Magnetic Position Detector

Hall Effect Sensing with Op-Amp Window Comparator

Submitted by

Tripti Patel
Roll No: 24116102

Sai Santosh
Roll No: 24116104

Btech – Semester IV
(Session: 2025-26)

Submitted to

Dr. Mayur Katwe
Supervisor
Department of Electronics and Communication Engineering
National Institute of Technology Raipur

Department of Electronics and Communication Engineering

Acknowledgement

We would like to express our sincere gratitude and deep appreciation to our respected project guide, Dr. Mayur Katwe, Department of Electronics and Communication Engineering, National Institute of Technology, for his valuable guidance, constant encouragement, and insightful suggestions throughout the completion of our project. His expert supervision and continuous motivation have been instrumental in the successful execution of this work.

We are also thankful to the Department of Electronics and Communication Engineering and the college administration for providing us with the facilities, resources, and a supportive environment to carry out our project work effectively.

Finally, we extend our heartfelt thanks to our classmates, friends, and family members for their continuous cooperation, encouragement, and moral support, which greatly contributed to the successful completion of this project.

Tripti Patel

Sai Santosh

B.Tech ECE, NIT Raipur

1. ABSTRACT

This project presents the design and implementation of a Magnetic Position Detector — a non-contact sensing system that uses a Hall Effect sensor (SS49E) in conjunction with a dual op-amp Window Comparator built around the LM358N to detect and classify the proximity of a permanent magnet. The window comparator defines a detection band bounded by two independent threshold voltages: when the magnet is far away or absent, neither comparator threshold is met and only the green power LED remains lit; as the magnet approaches within a moderate range, the yellow LED activates indicating a magnetic field is present; and when the magnet comes sufficiently close, the red LED activates confirming a definite detection event. This two-state LED indication provides clear, unambiguous position feedback.

The motivating real-world application for this design is the lid detection mechanism used in modern laptops — where a small magnet embedded in the display bezel interacts with a Hall Effect sensor on the base to trigger sleep mode on lid closure. This project realises that principle at the circuit level, demonstrating how analog circuitry alone can implement reliable positional intelligence without any microcontroller or firmware. The system was first validated on a breadboard and subsequently realized on a single-layer copper-clad PCB fabricated in-house using the toner-transfer etch method.

2. TABLE OF CONTENTS

3. INTRODUCTION

Every time you close a laptop and it immediately dims the screen and enters sleep mode, a small but elegant piece of engineering is at work beneath the surface. There is no mechanical switch on the hinge, no contact sensor on the bezel — instead, a tiny permanent magnet embedded in the display frame passes over a Hall Effect sensor on the base of the laptop. The sensor detects this magnetic proximity, signals the system, and sleep mode is triggered. When the lid reopens, the magnet moves away, the sensor returns to its resting state, and the machine wakes up. The same principle governs the smart covers of tablets that pause video on being closed, and flip cases on smartphones that lock the screen.

This project builds and analyses exactly that mechanism. The Magnetic Position Detector uses an SS49E Hall Effect sensor whose analog output voltage shifts in proportion to the proximity of a magnet. Two LM358N operational amplifiers are configured as a Window Comparator — a circuit topology that defines both a lower and an upper threshold voltage, activating its output only when the input falls within that defined band. This means the system does not merely detect whether a magnetic field exists; it determines whether the magnet is close enough to constitute a genuine detection event, while ignoring weaker, more distant fields. The result is a two-state indicator: a yellow LED signals that a magnetic field is in the vicinity, and a red LED confirms the magnet has reached the target detection proximity.

What makes this project particularly meaningful is that the window comparator — a circuit taught in analog electronics courses as a textbook topology — here finds direct expression in a real, ubiquitous application. The entire system is implemented using only passive components, two op-amps, and a Hall sensor, with no microcontroller or software involved. This demonstrates the power and elegance of pure analog design. The prototype was first built and verified on a breadboard, then transferred to a single-layer copper-clad PCB fabricated in the laboratory using the toner-transfer and chemical etching process.

4. OBJECTIVES OF THE PROJECT

- To implement a non-contact magnetic position detection system using the SS49E linear Hall Effect sensor as the primary transducer.
- To design and analyse a Window Comparator using two LM358N operational amplifiers, establishing independent lower and upper voltage thresholds that define a magnetic detection window.
- To demonstrate a two-state indication system — yellow LED for field presence, red LED for confirmed detection proximity — without any digital logic or microcontroller.
- To understand and connect the circuit's operation to the real-world application of laptop lid detection and similar magnetic proximity sensing in consumer electronics.
- To validate the design through breadboard prototyping followed by a single-layer PCB fabricated in-house using toner transfer and chemical etching.
- To produce a complete, documented design suitable for academic submission and professional portfolio presentation.

5. Block Diagram

The system is organized into four sequential functional blocks, each corresponding directly to a section of the actual schematic.

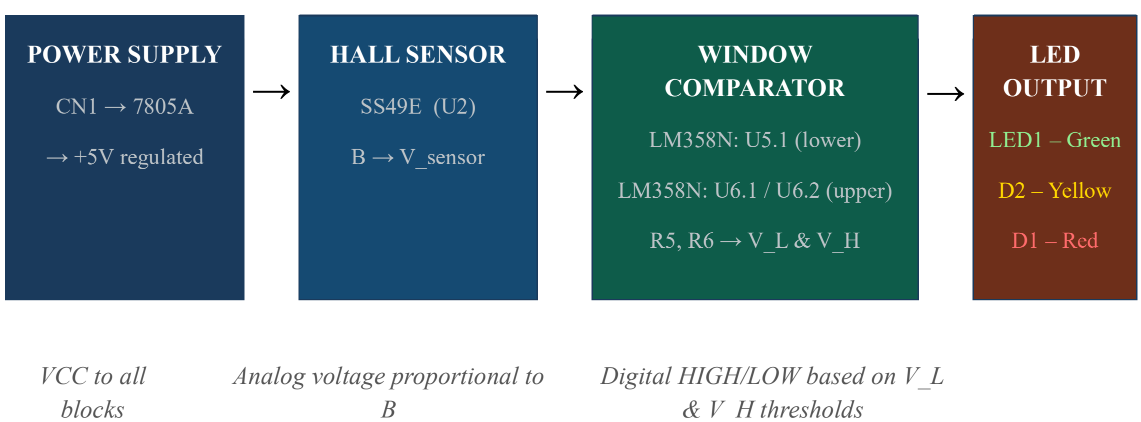


Figure 5.1: Functional Block Diagram of Magnetic Position Detector

The Power Supply block (CN1 input → 7805A regulator) provides a clean +5V to all other blocks. The Hall Sensor block (SS49E, U2) outputs an analog voltage that shifts with magnetic proximity. The Window Comparator (U5.1 as lower-bound comparator, U6.1 and U6.2 as upper-bound and output-combining stages) evaluates that voltage against two reference thresholds derived from the R2–R5–R6 divider network. The LED Output stage translates the comparator logic into the two-state visual indication described in this report.

6. Hardware Components Used

S.No.	Ref.	Component	Value	Role in Circuit
2	U1	Voltage Regulator	7805A	Regulates input to a stable +5V supply (VCC) for the entire circuit
3	C1, C2	Ceramic Capacitor	100 nF	Decouples the 7805A input and output pins; suppresses supply-line noise
4	U2	Hall Effect Sensor	SS49E	Transduces magnetic flux density into a proportional analog output voltage (0–5V)
5	C3	Ceramic Capacitor	100 nF	Decouples the VCC pin of the SS49E sensor
6	R5, R6	Potentiometer (Trim Pot)	10 kΩ	Variable voltage dividers used to precisely calibrate the Lower (Yellow) and Upper (Red) detection thresholds.
7	U5 (U5.1)	Op-Amp	LM358N	Lower-bound comparator — output goes HIGH when V_sensor exceeds V_L
8	U6 (U6.1/U6.2)	Op-Amp	LM358N	Upper-bound comparator (U6.1) and output combination stage (U6.2); together with U5.1 form the complete window comparator
9	R3, R4	Resistor	1 kΩ	Current-limiting resistors for D1 (Red) and D2 (Yellow) LEDs
10	R1	Resistor	1 kΩ	Current-limiting resistor for LED1 (Green power indicator)
11	LED1	Green LED	KT-0603R	Power-on indicator — ON whenever VCC is present; not part of detection logic

S.No.	Ref.	Component	Value	Role in Circuit
12	D1	Red LED	KT-0603R	Detection confirmed — lights when magnet is within the defined proximity window
13	D2	Yellow LED	KT-0603R	Field present — lights when magnetic field is sensed but magnet is not yet close enough to trigger detection window

Table 6.1: Hardware Components with Reference Designators from Schematic

7. Circuit Diagram & Description

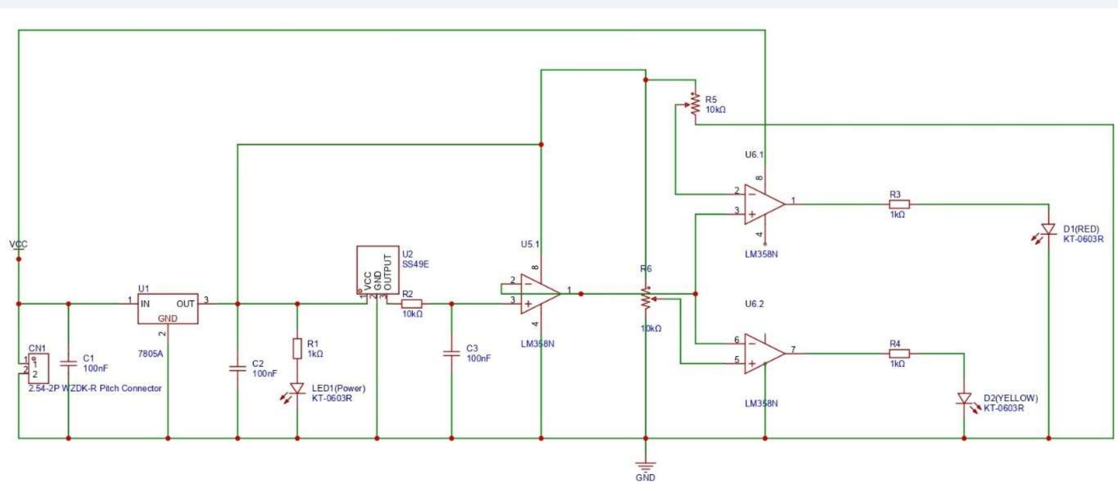


Figure 7.1: Full Circuit Schematic (EasyEDA)

7.1 Power Supply Stage — CN1, U1 (7805A), C1, C2

An unregulated DC supply enters the board through the 2-pin connector CN1. This feeds the input pin of the 7805A linear voltage regulator (U1), which outputs a stable +5V (VCC). Capacitor C1 (100 nF) at the regulator's input and C2 (100 nF) at its output suppress noise and ensure regulator stability. VCC is distributed to the SS49E sensor, both LM358N op-amps, and all LED branches.

7.2 Sensing Stage — U2 (SS49E), C3

The SS49E (U2) is a three-pin linear Hall Effect sensor: VCC (pin 1), GND (pin 2), OUTPUT (pin 3). With no magnetic field applied, the output rests at approximately VCC/2 = 2.5V. As a magnet approaches, the output deviates from this midpoint — rising toward VCC for a south-pole field and falling toward GND for a north-pole field — with the deviation growing larger as the magnet gets closer. C3 (100 nF) on the sensor's supply pin suppresses any localized high-frequency noise. The sensor's output is fed directly as the input signal (V_sensor) to the window comparator stage.

7.3 Window Comparator Stage — U5.1, U6.1, U6.2 (LM358N), R2, R5, R6

The window comparator is the analytical core of this project. The resistor network formed by R2 (10 kΩ), R5 (10 kΩ), and R6 (10 kΩ) connected in series between VCC and GND creates two stable reference voltages: V_L (lower threshold) at the junction of R6 and R5, and V_H (upper threshold) at the junction of R5 and R2. With equal resistor values, these thresholds are evenly spaced across the supply rail.

U6.1 serves as the upper-bound comparator. When the sensor voltage (V_sensor) exceeds the high threshold (V_H), the output of U6.1 goes HIGH, activating the Red LED logic. Crucially, the circuit is designed with **priority logic**: when the Upper Threshold is triggered (Magnet is very close), the drive signal for the Yellow LED is overridden or superseded by the Red LED state. This ensures a clean transition: the user sees *only* Yellow for 'Approaching' and *only* Red for 'Arrived', eliminating ambiguity.

8. WORKING PRINCIPLE

8.1 The Hall Effect and SS49E Sensor

The Hall Effect describes the generation of a transverse voltage across a current-carrying conductor placed in a perpendicular magnetic field. The SS49E integrates this phenomenon in a compact, calibrated IC that outputs a linear analog voltage directly proportional to the applied magnetic flux density. At zero field, the output is at the midpoint of the supply — approximately 2.5V for a 5V supply. This resting voltage is the baseline from which all detection decisions are made.

8.2 Window Comparator — Two-State Detection

A single comparator can only distinguish between two states: input above or below one threshold. The window comparator, by defining both a lower threshold V_L and an upper threshold V_H, creates three distinguishable zones for V_sensor. The detection logic of this project maps those zones to two visible states as follows:

Magnet State	Window Comp. Output	LEDs Active	Meaning
Far / Absent	Low Voltage	**Green Only**	System Ready / Idle
Approaching	V_sensor > V_Lower	**Yellow Only**	Warning: Field Detected
Contact / Close	V_sensor > V_Upper	**Red Only**	Critical: Position Confirmed

Table 8.1: Detection State Table

In practical operation the user observes: at a distance, only the green LED is on. As the magnet is brought closer, the yellow LED switches on — the field is sensed. Bringing the magnet to the precise detection distance switches on the red LED, confirming the target position has been reached. This graduated response is far more informative than a binary on/off signal, and directly mirrors the nuance required in applications such as laptop lid detection, where a definite closed-position signal must be distinguished from a merely-nearby magnet.

8.3 Real-World Parallel — Laptop Lid Detection

In a laptop, the display lid carries a small neodymium magnet, typically embedded in the corner of the bezel. The base of the laptop houses a Hall Effect sensor positioned to align with that magnet only when the lid is fully closed. As the lid closes, the magnet approaches the sensor, the sensor voltage deviates from its resting midpoint, and when the lid is fully shut — and only then — the sensor voltage crosses the system's detection threshold, signalling the OS to sleep. The window comparator ensures that the signal is only registered at the correct position: a slightly ajar lid, or a nearby external magnet, is not enough.

This project's circuit is a direct hardware-level implementation of that exact logic. The SS49E plays the role of the embedded laptop sensor; the permanent magnet plays the role of the lid-mounted magnet; and the window comparator replaces the firmware threshold comparison. The red LED corresponds to the sleep-trigger signal. The elegance of this project lies in the fact that this entire decision process — sensing, thresholding, and output driving — is achieved with two op-amps, three resistors, and a Hall sensor, without a single line of code.

9. HARDWARE IMPLEMENTATION / PROTOTYPE

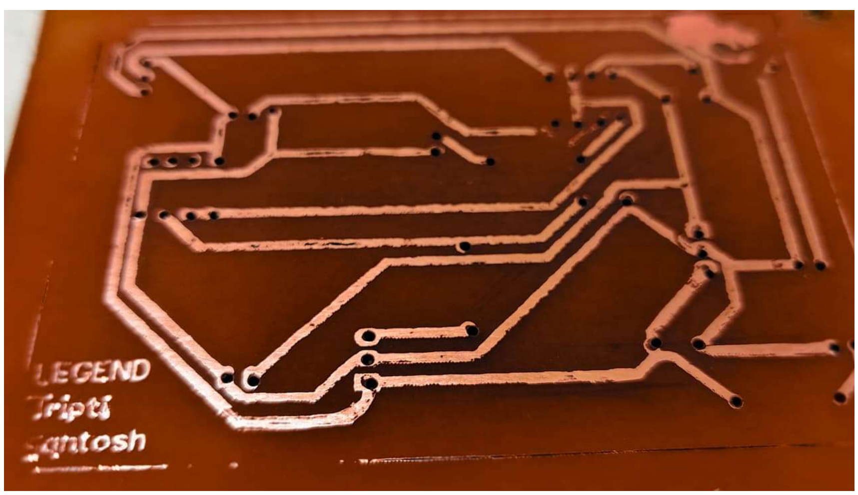
9.1 Breadboard Prototyping

The circuit was first assembled and verified on a solderless breadboard before committing to PCB fabrication. This stage allowed real-time adjustment of the threshold resistor values (R2, R5, R6) and verification of the sensor's response characteristics using a multimeter across the SS49E output pin. The breadboard prototype confirmed correct two-state LED behaviour across varying magnet distances, and validated that the LM358N comparator outputs were clean and stable without oscillation.

9.2 PCB Fabrication — Toner Transfer and Chemical Etching

Following breadboard validation, the circuit was transferred to a single-layer copper-clad PCB using the following in-house fabrication process:

1. The PCB layout designed in EasyEDA was printed onto glossy paper using a laser printer, producing a mirrored toner image of the copper traces.
2. The copper-clad board was cleaned with steel wool and isopropyl alcohol to remove oxidation and ensure good toner adhesion.
3. The printed layout was placed face-down on the copper surface and ironed at high heat, transferring the toner from the paper onto the copper.
4. The board was soaked in water and the paper backing was carefully peeled away, leaving the toner pattern adhered to the copper.
5. The board was immersed in a ferric chloride ($FeCl_3$) etching solution. The solution dissolves the exposed copper while the toner acts as an etch resist, protecting the intended trace pattern.
6. After etching was complete, the board was removed, rinsed thoroughly in water, and the toner was removed using acetone, revealing the clean copper traces.
7. Component holes were drilled at the appropriate pad locations using a 1mm drill bit.
8. All components were soldered onto the board and a continuity check was performed



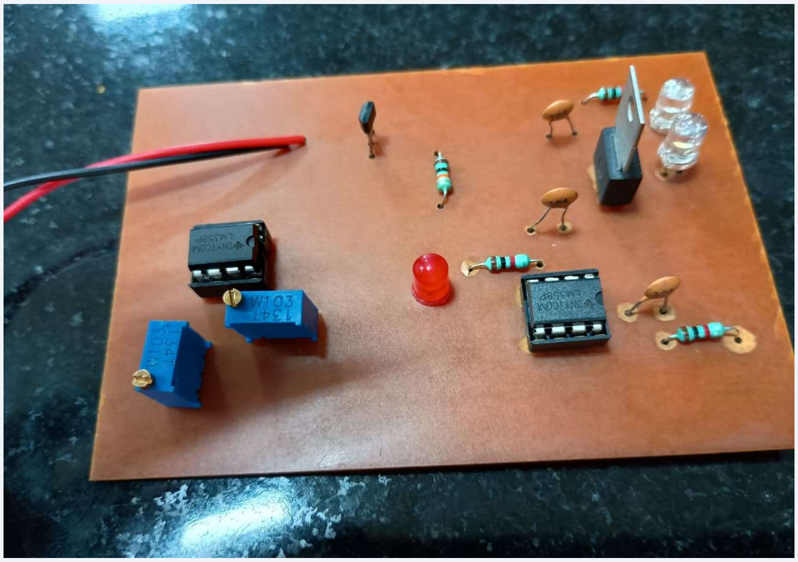


Figure 9.2: Fabricated Single-Layer PCB

10. APPLICATIONS

10.1 Laptop Lid and Smart Cover Detection

As described throughout this report, the most direct application of this circuit is the lid-close detection mechanism used in laptops, tablets, and smartphones. The window comparator ensures the detection is triggered only at the precise closed position, preventing false activations from nearby magnetic interference. This circuit demonstrates at the hardware level what commercial devices achieve at the system level.

10.2 Industrial Automation: "Through-Wall" Cylinder Sensing

In heavy industry, robots use pneumatic (air-powered) cylinders to push and lift objects. The machine must know if the cylinder is fully extended without physically touching it.

> **The Challenge:** You cannot drill a hole into a high-pressure air cylinder to install a switch, as it would leak.

The Solution: Manufacturers place a magnetic ring on the internal piston. The cylinder body is made of **Aluminium** (a non-ferrous metal), which allows magnetic fields to pass through it.

Our application: By strapping this Hall Effect monitor to the **outside** of the cylinder, the system detects the internal piston's position through the solid metal wall. This allows for "Non-Invasive Sensing" in pressurized or hazardous environments.

10.3 Security Systems

- Door and window intrusion detection — window comparator rejects false triggers from weak ambient magnetic fields.
- Anti-tamper sensing in sealed enclosures where removal of a magnetic shield triggers an alert.
- Magnetic card verification at access control terminals.

10.4 Automotive Safety: ABS & Speed Sensing

Anti-Lock Braking Systems (ABS) require precise wheel-speed data to prevent skidding during emergency stops.

- **The Implementation:** A toothed metal gear ("Tone Ring") is attached to the wheel hub. As the gear spins, the teeth pass near the Hall sensor, creating distinct magnetic pulses.
- **Reliability:** Unlike optical sensors (which fail if covered in mud or brake dust) or mechanical switches (which wear out from friction), this magnetic sensor is impervious to dirt, oil, and vibration, making it the industry standard for life-critical automotive safety.

11. ADVANTAGES & LIMITATIONS

11.1 Advantages

- Non-contact operation with no mechanical wear — ideal for high-cycle applications such as laptop hinge sensing where a switch would fail quickly.
- The window comparator provides meaningful two-state position discrimination rather than a simple presence/absence signal, enabling the system to confirm not just that a magnet is near but that it has reached the target distance.

- The detection window is easily reconfigured by changing R2, R5, and/or R6, allowing the circuit to be tuned for different magnet strengths and sensing distances without redesign.
- Entirely analog — no microcontroller, firmware, or programming required. The system powers on and operates immediately, with no boot time or software complexity.
- The SS49E is immune to dust, moisture, and vibration, making the sensing element inherently reliable in real-world environments.
- Simple, low-cost bill of materials — the LM358N and SS49E are standard components available from any electronics supplier.

11.2 Limitations

- The system provides position zones (two visible states) rather than a continuous quantitative distance measurement. For precise distance readout, an ADC and microcontroller would be required.
- The LM358N is not a rail-to-rail op-amp; its output cannot swing fully to VCC, which slightly limits the usable comparator output headroom near the supply rails.
- The detection range is limited to a few centimetres with a standard permanent magnet; sensing over longer distances would require a stronger magnet or a more sensitive sensor variant.
- Temperature-induced drift in the SS49E output and the LM358N input offset voltage can subtly shift the effective thresholds in extreme operating conditions.

12. RESULT

The fabricated Magnetic Position Detector prototype was tested by methodically varying the distance between a neodymium permanent magnet and the SS49E sensor. The results confirmed the intended two-state behaviour cleanly and consistently.

At large distances — or with no magnet present — the SS49E output rests close to 2.5V. This is within the inactive zone of the window comparator, and only the green power LED (LED1) remains lit. As the magnet is brought progressively closer, the sensor output voltage begins to rise. Once it crosses the lower threshold V_L, the output of U5.1 goes HIGH and the Yellow

LED (D2) switches on, signalling that a magnetic field is now present and being sensed. The red LED remains off at this stage.

As the magnet is brought still closer — to within the target detection proximity — the sensor voltage rises into the window band between V_L and V_H. Both comparator conditions are now simultaneously satisfied, and the window comparator output goes HIGH. The Red LED (D1) switches on, providing an unambiguous confirmation that the magnet has reached the intended detection position. Moving the magnet away reverses this sequence: the red LED extinguishes first as the sensor voltage drops below V_H, followed by the yellow LED as it falls below V_L, returning the system to its resting state with only the green LED lit.

The response was repeatable across multiple test cycles with no observed chattering or instability at the threshold transitions. The breadboard and PCB prototypes produced identical behaviour, confirming the correctness of the design and the fidelity of the PCB fabrication.

13. CONCLUSION

The Magnetic Position Detector demonstrates how two foundational analog building blocks — the Hall Effect sensor and the op-amp window comparator — combine to produce a system with practical, real-world relevance. The window comparator topology, realised using U5.1 and U6.1/U6.2 of the LM358N, is the design's central contribution: by defining both a lower and an upper voltage threshold around the SS49E sensor output, the circuit achieves two-state position discrimination — yellow for field present, red for position confirmed — without any digital logic or firmware.

The project is directly grounded in a compelling application: the lid detection mechanism used in every modern laptop. Recognizing that a circuit topology taught in analog electronics coursework is the same mechanism that determines when your laptop goes to sleep is precisely the kind of insight that connects academic study to engineering practice. This project makes that connection explicit, building the mechanism from scratch and verifying it at the hardware level.

The complete development cycle — schematic design in EasyEDA, breadboard validation, and single-layer PCB fabrication using toner-transfer etching — provided hands-on exposure to the full span of hardware product development. The result is a functional, well-characterized prototype whose design choices are each justified by clear engineering reasoning.

14. FUTURE SCOPE

1. Hysteresis Implementation (Schmitt Trigger)

To improve stability, positive feedback can be added to the comparator stage to create hysteresis. This would prevent "relay chatter" or LED flickering when the magnet hovers exactly at the threshold distance.

2. Wireless Integration for IoT Monitoring (Wi-Fi / Bluetooth)

The current analog output could be interfaced with a wireless microcontroller (such as an ***ESP32*** or ***Arduino Nano 33 IoT***).

- **Application:** This would allow the sensor to transmit real-time position data to a central dashboard or smartphone app via **Wi-Fi** or **Bluetooth Low Energy (BLE)**.
- **Use Case:** In a factory setting, a maintenance engineer could remotely monitor the status of hundreds of pneumatic cylinders or security doors from a single control room without running physical wires to each machine.

3. 3D Position Tracking Using three Hall sensors mounted orthogonally (X, Y, Z axes), the system could track the precise 3D location of a magnet in free space. This is the working principle behind modern VR controllers and advanced robotics.

4. Power Electronics Integration: MOSFET-Based Actuation

Currently, the system indicates detection visually using LEDs. In a commercial iteration, the output of the LM358 Window Comparator would be connected to the **Gate of a Power MOSFET** (e.g., IRF540N).

- **The Upgrade:** This modification converts the device from a passive "monitor" into an active "switch."

- **The Mechanism:** When the magnet is detected (Red Zone), the Op-Amp sends a HIGH signal to the MOSFET Gate. The MOSFET then closes the circuit for a high-current load.
- **Real-World Use:** This allows the tiny Hall signal to drive **Electromagnetic Door Locks (Solenoids)**, **High-Power Alarm Sirens**, or **Industrial DC Motors** directly, creating a "Touchless Safety Switch" capable of handling several Amperes of current.