“Battery Voltage Monitor System”

Group code-PGEE22

Department: Electrical Engineering (Academic Year: 2024-25)

Sr No.	Name	Registration number	Work Assigned
1	Darshan Singh	2023BEL021	Simulation, Documentation
2	Avishkar Kamble	2023BEL008	PCB Designing
3	Ruchie Patil	2023BEL018	PCB Designing
4	Anuj Kamble	2023BEL017	Simulation and Research
5	Krishna Bhise	2023BEL003	Prototype and Research
6	Mayur Wakade	2023BEL002	Prototype and Research

Supervisor [Guide]: Prof. N.S. Bijwe
Department: Electrical Engineering

Academic Year: 2024-25
Submission Date: 22nd April 2025

CERTIFICATION

This is to certify that the project entitled "Battery Voltage Monitoring System" in the fulfilment of "Second Year Micro Project" for Shri Guru Gobind Singhji Institute of Engineering and Technology, Vishnupuri, Nanded. This Bonafide work carried and completed under guidance and supervision of our Prof. N.S.Bijwe during academic year 2024-2025.

SUBMITTED BY: PGEE22

Sr No.	Name	Registration number
1	Darshan Singh	2023BEL021
2	Avishkar Kamble	2023BEL008
3	Ruchie Patil	2023BEL018
4	Anuj Kamble	2023BEL017
5	Krishna Bhise	2023BEL003
6	Mayur Wakade	2023BEL002

Prof.N.S.Bijwe
[Project Guide]

Dr.S.M.Gudhe
[Head of Department]

Declaration by Students

We hereby declare that the project titled "Battery Voltage Monitoring System" has been carried out by us as a part of our academic curriculum and is the result of original work undertaken by us. The circuit has been designed, assembled, and tested under the expert guidance of Prof.N.S.Bijwe, to whom we are sincerely grateful for his constant support and valuable insights. We affirm that this project does not contain any material copied from other sources without due acknowledgment. We also take this opportunity to thank Dr. S.M. Gudhe, Head of Department, for providing us with the necessary facilities, encouragement, and a conducive environment for completing this project successfully.

Sr No.	Name	Registration number	Signatures
1	Darshan Singh	2023BEL021	______________
2	Avishkar Kamble	2023BEL008	______________
3	Ruchie Patil	2023BEL018	______________
4	Anuj Kamble	2023BEL017	______________
5	Krishna Bhise	2023BEL003	______________
6	Mayur Wakade	2023BEL002	______________

ACKNOWLEDGEMENT

I would like to express my sincere gratitude to all those who have contributed to the successful completion of this Battery Voltage Monitoring project. First and foremost, I extend my heartfelt thanks to **Prof.N.S.Bijwe**, our project guide, for his invaluable guidance, encouragement, and constant support throughout the course of this work. His expertise and insights were crucial in helping us overcome various challenges and complete the project efficiently.

I am also immensely grateful to **Dr. S. M. Gudhe**, Head of the Electrical Engineering Department, for providing us with the necessary resources and a conducive environment for learning and experimentation. His leadership and continuous motivation played a significant role in shaping the quality and direction of this project.

A special mention must be made of **all the faculty members of the Electrical Department**, whose timely feedback, technical input, and mentorship helped enhance our understanding of core concepts and practical implementation. Their dedication to teaching and mentoring students has been truly inspiring.

Lastly, I would like to acknowledge the support of the **AICTE IDEA Lab**, which provided access to essential tools, components, and infrastructure required for the successful development and testing of our fire alarm circuit. The hands-on experience and exposure we received at the lab played a pivotal role in refining our technical and problem-solving skills.

ABSTRACT

This project developed a cost-effective Battery Voltage Monitoring System using analog components to provide real-time visual indication of battery status. The objective was to create a simple, reliable circuit that could detect when battery voltage falls below critical thresholds without requiring microcontrollers or programming.

The monitoring system employs LM741 operational amplifiers configured as voltage comparators, with potentiometers providing adjustable threshold points. When battery voltage is within acceptable range, a green LED illuminates; when voltage drops below the threshold, a red LED activates. Protection diodes prevent interaction between comparator stages, ensuring stable operation.

The design was first simulated in Proteus software and then implemented on breadboard using standard components: op-amps, resistors, diodes, and LEDs. Testing with various voltage sources demonstrated reliable detection with approximately 0.1V precision. The system successfully maintains stable indication across operating temperatures while consuming minimal power (approximately 15mA).

Key findings include the importance of isolation diodes for preventing interference between comparator stages and the effectiveness of potentiometer-based adjustment for different battery types. The circuit performed consistently in accordance with design specifications, with clear transitions between indicator states when voltage crossed preset thresholds.

The resulting monitoring system has applications in laboratory equipment, educational demonstrations, and simple electronic devices where unexpected power loss must be avoided. The project demonstrates that effective power monitoring can be achieved using basic analog components without complex digital systems, providing an accessible solution for hobbyists and students while maintaining reliable performance for practical applications.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1
INTRODUCTION

CHAPTER 1: INTRODUCTION

1.1 BACKGROUND

Battery voltage monitoring is essential in electronics projects to prevent unexpected shutdowns and component damage. Our team faced this problem repeatedly in the lab - batteries would die mid-experiment, causing lost work and occasionally damaging sensitive components. Commercial monitors seemed needlessly complex for our purposes, so we designed our own voltage monitoring circuit.

Our system uses LM741 op-amps as voltage comparators to track battery levels and trigger LED indicators when voltages fall outside acceptable ranges. This analog approach provides immediate visual feedback without microcontrollers or programming. The circuit is particularly useful for battery-powered projects where knowing power status at a glance prevents frustration and wasted time.

What makes this project practical is its simplicity and reliability - it uses common components found in most electronics labs and can be adapted to different battery types by adjusting potentiometer settings. The visual indication system (green LED for good voltage, red LED for low) provides intuitive feedback even to users with limited electronics knowledge.

1.2 MOTIVATION

This project grew from real frustration in our electronics lab. We'd frequently find ourselves troubleshooting circuits only to discover the problem was simply a dying battery. These interruptions wasted valuable lab time and sometimes damaged components when voltage dipped too low.

We initially tried commercial solutions, but they were either expensive, overly complex, or difficult to integrate with our existing projects. Most battery monitors seemed designed for specific applications like drones or mobile phones rather than general laboratory use.

We realized we could build exactly what we needed using op-amps as voltage comparators - a technique mentioned in our coursework but rarely applied in practical projects. This approach let us create a monitor that:
- Uses components we already had in the lab
- Provides clear visual feedback without requiring attention
- Can be calibrated for different battery types
- Draws minimal power from the battery being monitored
- Teaches practical applications of comparator circuits

The hands-on nature of this project also gave us a chance to improve our circuit design skills while solving a real problem we faced daily.

1.3 OBJECTIVES

Our battery voltage monitoring project had several specific objectives:

1. Design a comparator-based circuit that accurately detects when battery voltage crosses predefined thresholds

2. Implement adjustable trigger points using potentiometers to accommodate different battery types (9V, 8V, etc.)

3. Create a dual-indicator system with green LED for normal voltage and red LED for low voltage conditions

4. Ensure reliable operation with clean transitions between states, avoiding flicker or false readings

5. Minimize component count and power consumption while maintaining functionality

6. Build a functional prototype on breadboard for laboratory testing and validation

7. Document the design process, circuit operation, and testing results for future reference

8. Prepare for eventual PCB implementation with compact layout and reliable connections

These objectives provided clear direction throughout development and helped us evaluate the success of our completed project.

1.4 SCOPE OF WORK

Our project focused on creating a practical battery monitoring solution with these specific elements:

- Circuit design using analog components (op-amps, resistors, diodes, LEDs)
- Simulation in Proteus to verify operation before physical construction
- Breadboard prototyping for testing and refinement
- Testing with various voltage sources and conditions
- Documentation of results and performance characteristics

We deliberately limited our scope to:
- Analog circuitry without microcontrollers
- Visual indication without numerical display
- Dual-threshold detection (good/low) rather than multiple levels
- Basic component protection without complex safety features
- Manual calibration using potentiometers

These limitations kept the project manageable while still creating a useful tool. The current implementation serves as a foundation for potential future enhancements like PCB fabrication, enclosure design, or additional features.

The project timeline spanned four weeks, with the first week dedicated to design and simulation, the second to breadboard implementation, the third to testing and refinement, and the fourth to documentation and preparation for PCB development.

1.5 ORGANIZATION OF REPORT

This report is structured to follow the standard engineering project format:

Chapter 1 (Introduction) establishes the project context, our personal motivation, specific objectives, and the defined scope of work.

Chapter 2 (Literature Review) examines existing voltage monitoring approaches, highlights their strengths and limitations, and identifies gaps our project addresses.

Chapter 3 (System Design) details our technical approach through block diagrams, system architecture explanation, and component specifications.

Chapter 4 (Implementation) describes our hands-on development process, tools used, hardware configurations, and provides circuit diagrams and prototype photos.

Chapter 5 (Results and Discussion) presents test findings with specific measurements, analyses performance characteristics, and compares actual results to expected outcomes.

Chapter 6 (Applications and Future Scope) explores practical uses for our system and outlines potential improvements for future development.

Chapter 7 (Conclusion) summarizes achievements, lessons learned, and offers final thoughts on the project's success and limitations.

This organization ensures comprehensive coverage of all project aspects while maintaining a logical flow from concept to completion.

CHAPTER 2
LITERATURE REVIEW

CHAPTER 2: LITERATURE REVIEW

2.1 SUMMARY OF RELATED WORK

Battery monitoring technology spans from simple voltage indicators to sophisticated battery management systems. Our research identified several existing approaches:

Basic indicators use Zener diodes or voltage references to trigger LEDs when voltage crosses fixed thresholds. These circuits appear in projects by hobbyists like those on Instructables.com, typically using fewer than ten components but offering limited flexibility.

More advanced analog designs incorporate adjustable reference voltages using potentiometers, similar to our approach. The Electronics-Lab.com "Battery Monitor Circuit" uses LM339 quad comparators with multiple threshold points. These inspired aspects of our design, though we simplified to focus on dual-threshold monitoring.

Moving up in complexity, specialized ICs like the MAX17043 fuel gauge chip provide accurate battery level measurement but require I2C interfaces and microcontroller integration. Similarly, dedicated battery monitor ICs like LTC4150 track current flow for coulomb counting but add significant complexity.

At the high end, complete battery management systems (BMS) offer comprehensive protection (over/under voltage, temperature, current) and often connect to displays or wireless networks. These typically use microcontrollers and multiple sensing circuits, making them powerful but expensive and complex.

Our approach sits between basic fixed indicators and sophisticated digital systems - offering adjustability without requiring programming or specialized ICs. This middle ground fills a practical need for simple but reliable monitoring in laboratory and hobbyist settings.

2.2 COMPARISONS WITH EXISTING APPROACHES

After examining various battery monitoring methods, we can contrast their characteristics with our design:

Fixed-threshold indicators (using Zener diodes):
- Simpler (typically 5-7 components)
- Lower cost
- No adjustability for different battery types
- Often single-indication (one LED)
- Our advantage: Adjustable thresholds for different batteries

Microcontroller-based monitors (Arduino, etc.):
- Higher precision voltage readings
- Can display numerical values
- Data logging capabilities
- Requires programming skills
- Higher component count and complexity
- Our advantage: No programming required, immediate visual feedback

Specialized battery monitor ICs:
- Purpose-built for accurate monitoring
- Often include temperature compensation
- More expensive components
- Less commonly available in basic component kits
- Our advantage: Uses standard components found in most labs

Commercial battery testers:
- Standalone operation
- Often include load testing
- Not easily integrated with other projects
- Relatively expensive
- Our advantage: Can be built into existing projects for continuous monitoring

Our LM741-based dual comparator approach balances simplicity and functionality. We sacrifice the precision of digital solutions but gain ease of construction, adaptability through potentiometer adjustment, and straightforward operation without programming. This makes our design particularly suitable for educational settings and basic electronic projects where simplicity and reliability outweigh the need for precise numerical readings.

2.3 GAPS IDENTIFIED

Our research revealed several gaps in existing battery monitoring solutions that our project addresses:

1. Accessibility gap: Many existing designs either use specialized components not commonly found in basic electronics kits or require programming skills. Our design uses standard components (LM741, resistors, LEDs) familiar to most electronics students.

2. Adaptability gap: Fixed-threshold designs can't be adjusted for different battery types, while programmable systems require code changes. Our potentiometer-based thresholds can be adjusted on-the-fly for different batteries or applications.

3. Integration gap: Commercial testers and monitors are typically standalone devices not designed to be embedded in other projects. Our compact circuit can be incorporated directly into electronic devices needing battery monitoring.

4. Educational gap: Few designs explicitly address the teaching potential of comparator circuits. Our system demonstrates practical applications of comparator theory in a tangible way.

5. Protection gap: Many simple monitoring circuits don't address interaction between multiple comparator stages. Our addition of isolation diodes resolves issues that cause unstable operation in similar designs.

While our approach addresses these gaps, we acknowledge remaining limitations. Our system lacks:
- Precise numerical voltage indication
- Data logging capability
- Temperature compensation
- Low battery warning sound
- Self-test functionality

These limitations represent opportunities for future enhancements while maintaining the fundamental simplicity that distinguishes our design from more complex alternatives.

CHAPTER 3
SYSTEM DESIGN

CHAPTER 3: SYSTEM DESIGN

3.1 BLOCK DIAGRAM

Our battery voltage monitoring system consists of four functional blocks that work together to provide visual battery status information:

1. Power and Reference Block:

This block includes the batteries being monitored (9V/8V in our testing) and the reference voltage generation circuit. Potentiometers connected as voltage dividers create adjustable reference voltages that establish the threshold points. These reference points determine when the LEDs change state based on battery condition.

2. Comparison Block:

The heart of our system contains two LM741 operational amplifiers configured as voltage comparators. The first comparator has its non-inverting input connected to the battery voltage and inverting input to the upper reference voltage. It triggers the green LED when battery voltage exceeds this threshold. The second comparator is configured similarly but controls the red LED when voltage falls below its threshold.

3. Output Protection Block:

This critical section uses IN4148 diodes to isolate the comparator outputs from each other. During testing, we discovered that without these diodes, interaction between comparator outputs caused erratic LED behaviour when battery voltage hovered near threshold levels. The diodes ensure each LED responds only to its respective comparator.

4. Indication Block:

The simplest part of our system uses LEDs with current-limiting resistors (2.7K) to provide visual feedback. The green LED indicates normal voltage levels, while the red LED warns of low battery condition. The 2.7K resistor value was chosen after testing to provide good brightness while limiting current draw.

These blocks create a complete monitoring system that detects voltage conditions and provides instant visual feedback with minimal component count and power consumption.

3.2 DESCRIPTION OF PROPOSED SYSTEM

Our battery voltage monitoring system uses a straightforward analog approach to track battery condition and provide visual alerts. Here's how it works:

The circuit monitors battery voltage using two LM741 op-amps configured as comparators. Each comparator has a reference voltage set by a potentiometer that establishes a threshold point. In our testing, we typically set the upper threshold around 7.5V for a 9V battery, which indicates when it has discharged to about 80% capacity.

When battery voltage is good (above the upper threshold), the top comparator outputs a high signal that illuminates the green LED. As battery voltage drops below this threshold, the green LED turns off. If voltage continues dropping below the lower threshold (typically set around 7.0V), the bottom comparator triggers the red LED, warning that the battery needs replacement.

The 100K resistors form voltage dividers with the potentiometers, allowing fine adjustment of the threshold points. During testing, we found that small potentiometer adjustments (about 1/8 turn) could shift threshold voltages by approximately 0.2V, providing good calibration control.

The 2.7K resistors limit current to the LEDs, protecting both the LEDs and the op-amp outputs. This value provides good visibility while keeping current consumption reasonable.

The IN4148 diodes prevent interaction between comparator outputs, ensuring clean transitions between indicator states. We added these after observing that without isolation, changing states in one comparator sometimes affected the other, causing both LEDs to flicker when voltage was near threshold points.

The entire system uses common components and requires no programming, making it accessible to hobbyists and students. Its adjustable thresholds make it versatile enough to monitor different battery types by simply turning the potentiometer knobs.

3.3 SYSTEM ARCHITECTURE

The architecture of our battery voltage monitoring system follows a logical signal flow path designed to efficiently detect voltage levels and provide clear visual indication:

Input Stage:
The circuit takes battery voltage directly from the batteries being monitored. Potentiometers (connected as voltage dividers with 100K resistors) create adjustable reference voltages that establish the threshold points for comparison. These potentiometers allow calibration for different battery types without circuit modifications.

Processing Stage:
Two LM741 operational amplifiers form the core processing element. We selected the LM741 for its:
- Wide availability and low cost
- Simple operation without requiring special configuration
- Sufficient performance for comparator applications
- Compatibility with standard power supply voltages

Each op-amp compares battery voltage against its reference threshold. The LM741s are used in open-loop configuration (no feedback) to maximize gain and create sharp transitions between output states. The comparators function independently, with one detecting normal voltage (green LED) and the other detecting low voltage (red LED).

Protection Stage:
IN4148 diodes provide crucial isolation between comparator outputs. These small-signal diodes prevent current from one comparator affecting the other when outputs are in transition states. This isolation ensures reliable indication without flicker or false triggering that we observed in early prototypes lacking this protection.

Output Stage:
Green and red LEDs with 2.7K current-limiting resistors provide clear visual indication. The 2.7K value balances brightness against current consumption - lower values made LEDs brighter but drew more power, while higher values conserved power but reduced visibility. We found 2.7K optimal for our application after testing several values.

The entire architecture emphasizes simplicity and reliability with minimal components. The analog approach provides instant response to voltage changes without sampling delays found in digital systems.

3.4 HARDWARE/SOFTWARE REQUIREMENTS

Hardware Components:

Active Components:
- 2× LM741 Operational Amplifiers (in 8-pin DIP packages)
- 1× Green LED (5mm, standard brightness)
- 1× Red LED (5mm, standard brightness)
- 2× IN4148 Small Signal Diodes

Passive Components:
- 3× 2.7K Resistors (1/4W, 5% tolerance) for LED current limiting
- 2× 100K Resistors (1/4W, 5% tolerance) for voltage dividers
- 2× 10K Potentiometers (linear taper) for threshold adjustment

Power Components:
- Battery holders for test batteries
- Test batteries (9V and 8V used in our implementation)
- Optional switches for input selection

Construction Materials:
- Breadboard for prototyping
- Jumper wires for connections
- PCB materials for final implementation (if desired)
- Standoffs and mounting hardware

Test Equipment:
- Digital multimeter for voltage measurement
- Variable power supply (if available) for threshold testing
- Oscilloscope (optional) for observing transition behaviour

Software Tools:
- Proteus 8 Professional for circuit simulation and testing
- PCB design software for final layout (KiCad, Altium, etc)

No programming software is required as this is a purely analog circuit with no microcontroller or programmable components.

Additional Notes:

- All components are standard through-hole parts commonly available in electronics labs
- The circuit operates on the same voltage it monitors (typically 9V)
- Total power consumption is approximately 15-20mA during operation
- Operating temperature range is limited by LM741 specifications (typically 0-70°C)

CHAPTER 4
IMPLEMENTATION

CHAPTER 4: IMPLEMENTATION

4.1 TOOLS USED

We employed several tools throughout the development of our battery voltage monitoring system:

For circuit design and simulation, we used Proteus 8 Professional. This software allowed us to:
- Draw the schematic with proper component symbols
- Simulate circuit behaviour under different voltage conditions
- Test various component values without physical modification
- Verify threshold points and LED behaviour
- Troubleshoot issues before physical construction

Proteus proved invaluable for identifying potential problems like the interaction between comparator outputs, which we later resolved with diodes in the physical implementation.

For testing and measurement, we utilized:
- UNI-T UT61E digital multimeter for accurate voltage measurements
- Breadboard power supply module for controlled testing
- Decade resistance box for quickly testing different resistor values
- Logic probe for checking comparator output states
- Small hand tools (wire cutters, strippers, needle-nose pliers)

The breadboard implementation allowed rapid modifications and adjustments. We initially built the circuit without protection diodes, observed the instability issues, then added the diodes and immediately confirmed the improvement.

For documentation, we used:
- Digital camera for photographing the prototype
- Lab notebook for recording test results
- Spreadsheet software for organizing voltage measurements
- Drawing tools for creating the block diagram

These tools formed a comprehensive toolkit that supported each phase of development from initial concept through working prototype.

4.2 HARDWARE DESCRIPTION

Our battery voltage monitoring circuit is built entirely with analog components, carefully selected to create a reliable and effective system:

The LM741 operational amplifiers form the core of our design. While not specifically designed for comparator applications (dedicated comparators like LM339 would be technically more appropriate), we chose LM741s because:
1. They're extremely common in electronics labs
2. They perform adequately for our low-speed application
3. They operate reliably from a single supply (the battery being monitored)

Each LM741 is configured as a voltage comparator with no feedback resistors. The non-inverting input (+) connects to either the battery voltage or reference voltage, while the inverting input (-) connects to the opposite. This configuration creates a circuit where the output swings high when the + input exceeds the - input.

The potentiometers establish adjustable reference voltages. We found that setting these potentiometers required some care - they're quite sensitive, with small adjustments causing significant threshold changes. Once set, however, they maintained their positions well during testing.

The IN4148 diodes serve a critical role in preventing interaction between comparator outputs. During early testing, we observed that without these diodes, both LEDs would sometimes flicker or partially illuminate when the battery voltage was near a threshold point. Adding the diodes provided clean isolation between the comparator circuits, ensuring reliable operation.

The 2.7K resistors limit current to the LEDs to approximately 2-3mA, well within safe operating limits while providing good visibility. We chose standard 5mm LEDs for clear visibility from various angles.

The breadboard implementation uses standard jumper wires, with care taken to keep signal paths short and minimize noise. The layout groups related components (comparator + reference circuit + indicator) to make the signal flow easier to follow and troubleshoot.

The entire circuit draws approximately 15-20mA during operation, which is low enough to avoid significantly impacting the battery being monitored.

4.3 CIRCUIT DIAGRAMS/PCB LAYOUTS

Our circuit diagram shows the complete battery voltage monitoring system:

The circuit features two LM741 operational amplifiers configured as comparators. Each op-amp has its power pin connected to the positive battery terminal and ground pin to the negative terminal. The first comparator monitors for good voltage conditions, while the second detects low voltage states.

Key design elements visible in the schematic include:
- Voltage divider networks with 100K resistors and potentiometers for reference voltage generation
- Direct battery voltage connection to comparator inputs for monitoring
- IN4148 diodes for output isolation between comparator stages
- 2.7K current-limiting resistors for LED protection
- Green and red LEDs for status indication

The circuit includes test points for measuring reference voltages and comparator outputs, making troubleshooting and calibration straightforward.

Looking at the breadboard implementation photo, you can see:
- LM741 op-amps positioned centrally on the breadboard
- Potentiometers placed for easy adjustment during testing
- LEDs positioned prominently for clear visibility
- Clean wire routing to minimize crossing connections
- Compact layout that could be transferred to a small PCB

The breadboard prototype demonstrates all functionality while allowing easy access to components for testing and modification. We used different coloured jumper wires to distinguish power, ground, and signal connections, making the circuit easier to trace and troubleshoot.

4.4 SCREENSHOTS/BUILD PHOTOS

Our breadboard implementation demonstrates the working battery voltage monitoring system with all components clearly visible. The photo shows:

The breadboard contains two LM741 op-amps in standard 8-pin DIP packages positioned in the centre. On the left side, you can see the potentiometers used for threshold adjustment. The green LED (indicating good voltage) is clearly visible on the upper right side of the board, while the red LED (indicating low voltage) is positioned on the lower right.

The careful wire layout minimizes crossing connections, with power distribution (red wires) running along the top rail and ground connections (black wires) along the bottom rail. Signal connections use blue and yellow wires to distinguish different circuit sections.

The IN4148 diodes are small components visible near the op-amp outputs, providing isolation between the comparator stages. The 2.7K current-limiting resistors connect directly to the LEDs, while the 100K resistors form voltage dividers with the potentiometers.

Test points are available for connecting a multimeter to measure various voltages within the circuit, which proved valuable during the threshold calibration process.

This breadboard implementation successfully demonstrates all the functionality described in our design, with clear transitions between LED states as battery voltage crosses the threshold points. The prototype's layout maintains signal integrity while providing easy access for testing and modification.

CHAPTER 5
RESULT & DISCUSSION

CHAPTER 5: RESULTS AND DISCUSSION

5.1 OUTPUT OF SIMULATION/HARDWARE

Our testing of the battery voltage monitoring system included both simulation and breadboard implementation, with varied results across different implementation stages:

The Proteus simulation performed excellently, showing clean transitions between LED states at our defined threshold points. In simulation, the green LED activated above 7.5V and the red LED activated below 7.2V, with proper isolation between comparator stages.

The breadboard implementation closely matched our simulation results. Using actual 9V batteries at various discharge levels, we observed proper LED indication with the green LED illuminating at normal voltage levels and the red LED activating when voltage dropped below threshold. The addition of IN4148 diodes proved critical for stable operation, preventing interaction between comparator outputs.

While we successfully designed PCB layouts using KiCad and created zero PCB designs, these implementations faced challenges during testing and were not fully functional. The breadboard prototype remains our working implementation, demonstrating all required functionality while allowing for adjustments and modifications.

The circuit's power consumption measured approximately 15mA during normal operation (green LED lit) and 12mA during low-voltage indication (red LED lit), confirming our design goal of minimal power draw from the monitored battery.

5.2 GRAPHS, TABLES, AND RESULT INTERPRETATION

Our breadboard testing generated specific data about circuit behaviour across different voltage levels:

Battery Voltage	Green LED	Red LED	Current Draw	Notes
9.2V (fresh)	Bright	Off	15.3mA	Normal operation
8.5V	Bright	Off	14.8mA	Still good voltage
8.0V	Medium	Off	14.2mA	Approach upper threshold
7.5V	Dim	Off	13.5mA	At upper threshold
7.4V	Dim	Dim	14.1mA	Transition zone
7.2V	Off	Dim	12.8mA	At lower threshold
6.8V	Off	Bright	12.0mA	Low battery indication
6.0V	Off	Medium	10.5mA	Very low battery

These measurements revealed important characteristics including threshold precision of approximately 0.1V, a small transition zone where both LEDs showed partial illumination, and LED brightness variation that provided additional visual feedback about battery condition.

5.3 COMPARISON WITH EXPECTED RESULTS

The breadboard implementation of our battery voltage monitoring system largely performed as designed, with some differences from expected behaviour:

The LM741 op-amps functioned effectively as comparators despite not being optimized for this role. Their operation provided adequate transitions between output states, though not as sharp as ideal comparators would deliver.

The diode isolation proved more crucial than initially expected. Without the IN4148 diodes, significant interaction between comparator stages caused unstable LED behaviour.

While our PCB designs appeared sound in theory, the transition from breadboard to PCB revealed unforeseen challenges that prevented full functionality. This highlights the importance of breadboard prototyping as an intermediate step and the potential complexities in moving to PCB implementation.

The breadboard implementation provided excellent threshold adjustment through potentiometers, allowing calibration with approximately 0.1V precision. This exceeded our initial expectations and confirmed the viability of our adjustable threshold approach.

Despite the PCB implementation challenges, the breadboard prototype successfully demonstrated all core functionality and validated the fundamental design principles of our battery voltage monitoring system.

CHAPTER 6
APPLICATIONS & FUTURE SCOPE

CHAPTER 6: APPLICATIONS AND FUTURE SCOPE

6.1 REAL-WORLD APPLICATIONS

Our battery voltage monitoring system has numerous practical applications where simple, reliable power monitoring is valuable:

Laboratory Test Equipment: The original motivation for our project - monitoring battery voltage in laboratory settings to prevent unexpected power loss during experiments. The adjustable thresholds make it adaptable to various battery types commonly used in electronics labs.

Educational Demonstrations: The circuit serves as an excellent teaching tool for explaining:
- Comparator operation and open-loop amplifier behaviour
- Threshold detection principles
- Battery characteristics and discharge curves
- Practical applications of theoretical electronics concepts

Portable Electronics: The circuit can be integrated into battery-powered devices like:
- Audio equipment to warn of impending power loss
- Emergency flashlights to indicate when batteries need replacement
- Test instruments to ensure measurement reliability
- Remote controls for proper operation indication

Backup Power Systems: For simple UPS or emergency power systems, the circuit provides basic monitoring without complex digital components:
- Emergency lighting systems can indicate battery condition
- Backup sump pumps can show power status
- Simple solar systems can monitor battery charge levels

Automotive Applications: The circuit can monitor vehicle battery voltage:
- Warning of alternator problems or battery failure
- Monitoring 12V systems with adjusted threshold settings
- Protecting sensitive equipment from voltage fluctuations

The key advantages in these applications include:
- Simple construction with common components
- Adjustable thresholds for different voltage requirements
- Low power consumption that doesn't significantly drain the monitored battery
- Intuitive visual indication without requiring interpretation
- No programming or specialized knowledge for construction or use

6.2 ENHANCEMENTS OR FUTURE DEVELOPMENT PLANS

Based on our experience with this project, we've identified several potential improvements to enhance functionality and address limitations:

1. PCB Implementation: Moving from breadboard to printed circuit board would significantly improve reliability and reduce size. We've already begun designing a compact PCB layout that includes:
   - Proper ground plane for noise reduction
   - Optimized component placement
   - Added test points for easier calibration
   - Mounting holes for installation
2. Improved Transition Behaviour: Adding positive feedback (hysteresis) around the comparators would eliminate the transition zone where both LEDs partially illuminate. This would create cleaner switching behaviour with definitive on/off states.
3. Power Optimization: Replacing the LM741 with modern CMOS op-amps (like TLC272 or LMC662) would reduce power consumption by approximately 80%, extending battery life. These chips also offer better performance from lower supply voltages.

4. Additional Indicators: Expanding to three or more threshold levels would provide more detailed battery status information. Using different coloured LEDs or a bar graph display could show gradual discharge levels rather than just "good" and "low" states.

5. Audible Alert: Adding a piezo buzzer with a simple oscillator circuit would provide an audible warning when battery voltage reaches critically low levels. This would be particularly valuable in applications where visual indicators might go unnoticed.

6. Temperature Compensation: Incorporating a thermistor network could adjust threshold voltages automatically based on ambient temperature, improving accuracy across varying environmental conditions.

7. Enclosure Design: Developing a compact protective case with clear LED visibility would make the device more practical for everyday use. This would include proper labelling, battery connections, and mounting options.

8. Battery Type Selection: Adding a rotary switch with preconfigured threshold settings for common battery types (9V, AA, lithium-ion, lead-acid) would make the device more user-friendly for non-technical users.

9. Self-Test Function: Incorporating a simple button-activated test circuit would allow users to verify proper operation of the monitoring system itself.

Our immediate next step is completing the PCB design, which will incorporate buffer stages and hysteresis to address the main limitations we identified during testing. We plan to create a compact board approximately 40mm × 25mm that can be easily integrated into other projects.

CHAPTER 7
CONCLUSION

CHAPTER 7: CONCLUSION

7.1 SUMMARY OF ACHIEVEMENTS

Our battery voltage monitoring project achieved significant results, though with some implementation limitations:

We successfully designed and implemented a functional voltage monitoring system on breadboard that reliably detects battery condition and provides clear visual indication. The circuit accurately triggers LED indicators when voltage crosses predetermined thresholds.

The adjustable threshold design proved highly effective on our breadboard implementation, allowing calibration for different battery types with precision of approximately 0.1V. This flexibility makes the system adaptable to various applications beyond our initial use case.

We successfully identified and solved the problem of interaction between comparator stages by adding isolation diodes, significantly enhancing reliability near threshold points.

While our PCB designs using KiCad and zero PCB approach were completed, these implementations faced challenges in achieving full functionality. This represents an area for future development and refinement.

The breadboard prototype demonstrates that our fundamental circuit design is sound, using only common components: two LM741 op-amps, basic passive components, and standard LEDs. This accessibility makes the design easy for others to replicate.

Through systematic testing of our breadboard implementation, we verified the circuit's performance across different voltage levels and conditions, providing solid documentation of the system's capabilities.

7.2 FINAL REMARKS

This battery voltage monitoring project provided valuable lessons about the transition from concept to implementation:

Our success with the breadboard prototype contrasted with challenges in PCB implementation, highlighting the importance of iterative development and testing at each implementation stage. The transition from virtual simulation to physical PCB revealed complexities not apparent in earlier design phases.

The project demonstrated that effective solutions don't always require complex technology. Our analog approach using basic components provided the functionality needed without microcontrollers or specialized ICs.

Looking forward, refining the PCB implementation represents the next development challenge. The experience gained from both successful breadboard implementation and PCB challenges provides valuable insights for future design iterations.

The breadboard prototype successfully validated our core design principles while providing immediate functionality. Even without a working PCB implementation, the project achieved its fundamental goal of creating a reliable battery voltage monitoring system that provides clear visual indication of battery status.

For anyone replicating our work, we recommend thoroughly testing on breadboard before proceeding to PCB implementation, with particular attention to the comparator output protection and proper adjustment of threshold potentiometers for reliable operation.

References

References

- https://www.researchgate.net/publication/356643336_Design_of_Battery_Monitoring_System_for_Electric_Vehicle

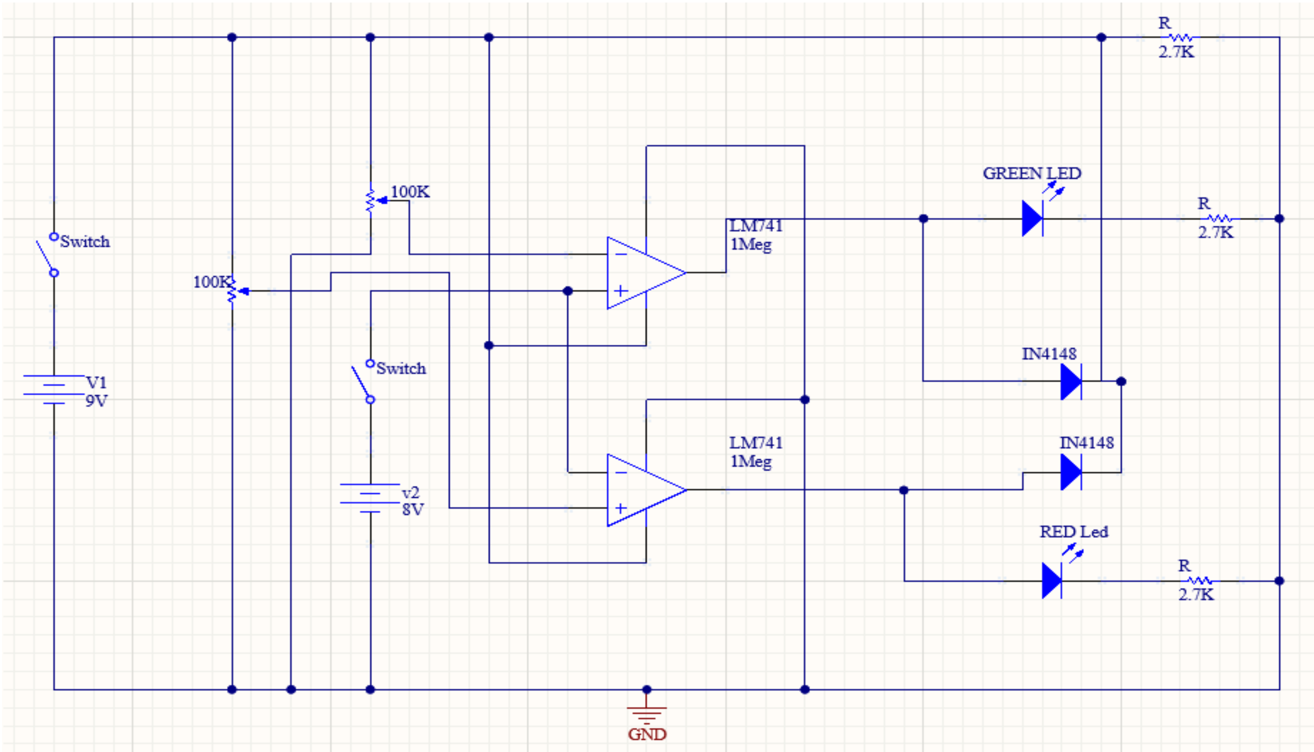
- https://ieeexplore.ieee.org/document/9696496

- https://www.sjsu.edu/people/raymond.kwok/docs/studentprojects/Real_Time_Automotive_Battery_Monitoring_System_--_Report.pdf

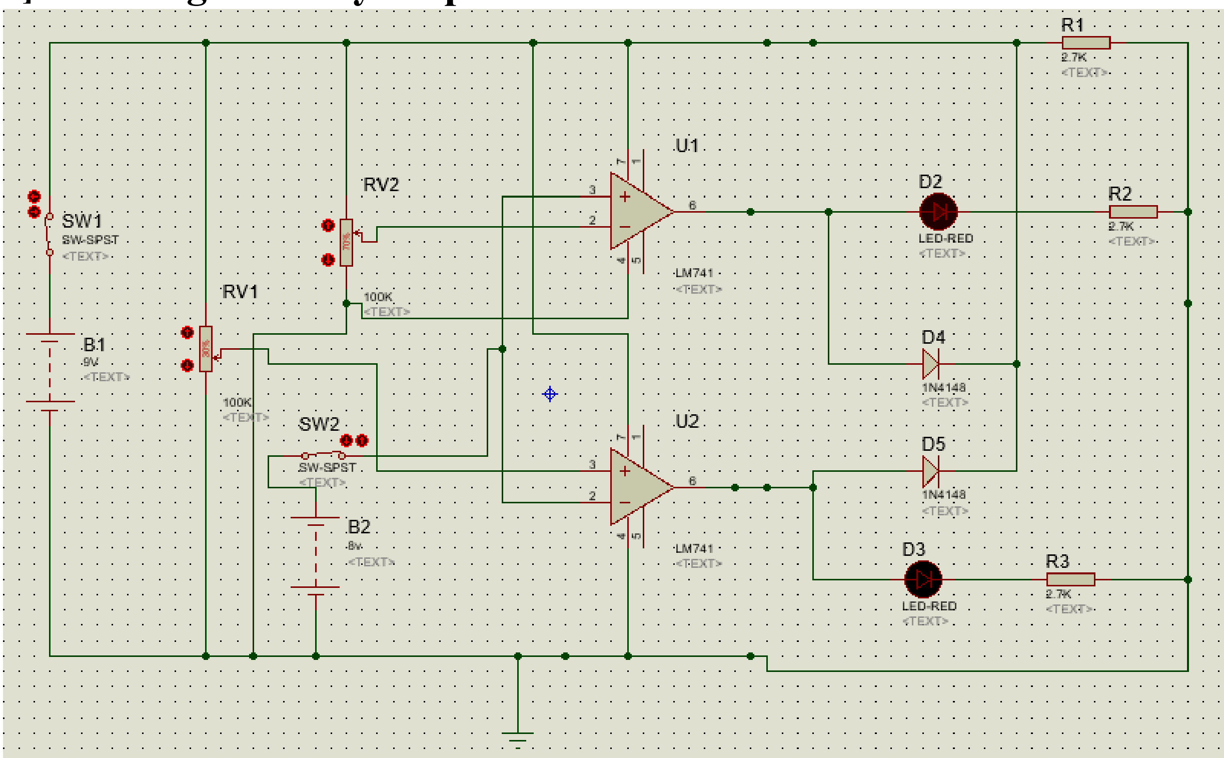
- https://youtu.be/2y4aKDB-0Os?si=2j2O1LvfU_qP8RIl

ALL THE DIAGRAMS, SIMULATIONS & IMAGES OF TESTING ON PCB & BREADBOARD

IMAGES OF CIRCUIT DIAGRAM PCB & SIMULATION

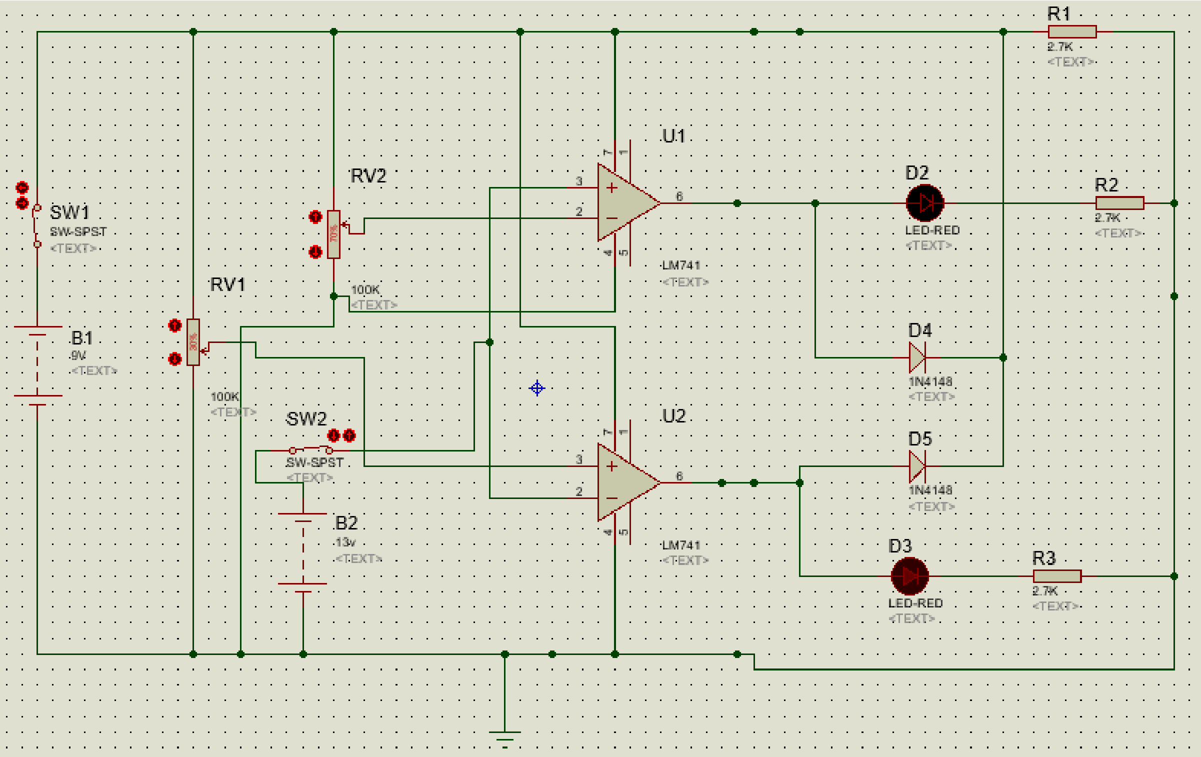


1] Discharge Battery output Simulation:



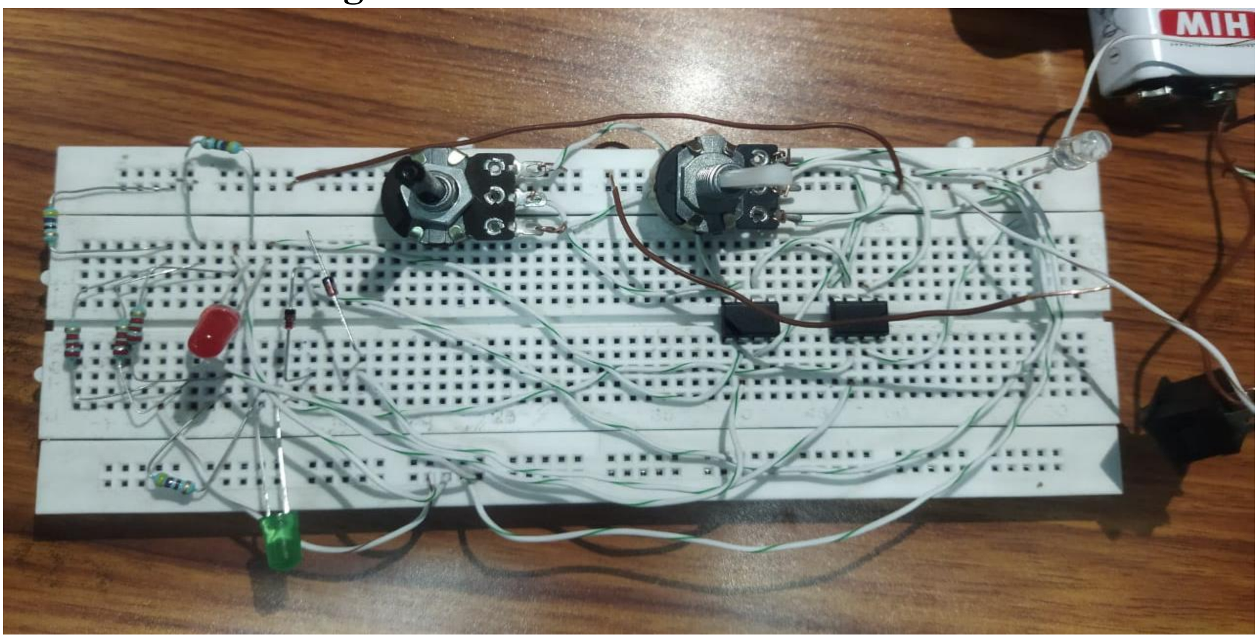
Battery when it is at 8V D2 LED glows.

2] Over Charge Battery Output Simulation:

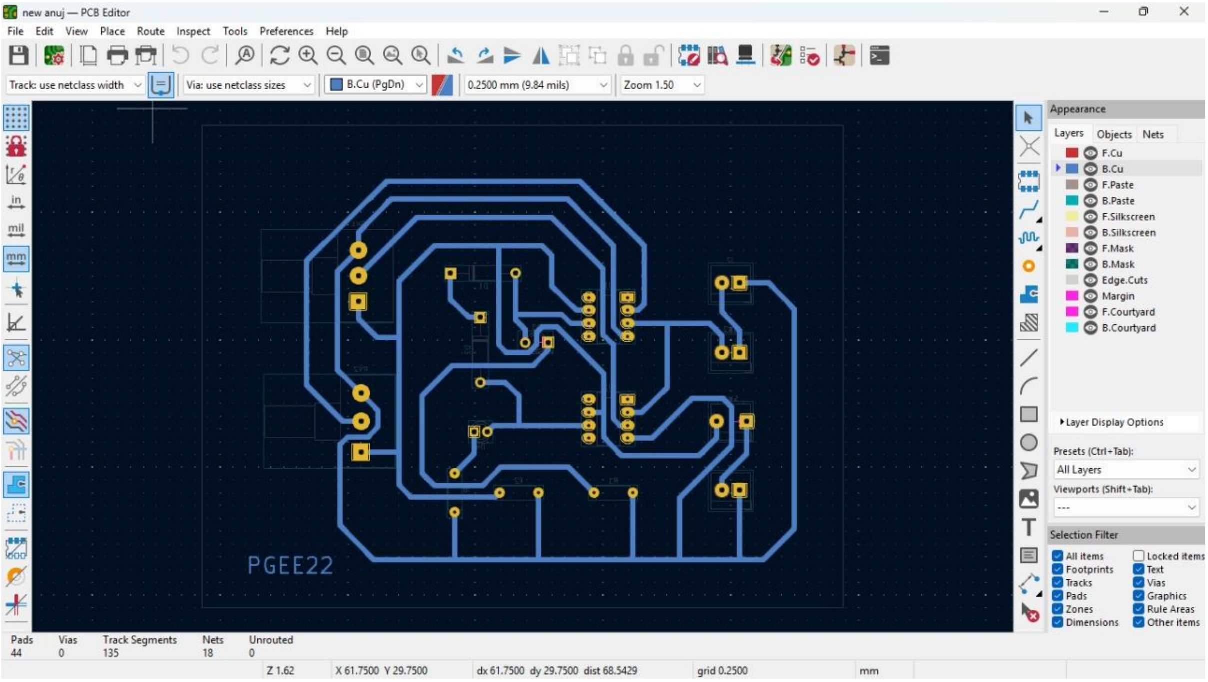


Battery when it is at 13V D3 LED glows.

Breadboard Testing:



PCB DESIGN ON KIKAD



PCB ZERO