December 18, 2009

Dr. John S. Bird
School of Engineering Science,
Simon Fraser University,
Burnaby, BC, V5A 1S6

Re: Post-Mortem report of Auto-Splice Conductivity Analyzer

Dear Dr. Bird:

The enclosed document, *Post-Mortem Report of Auto-Splice Conductivity Analyzer*, outlines the process Prospect1 Inc. went through during various stages of design, implementation and modification of our ENSC 440 project. The aim of this project was to design a device that could measure variable magnetic field intensity in splices in overhead transmission lines. This would then be used to analyze the imbalance of current in individual strands which would help the user identify the extent of damage present in a splice.

This document details the current state of the device, changes made during the design, manufacturing and implementation processes and also future upgrades of the device that can be executed later. Furthermore, some of the roadblocks we faced in terms of budget and time constraints during this project are also outlined here. Additionally, interpersonal communication skills and technical as well as theoretical knowledge of some concepts we learnt during the project are also mentioned here.

Prospect1 Inc. consists of four enthusiastic and hard working fourth year Engineering Science students: Amir Najafzadeh, Milad Moezzie, Sam Hoque and Zhouhao Cui. We are very excited about the opportunity this project may hold in lessening the failure rates of automatic splices in overhead distribution systems. Please feel welcome to contact us if you have any questions or concerns by phone at (778) 239-1144 or by e-mail at prospect-1@sfu.ca

Sincerely yours,

Sam Hoque
CEO Prospect1 Inc.

Enclosure: *Proposal for Auto-Splice Conductivity Analyzer*

Post-Mortem Report of

Auto-Splice Conductivity Analyzer

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Glossary

ASCA	Auto-Splice Conductivity Analyzer
ACSR	Aluminum Conductor Steel Reinforced (overhead wire)
LCD	Liquid Crystal Display
LED	Light Emitting Diode
MCU	Arduino Duemilanove Micro Controller
Splice	An electrical splice is the joining of two or more electrical conductors by mechanically twisting them together or by using a special splicing device [2]
User	Certified Technicians/Electricians who are authorized to perform maintenance and testing on overhead transmission lines

1. Introduction

At the beginning of the semester, the idea of an Auto-Splice Conductivity Analyzer (ASCA) had initially gathered the four members of Prospect1 Inc. During the past 13 weeks; determined, disciplined and tireless hard work has led to the realization of the idea. From designing the device to its final implementation, the journey was a memorable one. This report has an in-depth look into the process of how this device has come to its completion from the beginning till the end.

2. Current State of Device

In overhead wires, as splices age, Aluminum components oxidize to form an insulating barrier thereby increasing their resistance and causing a current imbalance in cables' strands [1]. We concentrated our effort on the study of this current imbalance and the resulting magnetic field around the cables' strands and came up with ASCA – a device that uses Hall Effect Sensors to measure this change in magnetic field intensity to monitor failure in splices.

2.1 Preliminary High Level System Design

The ASCA system at a high-level was modeled as the following during the earlier parts of the semester (shown in Figure 2.1).

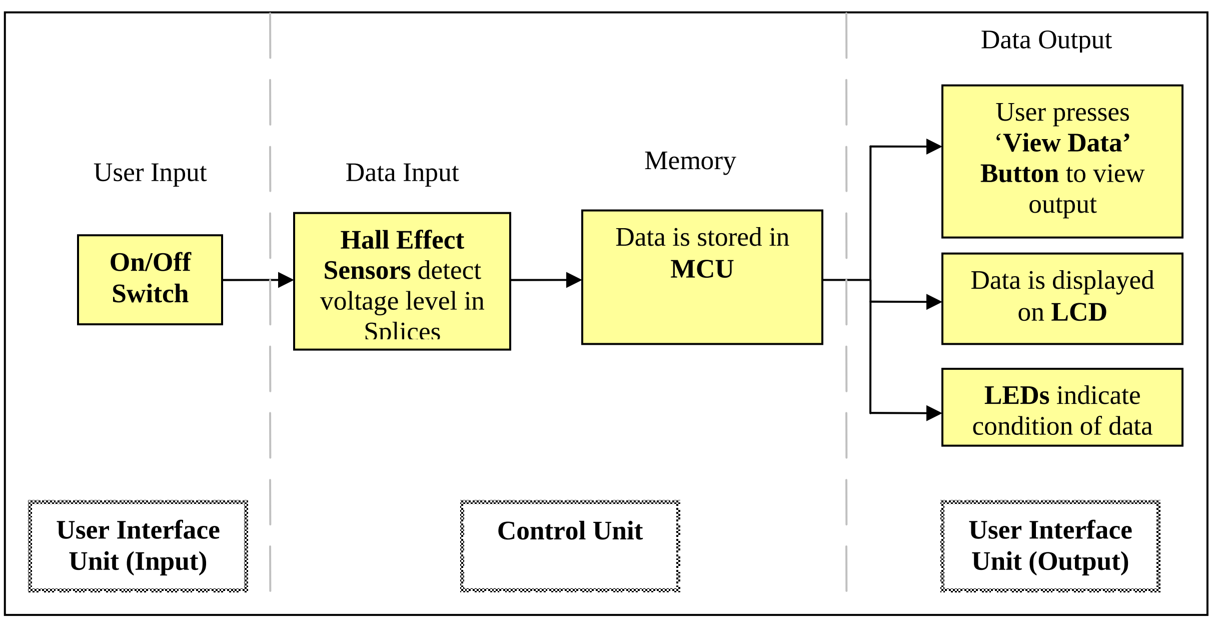


Figure 2.1: Preliminary High-Level Functional Block Diagram

It is made up of an Arduino Duemilanove Micro Controller (MCU) a couple of DN6847 Hall Effect Sensors and shifter circuits. This is the heart of the device and takes care of most of the functionality of the device. Primary functions of the control unit include:

- To obtain data through the Hall Effect Sensors.
- To store data in MCU.
- To convert the information received from analog to digital.
- To send the output display to the LCD.
- To send output information to appropriate LEDs.

The user interface unit can be subdivided in to two components, the input and the output. The input is an 'On/Off' switch which is connected to a relay switch to operate the device using a remote control. And the output consists of a LCD and three LEDs. The device is turned on by using a remote switch by the user. After obtaining data, the user presses the 'View Data' button to observe captured data. The data is then analyzed and appropriate data is displayed on the LCD along with an LED indicator. The three LEDs on the device represent the following:

- Green LED: Data is within optimal range.
- Red LED: Data is out of range.
- Blue LED: Data is irrelevant or there is insufficient data. Further testing required.

2.2 Current High Level System Design

The ASCA system at a high-level was modeled as the following during the earlier parts of the semester (shown in Figure 2.1).

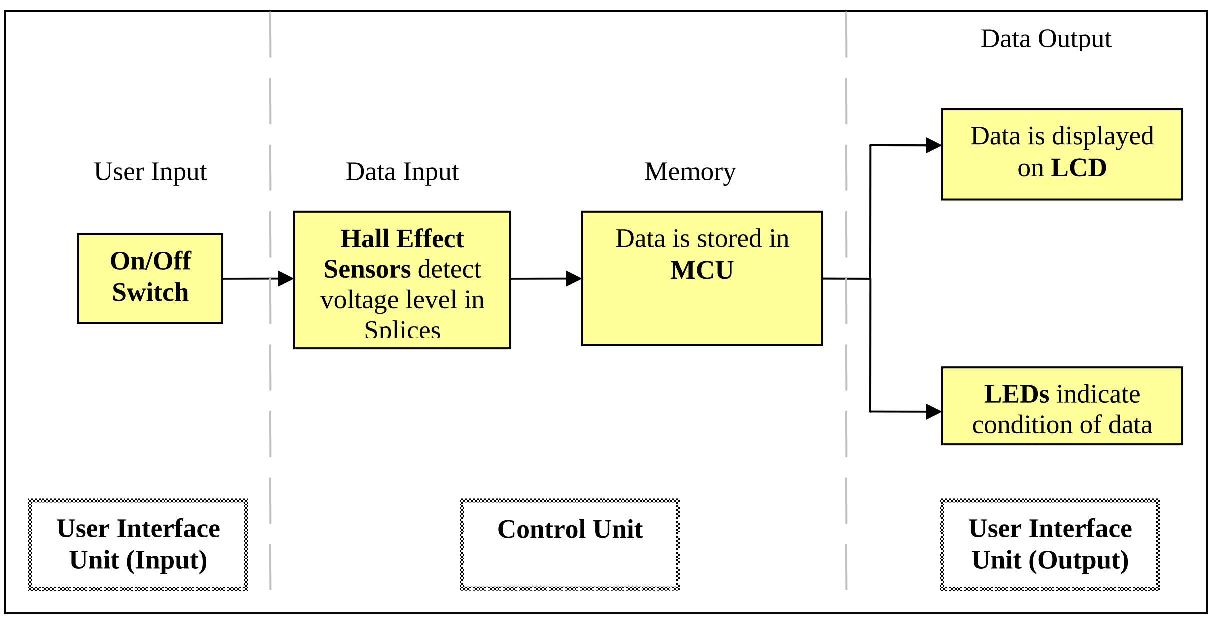


Figure 2.2: Current High-Level Functional Block Diagram

2.2.1 Control Unit

In the current design, basic functionality of the Control Unit had not changed much. The MCU was still used to obtain data through the Hall Effect Sensors and later convert the information received from analog to digital to display it on the LCD and appropriate LEDs.

It was noticed that in order to derive desired results, the Control Unit needed to be modified according to the following:

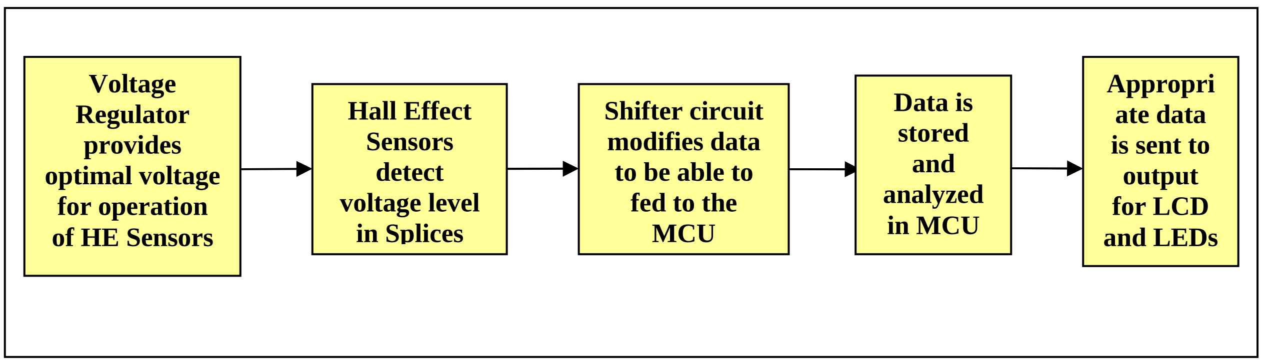


Figure 2.2.1: Modified High-Level Functional Block Diagram for the Control Unit

2.2.1.1 Voltage Regulator

The voltage regulator was designed with the help of a couple of capacitors, resistors and a variable LM117 voltage regulator [2]. Our input voltage for the device was standing at 12V while the HE Sensors needed a stable input voltage of 4V. The voltage regulator was tuned to achieve necessary input voltage.

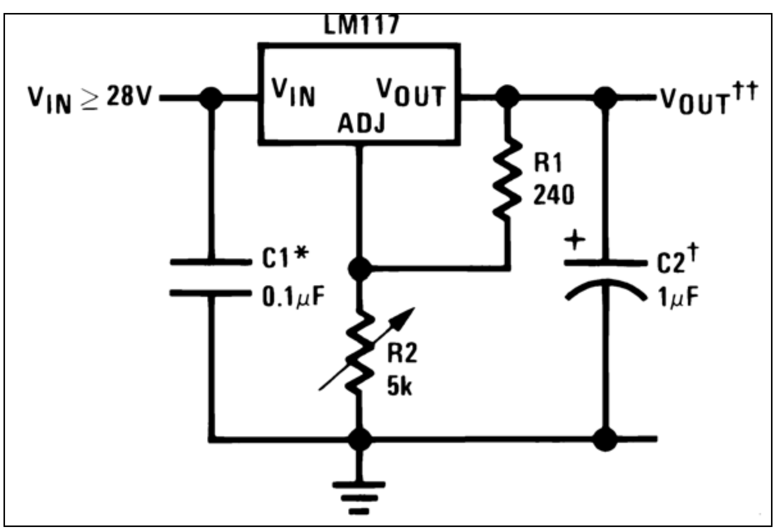


Figure 2.2.1.1: Design Schematic for a Voltage Regulator

2.2.1.2 Shifter Circuit

When tests were carried out on the HE sensors, it was observed that with one or two strands not conducting current the output voltage oscillated from 16-33 mV and 14-25 mV. Overall, the output voltage ranged from 2.4601 V to 2.508 V, which is a range of only 40.7 mV.

The minimum input data fed to the MCU for proper analysis is 10mV. As this variance in voltage obtained from the Hall Effect Sensor is small, it can lead to misrepresentation of data when fed to the MCU. This is why we needed to implement a shifter circuit. Not only it amplifies this range of 60.7 mV, it also ensures that the range of 2.4601V-2.508V is mapped to 0V-5 V, which is the operating range of the MCU. This shifter circuit consists of an LM358 Op-Amp, voltage regulator, trimmer potentiometer and other resistors as shown in figure 2.2.1.2. There was a need to implement a voltage regulator here as well as the Op-Amp needs a constant input voltage of 5V.

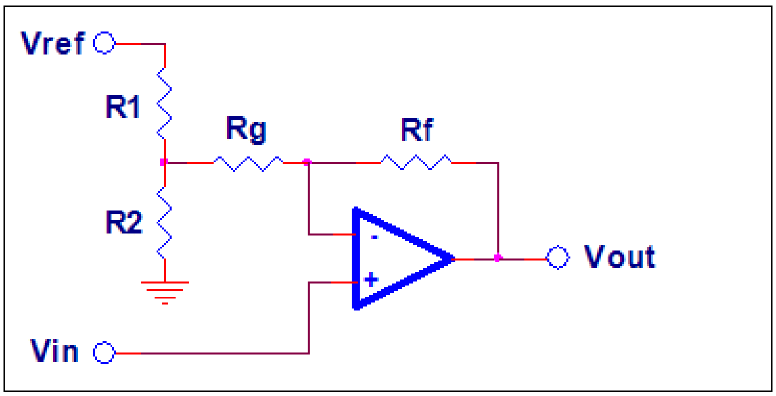


Figure 2.2.1.2: Design Schematic for a Shifter Circuit

Necessary calculations that map the output voltage range of 2.4601V-2.508V to 0V-5 V are attached. By selecting appropriate resistor values, we were successfully able to have input voltage of 0V-5V for the MCU input.

$$Vout = m \times Vin - b$$

$$m = \frac{Rf + Rg + R1 \| R2}{Rg + R1 \| R2}$$

$$b = Vref \times \left(\frac{R2}{R1 + R2}\right) \times \left(\frac{Rf}{Rg + R1 \| R2}\right)$$

2.2.2 User Interface Unit

Initially the device was designed to start scanning data as soon as the device was turned on till the end of scanning period (15 seconds, which can be modified). This posed a potential problem as the user may not be ready to scan at the moment when it was turned on. Initially we implemented a delay so the user may get ready to scan and the scanning process may begin. But depending on users, this delay may vary and as such it was not an efficient method.

Thus we implemented a remote control to turn the device on. It would not only let the user decide when to turn it on, but also is an attractive safety feature. Due to the dangers of a live overhead wire, proper distance needs to be maintained from the wire for the user's safety. With the implementation of the remote, which has operating range of 50 meters, it lets the user stay away from the cable and turn the device on to start the scanning process.

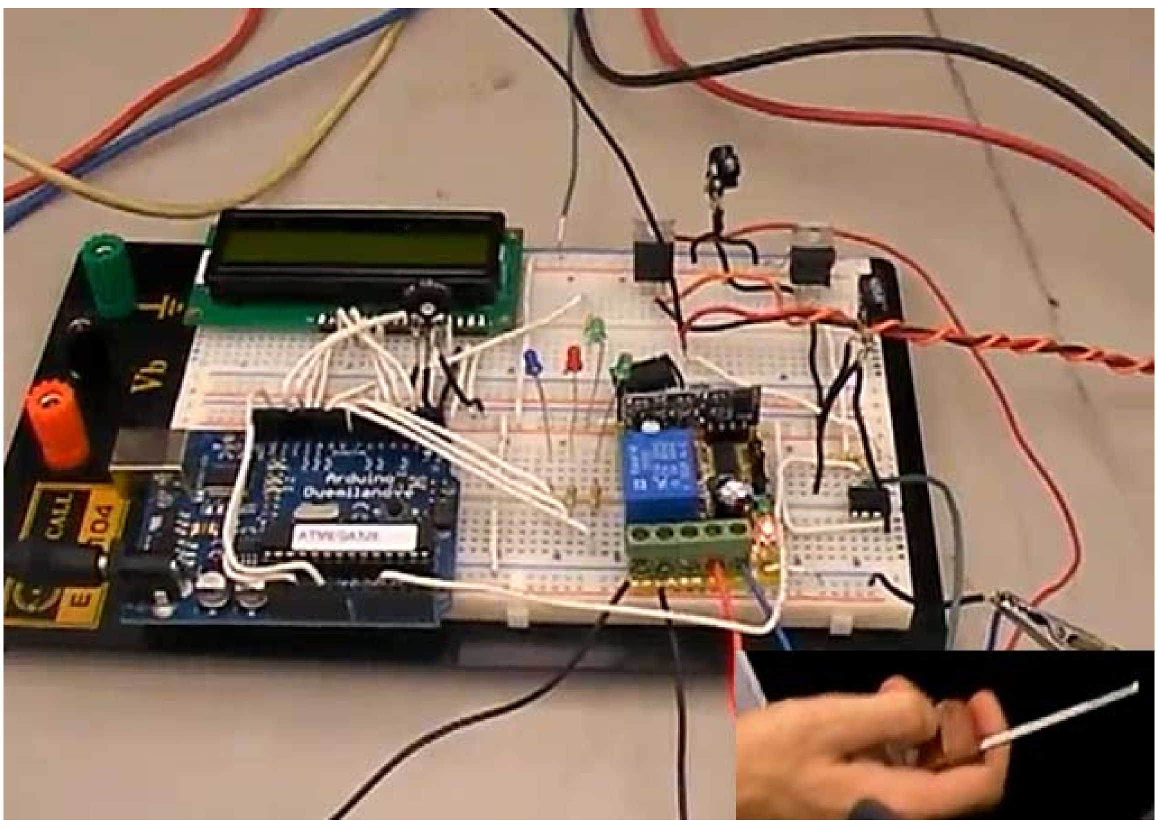


Figure 2.2.2.1: Implementation of a Remote Control

Also, the 'View Data' button was removed. This button was initially designed to show output data on the LCD and LEDs when it would have been pressed. We programmed the MCU in such a way, so it would analyze captured data and only show relevant maximum value as the output. This simplified the device by eliminating a step in terms of viewing output data.

2.3 Change in Design Schematic

Initial deign schematic for the ASCA device had two HE Sensors (Figure: 2.3.1). It was later determined that two sensors, when implemented together was introducing more noise which was inconclusive to derive desired results. It also did not have any shifter circuit or voltage regulators in the design. Also, there was no remote control switch implemented either. Here is how it was designed earlier:

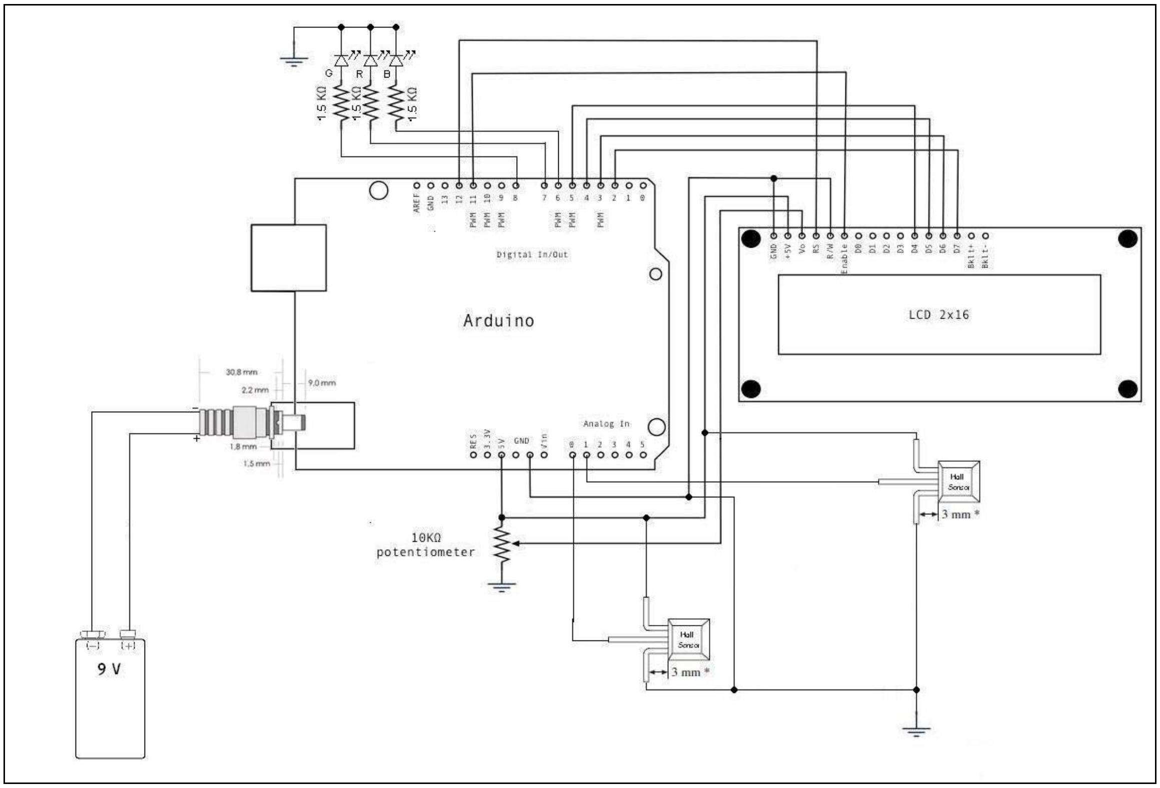


Figure 2.3.1: Original Design Schematic of the ASCA device

After going through a number of tests and development of the prototype device, one HE sensor was removed, shifter circuit and voltage regulator were added and a remote control switch was implemented. This is how it looked later:

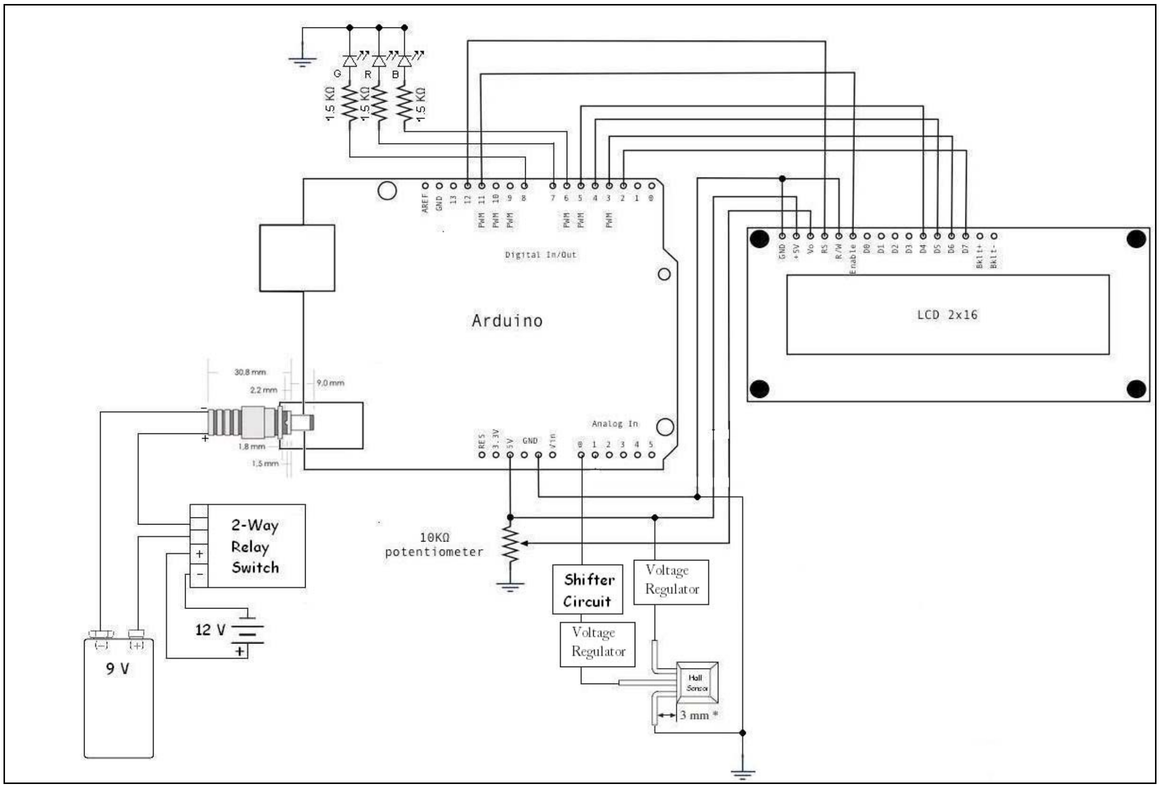


Figure 2.3.2: Modified Design Schematic of the ASCA device

2.4 Change in Mechanical Design

Initially the device was deigned to be mounted on the wire and slide it along its length using a hotrod attached to the device. This would have exposed the rest of the components along with the HE sensors to the magnetic field along the wire. Implications of such an induced magnetic field can be potentially dangerous to the device’s functionality. Thus it was decided that the HE Sensors will be separated from the device and the user interface unit will be protected from such a magnetic field.

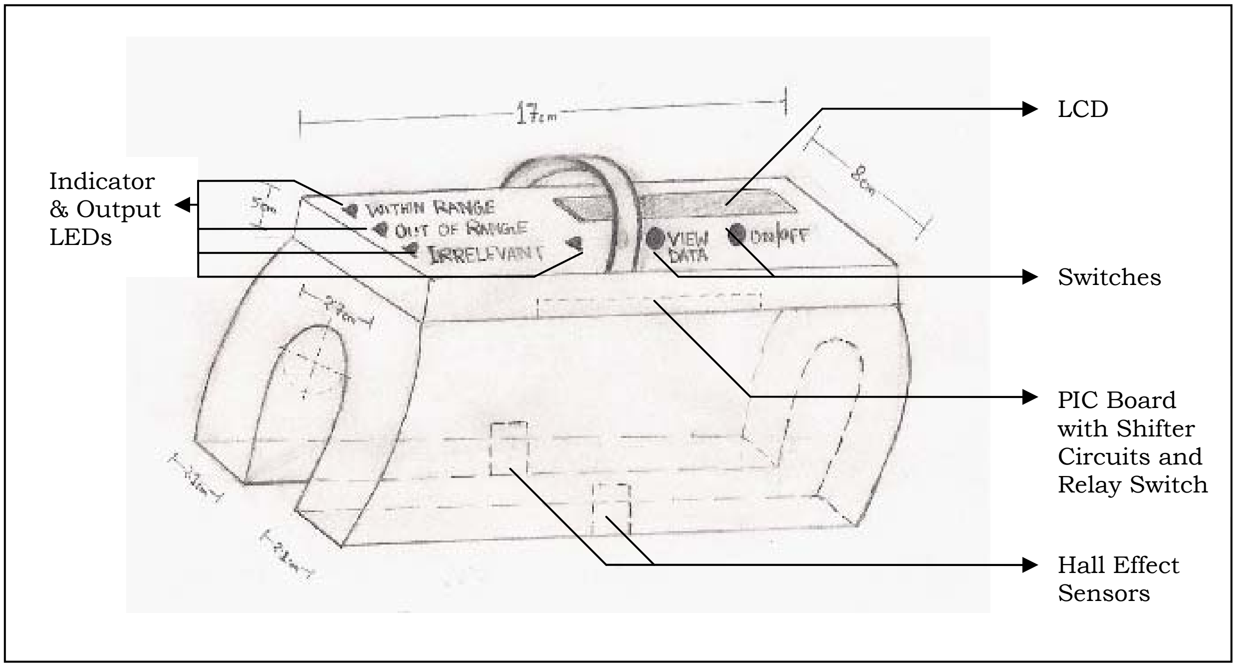


Figure 2.4.1: Initial Mechanical Design of the ASCA device

After the changes, the HE sensors were attached to a plastic wrench. The distance where the HE sensors are placed from the wire is critical for the device to obtain accurate data as this distance is directly related to the amount of magnetic field introduced by the wire. By having the HE sensors mounted on a wrench, it would still allow the HE sensors to be adjusted correctly along the length of the splice and also save the rest of the components from the magnetic field. The user interface unit mostly remained the same.

Figure 2.4.2: Repositioning of the HE Sensors on the ASCA device

3 Future upgrades

3.1 Analyze Splice health to determine its trend

The MCU captures all the data captured during the scanning process and stores it in its memory. It only shows the most relevant maximum data as output although the rest of the data is still stored. The memory is only reset when the user turns the device off.

The MCU can be programmed to keep the stored data to further analyze the health of the splice and its trends. There is a built-in USB port on the device and it can be utilized to transfer this data to a computer. Engineers then can use this data to observe splices of which areas are more prone to failure and relate it to the area's power consumption, geographical position and weather conditions.

3.2 Hall Effect Sensor Noise Reducing Circuit

This is a very simple circuitry that might be used to reduce introduced noise. Although the effect of this circuit can be minimal, this can be particularly useful where the data is irrelevant. In such cases, some data signals exceed the maximum or minimum allowable range. This circuit can then be useful in distinguishing between useful and distorted data.

3.3 Integrating Hot Stick and separating the user interface unit

The ASCA device has multiple power sources. This of course gives the device added portability as well as a chance to power/operate the device from a laptop or an alternating power source. In future models, for instantaneous observations, the user interface unit can be separated and held in hand while the rest of the device is mounted on overhead wire. For this model to be produced, wiring needs to be incorporated with the hot stick.

4 Troubleshooting the device

If it is doubted that the device is not performing as it is supposed to, a couple of simple tests can be done to find out if it requires maintenance. The HE sensors are observing a magnetic field which is due to an alternating current in the wire. Thus the output of the sensors should deduce a sinusoidal waveform. Also, after the shifter circuit (when the range has been amplified), it should show a half wave sinusoidal waveform. A test engineer can easily check this and determine if the output is as desired. If these two tests fail, the device should be checked immediately.

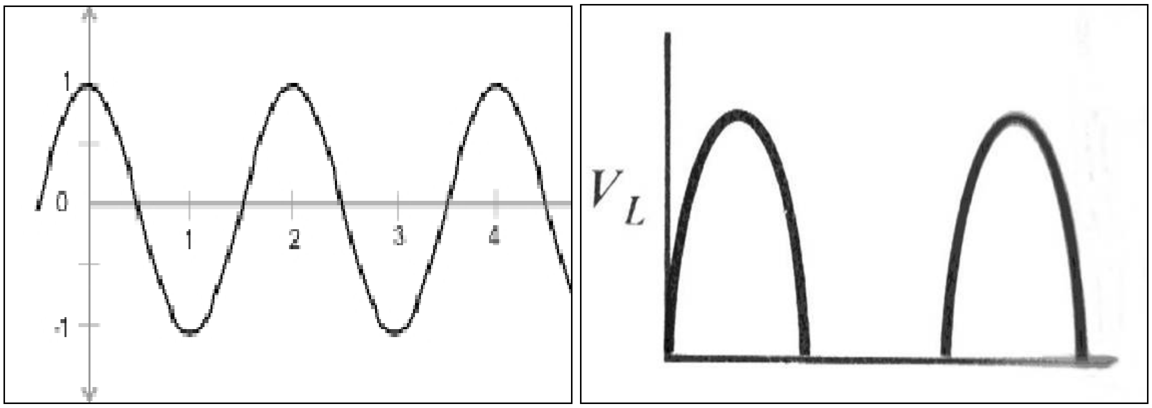


Figure 4.1: (a) A sinusoidal waveform (b) A half wave Sinusoidal wave form

5 Budgetary and Time Constraints

A tentative budget was initially outlined earlier in the semester. Most of these categories were overestimated by at least 10% to take emergencies in to account. In the final analysis the total cost of achieving the whole project was reduced by more than half. We were able to achieve this as we were able to find most of the parts from local vendors at a discounted rate. Here is a breakdown:

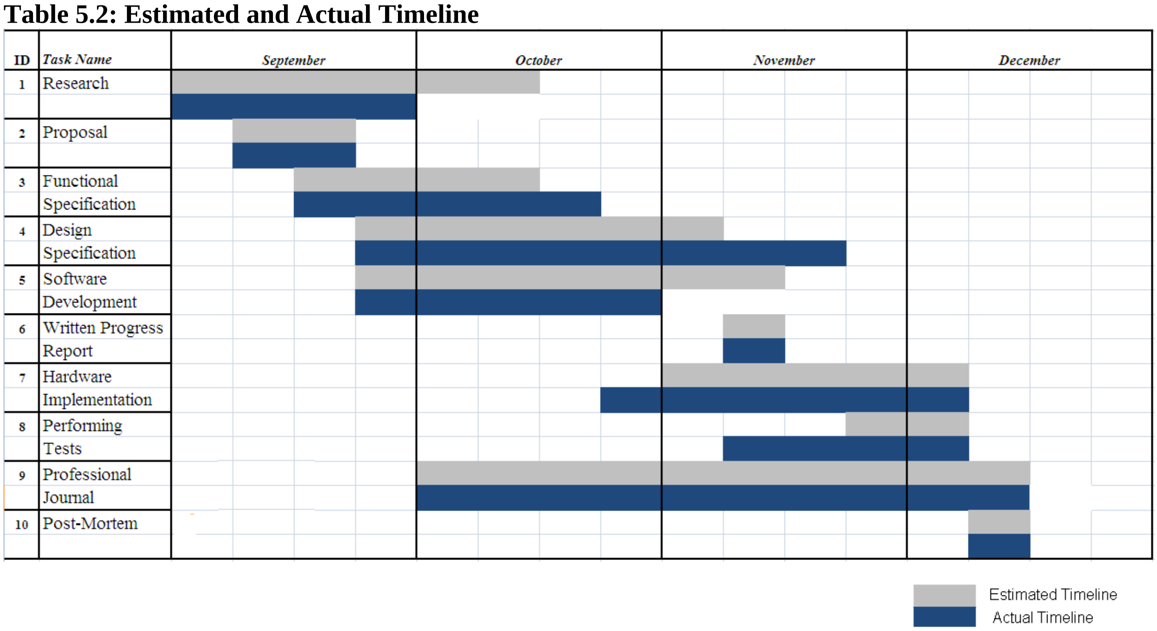
Table 5.1: Tentative Budget

Equipment List	***Estimated Unit Cost***	***Actual costs***
Transmission Line Cable	$70.00	$70.00
Butterfly Microcontroller	$160.00	$45.00
Hall Effect Sensors 1.Allegro-A1321LUA-T	$15.00	$50.00
2.Allegro-A1322LUA-T	$15.00	
3.Allegro-A1323LUA-T	$15.00	
4.Allegro-A1301KUA-T	$15.00	
5.Allegro-A1302KUA-T	$15.00	
6.Allegro-A1373LKB-T	$15.00	
Bred Board	$30.00	$21.00
Batteries	$40.00	$35.00
Cables/Connectors	$60.00	$25.00
Capacitors/Resistors/LEDs/LCD	$35.00	$21.00
Hot Rod	$100.00	$0.00
Safety Equipments	$150.00	$0.00
Miscellaneous	$150.00	$25.00
Total	**$885.00**	**$292.00**

Although, it cost us $292.00 to prepare the prototype device, there were a lot of additional parts ordered as backup. Also this number contains the cost of preparing test equipments. If one was to solely consider the price of this prototype device it will trim down to about ~$100. In mass production, this figure will easily come down further. Along with the device's accuracy in functionality such a price makes the ASCA device financially lucrative and easily marketable.

In terms of time, we were able to meet most of our deadlines. We had a bit of an issue preparing the 'Design Specifications' as the understanding was not clear. Later it was modified and updated. We were also ahead in few areas as software and hardware development. This helped perform early tests and optimize the device as necessary. The following is a summary.

Table 5.2: Estimated and Actual Timeline



5 Experiences gained

Sam Hoque

This was by far the most useful course I have enrolled in during my undergraduate career. The course is very well organized with specific requirements that have clearly identified deadlines. This helped in staying on track to fulfill the requirements of this course. The ASCA device dealt with a problem that is related to power electronics, transmission lines and load distribution. These are some of the issues a local power utility faces. As a graduating engineer, this is the field I would like to pursue as a career. Thus the research done during this project was immensely helpful. As there was no spoon feeding in this course and most of the ideas and research work were done by us, it taught us a number of valuable lessons. It was a satisfying to combine years of lab and course knowledge to come up with the ASCA device. Basic circuitry skills from ENSC 225, ENSC325; Power distribution ideas from ENSC 320; Magnetic Field theories from PHYS 326 and a number of other ideas obtained during the undergraduate career helped in shaping this project. Leadership, management skills, interpersonal communication skills, discipline, conflict resolution etc. are some of the other qualities that were necessary to be successful in this project.

In terms of specific skills and knowledge gained, operation of different circuit block and how they perform when integrated were valuable lessons. Small tolerances can be amplified and cause a huge distortion in results. One needs to be particularly careful of tolerance levels when integrating. Before the final demo when the prototype device was not giving us desired output, we had to take it apart and test individual components. From testing the accuracy of a resistor value to the performance of a shifter circuit as a whole – these kinds of tests helped clear a lot of concepts that I had earlier learnt about in other courses.

Also during the write up of various reports, it showed the importance of documentation. As an engineer it is easy to get carried away by the technical side of a device. But if proper documentation is not maintained, not only it becomes harder for troubleshooting/ upgrading later on; but also it becomes very hard to understand what the other member of the group may have tried to do.

Overall, it was a satisfying experience. Although there were the frustration of feeling lost and sleep deprived from time to time, I feel this experience will hold me in good stead for the future.

Zhouhao Cui

This project requires a lot of hard work, determination and very good time management skills. When taken with other courses, time management becomes especially crucial. For the ASCA device we used the Arduino Duemilanove which uses the Atmel ATmega328 chip. It was the first time I programmed this chip. Initially a lot of time was spent to understand how it functions. The manufacturer's website was a big help. The manufacturer has provided a software to program this chip which is mainly C++ based. With my knowledge of C++ I was able to program this chip as desired. At times it was a bit tricky to perform certain operations. I would certainly say that my C++ skills were enhanced after doing this project.

During the design process, a shifter circuit and a voltage regulator were necessary. I did a number of researches and was able to find relevant designs for the ASCA device. After collecting necessary components the circuits were built and were tested and optimized according to the need of the device.

It was also a learning experience working on such an involving project in a team. Not only it increases responsibility on each member, but at time one has to stand up and take leadership to get the job done. Managing time with other course related work was a challenge, but not impossible.

Amir Najafzadeh

At the end of this project, I was able to map my university studies with applied concepts and practices. It is easier to understand them in theory as most scenarios are considered ideal. In the real world, where the theory is applied, the results usually are not the same as of the 'ideal' world. We were able to observe this fact throughout this project.

Having specific tasks with set deadlines help shape a project. Deadlines in real world are much more crucial as most of the time work is done in team. Delay on one's behalf can cause the whole team to slow down. That is why managing one's time is very crucial in such group projects.

I had done a number of different tests on Hall Effect sensors. Throughout my tests I observed that DN6847 Hall Effect Sensors were much more accurate and gave a better, more concise value than A1323LUA-T Hall Effect Sensors. Also, how the sensor is held against a live wire matters too. Not only in its orientation, but also in angle as the magnetic field varies at different positions and different angles.

In order to create a test setup where the ASCA device could have been tested we needed to simulate live wire which had high voltages and high current running through it. I designed the test setup using a kettle to obtain such a scenario and appropriate tests were done.

Milad Moezzie

This was a very well structured learning curve in my educational career. I was able to utilize the knowledge accumulated over the last 4 years during my undergraduate studies. There were a lot of concepts that were integrated during this project. Initially we identified the primary components necessary to build the ASCA device. From there on it was a journey on how to combine these components and what other circuitry we may have to add in between.

Throughout this process, it was identified that, a shifter circuit will be essential and one was designed. Voltage regulators were also necessary both for the HE sensor and the shifter circuit. I was involved in heavy testing of the HE sensor. We faced a number of dilemmas when testing these sensors. Initially the sensors were not strong enough to detect the magnetic field. We had to order different sensors to find out which one may be a viable option for the project. During these tests I observed how the magnetic field intensity changes due to a change in distance, radius of conductor, angle or position of sensor etc. all of these test results support the theory related to magnetic field.

Shifter circuit shifts a certain voltage level to another voltage level. It can also be designed to amplify that certain range to a more favorable one. Finding proper output voltage range values for the shifter circuit was a challenge as the input voltage range was so little (~40mV). We had to test it a number of time with variable resistors. It was interesting to watch the different gains obtained at different times.

Sufficient communication skills, problem solving skills and time management skills were also necessary to achieve success in this project.

Conclusion

Prospect1 Inc. is planning to enter the Auto-Splice Conductivity Analyzer to the market after passing all the safety and quality assurance tests. In terms of pricing the Auto-Splice Conductivity Analyzer is manufactured at a very reasonable price and thus would easily attract potential vendors.

References:

[1] Ensuring the Health of Our Power Lines, “Power line and connector splice sensor”, http://www.swri.org/3PUBS/ttoday/Summer06/PoweLines.htm

[2] http://www.national.com/images/pf/LM317/00906301.pdf