Project Mech 207

Lab 3

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LED Bar Graph Voltage Meter

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Checklist

[X] Proposal submitted

[X] Major parts procured

[X] Subcircuits verified (photos + plots)

[X] Integrated build done (safe, tidy)

[X] Demo script ready (what you’ll show in 5-10 minutes)

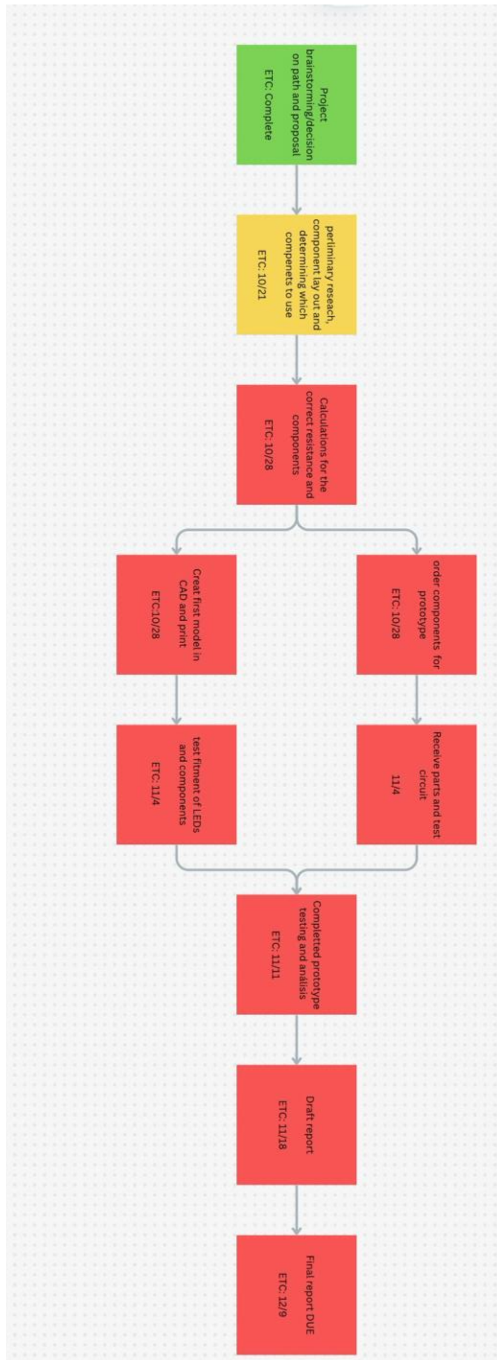
[X] Final report compiled (PDF)

Proposal

In this project, we propose developing a universal battery tester for 9-volt batteries. The device uses Zener diodes, resistors, and LEDs to create a five-segment bar graph that visually displays a battery's remaining charge. This tester provides a simple, low-cost, and reliable way to assess battery health, making it useful for both educational purposes and practical applications in electronics labs. Each LED corresponds to a specific voltage threshold, allowing the user to quickly interpret the approximate battery level.

The design emphasizes key analog measurement principles such as Zener breakdown behavior, current limiting through resistor selection, and circuit calibration. By applying these concepts, the project reinforces core ideas from MECH 207 while demonstrating how basic components can be combined to form an effective voltage-indication device.

Block Diagram



Block diagram (1): shows the plan that we have created

Background Research

This project focuses on designing and testing an LED Bar Graph Voltage Meter using basic analog circuit principles to display a battery's charge level. The goal is to understand how voltage can be measured and represented using Zener diodes, LEDs, and standard components in simple sensing and indication circuits. The theoretical foundation relies on Ohm's Law and Zener breakdown behavior.

- **Ohm's Law (V = IR)** explains how we determined the resistor values needed to set safe and consistent current levels through both the LEDs and the Zener-diode stages. Each LED has a specific forward voltage and desired operating current, so we calculated its series resistor using $R = \left(\frac{V_{supply} - V_f}{I_{target}}\right)$**.** This ensured appropriate brightness and prevented overcurrent. For the Zener stages, Ohm's Law also governed the current once each diode reached its breakdown voltage. By selecting resistor values that matched the expected Zener current range, we ensured that each diode entered breakdown cleanly at its intended threshold, creating predictable activation points across all five stages.

- **Zener diodes** operate by entering the breakdown region when the voltage across them exceeds their specified voltage (V_Z). Once V_{in} The voltage rises to approximately the diode's $V_Z threshold$. The diode begins to conduct, and current flows through its branch, illuminating the corresponding LED. Each Zener diode in the circuit is selected to have a slightly different breakdown voltage so that it activates at a distinct input threshold.

- **LEDs** convert electrical energy into light when forward-biased (typically 1.8 – 2.2 V for red or green diodes). Series resistors limit current according to $I = (V_{supply} - V_f)/R$, protecting the LEDs from damage.

By combining these elements, the circuit produces a stepped response: as the battery voltage increases, additional Zener diodes reach breakdown and additional LEDs turn on. The result is an analog-to-visual indicator that approximates the battery's remaining charge. This project links theoretical ideas such as Ohm's Law, Zener breakdown, and current limiting to a functional measurement circuit, reinforcing core concepts in circuit analysis, design, and verification.

Biasing and Threshold

Biasing

In this circuit, biasing refers to supplying each Zener diode with enough voltage to reach its breakdown region. Once the battery voltage exceeds the breakdown voltage of a given Zener, it conducts and allows current to flow through the LED branch. The resistor in each stage controls this current, ensuring reliable illumination without exceeding safe limits.

Thresholds

Each LED turns on when the input voltage satisfies:

$$V_{IN(threshold)} = \left(V_Z + V_{drop(LED)}\right)$$

Equation: Voltage Threshold (simplified)

This creates five distinct voltage thresholds. Because each Zener diode has a different breakdown voltage, the LEDs turn on sequentially as battery voltage increases, forming a stepped visual indication of battery charge level.

Zener Diode Orientation and Biasing

Each Zener diode in the circuit is oriented with its cathode connected toward the positive input voltage and its anode connected toward ground. This orientation places the diode in reverse bias, which is required for Zener breakdown behavior. In reverse bias, the diode blocks current until the input voltage reaches its specified breakdown voltage.

Once the battery voltage exceeds this breakdown level, the Zener diode enters its reverse breakdown region, allowing current to flow from the cathode to the anode. This controlled breakdown is what biases the stage into conduction and supplies current to the corresponding LED. Unlike a transistor stage, the Zener does not “saturate”; instead, it maintains a nearly constant voltage equal to its breakdown voltage while regulating the current flowing through the branch.

If the input voltage remains below the diode’s breakdown voltage, the Zener stays reverse-biased and non-conducting, preventing the LED from turning on. Because each Zener diode in the design has a different breakdown voltage, they activate at distinct input thresholds, enabling the stepped, sequential illumination of the LED bar graph.

Preliminary Design

The preliminary design is divided into three main sections:

1. **Input Stage (Battery Input):**
   Provides the 9-volt battery voltage directly to the Zener diode stages. No divider is used in the final design.
2. **Control Stage (Diode Network):**
   Each Zener diode acts as a voltage-level barrier, turning on sequentially as the input voltage rises.
3. **Output Stage (LED Bar Graph):**
   Five LEDs provide a visual indicator of voltage, with one LED per step from low to full charge.

Design Overview

This project is an LED bar graph voltage meter. It reads a battery's voltage and turns on 1–5 LEDs to show the level. The circuit has three simple parts:

1. **1. Comparator and Control Stage (Zener-Diode Network)**
   Five Zener diodes act as simple voltage thresholds. Each diode is selected for a different Zener voltage, so it begins to conduct only when the input exceeds its breakdown level. As the input increases, more Zener diodes enter breakdown, and each one triggers its corresponding LED to turn on.
2. **LED Display Output**
   Five LEDs form a small "bar graph." One LED means low voltage, and all five means high voltage. Each LED represents a step (about 20% per step). This gives a quick, easy-to-read indication of battery level.

Initial Parts List

Component	Specification	Quantity	Notes
Red LED	Red LED	1	Indicates the lowest voltage level
Yellow LED	Yellow LED	1	Indicates low–medium level
Yellow LED	Yellow LED	1	Indicates medium level
Green LED	Green LED	1	Indicates a good level
Green LED	Green LED	1	Indicates full level
Fixed Resistor for Red LED	200 Ω	1	LED current limiter

Fixed Resistor for Orange LED	200 Ω	1	LED current limiter
Fixed Resistor for Yellow LED	10,000 Ω	1	LED current limiter
Fixed Resistor for Green (Medium) LED	110 Ω	1	LED current limiter
Fixed Resistor for Green (High) LED	3800 Ω	1	LED current limiter
Zener Diode	2.5 V	1	To activate the lights
Zener Diode	3 V	1	To activate the lights
Zener Diode	3.75 V	1	To activate the lights
Zener Diode	5 V	1	To activate the lights
Zener Diode	6 V	1	To activate the lights
Power Source	9-volt alkaline battery + clip	1	Circuit supply
Protoboard	Protoboard	1	Assembly platform
Wires		As needed	Interconnects

Table (1): Shows the initial part list

Testing and Verification Plan

Step 1 – Single-Stage Threshold Test

Build one Zener + LED stage. Sweep the input slowly with a bench supply. Record the input voltage where the LED turns on. Compare this value to the expected Zener breakdown voltage plus LED forward voltage.

Step 2 – Full Chain Behavior

Add the remaining stages. Verify that LEDs turn on in order (1 through 5) with no flicker. If two LEDs overlap too much, tweak the bias resistors or slightly trim with the potentiometer.

Step 3 – Loaded Measurement

Add a small load resistor at the input (to mimic real battery use). Repeat the measurement and ensure the thresholds remain reasonable.

Step 4 – Calibration and Data

Use the potentiometer to set clean, repeatable steps. Record the final turn-on voltages for each LED. Take photos and save measurements in the notebook.

Expected Results

As the battery voltage increases, LEDs turn on one at a time as the Zener diodes reach their breakdown voltages. The five Zener thresholds span the typical voltage range of a 9-volt battery. After calibration, the sequence should be stable, easy to read, and repeatable.

Circuit Design and Parts

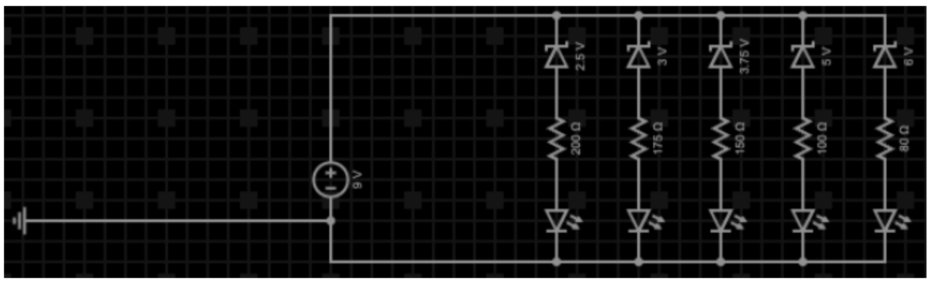


Figure (1): Simulated Circuit design

Equations and Method

Resistor current (assumed steady DC): $I = (V_{BATT} - V_F) / R$

Voltage across resistor: $V_R = I \times R$

Power in resistor: $P_R = I^2 \times R$

Power in LED: $P_{LED} = I \times V_F$

Branch power from source: $P_{branch} = V_{BATT} \times I$

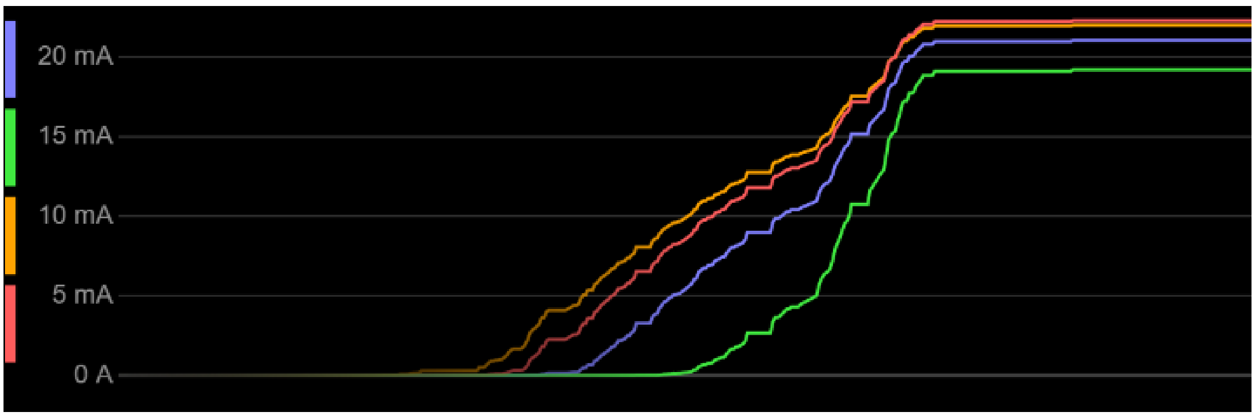
For justification, currents are taken from the design target values. Using those currents, we compute voltage drops and powers to verify resistor values

Per-Branch Calculations at $V_{BATT} = 9.6$ V

LED Color	Resistor (Ω)	LED Vf (V)	Current (mA)	V_R (V)	$V_{remaining}$ (V)	P_R (mW)	P_{LED} (mW)
Red	200	2.00	22.3	4.46	3.14	99.5	44.6
Orange	220	2.01	22.7	4.99	2.60	113.4	45.6
Yellow	175	2.01	21.5	3.76	3.83	80.9	43.2
Green (Medium)	150	2.00	19.8	2.97	4.63	58.8	39.6

Green (High)	80	1.95	13.1	1.05	6.60	13.7	25.5

Simulation Results



Graph (1): Shows the chart of how each part of the circuit reacts when the voltage increases, also causing the current to increase.

The behavior shown in the graph closely matches the theoretical expectations for our circuit. When no voltage is applied, the current through each LED is zero, meaning none of the LEDs are illuminated. Once voltage is introduced, we observe a gradual, almost linear increase in current for each LED as the circuit transitions out of its transient state.

The purpose of this circuit is to indicate the approximate battery voltage using an LED bar display. This is demonstrated in the graph by noting the point at which each LED begins to conduct current. For example, the orange line (representing the red LED in the physical circuit) begins to rise first, corresponding to roughly 20% battery level. The purple line, which represents approximately 60% battery level, begins conducting noticeably later. This staggered behavior occurs because each LED is biased to turn on only after the sensed voltage reaches its specific threshold, meaning lower-percentage LEDs activate first and higher-percentage LEDs last. Our simulation time scale is extremely small, so this staggered time would appear instantaneous in real life.

Once the circuit reaches steady state, the current through each active LED becomes constant, indicating that the battery voltage is no longer changing and the system has fully settled. The circuit is intentionally designed with current-limiting resistors so that each LED receives enough current to illuminate safely bright enough to be visible, but not high enough to risk damage to the circuit.

Prototype – Initial Measurements + Troubleshooting

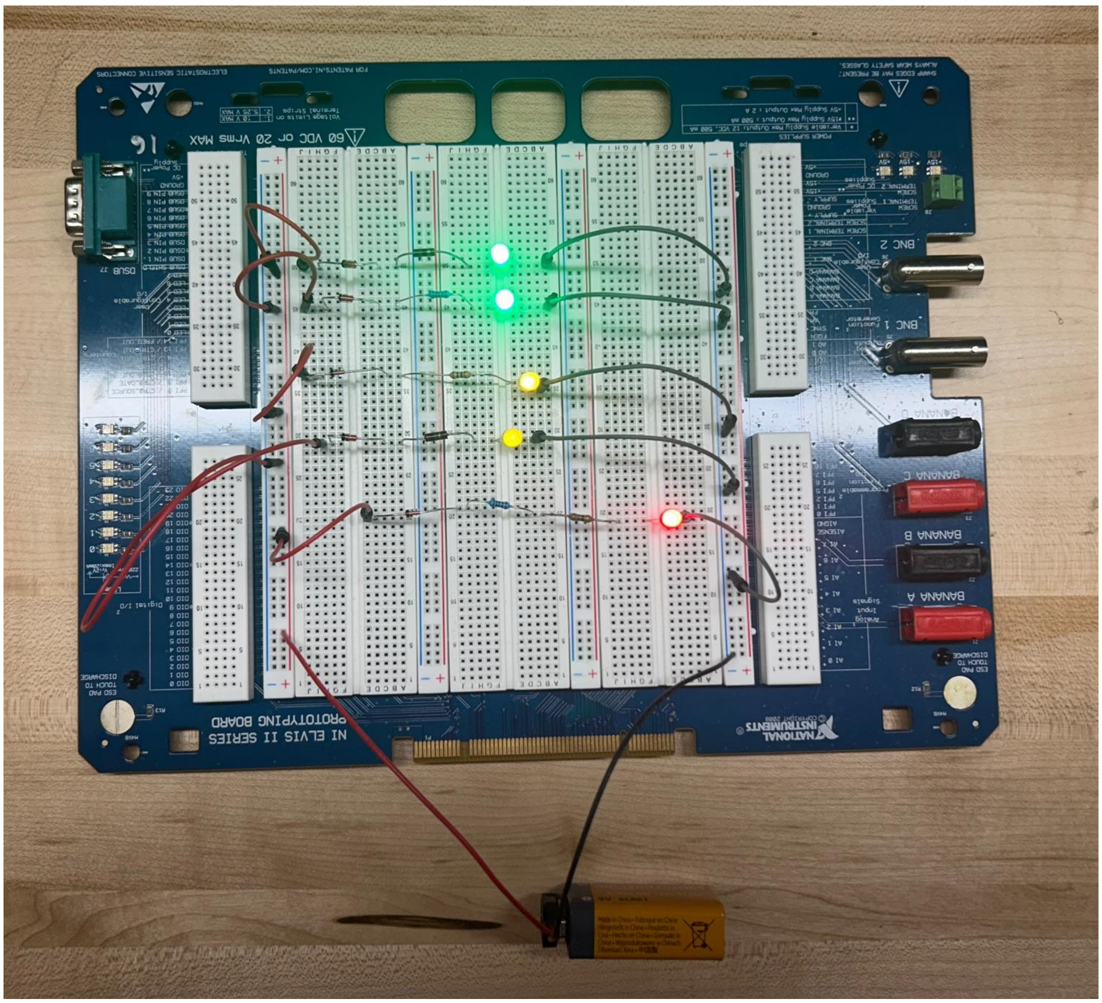


Figure (2): Shows our initial prototype with all LEDs on.

During our initial testing, the circuit performed well overall. When the battery was fully charged, all LEDs illuminated as expected, confirming that the bar-graph concept functions correctly. However, we did observe some inconsistencies at lower voltages. Specifically, when the input dropped to around 6 volts or below, several of the green LEDs still turned on when they should not have.

This behavior suggests a potential issue with the voltage-threshold components, such as the Zener diodes. We did not have access to the initial Zener diodes that we had designed our circuit for, so we had to improvise with the equipment provided. Our next step will be to diagnose whether any Zener diodes are out of tolerance or don't match our simulated circuit closely enough. Despite these discrepancies, the initial results indicate that the design is fundamentally sound and capable of achieving the intended voltage-indication functionality.

Final Parts List

Component	Specification	Quantity	Notes
Red LED	Red LED	1	Indicates the lowest voltage level
Yellow LED	Yellow LED	1	Indicates low–medium level
Yellow LED	Yellow LED	1	Indicates medium level
Green LED	Green LED	1	Indicates a good level
Green LED	Green LED	1	Indicates full level
Fixed Resistor for Red LED	2,000 Ω	1	LED current limiter
Fixed Resistor for Orange LED	200 Ω	1	LED current limiter
Fixed Resistor for Yellow LED	10,000 Ω	1	LED current limiter
Fixed Resistor for Green (Medium) LED	110 Ω	1	LED current limiter
Fixed Resistor for Green (High) LED	3800 Ω	1	LED current limiter
Zener Diode	3.0 V	1	To activate the lights
Zener Diode	3.3 V	1	To activate the lights
Zener Diode	5 V	1	To activate the lights
Zener Diode	5.7 V	1	To activate the lights
Zener Diode	6.2 V	1	To activate the lights

Power Source	9-volt alkaline battery + clip	1	Circuit supply
Protoboard	Protoboard	1	Assembly platform
Wires		As needed	Interconnects

Table (2): Shows the table with all parts used in the final assembly.

Data From Prototype

After last week's issue with the Zener diodes not tripping at their intended thresholds, we revisited our calculations and adjusted the design accordingly. By recalculating the expected trigger points and comparing them to the prototype's actual behavior, we identified where the voltage thresholds were drifting.

With these updated calculations, we selected new Zener diode values and modified the surrounding resistor network to bring each LED's activation point much closer to the ideal voltage levels. In the photo below, you can see the updated Zener diode selections along with the revised resistor values that now produce significantly more accurate trigger behavior.

Overall, these adjustments improved the consistency of the voltage indicators and brought the prototype much closer to our target performance.

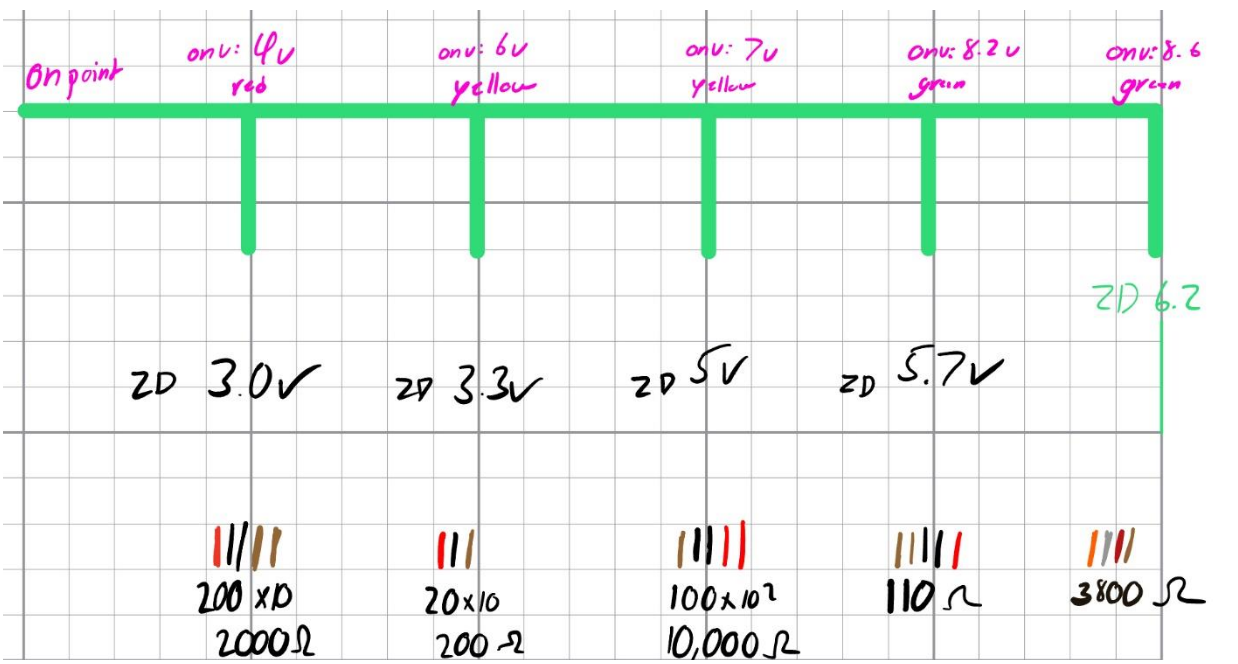


Figure (3): Shows the refined schematic with all-new values.

With this refined schematic, we collected data on when the lights will turn on and off and, roughly, what they mean in terms of capacity charge.

Red LED	1st Yellow LED	2nd Yellow LED	1st Green LED	2nd Green LED	Which LED
3.0 V	3.3 V	5 V	5.7 v	6.2 V	Zener diode
2000Ω	200 Ω	10,000 Ω	110 Ω	3800 Ω	Resistor
Battery<20%	Battery<35%	Battery<53%	Battery<75%	Battery≤100%	Battery percentage

Table (3): Shows the Zener diode and resistor that were used, and what percentage each led would turn on and represent.

The measured trigger points for each LED closely align with our updated calculations. We intentionally designed the bar graph to show gradual voltage steps at lower battery levels, and the data reflect that behavior, especially in the red and yellow LED ranges. As the voltage approaches the final two LEDs, the activation thresholds become more refined, matching our target values for the 1st and 2nd green LEDs at approximately 5.7 V and 6.2 V.

Main Prototype and Packaging

At this point in the project, we have completed assembly of the main circuit board, with all components soldered and connected. This is shown in the figure below.

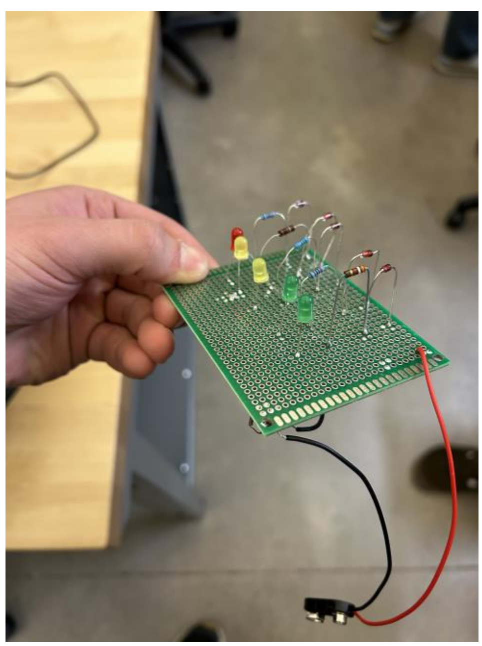


Figure (4): Circuit board for main prototype

Our design will be encased in a custom 3D-printed case. In this design, a platform holds the board, and there will be a hole on the side of the box so the battery connector can be inserted into a 9V battery. This makes the battery connector safer, as you are not touching any live wires in the system, and the 3D model for this is shown in Figure (5).

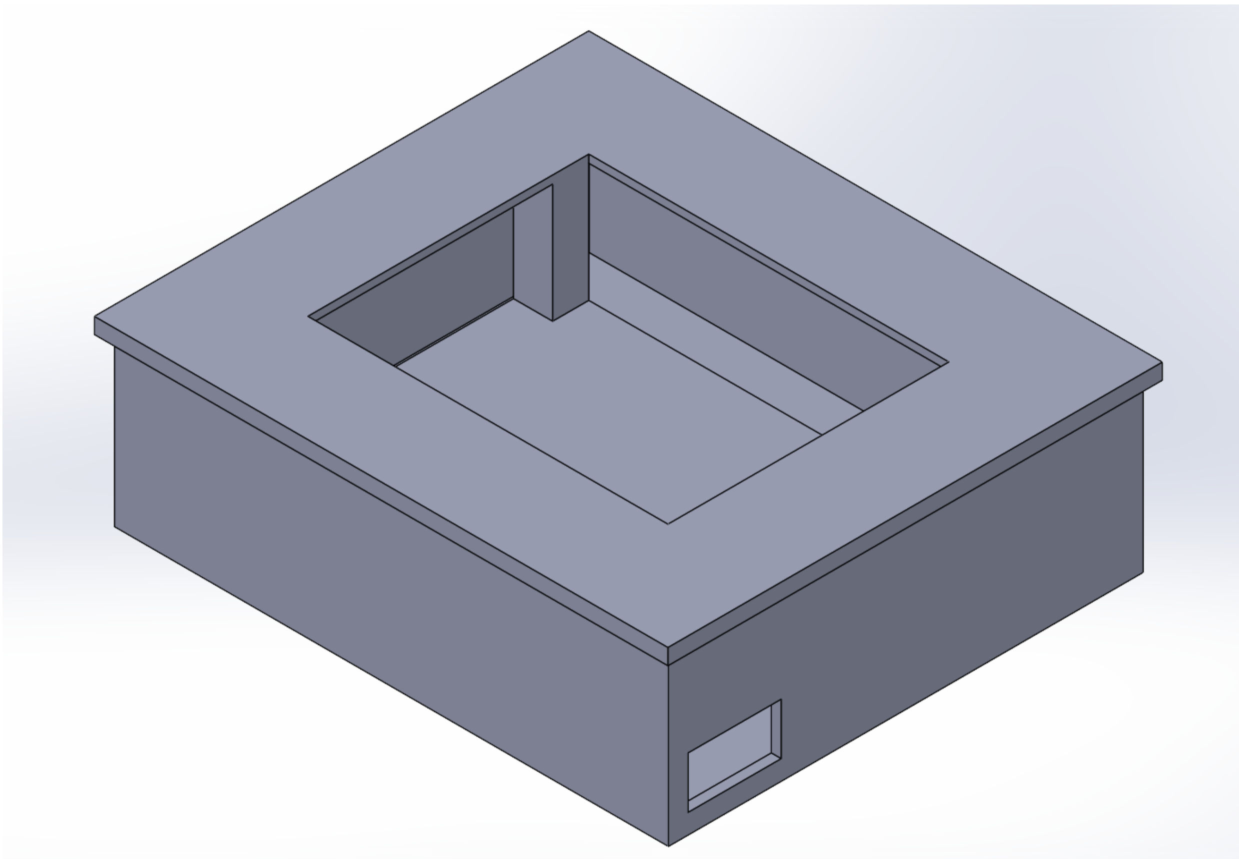


Figure (5): CAD file for the case that was built to hold our circuit.

Final Product

Our final LED bar-graph battery indicator performs as intended. After recalculating the trigger thresholds and adjusting the Zener diode and resistor values, each LED now activates at the correct voltage, providing a clear and accurate representation of the battery percentage. Prototype testing confirmed stable behavior, smooth transitions between thresholds, and reliable operation across the full voltage range.

We have designed a case that comfortably fits our product, ensuring a clean, protective look. This case consists of two parts: the base and the top. This allows for the circuit to be pulled out with the top and put back in with a smooth fit. Along with that, we implemented a square cutout on the side of the base to allow the 9V connector to pass through. This provides a user-friendly, efficient way to plug in and test 9-volt battery voltage levels. Our final design for this project is shown in Figure (6).

Figure (6): Shows the final product of our project

References

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