was chosen to correlate with most automatic locks that self lock at 15 mph. Coil size was increased to 1000 turns to accomplish this.

9.4 Power Regulation

Raw power was taken from the coil in pulses. Power was generated at the coil leads every time a magnet was driven past the coil. The nature of the power generation system produced a voltage waveform that looks similar to an electrocardiogram. A sample voltage waveform from the team’s test apparatus is shown below:

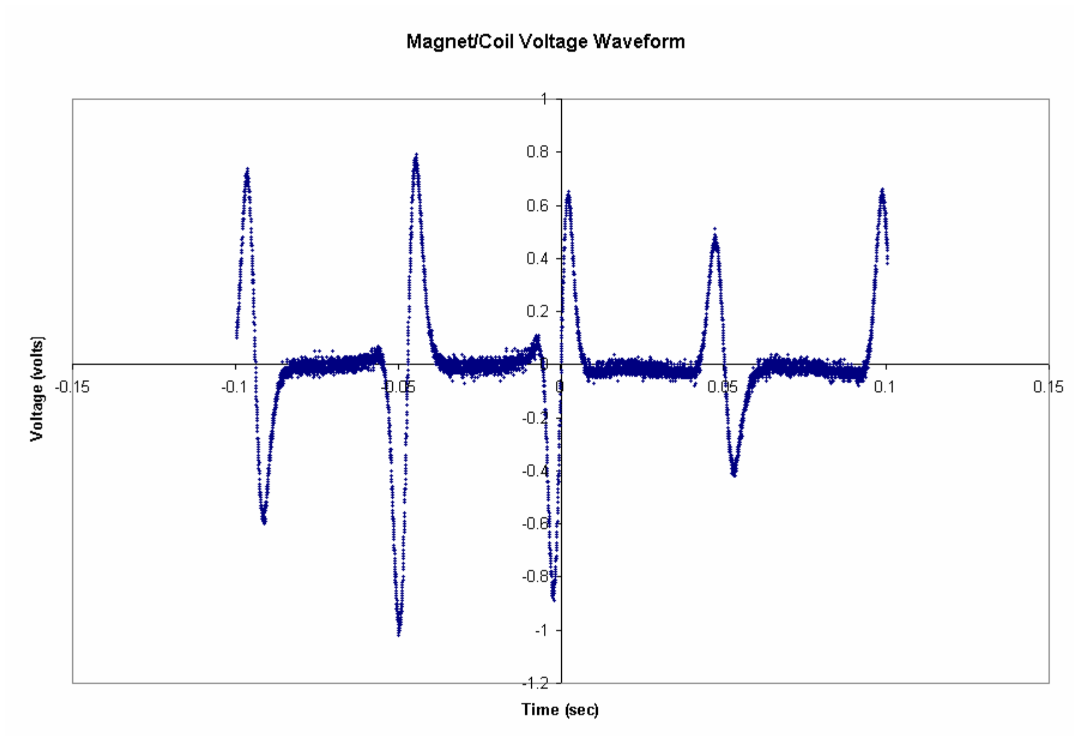

Figure 19. Sample Source Voltage Waveform from the Coil

In order know that the magnet and coil setup could produce enough power to run the sensor, a test was run to see how much power the sensor consumed. A test resistance was connected in series with the sensor, and power was provided to the system using the magnet and coil setup. The test resistance allowed the inference of power consumption levels for the sensor. The test circuit is shown below in Figure 20. A graph of one period of the voltage signal at the test resistance is shown in Appendix 9. Based on this typical sensor pulse period, sensor power consumption levels were inferred using the calculations in Appendix 10.

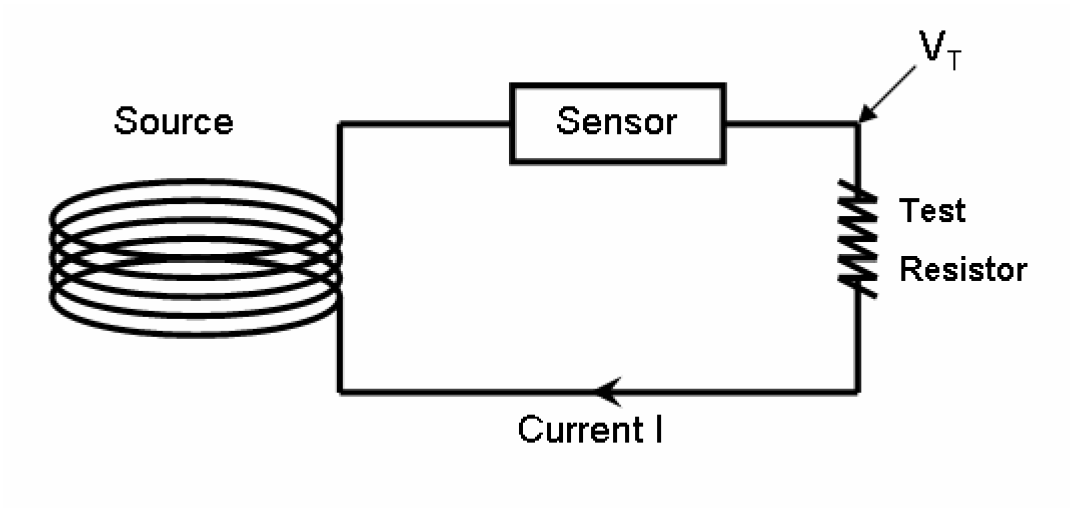

Figure 20. Sensor Power Consumption Test Circuit

The calculations in Appendix 10 showed that the average power consumed by an operating sensor is about 0.0013W. A raw power calculation showed that our test apparatus could provide 0.0045W at a relatively low wheel speed (about 10mph). This information showed that the test apparatus was capable of powering the sensor. Raw power calculation test numbers are shown in Appendix 11.

Once sufficient voltage was obtained from the test apparatus, it was necessary to implement a power regulation circuit to harness the raw power from the coil. As stated above, power was taken from the coil in pulses. Pulsing power would not allow for proper functionality of the sensors. The tire pressure sensors used for the project required 3 volts DC to operate correctly. The team's new challenge was to turn the pulses from the coil into a DC power source for the sensors. Power regulation testing commenced with the acquisition of a breadboard. A breadboard was used to implement different power regulation circuits; it allowed the team to easily swap out circuit components for testing purposes.

First, a diode was added to one side of the coil for half-wave rectification of the waveform. This diode effectively nullifies the bottom half of the waveform generated by the magnet and coil. Instead of a full wave oscillating about a reference point, half of the power wave is cut out of the picture. This rectification of the waveform is necessary as current can only be allowed to flow one way through the pressure sensor. The schematic below shows a 3V sinusoidal voltage source placed across a load. The waveform across the load is not rectified.

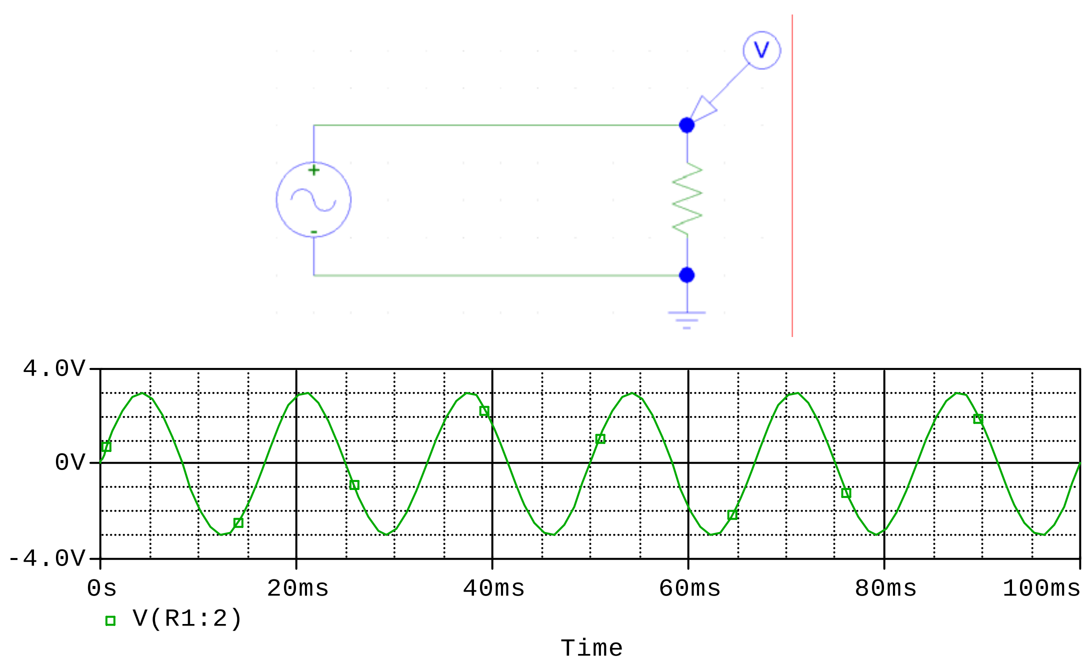

Figure 21. Sinusoidal Voltage Source and Accompanying Waveform

The schematic below shows the same 3V sinusoidal voltage source; however, a diode is rectifying this circuit. The waveform shows the half-wave rectification.

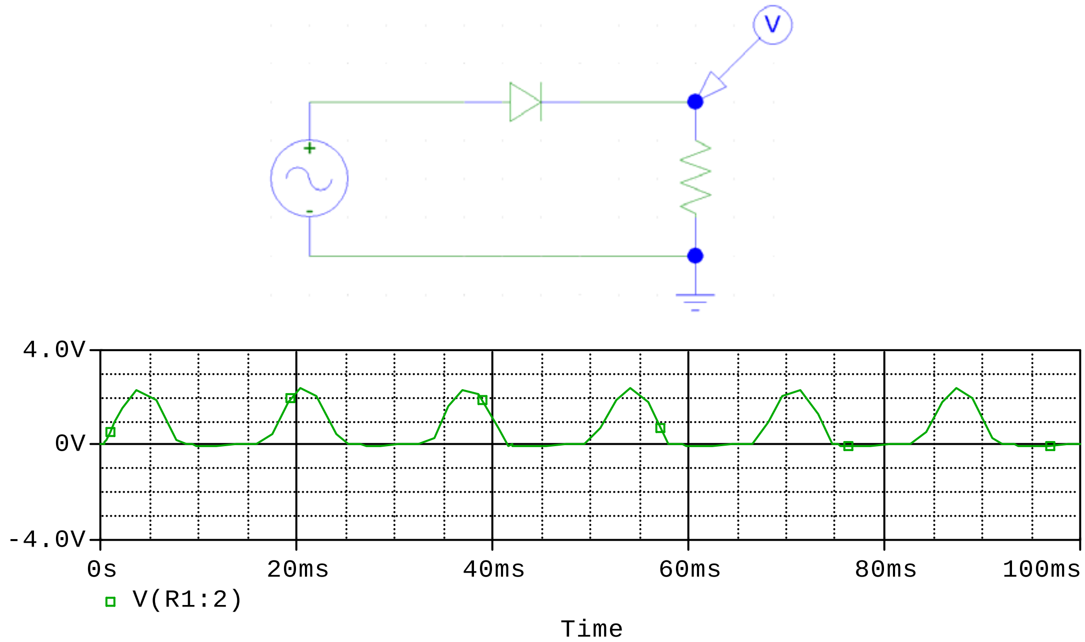

Figure 22. Diode Applied to Sinusoidal Voltage Source (half-wave rectification)

Full-wave rectification would give a more efficient use of power. All power, both positive and negative spikes shown in the waveform of Figure 19 would be utilized with full-wave rectification instead of just chopping off the bottom half as with half-wave rectification. However, more power is required to use a full-wave rectifier because two diodes are used at any given time instead of just one. A single diode has a 0.7V drop associated with it. A full-wave rectifier has a1.4V drop associated with it because it uses two diodes. The team felt that the extra 0.7V drop would have been detrimental to the system. The minimum vehicle speed at which the sensors would go operational would have necessarily increased due to the extra power needs. The team felt it was important to keep the minimum operational speed as low as possible.

Next, a capacitor was added between the load and reference to smooth out waveform oscillations. The capacitor imparts DC behavior onto the power generation system. One can think of the power pulses provided by the magnet and coil as water drops. A capacitor acts as a bucket to catch these "drops" of power, and it allows the power drops to leak through a hole in the bottom of the "bucket" via a continuous stream of power. The schematic below shows the capacitor implemented into the power regulation circuit. The waveform shows that the original sinusoidal voltage signal has been transformed to a DC signal.

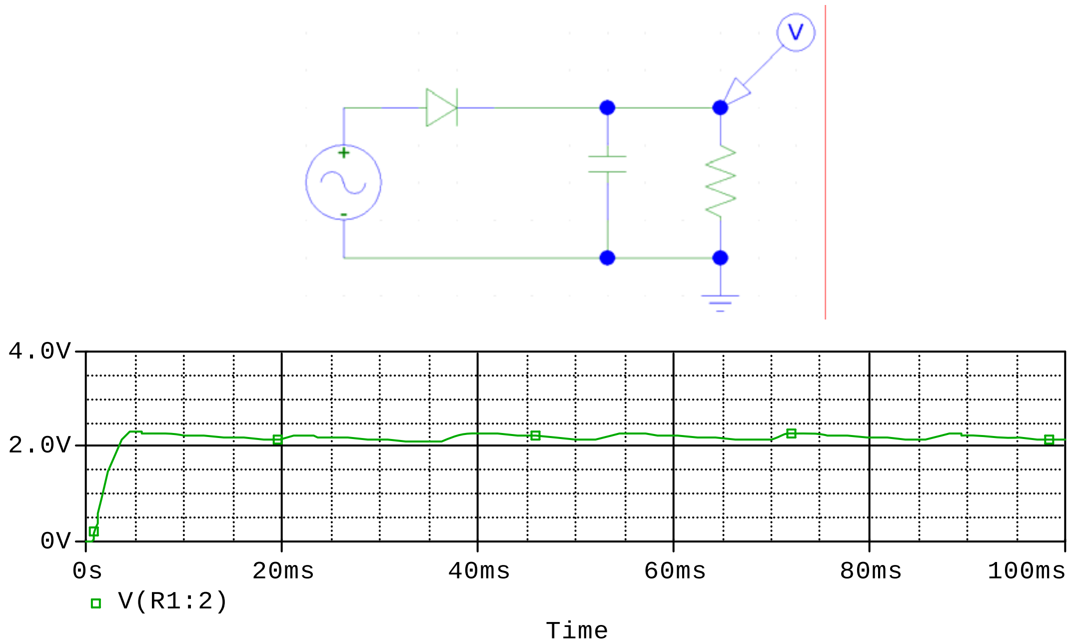

Figure 23. Filtering Capacitor Applied — Effective DC Voltage Obtained

Once DC power behavior was accomplished, the next problem the team faced was voltage regulation. A higher wheel speed corresponds to a greater change in flux and a consequent greater voltage at the coil leads. As stated above, the sensors used for the project required 3 volts DC. A voltage above 3V was not desirable for fear that the sensor might be damaged. DC-DC voltage regulators were used to ensure that the proper voltage level (3VDC) was applied to the sensors. The particular voltage regulators used for this project (National Instruments LP2950) had a "sawtooth" waveform output associated with them. Thus, a small filtering capacitor (2.2uF) was required to be across the voltage regulator output and the reference voltage. Using a relatively large electrolytic capacitor (3300uF) in the power regulation circuit for main power storage, the team successfully powered a tire pressure sensor using a magnet and coil. The circuit as it is described above is shown in the figure below. Though this regulation circuit gave limited success, the power regulation project was not complete.

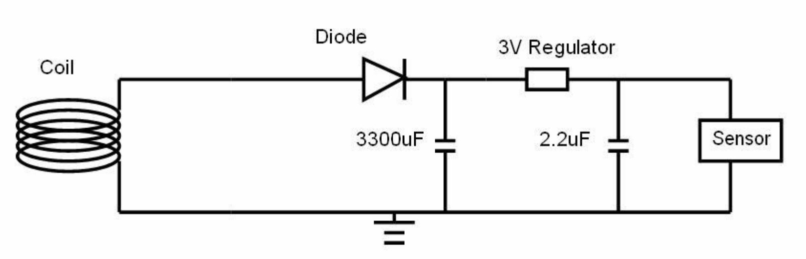

Figure 24. 3V Regulation Protects Sensor

Proper sensor function using the proposed power system required that the wheel spin in order for power to be generated. Once the wheel stopped spinning, power would cease to be generated, and the sensor would cease to function. A proposed solution to this problem was the use of a super capacitor for main power storage. These capacitors have very large capacitances, and they are capable of powering low-power applications for long periods of time. The team obtained several super capacitors of various capacitances, and testing found that these capacitors did not charge to a working voltage in an acceptable amount of time. Also, super capacitor discharge times were not as long as the team had hoped they would be. The team desired a discharge time of about ten hours, which would allow a system owner to sleep through the night, come out to their vehicle, and still have power at their tire pressure sensors. However, super capacitor testing showed that a ten hour discharge time could not be attained with the team's specific sensor application. Super capacitor charge and discharge tests are shown in Appendix 12. Another reason that super capacitors were not a feasible option is that they are relatively expensive (see Appendix 13 for super capacitor pricing), even when they are purchased in large quantities. For these reasons, the team decided to use electrolytic capacitors for the power regulation element of the project. Electrolytic capacitors have much lower charge storage than super capacitors, but they are also significantly cheaper (see Appendix 14 for electrolytic capacitor pricing).

The team decided that it would be acceptable to use electrolytic capacitors as the main storage element in the power regulation circuit despite their relatively low storage capacity. The decision to use electrolytic capacitors constrained the design to a small power discharge time. This means that once the wheel stops, power to the sensor is lost quickly. This is a drawback to the design; however, when power is not generated, the last pressure signal sent before the sensor lost power is stored by the pressure display module inside the vehicle cabin. Once the wheel begins to turn and the power regulation circuit is charged, the sensor will power up, and the sensor reading on the display module will refresh.

In order to maximize discharge time and protect the storage capacitor, a second stage was added to the power regulation circuit. A 5VDC regulator was placed on the front side of the main storage capacitor. A 2.2uF capacitor was added between the input of the 5 volt regulator and the reference voltage to filter oscillations into the regulator. It was later discovered that there is an inherent capacitance of about 94pF between the 5 volt regulator input and ground, and this 2.2uF capacitor is not actually necessary. The 5 volt regulator prevents the capacitor from seeing excessive voltage levels which could cause the capacitor to fail catastrophically, and it also allows the capacitor to charge up to 5VDC. Allowing the main capacitor to charge to 5V allows for a 2V buffer (from 5V down to 3V) where the sensor is still operational even though no power is generated from the wheels. The capacitor discharges through the sensor, and the voltage level dissipates from 5V to 3VDC in about 10-15 seconds. See Appendix 15 for capacitor discharge test numbers. The power regulation circuit as it is described above is shown below:

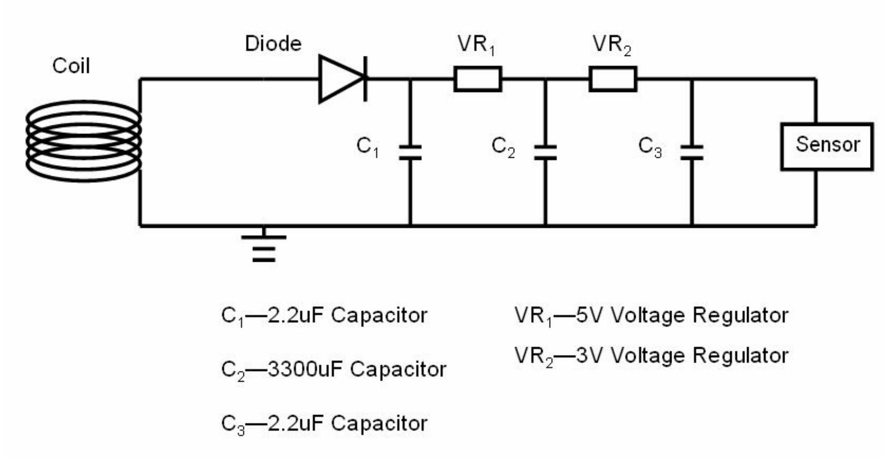

Figure 25. Final Circuit Layout

9.5 PCB Manufacturing

In order to make the electrical design compact so that the circuit can actually fit with the sensor and inside the sensor bracket, a small printed circuit board (PCB) was manufactured. The PCB layout is shown below.

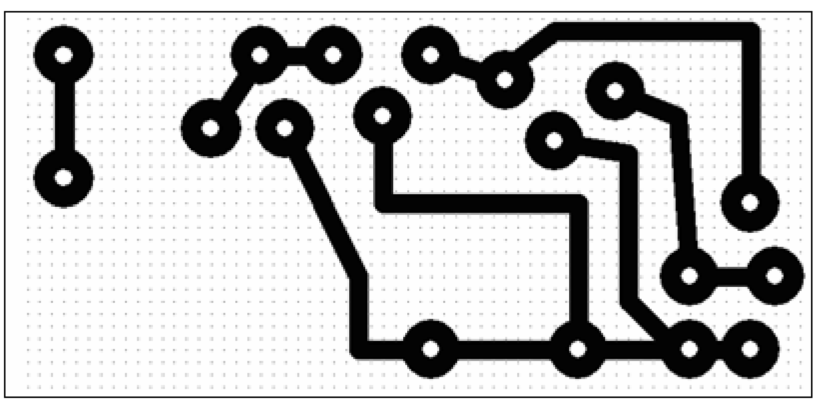

Figure 26. PCB Layout

9.6 Finite Element Analysis

One obstacle encountered during the design process was sensor operating environment; more specifically, the magnets mounted to the brake caliper. Due to friction during braking, the temperature of the brake assembly can become very high. Final mounting consists of attaching magnets to the brake caliper. This raised the question whether or not the magnets would lose magnetic field strength at the high temperatures. A model was developed using a worst-case scenario having the magnet mounted directly to the top of a caliper on a hot day. This test would produce a maximum temperature that the magnet would see assuming the mounting bracket did not dissipate any heat. The image below shows the CAD model that was used in the analysis.

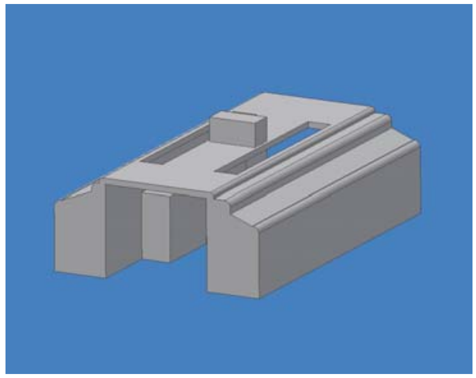

Figure 27. Caliper FEA Model

To validate FEA results, one group member drove a car around doing some heavy braking. The caliper temperature was measured using a laser pyrometer. This was repeated for a variety of driving and braking conditions and then compared to similar FEA results. The results from real world testing matched FEA results. The images below show the heating and cooling loads that were applied to the model, as well as the results of the initial model.

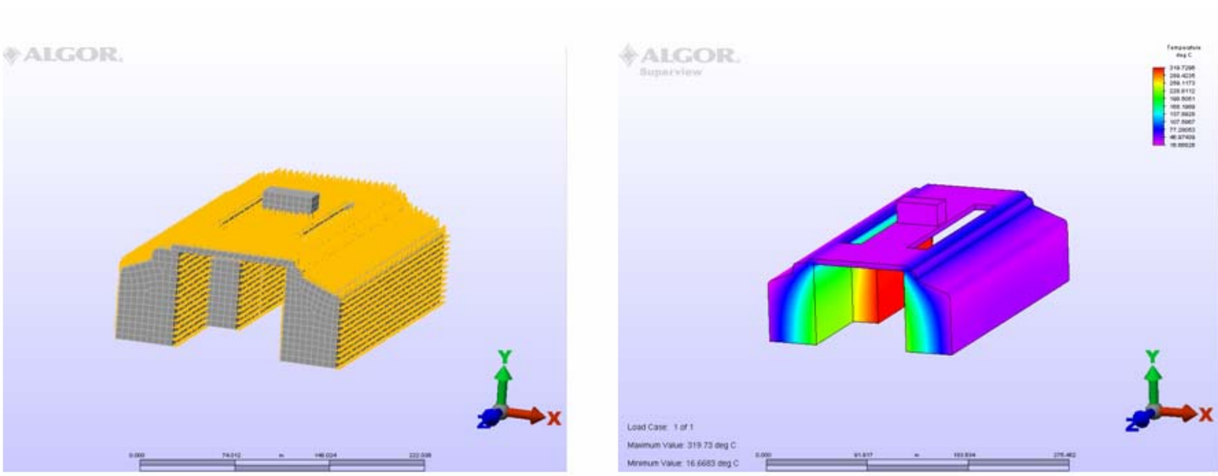

Figure 28. Load Diagram (Left) and Thermal Distribution (Right)

Convective loads were applied to the exterior surfaces of the caliper to model heat loss due to air running over the surface. Braking heat was modeled as a radiation load applied to the inside of the surfaces of the caliper, using different view factors depending on the surface. This model led to a temperature of approximately 29˚C at the interface between the magnet and the caliper.

Once the model was verified, other simulations were run with higher and lower ambient air temperatures. The extreme low test assumed –20˚C air and the extreme high test assumed 40˚C air. The images below show the results and temperature distributions for each model.

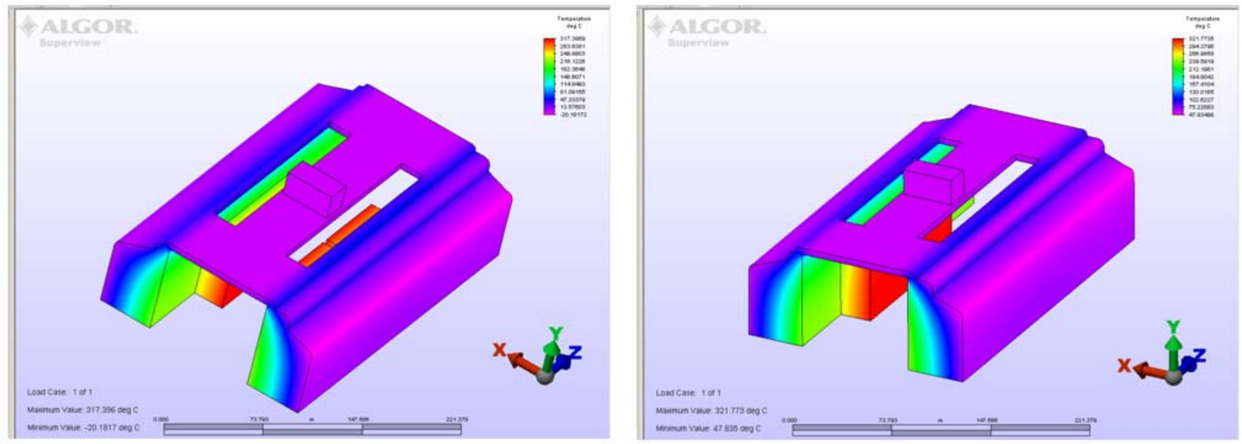

Figure 29. -20C Temperature Results (Left) and 40C Temperature Results (Right)

Though there was a similar temperature distribution in the setups, the interface temperatures varied by over 60˚C. For the cold model, the interface temperature was approximately 2˚C. For the hot model, the interface temperature was approximately 65˚C. The magnets that were purchased have a max temperature rating of 80˚C before their magnetism begins to fade. From the finite element analysis it was shown that the proposed mounting solution does not degrade magnet performance due to temperature.

9.7 Mounting

One of the mechanical challenges of this project was mounting the magnets. The design called for the magnets to be mounted inside the wheel well. The wheel well of a car is a very harsh environment that experiences many types of mechanical and thermal stresses. It also has very limited space. The magnet mounting design had to be robust to handle environmental stresses and compact so that it could fit inside the wheel well. The team produced two ideas for mounting magnets inside the wheel well. One mounting option adapts a magnet mounting bracket to a brake caliper as an aftermarket addition. The bracket would be secured to the caliper using the existing caliper mounting holes; it holds a threaded boss that allows fine magnet height adjustments for different vehicles. Since the power in the coil heavily depends on the proximity of the magnet to the coil, it is important that the magnet height be adjustable for vehicle portability. The figure below shows a prototype drawing of the aftermarket bracket design.

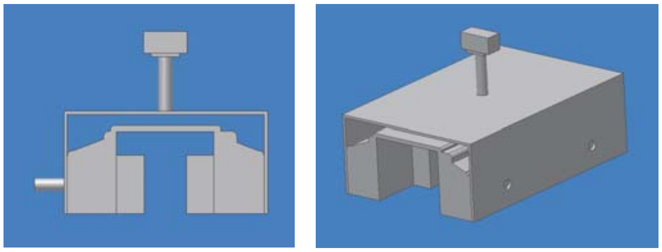

Figure 30. Aftermarket Magnet Bracket

The other design idea would be implemented during brake manufacturing. The production design would implement a threaded boss either welded or cast right onto the caliper. This would be a simple yet robust design that would still allow for the use of an adjustable rod to set magnet height. The magnets are mounted on a long platform contoured to the curvature of the wheel. The platform allows two sets of magnets to be mounted on each caliper while keeping enough distance between the magnets to keep the fields from interfering with each other. The image below shows a picture of a production model.

Figure 31. Production Bracket Assembly

10. Christian Perspective

A moral perspective is important in any undertaking in life, including technological design. Christian engineers in particular have an obligation to consider the ethical implications of their ideas and products. The design norms presented in lecture give a guide to conscious decision-making with respect to engineering design. Several design norms are apparent in the implementation of this particular project: stewardship, caring, and cultural appropriateness.

First, stewardship could be defined as properly managing the resources one is given. Design of a battery-free device displays this idea of stewardship through consciously trying to conserve natural resources. By designing an alternative power generation system for tire pressure sensors, the need for batteries will hopefully be eliminated, thereby reducing the amount of waste to landfills. Secondly, the project saves energy. The magnetic induction design essentially transforms energy from one form to another. The induction method increases energy efficiency associated with a moving automobile by converting kinetic energy that would normally be wasted into electric energy.

The design norm of cultural appropriateness is also evident in the new design. The pressure sensor power system could be applied to any automobile because all automobiles use pressurized tires. Most families in the United States have at least one automobile, and many have multiple vehicles. The proposed technology could easily be used by millions of American drivers if it were implemented by automotive manufacturers.

Finally, the proposed design also addresses the design norm of caring. People that cannot afford to replace their TPMS would be at a disadvantage with a conventional system. By prolonging the working life of tire pressure sensors, the new pressure sensor power system increases the safety of automobiles. In extreme cases, knowledge of tire pressure could prevent a blowout and save lives.

11. Costs

Team 8
Preliminary Budget
11/11/2005

Project Expenses:

Sensors/Sensor System	$65
Batteries	$0
Test Apparatus:	$0
Steel	(buy)
Electric motor	(borrow)
Wheels	(have)
Bearing	(buy)
Wheels studs	(buy)
Misc. hardware	(buy)
Magnets	$30
Coils/Wires	$0
Electronic Components	$91
Contingency expenses	$60
Total Cost:	$246

R&D Costs

Labor		**$20/hr**
Total Hrs	(24hrs/week)	1080
Total Cost		$21,600
Professor Time		**$30/hr**
	45 hrs	$1,350
Industrial consultant time		**$40/hr**
JCI	2 hrs	$80
Greg Bock	2 hrs	$80
Subtotal: Labor Cost		$160

Total Material Cost:	$246
Labor Cost:	$23,110
Total Cost:	$23,356

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10. Wyczalek, Floyd A. "Electric Vehicle Regenerative Braking." *Proceedings of the Intersociety Energy Conversion Engineering Conference* (1992): 3.185-90.

Appendix 1: Magnet Pricing [1]

 More Info	D063A-AU ~ 1/8" Dia x 1/16" Thick NdFeB Disc Magnet, Au plated. (1 Item = 100 magnets) Price US$12.00	Qty 1	buy
 More Info	D063B ~ 1/4" Dia x 1/16" Thick NdFeB Disc Magnet, Ni-Cu-Ni plated. (1 Item = 50 magnets) Price US$7.00	Qty 1	buy
 More Info	D063C ~ 3/8" Dia x 1/16" Thick NdFeB Disc Magnet, Ni-Cu-Ni plated. (1 Item = 50 magnets) Price US$10.00	Qty 1	buy
 More Info	D063D ~ 1/2" Dia x 1/16" Thick NdFeB Disc Magnet, Ni-Cu-Ni plated. (1 Item = 50 magnets) Price US$15.30	Qty 1	buy
 More Info	D094A ~ 1/8" Dia x 3/32" Thick NdFeB Disc Magnet, Ni-Cu-Ni plated. (1 Item = 80 magnets) Price US$8.40	Qty 1	buy

Appendix 2.a: Preliminary Calculations and Magnet Specifications

$d = 0.00635$ [m]

$a = 0.25 \cdot 3.14 \cdot d^2$

$n = 500$

$t = \frac{l}{n} \cdot \left| 39.3701 \cdot \frac{in}{m} \right|$

$l = 0.0508$ [m]

$emf = 3$ [V]

$emf = n \cdot a \cdot \frac{\delta_b}{\delta_t}$

$speed = 13.4$ [m/sec]

$diam = 0.6604$ [m]

$circ = 3.14 \cdot diam$

$RPM = \frac{speed}{circ} \cdot 60$ [sec/min]

$\delta_t = \frac{l}{speed}$

$req_b = \delta_b \cdot \left| 10000 \cdot \frac{gauss}{tesla} \right|$

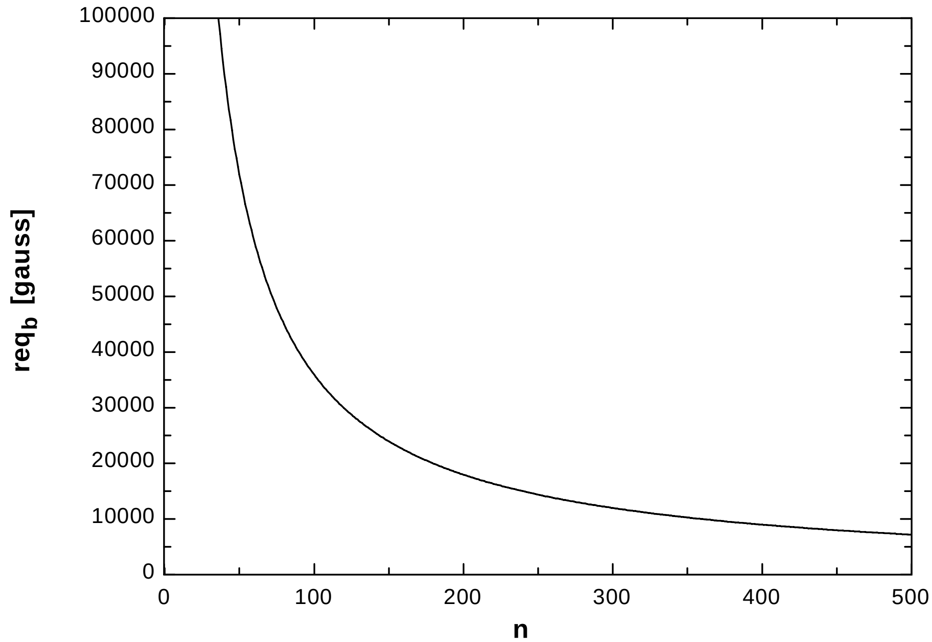
Unit Settings: [kJ]/[C]/[kPa]/[kg]/[degrees]

$a = 0.00003165$ [m^2]	circ = 2.074 [m]	d = 0.00635 [m]	$\delta_b = 0.7186$ [Tesla]
$\delta_t = 0.003791$ [sec]	diam = 0.6604 [m]	emf = 3 [V]	l = 0.0508 [m]
n = 500	$req_b = 7186$ [gauss]	RPM = 387.7 [1/min]	speed = 13.4 [m/sec]
t = 0.004 [in]			

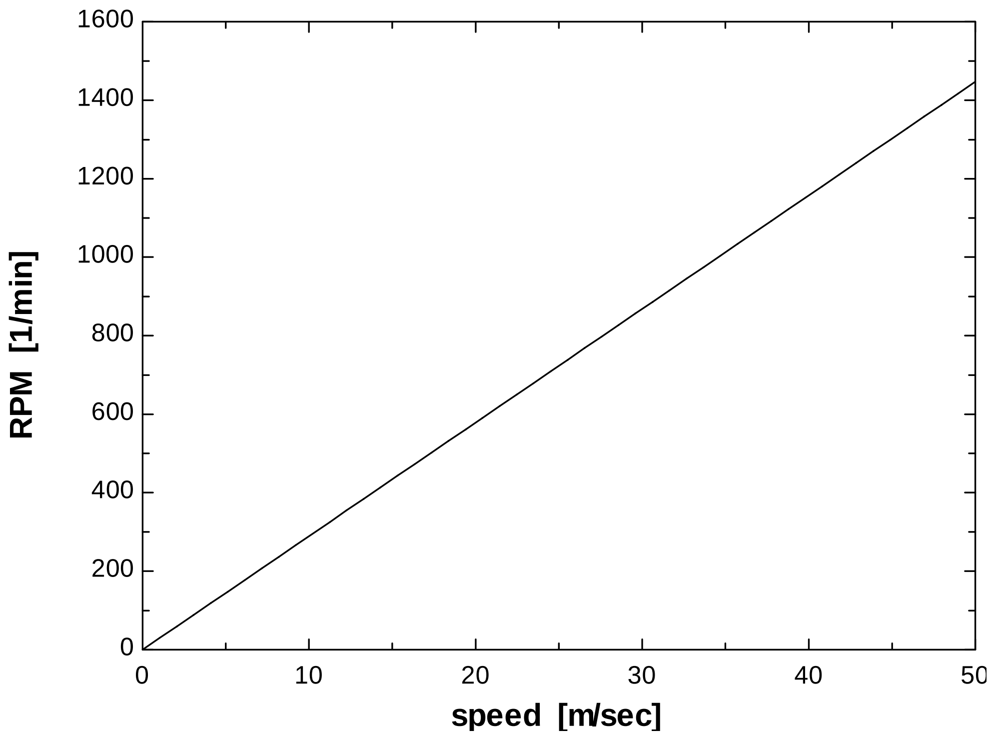
No unit problems were detected.

Calculation time = .0 sec

Appendix 2.b: Preliminary Correlations



Required Magnetic Field Strength (reqb) Vs. Number of Turns in Coil (n)



Motor Speed (RPM) Vs. Vehicle Speed (m/sec)

Appendix 3: Piezoelectric Specifications [8]

	Part Number ↓	Description	Price ↓
	Press-ICP-2300V6	10,000 psi range, .5 mV/psi, acceleration compensated, .217 diameter diaphragm **...more »**	**$375.00** **Add to Cart**
	Press-ICP-2300V5	5000 psi range, 1 mV/psi, acceleration compensated, .217 diameter diaphragm **...more »**	**$375.00** **Add to Cart**
	Press-ICP-2300V4	1000 psi range, 5 mV/psi, acceleration compensated, .217 diameter diaphragm **...more »**	**$375.00** **Add to Cart**
	Press-ICP-2300V3	500 psi range, 10 mV/psi, acceleration compensated, .217 diameter diaphragm **...more »**	**$375.00** **Add to Cart**
	Press-ICP-2300V1	250 psi range, 20 mV/psi, acceleration compensated, .217 diameter diaphragm **...more »**	**$375.00** **Add to Cart**
	Press-ICP-2200V1	100 psi range, 50 mV/psi, acceleration compensated, .217 diameter diaphragm **...more »**	**$385.00** **Add to Cart**
	Press-ICP-2013V	2.5 psi range, 2000 mV/psi, microphone, 78.7 db resolution **...more »**	**$575.00** **Add to Cart**
Image Not Available	Press-ICP-2005V	50 psi range, 100 mV/psi, acceleration compensated, TNC connector, 1/8-27 NPT mount **...more »**	**$599.00** **Add to Cart**
	Press-ICP-2011V	1000 psi range, 5 mV/psi, in cylinder engine combustion sensor **...more »**	**$765.00** **Add to Cart**

Appendix 4: Thermocouple Specifications (Type E)

Thermoelectric Voltage in Millivolts

°C	-10	-9	-8	-7	-6	-5	-4	-3	-2	-1	0	°C
-260	-9.835	-9.833	-9.831	-9.828	-9.825	-9.821	-9.817	-9.813	-9.808	-9.802	-9.797	-260
-250	-9.797	-9.790	-9.784	-9.777	-9.770	-9.762	-9.754	-9.746	-9.737	-9.728	-9.718	-250
-240	-9.718	-9.709	-9.698	-9.688	-9.677	-9.666	-9.654	-9.642	-9.630	-9.617	-9.604	-240
-230	-9.604	-9.591	-9.577	-9.563	-9.548	-9.534	-9.519	-9.503	-9.487	-9.471	-9.455	-230
-220	-9.455	-9.438	-9.421	-9.404	-9.386	-9.368	-9.350	-9.331	-9.313	-9.293	-9.274	-220
-210	-9.274	-9.254	-9.234	-9.214	-9.193	-9.172	-9.151	-9.129	-9.107	-9.085	-9.063	-210
-200	-9.063	-9.040	-9.017	-8.994	-8.971	-8.947	-8.923	-8.899	-8.874	-8.850	-8.825	-200
-190	-8.825	-8.799	-8.774	-8.748	-8.722	-8.696	-8.669	-8.643	-8.616	-8.588	-8.561	-190
-180	-8.561	-8.533	-8.505	-8.477	-8.449	-8.420	-8.391	-8.362	-8.333	-8.303	-8.273	-180
-170	-8.273	-8.243	-8.213	-8.183	-8.152	-8.121	-8.090	-8.059	-8.027	-7.995	-7.963	-170
-160	-7.963	-7.931	-7.899	-7.866	-7.833	-7.800	-7.767	-7.733	-7.700	-7.666	-7.632	-160
-150	-7.632	-7.597	-7.563	-7.528	-7.493	-7.458	-7.423	-7.387	-7.351	-7.315	-7.279	-150
-140	-7.279	-7.243	-7.206	-7.170	-7.133	-7.096	-7.058	-7.021	-6.983	-6.945	-6.907	-140
-130	-6.907	-6.869	-6.831	-6.792	-6.753	-6.714	-6.675	-6.636	-6.596	-6.556	-6.516	-130
-120	-6.516	-6.476	-6.436	-6.396	-6.355	-6.314	-6.273	-6.232	-6.191	-6.149	-6.107	-120
-110	-6.107	-6.065	-6.023	-5.981	-5.939	-5.896	-5.853	-5.810	-5.767	-5.724	-5.681	-110
-100	-5.681	-5.637	-5.593	-5.549	-5.505	-5.461	-5.417	-5.372	-5.327	-5.282	-5.237	-100
-90	-5.237	-5.192	-5.147	-5.101	-5.055	-5.009	-4.963	-4.917	-4.871	-4.824	-4.777	-90
-80	-4.777	-4.731	-4.684	-4.636	-4.589	-4.542	-4.494	-4.446	-4.398	-4.350	-4.302	-80
-70	-4.302	-4.254	-4.205	-4.156	-4.107	-4.058	-4.009	-3.960	-3.911	-3.861	-3.811	-70
-60	-3.811	-3.761	-3.711	-3.661	-3.611	-3.561	-3.510	-3.459	-3.408	-3.357	-3.306	-60
-50	-3.306	-3.255	-3.204	-3.152	-3.100	-3.048	-2.996	-2.944	-2.892	-2.840	-2.787	-50
-40	-2.787	-2.735	-2.682	-2.629	-2.576	-2.523	-2.469	-2.416	-2.362	-2.309	-2.255	-40
-30	-2.255	-2.201	-2.147	-2.093	-2.038	-1.984	-1.929	-1.874	-1.820	-1.765	-1.709	-30
-20	-1.709	-1.654	-1.599	-1.543	-1.488	-1.432	-1.376	-1.320	-1.264	-1.208	-1.152	-20
-10	-1.152	-1.095	-1.039	-0.982	-0.925	-0.868	-0.811	-0.754	-0.697	-0.639	-0.582	-10
0	-0.582	-0.524	-0.466	-0.408	-0.350	-0.292	-0.234	-0.176	-0.117	-0.059	0.000	0

0	0.000	0.059	0.118	0.176	0.235	0.294	0.354	0.413	0.472	0.532	0.591	0
10	0.591	0.651	0.711	0.770	0.830	0.890	0.950	1.010	1.071	1.131	1.192	10
20	1.192	1.252	1.313	1.373	1.434	1.495	1.556	1.617	1.678	1.740	1.801	20
30	1.801	1.862	1.924	1.986	2.047	2.109	2.171	2.233	2.295	2.357	2.420	30
40	2.420	2.482	2.545	2.607	2.670	2.733	2.795	2.858	2.921	2.984	3.048	40
50	3.048	3.111	3.174	3.238	3.301	3.365	3.429	3.492	3.556	3.620	3.685	50
60	3.685	3.749	3.813	3.877	3.942	4.006	4.071	4.136	4.200	4.265	4.330	60
70	4.330	4.395	4.460	4.526	4.591	4.656	4.722	4.788	4.853	4.919	4.985	70
80	4.985	5.051	5.117	5.183	5.249	5.315	5.382	5.448	5.514	5.581	5.648	80
90	5.648	5.714	5.781	5.848	5.915	5.982	6.049	6.117	6.184	6.251	6.319	90
100	6.319	6.386	6.454	6.522	6.590	6.658	6.725	6.794	6.862	6.930	6.998	100
110	6.998	7.066	7.135	7.203	7.272	7.341	7.409	7.478	7.547	7.616	7.685	110
120	7.685	7.754	7.823	7.892	7.962	8.031	8.101	8.170	8.240	8.309	8.379	120
130	8.379	8.449	8.519	8.589	8.659	8.729	8.799	8.869	8.940	9.010	9.081	130
140	9.081	9.151	9.222	9.292	9.363	9.434	9.505	9.576	9.647	9.718	9.789	140
150	9.789	9.860	9.931	10.003	10.074	10.145	10.217	10.288	10.360	10.432	10.503	150
160	10.503	10.575	10.647	10.719	10.791	10.863	10.935	11.007	11.080	11.152	11.224	160
170	11.224	11.297	11.369	11.442	11.514	11.587	11.660	11.733	11.805	11.878	11.951	170
180	11.951	12.024	12.097	12.170	12.243	12.317	12.390	12.463	12.537	12.610	12.684	180
190	12.684	12.757	12.831	12.904	12.978	13.052	13.126	13.199	13.273	13.347	13.421	190
200	13.421	13.495	13.569	13.644	13.718	13.792	13.866	13.941	14.015	14.090	14.164	200
210	14.164	14.239	14.313	14.388	14.463	14.537	14.612	14.687	14.762	14.837	14.912	210
220	14.912	14.987	15.062	15.137	15.212	15.287	15.362	15.438	15.513	15.588	15.664	220
230	15.664	15.739	15.815	15.890	15.966	16.041	16.117	16.193	16.269	16.344	16.420	230
240	16.420	16.496	16.572	16.648	16.724	16.800	16.876	16.952	17.028	17.104	17.181	240
250	17.181	17.257	17.333	17.409	17.486	17.562	17.639	17.715	17.792	17.868	17.945	250
260	17.945	18.021	18.098	18.175	18.252	18.328	18.405	18.482	18.559	18.636	18.713	260
270	18.713	18.790	18.867	18.944	19.021	19.098	19.175	19.252	19.330	19.407	19.484	270
280	19.484	19.561	19.639	19.716	19.794	19.871	19.948	20.026	20.103	20.181	20.259	280
290	20.259	20.336	20.414	20.492	20.569	20.647	20.725	20.803	20.880	20.958	21.036	290
300	21.036	21.114	21.192	21.270	21.348	21.426	21.504	21.582	21.660	21.739	21.817	300
310	21.817	21.895	21.973	22.051	22.130	22.208	22.286	22.365	22.443	22.522	22.600	310
320	22.600	22.678	22.757	22.835	22.914	22.993	23.071	23.150	23.228	23.307	23.386	320
330	23.386	23.464	23.543	23.622	23.701	23.780	23.858	23.937	24.016	24.095	24.174	330
340	24.174	24.253	24.332	24.411	24.490	24.569	24.648	24.727	24.806	24.885	24.964	340
°C	0	1	2	3	4	5	6	7	8	9	10	°C

°C	0	1	2	3	4	5	6	7	8	9	10	°C
350	24.964	25.044	25.123	25.202	25.281	25.360	25.440	25.519	25.598	25.678	25.757	350
360	25.757	25.836	25.916	25.995	26.075	26.154	26.233	26.313	26.392	26.472	26.552	360
370	26.552	26.631	26.711	26.790	26.870	26.950	27.029	27.109	27.189	27.268	27.348	370
380	27.348	27.428	27.507	27.587	27.667	27.747	27.827	27.907	27.986	28.066	28.146	380
390	28.146	28.226	28.306	28.386	28.466	28.546	28.626	28.706	28.786	28.866	28.946	390
400	28.946	29.026	29.106	29.186	29.266	29.346	29.427	29.507	29.587	29.667	29.747	400
410	29.747	29.827	29.908	29.988	30.068	30.148	30.229	30.309	30.389	30.470	30.550	410
420	30.550	30.630	30.711	30.791	30.871	30.952	31.032	31.112	31.193	31.273	31.354	420
430	31.354	31.434	31.515	31.595	31.676	31.756	31.837	31.917	31.998	32.078	32.159	430
440	32.159	32.239	32.320	32.400	32.481	32.562	32.642	32.723	32.803	32.884	32.965	440
450	32.965	33.045	33.126	33.207	33.287	33.368	33.449	33.529	33.610	33.691	33.772	450
460	33.772	33.852	33.933	34.014	34.095	34.175	34.256	34.337	34.418	34.498	34.579	460
470	34.579	34.660	34.741	34.822	34.902	34.983	35.064	35.145	35.226	35.307	35.387	470
480	35.387	35.468	35.549	35.630	35.711	35.792	35.873	35.954	36.034	36.115	36.196	480
490	36.196	36.277	36.358	36.439	36.520	36.601	36.682	36.763	36.843	36.924	37.005	490
500	37.005	37.086	37.167	37.248	37.329	37.410	37.491	37.572	37.653	37.734	37.815	500
510	37.815	37.896	37.977	38.058	38.139	38.220	38.300	38.381	38.462	38.543	38.624	510
520	38.624	38.705	38.786	38.867	38.948	39.029	39.110	39.191	39.272	39.353	39.434	520
530	39.434	39.515	39.596	39.677	39.758	39.839	39.920	40.001	40.082	40.163	40.243	530
540	40.243	40.324	40.405	40.486	40.567	40.648	40.729	40.810	40.891	40.972	41.053	540
550	41.053	41.134	41.215	41.296	41.377	41.457	41.538	41.619	41.700	41.781	41.862	550
560	41.862	41.943	42.024	42.105	42.185	42.266	42.347	42.428	42.509	42.590	42.671	560
570	42.671	42.751	42.832	42.913	42.994	43.075	43.156	43.236	43.317	43.398	43.479	570
580	43.479	43.560	43.640	43.721	43.802	43.883	43.963	44.044	44.125	44.206	44.286	580
590	44.286	44.367	44.448	44.529	44.609	44.690	44.771	44.851	44.932	45.013	45.093	590
600	45.093	45.174	45.255	45.335	45.416	45.497	45.577	45.658	45.738	45.819	45.900	600
610	45.900	45.980	46.061	46.141	46.222	46.302	46.383	46.463	46.544	46.624	46.705	610
620	46.705	46.785	46.866	46.946	47.027	47.107	47.188	47.268	47.349	47.429	47.509	620
630	47.509	47.590	47.670	47.751	47.831	47.911	47.992	48.072	48.152	48.233	48.313	630
640	48.313	48.393	48.474	48.554	48.634	48.715	48.795	48.875	48.955	49.035	49.116	640
650	49.116	49.196	49.276	49.356	49.436	49.517	49.597	49.677	49.757	49.837	49.917	650
660	49.917	49.997	50.077	50.157	50.238	50.318	50.398	50.478	50.558	50.638	50.718	660
670	50.718	50.798	50.878	50.958	51.038	51.118	51.197	51.277	51.357	51.437	51.517	670
680	51.517	51.597	51.677	51.757	51.837	51.916	51.996	52.076	52.156	52.236	52.315	680
690	52.315	52.395	52.475	52.555	52.634	52.714	52.794	52.873	52.953	53.033	53.112	690
700	53.112	53.192	53.272	53.351	53.431	53.510	53.590	53.670	53.749	53.829	53.908	700
710	53.908	53.988	54.067	54.147	54.226	54.306	54.385	54.465	54.544	54.624	54.703	710
720	54.703	54.782	54.862	54.941	55.021	55.100	55.179	55.259	55.338	55.417	55.497	720
730	55.497	55.576	55.655	55.734	55.814	55.893	55.972	56.051	56.131	56.210	56.289	730
740	56.289	56.368	56.447	56.526	56.606	56.685	56.764	56.843	56.922	57.001	57.080	740
750	57.080	57.159	57.238	57.317	57.396	57.475	57.554	57.633	57.712	57.791	57.870	750
760	57.870	57.949	58.028	58.107	58.186	58.265	58.343	58.422	58.501	58.580	58.659	760
770	58.659	58.738	58.816	58.895	58.974	59.053	59.131	59.210	59.289	59.367	59.446	770
780	59.446	59.525	59.604	59.682	59.761	59.839	59.918	59.997	60.075	60.154	60.232	780
790	60.232	60.311	60.390	60.468	60.547	60.625	60.704	60.782	60.860	60.939	61.017	790
800	61.017	61.096	61.174	61.253	61.331	61.409	61.488	61.566	61.644	61.723	61.801	800
810	61.801	61.879	61.958	62.036	62.114	62.192	62.271	62.349	62.427	62.505	62.583	810
820	62.583	62.662	62.740	62.818	62.896	62.974	63.052	63.130	63.208	63.286	63.364	820
830	63.364	63.442	63.520	63.598	63.676	63.754	63.832	63.910	63.988	64.066	64.144	830
840	64.144	64.222	64.300	64.377	64.455	64.533	64.611	64.689	64.766	64.844	64.922	840
850	64.922	65.000	65.077	65.155	65.233	65.310	65.388	65.465	65.543	65.621	65.698	850
860	65.698	65.776	65.853	65.931	66.008	66.086	66.163	66.241	66.318	66.396	66.473	860
870	66.473	66.550	66.628	66.705	66.782	66.860	66.937	67.014	67.092	67.169	67.246	870
880	67.246	67.323	67.400	67.478	67.555	67.632	67.709	67.786	67.863	67.940	68.017	880
890	68.017	68.094	68.171	68.248	68.325	68.402	68.479	68.556	68.633	68.710	68.787	890
900	68.787	68.863	68.940	69.017	69.094	69.171	69.247	69.324	69.401	69.477	69.554	900
910	69.554	69.631	69.707	69.784	69.860	69.937	70.013	70.090	70.166	70.243	70.319	910
920	70.319	70.396	70.472	70.548	70.625	70.701	70.777	70.854	70.930	71.006	71.082	920
930	71.082	71.159	71.235	71.311	71.387	71.463	71.539	71.615	71.692	71.768	71.844	930
940	71.844	71.920	71.996	72.072	72.147	72.223	72.299	72.375	72.451	72.527	72.603	940
950	72.603	72.678	72.754	72.830	72.906	72.981	73.057	73.133	73.208	73.284	73.360	950
960	73.360	73.435	73.511	73.586	73.662	73.738	73.813	73.889	73.964	74.040	74.115	960
970	74.115	74.190	74.266	74.341	74.417	74.492	74.567	74.643	74.718	74.793	74.869	970
980	74.869	74.944	75.019	75.095	75.170	75.245	75.320	75.395	75.471	75.546	75.621	980
990	75.621	75.696	75.771	75.847	75.922	75.997	76.072	76.147	76.223	76.298	76.373	990
°C	0	1	2	3	4	5	6	7	8	9	10	°C

Appendix 5: List of Potential Customers

1. Auto Makers
    a. BMW
    b. DCX
    c. Ford
    d. Freightliner
    e. GM
    f. Honda
    g. Hyundai
    h. International
    i. Kenworth
    j. Kia
    k. Nissan
    l. Peterbilt
    m. Toyota
    n. VW
    o. Western

2. Tire Pressure Monitoring System Makers
    a. American Products Company
    b. Beru
    c. Doran Pressure Pro
    d. Entire Solutions
    e. Fleetwood Industries
    f. Freescale
    g. Orange-Electronic
    h. Pacific
    i. Schrader
    j. Smartire

Appendix 6: Number of New Cars Sold Yearly (1986-2004)

EconStatstm Your Best Source for Economic and Financial Data.

New Vehicle Sales by Year and by manufacturer.
Sales in USA only.

SALES
Monthly Sales data. Sources: NADA and EconStatstm
You are at --> **Yearly Sales** data. Sources: NADA (May 2004) and EconStatstm

PRODUCTION
Monthly production data. Sources: US Federal Reserve and EconStatstm
Yearly production data. Sources: US Federal Reserve and EconStatstm

Frequency: yearly
Source: Automotive News
NADA Industry Analysis Division
http://www.nada.org/pdf/ND_TNVD.pdf
file : wauto_a

					New-Vehicle Sales by Manufacturer							
year	new cars	light trucks, (vans, pick-, ups & SUVs)	total	avg retail sell price	Daimler Chrysler	Ford	General Motors	Toyota	Honda	Nissan	Volks-wagen	other imports
2004	7505900	9360600	16866500	$ 28050	2206000	3271100	4657400	2060050	1394400	855000	334050	2088500
2003	7609800	9024900	16634700	$ 27550	2127450	3437700	4716050	1866300	1349850	794800	389100	1953450
2002	8103200	8714300	16817500	$ 26150	2205450	3576250	4815150	1756150	1247850	739850	423850	2052950
2001	8422600	8699300	17121900	$ 25800	2273200	4115600	4852500	1741300	1207600	703700	438900	1989200
2000	8846900	8502800	17349700	$ 24923	2522700	4147700	4911700	1619200	1158900	752800	435900	1800800
1999	8698600	8197200	16895800	$ 24450	2638600	4115600	4974600	1475400	1076900	677900	381500	1555300
1998	8137400	7404500	15541900	$ 23600	2510000	3860200	4570100	1361000	1009600	621600	267200	1342300
1997	8272100	6858100	15130200	$ 22650	2303800	3807100	4734100	1230100	940400	728400	172000	1214400
1996	8526800	6570400	15097200	$ 21900	2450800	3843400	4743600	1159700	843900	749800	163300	1142700
1995	8635000	6093100	14728100	$ 20450	2164300	3801000	4841600	1083400	794600	770300	106600	1166300
1994	8990500	6068100	15058600	$ 19200	2204000	3818100	5015900	1088100	788200	774300	109600	1260400
1993	8517900	5378100	13896000	$ 18200	2047800	3562400	4667000	1033200	717400	687700	62100	1118400
1992	8213100	4647400	12860500	$ 17100	1713000	3192500	4397500	1023600	768800	585500	90600	1089000
1991	8174700	4135300	12310000	$ 16050	1507700	2867400	4319700	1010500	803400	583400	109000	1109000
1990	9300200	4557500	13857700	$ 15900	1698100	3317100	4934300	1058000	854900	621600	157500	1216300
1989	9777400	4763000	14540400	$ 15400	2004000	3579900	5106200	945400	783100	664200	154900	1302700
1988	10453000	4921900	15374900	$ 14100	2208100	3751900	5511400	936000	769000	642500	197200	1359000
1987	10187500	4706200	14893700	$ 13450	2013000	3459800	5213200	932400	738300	742200	243700	1551100
1986	na	na	na	$ 12950								

Appendix 7: Direct Material and Labor Cost

Item	Quantity	Unit Price	
reg - 3V	25000	0.3372	digikey
reg - 5V	25000	0.28175	digikey
cap - 2.2uF	25000	0.045	digikey
cap - 2.2uF	25000	0.045	digikey
cap - 3.3mF	25000	0.1608	digikey
diode	25000	0.0552	digikey
pcb	25000	0.010333	PCB123
coil	25000	0.383972	Paramount Wire Co.
		0.975	
		Material Cost / Wheel	
		5.219255	
		Total Direct Material - 4 Wheels	
		20.87702	

Labor/Overhead	**Work Time / Unit**
$40/hr.	0.25 hrs.

Total Labor Cost / Unit
$10

Appendix 8: Sample Shipping Quote

(from Grand Rapids, MI to Lake Worth, FL)

HOME INSTANT QUOTE MY ACCOUNT TRACK SHIPMENTS SHIPPING PACKAGING FULFILLMENT NEW CUSTOMERS

SHIPMENT SPECIFICATIONS

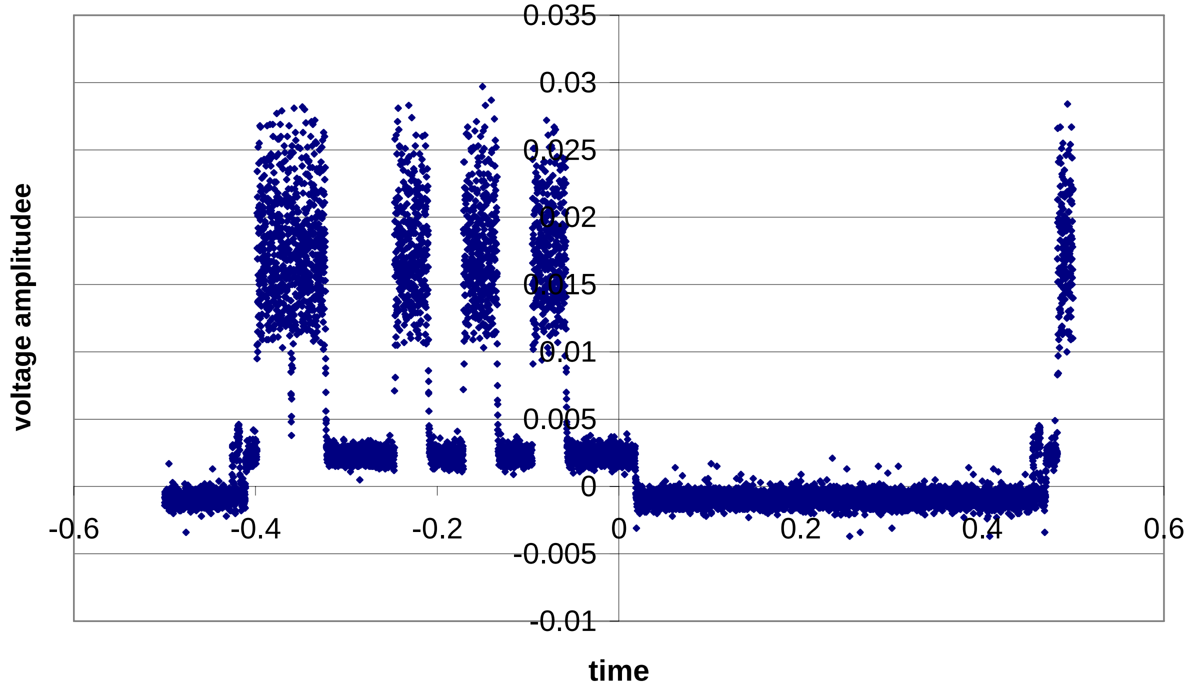
From: Grand Rapids, MI (49506)
To: Lake Worth, FL (33460)
Distance: 1169 Miles

Pieces:	1
Weight:	3500
Dim Weight:	356
Dims:	48" x 48" x 30"
Freight Class:	50 estimated
Declared Value:	None
Shipment Description:	electronics

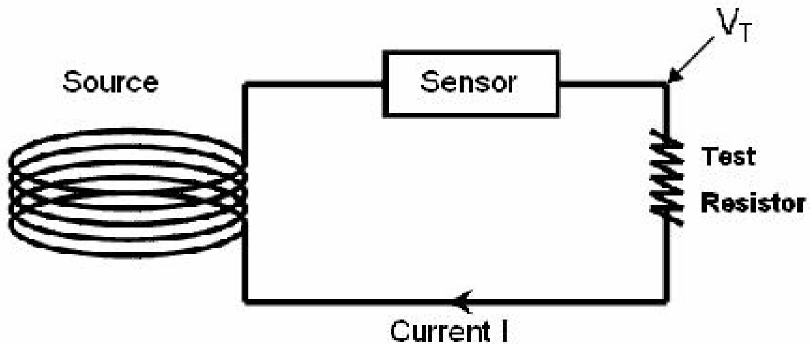
PLEASE SELECT A SERVICE OPTION

Type:	**Transit Time:**	**Base Price:**
Standard LTL	3-7 Days	$1251.65
Three Day Freight	3 Days	$3030.25

Appendix 9 : Test Resistor Power Pulse Period



Appendix 10: Sensor Power Calculations Inferred from Appendix 9



Test Voltage

$$V_T := 0.08760 \cdot V$$

Circuit Current

$$I := \frac{V_T}{99 \cdot ohm} \qquad I = 8.84848 \times 10^{-4} A$$

Sensor Resistance

$$R_{sensor} := \frac{2.995 \cdot V - V_T}{I} \qquad R_{sensor} = 3.286 \times 10^{3} \Omega$$

Power at Each Pulse

$$P_{pulse} := I^2 \cdot R_{sensor} \qquad P_{pulse} = 2.573 \times 10^{-3} W$$

Energy at Each Pulse

$$t_{pulse} := 0.4413 \cdot s$$

$$E_{pulse} := P_{pulse} \cdot t_{pulse} \qquad E_{pulse} = 1.135 \times 10^{-3} J$$

Total Power Consumed

$$t_{period} := 0.8756s$$

$$P_{total} := \frac{E_{pulse}}{t_{period}} \qquad P_{total} = 1.297 \times 10^{-3} W$$

Appendix 11: Raw Power Generation

4/27/2006

Coil Voltage Across 981 Ohms — Test Resistance = 981 Ohms

Motor Speed (%)	Voltage Amplitude (V)	Power Pulse (W)
10	2.1	0.004495413
20	5.5	0.030835882
30	9	0.082568807
40	12	0.146788991
50	16	0.260958206

Coil Voltage Across 99 Ohms — Test Resistance = 99 Ohms

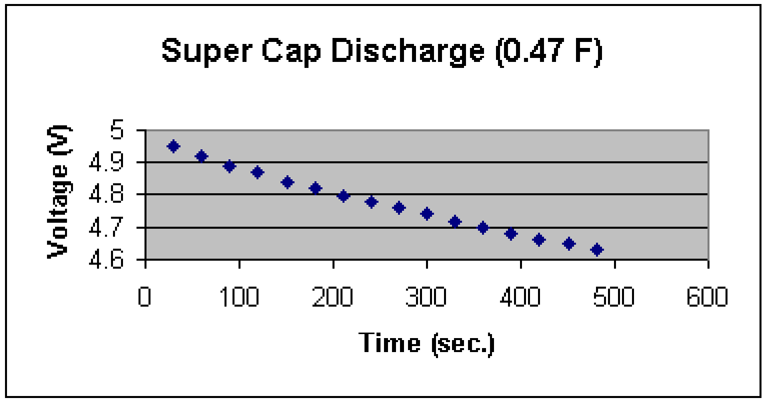
Motor Speed (%)	Voltage Amplitude (V)	Power Pulse (W)
10	1.8	0.032727273
20	5	0.252525253
30	8	0.646464646
40	11.5	1.335858586
50	13	1.707070707

Appendix 12:

Super Capacitor Discharge Test (1)

SuperCap Discharge (0.47F) 3/11/2006
Drained Across 100kOhms

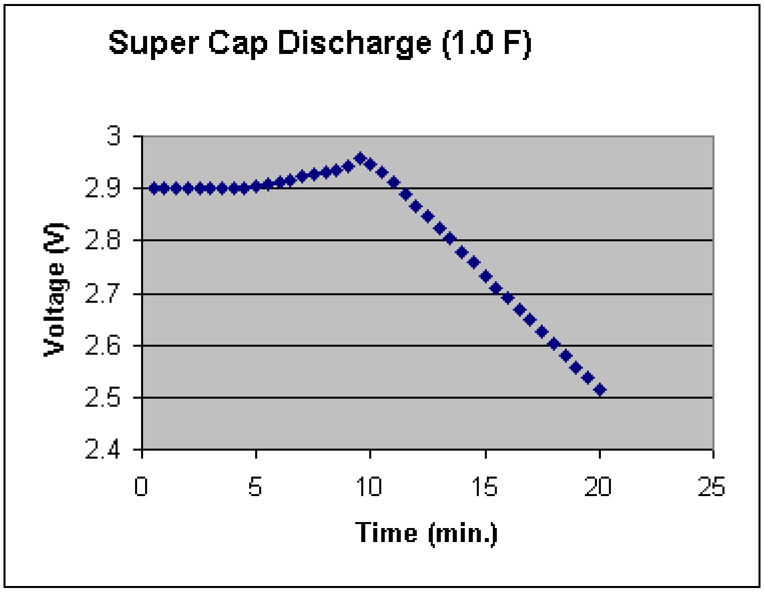
Time (s)	Voltage (V)
30	4.95
60	4.92
90	4.89
120	4.87
150	4.84
180	4.82
210	4.8
240	4.78
270	4.76
300	4.74
330	4.72
360	4.7
390	4.68
420	4.66
450	4.65
480	4.63



Super Capacitor Discharge Test (2)

SuperCap Discharge 2 (0.47F) Drained Across 1kOhm 3/29/2006

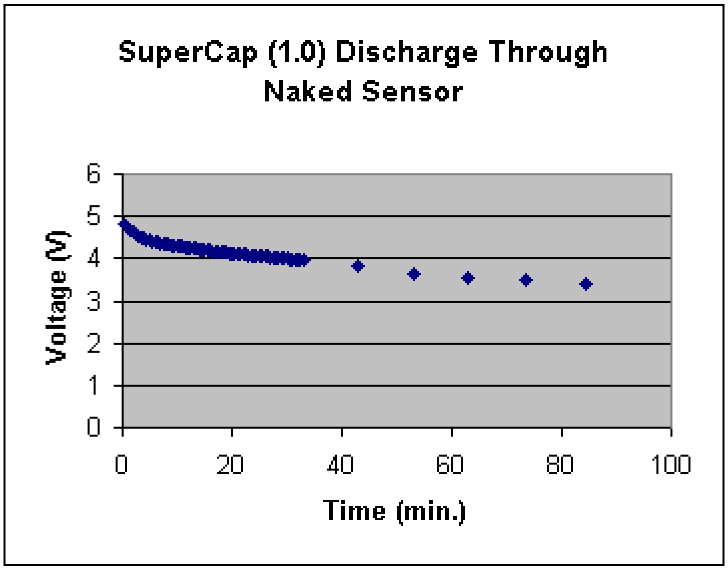
0.5	2.9
1	2.9
1.5	2.9
2	2.899
2.5	2.899
3	2.899
3.5	2.899
4	2.9
4.5	2.901
5	2.905
5.5	2.907
6	2.912
6.5	2.917
7	2.923
7.5	2.928
8	2.932
8.5	2.936
9	2.941
9.5	2.957
10	2.947
10.5	2.93
11	2.911
11.5	2.889
12	2.868
12.5	2.847
13	2.826
13.5	2.804
14	2.78
14.5	2.758
15	2.733
15.5	2.709
16	2.691
16.5	2.669
17	2.647
17.5	2.624
18	2.602
18.5	2.58
19	2.557
19.5	2.536
20	2.515



Super Capacitor Discharge Test (3)

SuperCap Discharge (1.0 F) 4/1/2006
Drained Across Sensor

Time (min.)	Voltage (V)
0.5	4.83
1	4.73
1.5	4.67
2	4.61
2.5	4.56
3	4.52
3.5	4.49
4	4.47
4.5	4.45
5	4.43
5.5	4.41
6	4.4
6.5	4.38
7	4.37
7.5	4.35
8	4.34
8.5	4.33
9	4.32
9.5	4.31
10	4.3
10.5	4.29
11	4.28
11.5	4.27
12	4.26
12.5	4.25
13	4.24
13.5	4.23
14	4.22
14.5	4.21
15	4.2
15.5	4.19
16	4.19
16.5	4.18
17	4.17
17.5	4.16
18	4.15
18.5	4.14
19	4.14
19.5	4.13
20	4.12
20.5	4.12
21	4.11

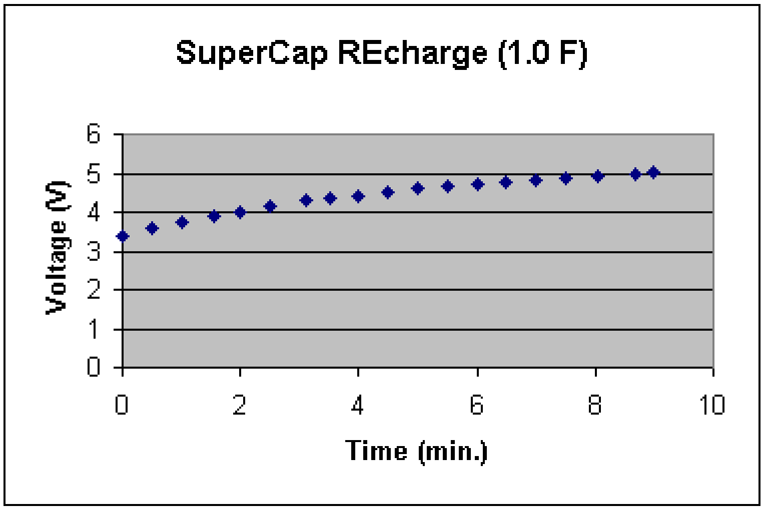


21.5	4.1
22	4.1
22.5	4.09
23	4.08
23.5	4.08
24	4.07
24.5	4.06
25	4.06
25.5	4.05
26	4.05
26.5	4.04
27	4.03
27.5	4.03
28	4.02
28.5	4.01
29	4.01
29.5	4
30	4
30.5	3.99
31	3.99
31.5	3.98
32	3.98
32.5	3.97
33	3.96
43	3.82
53	3.64
63	3.56
73.5	3.48
84.5	3.39

Super Capacitor Recharge Test (4)

SuperCap Recharge (1.0 F), 500 turn coil, 2 sets of 2 magnets stacked

Time (min.)	Voltage(V)
0	3.36
0.5	3.59
1	3.75
1.5666	3.91
2	4.02
2.5	4.14
3.1	4.29
3.5	4.34
4	4.42
4.5	4.51
5	4.59
5.5	4.65
6	4.72
6.5	4.78
7	4.84
7.5	4.89
8.05	4.94
8.666	4.99
9	5.02



Appendix 13: Supercapacitor Pricing

		Price Break	Unit Price	Price
Digi-Key Part Number	283-2498-ND	1	6.24000	6.24
Manufacturer Part Number	A1020-2R5105	10	4.56000	45.60
Description	CAPACITOR 1.0F 2.5V RAD AEROGEL	100	3.72000	372.00
Quantity Available	294	250	3.48000	870.00
		500	3.36000	1680.00
		1000	3.30000	3300.00
		2500	3.12000	7800.00
		5000	3.00000	15000.00
		10000	2.94000	29400.00
All prices are in US dollars				

		Price Break	Unit Price	Price
Digi-Key Part Number	283-2497-ND	1	4.48000	4.48
Manufacturer Part Number	A0820-2R5474	10	3.12000	31.20
Description	CAPACITOR .47F 2.5V RAD AEROGEL	100	2.56000	256.00
Quantity Available	107	250	2.40000	600.00
		500	2.28000	1140.00
		1000	2.24000	2240.00
		2500	2.12000	5300.00
		5000	2.04000	10200.00
		10000	2.00000	20000.00
All prices are in US dollars				

Appendix 14: Electrolytic Capacitor Pricing

Digi-Key Part Number	565-1651-ND	**Price Break**	**Unit Price**	**Price**
Manufacturer Part Number	EKZE100ELL332MK25S	1	0.57000	0.57
		10	0.42300	4.23
Description	CAP 3300UF 10V ELECT KZE RAD	100	0.31080	31.08
		1000	0.17854	178.54
		5000	0.17193	859.63
Quantity Available	168	10000	0.16531	1653.13
All prices are in US dollars				

Digi-Key Part Number	565-1635-ND	**Price Break**	**Unit Price**	**Price**
Manufacturer Part Number	EKZE6R3ELL332MK20S	1	0.49000	0.49
		10	0.36100	3.61
Description	CAP 3300UF 6.3V ELECT KZE RAD	100	0.25820	25.82
		1000	0.14458	144.58
		5000	0.13425	671.26
Quantity Available	1581	10000	0.12909	1290.88
All prices are in US dollars				

Digi-Key Part Number	565-1670-ND	**Price Break**	**Unit Price**	**Price**
Manufacturer Part Number	EKZE160ELL332MK35S	1	0.67000	0.67
		10	0.49900	4.99
Description	CAP 3300UF 16V ELECT KZE RAD	100	0.36660	36.66
		1000	0.21061	210.61
		5000	0.20281	1014.07
Quantity Available	2771	10000	0.19501	1950.13
All prices are in US dollars				

Appendix 15:

Electrolytic Capacitor Discharge Test (1)

Capacitor Testing (sensor load) 4/19/2006

Letter Code	Capacitor Capacitance	Voltage Rating	Charge Time (0-5V) sec.	Discharge Time Through Sensor Load (5-3V)
lxz	6800uF	6.3	14	23
			13	20
lxz	3300uF	16	11	12
			10	12
kze	5600uF	10	12	17
			11	16
lxz	12000uF	10	18	37
			18	36
kze	1200uF	10	10	5
			9	5
kze	3300uF	10	10	11
			10	11
lxz	3300uF	6.3	11	11
			10	12
kze	3300uF	6.3	11	11
			10	11
lxz	1500uF	10	9	6
			9	7
kze	1500uF	6.3	10	6
			9	6
lxz	3300uF	10	10	12
			10	12
kze	1000uF	6.3	10	4
			9	4
lxz	1200uF	6.3	9	4
			9	5
lxz	1500uF	16	10	5
			9	6
kze	6800uF	6.3	12	19
			12	19
lxz	820uF	6.3	9	3
			9	4
kze	1000uF	16	9	4
			9	4
kze	3900uF	16	10	12
			10	13
lxz	6800uF	10	12	19
			12	20
lxz	15000uF	6.3	21	41
			21	43

Electrolytic Capacitor Discharge Test (2)

Capacitor Testing 4/18/2006

Letter Code	Capacitor Capacitance	Voltage Rating	Charge Time (0 - 5V) (sec.)	Discharge Time Through 100Ohm Load (5-3V) (sec.)
lxz	6800uF	10V	13	79
lxz	15000uF	6.3V	21	185
kze	3900uF	16V	12	52
kze	6800uF	6.3V	14	79
lxz	1500uF	16V	10	21
lxz	820uF	6.3V	10	13
kze	1000uF	16V	10	14
kze	1000uF	6.3V	10	15
lxz	1200uF	6.3V	11	17
surface mount	3300uF	10V	11	40

Electrolytic Capacitor Discharge Test (3)

Capacitor Testing 4/17/2006

Letter Code	Capacitor Capacitance	Voltage Rating	Charge Time (0 - 5V)	Discharge Time Through 100Ohm Load (5-3V)
kze	3300uF	10V	25sec	44sec
kze	3300uF	6.3V	29sec	42sec
kze	5600uF	10V	18sec	62sec
kze	1200uF	10V	13sec	18sec
lxz	1500uF	6.3V	13sec	22sec
lxz	6800uF	6.3V	17sec	84sec
lxz	12000uF	10V	22sec	144sec
lxz	1500uF	10V	13sec	21sec
lxz	3300uF	16V	14sec	43sec
lxz	3300uF	6.3V	14sec	46sec
	3300uF	10V	14sec	43sec

Appendix 16: Motor Speed Test

Motor Speed Test with Tire On 5/2/2006

Motor Speed (%)	RPM	MPH
20	246	18.6
25	313	23.7
30	393	29.8
35	464	35.2
40	551	41.7
45	626	47.4
50	694	52.6

Appendix 17: Voltage Regulator Input/Output Test

Voltage Regulator Test (input-output) 5/2/2006

5V Regulator

Vin	Vout
0.5	0
1	0.01
1.51	1.49
2.01	1.99
2.51	2.49
3.01	3
3.52	3.5
4.02	4.01
4.52	4.5
5.03	4.98
5.08	5
1	0.01
0.5	0

3V Regulator

Vin	Vout
0.5	0
1	0.01
1.5	1.48
2	1.98
2.51	2.49
3.01	2.97
3.07	2.99
1	0.01

Appendix 18: Sensor Power Pulse Test

Tests 1, 2, 3, 4 under low pressure (<15psi)
Test 5 under high pressure (>20psi)

Test 1

Time (sec.)	Event
0	flatline
50	pulse

Test 2

Time (sec.)	Event
0	flatline
50	pulse once
105	pulse again
135	pulse continuous

Test 3

Time (sec.)	Event
0	flatline
50	pulse once
105	pulse again
135	pulse continuous
362	flatline

Test 4

Time (sec.)	Event
0	flatline
48	pulse
102	pulse
158	pulse
213	pulse
267	pulse
321	pulse
376	pulse

Test 5

Time (min.)	Event
6.38	pusle continuous
10.24	flatline
10.42	pulse continuous
14.32	flatline
14.45	pulse continuous
18.34	flatline
18.46	pulse continuous

Appendix 19 - Financial Forecast Documents:

Team 8 : QMKD Inc.
2007 Balance Sheet
For Each Month

	January	February	March	April	May	June	July	August	September	October	November	December
Assets												
Current assets:												
Cash	$ 10,000	$ 10,000	$ 10,000	$ 10,000	$ 10,000	$ 10,000	$ 10,000	$ 10,000	$ 10,000	$ 10,000	$ 10,000	$ 10,000
Accounts receivable	130,000	130,000	130,000	130,000	130,000	130,000	130,000	130,000	130,000	130,000	130,000	130,000
Office Supplies	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000
Inventories	44,900	44,900	44,900	44,900	44,900	44,900	44,900	44,900	44,900	44,900	44,900	44,900
Total current assets	186,900	186,900	186,900	186,900	186,900	186,900	186,900	186,900	186,900	186,900	186,900	186,900
Property, plant, and equipment:												
Equipment	12,000	12,000	12,000	12,000	12,000	12,000	12,000	12,000	12,000	12,000	12,000	12,000
Furniture & Fixtures	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000
Less: Accumulated depreciation	(142)	(284)	(426)	(568)	(710)	(852)	(994)	(1,136)	(1,278)	(1,420)	(1,562)	(1,704)
Net property, plant, and equipment	16,858	16,716	16,574	16,432	16,290	16,148	16,006	15,864	15,722	15,580	15,438	15,296
Total assets	$ 203,758	$ 203,616	$ 203,474	$ 203,332	$ 203,190	$ 203,048	$ 202,906	$ 202,764	$ 202,622	$ 202,480	$ 202,338	$ 202,196
Liabilities and Shareholders' Equity												
Current liabilities:												
Accounts payable	$ 120,000	$ 120,000	$ 120,000	$ 120,000	$ 120,000	$ 120,000	$ 120,000	$ 120,000	$ 120,000	$ 120,000	$ 120,000	$ 120,000
Wages & Salary Payable	9,840	9,840	9,840	9,840	9,840	9,840	9,840	9,840	9,840	9,840	9,840	9,840
Notes payable-line of credit	38,500	56,940	75,380	93,820	112,260	130,700	149,140	167,580	186,020	204,460	222,900	241,340
Total current liabilities	168,340	186,780	205,220	223,660	242,100	260,540	278,980	297,420	315,860	334,300	352,740	371,180
Long-term liabilities:												
Notes payable	-	-	-	-	-	-	-	-	-	-	-	-
Total long-term liabilities	-	-	-	-	-	-	-	-	-	-	-	-
Shareholders' equity:												
Additional Paid-in Capital	54,000	54,000	54,000	54,000	54,000	54,000	54,000	54,000	54,000	54,000	54,000	54,000
Retained earnings	(18,582)	(37,164)	(55,746)	(74,328)	(92,910)	(111,492)	(130,074)	(148,656)	(167,238)	(185,820)	(204,402)	(222,984)
Total shareholders' equity	35,418	16,836	(1,746)	(20,328)	(38,910)	(57,492)	(76,074)	(94,656)	(113,238)	(131,820)	(150,402)	(168,984)
Total liabilities and shareholders' equity	$ 203,758	$ 203,616	$ 203,474	$ 203,332	$ 203,190	$ 203,048	$ 202,906	$ 202,764	$ 202,622	$ 202,480	$ 202,338	$ 202,196

Team 8 : QMKD Inc.
2008 Balance Sheet
For Each Quarter

	March	June	September	December
Assets				
Current assets:				
Cash	$ 10,000	$ 10,000	$ 10,000	$ 10,000
Accounts receivable	140,000	140,000	140,000	140,000
Office Supplies	2,000	2,000	2,000	2,000
Inventories	44,900	44,900	44,900	44,900
Total current assets	196,900	196,900	196,900	196,900
Property, plant, and equipment:				
Equipment	5,000	5,000	5,000	5,000
Furniture & Fixtures	12,000	12,000	12,000	12,000
Less: Accumulated depreciation	(2,130)	(2,556)	(2,982)	(3,408)
Net property, plant, and equipment				
Total assets	$ 211,770	$ 211,344	$ 210,918	$ 210,492
Liabilities and Shareholders' Equity				
Current liabilities:				
Accounts payable	$ 120,000	$ 120,000	$ 120,000	$ 120,000
Wages & Salary Payable	9,840	9,840	9,840	9,840
Notes payable	321,412	337,484	353,556	369,628
Total current liabilities	451,252	467,324	483,396	499,468
Long-term liabilities:				
Notes payable	0	0	0	0
Total long-term liabilities				
Shareholders' equity:				
Additional Paid-in Capital	54,000	54,000	54,000	54,000
Retained earnings	(239,482)	(255,980)	(272,478)	(288,976)
Total shareholders' equity	(185,482)	(201,980)	(218,478)	(234,976)
Total liabilities and shareholders' equity	$ 211,770	$ 211,344	$ 210,918	$ 210,492

Team 8 : QMKD Inc.
2009 Balance Sheet
For Each Quater Ending

	March	June	September	December
Assets				
Current assets:				
Cash	$ 10,000	$ 10,000	$ 10,000	$ 10,000
Accounts receivable	150,000	150,000	150,000	150,000
Office Supplies	2,000	2,000	2,000	2,000
Inventories	50,000	50,000	50,000	50,000
Total current assets	212,000	212,000	212,000	212,000
Property, plant, and equipment:				
Equipment	5,000	5,000	5,000	5,000
Furniture & Fixtures	12,000	12,000	12,000	12,000
Less: Accumulated depreciation	(3,834)	(4,260)	(4,686)	(5,112)
Net property, plant, and equipment				
Total assets	$ 225,166	$ 224,740	$ 224,314	$ 223,888
Liabilities and Shareholders' Equity				
Current liabilities:				
Accounts payable	$ 120,000	$ 120,000	$ 120,000	$ 120,000
Wages & Salary Payable	9,840	9,840	9,840	9,840
Notes payable	313,718	296,810	279,902	262,994
Total current liabilities	443,558	426,650	409,742	392,834
Long-term liabilities:				
Notes payable	0	0	0	0
Total long-term liabilities	0	0	0	0
Shareholders' equity:				
Additional Paid-in Capital	54,000	54,000	54,000	54,000
Retained earnings	(272,392)	(255,910)	(239,428)	(222,946)
Total shareholders' equity	(218,392)	(201,910)	(185,428)	(168,946)
Total liabilities and shareholders' equity	$ 225,166	$ 224,740	$ 224,314	$ 223,888

2007 Budgeted Income Statement
For Each Month

	January	February	March	April	May	June	July	August	September	October	November	December	Total
Sales	$ 260,000	$ 260,000	$ 260,000	$ 260,000	$ 260,000	$ 260,000	$ 260,000	$ 260,000	$ 260,000	$ 260,000	$ 260,000	$ 260,000	$ 3,120,000
Cost of goods sold													
Materials	(228,800)	(228,800)	(228,800)	(228,800)	(228,800)	(228,800)	(228,800)	(228,800)	(228,800)	(228,800)	(228,800)	(228,800)	(2,745,600)
Labor	(4,680)	(4,680)	(4,680)	(4,680)	(4,680)	(4,680)	(4,680)	(4,680)	(4,680)	(4,680)	(4,680)	(4,680)	(56,160)
Gross Margin	26,520	26,520	26,520	26,520	26,520	26,520	26,520	26,520	26,520	26,520	26,520	26,520	318,240
Expenses													0
Bad debt	(260)	(260)	(260)	(260)	(260)	(260)	(260)	(260)	(260)	(260)	(260)	(260)	(3,120)
Rent	(20,000)	(20,000)	(20,000)	(20,000)	(20,000)	(20,000)	(20,000)	(20,000)	(20,000)	(20,000)	(20,000)	(20,000)	(240,000)
Depreciation	(142)	(142)	(142)	(142)	(142)	(142)	(142)	(142)	(142)	(142)	(142)	(142)	(1,704)
Equipment lease	(7,500)	(7,500)	(7,500)	(7,500)	(7,500)	(7,500)	(7,500)	(7,500)	(7,500)	(7,500)	(7,500)	(7,500)	(90,000)
Utilities	(2,200)	(2,200)	(2,200)	(2,200)	(2,200)	(2,200)	(2,200)	(2,200)	(2,200)	(2,200)	(2,200)	(2,200)	(26,400)
Salaries	(15,000)	(15,000)	(15,000)	(15,000)	(15,000)	(15,000)	(15,000)	(15,000)	(15,000)	(15,000)	(15,000)	(15,000)	(180,000)
Income from operations	(18,582)	(18,582)	(18,582)	(18,582)	(18,582)	(18,582)	(18,582)	(18,582)	(18,582)	(18,582)	(18,582)	(18,582)	(222,984)
Income taxes	0	0	0	0	0	0	0	0	0	0	0	0	0
Net income	$ (18,582)	$ (18,582)	$ (18,582)	$ (18,582)	$ (18,582)	$ (18,582)	$ (18,582)	$ (18,582)	$ (18,582)	$ (18,582)	$ (18,582)	$ (18,582)	$ (222,984)

2008 Budgeted Income Statement
For Each Month

	March	June	September	December	Total
Sales	$1,170,000	$1,170,000	$1,170,000	$1,170,000	$4,680,000
Cost of goods sold					
Materials	(1,029,600)	(1,029,600)	(1,029,600)	(1,029,600)	(4,118,400)
Labor	(21,060)	(21,060)	(21,060)	(21,060)	(84,240)
Gross Margin	119,340	119,340	119,340	119,340	477,360
Expenses					
Bad debt	(1,170)	(1,170)	(1,170)	(1,170)	(4,680)
Rent	(60,000)	(60,000)	(60,000)	(60,000)	(240,000)
Depreciation	(568)	(568)	(568)	(568)	(2,272)
Equipment lease	(22,500)	(22,500)	(22,500)	(22,500)	(90,000)
Utilities	(6,600)	(6,600)	(6,600)	(6,600)	(26,400)
Salaries	(45,000)	(45,000)	(45,000)	(45,000)	(180,000)
Income from operations	(16,498)	(16,498)	(16,498)	(16,498)	(65,992)
Income taxes	-	-	-	-	-
Net income	$ (16,498)	$ (16,498)	$ (16,498)	$ (16,498)	$ (65,992)

2009 Budgeted Income Statement
For Each Month

	March	June	September	December	Total
Sales	$1,560,000	$1,560,000	$1,560,000	$1,560,000	$6,240,000
Cost of goods sold					
Materials	(1,372,800)	(1,372,800)	(1,372,800)	(1,372,800)	(5,491,200)
Labor	(28,080)	(28,080)	(28,080)	(28,080)	(112,320)
Gross Margin	159,120	159,120	159,120	159,120	636,480
Expenses					
Bad debt	(1,560)	(1,560)	(1,560)	(1,560)	(6,240)
Rent	(60,000)	(60,000)	(60,000)	(60,000)	(240,000)
Depreciation	(426)	(426)	(426)	(426)	(1,704)
Equipment lease	(22,500)	(22,500)	(22,500)	(22,500)	(90,000)
Utilities	(6,600)	(6,600)	(6,600)	(6,600)	(26,400)
Salaries	(45,000)	(45,000)	(45,000)	(45,000)	(180,000)
Income from operations	23,034	23,034	23,034	23,034	92,136
Income taxes	(6,450)	(6,450)	(6,450)	(6,450)	(25,798)
Net income	$ 16,584	$ 16,584	$ 16,584	$ 16,584	$ 66,338

QMKD Company
2007 Statement of Cash Flows
For Each Month

	January	February	March	April	May	June	July	August	September	October	November	December	Total
Cash Flows from Operative Activities													
Net income	$ (18,582)	$ (18,582)	$ (18,582)	$ (18,582)	$ (18,582)	$ (18,582)	$ (18,582)	$ (18,582)	$ (18,582)	$ (18,582)	$ (18,582)	$ (18,582)	$ (222,984)
Adjustments to reconcile net income to cash provided by operating activities:													
Depreciation and amortization	(142)	(142)	(142)	(142)	(142)	(142)	(142)	(142)	(142)	(142)	(142)	(142)	(1,704)
Provision for uncollectible accounts	(260)	(260)	(260)	(260)	(260)	(260)	(260)	(260)	(260)	(260)	(260)	(260)	(3,120)
Changes in operating assets and liabilities													
(Increase) decrease in receivables	(130,000)	-	-	-	-	-	-	-	-	-	-	-	(130,000)
(Increase) decrease in other current assets	(66,900)	-	-	-	-	-	-	-	-	-	-	-	(66,900)
Increase in accounts payable and other operating liabilities	129,840	-	-	-	-	-		-	-	-	-	-	129,840
Net cash provided by operating activites	(76,044)	(18,984)	(18,984)	(18,984)	(18,984)	(18,984)	(18,984)	(18,984)	(18,984)	(18,984)	(18,984)	(18,984)	(284,868)
Cash Flows from Investing Activities													
Purchase of equipment	(17,000)	-	-	-	-	-	-	-	-	-	-	-	(17,000)
Sale of equipment	-												
Net cash outflows from investing activities	-												
Cash Flows from Financing Activities													
Proceeds from note payable	38,500	18,440	18,440	18,440	18,440	18,440	18,440	18,440	18,440	18,440	18,440	18,440	241,340
Principle payment on n/p	-	-	-	-	-	-	-	-	-	-	-	-	-
Issuance of common stock	-	-	-	-	-	-	-	-	-	-	-	-	-
Net cash inflows from financing activities	38,500	18,440	18,440	18,440	18,440	18,440	18,440	18,440	18,440	18,440	18,440	18,440	241,340
Net cash increase (decrease) in cash	(37,543.67)	(544.00)	(544.00)	(544.00)	(544.00)	(544.00)	(544.00)	(544.00)	(544.00)	(544.00)	(544.00)	(544.00)	(43,527.67)
Adjustment for incorrect COGS													
Cash and Cash Equivalents at Month Start	-	(37,544)	(38,088)	(38,632)	(39,176)	(39,720)	(40,264)	(40,808)	(41,352)	(41,896)	(42,440)	(42,984)	
Cash and Cash Equivalents at Month End	(37,544)	(38,088)	(38,632)	(39,176)	(39,720)	(40,264)	(40,808)	(41,352)	(41,896)	(42,440)	(42,984)	(43,528)	$ (43,528)

QMKD Inc.
2008 Statement of Cash Flows
For Each Month

	March	June	September	December	Total
Cash Flows from Operative Activities					
Net income	$ (16,498)	$ (16,498)	$ (16,498)	$ (16,498)	$ (65,992.00)
Adjustments to reconcile net income to cash provided by operating activites:					
Depreciation	568	568	568	568	2,272
Provision for uncollectible accounts	1,170	1,170	1,170	1,170	4,680
Changes in operating assets and liabilities					
(Increase) decrease in receivables	(10,000)	-	-	-	(10,000)
(Increase) decrease in other current assets	-	-	-	-	-
Increase in accounts payable and other operating liabilities	-	-	-	-	-
Cash provided by operating activites	(24,760)	(14,760)	(14,760)	(14,760)	(69,040)
Cash Flows from Investing Activities					
Purchase of equipment	-	-	-	-	-
Sale of equipment	-	-	-	-	-
Net cash outflows from investing activities	-	-	-	-	-
Cash Flows from Financing Activities					
Proceeds from note payable	80,072	16,072	16,072	16,072	128,288
Principle payment on n/p	-	-	-	-	-
Issuance of common stock	-	-	-	-	-
Payment of dividends	-	-	-	-	-
Net cash inflows from financing activities	80,072	16,072	16,072	16,072	128,288
Net cash increase (decrease) in cash	55,312	1,312	1,312	1,312	59,248
Cash and Cash Equivalents at Quarter Start	(43,528)	11,784	13,096	14,408	15,720
Cash and Cash Equivalents at Quarter End	11,784	13,096	14,408	15,720	15,720

QMKD Inc.
2008 Statement of Cash Flows
For Each Month

	March	June	September	December	Total
Cash Flows from Operative Activities					
Net income	$ (16,584)	$ (16,584)	$ (16,584)	$ (16,584)	$ (66,336)
Adjustments to reconcile net income to cash provided by operating activites:					
Depreciation	426	426	426	426	1,704
Provision for uncollectible accounts	1,560	1,560	1,560	1,560	6,240
Changes in operating assets and liabilities					
(Increase) decrease in receivables	(10,000)	-	-	-	(10,000)
(Increase) decrease in other current assets	-	-	-	-	-
Increase in accounts payable and other operating liabilities	-	-	-	-	-
Cash provided by operating activites	(24,598)	(14,598)	(14,598)	(14,598)	(68,392)
Cash Flows from Investing Activities					
Purchase of equipment	-	-	-	-	-
Sale of equipment	-	-	-	-	-
Net cash outflows from investing activities	-	-	-	-	-
Cash Flows from Financing Activities					
Proceeds from note payable	(55,911)	(16,908)	(16,908)	(16,908)	(106,635)
Principle payment on n/p	-	-	-	-	-
Issuance of common stock	-	-	-	-	-
Payment of dividends	-	-	-	-	-
Net cash inflows from financing activities	(55,911)	(16,908)	(16,908)	(16,908)	(106,635)
Net cash increase (decrease) in cash	(80,509)	(31,506)	(31,506)	(31,506)	(175,027)
Cash and Cash Equivalents at Month Start	15,720	(64,788)	(96,294)	(127,800)	(159,306)
Cash and Cash Equivalents at Month End	(64,788)	(96,294)	(127,800)	(159,306)	(159,306)

Tire Pressure Sensor Power System
Break Even Analysis

1. Projected Sales

Lowest estimate number of car sales per year	**12,000,000**	**cars**
Percentage of cars that will require	**65**	**%**
Percentage of the market we will permeate in year 1	**2**	**%**
Percentage of the market we will permeate in year 2	**3**	**%**
Percentage of the market we will permeate in year 3	**4**	**%**
Number of tire pressure sensor power system per car	**4**	**units**
Number of tire pressure sensor power systems we will power in year 1	**624,000**	**units**
Number of tire pressure sensor power systems we will power in year 2	**936,000**	**units**
Number of tire pressure sensor power systems we will power in year 3	**1,248,000**	**units**

2. Variable Cost per unit

Direct Materials (per unit)

Coil	$	0.10	
Magnet		0.50	
Capacitor		2.00	
Printed circuit board (PCB)		0.70	
Diode		0.10	
Bracket		1.00	
Total	$	4.40	

Direct Labor (per unit)

120 units produced per hour
labor costs: $10.80 per hour

Direct labor cost per unit	$	0.09	
Total Direct Costs per unit			$ 4.49

3. Break even analysis

Variable Costs	+ Fixed Costs	=	Sales
4.49x	541,224	=	5x

541224 = .51x

1061224 = x

Break even point for year 1 : 1,061224 units

Ratio Analysis for QMKD Inc.

Liquidity Ratios		2007	2008	2009
Current Ratio	current assets / current liabilities	0.50	0.39	0.54
Quick Ratio	Quick assets / Current liabilities	0.50	0.30	0.41
Financing Ratios				
Debt to equity ratio	total liabilities / shareholder's equity	(2.20)	(2.13)	(2.33)
Activity Ratios				
Receivables turnover ratio	net sales / accounts receivable	24.00	33.43	41.60
Inventory turnover ratio	cost of goods sold / inventory	62.40	93.60	112.07
Asset turnover ratio	net sales / total assets	15.43	22.23	27.87
Average collection period	365 / receivables turnover ratio	15.21 days	10.92 days	8.77 days
Average days in inventory	365 / Inventory turnover ratio	5.85 days	3.90 days	3.26 days
Profitability ratios				
Profit margin on sales	net income / net sales	(0.07)	(0.01)	0.01
Return on assets	net income / total assets	(1.10)	(0.31)	0.30
Return on Shareholder's Equity	net income / shareholder's equity	1.32	0.28	(0.39)