Boston University
Electrical & Computer Engineering
EC464 Capstone Senior Design Project

User's Manual

Parallel Battery Management Evaluation Board

Submitted to

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by

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Executive Summary

Our senior design project involves designing and fabricating a small-scale enclosure capable of showcasing the parallel battery management functionality of the MAX17330 chip: a proprietary fuel gauge with integrated battery charging and protection. Through our smart charging structure, we aim to create a product that can efficiently showcase Analog Devices, Inc.’s (ADI) battery management integrated circuits (ICs) on a single platform and display the increased longevity of batteries when placed within this system. With more and more companies becoming reliant on technology with multiple independent batteries within a single product, the need for parallel battery management has skyrocketed as of late. Our product will address these needs while also helping reduce the growing issue of electronic waste caused by battery misuse. Our final deliverable will require a technical approach that will include careful examination of each ICs datasheet, extensive research into complex circuit structures, design and development of a 3D printed enclosure, and the employment of Inter-Integrated Circuit (I2C) protocols via MicroPython. The innovative aspect of our final product is that we will be interconnecting custom hardware and software to achieve new functionality in an already existing ADI product. Our final product will take in power via a type-C USB programmable power supply (PPS), go through a type-C power delivery controller (MAX 77958), followed by a switched capacitor (MAX77932) as a form of voltage division. Then, the system will divide between two MAX17330 chips, each charging or discharging its own battery. The overall unit will be controlled by a microcontroller which will communicate with an LCD. On this LCD, we will display valuable information read from the MAX17330’s registers such as the batteries’ respective states-of-charge and the charging or discharging currents. ADI will use our product at trade shows to show potential clients the versatility and efficiency of the MAX17330 in a parallel battery management system.

1 Introduction

[Discuss the <u>purpose</u> of the project. State how your approach has solved your user's problem/needs.]

Analog Devices tasked us with designing a printed circuit board (PCB) with Type-C PPS input and software to showcase the parallel battery management functionality of the MAX17330 (charger, fuel gauge, and protector for lithium-ion batteries) for their technology demonstrations and trade shows. Due to some timing issues between the printing and designing of the PCB, we had to change our final product from a PCB to a modular evaluation package.

Nevertheless, our project proved valuable by discovering the capabilities of joining the major system components. Our articulate and compact system effectively unifies the MAX77958, MAX77932, and 3.5-volt lithium battery with MAX17330. In simpler terms, power is able to flow from a USB C power delivery controller (MAX77958) to a switched capacitor converter (MAX77932) and finally to the MAX17330 and the battery.

Our unique system allows the user to observe the charging and discharging of two parallel lithium batteries with our LCD display connected to the appropriate MAXIM chips and the pico microcontroller. Thus, our device lets anyone understand the MAX17330’s functionality and applications. We believe that with our orientation, any person will be able to trace the power flow and better understand the charger, fuel gauge, and protector applications of the MAX17330

The device has both hardware and software components. The hardware features include a casing for all the evaluation boards that will be able to take a type-C input and charge two batteries at the same time, all the while utilizing ADI’s featured chips as well as other components shown in the visualization. The software deliverables can be condensed into the following: we will display charging progress with real time updates on an LCD, as well as make sure that once a battery is full, the other battery will charge quicker.

Firstly, we created a modular evaluation package that can take a type-C input. This input can power all hardware components on the board and, ultimately, charge two batteries in parallel. Moreover, this package should be able to hold batteries and properly connect them to the battery chargers. Next, there also must be an LCD that can display various information such as the current state of charge of the batteries and how much current is being drawn to the batteries. Overall, the package should be able to charge the batteries, allow them to discharge, and display the required information.

For the software part of the project, we need to be able to know which battery (or batteries) are being charged/discharged, meaning we need to know the direction of the current. One of the deliverables will be the ability to display this in real-time on the LCD. On the same LCD, we should be able to display the percentage of battery capacity that has been filled on each battery so far. Designing a proper user interface will be a challenge because of the large amount of information that needs to be displayed, making it another deliverable in and of itself. Finally, the device should be able to direct all current to a non-full battery if the other battery is full, leading to a faster charging time for that last battery.

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Because of the relatively low voltage and low current traveling through our developed circuit, and the use of USB-C protections, we do not see much of a risk from electrical hazards when a user operates our product. One thing we do advise our users is to utilize a power source that is PPS (programmable power supply) compatible. This will help ensure functionality as well as safety. In addition, the user should pay close attention and ensure a stable and strong connection between the electrical outlet and the power brick. This is the only physical connection the user will have to make. Coverings over soldered connections should protect the user from any other hazards.

In the remaining portions of the user manual, we will discuss the user interface, the physical layout, appropriate setup instructions, as well as the operation conditions for our system. Finally, we will discuss the technical and underlying physics behind the major components of our project, as well as technical standards of the industry.

2 System Overview and Installation

2.1 Overview block diagram

CHARGING BLOCK DIAGRAM

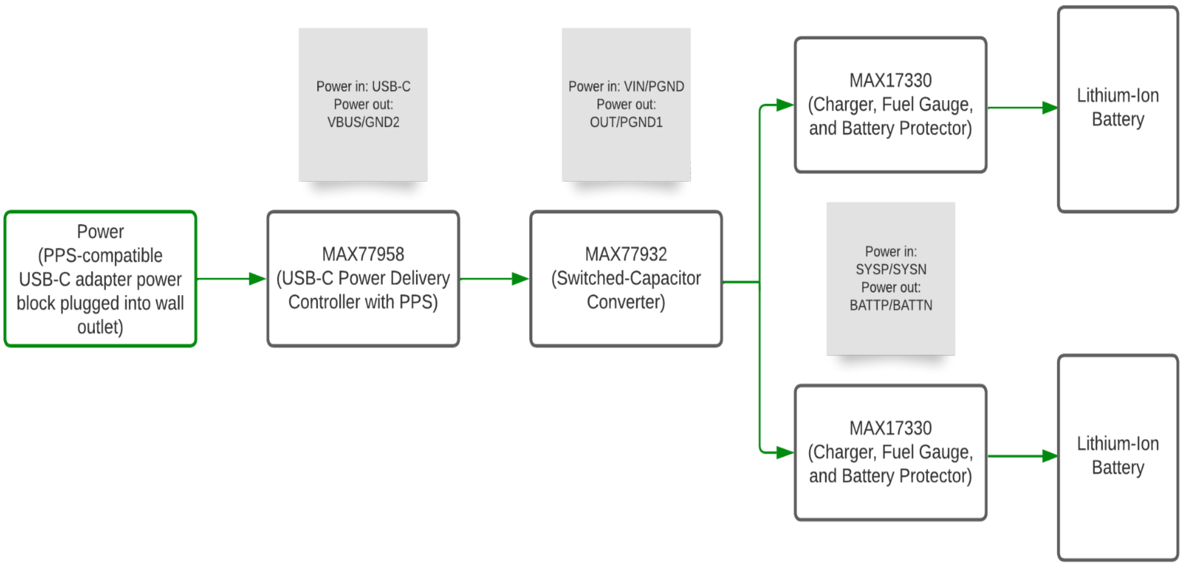

Figure 1: Charging orientation block diagram

The block diagram in figure 1 above depicts the power flow that occurs for our system during the charging phase of the batteries. First, the main power input is injected into the system via a PPS-compatible USB-C power block. This power block can be plugged into an ordinary 120-volt USA electrical outlet or a 220-volt European outlet.. From the input power block, power travels through the MAX77958 chip where the voltage is controlled for USB-C power standards and delivery. This is mainly for safety precautions. The power then flows to the switched capacitor where the voltage prepares to be split to the parallelly connected portion of the circuit. On each new branch of the circuit, voltage is proportionally split between the two MAX17330s, which are each connected to their own battery. In this orientation, each battery will charge as needed depending on the current state of charge. The MAX17330 during charging operates as a charger and fuel gauge.

DISCHARGING BLOCK DIAGRAM

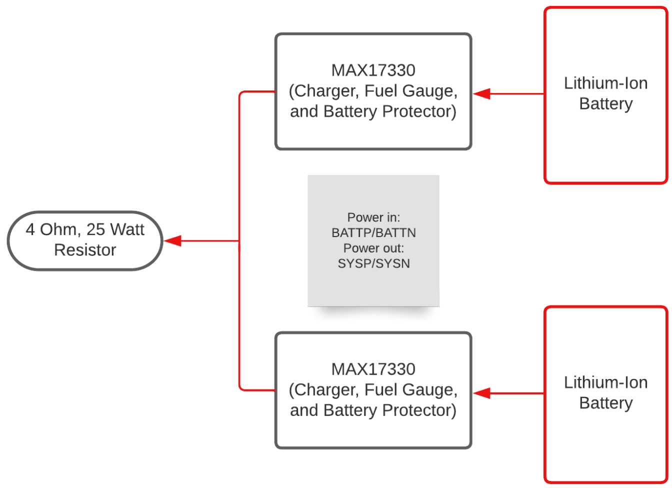

Figure 2: Discharging orientation block diagram

In figure 2 above, we have depicted the discharging block diagram of our system. Power dissipates from each lithium-ion battery to the MAX17330, which in this case is operating as a battery protector. From each MAX17330, power then gets terminated at an electronic load, which we chose to represent as a 4-ohm, 25-watt resistor. For safety purposes, we have chosen this specific resistor as opposed to other alternatives. This will be discussed in detail later in the report.

2.2 User Interface

With our completed project, the user will have minimal interactions with the completed circuitry. After the power connection is made to the wall outlet, the user will have the option to toggle between certain displays of the LCD. Battery life as a percentage and battery status (charging or discharging) will be the main settings that the user will be able to toggle between. This process is designed to be simple as possible for the user.

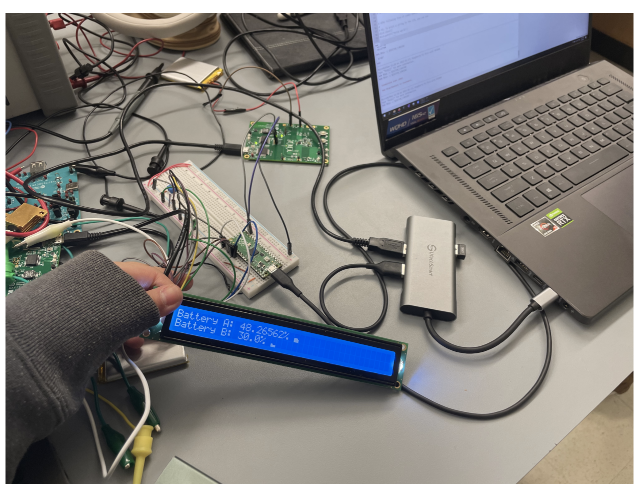

Figure 3: LCD battery level display

2.3 Physical description.

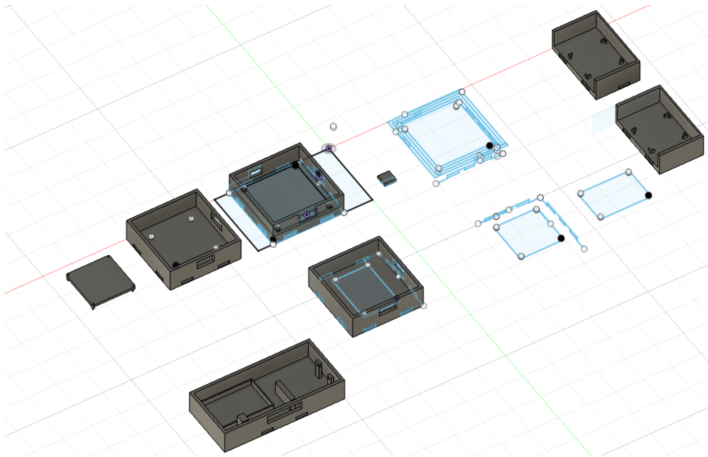

Figure 4: CAD drawing of the casing of all the boards and their connections

Figure 5: Complete Second Prototype

The aim of our physical design is to make the process of parallel battery charging with the MAX17330s as simple as possible for the user. All of the evaluation boards are preconnected and protected within a well-designed container. This system will have an LCD that will be able to display important information, like the battery capacity of each battery and whether the batteries are charging or discharging. The casing for the PPS controller will have holes for the USB-C connector and both of the casings for the MAX17330 evaluation boards will have holes to allow for easy access to the battery connections.

Add more images of the different LCD displays, what the different modes are called, and how they are toggled. This is important UI/UX information to detail here.

2.4 Installation, setup, and support

In terms of installation, our system is fairly straightforward for the user. The user will ultimately be responsible for two things: a connection from an ordinary wall outlet to the MAX77958 and the connections needed to toggle between charging and discharging orientations.

For power input, we suggest that the user has an accredited PPS-compatible, Type-C power block for optimum functionality of the system. If the power block is not PPS compatible, it is very possible that the power flow will be stopped at some point within the system, and the batteries will not be able to charge effectively. We also recommend that the user ensures a strong physical connection between the power supply and the wall outlet. In other words, the hot and neutral prongs of the plug should have a sturdy and stable connection with the wall.

To change between charging and discharging, the user will also be responsible for some connections. It is expected that most of these connections will already be made when the user receives the product; however, for clarity, we have chosen to include all the connection intricacies in the user's manual, as follows: For charging, two separate connections should be made from the VBUS and GND2 pins of the MAX77958 chip to the VIN and PGND pins of the MAX77932 respectively. It is then necessary to make the proper connections to the MAX17330 chips (charger, fuel gauge, and battery protector). Two connections should be made from the OUT and PGRD1 pins of the MAX77932 to the SYSP and SYSN pins of the MAX17330 respectively. Additionally, for a dual battery setup, there should be two MAX17330 chips used and connections should be made from the OUT and PGRD1 pins of the MAX77932 to the SYSP and SYSN pins of each MAX17330 chip respectively. Finally, a connection should then be made from the BATTP and BATTN pins of the MAX17330 chip to the positive and negative terminals of the battery.

For discharging, connections should be made from the positive and negative terminals of the battery to the SYSP and SYSN terminals of the MAX17330. For a dual battery setup, a second set of these connections should be made so that each battery is effectively connected to its respective MAX17330 chip. Next, a connection will have to be made from the BATTP and BATTN of the MAX17330 to each end of a 4-ohm 25-att resistor. In the case of a dual battery setup, this connection should be made for the second MAX17330 board as well.

3 Operation of the Project

[This section describes how to use the project. Anticipate what the User needs to know and do Set-up and configuration were discussed in Section 2 already.]

3.1 Operating Mode 1: Battery Charging

The primary mode of our device is battery charging, in which each battery connected is being fed power, thus increasing their battery levels. Under battery charging, we anticipate that the battery of a lesser charge level will be allocated a larger proportion of the total power in the system. The battery that is charged more already will be given less of the total power of the system.

In this mode, the user will still have the option to toggle between display options of the LCD. This, however, is no different from the other modes of operation that will be discussed below.
Abnormal results may include overcurrent (greater than .65 A) or overvoltage (greater than 4 volts) at any point in the circuit. With a handheld meter, the user is able to check for these abnormalities. In the case of an abnormality, we suggest that the user removes power from the circuit by unplugging the PPS USB-C brick from the wall outlet. We then recommend a simple power cycle. If the issue persists, further investigation will have to be done on each demo board and the batteries.

3.2 Operating Mode 2: Battery Discharging

The second prominent mode of our project is battery discharging. In this mode, we look to safely and slowly discharge each battery when the power is no longer in use. In this mode, the user will still have the option to toggle between display options of the LCD. The battery discharge could potentially overhead the electronic load. In the model, our electronic load is represented by a 25-watt, 4-ohm resistor. As a result of intaking an excess amount of power, it is possible that this resistor heats up excessively. Admittedly, the resistor should be moderately warm, nevertheless, ideally our discharge rate will be so low that the resistor should not be too hot to comfortably touch. If overheating occurs, make sure to check the resistor connections as well as the connections on the MAX17330.

3.3 Safety Issues

There are no safety issues inherent in this project. This is because the baseline of the circuitry within our system is a part of evaluation boards that have been rigorously tested by electrical engineers at Analog Devices Inc. This means that each evaluation board has defensive circuitry that will protect the electronic component from overcurrent or any other spikes in voltage. This means that there are no potential causes for fires or explosions. Also because all of these boards pass inspection and meet industry standards, there are no hazardous materials present within or inside any electronic components.

Our engineering product will also only require a 5V input. We are not working with high levels of current, so there is no inherent danger with our system. There is only one connection required by the user and our system removes any possible chances of misconnections. This ultimately means that the system is entirely safe for users.

4 Technical Background

As a user of our final product, it is important to moderately understand the fundamental elements of parallel battery charging and discharging. Parallel charging is not what it intuitively sounds like. The batteries are not actually connected in the well-known parallel orientation studied in all fundamental circuits classes. Instead, this refers to two different batteries being able to independently, or jointly operate a single electronic device or load.

We see this same parallel battery charging concept in many of today’s consumer electronics. The Ring camera is just one of the many examples. Each camera actually has two batteries jointly powering the camera. In most situations, one battery–typically of the higher charge percentage–will be used to power the camera while the other battery charges. In some cases, both batteries will jointly charge the camera. Other consumer electronics such as the Meta Quest 2 and the Airpod Pros use the same physical and electrical charging concept used in our project.

Another important technical aspect of our project is the switch capacitor. This switch capacitor is used to separate the voltage before it branches off to the separate MAX17330 and the battery itself. In general, a switch capacitor is a type of circuit that can be used for voltage division that we need in our project. Switched capacitor circuits utilize capacitors to temporarily store and transfer charge between two nodes in the circuit. By controlling the timing and frequency of switches that connect and disconnect the capacitors, the circuit can effectively create a variable resistor that can be used for voltage division.

In a switch capacitor voltage divider circuit, the input voltage is connected to a capacitor network that is switched on and off at a certain frequency. The capacitor network effectively divides the input voltage into smaller voltages that are proportional to the capacitance ratios of the capacitors. By selecting appropriate capacity [?]ratios and controlling the switching frequency, the voltage division ratio can be adjusted to match the desired output voltage.

One advantage of switch capacitor circuits is that they can be implemented using digital signal processing techniques, making them suitable for use in integrated circuits and other digital systems. Additionally, switch capacitor circuits can be more efficient than traditional resistor-based voltage dividers, since they can reduce the amount of power dissipated as heat. Due to safety, cost-effectiveness, and efficiency, we felt that it was the best electronic circuit element to use for our purposes.

Finally, to completely understand the purpose of our project, we believe that a basic understanding of the MAX17330 would be helpful. At a high level, the MAX17330 is a highly integrated battery management IC (integrated circuit) designed for use in single-cell lithium-ion (Li-ion) or lithium-polymer (Li-poly) battery systems. The MAX17330 provides a range of advanced features for battery monitoring and management, including high-accuracy coulomb counting, temperature sensing, and cell balancing. It also includes an integrated fuel gauge algorithm that uses a combination of voltage, current, and temperature measurements to estimate the state of charge (SOC) and state of health (SOH) of the battery.

One of the key features of the MAX17330 is its high level of integration. It includes a number of components that are typically found in separate devices, such as a current sense amplifier, a temperature sensor, and a cell balancer. This can help to reduce the overall system cost and complexity, as well as improve the reliability and performance of the battery management system.

The MAX17330 also includes a number of built-in safety features to protect the battery and the system from overvoltage, undervoltage, overcurrent, and overheating conditions. These features help to prevent damage to the battery and ensure safe operation under a wide range of operating conditions.

Overall, the MAX17330 is a highly advanced and capable battery management IC that can help to improve the performance, reliability, and safety of single-cell Li-ion or Li-poly battery systems. It is used in a wide range of applications, including portable electronics, medical devices, and automotive systems.

5 Relevant Engineering Standards

Important Battery Charging Standards:

- IEC 60335-2-29: This standard applies to safety requirements for battery chargers, including both mains-operated and battery-operated models.
- IEEE 1725: This standard applies to rechargeable batteries used in portable electronic devices, such as cell phones and laptops. It covers safety requirements for the batteries themselves, as well as charging systems and charging connectors.
- UL 2054: This standard applies to safety requirements for batteries used in portable electronic devices, including both primary (non-rechargeable) and secondary (rechargeable) batteries.
- IEC 61982: This standard applies to safety requirements for secondary batteries and battery installations, including charging systems.

Important Battery Discharging Standards:

- EEE 450: This standard, also known as the Recommended Practice for Maintenance, Testing, and Replacement of Vented Lead-Acid Batteries for Stationary Applications, provides guidance on the maintenance and testing of vented lead-acid batteries used in stationary applications, such as backup power systems.
- IEEE 1188: This standard, also known as the Recommended Practice for Maintenance, Testing, and Replacement of Valve-Regulated Lead-Acid (VRLA) Batteries for Stationary Applications, provides guidance on the maintenance and testing of valve-regulated lead-acid batteries used in stationary applications, such as backup power systems.
- UL 1989: This standard covers the safety of lithium-ion batteries used in portable power packs, power banks, and other similar devices.
- UL 1642: This standard covers the safety of lithium batteries used in portable electronic devices.
- UL 2271: This standard covers the safety of lithium-ion batteries used in hoverboards, electric bicycles, and other similar devices.
- ANSI/UL 1973: This standard covers the safety of batteries and battery systems used in electric vehicles.

Ultimately, following many of these standards is not only necessary by law, but also creates a safe product, and–to a certain degree–standardizes products in this industry to make it easier for the user to select and compare similar products in the market. We are proud to say that our product aligns with all of the industry’s main charging and discharging standards.

6 Cost Breakdown

Project Costs for Production of Beta Version				
Item	Quantity	Description	Unit Cost	Extended Cost
1	4	MAX17330 Evaluation Board/Kit (Paid for by ADI)	$112	
2	2	MAX77958 Evaluation Board/Kit (Paid for by ADI)	$112	
3	2	MAX77932 Evaluation Board/Kit (Paid for by ADI)	$108	
4	2	MAX77986 Evaluation Board/Kit (Paid for by ADI)	$101	
5	5	Adafruit Industries 1.2 Ah Lithium-ion Battery	$49.75	
6	5	Adafruit Industries 2.5 Ah Lithium-ion Battery	$74.75	
7	5	Adafruit Industries 4.4 Ah Lithium-ion Battery	$99.75	
8	1	Focus LCDs 40x2 Segment LCD	$33.17	
9	1	Focus LCDs 40x4 Segment LCD	$33.33	
10	1	DigiKey Shipping Cost & Sales Tax	$40.17	
11	1	Raspberry Pi Pico	$4	
12	1	120pcs Set of Jumper Wires	$7	
Beta Version-Total Cost (342.92)				

Ultimately our budget is composed of two main components: the physical boards and the interface and software components surrounding them. The bulk of the project's costs are the physical evaluation boards that were provided to us by analog devices. These boards cost a total of $433 of our $775.92 total costs. These costs are not included in our total above because Analog Devices did end up paying for it.

The components that our group actually bought from our budget were essentially batteries and LCDs. These made up the remaining $342.92 that are shown above. In total, our costs are well below the total budget of $1000.

7 Appendices

7.1 Appendix A - Specifications

Requirement	**Value**
Physically Portable System	16x12x5” or smaller
Sizeable/Visible LCD	6x1” or larger
LCD Screen Toggling	Ability to see all relevant information in 10s or less
Battery Charge Error	$\pm$ 1% error
Total Production Cost	$1000 or less
Setup Time	All boards can be swapped within 5 minutes

7.2 Appendix B – Team Information

Team one, or team Analog Devices, is composed of 5 members: three electrical engineers, a computer engineer, and biomedical and computer double major. We have a well rounded team with various industrial and technical backgrounds that are pertinent to the project at hand. Throughout the course of product development, we have worked together and leveraged our personal skills sets to achieve a common end goal: a fully functional parallel battery evaluation board. Below we have listed the brief bios of each team member.

David Liu is a senior (May 2023) student attending Boston University as an electrical engineering student. He also intends on graduating with a MS in Electrical Engineering by December of 2023. He started as a computer engineering student, until he switched to electrical engineering after discovering his passion for hardware and semiconductor physics. After taking courses in analog electronics, and semiconductor physics he is hoping to apply that knowledge into practical applications. David has already been able to apply some aspects of his knowledge while interning at a semiconductor fabrication facility. He can be contacted by his email: liudavid@bu.edu, or by phone: 617-797-4879.

Harry Katsaros is a senior anticipating graduating from Boston University in spring of 2023 with a BS in electrical engineering. Harry has special interests in electrical panel design and assembly, as well as renewable technologies such as solar energy. With experience working on the business and financial side of engineering with both Schneider electric and Captona LLC's corporate sectors, Harry has a comprehensive understanding of the consumer and engineering end of every product, as well as a knack for project budgeting. Harry also has 3 years of technical experience including inverter and transformer maintenance, small panel and cabinet assembly, and general manufacturing. Harry can be contacted by his email: katsaros@bu.edu, or by phone: 508-665-9155.

Sunwoo Park is a senior expected to graduate in the spring of 2023 from Boston University with a BS in computer engineering. She aspires to specialize in low-level electronics, whether it be working with firmware or testing and applications of integrated circuits (ICs). She has experience interning as an applications engineer at Analog Devices, Inc., from which she gained valuable industry skills and knowledge such as navigating datasheets, testing ICs in an electronics lab with multimeters and oscilloscopes, programming microcontrollers to read and write to ICs via I2C protocol, and analyzing and organizing data collected during IC tests to validate a particular function. Following the completion of her undergraduate education, she plans to join Analog Devices Inc. as a full-time Applications Engineer to cultivate her knowledge and skills in the IC industry. Sunwoo can be contacted by her email: sunpark@bu.edu, or by phone: 509-342-9081

Eric Cho is a senior anticipating graduating from Boston University in spring of 2023 with a BS in electrical engineering. He also has a minor in system engineering and concentration in nanotechnology. Eric has wide interests in electrical engineering spanning from robotics to microelectronics. He has had professional experience at companies such as Roche and Hologic where he has had the opportunity to work on both the hardware and software of complex electromechanical devices. These opportunities in industry have exposed him to PCB layout, robotics software, and circuit design/testing. Eric plans to work with Analog Devices Inc. post graduation on a MEMS team where he will get to design chips and microelectronic circuits similar to the ones used for this project. Eric can be contacted by his email: ericcho@bu.edu, or by phone at 520-343-4973.

Antonio Alonso is a senior expected to graduate in the spring of 2023 with a double major in biomedical engineering and computer engineering from Boston University; in addition to this, he is also pursuing a machine learning concentration. In the past he interned at Amazon Pharmacy as a software development engineering intern, combining his BME and CE expertise as well as his knowledge of machine learning algorithms, after graduating he will return to Amazon Pharmacy for a full time position as a software development engineer. Antonio learned valuable lessons on agile software development and plans to apply those skills in this project. Antonio can be reached at his email: aalonso1@bu.edu, or by phone at 617-909-9835.