BikeBike Revolution: Energy Efficient E-Bike

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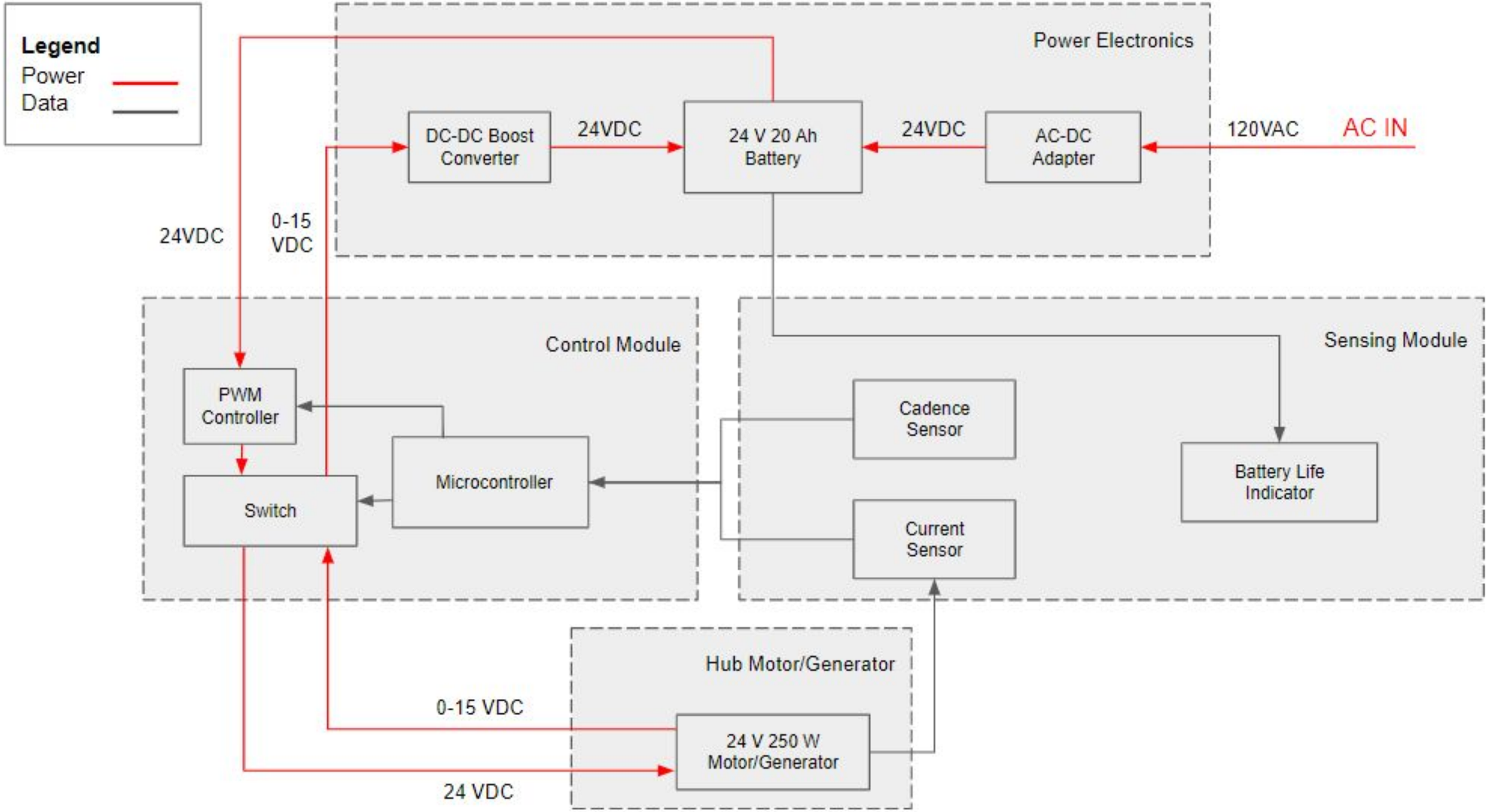
Introduction

- Combining indoor and outdoor forms of biking
- Energy saving solution for exercise for a large audience
  - 8 hours of indoor biking = 800 Wh
  - Most E-bikes take 300 - 1000 Wh
- Environmentally friendly and has high potential for improvement

Pedal power from a bike generator

Energy stored in the battery of an E-bike

Block Diagram



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Project Overview

Hardware:

Battery (24 V 20 Ah)

Grid power and AC-DC adapter

Boost converter

Motor / Generator (24 V 250 W)

Battery life indicator

Software + Hardware:

Microcontroller

- PWM Controller
- Cadence Sensor

Current Sensor

Switch

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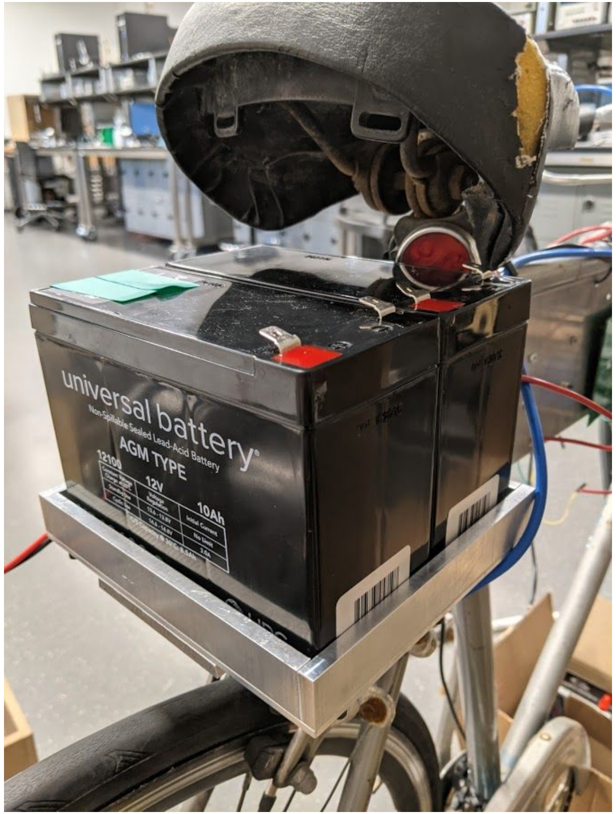
Battery Requirements

- Battery must be able to power the motor for at least 1 hour
- Charge at 100% efficiency from the grid through the AC-DC adapter
- Charge from the generator through the boost converter



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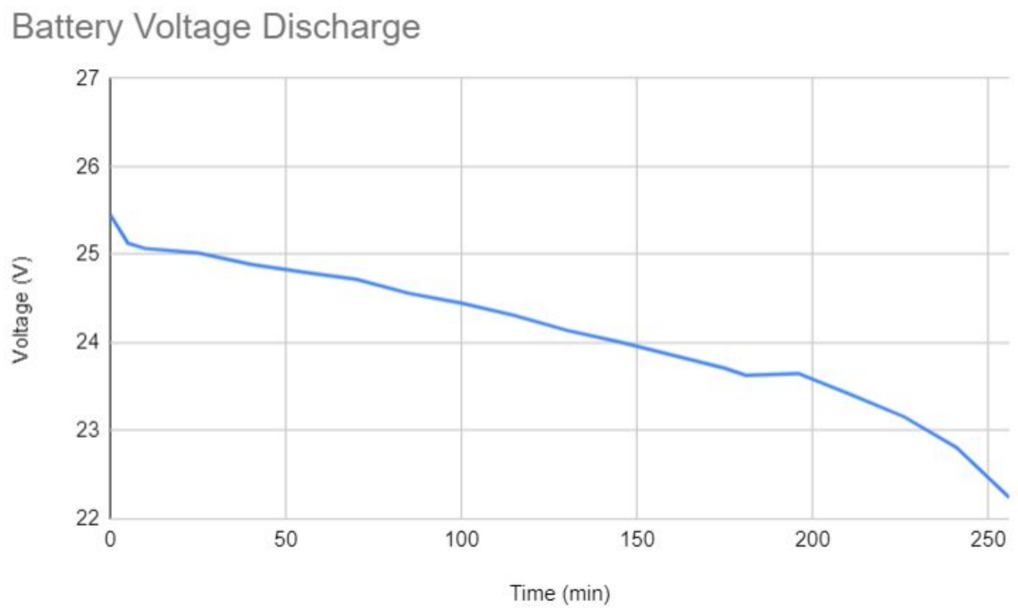
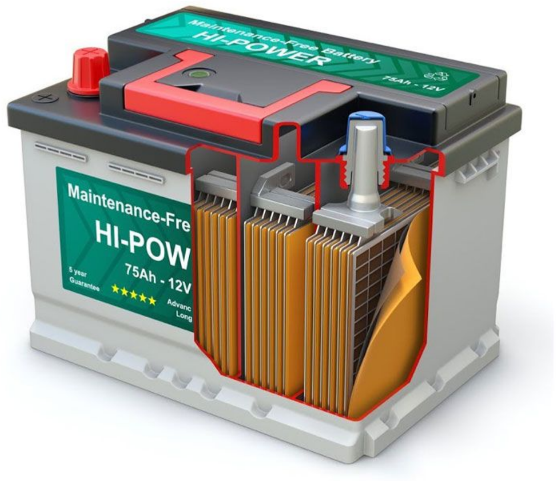
Battery Results



- Voltage discharge data for the battery life indicator
- Ran the motor with the battery for 2+ hours

Lead-Acid Battery Safety Issues

- Chemical (corrosive) hazards
- Risk of fire or explosion
- Electrical shocks
- Ergonomic hazards related to their heavy weight
- Transportation hazards
- Correct clip connection ratings



Battery Challenges

- Not able to test the battery with boost converter
  - Boost was not able to function in time for the full testing in generator mode
- Electrical shock concerns
  - Lower current rated alligator clips should not be used on battery leads

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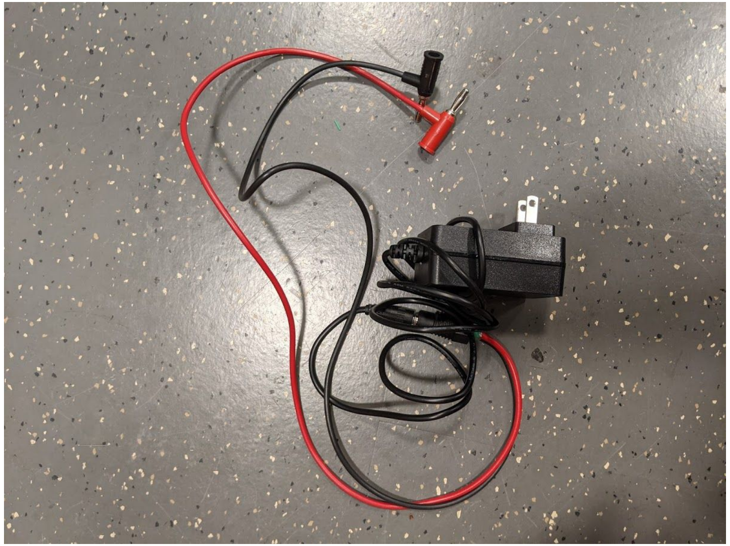
Grid Power and AC-DC Adapter

- Outputs constant 120±0.5VAC power
- Takes in 120±0.5VAC from outlet and outputs 24 ±1 V DC through the port to the battery
- Charged the battery at a consistent rate
- 1 hour charge from 22 V to 24 V



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Boost Converter

- Input 10-40 V from the generator
- Output a constant 24 ± 1 V to the battery

10 uH inductor

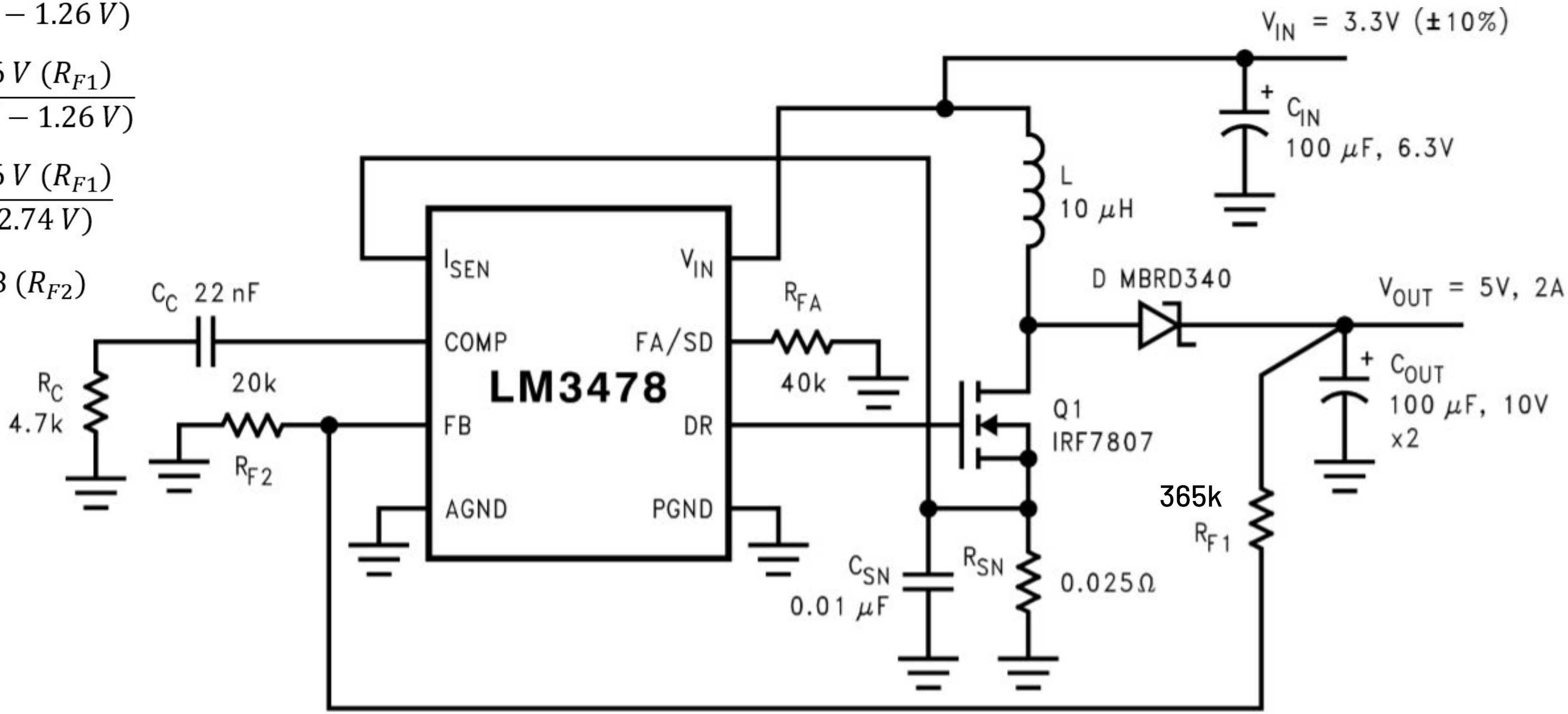
Boost Converter Schematic

$$R_{F2} = \frac{1.26\,V\,(R_{F1})}{(V_{out} - 1.26\,V)}$$

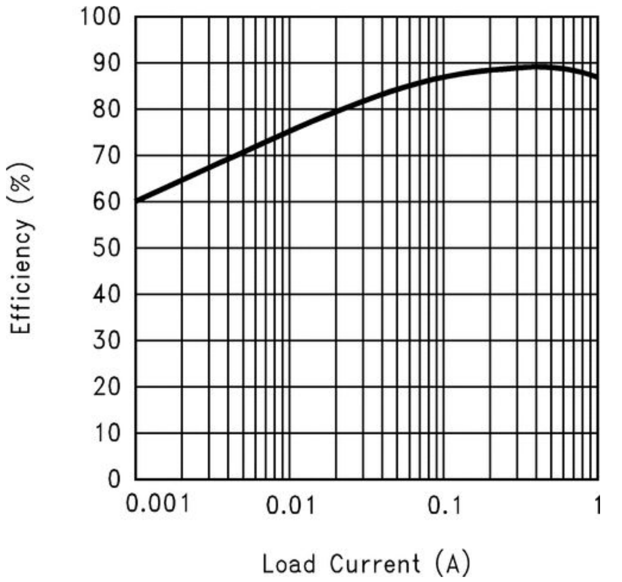
$$R_{F2} = \frac{1.26\,V\,(R_{F1})}{(24\,V - 1.26\,V)}$$

$$R_{F2} = \frac{1.26\,V\,(R_{F1})}{(22.74\,V)}$$

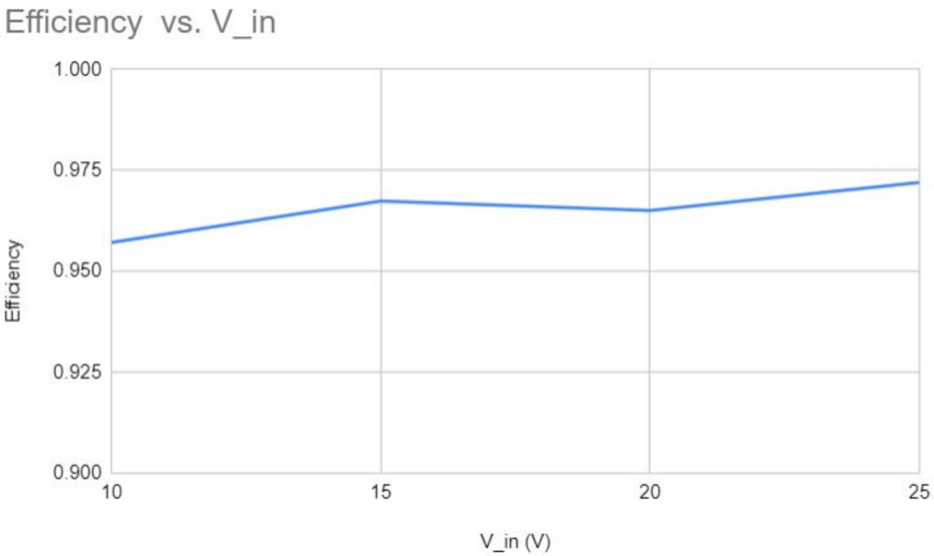
$$R_{F1} = 18\,(R_{F2})$$



Boost Converter Results



Efficiency vs. Load Current
from LM3478 datasheet



Efficiency vs. Input Voltage
from testing

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Boost Converter Data and Challenges

V_in	I_in	P_in	V_out	I_out (A)	P_out	Efficiency
10	1.13	11.3	22.3	0.485	10.8155	0.9571238938
15	0.89	13.35	24.6	0.525	12.915	0.9674157303
20	0.67	13.4	24.4	0.53	12.932	0.9650746269
25	0.56	14	25.2	0.54	13.608	0.972

$$P_{in} = V_{in}I_{in}$$

$$P_{out} = V_{out}I_{out}$$

$$\eta = \frac{P_{out}}{P_{in}}$$

- Component unit testing on the circuit design
- Testing with maximum ratings
- Testing above 30 V input

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Motor / Generator

- The generator must be able to produce at least 100 W of power
- The motor has three modes when in motor mode: off, low speed, and high speed

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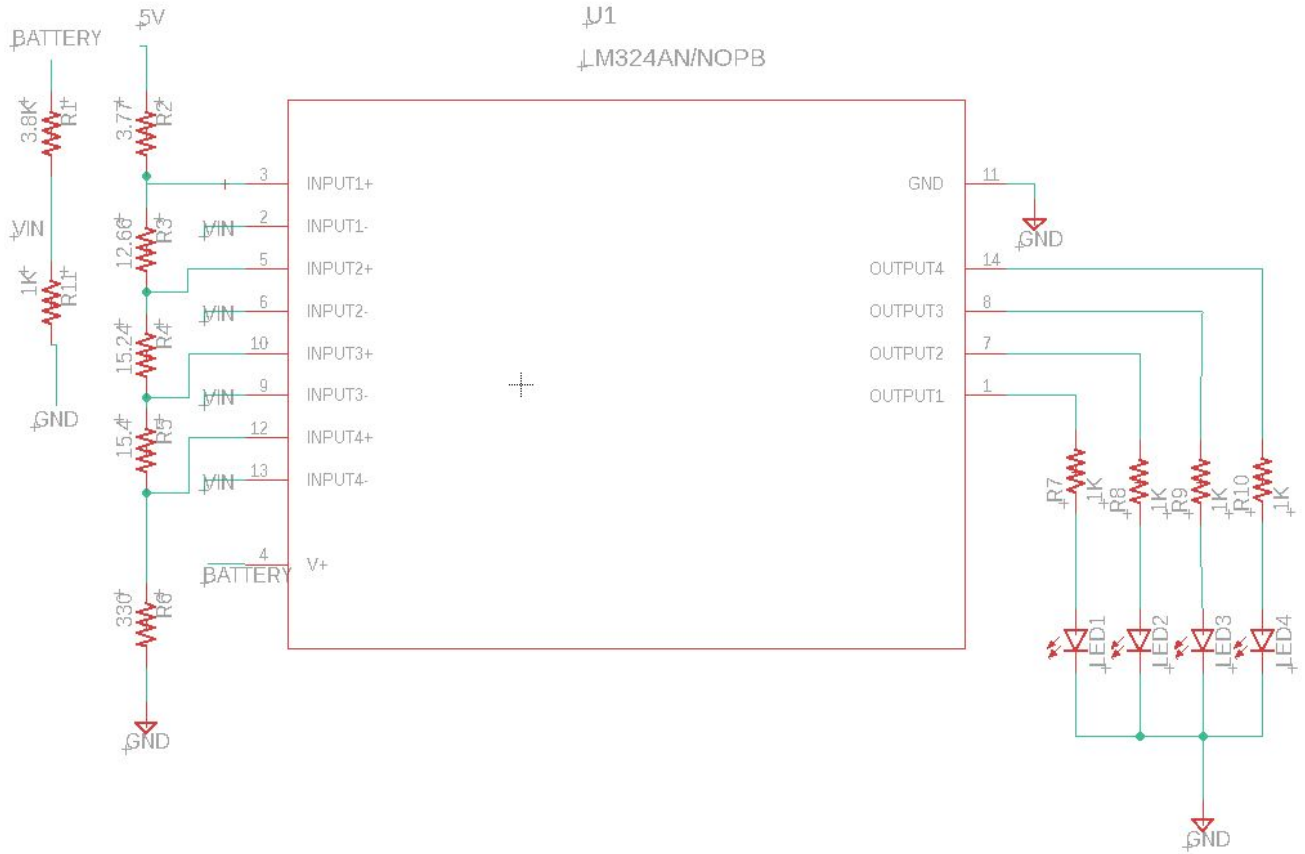
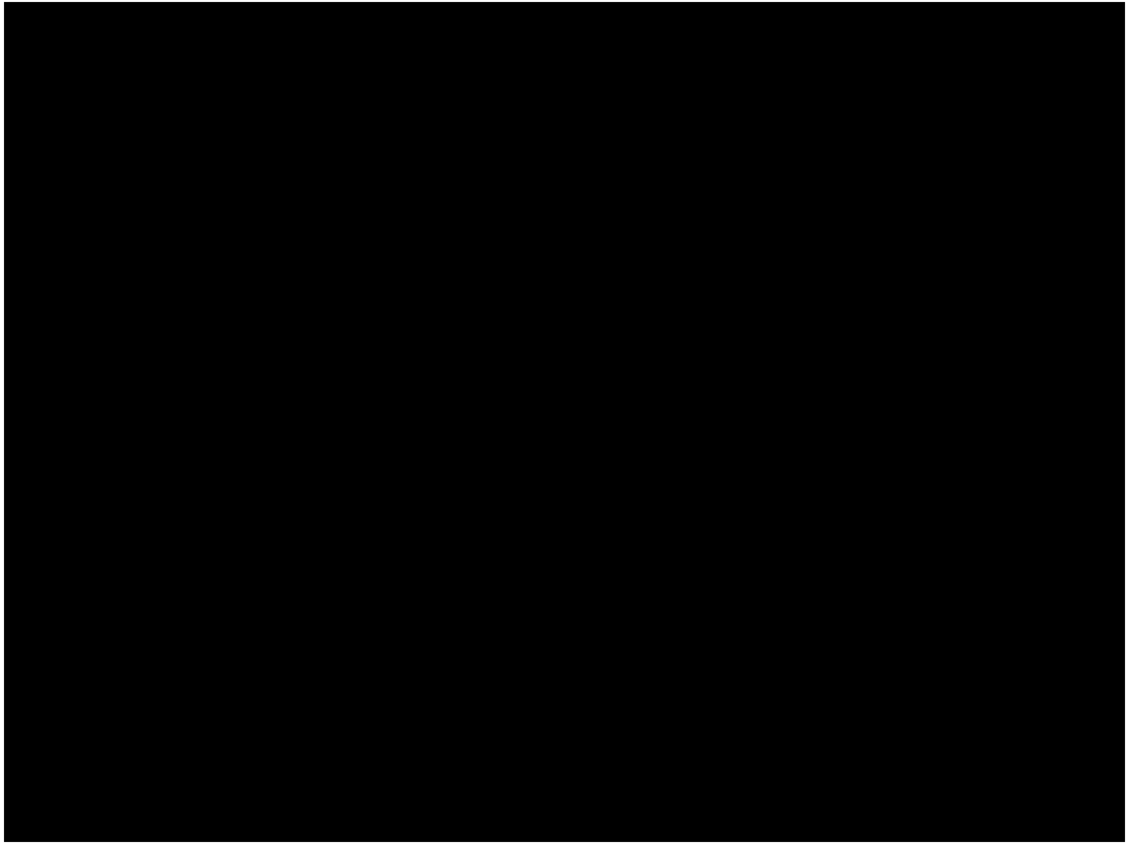
Battery Life Indicator

- Each LED must light up at its corresponding charge (25%, 50%, 75%, 100%)
- Used battery voltage curve to determine approximate percentage
    - 24 V, 23 V, 22 V, 21 V corresponds to the percentage
- Challenges:
    - Flipped LED on PCB

Battery Life Indicator Schematic

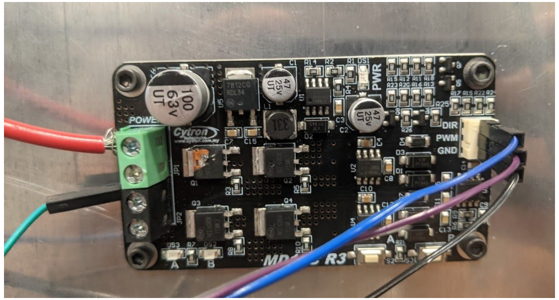


Battery Life Indicator Test



Microcontroller / PWM Controller / Cadence Sensor

- For motor functionality (pedal assist)
- Microcontroller communication with:
  1. PWM controller
     - Change motor speed depending on cadence sensor signal
  2. Cadence sensor
     - Read signal that varied frequency from pedaling speed



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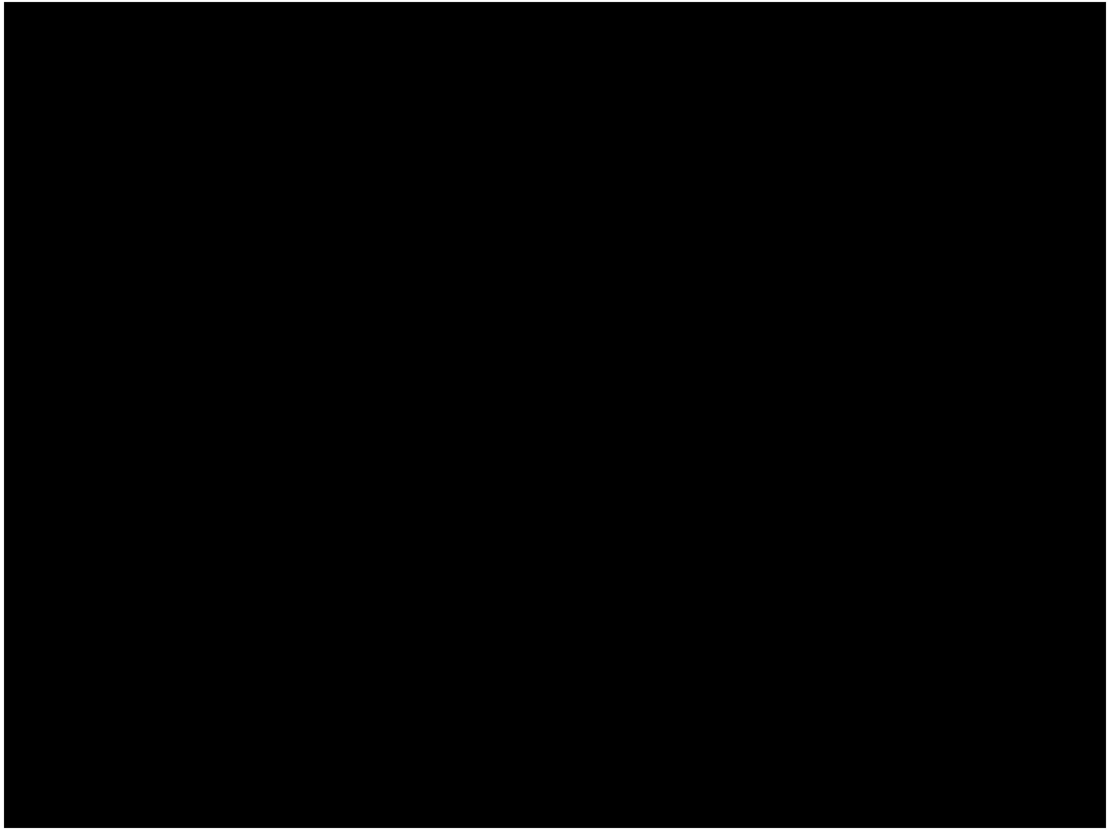
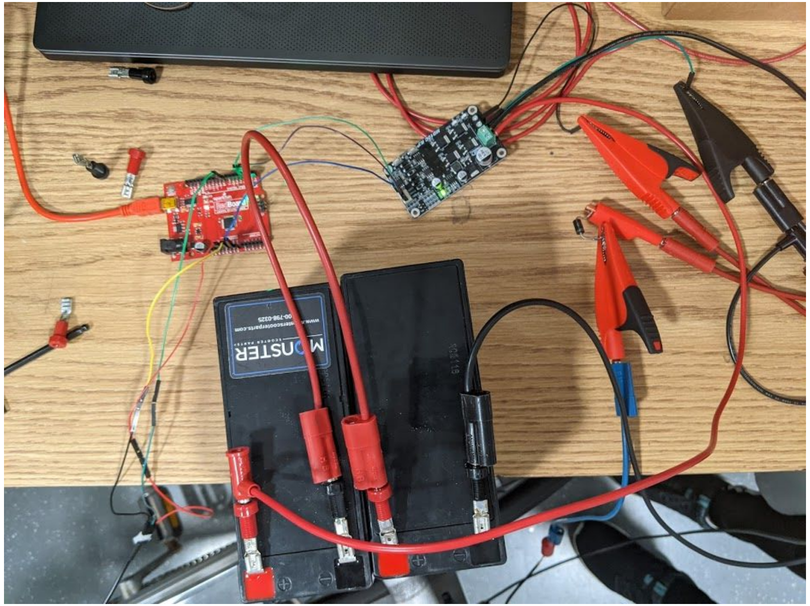
Cadence Sensor Signal



Microcontroller / PWM Controller / Cadence Sensor

- Cadence sensor -> PWM controller -> battery and motor of the bike
- Open-loop feedback
- Pedal assist functionality
  - 0 Hz = no assistance
  - 6-10 Hz = some assistance
  - > 11 Hz = full assistance
- Challenges:
  - Not able to transfer from Arduino



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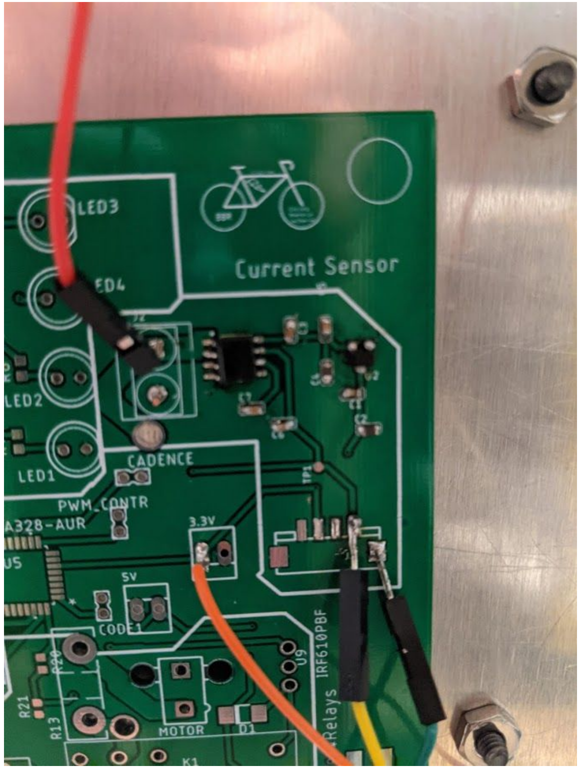
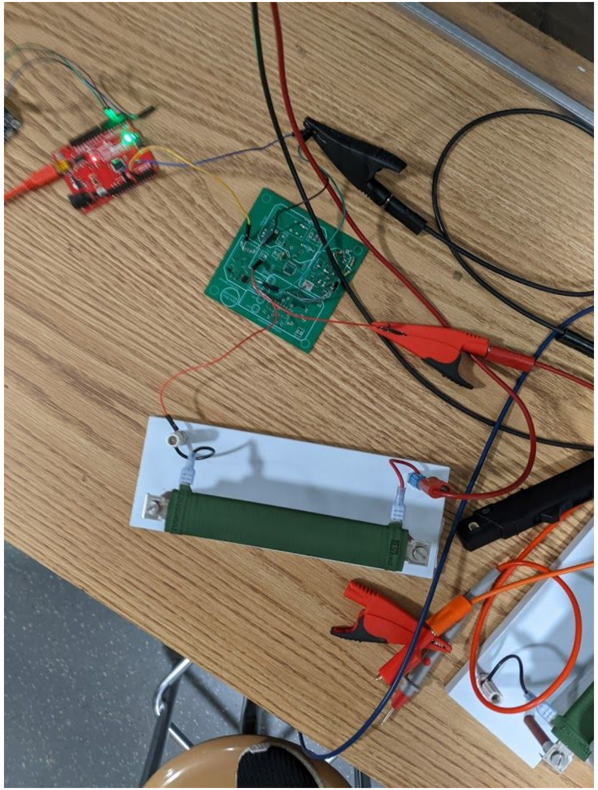
Current Sensor

- Safety feature of our design
- Communicates with switch relay
- Measures current output of the generator
    - If above 10.5A threshold, send signal to turn off switch



Current Sensor Testing

- Input voltage of 10 V
- Load resistance of 10 Ω
- Current sensor reading ~ 1 A
- Challenges:
  - PCB layout in parallel instead of series
  - Without load, generator was slipping



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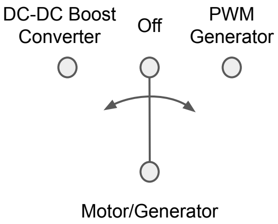
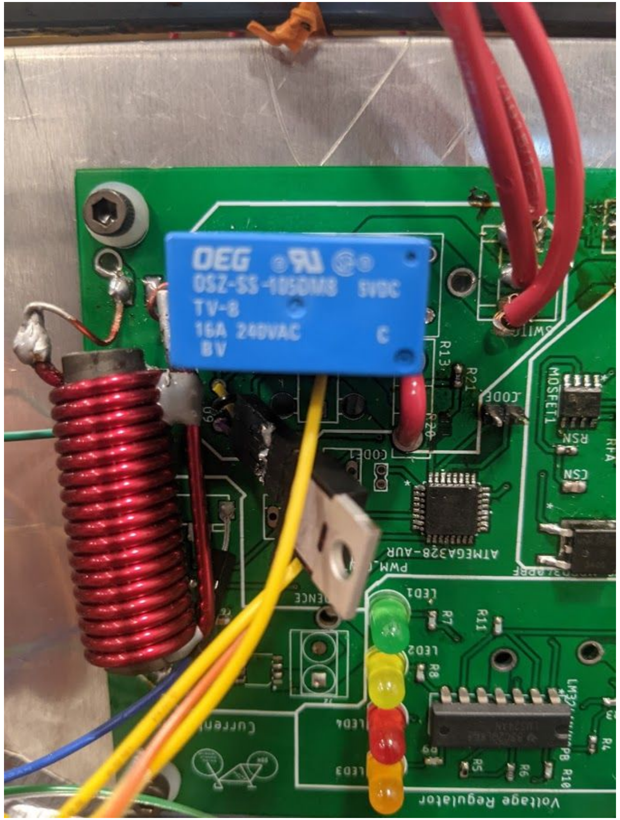
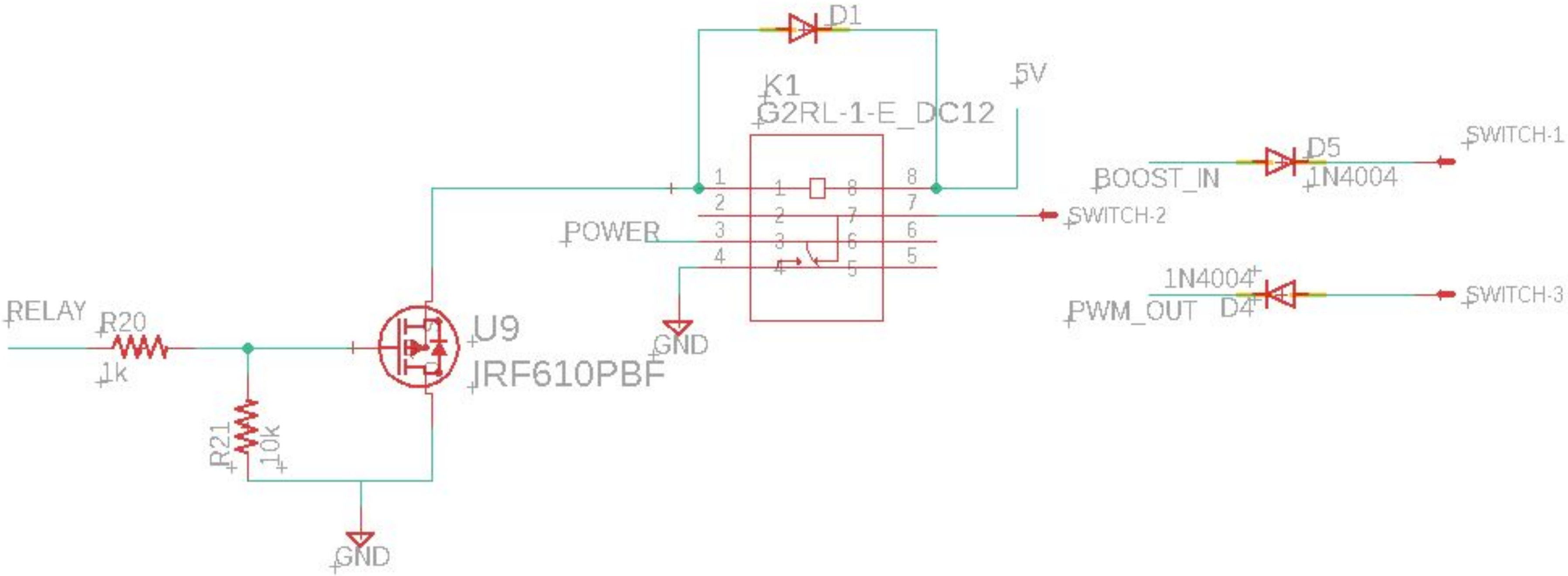
Switch

- Let ≤ 10.5A from the generator flow in generator mode
  - Current greater than 10.5 A will disconnect the generator
- The switch can select between the motor mode, generator mode, and off





Switch Schematic



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Switch Testing and Challenges

- Relay control
  - Sent 5V and 0V from the microcontroller to turn relay on and off
  - Confirmed voltage applied into the relay and out of the relay matched
  - Some relays did not work and unit testing helped with solution
  - Designing with the appropriate MOSFET
- Switch
  - Measured that current flows in the motor/generator mode and no current flows when the switch is off

Conclusions

- Our design functioned as expected!?
  - Not able to demonstrate :(
- Issues arose due to condensed timeline
  - PCB revisions
  - Wait time for part delivery
- Rewarding to see design come together in a physical form

Future Work

- Higher quality components
  - Boost converter:
    - More robust → charging efficiency
  - Battery:
    - Lithium-ion for better performance
  - Motor:
    - Higher rating to increase pedal-assist feature or support full E-Bike mode
    - Making it a hub motor / generator for cleaner integration

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Questions?

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References

- https://www.ti.com/lit/ds/symlink/lm3478.pdf?ts=1619801056019
- https://www.concordia.ca/content/dam/concordia/services/safety/docs/EHS-DOC-146_LeadAcidBatteries.pdf
- https://www.mrpositive.co.nz/buying/knowledge-base/lead-acid-battery-types/
- https://keple.com/crocodile-clips-electrical-insulated-wire-multimeter-test-leads-set-alligator-clip-clamps-double-ended-voltage-tester-cable-0-5-meter-red-black.html
- https://www.cyclevolta.com/understanding-e-bike-power-range-and-energy/#:~:text=But%20when%20it%20comes%20to,horsepower%20to%20about%201.2%20hp.

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