Universal Battery Charger/Discharger

ECE 445

Fall 2024

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Project Proposal

I. Introduction

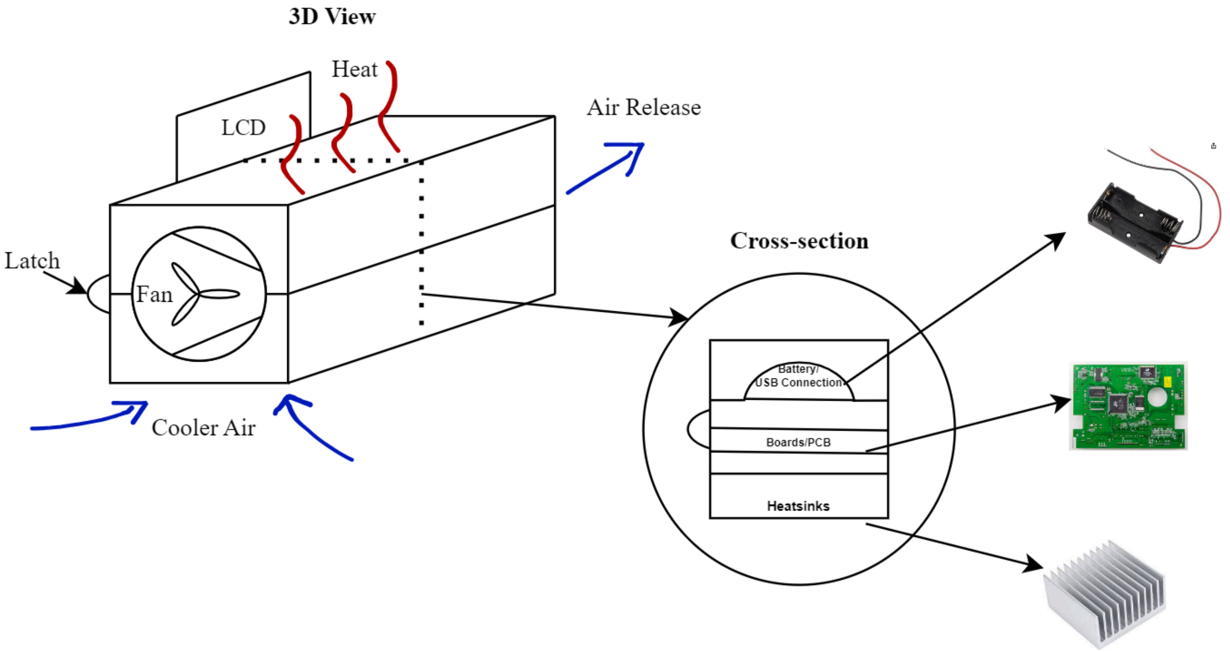
1.1 Problem:

Batteries are a common and underestimated fire hazard in many homes, especially where a lack of knowledge meets convenience. There are a rapidly growing number of videos online of trash cans bursting into flames or dogs starting fires by chewing on charge banks. A partially charged battery in a trash compactor could lead to devastating damages, added expenses, and, in severe cases, casualties. As society grows more dependent on portable and sophisticated electronics, proper battery disposal is crucial in preventing potential hazardous situations.

1.2 Solution:

A battery discharger that rapidly discharges a battery for safe disposal by using variable paths to maximize current flow within normal battery operating temperatures. Real-time monitoring of circuit and system conditions would allow the system to fine tune the rate of cooling and heat generation to maintain safety as the attached cells expend amp hours. It would also allow quick fault detection and rapid response to battery failure, preventing damaged cells from igniting. The system would also, when directed by the user, charge rechargeable batteries using similar safety margins.

1.3 Visual Aid:

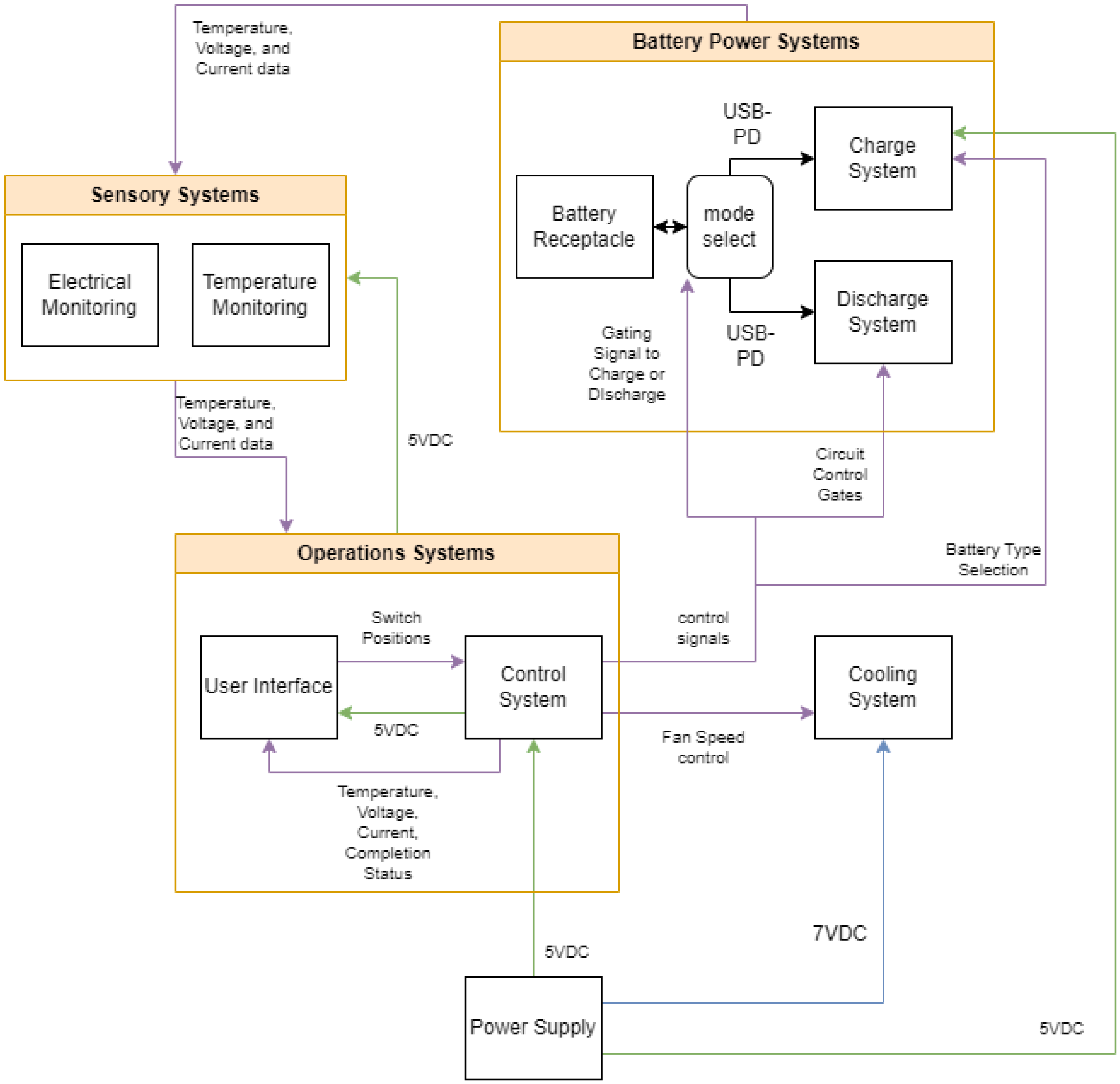


1.4 High Level Requirements:

- Be able to discharge continuously at 1-3A to a condition the battery can be considered safe to common trash-borne hazards.
- Maintain temperature within safe battery limits to enable maximum sustained charge/discharge rate without exceeding hazard thresholds (120F steady state, 140F transient for discharge, 110F steady state to 120F transient for charge (105F for lithium) (Energizer), (Energizer), +/- 2F margin of error).
- Be able to cycle active circuits based on system conditions to maximize charge/discharge, minimize system temperature(as much as feasible to at least be safe), and maximize system's operating lifetime. This should include rapid response (within 1s with 10% margin of error) to emergent conditions, such as battery failure, exceeding transient temperature limits, and thermal runaway.

II. Design

2.1 Block Diagram:



2.2 Subsystems Overview and Requirements:

Battery Receptacle Subsystem:

This subsystem holds two battery receptacles, one for AA batteries and another for AAA batteries. This is where the soon to be charged/discharged batteries will be placed in the system. Each receptacle will hold two batteries. This system will also include a USB connection port for USB battery inputs. Based on the user's input preferences, the control system picks which receptacle or port is in use and dictates whether it is connected to the charge or discharge subsystem. Furthermore, this subsystem is connected directly to the electrical monitoring subsystem in order to record the electrical charge and current flow from the battery. It is also connected to the temperature monitoring subsystem in order to pass on temperature readings from the system and batteries.

Battery Receptacle Requirements:

The Battery Receptacle Subsystem must be able hold batteries, transfer their energy to the necessary circuits, and leave the batteries exposed to airflow to aid in cooling. This subsystem must be able to handle 5Vdc and 3A.

Cooling Subsystem:

Since we will be rapidly charging/discharging a battery, the internal temperature may become too hot for the system to remain safely operational. This subsystem focuses on keeping the overall circuit in a stable and controlled environment. The cooling subsystem will consist of a fan (PN:ROB-09238) that receives input from the control system and a heatsink that is located near heat generating components. The fan will turn on or off based on the signal sent by the control system. Furthermore, the cooling subsystem will be directly connected to the power supply, powered independently from the rest of the circuit.

Cooling Subsystem Requirements:

The Cooling Subsystem must be able to collect and disperse heat to the air to cool the system down, at a rate potentially exceeding 50W of heat generation by the system. The heat sink must be in close enough proximity to vulnerable components to aid this, but not so close that airflow or other operations are unnecessarily restricted. The fan must be able to accept 12 Vdc as a power source.

Temperature Monitoring Subsystem:

This subsystem is made up of temperature sensors (PN:LM235Z) placed around the battery output, charge system, and discharge system. By monitoring and sending this information to the control subsystem, the temperature monitoring subsystem protects the overall circuit from overheating. The temperature sensors output data in the form of analog voltage. Luckily, the microcontroller we chose comes with 8 general purpose ADC (Analog to Digital Converter) pins. Three of these ADC pins will be connected to each temperature sensor's output. The microcontroller will communicate with the sensors using a standard GPIO (General Purpose Input/Output) protocol. The data this subsystem outputs helps tell the control subsystem whether to toggle on/off the fan, force shutdown the circuit, alter the charge/discharge rate, or do nothing.

Temperature Monitoring Requirements:

This subsystem must be able to monitor temperatures at vital points within a +/- 2C accuracy and relay it to the Control system for use in system operations.

Electrical Monitoring Subsystem:

This subsystem is made up of voltage and current sensors(LAH 25-NP) placed near the batteries. Its purpose is to ensure that the circuit doesn't exceed a certain current or voltage level. It monitors and sends this information to the control system. Both the current and voltage sensor outputs will be connected to its own ADC pin on the microcontroller. The microcontroller will communicate with the electrical sensor using standard GPIO protocol. This system's output helps the control subsystem figure out appropriate voltage and current levels that need to be supplied to the system.

Electrical Monitoring Requirements:

The Electrical Monitoring system should be able to accurately (+/- 1%) determine the current and voltage at the battery output, and send it to the Control system for use in system operation and failure detection.

Charge Subsystem:

This subsystem's purpose is to recharge the desired battery introduced to the system. It is made up of two battery charging IC's, one for lithium types(PN:BQ25820) and the other for nickel types (PN:BQ25172). These IC's will be programmed to accept AA or AAA batteries. There is also an MOSFET that controls current flow to the IC during the charge phase. Furthermore, we will include a USB-C port that acts as a 5Vdc supply to any battery that accepts it. This subsystem will be connected to the battery receptacle subsystem via a mode selector to determine whether it's working on a AA or AAA battery. The control system will send signals to the MOSFET to aid in current flow to the IC. If an overtemperature condition occurs, current flow will be removed until resolved.

Charge Subsystem Requirements:

Requirements	Verification
- Provide stable 5Vdc (+/-.3Vdc) for charging USB compatible batteries	1. Connect USB-C charging port to a 5V load and verify with a multimeter that output remains within the threshold.
- Safely charge AA/AAA batteries at 1.2Vdc (+0.1/-0.2Vdc) with safe current levels	1. Connect AA/AAA battery and verify charging voltage is between 1 and 1.3 Vdc.
- Enable isolation of the charging subsystem when not in use.	1. Simulate control signals to isolate the charging system. Confirm with the multimeter no current flow.

Discharge System:

This subsystem controls the safe discharge of batteries by using a custom-made PCB that will function as a current divider. MOSFETs controlled by the control system will regulate discharge paths and manage energy dissipation. The control system will adjust based on discharging rates and will minimize heat buildup. The Discharge system will be connected to the battery receptacle subsystem and will work in conjunction with the electrical and temperature subsystems to keep discharge rates at a safe level. When not in use this system will be isolated for overall safety.

The discharge system accomplishes this by using ten branches of resistors in parallel. Each resistor branch has a 10 ohm resistor (PN: LTR18EZPF10R0). When the MOSFETs are gated on with a potential of 5V applied, you will get a discharge rate of 500 mA across a resistor branch. These can be stepped up to a discharge rate of 3A in six increments. With 3V instead, the discharge rate per branch will be 300 mA, which can be stepped up in ten increments, using all of the branches. When isolated, all MOSFETs will be deenergized, isolating the discharge system.

Discharge System Requirements and Verification:

Requirements	Verification
- The Discharge System must be able to safely discharge 3A from 5V and 3V potentials.	1. Single Branch test: With a 5V potential test each branch of the discharge path. Monitor for temperature changes for 30 minutes or stabilization (+/-1C). The test will be considered satisfactory if temperature remains below 60C or stabilizes for 5 minutes below 60C. 2. Whole Subsystem test: With a 5V and 3V potential (separately) verify that you can achieve a 3A discharge rate. 3. Stress test: with a 5V potential and the circuit aligned to achieve 3A discharge, monitor temperatures for an hour or until stabilization(+/-1C). The test will be considered satisfactory if the temperature remains below 60C (+/-1) or stabilizes for 5 minutes below 60C.
- The Discharge System must be able to be isolated from the other systems.	1. Simulate control signals from the Control System on the isolating gates. The test will be considered satisfactory if the path to the system reads as OPEN or not shorted as appropriate on the diode setting of a multimeter.
- The Discharge system must be able to alter the discharge current in at least six increments up to 3A.	1. With 3V potential, gate each branch on, one at a time, and measure the current across the resistor branch with a multimeter. Readings should be in increments of .3A +/-30mA. Final reading should be 3A +/- 200mA. 2. With 5V potential, gate six branches on, one at a time, and measure the

	current across the resistor bank with a multimeter. Readings should be in increments of .5A +/-50mA. Final reading should be 3A +/- 200mA.

Control System:

The Control Subsystem is the central point of the system. It will be responsible for managing the Electrical and Temperature subsystems and adjusting operations where necessary. It processes data to alter current paths through the charge and discharge systems ensuring safe and adequate performance. This subsystem also controls the cooling subsystem, and will remove power to the fan in the event of thermal runaway to limit oxygen addition to a fire hazard. An ATMEGA328 (Atmel) microcontroller will be the core of the control system, which will execute any necessary commands to successfully manage the system. It will interface with all other subsystems ensuring proper operation based on real time data.

Control System Requirements:

This subsystem must be able to send control signals of varying voltages sufficient to alter fan speed and control IGBTs that gate off portions of the Charge and Discharge system when they are not in use. It must also be able to receive accurate signals from the temperature and electrical monitoring subsystems (within +/-1% of the actual value sensed), as well as the positions of the User Interface Subsystem switches, and interpret that information to make decisions to alter the current state of the overall system. It must be able to respond to these situations within one second (+/- 10%) of the event occurring.

User Interface Subsystem:

The User Interface Subsystem allows the user to control and monitor the subsystems operation. The User Interface will accept input to determine whether the system should be in charge/discharge mode and what kind of battery is currently in use (lithium or nickel). This subsystem will contain external switches for selecting charge/discharge, type, and an on/off switch. The subsystem also features an LCD display that will show the charge/discharge status to keep the user informed on the status of the system.

User Interface Requirements:

The subsystem should be able to provide clear signals to the Control System. Indications should be clearly readable and easily understood by the user.

Power Supply Subsystem:

The Power Supply Subsystem will provide the electrical input to power the system. It will utilize an AC/DC converter (designed by us) to step voltage down from 120Vac to 12Vdc for the fan. We would then use a Voltage regulator (PN:Texas Instruments uA7805) to step this down to 5Vdc for use by the rest of the system. This system will ensure a stable power supply which will allow for the systems control, monitoring, and other components to behave as needed.

Power Supply Requirements:

This subsystem must be able to receive power from a standard 120 Vac electrical outlet, pass it along to the fan in the cooling system, and reduce it to 5Vdc (+/- .3Vdc) for the rest of the system to use and 12Vdc(+/-0.5Vdc) for fan use.

2.3 Tolerance Analysis:

The batteries (located in the Battery Receptacle) will likely be the most limiting part of the design. Because a battery will be a temporary addition to the system, we must account for damage and conditions that might be outside of our control being introduced to the system. For this reason, the battery will be the most likely source of faults and irregular conditions. However, there is very little we can do about the batteries, so we will instead focus on analyzing the discharge and cooling subsystems, incorporating the limiting nature of the battery.

The batteries will also be the limiting component when it comes to temperature. Most batteries have a maximum operating temperature of 60 C, and should ideally be maintained below 50 C. IC chips often are limited at 70, and individual board components can have operating temperatures exceeding 130 C (the resistors we will be using to dissipate energy will likely have 155 C, far exceeding 130 C). Because the battery will also be the power sink/source for the charge and discharge circuits, it will also match their power utilization.

The most limiting thermal conductivity identified (Zeng et al. #) is 0.15W/(m*K) which corresponds to a thermal resistance of 6.67 C/W. For the maximum expect power supplied by the battery:

$$Tf = Ti + Q*R$$

Where Tf, Ti, Q, and R are the final temperature, initial temperature, power and thermal resistance, we have:

$$T_f = 30C + ((5V * 3A) * 6.67C/W)) = 130\ C$$

using a high room temperature, the maximum specifications of USB-C and assuming only the most limiting part of the battery is able to disperse heat in the most limiting direction. Despite this being a next-to-impossible worst case, it clearly illustrates the need for good thermal design and current control methods. If we limit current flow in high temperature conditions, and good airflow improves thermal performance, we might instead see

$$T_f = 30C + ((5V * 1.5A) * 3.33C/W)) = 55\ C$$

Using the same limiting component, adjusted by a coefficient of ½, the temperature is more manageable. Despite the massive difference, we can conclude that these numbers can be fairly reasonable based on the differences people saw when researching the change in thermal conductivity in heat sinks when airflow is provided ("How Air Velocity Affects - The Thermal Performance of Heat Sinks: A Comparison of Straight Fin, Pin Fin and maxiFLOWTM Architectures"). In the prior cited document, a reduction of half was witnessed unilaterally in an airflow environment of 1 m/s. Given that we were assuming zero consideration for thermodynamics in the original scenario, our new numbers are conservative.

These considerations are so limiting, that our entire system is designed around their mitigation while still maintaining practical use. Each of our High Level Requirements has this mindset at its center. Our current limits take into account the variance necessary to limit heat generation while still discharging effectively. Given thermal momentum and accuracy of components, we are limiting temperatures to the operational maximum only in transients with the ideal operational temperature being a steady state limit, and to do that we are designing flexible discharge paths to adjust current dynamically while fan speed can be changed on the fly.

With accurate temperature monitoring, effective cooling, and timely limitation of heat generation, the system is maintained safe, even in transient conditions.

III. Ethics and Safety

3.1 Safety:

The purpose of this project is to design a device that enables people's homes and businesses to be more safe. In this vein, it would be remiss not to examine the possible safety issues with the product.

The largest safety issue has to do with fire prevention. To this end, we intend to design a system that will, when working properly, not only limit fire hazards but also work to actively prevent them. The system will have expectations of system response, and will refuse to perform potentially dangerous tasks if a mismatch between response and expectation is detected. Specifically, for example, if the battery exceeds the transient temperature threshold, the system will isolate charging and discharging systems. If temperature continues to increase, all power to the system will shut off, including the fan, to prevent oxygen from reaching a potential developing fire.

That being said, the system will only be as safe as our own efforts allow. Our team will spare no effort to ensure that the system will prevent fires rather than enable them. To use a standard for battery safety, we will use the ECE 445 Battery Safety Guidelines (Spring 2016 Course Staff), as well as applicable portions of the UN's Global Technical Regulation on the Electric Vehicle Safety (United Nations), particularly on battery handling and inspection.

3.2 Ethics:

Our team will maintain intellectual and ethical honesty in our endeavors. In accordance with IEEE code (IEEE), section 1, parts 1-6, we will cut no corners and use the most accurate data we can acquire. If certain efforts or behaviors would benefit the individual, team, or project to the detriment of society or the community, they will be discarded in favor of earnest work towards the betterment of each. Particularly, we will "seek, accept, and offer honest criticism of technical work, [acknowledge] and correct errors, [be] honest and realistic in stating claims or estimates based on available data, and [credit] properly the contributions of others", to quote the IEEE code of ethics.

IV. References

Duracell. *AA 2500mAh Nickel Metal Hydride Battery*. AA25HP1118 datasheet. https://www.duracell.com/wp-content/uploads/2018/12/AA2500HP-PREMIUM-v1.0.pdf. Accessed 18 September 2024.

Energizer. *Rechargeable AA-2650 (HR6)*. IEC-HR6 datasheet. https://data.energizer.com/pdfs/hr6-2650_eu.pdf. Accessed 18 September 2024.

"How Air Velocity Affects - The Thermal Performance of Heat Sinks: A Comparison of Straight Fin, Pin Fin and maxiFLOWTM Architectures." *Advanced Thermal Solutions, Inc.*, https://www.qats.com/cms/wp-content/uploads/2013/09/Qpedia_Oct08_How-Air-Velocity-Affects-HS-Performance.pdf. Accessed 29 September 2024.

IEEE. "IEEE - IEEE Code of Ethics." *www.ieee.org*, https://www.ieee.org/about/corporate/governance/p7-8.html. Accessed 18 September 2024.

Atmel. *ATmega48A/PA/88A/PA/168A/PA/328/P datasheet*. ATmega48A/PA/88A/PA/168A/PA/328/P datasheet. 2020. Accessed 18 September 2024.

Spring 2016 Course Staff. "Safe Practice for Lead Acid and Lithium Batteries." *ECE 445 Course Website*, 13 April 2016, https://courses.grainger.illinois.edu/ece445/documents/GeneralBatterySafety.pdf. Accessed 29 September 2024.

United Nations. "Global Technical Regulation on the Electric Vehicle Safety (EVS)." *UNECE*, 3 May 2018, https://unece.org/fileadmin/DAM/trans/main/wp29/wp29wgs/wp29gen/wp29registry/ECE-TRANS-180a20e.pdf. Accessed 29 September 2024.

Zeng, Yuqiang, et al. “A review of thermal physics and management inside lithium-ion batteries for high energy density and fast charging.” *Energy Storage Materials*, vol. 41, 2021, pp. 264-288. *Digital Object Identifier*, https://doi.org/10.1016/j.ensm.2021.06.008. Accessed 18 September 2024.