Real Time Automotive Battery Monitoring System

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Executive Summary

The battery monitoring system developed is used to prevent people from being stranded. This device makes sure that no matter what, a car will be able to start and that a person will not be left with a dead battery. This report is about the Features and Specifications related to the battery monitoring system. Next the hardware circuitry will be discussed including, project flow, hardware components, implementing circuit in PSpice, and the circuit on a bread board. Following will be the verification, testing and analysis of the hardware and concepts. Finally, the cost and price estimation will be discussed. The conclusion will state our results and completely explain the project.

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Introduction

The purpose of the Real Time Automotive Battery Monitoring System is to prevent the discharge of a car battery beyond the point of restarting the car. This is a common issue that can leave a person stranded and highly inconvenienced. Also, draining a battery drastically reduces the life of a car battery. Cars run on lead-acid batteries and so disposal of them is very bad for the environment. It is also costly and time-consuming to get a battery replaced. Finally, running on a bad battery can reduce the life span of the car's alternator. In general, there are many costs and inconveniences that arise from discharging a car battery. The Battery Monitoring System is a cheap, simple-to-install and easy-to-use device that solves this issue effectively.

Features

The real time battery monitoring system (BMS) has the ability to monitor a car's battery and disconnect it from the car before it is completely discharges. The BMS prevents a user from draining a car battery beyond the point of not being able to restart the engine. After the BMS is activated the user is able to determine if the system is active by an indicator light. With the use of an override switch, the user can switch the BMS on and off. This option will provide access to the car battery directly after the BMS is activated. If the battery is discharged to approximately 11.8V +/- 0.15V, the BMS system will activate and it will disconnect the battery from discharging.

Specification

The input voltage is 3V to 15V. At 12V, the device dissipates 36mW. When the voltage reaches 11.8V, it activates the relay which opens the circuit to the battery from the car. This operation will vary between 12.05V to 11.65V. Although the relay is designed to handle only 10A, it can handle up to 13A. This accounts for running multiple devices in the car. The device is overridden by the user disabling switch which reconnects the vehicle with the rest of the car.

Equations and Calculations

The LM385 is used to maintain the reference voltage at 2.5V. The equation provided by National Semiconductor's datasheet for the LM385 was used to acquire this value.

$$V = 1.24\left(\frac{R_3}{R_2} + 1\right)$$
$$2.5 = 1.24\left(\frac{10k}{R_2} + 1\right) \qquad \text{Equation 1}$$
$$R_2 = 16k\Omega$$

2.5V was used to indicate the 11.8V. In order to do this, the voltage across the battery was needed to be stepped down in a manner that the voltage at 11.8V would be seen by the device as 2.5V. This was done through the voltage drop across the resistor at the output of the second LM324 operational amplifier. A diode was placed at this point to measure the current to find an appropriate resistor value. The current, when the voltage on the battery was 12V, measured at this node going into the amplifier was 0.698mA with a voltage drop of 1.815V. Using Ohm's Law

$$R = \frac{V}{I}$$
$$R = \frac{1.815V}{0.698mA} \qquad \text{Equation 2}$$
$$R = 2.61k\Omega$$

we see that the resistor value should be 2.61kΩ. Additionally, this gives the final reference stage for the comparator that is connected to the control relay. The voltage drop across that resistor was 1.55V when the voltage was at the critical voltage, 11.8V, which needed to be associated to the 1.55V. A simple voltage divider across the battery terminals compares the voltage of the battery to the reference voltage. To find the correct divider network, we use ratios.

$$\frac{2.62V - 1.23V}{2.78V} = .536 \qquad \text{Equation 3}$$

This value gives us the percentage voltage that the divider needs to provide. Establishing that the total value of the divider network is 100kΩ, the lower resistor yields 53.6kΩ and the upper resistor is 46.4kΩ.

Hardware Circuitry

Hardware Components:

The real time battery monitoring system consists of several components that are collaborated together. The device interrupts the 12V connection from the battery to the car with a 10A relay. This is to open or close the connection from the battery to the car. The BMS consists of one LM385 voltage regulator diode, one LM324 low power quad operational amplifier, one 10K potentiometer, nine high precision 1/8W resistors, one SPDT 10A relay, three LEDs, one LM741 operational amplifier, and one SPST sliding switch.

To monitor the voltage across the battery, it is stepped down by a voltage divider network. A reference voltage is created by a zener diode buffered by another LM324 operational amplifier. Another LM324 amplifier is used to buffer the signal further, which is connected to a resistor. The voltage drop across this resistor is the reference in which the divider network is compared to. The output of this comparator is connected to the control of the relay. When the voltage drops to the critical level, approximately 11.8V, it deactivates the relay which opens the connection to the car via the relay.

The components and the specifications are as follows:

The LM385 is used to provide fixed voltage tolerance. The LM385 uses only transistors and resistors. As a result, it has a capability of low noise and good long term stability result. The wide dynamic operating range allows its use with widely varying supplies with excellent regulation of voltage. The exceptionally low power drain of the LM385 makes it useful for micro power circuitry. This voltage reference can be used to make portable meters, regulators or general purpose analog circuitry with battery life approaching shelf life. The broad range operating current allows it to substitute older references with a small precision tolerance part.

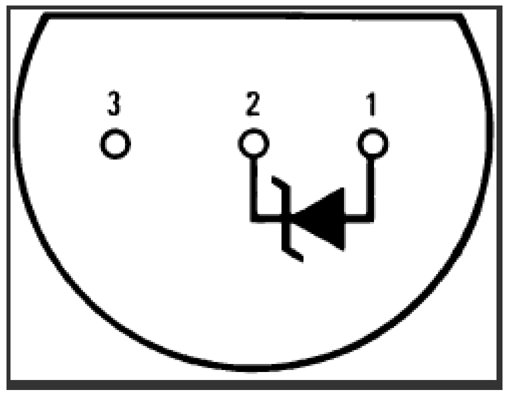

Figure 1 LM385

Spec of LM385

- ±1% and 2% initial tolerance
- Operating current of 10µA to 20mA
- 1Ω dynamic impedance
- Low temperature coefficient
- Low voltage reference—1.235V
- 2.5V device and adjustable device also available
- High temperature resistance 0°C to 70°C (National Semiconductor Corporation)

The LM324 consists of three independent, high gain internally frequency compensated operational amplifiers. These are designed exclusively to operate from a single power supply over a wide range of voltages. Operation from variety power supplies is also achievable and the low power supply current drain is independent of the magnitude of the power supply voltage. Application areas include transducer amplifiers, DC gain blocks and all the conventional op amp circuits which now can be more easily implemented in single power supply systems. The LM324 op amp is directly operated off of the standard +5V power supply voltage which is used in digital systems and will easily provide the required interface electronics with ±15V power supplies.

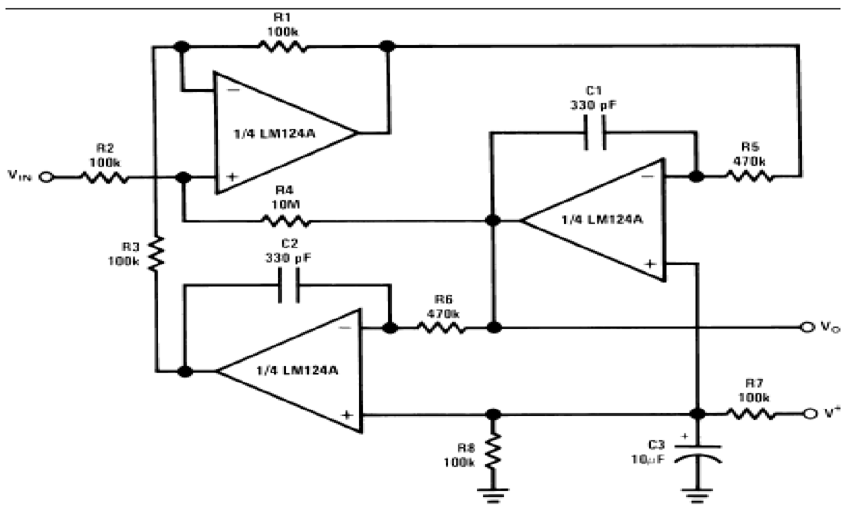

Figure 2 LM324

Spec of LM324

- Internally frequency compensated for unity gain
- Large DC voltage gain 100 dB
- Wide bandwidth (unity gain) 1 MHz (temperature compensated)
- Wide power supply range: Single supply 3V to 32V or dual supplies ±1.5V to ±16V
- Very low supply current drain (700 μA)-essentially independent of supply voltage
- Low input biasing current 45 nA (temperature compensated)

- Low input offset voltage 2 mV and offset current: 5 nA
- Input common-mode voltage range includes ground
- Differential input voltage range equal to the power supply voltage
- Large output voltage swing 0V to V^+ - 1.5V (National Semiconductor Corporation)

The 10k ohm potentiometer gives a variable resistance in any circuit with this 10K multi-turn ceramic/metal PC trimmer. It is rated 3/4-Watts (max. 1.25W) and includes an adjustment screw. The 10K POT comes with a 10KW 0.75W 15-Turn PC-Mount Trimmer inside.

The BMS used nine high precision with 1% tolerance and 1/8W resistors to provide the most accurate and precise voltage drop and current. The values are as follows: one 221 Ω resistor, this will limit and control the current going to the second LED. The 1K Ω resistor together with the 6098 Ω resistor is used as a voltage divider. The output of these resistors goes in to the LM324 inverting pin that will control the second LED. One 1.5K Ω resistor was to control the flow of the current that goes to the first LED. The 10K Ω resistor was used as a voltage divider for the LM385 to provide precise voltage drop together with the 16k Ω resistor. One 50KΩ resistor, which will limit the high current coming into the circuit form the car battery.

The SPDT 10A relay was used to control the utility of the BMS collaborated with the car battery. The heavy-duty contact rating and small size make this 10-amp SPDT relay excellent for PC-mounting. This relay has only 400 Ω resistance inside the coil. This gives the circuit a small amount of voltage drop across it.

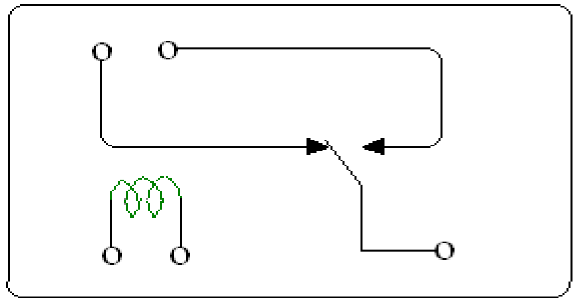

Figure 3 SPDT Relay

Spec of SPDT 10A Relay:

- Coil rating of 12VDC 30mA
- Resistance 400 ohms
- Min Operating Temperature -30 Fahrenheit
- Max Operating Temperature 65 Fahrenheit (National Semiconductor Corporation)

In addition to SPDT relay, LM324 and LM385, LM741 operational amplifier is used as comparator. The comparator is used turn on and off the output when it reaches 11.8V. The LM741 series operational amplifiers are used for general purpose which has features that helps to improve the performance of a circuit over industry standards.

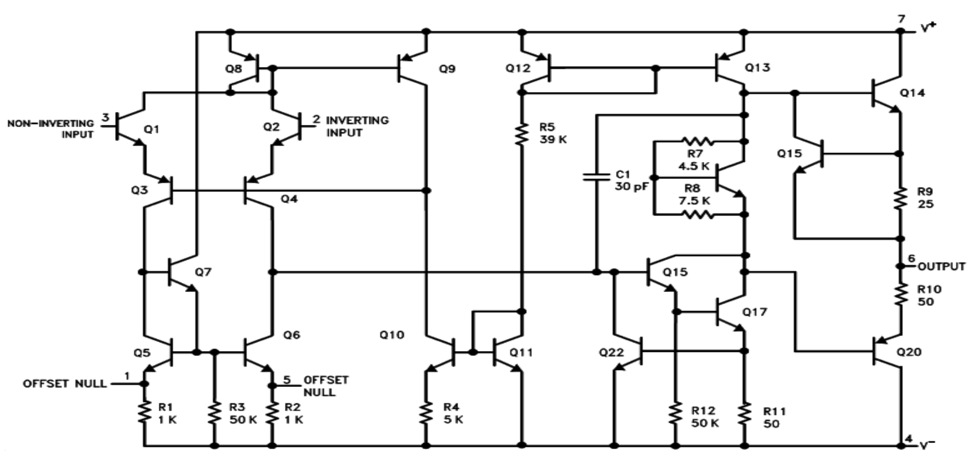

Figure 4 LM741

Spec of LM 741

- Supply Voltage ±22V
- Power Dissipation 500 mW
- Differential Input Voltage ±30V
- Input Voltage (Note 4) ±15V
- Output Short Circuit Duration Continuous
- Operating Temperature Range −55°C to +125°C
- Storage Temperature Range −65°C to +150°C
- Junction Temperature 150°C (National Semiconductor Corporation)

SPST Sliding Switch is one of the main useful parts of the BMS. After the BMS is activated, the user has to override the device in order to connect the battery to the car. For instance, if a battery discharge is detected, the BMS will be activated and the battery will be disconnected from the car. When the user comes back to start the car, there will be no connection to the car unless the BMS is detached from the relay circuit. For this purpose a Single Pole Single Throw switch will be sufficient. The specification is as follows:

CONTACT RATING:

- Q contact material (S1XX, S2XX Models):
- 6 AMPS @ 125 V AC; 6 AMPS @ 250 V AC; 1 AMP @125 V DC (UL/CSA).
- ELECTRICAL LIFE: 10,000 make-and-break cycles at full load.

CONTACT RESISTANCE:

- Below 10 m ½ typ. Initial @ 2-4 V DC, 100 mA, for both silver and gold plated contacts

- INSULATION RESISTANCE: 109 ½ min.
- DIELECTRIC STRENGTH: 1,000 Vrms min. @ sea level.
- OPERATING TEMPERATURE: -30ºC to +65ºC
- STORAGE TEMPERATURE: -30ºC to +85ºC (National Semiconductor Corporation)

Light Emitting Diodes (LED) are used for indicator purposes. Since LEDs require very little current, it will not affect the circuit. The specifications are as follows:

- High Contrast, UL 94 V-0 rated, black housing
- Oxygen index: 32%
- Polymer content: PBT, 0.160 g
- Housing stand-offs facilitate PCB cleaning
- Solder ability per MIL-STD-202F, method 208F
- LEDs are safe for direct viewing per IEC 825-1, EN-60825-1
- LED Protrusion: ±0.04 mm [±0.016] (National Semiconductor Corporation)

Implementing Circuit in PSPICE, Simulations

The first step in creating our circuit was to try and model the design in PSpice to get a better understanding of the operation of the circuit. Figure 5 shows the PSPICE design that we came up with while Appendix F and Appendix G show the results of the simulations. The simulation results helped the circuit design to be built on solder less circuit board.

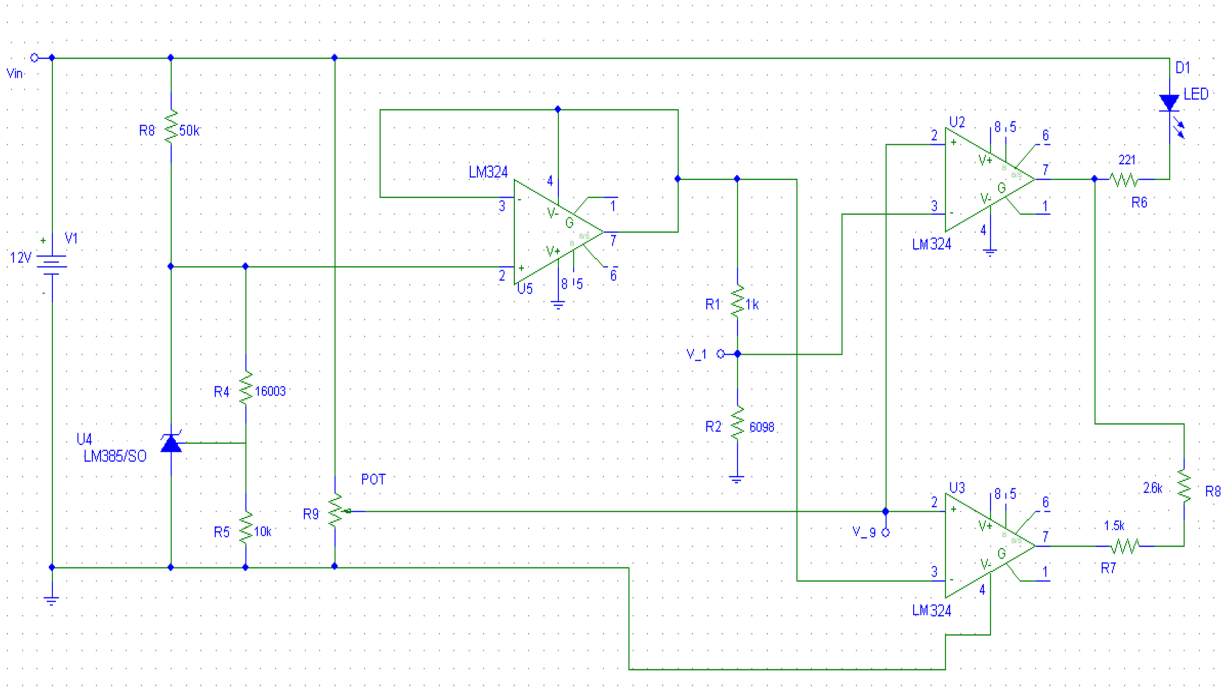

Figure 5: PSPICE Model of Design

Implementing of Electronics Devices on Breadboard

While the circuit was being modeled in PSpice, we were implementing a smaller scale version using a solder less breadboard. Figure 6 shows a sketch of the experimental setup in its final stage.

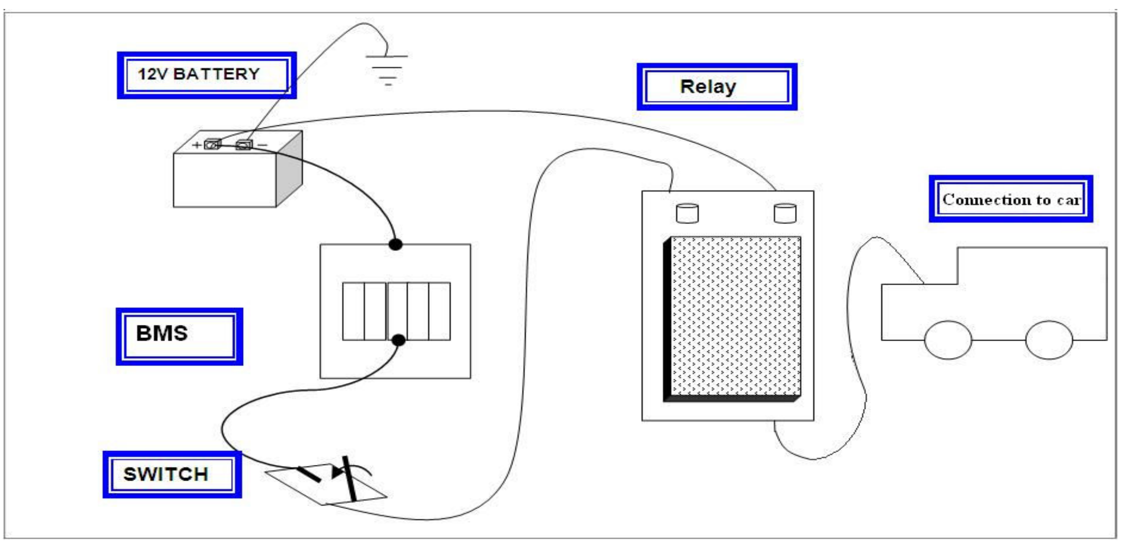

Figure 6: Sketch of Experimental Setup

In our design, we had available a 12V power supply, a switch, a breadboard with most of the transistors needed, (LM385, LM741, etc.), and a relay. The power supply was used in all parts of our testing and trouble shooting. This Real Time Battery Monitoring System is capable of operating in a car battery. However, since it is difficult to drain the car battery in few seconds linearly and show the demonstration, a DC power supply is used.

After implementing the circuit on the solder less board, the final result was tested using LED light. At the end of the circuit, the relay was not turning on and off. It was noticed that the current was decreasing linearly. When the voltage was reduced to 11.8V, the LED did not actually turned off but very dim to detect it with human eyes. To resolve this problem, a comparator was used by taking the voltage drop across the two ends of LED. To avoid the PN-Junction characteristics, a resister with a similar voltage drop was replaced. The value of the resistor was calculated by measuring the current and voltage drop across the LED and using simple Ohm's Law.

This will give the two voltages to be compared for the voltage comparator. Figure 7 below shows how the comparator is connected to the circuit. The output of the LED D2 is connected to the inverting input of the LM741 operational amplifier. When the LM741 amplifier activates, it powers the indicator LED telling the user in the cabin of the car that the device is activated. This output is overridden by the switch, which opens the connection from the comparator operational amplifier to the activation input of the relay, which re-establishes the connection between the car and the battery.

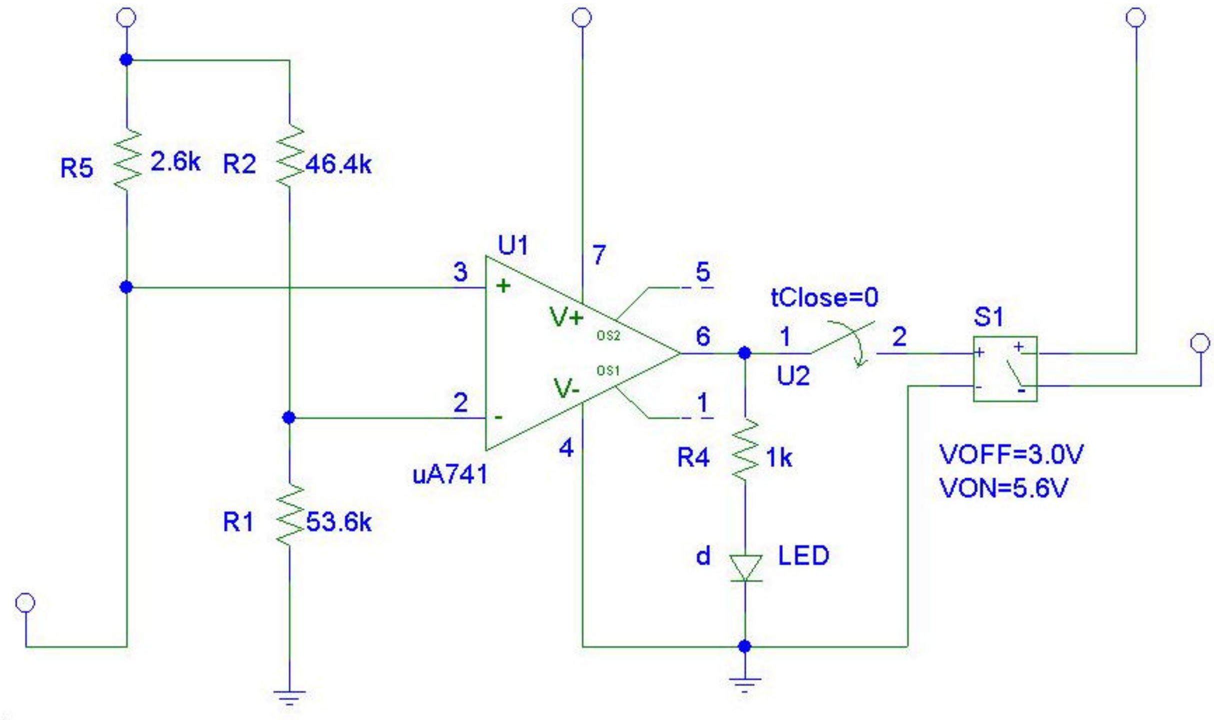

Figure 7 Voltage Comparator

Verification, Testing, Validation, and Analysis

Before the hardware implementation, the design was placed in PSpice and simulated to obtain the two different voltages seen across the two LEDs (D1 and D2). The D1 LED represents the voltage required to power another device in the vehicle such as car alarms and radio, etc. The D2 LED represents the main device which is the headlight of the car. From our test, it was verified that D1 LED was able to function until the voltage supply drops to ~3V. After the BMS is activated and disconnects the battery from the car, there is still a minimal voltage supply.

The testing involved a power supply, a test LED, and multi-meters. When we tested the design for the first time, a test LED was used to observe if the light source would give us the desired characteristics. The problem we found was that the LED's voltage was decreasing linearly. In order for the device to be successful, the LED would have to turn on and completely off like a light switch. This trait would represent the light source being on when the car battery is at full charge at approximately 12.5V and cutoff at a reasonable voltage at around 11.8V. A voltage comparator was built after the battery monitoring circuit to compare the voltage difference to allow the voltage cutoff point to occur with the relay.

When our voltage disconnect point was achieved, the group continued to drop the voltage pass 11.8V and back to 12.5V to see if the test LED would turn on and off. The group carefully monitored the voltage drops and the currents in the circuit and replaced the test LED with a resistor with the same resistance. The ON/OFF switch for the circuit was placed before the relay in the circuit and was switch on and off after the voltage was 11.8V to observe if the light source would turn on again. Lastly the indicator light was placed at the output of the voltage comparator but before the relay.

When the fog light is on at 12.5V, the indicator light (red LED) is off. When the fog light turns off at 11.8, the indicator light turns on until the voltage gets turns on the fog light again. All of these proposed features were tested and it all performed the way it should.

Conclusion

The components used for this project was mainly purchased from HSC Electronic Supply and Radio Shack. The real time battery monitoring system consists of several components that are collaborated together. The BMS consists of one LM385 voltage regulator diode, one LM324 low power quad operational amplifier, one 10K potentiometer, nine high precision 1/8W resistors, one SPDT 10A relay, three LEDs, one LM741 operational amplifier, and one SPST sliding switch. The cost of each component and the entire product can be found in appendix C.

The group made every effort to prioritize the time for research, gathering parts, building the project, and testing the design. The building and testing of the design took the majority of our schedule because it required additional research and parts to fine tune the values we wanted in our design. After we had acquired the cutoff voltage, testing continued until the cutoff voltage was guaranteed.

Each group member had equal responsibilities on the project. Whatever task needed to be done to move the design forward, that person would take that role. As time became a major problem, the work load would shift between each member but everyone made the effort to make the project a success.

Since the design was constructed to show the application of a device being disconnected from the car battery, the final consumer product would cost more to allow a more user friendly design. It is understood that in today's society, many people would spend money on a design that is easy to use and inexpensive. Further research and planning would be placed on the location of the BMS with respect to where the ON/OFF switch and indicator light would be installed on the car dash. In its current state, the BMS would be installed on the car battery with the indicator light and the switch attached to the BMS. If the user experiences a car that doesn't start, he/she would have to open their car hood and observe that the BMS device is active by the red indicator light. The next instruction is to toggle the switch to reset the BMS, restart the car to charge the battery, and user would be able to drive the car.

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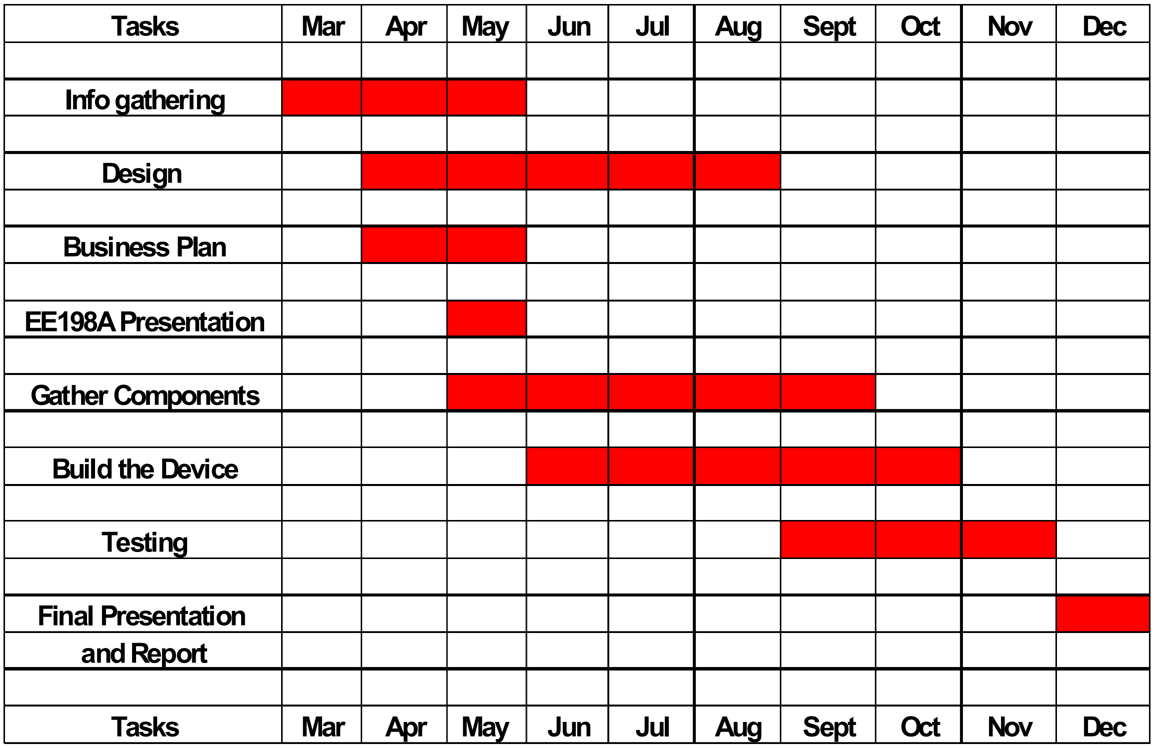
Appendix A – Car Battery Experiment Data

Time (mins)	Voltage	Current	Time (mins)	Voltage	Current
1:30	11.96	6.5	2:07	11.39	10.41
1:31	11.96	6.5	2:08	11.39	10.41
1:32	11.96	6.5	2:09	11.38	10.4
1:33	11.96	6.5	2:10	11.38	10.4
1:34	11.96	6.5	2:11	11.37	10.39
1:35	11.96	6.5	2:12	11.37	10.39
	Change Current		2:13	11.37	10.39
1:37	***11.53***	***10.53***	2:14	11.36	10.39
1:38	11.53	10.53	2:15	11.35	10.38
1:39	11.52	10.48	2:16	11.35	10.38
1:40	11.51	10.45	2:17	11.35	10.38
1:41	11.51	10.45	2:18	11.34	10.38
1:42	11.51	10.45	2:19	11.34	10.38
1:43	11.49	10.47	2:20	11.33	10.37
1:44	11.49	10.47	2:21	11.33	10.37
1:45	11.49	10.47	2:22	11.33	10.36
1:46	11.49	10.47	2:23	11.33	10.36
1:47	11.49	10.47	2:24	11.32	10.35
1:48	11.49	10.47	2:25	11.32	10.31
1:49	11.49	10.47	2:26	11.31	10.31
1:50	11.49	10.47	2:27	11.31	10.3
1:51	11.46	10.48	2:28	11.3	10.28
1:52	11.46	10.48	2:29	11.3	10.28
1:53	11.45	10.46	*2:30*	*11.29*	*10.27*
1:54	11.45	10.45	2:31	11.29	10.27
1:55	11.44	10.43	2:32	11.29	10.15
1:56	11.44	10.43	2:33	11.29	10.15
1:57	11.44	10.43	2:34	11.29	10.14
1:58	11.43	10.43	2:35	11.28	10.13
1:59	11.43	10.43		*Restart Attempt (Failed)*	
2:00	11.42	10.43	**2:37**	**11.35**	**10.3**
2:01	11.41	10.42	2:38	11.33	10.33
2:02	11.41	10.42	2:39	11.31	10.23
2:03	11.41	10.42	2:40	11.31	10.23
2:04	11.4	10.41	2:41	11.28	10.19
2:05	11.4	10.41	2:42	11.28	10.14
2:06	11.39	10.41	2:43	11.27	10.1

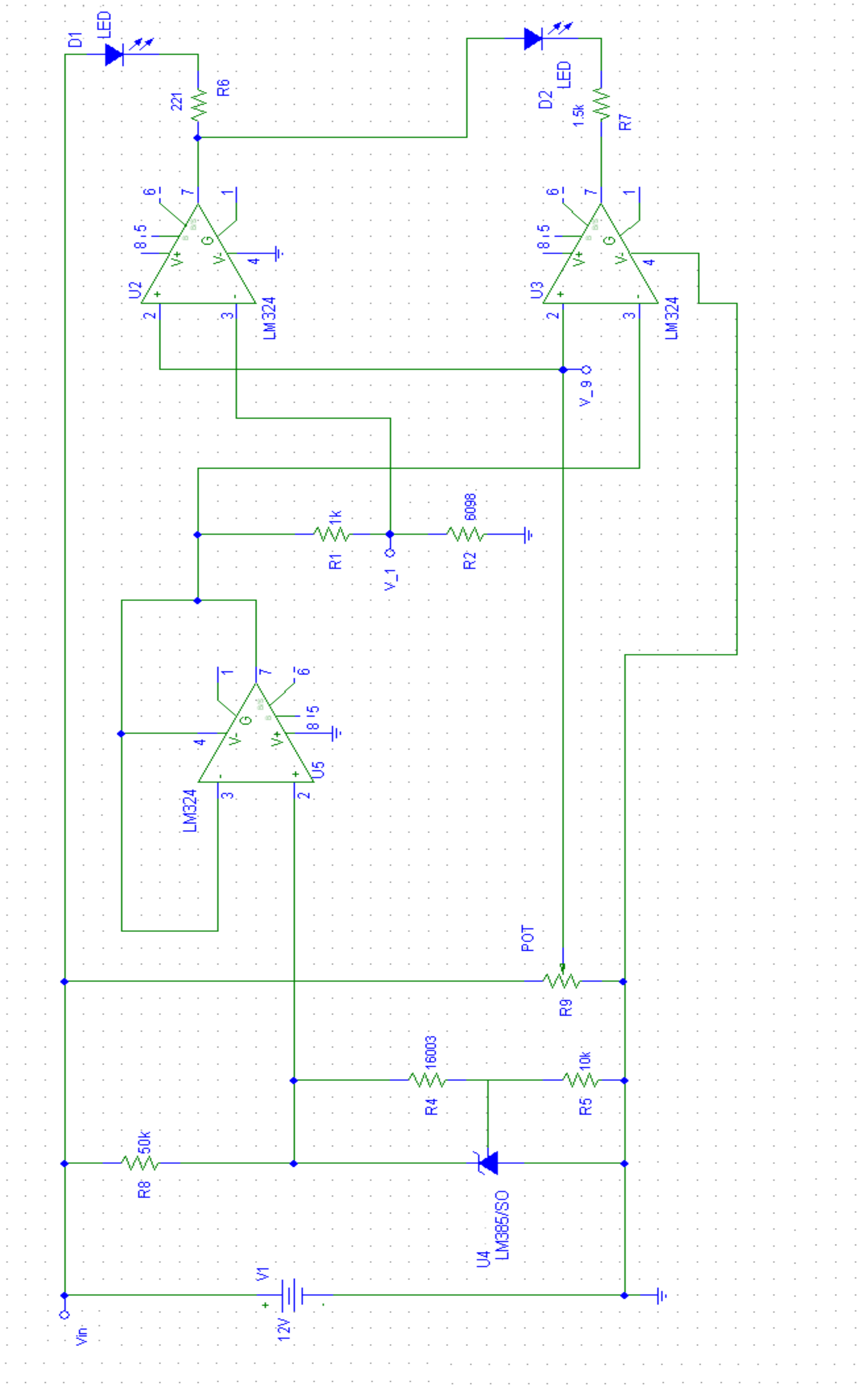
Appendix B – Project Timeline



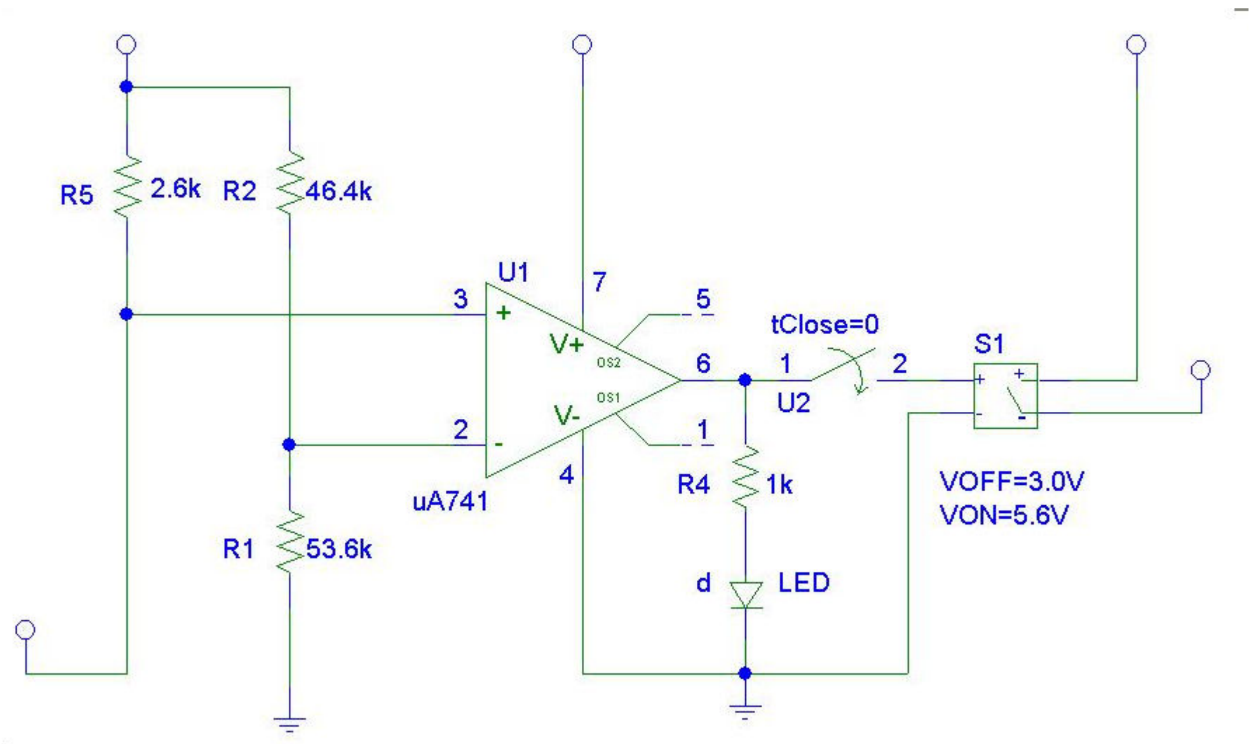
Appendix C – Bill of Materials

Component	Quantity	Price
LM385	1	$1.35
LM324	1	$0.59
POT (10K)	1	$1.40
Resistors	10	$0.50
SPDT Relay	1	$4.79
LED	2	$0.54
LM741	1	$0.49
Switch	1	$0.35
Miscellaneous (wire, mounting board, cover...)	~	$2.00
Subtotal		$12.01
Tax 8.25%		$0.99
Total		$13.00

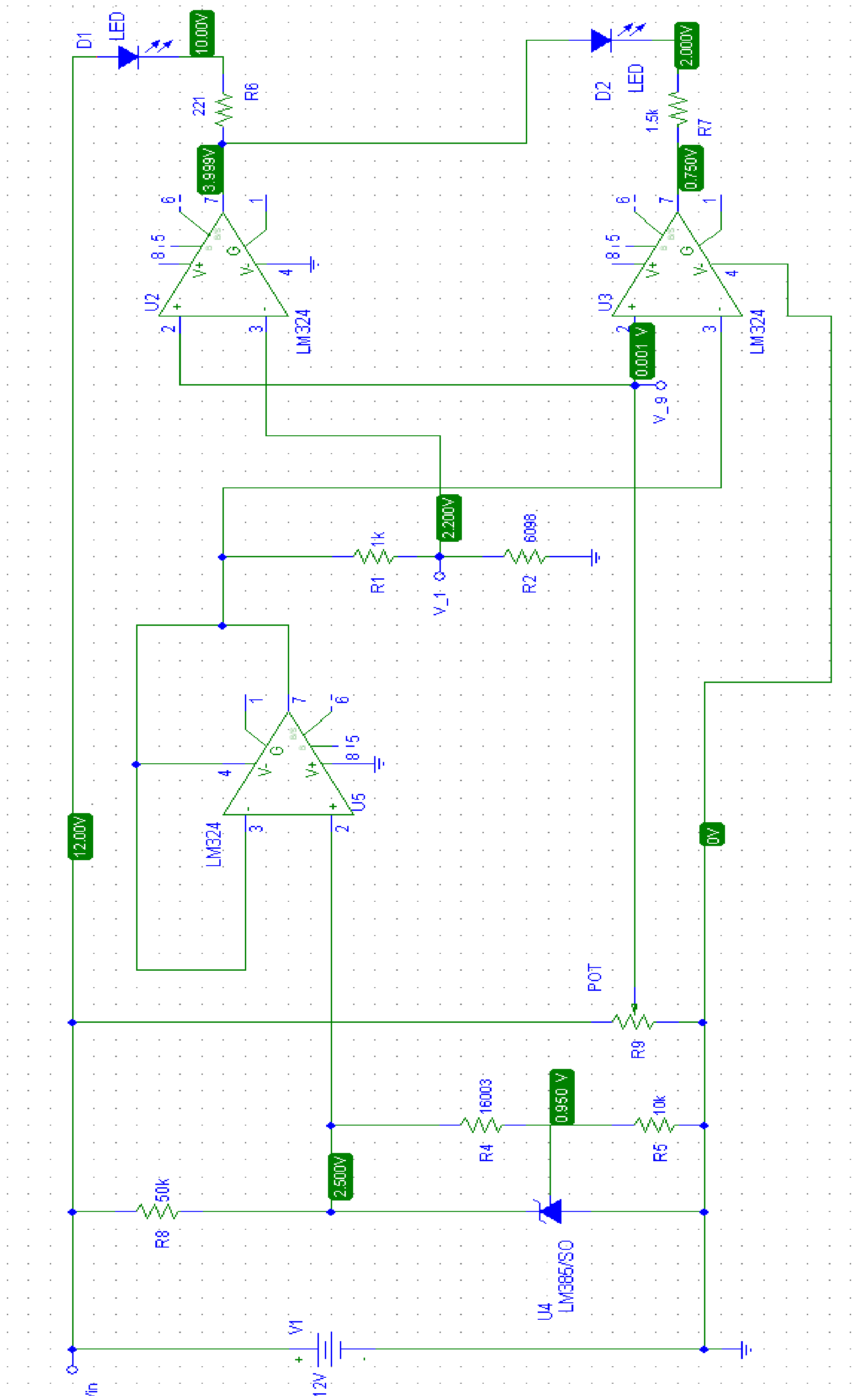
Appendix D – PSPICE Circuit Model 1



Appendix E – PSPICE Circuit Model 2



Appendix F- PSPICE Simulation 1



Appendix G – PSPICE Simulation 2