Power Scraping Module

DESIGN DOCUMENT

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Executive Summary

Development Standards & Practices Used

1) **Digital design standards**
   - Quartus prime circuit design for FPGA board.
   - Cadence simulated circuit testing.

2) **Circuit standards**
   - Readable circuit designs that follow design conventions.

3) **Electronic safety standards**
   - Follow all electrical safety procedures.

Summary of Requirements

1. Use an input of 1.1 V AC to charge a super capacitor and provide an p-p output voltage of at least 3 VDC.
2. The sinusoidal input is the only input in the system.
3. Must provide indication that the selected device is charging.
4. Provide estimation of how long a 20mA LED can be powered for every hour of charge time.

Applicable Courses from Iowa State University Curriculum

EE 201: Electric Circuits
EE 230: Electronic Circuits and Systems
EE 224: Signals and Systems I
EE 324: Signals and Systems II
EE 330: Integrated Electronics
CprE 281: Digital Logic
CprE 288: Embedded Systems I: Introduction
MATH 165: Calculus I
MATH 166: Calculus II
PHYS 221: Introduction to Classical Physics I
PHYS 222: Introduction to Classical Physics II
ENGL 314: Technical Communication

New Skills/Knowledge acquired that was not taught in courses

Product research and acquisition
Budget management
Professionalism and communication

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1 Introduction

1.1 Acknowledgement

Our team would like to thank the Department of Electrical and Computer Engineering for providing our team with resources, consultations, and experiences of the highest quality. We would like to thank our advisor professor Gary Tuttle, our client Micheal Retzler and Dakota McGilton for meeting with us bi-weekly and guiding us through the development process of our product. The team also appreciates the University's Electronics and Technology Group's (ETG) availability for providing all of the components for our project.

1.2 Problem and Project Statement

As the power needs for remote data transmission gets more efficient, there is a benefit to being independent of a replaceable power source. Collecting, converting and storing low voltage energy has its own unique challenges.

The goal of this project is to take a small and unusable AC voltage as a source and convert it to a usable DC voltage that can power various components in a system.

To accomplish this, an AC voltage of 1.1V peak-to-peak signal will be converted and boosted to a higher DC voltage preferably 3.0 V or greater, at which point it will be used to charge a power source, a battery or a super capacitor. The charged source can then be used to power elements in the system. We would be using a 20mA LED to make sure that our system is charging. Our LED will also show whether or not our is supercapacitor is already charged.

1.3 Operational Environment

The product is intended for a general use application, but it may be tailored to fit specific needs. For example, there may be cases where a remote microcontroller will be transmitting signals to a collection site. This application would be ideal when transmissions are infrequent or located in an unserviceable site.

1.4 Requirements

As stated earlier, the technical requirements are as follows:

- Use an input of 1.1 V AC Peak to Peak to charge a super capacitor and provide an output voltage of at least 3 VDC
- The sinusoidal input is the only input in the system
- Provide indication that the selected device is charging
- Provide estimation of how long a 20mA LED can be powered for every hour of charge time
- The overall device must be contained within a 6" by 6" space

1.5 Intended Users and Uses

The intent of this project in regards to our client is to research and develop a device that can collect, convert, and store low voltage energy. The purpose of the device we are building is an independent rechargeable power source to support power needs of remote data transmission. Our device would harvest and manage surplus energy from an energy harvesting device that would serve as low voltage input. An example use case would be for a photovoltaic cell to input into our device that will store energy over a period of time until enough is stored to power a wireless sensor in a network for a photovoltaic power station.

1.6 Assumptions and Limitations

Assumptions:

- Only one AC power source that is less than or equal to 1.1 V peak-to-peak
- The device will be protected by an encasing to prevent exposure to extreme operating conditions

Limitations:

- The cost to produce prototype and end product cannot exceed client budget
- Time constraint on exploring different approaches to generating a solution

1.7 Expected End Product and Deliverables

Semester 1:

1. **Project Timeline and Responsibilities document**
   A project timeline including technical tasks to be accomplished, and a tentative schedule of our meetings was requested by our client. In addition, we were asked to show which member of our group was responsible for each task to ensure that all members are contributing.

2. **Final Presentation**
   The purpose of this presentation will be to extensively review our system design, give a progress update on the prototype construction and testing, and give a look at what we intend to accomplish next semester.

3. **Mid-year Report**
   This design document will serve as the mid-year report as requested by the client. This document includes the research that went into the project, design proposal, and performance expectations.

Semester 2:

1. **Project Timeline and Responsibilities document**

   A project timeline including technical tasks to be accomplished in the second semester, and a tentative schedule of our meetings. An updated responsibilities document will outline the roles that members will need to perform for the finalization of the project.

2. Demonstrate Final Constructed Design

The final presentation in May 2020 will revolve around the analysis of our completed circuit design. We will provide test results to demonstrate the performance of circuit along with a live demo of our prototype. We will also display the fabricated PCB and disclose the work that went into making it.

3. Year-end Report

The final report will provide extensive details on the testing of the prototype and costs involved for the completion of the project. We will also write a reflection on the process of creating our design and lessons learned along the way. Lastly, we will provide suggestions of how this particular project can be improved.

2. Specifications and Analysis

2.1 Proposed Design:

Our proposed design includes the following:
A low voltage AC input signal will be fed into a rectifier circuit where it will be converted to a nonnegative signal. The signal will then be boosted to a larger voltage of around 3.3 V which will be used to store charge in the supercapacitor. The power supply will then power a 20mA LED and transmit power to other desired areas in the device.

The team has researched potential low-voltage and precision rectifiers that can be used, as well as which supercapacitor will best fit the needs of the project [1]. we also found boosters that will help us achieve the highest voltage boost while taking up lowest amounts of voltage. This is a schematic of our proposed design, we need more testing to figure out whether we will be making some changes to the design:

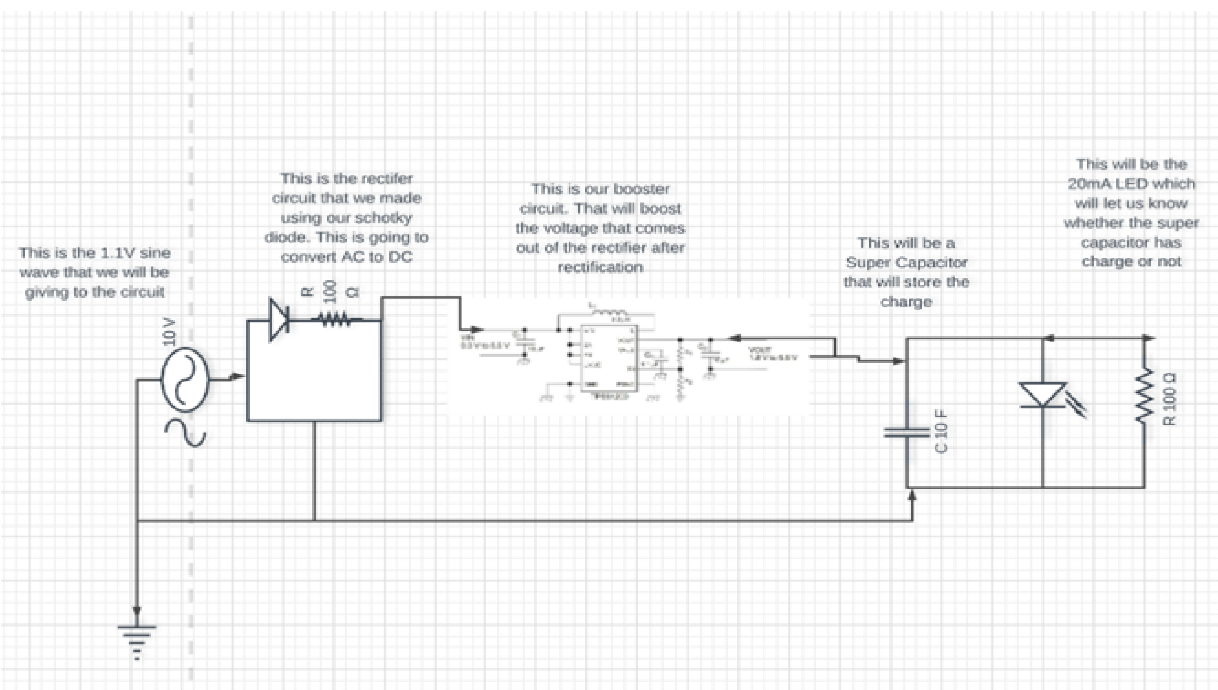

Figure 2.1.1 - Design Proposal Diagram

2.2 Design Analysis

Before we are able to analyze our entire design based on integrated testing, we have to analyze the effects of the individual stages on the system. Given our progress thus far into the semester we anticipate a full design analysis of our initial proposed design to be completed in January. There are three primary stages for the design of our system: rectification, boosting, and storing. Below is a design analysis of each thus far.

The first stage as mentioned in the proposed design section is the rectification stage. Here the main component is schottky diode which features a low voltage drop. Part of our design analysis is to explore two configurations for this stage: a full-wave and half-wave rectifier. A full-wave rectifier is more advantageous because it utilizes both cycles of the input thus allows for faster charging. The drawback of the full-wave rectifier is that it was expected to have a larger forward voltage drop than the half-wave. After initial testing we determined that the difference in voltage drop for the full-wave versus the half-wave is negligible. Thus we are going to implement the full-wave rectifier for the breadboard prototype. This design choice means that we will be able to charge the supercapacitor quicker while also still being able to strive for as low an input as possible.

The second stage of our design is the booster stage. Unfortunately, the booster we decided on and ordered has not been performing as expected. Testing for this stage has not produced results that demonstrate it can be used in our final design. When conducting our testing we saw that the booster we chose was able to boost the voltage significantly. However the voltage dropped rapidly almost immediately and went back to the initial voltage level. We are still determining why our booster does not work as expected. If this particular booster does not work we will explore finding or building one. Building a booster would significantly affect our project timeline, and may not perform well as pre-existing solutions.

The last stage of our design is the energy storage stage consists of a supercapacitor. After testing of this stage we confirmed the part ordered worked as expected. We do not anticipate any design changes for this stage at any point during the development process.

Our greatest strength in our design is the performance of our rectification stage. A primary objective of this project is to see how low of an input we can scrape in a usable DC voltage. The rectification stage potentially enables us to have input voltages around .4-.6 V peak to peak. Initially we suspected the voltage drop would be more significant and thus limit our ability to strive for a low input. Currently our greatest weakness is the booster stage because the component we selected is not performing as expected. If we can figure out what is wrong with the booster then the next challenge will be finding ways to improve on the efficiency of our design.

2.3 Development Process

Our development process will consist of continual testing, flexibility with design adjustments, and biweekly meetings with our client and faculty advisor. We will designate members that represents the clients interest by ensuring we are maintaining the requirements for the project. Other members will be in charge of being the primary contact for the client and facilitate our technical progress meetings. At these meetings we will create, and prioritize a backlog for the upcoming week then delegate responsibility based on availability. Since we will be solely working with hardware for the first semester diligent documentation will be of the utmost importance to keeping all members up to date on team progress.

2.4 Design Plan

Our design plan includes four stages: define, ideate, prototype, and testing. The intended purpose behind the first stage, defining, is to inform ourselves of the problem we are solving, and what solutions already exist. In this stage will meet with our client to help define the problem and constraints given their potential application of our design. Using the information acquired in the first stage to facilitate the ideation process. Here we will hold separate meetings for brainstorming solely with the team and with the faculty advisor. Once we determine what direction the project and confirm with advisor and client we can begin prototyping. We will prototype on a breadboard and determine if our proposed design meets client expectations. If it does we can begin to finalize our design. If not we will have to modify design or find a different approach. In both cases we will provide insight about our design and performance limitations to our client.

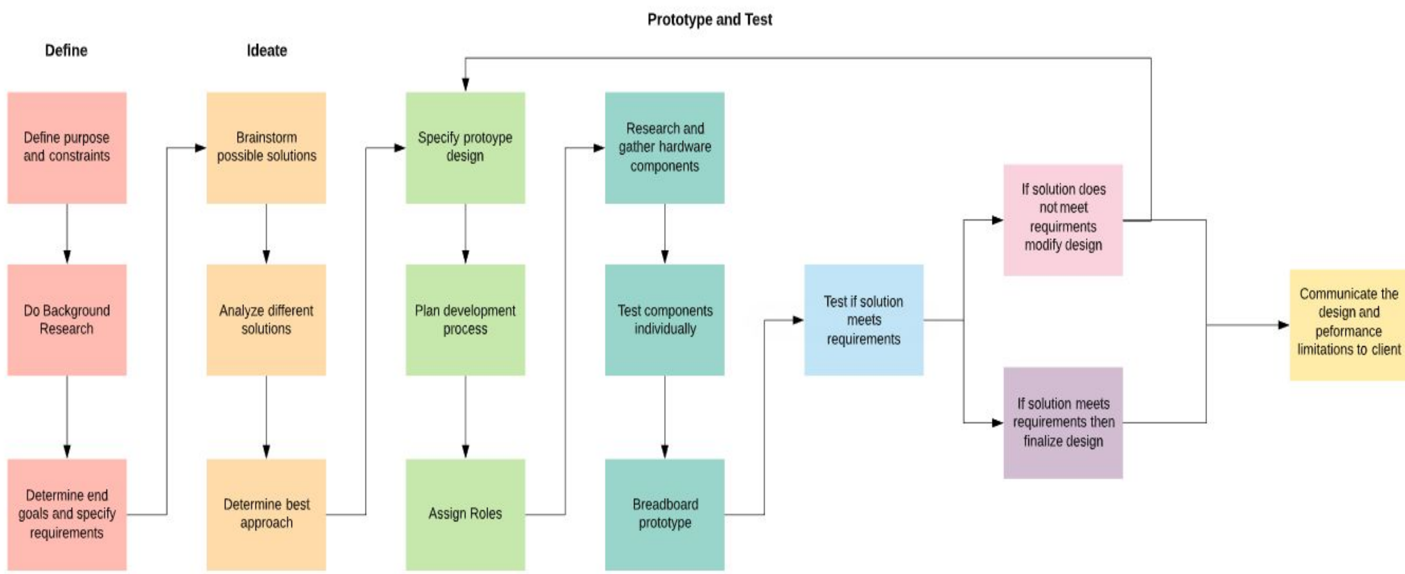

Figure 2.4.1 - Design Plan Diagram

3. Statement of Work

In this section we will be talking about all the work that we have done and what this project is about. We will be talking about the various considerations that we made in terms of the parts we used, the references we consulted, the documents we took some inspiration form and also how we plan on accomplishing all the tasks for this project.

3.1 Previous Work and Literature

We will be using Ultra-low Voltage Step-Up Converter and Power Manager manual written by Analog Devices, this document talks about ways and parts that are used and needed to convert very low voltages to high output voltages. One aspect of the project that is really similar to our project is that it makes use of an input AC voltage and then uses a rectifier to convert that low voltage into a DC signal and then also uses a booster to pump up to the voltage of our choosing.

There are technologies that exist and perform the same tasks but our voltage limitation of only 1.1 V P-P AC makes them less usable for us. Most of the devices that exist boost voltages from 2 V or higher to a specific output voltage. One other novel thing is that we are storing our charge, after the boost and rectification, into a super-capacitor as opposed to a battery and then feeding that charge to a 20mA LED that will help us see the time the Super-Capacitor can keep the LED lit.

The following list are the components selected for this project:

1. Supercapacitor [2]:

Digikey number :1572-1771-ND
Manufacture number: **DGH105Q5R5**

2. Schottky Diode [3]:

Digikey number: 1655-1922-3-ND;
Manufacture number: **95SQ015**

3. DC to DC Voltage Booster [4]:

Manufacture number: **TPS6120x**
Data sheet: http://www.ti.com/lit/ds/symlink/tps61200.pdf

3.2 Technology Considerations

Most of the technology that is used and available is not compatible with AC to DC operations. They are either available in AC to AC or DC to DC. Our project is a bit distinct in the sense that we are supposed to rectify our AC voltage input signal to a DC voltage using a rectification process. Unfortunately, the rectifiers that are readily available are mostly made up of diodes that require at least 0.7V of voltage drop. Unfortunately, we only have 1.1V input to feed the rectifier and to boost the voltage. This forces us to use a booster first to boost our voltage close to 4V and then instead of using a normal diode, that requires 0.7V of voltage drop, we use Schottky diodes that require only 0.3V of voltage drop. This will help us retain more voltage to boost it up to the required 3.3V and above.

Another limitation that we face is the fact that we are using a Half Wave Rectifier as opposed to a Full Wave Rectifier. The use of a half wave rectifier will significantly increase our time to charge the super-capacitor and the use of a full wave rectifier will increase the voltage drop giving us less voltage to work with in the first place. This is just a limitation that we would have to deal with because there is no technology in our knowledge that can help us retain most of the energy lost in rectification.

3.3 Task Decomposition

In order to solve the problem at hand, it helps to decompose it into multiple tasks and to understand interdependence among tasks. Our first job is to find the accurate design to make sure that it can help us achieve the required output. Use of a booster first will not work since most boosters take DC as input to give DC as output or take an AC as input to give AC as an output. This forces us to use just a rectifier first and then boost it up to the required voltage that would be stored in the super-capacitor: so here are the tasks that we would be doing.

1) Start researching all the parts, The booster, rectifier, super-capacitor and the LED

2) Choose a good booster that can take as low of a voltage as possible and then boost it to 3.3V and above

3) Make use of Schottky diodes that only require voltage drops of 0.2 to 0.3 V for them to operate. Use of normal diodes with 0.7V of drop will make our design options useless.

4) Choose a super-capacitor that can store a charge of 1 Farad or less. The higher the charge the level the longer it will take the super capacitor to charge.

5) Connect the external input source of 1.1V to the rectifier for rectification from AC to DC. Then use that DC voltage to pass it through the booster so that it can amplify the voltage to 3.3V and above. Store that charge into the super capacitor and then use that to light the LED.

As you can see, a systematic approach is needed to make sure that everything works the way it is needed and is also in the correct order due to the dependence of one part on to the next one.

3.4 Possible Risks and Risk Management

Risks:

Following are some of the risks that we will face during our project:

1. Making sure that our booster works as intended and amplifies a very small voltage usually in the range of 0.6-0.7 V to 3 V or above.
2. The diodes that we have bought should rectify the signal properly and do it with the least voltage possible. The reason for that is the fact that the more voltage we have at hand, the higher the boost in voltage that we can get out of the booster.

3. The super capacitors have a large enough capacitance to hold all the charge in the system, but not so big that it takes a very long time for the system to charge.

Risk Management:

Following are some of the ways we are going to tackle them:

1. We must make sure that we test each of the components for proper testing before the actual design for proper operation of the device.
2. If the booster does not work the way we intended it to work, we will have to make our own booster, fortunately we have proper designs for making a booster.
3. Consulting our faculty and our client for possible solutions to problems that are outside our skill level.
4.

3.5 Project Proposed Milestones and Evaluation Criteria

Preliminary design schematic:

Our first job would be to make a design schematic and test on a software such as P-spice to make sure that our design performs the way we intend to, by using the parts we deem would be needed for its proper operations.

Identify parts:

After our preliminary design is cleared in terms of what we require, we would want to make sure that the parts we choose meet the design schematic requirements as outlined by the client.

Complete design schematic:

After we have chosen our parts, we would have to make sure that we make any necessary changes that must be implemented for proper operation of our design after getting the parts and looking at their specifications.

Breadboard prototype:

Now since we would be done with the actual schematic and design, it is time for our testing of the design physically on a breadboard to identify any changes we can make to the design for its smooth operations

PCB prototype:

If everything works as we intend in the breadboard testing phase, we would be using the same design and implement it on a PCB prototype. That final design would be tested again for proper operation.

Evaluation Criteria:

These are the evaluation criteria that will determine the accurate working of our project:

1. Preliminary schematic must theoretically be able to perform desired functionality
2. Parts used must fit within project budget
3. Complete schematic must theoretically function within parts' characteristics
4. Breadboard prototype should function as desired before creating PCB prototype
5. PCB prototype must meet all functionality of project proposal

3.6 Project Tracking Procedures:

Using our timeline and project milestones, we will be tracking our progress by comparing our completion of the listed milestones against our planned deadline for those tasks. In addition, we will upload bi-weekly progress reports on our website. These reports will include what was accomplished that week, what are the assigned tasks for the upcoming week, and how many hours have been contributed by each member since the last report.

During our meetings with our faculty advisor, and client we will write down notes and upload to a group messaging platform. This would be done to ensure that everyone is aware of their responsibilities for that week, this will also ensure that we can hold each member of the team responsible for their tasks. Lastly, all progress will be documented in a shared google folder. This includes test results, class assignments, and an updated project timeline.

3.7 Expected Results and Validation:

Some of our main expected results would be to systematically test each of the parts in a simulated way so that we can test their validation and workings in an affected way. This would make sure that when we put everything together and we find a problem with our design we know where to look, this is one of the ways we would be making sure that our design is valid. The desired outcome at the end is that the finished module will work as an efficient power scraping device to effectively charge the supercapacitor using a low energy input signal. We will confirm that our solution works at high-level by testing this general-purpose module in a variety of usage scenarios to confirm its versatility. If multiple instances of our design can work effectively across these generalized cases, then it confirms that our design will work at high-level.

4. Project Timeline, Estimated Resources, and Challenges

Following is the timeline, the roles and responsibilities of each individual and the estimated resources that would be required for us to solve the project. We will also mention some of the challenges that we faced during our design process.

4.1 Project Timeline

Following are some of the stages that we covered to get through this project:

First Stage:

During this stage, we formatted a team and discussed the project description. Then we determined that the primary objective of the project is to research and develop a system which will efficiently collect, convert, and store a low-level AC voltage into a larger magnitude DC voltage.

In the next meetings, we set the roles and responsibilities for each member in the team. We also had a good experience with meeting with our faculty and client to learn that the general use project is to create a rechargeable power source for devices that are used or serviced infrequently so that it might be impractical or impossible to charge by conventional means. By the end of this stage, we were able to have preliminary design schematic and initial analysis to determine the components specification that will include a low input boost converter, a super capacitor, a switched mode power supply and a precision rectifier. All the components will be placed in a way that our system works as per the functional requirements. The voltage will be first rectified into DC using a precision rectifier and then a low input boost converter will boost the voltage into the required 3V DC that is needed to be stored in a 1 Farad super capacitor

Second Stage:

During this stage, we searched for parts, confirmed budget and timeline. We used the primary documents from the Journal of Material Science and Engineering and it was an amazing experience to discover some interesting documents such as “AC to DC Bridgeless Boost Converter for Ultra low Input Energy Harvesting” [5]. By the end of this stage, we decided to look at the voltage boosters and rectifiers being used by the industry to get these kinds of voltage boost. While 1.1V to 3V amplification is not very hard, access to no external power source for the rectifier causes a significant technological challenge. Finally, we were able to finish initial design to meet the project expectations according to project timeline.

Third Stage:

During this stage, we will be designing and building a prototype for our project to see how it performs and look for ways to make the design more efficient. After our meetings with our faculty and client, we have decided to create a module that will have input an AC voltage of less than 1.1v Peak-to-Peak and will have an output voltage rectified to 3.0V or more.

Fourth Stage:

During this stage, we will be using a synchronous boost converter, a super capacitor, and a rectifier. All the components will be placed in a way that our system works as per the functional requirements. The voltage will be first rectified into DC then a low input boost converter will boost the voltage into the required 3V DC that is needed to be stored in a super capacitor. After testing the on breadboard and looking for improvement and efficiency, we observed multiple challenges such as rectification loss which became a main challenge for us because the common challenge of low voltage circuit design is the voltage drop across subcomponents.

After much experimentation and testing, we decided to use half wave rectifier because of less voltage drops and slower charging time. By the end of this stage, we finalized the prototype design, design document and presentation for the design.

TASK NAME	START DATE	END DATE	DURATION* (WORK DAYS)	DAYS COMPLETE*	DAYS REMAINING*	TEAM MEMBER	PERCENT COMPLETE
First Sample Project							
Team Formations & Project Descriptions	8/26	8/31	6	6	0	Shahzaib Shahid	100%
Team Expectation and Setting Roles	9/2	9/7	6	6	0	Andesen Ande	100%
Meeting with Faculty & Design Document Formation	9/9	9/13	5	5	0	Benjamin Yoko	100%
Project Description & Lightening Talk	9/16	9/20	5	5	0	Ahmed Salem	100%
Pre-liminary Design Schematic	9/23	9/27	5	5	0	Jordan Fox	100%
Second Sample Project							
Assigning project	9/30	10/4	5	5	0	Shahzaib Shahid	100%
Search For Parts & meeting with Faculty and Client	10/7	10/11	5	5	0	Andesen Ande	100%
Confirm Budget, Confirm Timeline and Schedule	10/14	10/18	5	5	0	Benjamin Yoko	100%
Weekly Status Report 4, Design Document Version 2 (near completion), Contact Client	10/21	10/25	5	5	0	Ahmed Salem	100%
Build a Schematic & meeting with Faculty on design options	10/26	10/27				Jordan Fox	100%
Third Sample Project							
pre-liminary Design Schematic, Weekly Status Report #3, Design Document Expansion	10/28	11/1	5	5	0	Shahzaib Shahid	100%
Look For Parts, Confirm and Discuss Design with Faculty and Client	11/4	11/8	5	5	0	Andesen Ande	100%
Discuss Design, Look For more Parts, Confirm Budget, Confirm Timeline and Schedule	11/11	11/15	5	5	0	Benjamin Yoko	100%
Weekly Status Report 4, Design Document Version #2 (near completion)	11/18	11/29	12	12	0	Ahmed Salem	100%
Get Parts, Build Prototype on Breadboards, Weekly Status Report #5.	12/2	12/6	5	5	0	Jordan Fox	100%
Fourth Sample Project							
Build Prototype on Breadboards, Design Document V3,	12/9	12/13	5	5	0	Shahzaib Shahid	100%
Testing of the Breadboard Prototype, Weekly Status Report 6	12/10	12/14	5	5	0	Andesen Ande	100%
Check For Issues, Testing For Improvements, Design Efficiency Check	12/11	12/15	5	5	0	Benjamin Yoko	100%
Final Prototype Design and Testing. Final Design Document	12/12	12/16	5	5	0	Ahmed Salem	100%
Final Presentation for the Design.	12/13	12/17	5	5	0	Jordan Fox	100%

Figure 4.1.1 - Timeline and Task Breakdown

4.2 Feasibilty Assesment

The objective of the project is to create a circuit that takes in low input signal, boost, and stores that signal for later use. Our client has tasked us with researching the limitations from a design and components standpoint. Ideally we would like to explore a couple different design approaches such as using an IC transformer to boost the input signal before rectification. The biggest challenge will be to minimize losses in our circuit while operating at an extremely low voltage. We expect our complete proof of concept to provide useful insights into the limitations into a specific design approach.

4.3 Personnel Effort Requirements

This table represents the main tasks necessary to complete the project. Each major task is listed, described, and given an estimated time of completion. Justifications for each time estimate are given, but completed prior to any work. All time estimates are subject to change during the development process.

Table 4.3.1 - Task Breakdown for Project

Task	Description	Approx. Completion Time
Research Power Scraping Module	Research key topics: rectification, supercapacitors, DC-DC boosters.	5 hr This task includes all team members gathering information online.
Create an initial design of circuit	Outline objectives given by client. Brainstorm different designs and research components as a team. Assess design with client and faculty advisor.	15 hr Will require separate meetings between team, faculty advisor, and client.
Select and order components of the design	Browse the Digikey website and other resources for components for the prototype circuit. All parts must be approved by client and faculty advisor.	10 hr The collective time for each member to thoroughly research parts and agree on each other's selection.
Component Testing	Once the parts are received use lab instruments to test if parts perform according to part description.	15 hr We anticipate testing the booster module may take more time than other components because we are less familiar with it.
Integration Testing	Connect circuit components each stage at a time and test the performance	15+ hr Integration testing anticipated to take at least as long as the time required for testing individual components

Roles and Responsibilities:

Following are some of the roles and responsibilities that each one of us has to do during this year. These documented responsibilities will ensure that each member is held accountable for the responsibilities that the member does not finish.

Roles and Responsibility		
Names	Roles	Tasks
Shahzaib Shahid	Team Leader	Team Expectation and Setting Roles
		Preliminary Design Schematic
		Weekly Status Reports
		Meeting with Faculty & Design Document Formation
		Project Description & Lightening Talk
		Final Presentation for the Design
Jordan Fox	Chief Engineer	Confirm Budget, Confirm Timeline and Schedule
		Discuss Design, search For parts, confirm Budget, confirm timeline and schedule
		Final Design Document
		Weekly Status Reports
		Project Description & Lightening Talk
		Meeting with Faculty & Design Document Formation
Andesen Ande	Design Engineer	Look for parts, confirm and discuss design with faculty and client
		Get parts, build prototype on breadboards, weekly status reports
		Weekly status reports
		Meeting with faculty & design document formation
		Project Description & Lightening Talk
		Final presentation for the design.
Ben Yoko	Test Engineer	Final prototype design and testing.
		Testing of the Breadboard prototype, Weekly status report
		Check For Issues, testing for improvements, design efficiency check
		Weekly status reports
		Project Description & Lightening Talk
		Meeting with Faculty & Design Document Formation
Xiangyu Cao	Design Engineer	Look for parts, confirm and discuss design with faculty and client
		Get parts, build prototype on breadboards, weekly status reports
		Weekly status reports
		Meeting with faculty & design document formation
		Project Description & Lightening Talk
		Final presentation for the design.
Ahmed Salem	Test Engineer	Final prototype design and testing.
		Testing of the Breadboard prototype, Weekly status report
		Check For Issues, testing for improvements, design efficiency check
		Weekly status reports
		Project Description & Lightening Talk
		Meeting with Faculty & Design Document Formation

Figure 4.3.1 - Roles and Responsibilities of Team Members

4.4 Other Resource Requirements

In this section we will talk about all of the primary and secondary resources that we have used in our design:

Primary Resources Needed:

- Breadboard, and wires
- Supercapacitor - roughly 5 devices
- Schottky Diode - roughly 10 devices
- DC-DC booster - roughly 3 devices
- Power Supply, oscilloscope and digital multimeter provided by Iowa State University lab
- Scope of Work (SOW) provided by the client.
- Products specifications provided by supplier.
- Notes provided by the clients.
- Notes provided by the professor.

Secondary Resources Needed:

- Textbooks ,book reviews and research papers.
- Iowa state onlines primary the library.

4.5 Financial Requirements

The total budget for the completion of the project is expected to be less than $400. This amount is a conservative figure that accounts for both the prototyping and PCB fabrication costs for our circuit. Below is our first semester budget table that accounts for all materials that are not provided by Iowa State University. The difference between the total budget and the first semester budget is the money allocated for the PCB fabrication. Since we are not able to give an estimate for the PCB due to several factors affecting cost we gave a very conservative number well within our client's budget.

Table 4.5.1 - Budget for components to be ordered

Part Name	**Seller**	**Part Number**	**Amount Ordered**	**Total Cost per part**
Supercapacitor	Digi-Key	1572-1771-ND	5	$14.35
Schottky Diode	Digi-Key	1655-1922-3-ND	10	$5.02
DC-DC Booster	Digi-Key	1568-1155-ND	3	$47.85

Total Cost	$67.22

5. Testing and Implementation

In this section, we will present information regarding the testing we did for our project. This includes equipment testing, individual component testing, and system-level testing.

5.1 Interface Specifications

For testing of our prototype circuit lab instruments will be used to determine that each individual circuit component works as expected. Once we confirm that each component works separately we will begin to implement our circuit each stage at a time. Our plan is to test and observe how each individual component behaves when interfaced with another. This methodical way of testing allows us to identify any issues that may arise with interfacing immediately. Once our entire circuit performs as desired on the breadboard we will begin the next semester extensively testing. We will test different inputs and measure for every hour of scraping how long we can drive a 20 mA LED to understand the performance and design limitations.

5.2 Hardware and Software

The hardware used for testing our circuit includes a breadboard, multimeter, oscilloscope, and function generator, Cyclone IV FPGA. A breadboard is a construction base for rapidly prototyping a circuit. Circuit components are inserted into holes with metal strip bottom layer making it convenient for connecting instruments and other components. A multimeter is a device that can measure voltage, current, and resistance. Multimeter is used to observe that each individual components are working as intended. Tektronix 3021B function generator is a device that produces a time-varying voltage signal that is used as the input for our circuit. Agilent DSO-X-2024A digital oscilloscope is a device that takes voltage measurements rapidly and plots voltage as a function of time. The oscilloscope is used to observe the input-output relation to confirm the diode is rectifying as expected. The FPGA board is mainly for the user interface implementation and Quartus Prime is the main software we will be implementing the user interface. We will be using each of these five hardware tools to extensively test our parts and then the final operations as well.

5.3 Functional Testing

Functionality tests will be ran often throughout the development process to ensure that we are adhering to the client expectations as well as able to quickly identify what specifically is the problem. We will implement three phases of testing: unit, integration, and system. This a methodical approach often used in a software development however the principles of this method apply to the hardware development process.

The first phase is unit testing which will consist of evaluating individual circuit components. All unit test process are detailed in section 5.5, this section will briefly discuss the purpose and performance expectations. Our design as stated previously is comprised of three main components. The first unit test will be for the schottky diode. Here will will conduct two separate unit tests for two different configurations to gather information about the voltage drop. The results of this unit test will aid in us making a design choice as well as shaping our expectations for the next phase of testing. The second unit test will be for the supercapacitors. Here we were given nominal values from the manufacturer about the capacitance. In practice these values are not ideal, and thus need to be measured for true capacitance values and labeled. This is done to track if the components are within tolerance and to understand the results of later testing phases. The last unit test will be performed on the booster module to ensure that it boosts voltage within the advertised range of .3-5.5 V. For our application we will consider the lower part of the range.

The second phase is integration testing which will consist of evaluating circuit performance after adding parts sequentially. We will perform two separate integration tests. Our first integration test will be to connect the rectifier output to the booster module input. The output of the rectifier stage will me a DC voltage however we have must assess if the ripple voltage is small enough to not distort the output. If the smoothing capacitor value is correct then this should not be an issue. We will also check to see what the maximum and minimum output of these two stages are. The second integration test will consist of using lab generated signal as input for the booster and connecting the supercapacitor. This test will be a sanity check to see if these two components are behaving as expected.

Lastly, we will perform a full system integration test where all three components are connected and evaluated. Here we will input the 1.1 V peak and peak and decrement by .05 or .1 V and evaluate the output. We will probe at the connection points on the circuit to confirm results are consistent with expectations and evaluate the system output. We will measure for every hour of power scraping how long we can drive a 20 mA LED. All functional requirements as outlined from the client will be considered during this phase of testing.

5.4 Non-Functional Testing

Efficiency Testing:

There are three stages of the system that can improve the efficiency of the module.

1. Rectification Stage:
   The design we have now indicates that the full wave rectifier with the smooth capacitor gives the best output signal to the booster. but if we can maintain the output stability of the full wave rectifier with half wave rectifier we can potentially improve the efficiency of the system [6].

2. Voltage Boosting Stage:
   The voltage booster we bought has an efficiency around 90% which is high enough. but there might be room for improvement with different usage.

3. Output:
   When releasing the power from the super capacitor we can reduce the leakage current to make full use of the energy collected. this can increase the efficiency of the system, in terms of outputting energy.

Usability and Compatibility:

Since the desired outcome of our device is a relatively simple concept, take a small AC input and turn it into a usable DC output, there are a variety of applications it could be used for. As such, the usability and compatibility of our project go hand in hand. The use case for our device is any larger circuit that has small,miscellaneous AC voltages that could be applied to a specific purpose. For compatibility, we need to ensure that our device can effectively power a small DC component (a microcontroller being the simplest example) without burning out the device. This may require simple modifications regulating the power output, depending on the application. Testing for these conditions will require a prototype device to determine that it can actually receive the small AC input, and then boost, convert, and charge/power another device. This testing will take place during the second semester of our design project.

5.5 Process

In this section we will be discussing all of the components that we will be using and also show the circuits that we will use for their testing:

Rectifier Testing:

The following is the schematic of the halfwave rectifier. The purpose of this testing is to accurately record the behavior of a single diode and the amount of rectification we can achieve with a single diode. The advantage of a halfwave rectifier is its output voltage is higher due to the number of diodes we use, which is one. It can potentially reduce the difficulty of the voltage booster stage of the system. The input testing signal is 1.1V p-p sine wave at 1k Hz frequency. The diode is 95SQ015 Schottky diode which has an ultra-low forward voltage drop at about 0.35V. Following is a schematic of the half wave rectifier circuit.

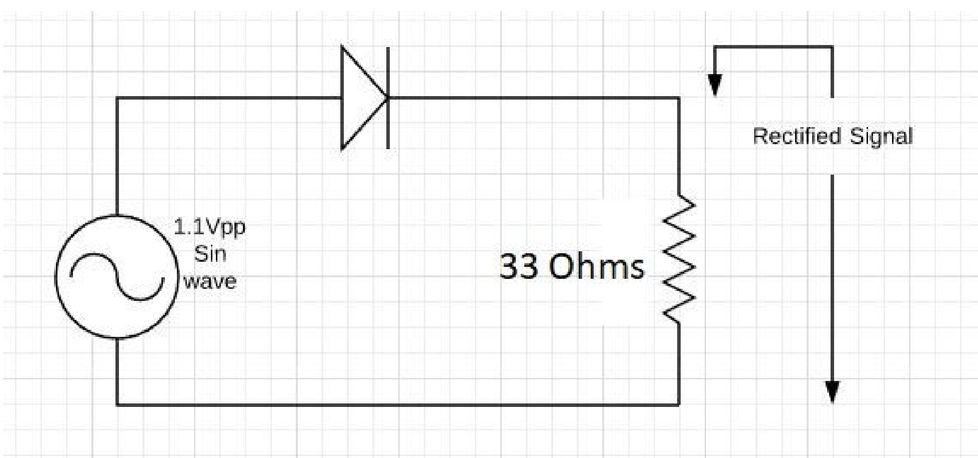

Figure 5.5.1 Half Wave Rectifier Schematic

The following is the schematic of the full wave rectifier design that we also tested to see which one is better for our design. The input testing signal is 1.1Vp-p sine wave at 1kHz frequency. The same diode is being used as in the half wave rectifier circuit. The only difference is that we have four diodes as opposed to one. The resistor is a 10k resistor. The expected waveform on the output end ideally is the absolute value of the sin wave. However, the input signal and output signal does not share the same ground, so it is not possible to present them on the same screen.

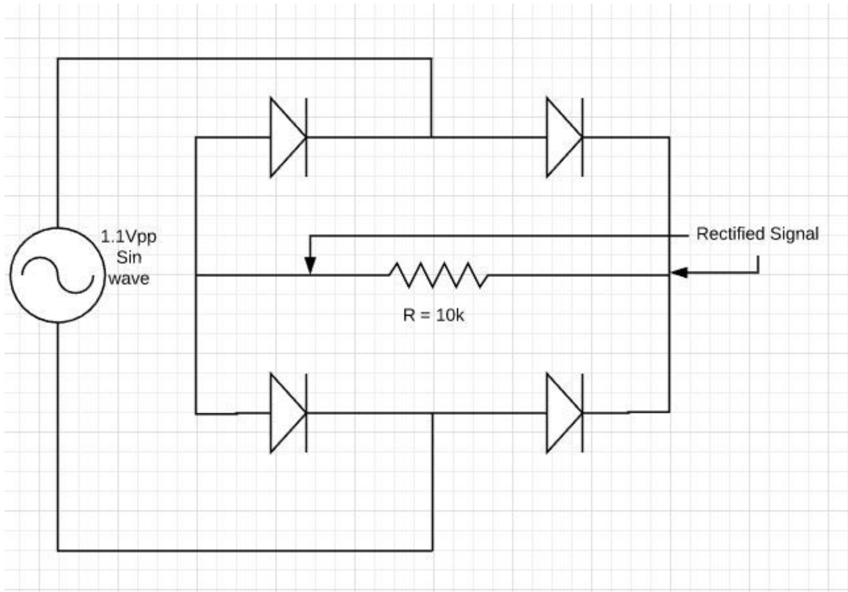

Figure 5.5.2 Full Wave Rectifier Schematic

The following is a schematic of another full wave bridge rectifier design that we used. we are using the same rectifier and the voltage source. However, we are adding a capacitor that has a 10uF capacitance. The advantage of this design is the Capacitor can smooth out the waveform to make it closer to the actual DC signal. The expected waveform on the output end ideally is the absolute value of the sin wave. following is a schematic of the design that we would be using:

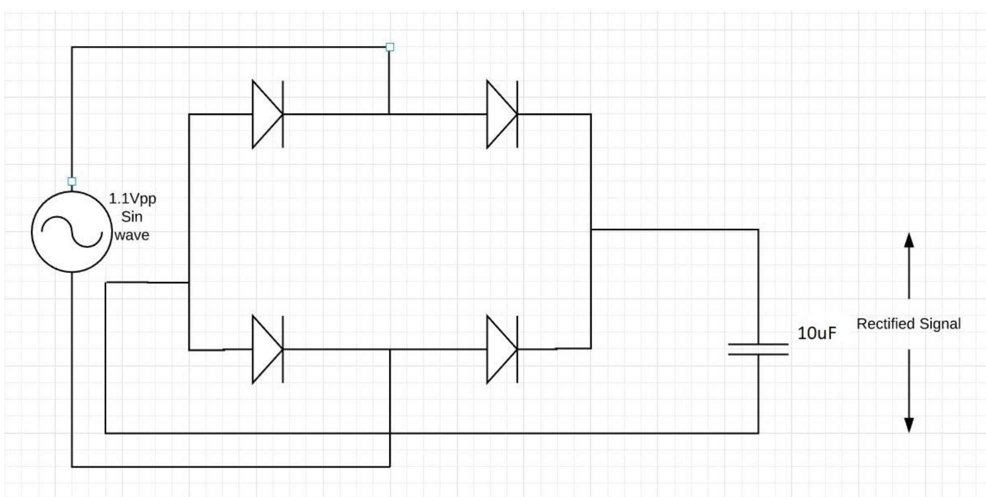

Figure 5.5.3 Full Wave Rectifier Schematic With Smoothing Cap

Booster Testing:

The following is a schematic of the voltage booster testing circuit. Since the senior design group got the booster in prototype board with all the components needed. So we can test the part directly with the protection circuit. The input we give the board was 0.3V DC, and we had a 10k protection resistor with the parasitic capacitor to prevent the analog circuit to interfere with the digital circuit.

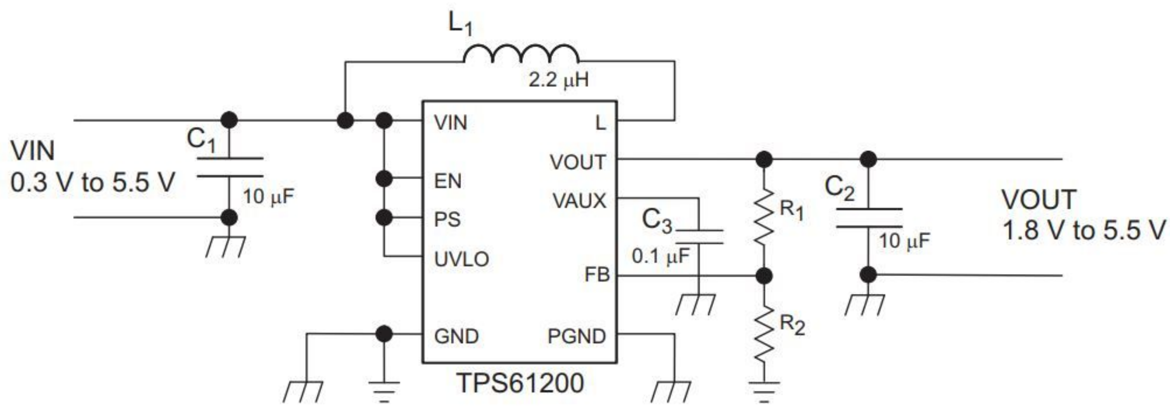

Figure 5.5.4 Booster Testing Schematic From Data Sheet

The booster was hooked up with a 0.3V DC voltage from a power source and the grounds were connected. A 10K resistor was also added in parallel as a protection resistor so that we don't burn the booster out. The following schematic shows how the circuit was hooked up onto a breadboard:

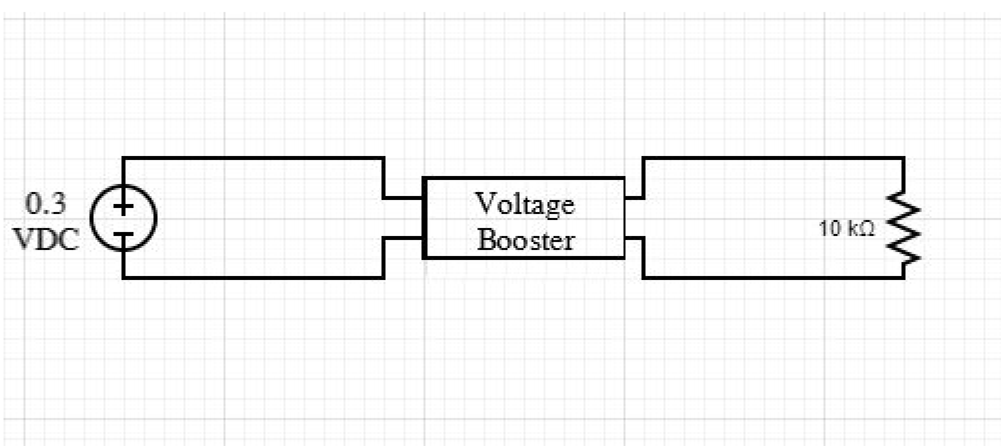

Figure 5.5.5 Booster Testing Schematic

After initial testing of the booster, the setup was reconfigured for an additional round of testing. This time, a 100 Ω resistor was placed in series with a red LED to act as the load of booster output. A DC voltage was applied as the input at varying levels, and a voltmeter was attached over the entire output to measure the boosted voltage. The results of this test are discussed in section 5.6 of the report.

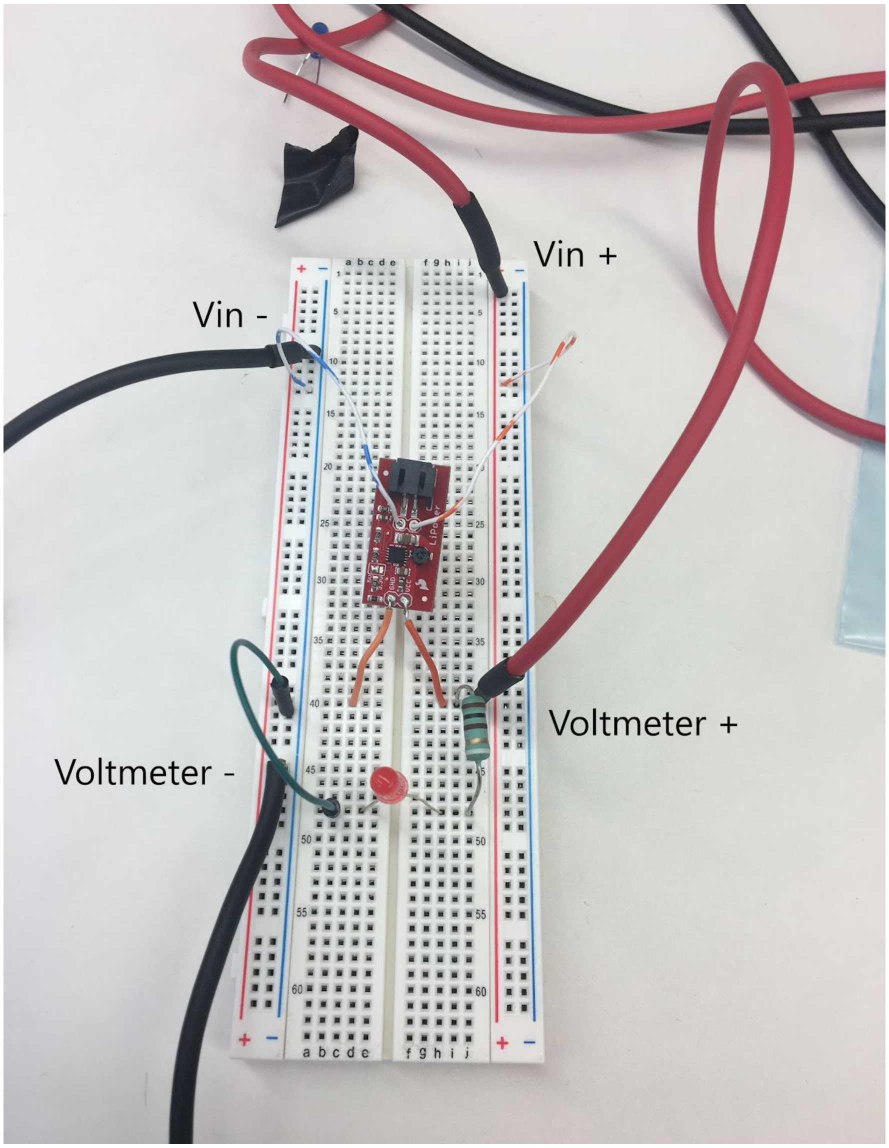

Figure 5.5.6 Breadboard setup for booster testing

Note: the ground output of the booster (lower left corner of chip) is completely isolated and does connect to the ground of the input. When this lead was connected to the grounding rail it appeared to short out the entire output and there was no voltage over the resistor or LED.

Super Capacitor Testing:

Functional Test - 1 Farad Supercapacitors:

One of the critical components to be used in the device is a 1 Farad supercapacitor. The team ordered five of these components, but before integrating them into the circuit, the characteristics needed to be verified. To test the capacitance, the following RC test circuit was constructed:

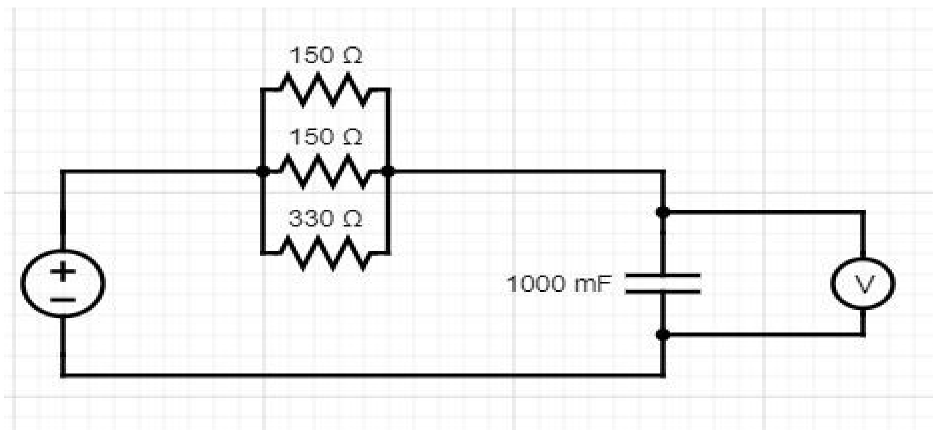

Figure 5.5.7 Supercapacitor Testing Schematic

Since the capacitors had such large capacitance value, they exceeded the limitations of the measuring equipment in the lab and had to be verified by measuring the voltage and time constant to calculate the capacitance value. The voltage supplied was 3 VDC for the input. A digital multimeter was attached across the capacitor to read the voltage value and monitor it over time. To do the test, a team member started a stopwatch at the exact moment the output from the power supply was turned on. The time was noted once the capacitor reached a voltage of 63.2% of the input voltage (in this case 1.896 VDC). Using this time value, in seconds, and the equivalent resistance of the parallel resistors, the capacitance of each capacitor was calculated and compared with its rated value.

A summary of data is provided in the following table:

Table 5.5.1 - Supercapacitor Testing Setup Information

Input Voltage	3 VDC
63.2 % Value	1.896 VDC
Calculated R_{EQ}	61.11 Ω
Measured R_{EQ}	65 Ω

An image of the physical test circuit used for testing is shown below:

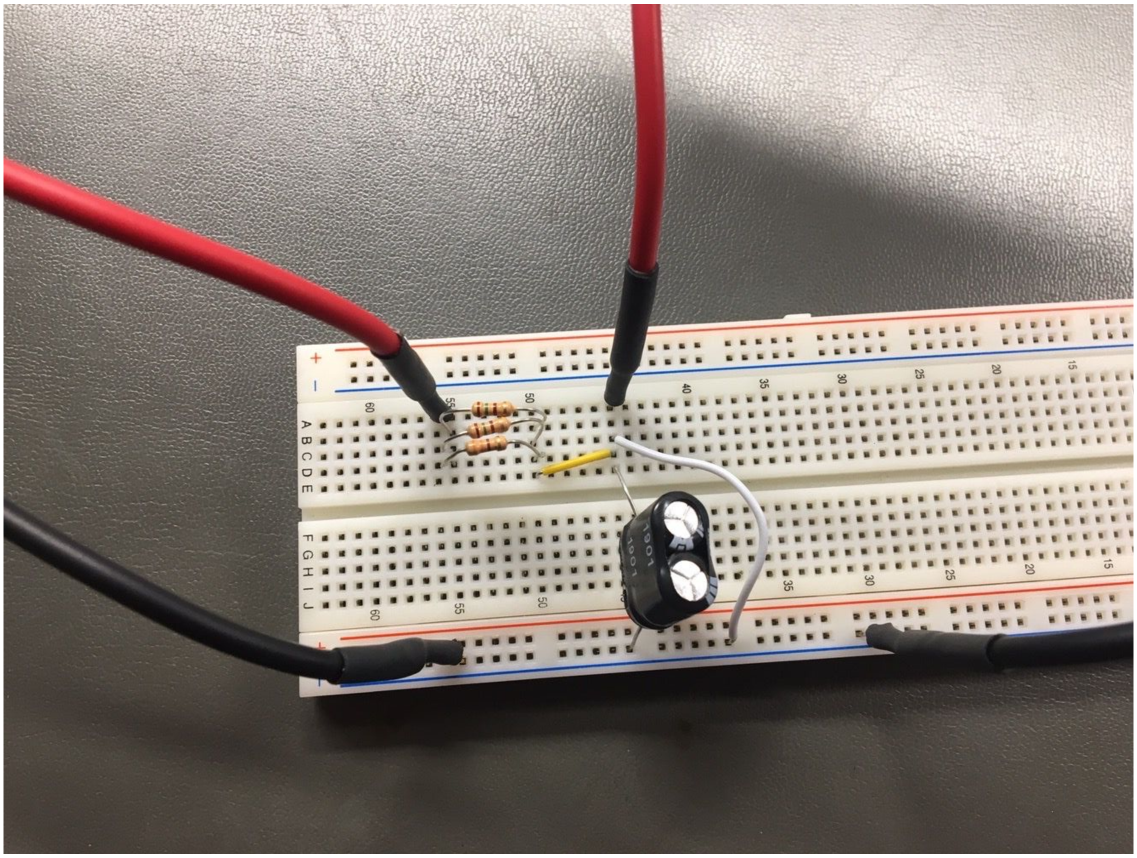

Figure 5.5.8 Supercapacitor Testing Circuit

The white jumper wire was used to short the capacitor to ensure it was fully discharged at the start of each test. It was removed simultaneously as the power supply output was turned on.

The results of the capacitor testing can be found in the following section (5.6).

5.6 Results:

Following are the results that we obtained for all of the components we tested, the way these parts were hooked up has already been shown in the section

Diode Testing:

For the single diode testing experiment we verified the forward voltage drop is about 0.35V. and it can successfully rectify the negative part of the signal. And also, we verified the turn on voltage to be 0.4 which is less than the specification of the design. Please refer to image 5.5.1

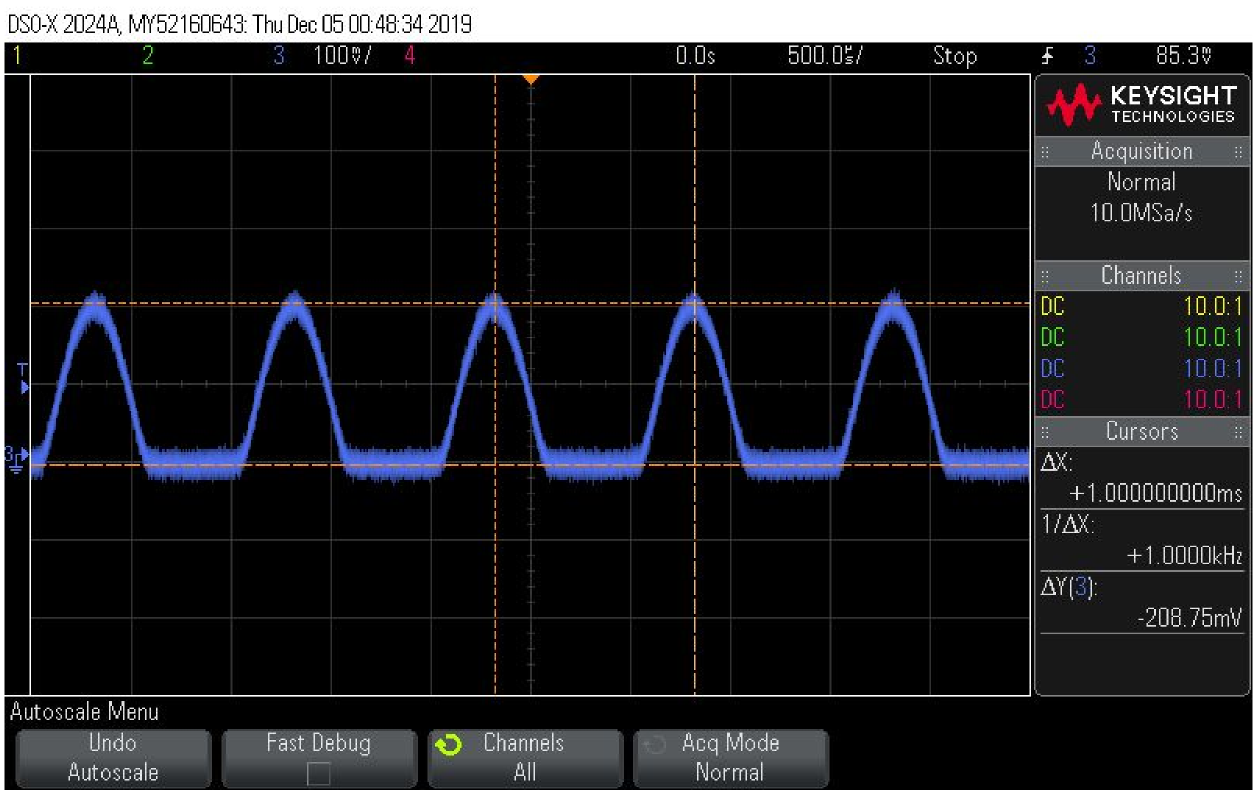

Figure 5.6.1 Half-wave Rectifier Test Output

For the full wave rectifier with resistor testing experiment we verified the ability of reverting the negative part to positive. and the voltage peaks at 460 mV which indicates the voltage drop of the rectifier is about 0.1V which is above expectations. See Image 5.5.2

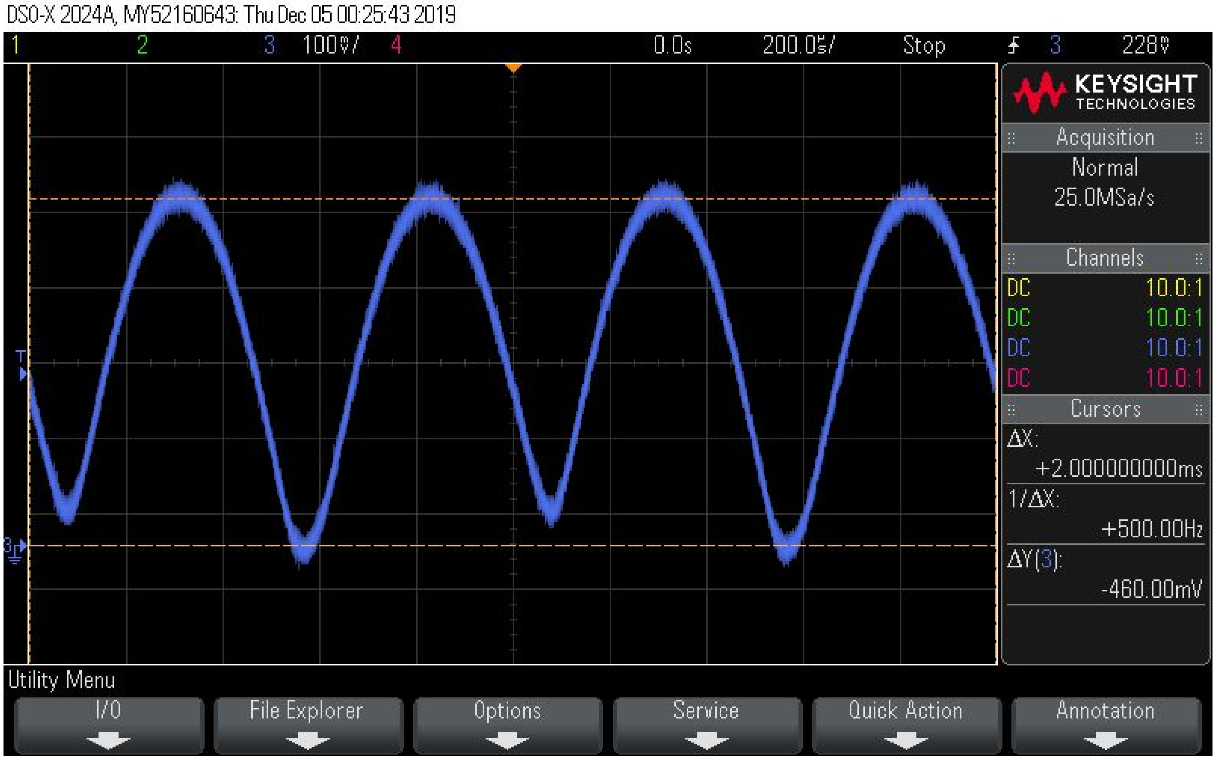

Figure 5.6.2 Full Wave Rectifier Testing Output

The result of full wave rectifier with smoothing capacitor was successful. We verified that the output voltage is about 330mV which is acceptable for the voltage booster to boost and the voltage is much more stable compared to the half wave rectifier and full wave rectifier without the smoothing capacitor.Refer to Image 5.5.3

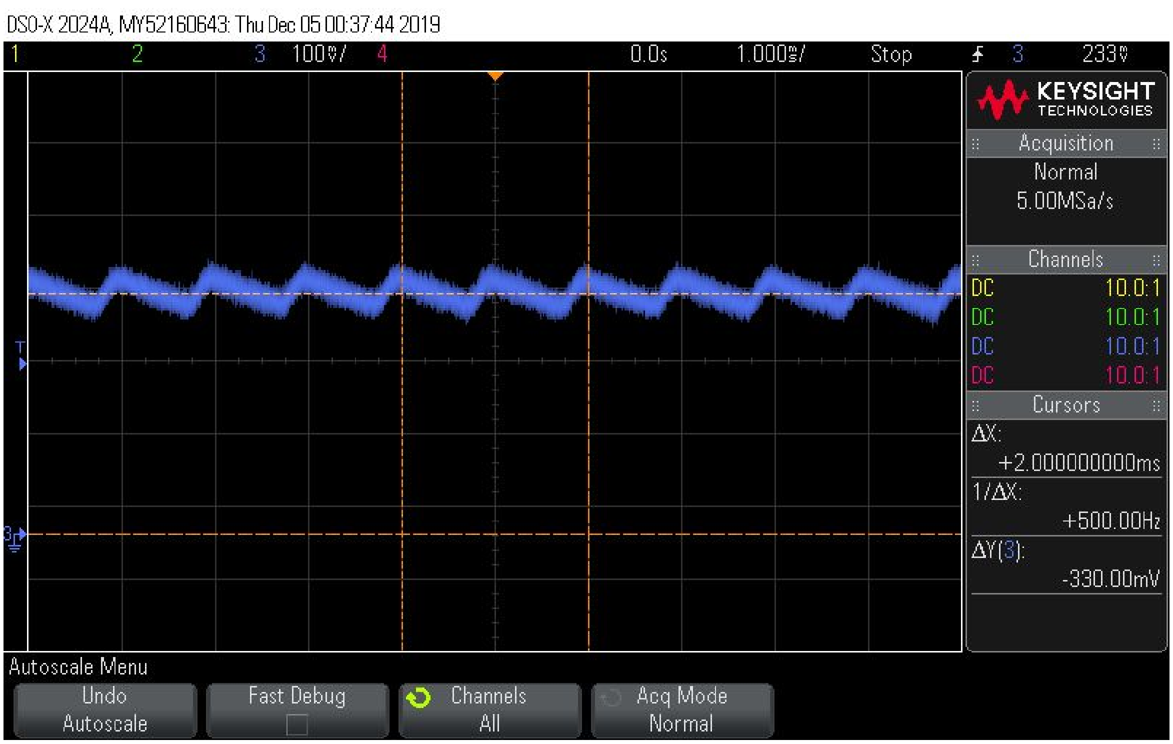

Figure 5.6.3 Full-wave Rectifier with Smoothing Capacitor Testing Output

Table 5.6.1 - Capacitor Measurement Results

Capacitor	Measured Time Constant (seconds)	Calculated Capacitance (Farads), $C=\tau/R$	% Error
1	62.67	0.964	3.6
2	63.72	0.98	2
3	60.1	0.925	7.5
4	64.67	0.995	0.5
5	64.1	0.986	1.4

From these testing results we determined that the capacitors would be acceptable for use in our design. Although there is some variation in the values, this can be accounted for due to the inexact nature of the test. Manually applying the output and tracking with a stopwatch while observing the voltmeter is not ideal like using an LCR meter or some form of automated test. However, since all of the capacitors behaved as expected during the test, we do not anticipate they will cause any issues.

Booster Testing Result:

The result didn't meet our design expectations since the output was not stable. Right after the input is given the output voltage instantly jump to 2.4V as expected but it keeps declining, all the way below to 1V. We are anticipating two possible causes:

1. Damage to the device when soldering the test leads on
2. The input signal polarity is critical, and a reversed input may have been applied during initial testing, damaging the device

Some other testing shows that the output only stabilizes at specific points in the testing. for example with a 100 ohms resistor and a 1.1V DC voltage we saw that the output did boost to 2.6V. However, changing the input to 1 V with the same setup results in the output decaying again. The table below contains the input and output voltages where the booster exhibited stable behavior.

Table 5.6.2 - Voltage Values from Booster Testing

Measurement	Voltage	Output Boost
1	1.1	2.6
2	1.2	2.78
3	1.3	3
4	1.4	3.27
5	1.5	3.5
6	1.6	3.75 - 4 (between these values)
7	1.7	Starts Decaying again

We are still trying to find solutions for this problem and would consult the help of our client and faculty if nothing progresses. If the booster doesn't work, we will just make a new booster by ourselves.

6. Closing Material

6.1 CONCLUSION

A significant amount of work has been accomplished throughout the semester on this project. From receiving the initial problem statement, additional clarification was needed from the client to determine what the expectations and deliverables were. After meeting with Honeywell (the client), it was determined that the desired power scraping module would receive a low input AC signal (1.1 V-P-P), convert the signal to DC, and then boost the signal to a higher voltage where it will charge a supercapacitor and then power a device of the client's choosing.

Having a clear outline of what project was, the team began designing the various stages of the power scraping module and sourcing the components to be used. After the components were obtained, a test plan for each component was developed to verify their functionality. The supercapacitors and Schottky diodes passed the initial acceptance testing, but the booster modules have been the source of much confusion. Throughout testing and consulting with the team faculty advisor, the boosters have been unpredictable and inconsistent. At this point, they are the main challenge facing the project. The next step is to continue testing and reach out to the vendor to inquire about the parts, but alternative boosters may be considered.

Once each individual stage of the device has been satisfied, the bulk of next semester will be assembling and testing the full prototype. After initial testing and analysing is complete, refinements can be made and a fully-functional power scraping module will be presented at the end of the spring semester.

There are a wide variety of applications that can benefit from the use of a power scraping device, including GPS or battery-free remote sensors for HVAC control and building automation, structural monitoring, and industrial control. To be able to create a device that would have such a high demand and large number of uses will be very satisfying.

6.2 REFERENCES

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6.3 APPENDIX

At this time there is no additional information that needs to be included as part of the Appendix.