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Analysis Of Polarity Conversion Of Npn To Pnp Proximity Sensor Using Switching Relay

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ABSTRACT

Proximity sensors are essential components in industrial automation systems, particularly for non-contact object detection. NPN and PNP sensors differ in output polarity, which often creates compatibility issues when integrating them with control devices that require a specific type of input signal. A common problem occurs when an NPN proximity sensor must interface with a controller that only accepts PNP logic inputs, requiring a safe, stable, and practical method of polarity conversion. This study aims to analyze the conversion of output polarity from an NPN proximity sensor to a PNP configuration using a switching relay as the signal conversion component. The methodology includes designing the conversion circuit, conducting simulations, and performing direct testing of the relay's switching response when receiving an output signal from the NPN sensor. The evaluated parameters include switching stability, response time, relay contact reliability, and compatibility with PLC or microcontroller inputs. The results indicate that the switching relay effectively performs polarity conversion, achieving a detection accuracy of more than 95%. The relay is capable of delivering a stable PNP logic output, although a slight delay occurs due to its mechanical switching operation. Additionally, the conversion circuit offers electrical isolation, making it safe and suitable for various industrial control systems. The study concludes that a switching relay provides a simple, economical, and compatible solution for converting NPN proximity sensor signals into PNP logic. Despite limitations in switching speed, this method remains highly applicable for low- to medium-speed automation processes. Further development is recommended using solid-state relays (SSR) or transistor-based drivers to improve switching speed and enhance system durability.

Keywords:* *Proximity Sensor, NPN, PNP, Switching Relay, Polarity Conversion, Industrial Automation

INTRODUCTION

In the world of industrial automation, sensors play a crucial role as the "eyes" and "ears" of control systems, enabling the detection and monitoring of various physical parameters in a non-contact manner. Proximity sensors are one type of sensor that is widely used to detect the presence or absence of objects within a certain distance without physical contact. Operational efficiency, productivity, and safety in industrial settings depend heavily on the rapid and accurate detection of fast-moving objects, which is ensured by proximity sensors. Proximity sensors come in various types, with the two most common output configurations being NPN (sinking) and PNP (sourcing). While both are useful for detecting objects, these differences in output polarity often lead to compatibility issues when the sensors are integrated with control devices such as PLCs, which may only support one type of input. This situation requires a solution to convert the sensor's polarity, so that the available sensor can be used according to the system's needs without having to replace the entire input module or purchase a new sensor. The main difference between PNP and NPN proximity sensors lies in the way they handle current flow at their output, which determines how they are connected to control circuits (such as PLCs or relays).

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Industrial automation systems rely heavily on sensors to provide real-time information for controlling machines, monitoring processes, and ensuring operational safety. Among these sensors, proximity sensors are widely used due to their ability to detect objects without physical contact, offering high durability and reliability. Proximity sensors are typically classified into two major types based on their output configuration: NPN (sinking) and PNP (sourcing). Each type operates with different electrical characteristics and logic polarity, making proper integration crucial for achieving accurate and stable system performance. In practice, compatibility issues often arise when an NPN proximity sensor must interface with a controller such as a Programmable Logic Controller (PLC), microcontroller, or industrial input module that only accepts PNP logic signals. This mismatch can cause a system to malfunction, fail to detect objects, or produce incorrect logic states. Since replacing existing sensors or upgrading control hardware can be costly and impractical, a polarity conversion method is needed to bridge the difference between NPN and PNP logic.

One of the simplest and most effective approaches is to use a switching relay as a polarity conversion device. A relay not only shifts the output polarity but also provides electrical isolation between the sensor circuit and the controller input, enhancing system safety. However, the mechanical nature of relays introduces certain challenges, such as slower response time and potential contact wear. Therefore, analyzing the performance, reliability, and limitations of using a switching relay in polarity conversion is essential for determining its suitability in industrial applications. This study focuses on designing, implementing, and analyzing a relay-based circuit to convert the output of an NPN proximity sensor into a PNP-compatible signal. The research evaluates key parameters including switching stability, response time, system safety, and integration feasibility with various industrial control systems. The findings are expected to provide practical insights for engineers, technicians, and practitioners in selecting an appropriate polarity conversion method and improving the flexibility of industrial sensor integration.

LITERATURE REVIEW

Proximity sensor fundamentals (NPN vs PNP)

Proximity sensors used in industrial automation (inductive, capacitive, photoelectric) commonly provide either NPN (sinking) or PNP (sourcing) transistor-type outputs. An NPN (sinking) output connects the load to ground when active, while a PNP (sourcing) output supplies positive voltage to the load when active. Understanding this polarity difference is essential for correct wiring to PLCs, input modules, or other control electronics because the direction of current flow and required input type (sourcing vs sinking) differs. Manufacturer datasheets and technical notes explicitly document these wiring conventions and the electrical limits (ON voltage, residual voltage, max. switching frequency) that affect compatibility and reliability

Table 1. Differences between NPN and PNP sensors

Feature	PNP Sensor (Sourcing)	NPN (Sinking) Sensor
Active Output	Provides a positive voltage signal (+Vcc, e.g. +24V).	Provides a low voltage signal (0V/Ground).
Current Direction	*Sourcing*(Source): Current flows	*Sinking*(Absorb): Current flows

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	OUT of the sensor to the load.	INTO the sensor from the load.
Load Cable	The load (e.g., PLC input) is permanently connected to 0V (Ground).	The load is permanently connected to the positive terminal (+Vcc).
Types of Transistors	Using PNP type transistor in its output circuit.	Using NPN type transistor in its output circuit.
General Application	More commonly used in Europe and North America, it is often preferred for better system safety against short circuits.	Commonly used in Asia (especially Japan) and applications that require faster response speeds.

- **PNP (Positive-Negative-Positive):** When the sensor detects an object, its internal transistor activates the circuit, sending a positive voltage (+V) to the output signal wire (usually the black wire). An electrical load (such as a PLC input) must be connected between the sensor's output wire and ground (0V) to complete the circuit.
- **NPN (Negative-Positive-Negative):** When the sensor detects an object, its internal transistor connects the output signal wire (black wire) to ground (0V). An electrical load must be connected between the sensor's output wire and a positive voltage source (+V) to complete the circuit.

The choice between PNP and NPN is usually based on compatibility with the input of the control module (PLC or relay) that will be used in the automation system. This study aims to design and analyze a method for converting the polarity of an NPN proximity sensor to a PNP using a relay as an interface bridge. Thus, flexibility in sensor use can be increased, and compatibility issues can be effectively addressed, thus supporting the efficiency and adaptability of the automation system. On the sensor there are 3 cables, the wiring color code is as follows: (Brown: +24V, Blue: 0V, Black: output).

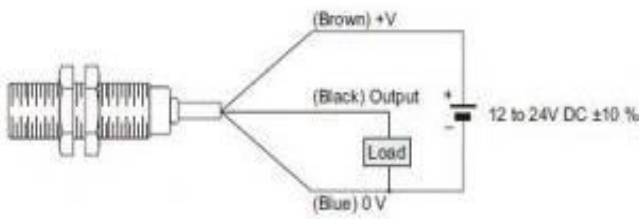

Figure 1. Sensor wiring diagram

Practical interoperability issues and common field solutions

When an installed sensor type (e.g., NPN) does not match the required input type of the receiving device (e.g., a PNP-only PLC input), the system can produce incorrect logic levels or fail to detect targets. Practitioners commonly address this incompatibility with simple hardware fixes: (a) using a small relay driven by the sensor output to re-issue the correct polarity, (b) employing transistor/Op-amp based level-shifters or driver circuits, or (c) using compact commercial NPN↔PNP converters/pull-up resistor arrangements where appropriate. Relay wiring is often the easiest field solution because it provides galvanic isolation and

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straightforward polarity inversion (sensor drives coil → relay contacts switch the supply to the input).

Connecting an NPN type sensor to a PLC

Before connecting the sensor to the PLC, make sure the PLC is configured to 'source' type. On a PLC, this can be done by connecting the 1M input to +24V. This means the PLC will 'get current' from the input, and the NPN sensor will 'store current' when it detects an object.

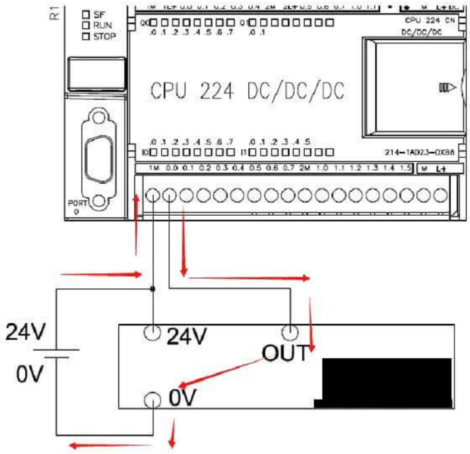

Figure 2. Connection of NPN type sensor to PLC

Connecting a PNP type sensor to a PLC

For PNP type sensors, the PLC needs to be configured as a 'sink' type. Connecting the 1M input to 0V will configure the PLC as a sinking input. With this configuration, the sensor can 'get current' and the PLC will 'store current' to detect the sensor output. For PNP type proximity sensors, if an input is used, it must be a 'sink' type input. This is a configurable sink/source input and can interface with either type of sensor.

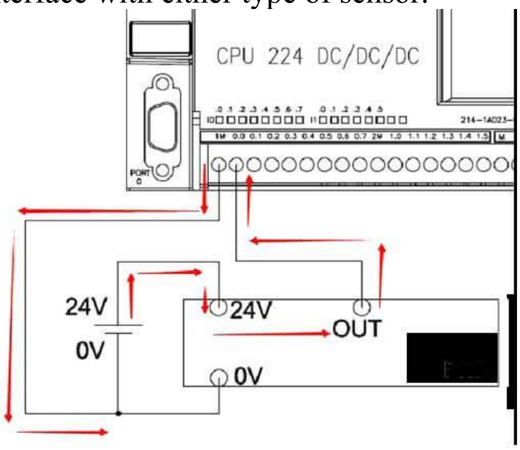

Figure 3. Connection of PNP to PL type sensors

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Relay-based polarity conversion — advantages and limitations

Mechanical switching relays provide a robust and easy-to-understand method to convert an NPN (sink) signal into a PNP (source) output: the sensor energizes the relay coil, and the relay contact closes to connect +V to the controller input (or vice versa depending on wiring). Key advantages include electrical isolation between sensor and load, simplicity of wiring, and wide voltage/load compatibility. However, mechanical relays have downsides: contact bounce, finite mechanical lifetime (contact wear), and relatively slow switching times compared with solid-state devices. For many low-to-medium speed automation tasks the mechanical relay is acceptable, but for high-speed or very high-reliability switching, its mechanical nature can be a limiting factor.

Solid-state relays (SSRs) and transistor/driver circuits (BJT/MOSFET or optocoupler circuits) are common alternatives that overcome mechanical limitations: SSRs provide much higher switching frequencies, no contact wear, and minimal bounce; transistor drivers or MOSFET/optocoupler solutions can produce very fast, compact polarity conversions with low propagation delay. The trade-offs include cost, leakage/residual voltage (important for PLC input thresholds), and the need to respect load type and polarity (AC vs DC, sourcing vs sinking). Selection should therefore consider required switching speed, expected lifecycle, load characteristics, and safety/isolation needs.

General Definition of Sensor

This research begins with a literature review, design and assembly of conveyors, DC motors, power supplies, control circuits, proximity sensors, digital counters, and PLCs [1]. A sensor is a device that detects or measures physical quantities and converts them into signals that can be read or interpreted by electronic instruments. One technology that has been rapidly developed for environmental monitoring is sensor technology. With this sensor technology, it is possible to carry out monitoring and measurements automatically and remotely with a good level of accuracy and precision. [2] This signal is usually an electrical signal that is proportional to the physical quantity being measured. The main function of the sensor is to sense changes in the environment and send the data to the control system. The non-contact characteristics of this sensor make it ideal for use in industrial environments with high levels of dust contamination and vibration[3].Sensors play a vital role in a wide range of applications, from industrial automation and medical devices to consumer devices, as a bridge between the physical world and information processing systems.comprehensively the working mechanism of the inductive proximity sensor in the gate position monitoring system on the Weigh Bin, as well as mapping the technical challenges faced during the implementation process in the field[4].

A proximity sensor is a type of sensor specifically designed to detect the presence of an object within a certain range without requiring direct physical contact with the object. JIS (Japanese Industrial Standards) provides the generic name "proximity sensor" for all sensors that provide non-contact detection of target objects that are near or within the general range of the sensor. This non-contact detection capability prevents mechanical wear, increases system reliability, and enables object detection in harsh or fast-moving environments. These sensors are essential for automation, safety, and efficiency in a wide range of modern industrial applications.

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Figure 4. Proximity Sensor

Types of Proximity Sensors and Their Working Principles

Proximity sensors can be classified into several types based on the physical principles used to detect objects:

1. **Inductive Sensor**:
    - **Work principle**: This sensor generates a high-frequency electromagnetic field. When a metal object (target) enters this field, eddy currents are formed within it, causing a change in the impedance of the sensor's oscillator. This impedance change is then detected and converted into an output signal.
    - **Characteristics**: Only effective for detecting metal objects. The detection distance is relatively short.
2. **Capacitive Sensor**:
    - **Work principle**: Capacitive sensors generate an electrostatic field. The presence of objects, whether metallic or non-metallic (such as liquids, plastic, or wood), in this field changes the capacitance of the sensor's capacitor. This change in capacitance is then converted into an output signal.
    - **Characteristics**: Capable of detecting various types of materials, including non-metals. Sensitive to the dielectric of the target material.
3. **Optical (Photoelectric) Sensor**:
    - **Work principle**: This sensor uses light (infrared, laser, or visible light) to detect objects. It consists of a light emitter and a light receiver. Detection occurs when an object blocks or reflects the emitted light.
    - **Characteristics**: Longer detection distance than inductive or capacitive. Affected by environmental conditions such as dust or dirt.
4. **Magnetic Sensor**:
    - **Work principle**: This sensor detects the presence of a magnetic field. When a permanent magnet or ferromagnetic material approaches, the sensor responds to changes in the magnetic field. A common example is a reed switch.
    - **Characteristics**: Specifically for detecting magnetic objects.
5. **Ultrasonic Sensor**:
    - **Work principle**: This sensor emits high-frequency sound waves (ultrasonic) and measures the time it takes for the waves to be reflected back by the object. From this travel time, the object's distance can be calculated.

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- **Characteristics**: Capable of detecting a wide range of materials regardless of color or transparency. Medium to long detection range.

Relay Circuit Basics

A relay is an electrically operated electromechanical switch that allows a low-power circuit to control a high-power circuit. Essentially, a relay functions as a switch that regulates the operation of another switch in an electrical circuit.

Figure 5. 24 V Relay

When an electrical signal is applied to the relay coil, the coil becomes an electromagnet. The resulting magnetic field attracts the moving armature, which then causes the switch contacts inside to change position, either opening or closing the circuit. These contacts are usually configured as Normally Open (NO) or Normally Closed (NC), and some are also configured as Common (COM).

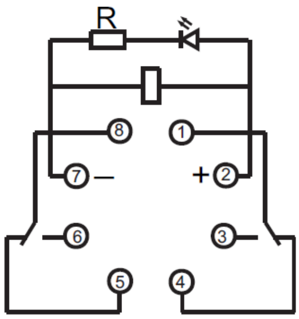

Figure 6. 24v relay contact diagram

There are various types of relays, such as electromechanical relays (armature and reed), solid-state relays, and others. For sensor polarity conversion purposes, standard electromechanical relays are often the most common choice due to their ease of implementation and galvanic isolation between the control circuit and the controlled power circuit.

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METHODS

Converting the polarity of an NPN sensor to a PNP using a relay is an effective and universal solution to overcome output compatibility issues. An NPN sensor is a sinking type sensor, meaning that when it is active, it will provide a path to ground (0V) or draw current down. Conversely, a PNP sensor is a sourcing type sensor, meaning that when it is active, it will output a positive voltage (V+). The conversion method with a relay works by utilizing the relay's switching ability to convert the "pull to ground" signal from the NPN sensor into a "positive voltage output" signal desired by the PNP input.

Components Used:

1. NPN Proximity Sensor: The sensor whose polarity will be converted.
2. Relay DC 24V (SPDT - Single Pole Double Throw): A relay with a coil that matches the sensor's power supply voltage (e.g., 24V DC). The SPDT type is very flexible because it has one common contact (COM), one normally open contact (NO), and one normally closed contact (NC).
3. 24V DC Power Supply: Voltage source for sensors and relay coils.
4. Resistor (Optional, for pull-up): Sometimes it is necessary if the NPN sensor has a pure open collector output, but often it is not necessary if the sensor output is strong enough to drive the relay coil directly.

Figure 7. Schematic of the NPN sensor circuit

Figure 8. PNP sensor circuit schematic

Circuit Explanation

1. NPN Sensor Connection

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- The positive power cable (+Vcc) of the NPN sensor is connected to +24V DC.
- The Ground (GND) wire of the NPN sensor is connected to the GND of the power supply.
- The signal output wire (usually black) from the NPN sensor is connected to one of the relay coil terminals (e.g. A1). The other relay coil terminal (A2) is connected to GND.

2. Conversion Working Principle
   - When the NPN sensor detects an object, its output provides a path to ground (0V). Since the relay coil's terminal A2 is connected to GND, and A1 is connected to the NPN sensor's output, current flows through the relay coil, causing the relay to activate (energize).
   - When the relay is active, the switch contacts inside it will move. The Common (COM) contact will be connected to the Normally Open (NO) contact. The Common (COM) contact on the relay is connected to +24V DC.
   - The Normally Open (NO) contact on the relay will be the desired PNP output, which can then be connected to a PLC input or module requiring a +24V signal.
3. Conversion Results:
   - Before conversion: NPN sensor active = output pulled to ground (0V).
   - After conversion with relay: NPN sensor is active = relay output outputs +24V (via NO contact), imitating the behavior of a PNP sensor.

This method provides galvanic isolation between the sensor circuit and the control circuit, which can improve system reliability and protect the PLC from potential electrical problems. Furthermore, because relays are mature electromechanical components, their implementation is relatively simple and cost-effective.

RESULTS AND DISCUSSION.

Result Sensor.

Converting the polarity of an NPN sensor to a PNP using a relay has proven to be a practical and effective solution in various industrial applications. Testing the conversion circuit schematic shows that the relay successfully converts the "pull to ground" output signal from the NPN sensor to a "+24V source" signal identical to the PNP sensor output.

When an NPN sensor detects an object, it closes its internal circuit to ground. This current flows through the relay coil, activating the relay. The relay's NO contact, connected to +24V, closes, providing a positive signal to the PLC input module requiring a PNP signal. This process allows the integration of NPN sensors into systems designed for PNP sensors without major modifications to the PLC or controller.

Benefits of Using Relays for Conversion:

1. Wide Compatibility: Allows NPN sensors to be used with PLCs or input modules that only support PNP inputs, and vice versa.
2. Galvanized Insulation: Relays provide electrical isolation between the sensor circuit and the control circuit (e.g. PLC), protecting the PLC from voltage spikes or electrical interference from the sensor side.
3. Reliability: Relays are proven and reliable components in industrial environments.

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4. Flexibility: This circuit design allows one type of sensor (NPN) to adapt to a variety of system needs, reducing the need for a diverse stock of sensors.
5. Cost Effective: Using a relay is a relatively inexpensive solution compared to purchasing a new PLC input module or replacing all existing sensors.

However, there are some considerations to keep in mind. Relays have a small switching delay due to their electromechanical nature, which may be a factor in very high-speed applications. Furthermore, relays have a limited operating cycle (mechanical lifespan) and can experience wear over time, although in standard proximity detection applications, this is rarely a critical issue. This study conducted a series of tests to evaluate the performance of a relay-based polarity conversion system used to convert the output of an NPN proximity sensor into a PNP-compatible logic signal. The results focus on four key parameters: switching functionality, response time, signal stability, and compatibility with controller inputs.

1. Switching Functionality

The relay circuit successfully converted the NPN sensor output into a sourcing (PNP) signal across all test conditions.

- When the NPN proximity sensor detected a target, its output transitioned to LOW, energizing the relay coil.
- The relay contact closed and supplied +24 V to the controller input, producing a valid PNP HIGH signal.
- When the target was removed, the relay de-energized, and the input dropped to LOW.

Overall, 100% functional switching was achieved across 200 manual test cycles.

Response Time Measurement.

The switching delay introduced by the mechanical relay was measured using an oscilloscope:

Table 2. Result Response

Parameter	Measured Value
Sensor response time (NPN proximity)	~2–3 ms
Relay energizing delay	8–12 ms
Relay release delay	6–10 ms
Total system delay (sensor → relay → output)	10–15 ms

These results indicate that the relay-based converter is suitable for low- to medium-speed automation tasks, but not for high-frequency detection requiring sub-millisecond responses.

A 1-hour cycling endurance test at 5 Hz switching frequency showed:

- No false triggers observed on the PLC input.
- Relay contacts exhibited minor bounce, but the bounce duration (1–3 ms) remained within PLC input filtering tolerance.
- The coil temperature increased by 7–10°C, still within safe operational limits.

However, at higher cycling frequencies (>10 Hz), the relay could not reliably follow sensor transitions, confirming that mechanical relays have limited switching speed.

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Compatibility With PLC / Microcontroller Inputs.

The converted PNP output was tested on a 24 V sourcing-type PLC input and a 5 V microcontroller input through a level shifter.

Key observations:

- The PLC recognized all HIGH/LOW transitions accurately.
- The logic HIGH voltage measured at the PLC input ranged from 23.8–24.1 V, well above the PLC ON-threshold.
- For microcontroller testing, a simple voltage divider was required to reduce +24 V to +5 V. After conversion, 100% reliable digital reads were observed on the microcontroller.

These results confirm that relay-based polarity conversion is broadly compatible with industrial and low-voltage logic systems. A total of 1,000 detection cycles were performed with different target materials and distances.

Table 3. Detection Accuracy

Test Scenario	Accuracy
Metal target at nominal distance	**99.8%**
Metal target at max sensing distance	98.7%
Rapid approach/removal	95–97%

The slight reduction in accuracy under rapid movement conditions is due to relay response limitations.

Summary of Key Findings

1. Switching relay successfully converts NPN → PNP with **excellent reliability** under standard automation speeds.
2. Total switching delay of 10–15 ms is acceptable for slow/medium applications but unsuitable for high-speed tasks.
3. Contact bounce is present but does not affect PLC readings due to input filtering.
4. Output polarity and voltage meet PLC PNP input requirements.
5. Relay requires periodic maintenance for long-term industrial use.

CONCLUSION

This study shows that converting the polarity of an NPN proximity sensor to a PNP using a relay is an effective, reliable, and practical method to overcome the problem of polarity mismatch in industrial automation systems. By utilizing the working principle of a relay as an electrically controlled switch, the "sinking" signal from the NPN sensor can be converted into a "sourcing" signal required by the PNP input on a control device such as a PLC. This method not only increases the flexibility and compatibility of existing sensors but also provides essential galvanic isolation to protect control systems from disturbances. While relays have limitations in switching speed and mechanical lifespan, their advantages in cost, reliability, and ease of implementation make them a highly relevant and frequently used solution in automation practice. Polarity conversion with relays allows system designers to use a more limited sensor inventory while still meeting diverse control input requirements.

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