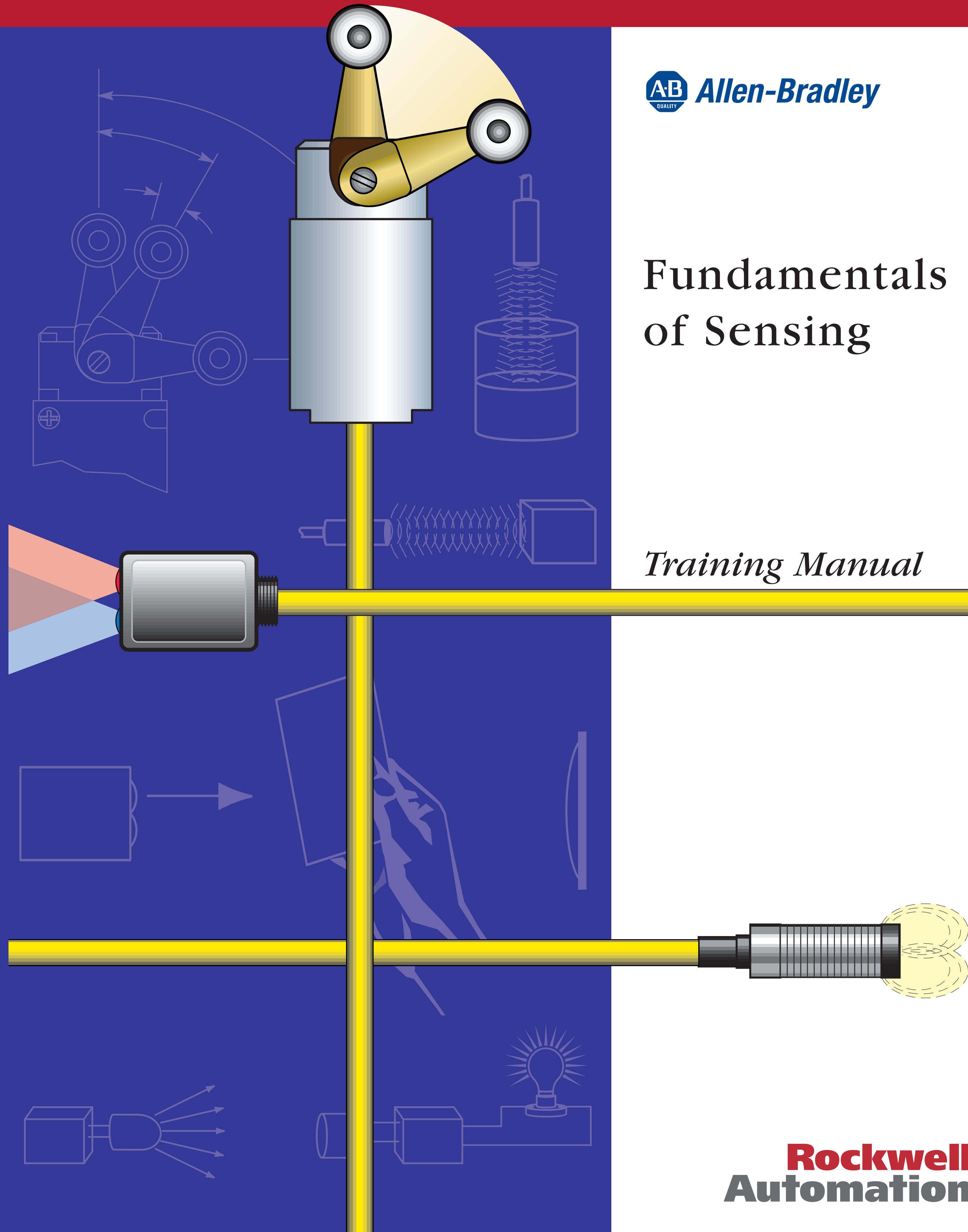
Allen-Bradley

Fundamentals of Sensing

Training Manual



Rockwell Automation

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Preface

Fundamentals of Presence Sensing is a single source of information on applying presence sensors, geared toward those who design, implement, manage, support, or sell presence sensing technology:

- Machine designers
- Controls and application engineers
- Manufacturing and quality engineers
- Engineering and maintenance technicians
- Engineering and trade school students
- Distributors, sales people and their managers

By combining basic sensor theory with application examples, *Fundamentals of Presence Sensing* provides a conceptual understanding of these technologies and how they relate to general industrial processes. Ultimately, this volume will help the user deduce rules for making design decisions linked to presence sensing.

On-Line Viewing Using Adobe Acrobat Reader

This book has been developed for viewing in print and on-line. If you are viewing the on-line version you will see green highlighted text; these are hyperlinks to additional information or glossary terms.

1

Sensor Application Basics

Industry continually strives to develop product faster and more cost effectively. By automating processes, manufacturers can realize these goals while maintaining higher levels of quality and reliability. Presence sensing technology is used to monitor, regulate and control these processes. More specifically, presence sensors help verify that critical process steps are completed as intended.

The first section of this chapter covers the terminology and basic operating principles common to all sensors; the remainder outlines a methodology for reviewing potential applications and selecting the best sensor for the job.

Later chapters will discuss, in some detail, the most prevalent technologies and their application:

- Limit Switches (Chapter 3)
- Inductive Proximity Sensors (Chapter 4)
- Capacitive Proximity Sensors (Chapter 5)
- Ultrasonic Proximity Sensors (Chapter 6)
- Photoelectric Sensors (Chapter 7)

What Is a Sensor?

A sensor is a device for detecting and signalling a changing condition. And what is this "changing condition"? Often this is simply the presence or absence of an object or material (discrete sensing). It can also be a measurable quantity like a change in distance, size or color (analog sensing). This information, or the sensor's output, is the basis for the monitoring and control of a manufacturing process.

Contact vs. Noncontact Technologies

Contact sensors are electromechanical devices that detect change through direct physical contact with the target object. Contact sensors:

- Typically do not require power.
- Can handle more current and better tolerate power line disturbances.
- Are generally easier to understand and diagnose.

Encoders, limit switches, and safety switches are contact sensors. Encoders convert machine motion into signals and data. Limit switches are used when the target object can handle the physical contact. Safety switches incorporate tamper resistant actuation and direct opening action contacts for use as machine guards and emergency stops.

Noncontact sensors are solid-state electronic devices that create an energy field or beam and react to a disturbance in that field. Some characteristics of noncontact sensors:

- No physical contact is required
- No moving parts to jam, wear, or break (therefore less maintenance)
- Can generally operate faster
- Greater application flexibility

Photoelectric, inductive, capacitive and ultrasonic sensors are non-contact technologies. Because there is no physical contact, the potential for wear is eliminated, however, there are some rare circumstances where there could be interaction between the sensor and target material. Non-contact sensors can also be susceptible to energy radiated by other devices or processes.

A Practical Example

An example of both contact and noncontact sensor use would be found on a painting line. A contact sensor can be used to count each door as it enters the painting area to determine how many doors have been sent to the area. As the doors are sent to the curing area, a noncontact sensor counts how many have left the painting area and how many have moved on to the curing area. The change to a noncontact sensor is made so there is no contact with, and no possibility of disturbing, the newly painted surface.

Discrete vs. Analog Detection

Discrete sensing answers the question, "Is the target there?" The sensor produces an On/Off (digital) signal as output, based on the presence or absence of the target.

Analog sensing answers the questions, "Where is it?" or "How much is there?" by providing a continuous output response. The output is proportional to the target's affect on the sensor, either in relation to its position within the sensing range or the relative strength of signal it returns to the sensor.

Sensor Characteristics/Specifications

When specifying sensors, it is important to understand the common terms or "buzz words" associated with the technology. While the exact terms differ from manufacturer to manufacturer, the concepts are globally understood within the industry.

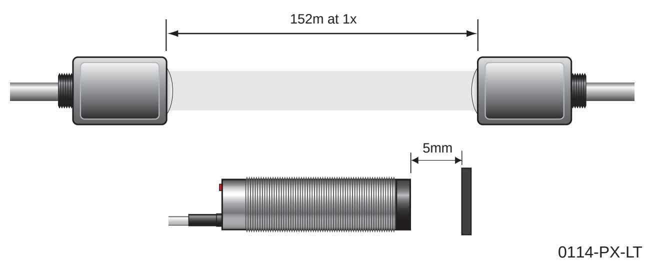
Sensing Distance

When applying a sensor to an application nominal sensing distance and effective sensing distance must be evaluated.

Nominal Sensing Distance

Nominal sensing distance is the rated operating distance for which a sensor is designed. This rating is achieved using standardized criteria under average conditions.

Figure 1.1:
Nominal Sensing Distance



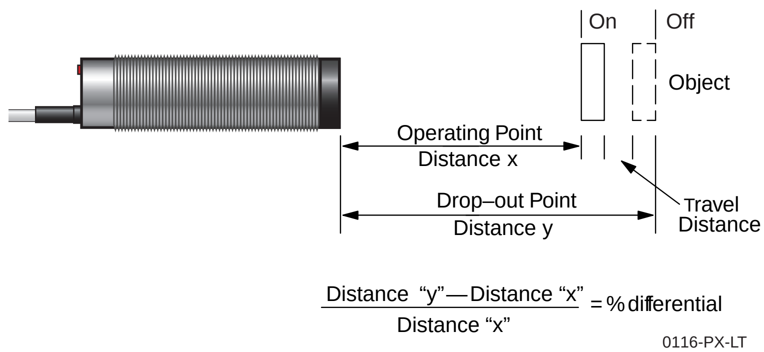
Effective Sensing Distance

The effective sensing distance is the actual "out of the box" sensing distance achieved in an installed application. This distance is somewhere between the ideal nominal sensing distance and the worst case sensing distance.

Hysteresis

Hysteresis or differential travel is the difference between the operate (switch on) and release (switch off) points when the target is moving away from the sensor face. It is expressed as a percentage of the sensing distance. Without sufficient hysteresis a proximity sensor will continuously switch on and off, or "chatter," when there is excessive vibration applied to the target or sensor. It can also be made adjustable through added circuitry.

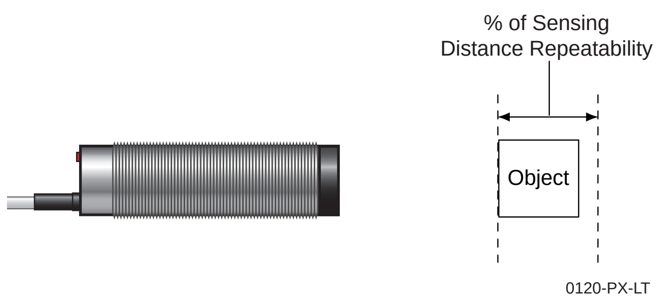
Figure 1.2:
Hysteresis



Repeatability

Repeatability is the ability of a sensor to detect the same object at the same distance at all times. Expressed as a percentage of the nominal sensing distance, this figure is based on a constant ambient temperature and supply voltage.

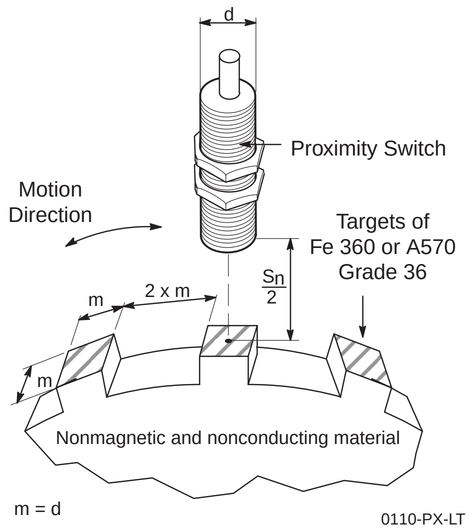
Figure 1.3:
Repeatability



Switching Frequency

Switching frequency is the number of switching operations per second achievable under standardized conditions. In more general terms, it is the relative speed of the sensor.

Figure 1.4:
Standardized Switching Frequency Setup



Response Time

The response time of a sensor is the amount of time that elapses between the detection of a target and the change of state of the output device (ON to OFF or OFF to ON). It is also the amount of time it takes for the output device to change state once the target is no longer detected by the sensor.

The response time required for a particular application is a function of target size and the velocity at which it passes the sensor.

Standards

An industrial control manufacturer has limited or no control over the following factors which are vital to a safe installation:

- Environmental conditions
- System design
- Equipment selection and application
- Installation
- Operating practices
- Maintenance

Presence Sensors and Switches, like all other electrical equipment, must be installed in accordance with specific National Electrical Codes (NEC). Three primary standards organizations have evolved:

- CENELEC—European Committee for Electrotechnical Standardization
- IEC—International Elecrotechnical Commission
- NEMA—National Electrical Manufacturers Association

Generally, CENELEC specifications are followed on installations in the European market, while installations in North America adhere to the NEMA standards. IEC covers standards on an international scale.

Agency Approvals

Many sensor manufacturers voluntarily submit their product designs for testing and approval by a recognized third party. In other cases, the manufacturer is allowed to self-certify that their designs conform to applicable standards. While typically not required for general use in the United States, you may be required to use suitably approved devices for equipment to some customers or for export.

Manufacturers' products bearing the mark of an agency will have a file listing allowing a customer or inspector to verify compliance. It is important to note that it is the design of a product that has been approved or certified, not the physical product itself.

Underwriters Laboratories (UL) and Canadian Safety Authority (CSA)

These North American agencies primarily perform tests to help insure the products are manufactured in accordance with the imposed requirements and, when used as intended, do not pose a shock or fire hazard to the user.

Factory Mutual (FM)

Factory Mutual is a North American agency concerned with verifying that products for use in hazardous locations (areas with potentially explosive atmospheres) conform with practices for intrinsic safety. These practices help insure that a device manufactured in accordance with the imposed requirements and used as part of an approved system maintains energy levels below that which could spark an explosion. The file for each product includes the authorized connection diagram.

European Community (CE)

These requirements affect nearly all phases of product design, construction, materials, use, and even disposal. Products without the CE mark are not allowed to be sold within the European Community. For sensors, CE addresses electromagnetic compatibility. The CE mark on a sensor indicates the sensor, up to a certain level, will not interfere with, or be affected by, other electronic devices.

Sensor Selection—A Methodical Approach

Within each system there are many operations or processes: fabrication, assembly, packaging, painting, material handling. Each can be broken down into smaller events like counting, indexing, ejection, spraying, filling, and conveying. A sensor could be of value to detect the changing conditions associated with an action or event.

Determine Where a Sensor May Be Needed

This process involves identifying key operations within the system and defining focus areas where conditions should be verified.

Identify the Functions

Identify what the system does or what you want it to do. Is it necessary for you to count product? Sort? Perform a quality check? Determine part orientation? Specifically:

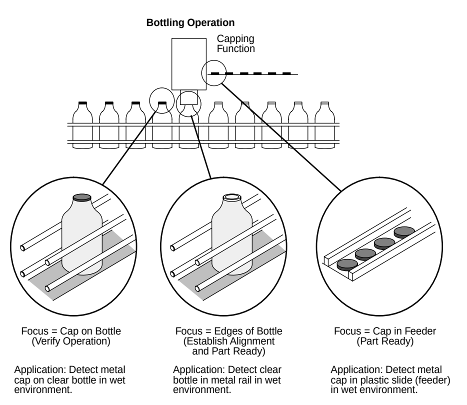
- What conditions must be met for each function to occur?
- What feedback is required during each function?
- What conditions must be met after each function to verify the function has occurred properly?

Identify the Area of Focus

Focus on the area where an action is taking place. Within this area, you will typically find a work piece and a mechanism that acts upon it. Investigate both to determine what is required for the function to be properly executed.

- Verification of work piece—Are there features or components of the work piece that must be present or in a particular orientation? What is the potential for the work piece itself to be oriented or damaged in a way that could adversely affect the process?
- Verification of mechanism—Is the mechanism or work piece driven by separate systems that could crash if one were present without the other being retracted? Is a particular component prone to breakage or wear?

Figure 1.5:
Bottling Operation



Determine if a Sensor Should Be Applied

You must now decide how important each of the areas you identified is to the process. The higher the level of automation the more important it is for these functions to execute properly. Specifically, you are asking:

- What is the impact of damage or loss?
- What is the likelihood of it occurring?
- How critical is it to process integrity?

If the answer to any one of these is "high," you need to consider implementing a sensor to monitor for a condition that, if present, could facilitate a system glitch.

The next step is to define what sensing functions need to be achieved and where the best location is to accomplish them. Are you trying to determine jam-ups in the system, high/low limits, sorting, speed sensing, or part positioning? This determines the location of the sensor and focuses on specific physical limitations. Now is also a good place to consider the following:

- "Are there safety or economic considerations?" If failure to detect the condition could result in a person being injured or killed, or if failure could result in a significant monetary loss, you should note the item for special consideration by an expert in these specific applications.
- "Is this the best place to perform the sensing function?" Often, in a sequence of operations, it is the end result that we are concerned with. In many cases, monitoring this end result can provide indication that the preceding actions have occurred properly. In other operations, the environment or space restrictions may prevent us from performing the detection function in the area of focus, but we can perform it more reliably while the work piece is in transit or in a preceding function.

Define the Application

You have identified an application that can benefit from implementing a sensor to detect a changing condition. With this as your focus, you must now determine:

- Available power
- Output/Load requirements
- Target characteristics
- Environmental conditions

Identify the Power Sources

What is the available power at the application point—AC or DC?

Based on the voltage commonly available in the field, sensors are generally designed to fall within one of four voltage ranges:

- 10-30V DC
- 20-130V AC
- 90-250V AC
- 20-250V AC/DC

AC sensors and switches can receive power directly from a power line or filtered source, eliminating the need for a separate power supply. AC devices and connection methods are also perceived as being more rugged.

DC sensors require a separate supply to isolate the DC portion of the AC signal. However, with voltages typically less than 30V, DC is considered safer than AC. DC sensors come in current source and current sink versions. Current source sensors supply power to the load which must be referenced to the ground or negative rail of the power supply. Current sink sensors supply ground to the load which must be referenced to a positive voltage that shares the same ground.

A number of manufacturers offer AC/DC devices that operate over a wide range of voltages from either power source. These sensors offer the convenience of being able to stock one device that can operate in a number of applications with different power supplies.

As a matter of general practice, you want to specify that your switches or sensors are powered from a stable source that is free of noise. Typically, this involves specifying an isolated line or separate supply to power the switches and sensors and staying well within the ratings.

Identify the Load Requirements

What will the sensor be affecting? In other words, what device will the sensor control directly and what are its characteristics? The electrical components in series between the sensor output and power or ground constitute what is referred to as the *input load* of the device and *output load* for the sensor. This load translates the electrical signals of the sensor output into electrical, mechanical, sound or light energy that initiates a change within the affected device. Key characteristics of the three types of circuit elements that can be found in the load:

- Resistive elements constitute an ideal type of load, dissipating power in direct proportion to the voltage applied.
- Capacitive elements are reactive and can appear to be a short circuit when first switched on.

- Inductive elements like relay coils and solenoids are also reactive elements that can create high voltage transients when switched off abruptly.

Does the sensor need to condition the output in order for it to be useful to the device it is interfacing with? If the event we are detecting is extremely fast, it may be necessary for the sensor or a conditioning circuit to provide a longer output pulse than the duration of the event. In other instances, like when the sensing function and action it initiates occur at two different places in the system, the output signal may need to be shifted by an interval of time.

Determine the Physical Properties of What You Are Detecting

For any sensing function you must identify the item you wish to detect (target); this may be an entire object or a *feature* of that object. You must also determine the variables associated with the target—presence, position, orientation, etc.—and how these variables affect the process. Finally, we must regard environmental conditions and their effects; insuring that the surroundings do not contain factors that affect the technology is an enormous factor in the reliability of the application.

Target Considerations

Properties of the target—size, material, color, opacity, etc.—will dictate the use of a particular technology and define limitations within that technology. For example, inductive sensors will only detect metal targets. However, the size and material of the target affect sensing range and speed. Further target considerations on specific sensing technologies can be found in their respective chapters later in this book.

Identify Environmental Influences

There are characteristics of the target, background and surroundings that influence the ability to differentiate one from the other. Ideally, the changing condition of the target you are trying to detect should be unique from related factors in the background and surroundings. For example, to detect changes in color, we must use light. A sensor that uses light to detect changes (a photoelectric sensor) in the color of our target could have trouble seeing the target if the surrounding was too opaque to transmit the light or if the background reflected more light than the target.

Table 1.1: Target and Environment

Target	Background	Surrounding
Mass		
Shape		
Structural Integrity		
Size	Proximity to Target	
Material	Material	Material
Opacity	Emissive Properties	Humidity
Reflective Properties	Reflective Properties	Transmissive Properties
Color	Color	Light
		Temperature
		Electromagnetic Interference
		Noise
Systemic		
Accessibility, Proximity to Sensor, Timeframe, Amount Exposed		

Sensor Selection

Now that you have documented the application and understand what must be detected, our discussion can be directed toward selecting a sensor. This is a process of determining which technology or technologies best utilize the strongest differentiating traits of the changing condition while being the least affected by background and surrounding conditions. There is rarely a single solution; each technology has strengths and weaknesses that make it a good or poor choice for a given application. It helps to view the overall system and gradually narrow your focus to specific processes. Determine how a sensor could enhance this process and how it relates to the overall system. The information derived through this approach can then be compared to information on available sensor types to determine the best product for the application. Ultimately, the chosen solution provides the best compromise of performance, reliability, availability and cost.

2

Outputs & Wiring

The connections between sensors, power supply and load devices are often called the electrical interface circuit. Each element is vital to the reliability of an application.

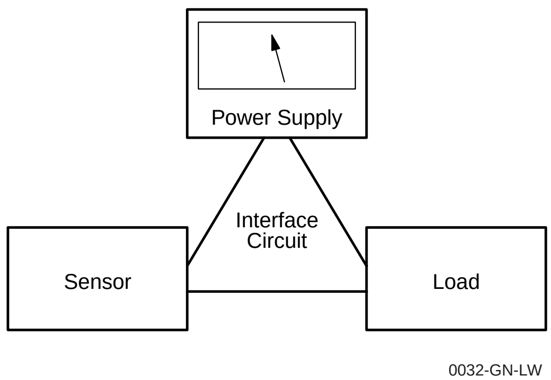


Figure 2.1:
Basic Electrical Interface Circuit

A reliable interface matches the requirements of all devices in the application and anticipates those of the environment in which it is applied. The power supply provides a level of voltage and current to the circuit that is shared by its devices. Because power is shared you must be concerned that each device will get the power it needs to operate reliably. This becomes increasingly important when multiple sensors and/or loads are connected with a low voltage DC supply. It also involves making sure no device gets too much current; most sensors fail because of improper installation, the most common problem being a direct connection of the sensor output to the power supply or AC line.

Power Supplies

As a matter of practice, you want to specify that your switches or sensors are powered from a stable source of power that is free of noise (noise, in this case, is undesirable energy induced in the system by other devices or electrical fields). Typically, this involves specifying an isolated line or separate supply to power the switches and sensors, staying well within the ratings of that supply. At the same time, it is also good practice to specify sensors that incorporate a degree of protection for potential power line events, i.e. short circuits and overloads.

Available Power

Four voltages are typically available to power industrial sensors:

- 12V DC
- 24V DC
- 120V AC
- 240V AC

Sensor Ratings

Industrial sensors are typically designed to operate within one of four voltage ranges:

- 10-30V DC
- 20-130V AC
- 90-250V AC
- 20-250V AC/DC

AC sensors and switches can receive power directly from the power line or a filtered source helping to eliminate the need for a separate power supply.

Most DC sensors require a separate supply that isolates the DC portion of the signal from the AC line.

Protection

Whether AC or DC, good practice dictates that sensor power should be from a separate, filtered source and the line protected with a properly rated fuse. This will protect the power supply and wiring but will do little to protect the solid state devices and sensors in the circuit.

Even fast-acting fuses and most electronic current-limiting circuits are too slow to protect the sensor from damage in the event of:

Short Circuit/Overload—Shortened current path (thus less resistance) allows excessive current to reach the device

Reverse Polarity—Positive and negative wires are not connected to their respective terminals

If these events are anticipated, specify a sensor with built-in reverse polarity, short-circuit and overload protection.

Current Flow

Typical power consumption for each sensor type:

- Photoelectric 35mA
- Ultrasonic 70mA
- Inductive 15mA
- Capacitive 15mA

Output Types

Output configurations fall into two categories, electromechanical and solid-state.

Electromechanical

- Relay
- Switch

Solid-State or Electronic

- Transistor
- Field Effect Transistor (FET)
- Triac
- Analog
- Network or Bus

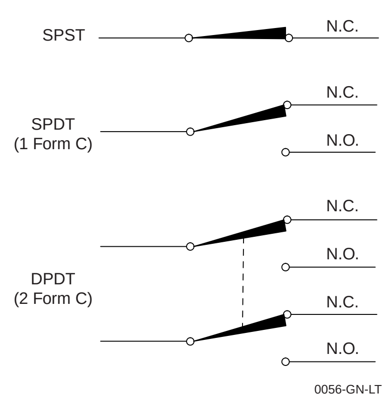
The type of output that you choose will depend on what you are interfacing to in your application and the output types available for the sensor you are working with.

Electromechanical

An electromechanical relay (or "dry contact") is actuated by energizing a wire coil which magnetically attracts an armature to physically open and close a circuit. When the circuit is open, no power is conducted across the contacts. When the circuit is closed, power is conducted to the load with virtually no voltage drop. A relay with an open contact in the rest (or un-energized) state is considered *Normally Open (N.O.),* whereas a relay with a closed contact in the rest state is *Normally Closed (N.C.).*

Because of the electrical isolation from the power source of the sensor, and due to the absence of leakage current (undesirable current present in the 'off' state), relays from multiple sources can readily be connected in series and/or parallel to switch AC or DC loads.

Figure 2.2:
Electromechanical Circuits



There are a number of different contact arrangements available:

- SPST—Single pole, single throw
- SPDT—Single pole, double throw (1 Form C)
- DPDT—Double pole, double throw (2 Form C)

Since relays are mechanical to some extent, they succumb to wear; therefore they have a finite life span. At low energy, contact oxidation can also cause degeneration of the contacts. Response times of relays are typically 15-25ms, much slower than most solid state outputs.

Solid-State

Solid-state outputs should be considered for applications that require frequent switching or switching of low voltages at low currents.

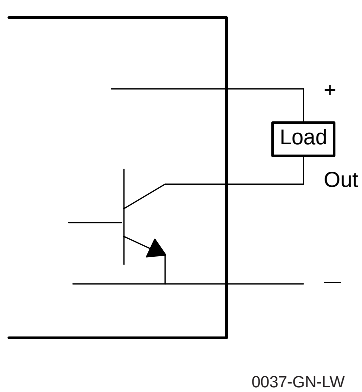
A solid-state switch is purely electronic—it has no moving parts.

NPN/PNP Transistor

Transistors are the typical solid-state output devices for low voltage DC sensors. Consisting of a crystalline chip (usually silicon) and three contacts, a transistor amplifies or switches current electronically. Standard transistors come in two types: NPN and PNP.

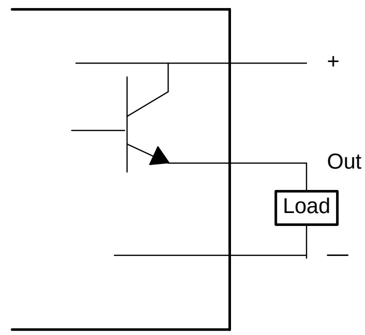
For an NPN transistor output, the load must be connected between the sensor output and the positive (+) power connection. This is also known as a 'sinking' output.

Figure 2.3:
NPN Transistor



A PNP transistor output is considered a 'sourcing' output. The load must be connected between the sensor output and the negative (-) power connection.

Figure 2.4:
PNP Transistor

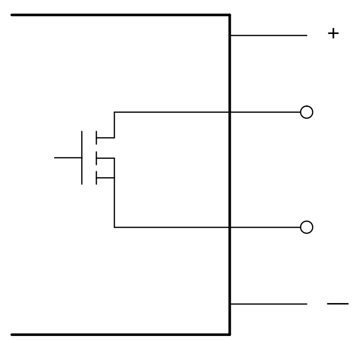


Transistors exhibit very low leakage current (measured in µA) and relatively high switching current (typically 100mA) for easy interface to most DC loads. Response times of sensors with transistor outputs can vary from 2ms to as fast as 30µs. However, NPN and PNP transistors are only capable of switching DC loads.

FET

The FET (Field Effect Transistor) is a solid-state device with virtually no leakage current that provides for fast switching of AC **or** DC power. It also requires only a small amount of current to change state–as little as 30µA. As a result, FETs are generally more expensive than standard transistor outputs.

Figure 2.5:
NFET



FET outputs can be connected in parallel like electromechanical relay contacts.

Power MOSFET

A Power MOSFET (Metal Oxide Semiconductor Field Effect Transistor) provides the very low leakage and fast response time benefits of an FET with high current switching capacity; Power MOSFET outputs can switch up to 500mA of current.

TRIAC

A TRIAC is a solid-state output device designed for AC switching only; in simplest terms, it is the AC equivalent of a transistor. TRIACs offer high switching current and low voltage drop, making them suitable for connection to large contactors and solenoids.

TRIACs exhibit much higher leakage current than FETs and Power MOSFETs. Leakage current can exceed 1mA, making TRIACs unsuitable as input devices for programmable controllers and other solid state inputs. Once a TRIAC is triggered it stays on as long as current is present, preventing the devices from being electronically short-circuit protected. A zero crossing of the 50/60Hz AC power sine wave is required to deactivate a TRIAC circuit. For most applications, however, Power MOSFETs provide better output characteristics.

Figure 2.6:
TRIAC

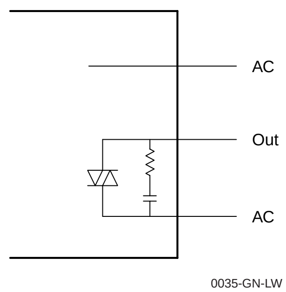
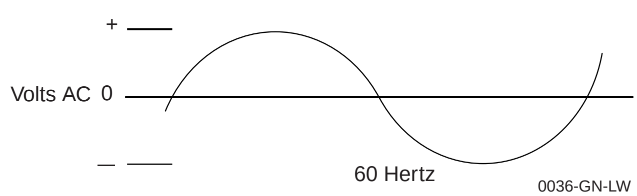


Figure 2.7:
TRIAC-Zero Crossing

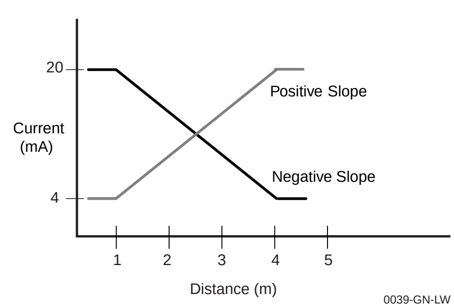


Analog Output

Analog output sensors provide a voltage or current output that is proportional, or inversely proportional, to the signal detected by the sensor.

Because analog sensors allow for the simultaneous detection of several factors, they are occasionally used in discrete sensing applications where one sensor must perform several functions. An example of this is the detection and sorting of light and dark colored packages.

Figure 2.8:
Analog Response



Network/Bus

In an effort to reduce system wiring, the networking of sensors is growing in popularity. Networking allows compatible sensors to be directly connected to a single backbone cable which is then interfaced to the controller. These sensors incorporate a bus/ network interface chip (integrated circuit) and firmware that allow them to receive power and communicate over common lines. Component cost is typically higher, but wiring and debugging are simplified.

Table 2.1: Output Strengths and Weaknesses

Output Type	Strengths	Weaknesses
Electromechanical Relay *AC or DC switching*	• Output is electrically isolated from supply power • Easy series and/or parallel connection of sensor outputs • High switching current	• No short circuit protection possible • Finite relay life • Slow
FET *AC or DC switching*	• Very low leakage current • Fast switching speed	• Low current output
Power MOSFET *AC or DC switching*	• Very low leakage current • Fast switching speed	• Moderately high output current
TRIAC *AC switching*	• High output current	• No short-circuit protection possible • Relatively high leakage current • Slow output switching
NPN or PNP Transistor *DC switching*	• Very low leakage current • Fast switching speed	• No AC switching

Wiring

2-Wire vs. 3-Wire

Sensors can also be broken down by their wiring configurations. The most common are 2-wire and 3-wire. Two-wire devices are designed to wire in series with the load. In a 3-wire configuration, two of the three leads supply power while the third switches the load. Both types can be wired strategically, in series or parallel configurations, to conserve inputs or perform logic.

Connecting 2-Wire Sensors in Series or Parallel

Two-wire sensors are the easiest devices to wire, but they can hinder the overall system performance. Two-wire sensors require power from the same line they are switching; this, combined with their characteristically higher voltage drop, typically limits the practical number that can be connected to two. In addition, because each device supplies power to the subsequent devices, response time is equal to the sum of the turn-on times for each device.

Figure 2.9:
Series Connection of 2-Wire Outputs

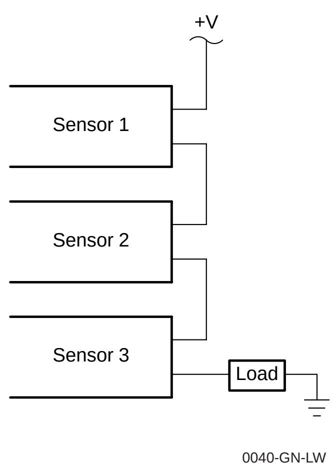
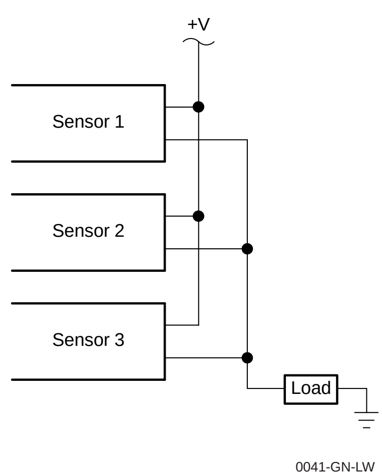


Figure 2.10:
Parallel Connection of 2-Wire Outputs



Connecting Relay Outputs in Series or Parallel

To simplify the wiring of relay outputs it helps to separate the output wiring from that of the power wiring. In either configuration, you will run the power wires in parallel, you are then free to connect the outputs in the configuration desired.

Figure 2.11:
Series Connection of Relay Outputs

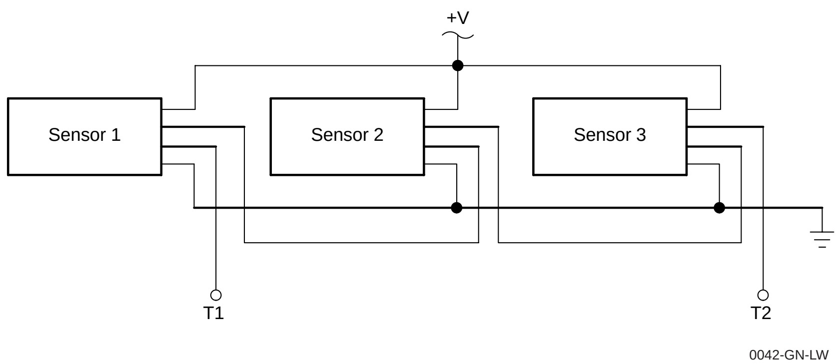
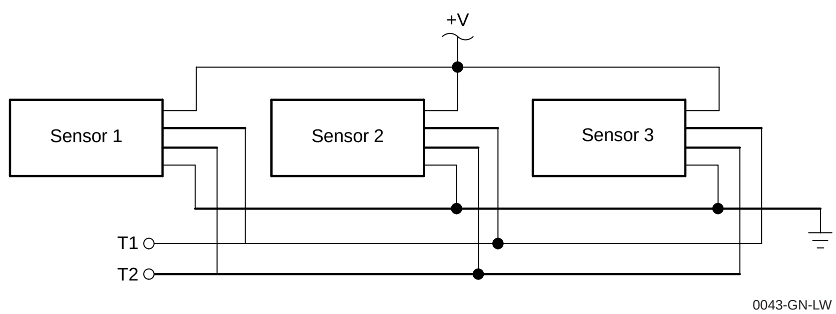


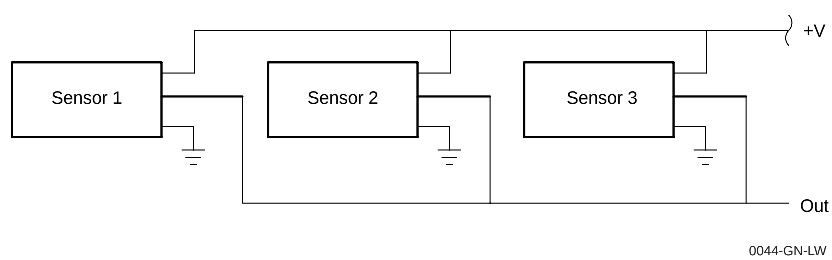
Figure 2.12:
Parallel Connection of Relay Outputs



Connecting 3-Wire Outputs in Parallel

Sensors with NPN or PNP transistor outputs are straightforward to wire in parallel. The low leakage current of transistor outputs allows a number of devices to be connected together before leakage current becomes a problem. Devices must all be of the same output configuration.

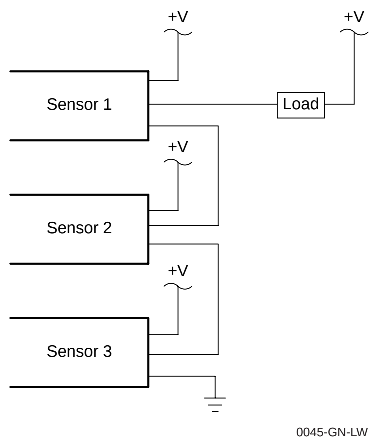
Figure 2.13:
Parallel Connection of 3-Wire Outputs



Connecting 3-Wire NPN Outputs in Series

Series connection of 3-wire NPN output devices requires each device in the series to supply negative to the next device with the last device in the chain supplying negative to the load. Because each device supplies power to the next, response time is equal to the response time of the first sensor plus the sum of the turn on times of the others. The output of each sensor must be capable of supplying the peak load currents of subsequent sensors plus the current of the load. To overcome the internal supply capacitance of subsequent sensors, a low value (10 ohm) resistor is sometimes required in series with each.

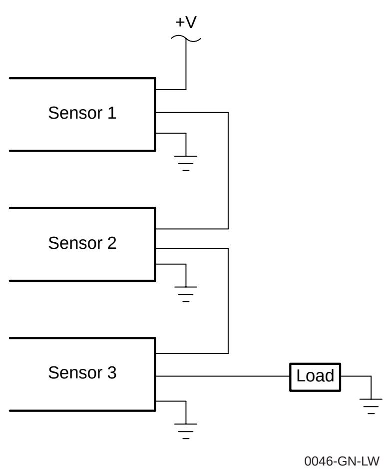
Figure 2.14:
Series Connection of NPN Transistor Outputs



Connecting 3-Wire PNP Outputs in Series

Series connection of 3-wire PNP output devices requires each device in the series to supply power to the next device with the last device in the chain supplying power to the load. Because each device supplies power to the next, response time is equal to the response time of the first sensor plus the sum of the turn on times of the others. The output of each sensor must be capable of supplying the peak load currents of subsequent sensors plus the current of the load. To overcome the internal supply capacitance of subsequent sensors, a low value (10 ohm) resistor is sometimes required in series with each.

Figure 2.15:
Series Connection of PNP Transistor Outputs



Output Timing and Logic

Special sensor functions may be built-in; otherwise these advanced capabilities are available as plug-in cards or as separate modules. Photoelectric sensors are somewhat unique among presence sensors because many offer integral timing or logic functions. In addition, sensors for specialized applications like motion detection or zero-speed may come with timing and logic pre-set for the application.

On Delay and Off Delay

On Delay and Off Delay are the most common timing modes.

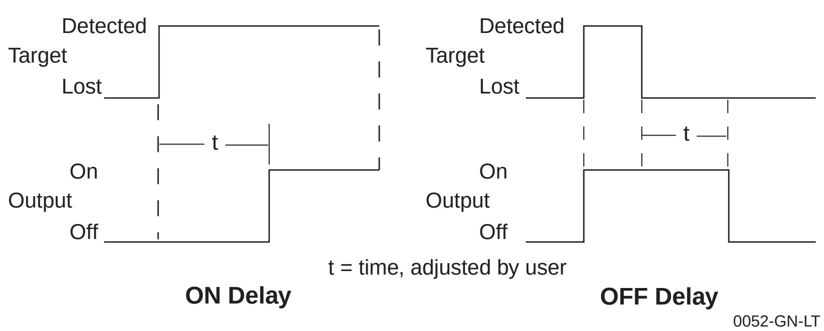
An On Delay timer will delay the operation of an output after a target is detected.

An Off Delay timer will delay the operation of an output after the target is no longer detected.

The delay time of most sensors is adjustable from less than a second to 10 seconds or more.

Some high speed sensors (less than 1ms response time) contain a selectable 50ms off delay time. This “pulse stretcher” is useful when it is necessary to slow down the OFF response time to allow a slower PLC or other machine logic to respond to the movement of materials in high speed applications.

Figure 2.16:
On/Off Delay



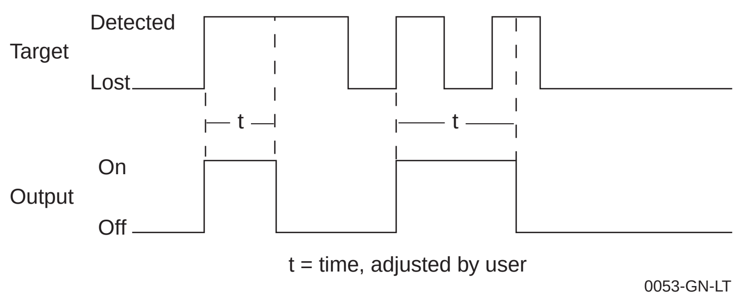
One-Shot

One-shot logic provides a single pulse output regardless of the speed at which a target moves past the sensor. The length of the pulse is adjustable.

One shot operation can provide different application solutions:

- In high speed operations—each time a target moves past the sensor it provides a pulse that is sufficiently long to allow other slower logic to respond.
- In slow speed operations—provides a brief pulse each time a target moves past the sensor to trigger a solenoid or other impulse device.
- Provides a leading edge signal regardless of target length.
- Provides a trailing edge signal regardless of target length.

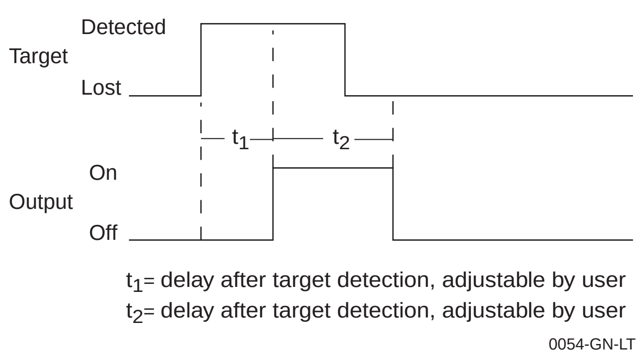
Figure 2.17:
One-Shot Timing



Delayed One-Shot

Delayed One-Shot logic adds an adjustable time delay before the one-shot output pulse occurs.

Figure 2.18:
Delayed One-Shot Timing

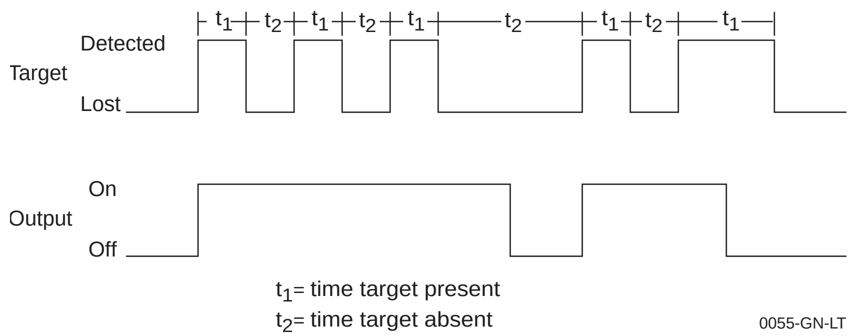


Motion Detector

Motion Detection logic provides the unique capability to detect the continuous movement of targets. The sensor will provide an output if it does not detect the motion of successive targets within the adjustable delay time.

Motion Detector logic is useful to detect a jam or void in material handling applications.

Figure 2.19:
Motion Detection Logic



3

Limit Switches

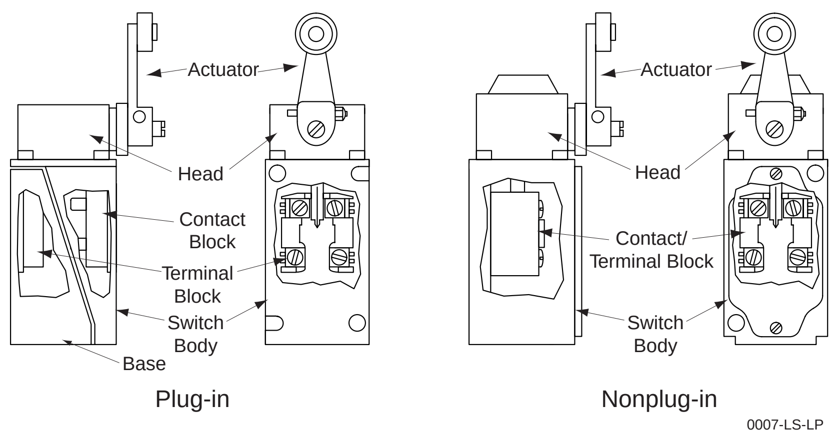
A limit switch is an electromechanical device that consists of an actuator mechanically linked to a set of contacts. When an object comes into contact with the actuator, the device operates the contacts to make or break an electrical connection.

Limit switches are used in a variety of applications and environments because of their ruggedness, ease of installation, and reliability of operation. They can determine the presence or absence, passing, positioning, and end of travel of an object. They were first used to define the limit of travel of an object; hence the name "Limit Switch."

Limit Switch Construction

Limit switches are designed in two body types: plug-in and nonplug-in. The differences and advantages of each are discussed more fully on page 3-3. The subassemblies which make up a limit switch are described below.

Figure 3.1:
Limit Switch Construction



Basic Components

Actuator

The actuator is the portion of the switch that comes in contact with the object being sensed.

Head

The head houses the mechanism that translates actuator movement into contact movement. When the actuator is moved as intended, the mechanism operates the switch contacts.

Contact Block

The contact block houses the electrical contact elements of the switch. It typically contains either two or four contact pairs.

Terminal Block

The terminal block contains the screw terminations. This is where the electrical (wire) connection between the switch and the rest of the control circuit is made.

Switch Body

The switch body houses the contact block in a plug-in switch. It houses a combination contact block and terminal block in the nonplug-in switch.

Base

The base houses the terminal block in a plug-in switch. Nonplug-in switches do not have a separate base.

NEMA vs. IEC

The enclosure and contacts for a limit switch are built and rated based on standards developed by committees such as the International Electrotechnical Commission (IEC) or the National Electrical Manufacturers Association (NEMA). NEMA and IEC style switches differ in many aspects including body size, mechanical life, durability, typical housing material, and mounting hole pattern. NEMA style switches are generally viewed to be more rugged and have longer service life while IEC "international" style products tend to be smaller and less costly. The standards and their differences are discussed more fully in the Sensor Application Basics module beginning on page 1-1.

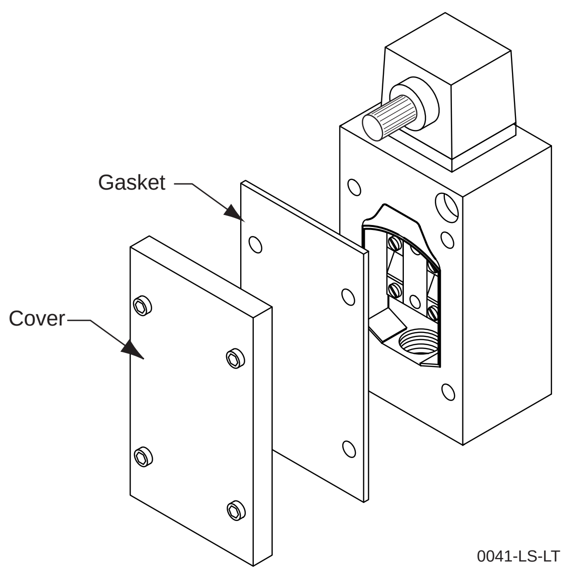
Plug-in vs Nonplug-in Housings

A NEMA style limit switch may be enclosed in a plug-in or a nonplug-in housing.

Nonplug-in Housings

The first housings developed were the nonplug-in type. They are box shaped with a separate cover. Seals between the head, body, and cover are maintained by an O-ring and a flat gasket. Nonplug-in style limit switches are offered in a wide range of styles conforming to IEC or NEMA specifications.

Figure 3.2:
Nonplug-in Housing



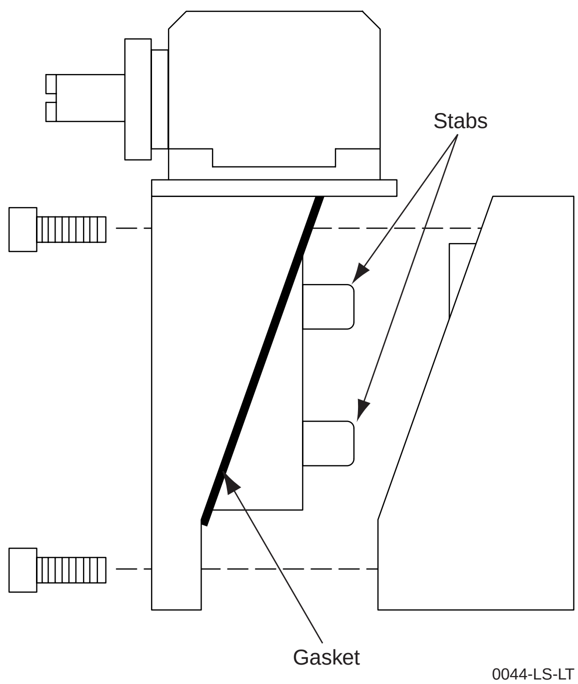
Plug-in Housings

Plug-in housings were developed to ease replacement of the switch if needed. In contrast to the box-and-cover concept, the plug-in housing splits in half to allow access to the terminal block for wiring. A set of stabs in the switch body “plugs” into sockets in the base to make electrical connections between the contact block and the terminal block.

The base of the plug-in houses the electrical wiring and is mounted at the initial installation. With no moving parts to break or wear, the base rarely needs to be replaced. If the switch is damaged or wears out, the switch body with head is removed, a new switch body with head is plugged into the base, and the switch is ready for operation. No rewiring is needed.

An O-ring provides the seal between the operating head and the switch cover while a custom-cut gasket guards the switch body against entry of oil, dust, water, and coolants.

Figure 3.3:
Plug-in Housing



Plug-ins are offered in a range of styles conforming to NEMA specifications.

The design benefits of the plug-in housing include:

- Installation without removal of the cover (cover removal required for some nonplug-in styles)
- No moving parts located in base
- Reduced downtime because head and body can be replaced quickly without disturbing wiring in base

Actuator Function and Types

When there is no force or torque applied to the actuator it is in the unactuated, free or rest position. The position to which the actuator must be moved in order to operate the contacts is called the trip point or operating position. When the motion of the actuator is reversed, the position at which the contacts return to their original state is called the reset point or releasing position.

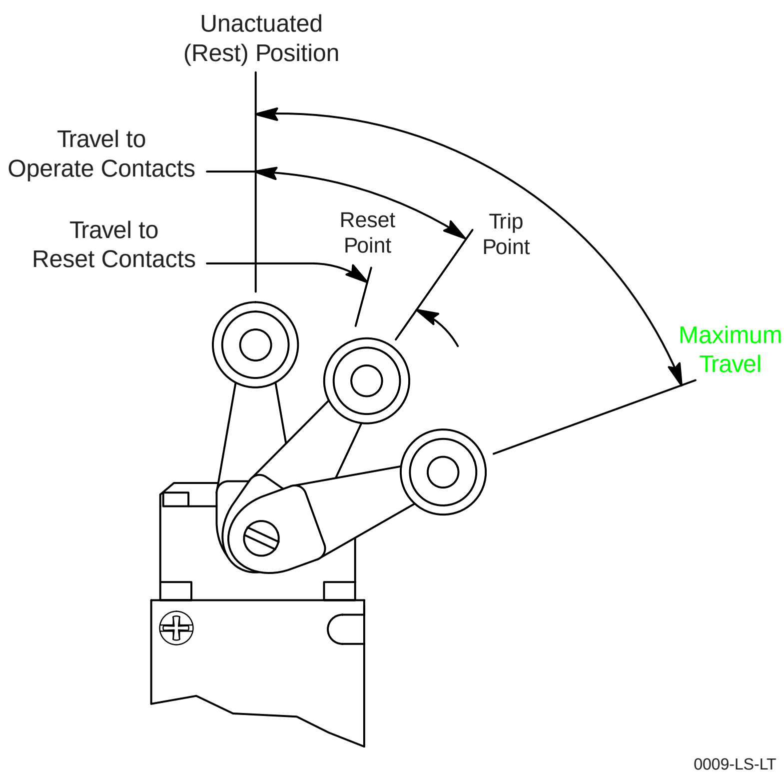
There are three common actuator types:

- Side rotary
- Side or top push
- Wobble stick or cat whisker

Side Rotary Actuation

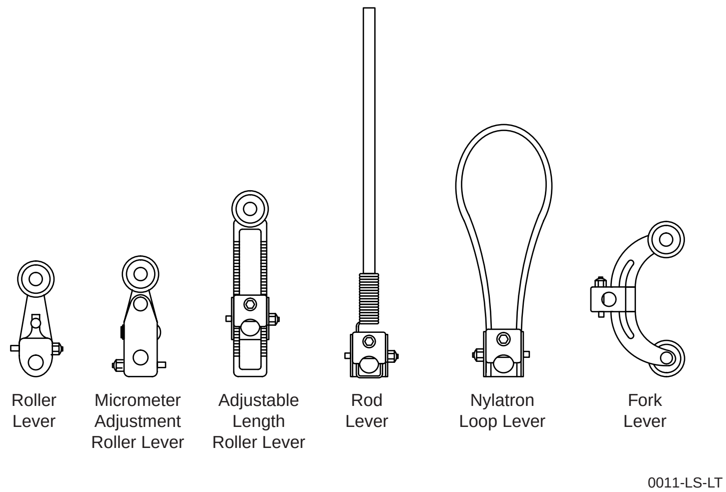
A side rotary actuator is a shaft protruding from the side of a limit switch head that operates the switch contacts when rotated. It can move in a clockwise and/or a counterclockwise direction and is designed for either uni- or bi-directional operation of the contacts. A lever arm is typically affixed to the shaft, allowing passing objects to activate the switch by pushing on the lever.

Figure 3.4:
Actuation of Side Rotary Switch with Lever Arm



Multiple lever arm types can be used with this type of switch.

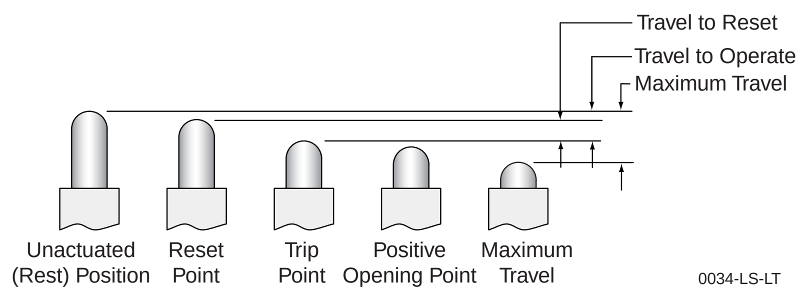
Figure 3.5:
Lever Arm Examples



Side or Top Push Actuation

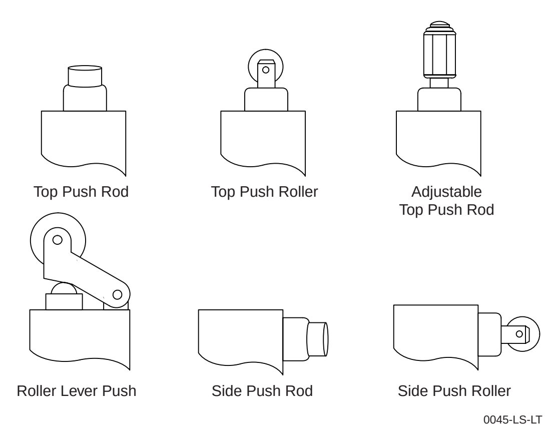
A side or top push actuator is a short rod (button) on the side or top of a limit switch head that operates the switch contacts when depressed. It is usually designed with a spring return mechanism that returns to its original position when the actuating force is removed. A few side push designs employ rods that have no spring return and must be pushed in the opposite direction to reset the contacts.

Figure 3.6:
Actuation of Top Push Limit Switch



This type of actuator is either a plain rod, a rod with a roller end, or a rod depressed by a lever.

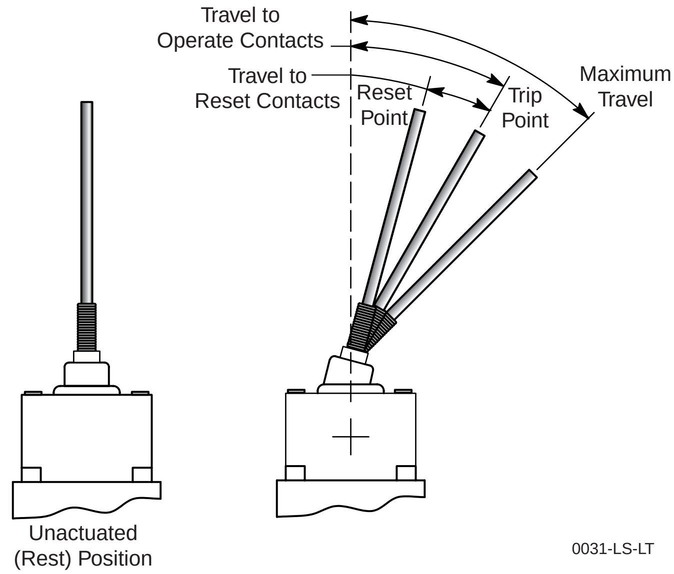
Figure 3.7:
Side and Top Push Actuator Examples



Wobble Stick/Cat Whisker Actuation

A wobble stick or cat whisker actuator is a long narrow rod on the top of a limit switch head which operates the switch contacts when deflected from the vertical position. Wobble sticks are typically nylon rods, while cat whiskers are made of flexible wire. They are capable of operating in any direction (movement similar to a joystick) and return to their original position when the actuating force is removed.

Figure 3.8:
Actuation of Wobble Stick Limit Switch



Contact Operation and Characteristics

Maintained vs. Momentary

The contacts of a limit switch change state when a predetermined force or torque is applied to the actuator. A spring return (momentary) switch returns its contacts to their original position when the operating force is removed. The contacts of a maintained switch remain in the actuated position until force or torque is applied in the opposite direction.

Two Circuit vs. Four Circuit

A typical limit switch contains either two or four contact pairs. Since each contact pair is used to open and close a control circuit, the switches are described as “two circuit” or “four circuit” devices.

Normally Open vs. Normally Closed

“Normally open” and “normally closed” describe the state of each contact pair when the switch is in the unactuated or rest position. Normally open contacts are open and normally closed contacts are closed when there is no force or torque on the actuator. In Figure 3.9 on the following page, contacts 1-2 are normally open and contacts 3-4 are normally closed.

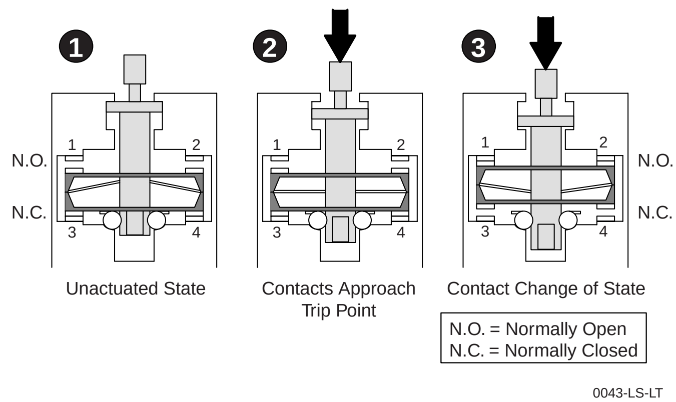
Snap Action Contacts

In this contact structure, movement of the actuator applies force to an overcenter mechanism, which creates a fast change in contact state when the trip point is reached. Reversing the motion of the actuator to a given reset point causes the contacts to snap back to their original position.

Snap action contacts have different trip and reset points. The distance between the trip and reset point is identified as the travel to reset, hysteresis, or differential. Finite travel to reset helps to avoid multiple changes of state if the object actuating the switch is subject to vibration.

Snap action contacts ensure repeatable performance in applications involving low speed actuators. The amount of travel of the contacts is also not dependent on the amount of travel by the actuator.

Figure 3.9:
Snap Action Contact Movement

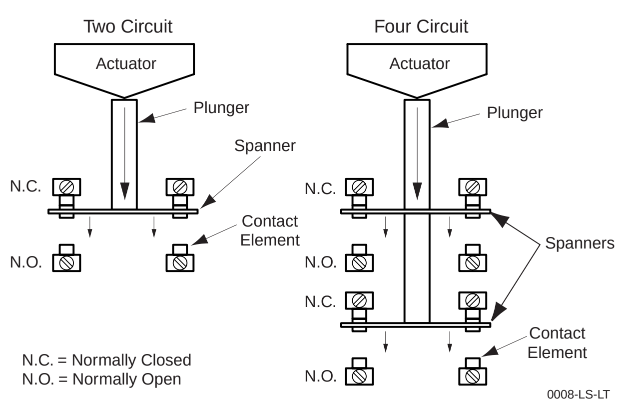


Slow Make and Break Contacts

In this contact structure, the speed and travel distance of the contacts is dependent on the speed and travel distance of the actuator and each contact pair has its own trip point. This is desirable when the user does not want all of the contacts to change state simultaneously.

Slow make and break contacts have no appreciable travel to reset. This means the trip point and reset point for a given contact pair are coincident.

Figure 3.10:
Slow Make and Break Contact Movement



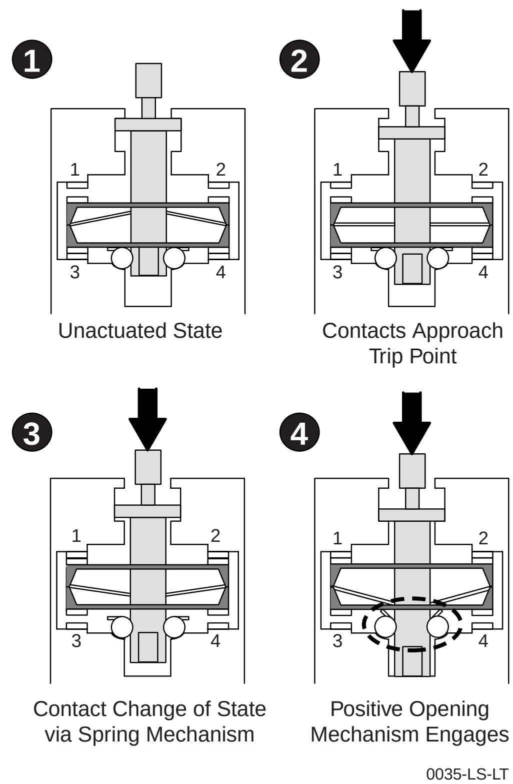
Direct Opening Action Contacts

Direct opening action contacts are known by many names, including "direct action," "positive opening," and "positive break." The IEC standard 60947-5-1 defines this feature as "the achievement of contact separation as the direct result of a specified movement of the switch actuator through nonresilient members (not dependent upon springs)."

Switches with direct opening action directly couple actuator force to the contacts so the force breaks open even a welded contact. Although the mechanisms may contain springs, they do not rely on the spring interface alone because a spring may fail or have insufficient strength to break a weld.

Direct opening action can be designed into both snap action and slow make and break limit switches.

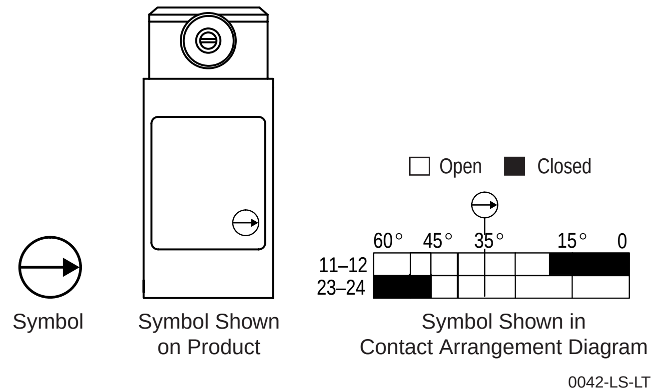
Figure 3.11:
Direct Opening Contact Movement on Snap Action Limit Switch



In many designs, the point at which the positive opening mechanism engages is beyond the normal trip point of the switch. This means that one must be careful to set up the limit switch application so that the actuator is always moved beyond the positive opening point. When this is not done, the switch may not open the normally closed contacts if a weld occurs.

Direct opening action designs are required for disconnect switches, emergency stop switches, safety limit switches, cable pull safety switches and safety gate interlock switches in many applications as specified in national and international standards. These products are marked with the direct opening action symbol as shown in Figure 3.12.

Figure 3.12: Direct Opening Action Symbol Appears on the Switch and in the Manufacturer's Literature



Contact Operating Characteristics

The specifications of force and actuator movement required to operate and reset the contacts are called "typical operating characteristics." For most limit switches, the typical operating characteristics are laid out in tabular form in the manufacturer's literature. These tables specify the torque or force and the actuator travel required to operate the contacts, the travel required to reset the contacts and the maximum allowable travel of the actuator.

NOTE Pretravel occurs before contact movement.

The travel to operate the contacts is sometimes called "pre-travel." The travel to reset the contacts is also known as "differential travel." The maximum travel of the actuator is also called "total travel." Instead of total travel, some manufacturers specify "overtravel," which is the distance or angle between the trip point and the maximum travel position. In this case, the total (maximum) travel is the sum of the travel to operate (pre-travel) and the overtravel.

For some IEC-style limit switches, the typical operating characteristics are presented in graphical form instead of tabular. These charts are known as "contact arrangement diagrams." Examples of such diagrams for snap action and slow make and break limit switches are shown below.

Figure 3.13: Contact Arrangement Diagram for Snap Action Switch

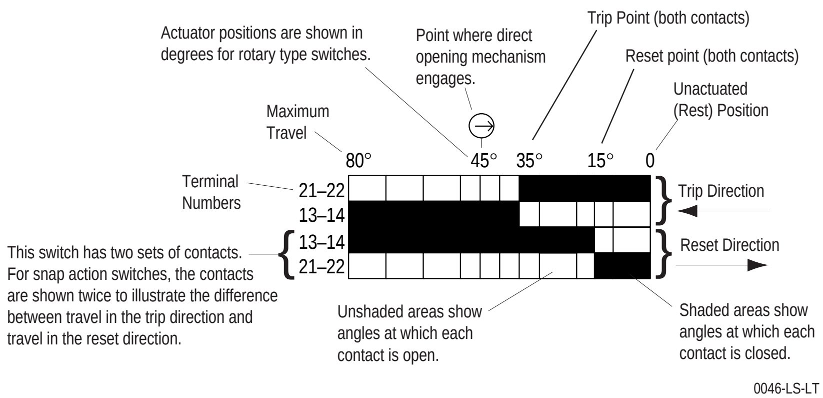
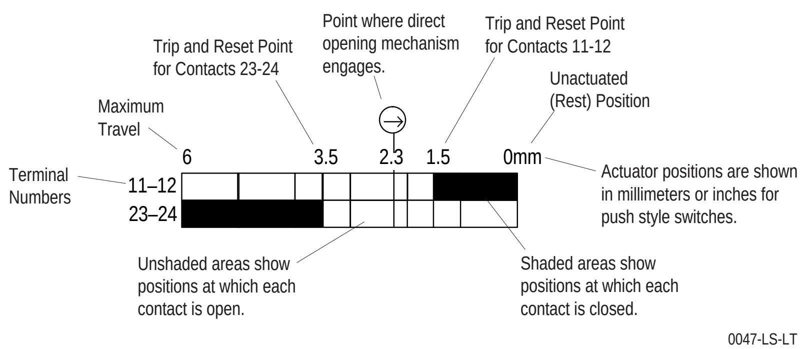


Figure 3.14: Contact Arrangement Diagram for Slow Make and Break Switch



Limit Switch Advantages and Disadvantages

Advantages

The mechanical advantages of limit switches are:

- Ease of use
- Simple visible operation
- Durable housing
- Well sealed for reliable operation
- High resistance to different ambient conditions found in industry
- High repeatability
- Positive opening operation of contacts (some models)

The electrical advantages of limit switches are:

- Suitable for switching higher power loads than other sensor technologies (5A at 24V DC or 10A at 120V AC typical vs. less than 1A for proximities or photoelectrics)
- Immunity to electrical noise interference
- Immunity to radio frequency interference (walkie-talkies)
- No leakage current
- Minimal voltage drops
- Simple Normally Open and/or Normally Closed operation

Disadvantages

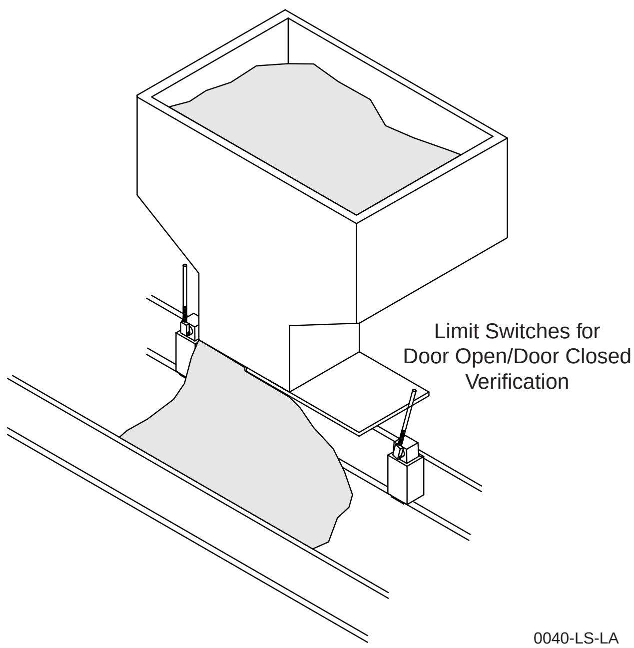
The disadvantages of limit switches are:

- Shorter contact life than solid-state technology
- Moving mechanical parts wear out eventually
- Not all applications can use contact sensing

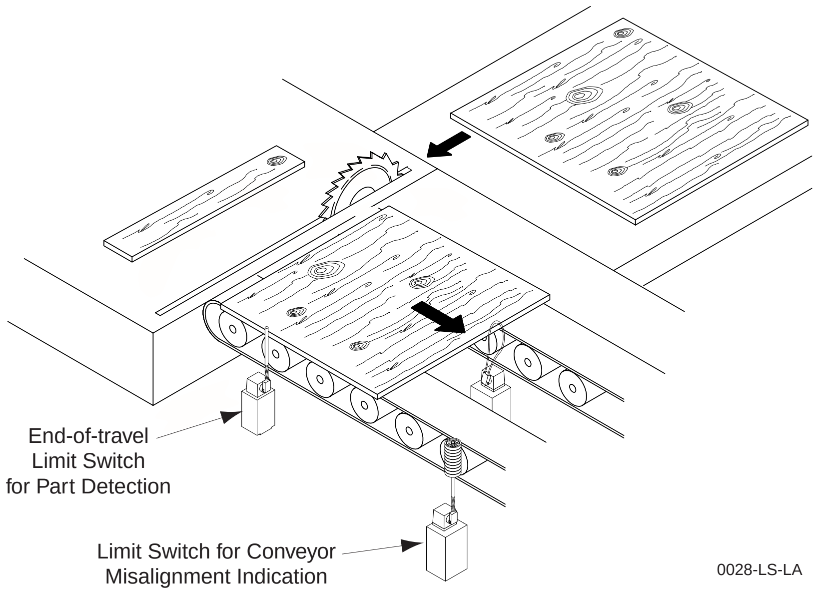
Typical Applications

- Conveyor systems
- Transfer machines
- Automatic turret lathes
- Milling and boring machines
- Radial drills
- High speed production equipment

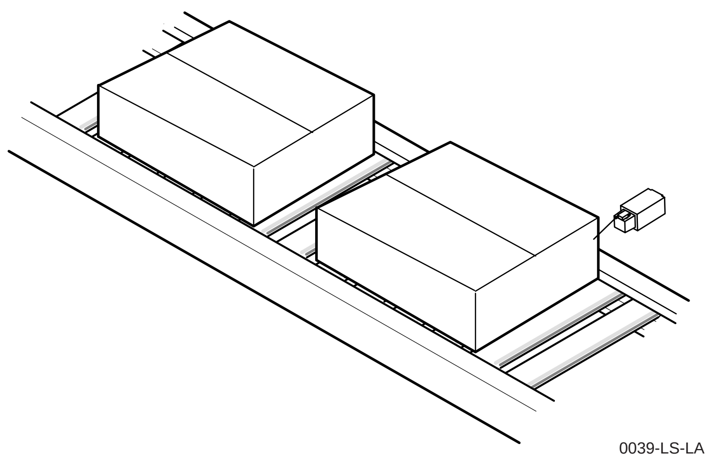
Example 3.1:
Position Verification



Example 3.2:
Woodworking



Example 3.3:
Counting and Parts Detection



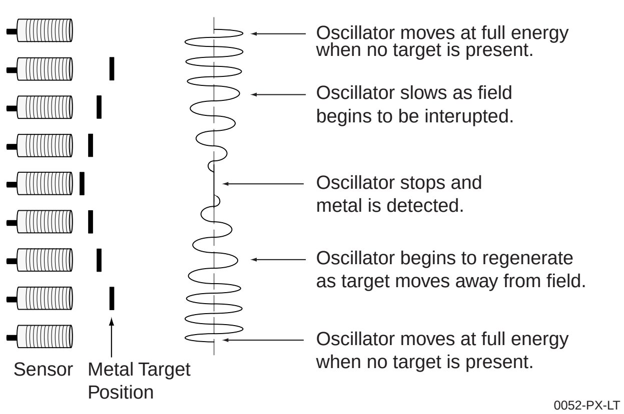
4

Inductive Proximity Sensing

Inductive proximity sensors are solid-state devices designed to detect metal objects. The non-contact nature of the technology coupled with the absence of moving parts means that with proper installation, inductive proximity sensors are not subject to mechanical damage or wear. Additionally, they perform well in very dirty environments, where they are unaffected by buildup of contaminants such as dust, grease, oil, or soot, on the sensing face. This makes inductive technology an ideal candidate for use in heavy-duty industrial applications.

An inductive proximity sensor operates on the basis of the Eddy Current Killed Oscillator (ECKO) principle. Inductive proximity sensors are designed to generate an electromagnetic field. When a metal object enters this field, surface currents, known as eddy currents, are induced in the metal object. These eddy currents drain energy from the electromagnetic field resulting in a loss of energy in the oscillator circuit and, consequently, a reduction in the amplitude of oscillation. The trigger circuit detects this change and generates a signal to switch the output ON or OFF. When the object leaves the electromagnetic field area, the oscillator regenerates and the sensor returns to its normal state.

Figure 4.1:
Typical Inductive Proximity Operation



Inductive proximity sensors detect both ferrous (containing iron) and nonferrous metals. Typically, inductive proximity sensors are used for position sensing of metal targets in automated machining, metal parts detection in automated assembly, and metal container presence sensing in automated food or beverage packaging.

Inductive Proximity Sensor Construction

An inductive proximity sensor consists of four basic components:

- Coil and ferrite core assembly
- Oscillator
- Trigger circuit
- Output circuit

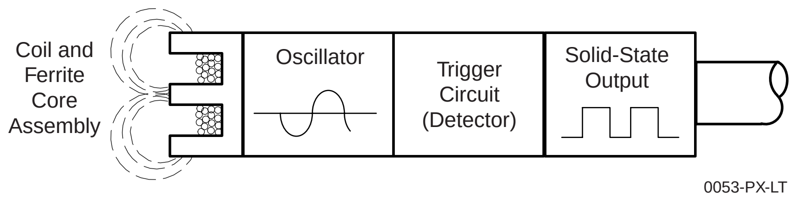


Figure 4.2:
Inductive Sensor Components

Basic Components

Coil/Core Assembly

The coil and ferrite core assembly generates an electromagnetic field from the electrical energy that the oscillator supplies.

Oscillator

The oscillator supplies electrical energy to the coil and ferrite core assembly.

Trigger Circuit

The trigger circuit detects changes in the amplitude of oscillation. The changes occur when a metal target enters or leaves the electromagnetic field radiating from the sensor face.

Solid-State Output

When a sufficient change in the electromagnetic field is detected, the solid-state output provides an electrical signal for an interface to a PLC or machine logic. This signal indicates the presence or absence of a metal target in the sensing field.

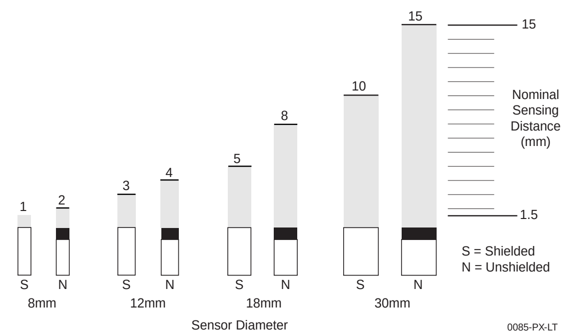
Shielded vs. Unshielded Construction

Every inductive proximity sensor can be classified as having either a shielded or unshielded construction.

Typical Shielded vs. Unshielded Sensing Distance

The operating distance of an inductive proximity sensor is a function of the diameter of the sensing coil and whether it is shielded. New inductive proximity configurations allow for extended sensing ranges.

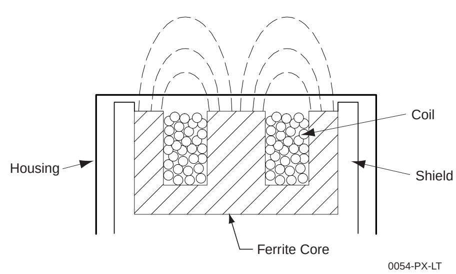
Figure 4.3:
Typical Nominal Sensing Distance, Shielded vs Unshielded



Shielded Construction

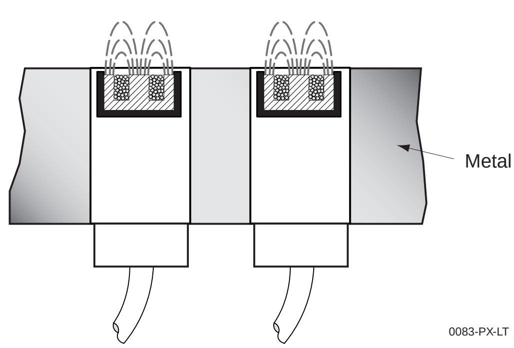
Shielded sensors are constructed with a shielding ring surrounding the core and coil assembly. This concentrates the electromagnetic field toward the front of the sensor face. In sensors with metal housings, the housing often provides this shielding.

Figure 4.4:
Shielded Sensor Coil and Core Assembly



Shielded construction allows the sensor to be mounted flush in surrounding metal without causing a false trigger.

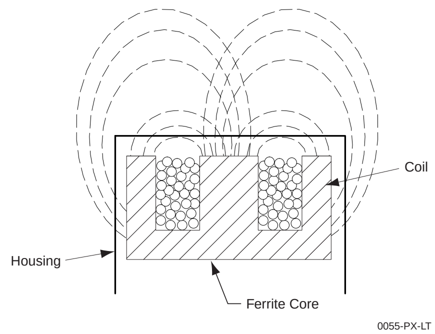
Figure 4.5:
Shielded Sensors Flush Mounted and Close Together



Unshielded Construction

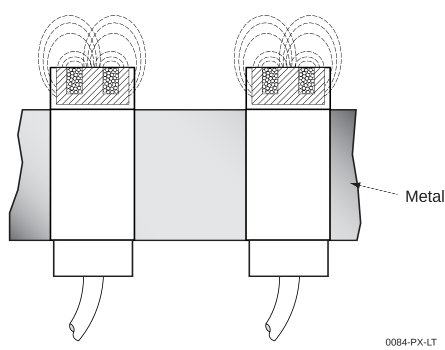
Unshielded sensors are not constructed with a metal band surrounding the core/coil assembly. The electromagnetic field generated by an unshielded sensor, therefore, is not concentrated as much toward the face of the sensor as in a shielded sensor. This makes unshielded sensors more sensitive to metals surrounding them. Unshielded construction allows as much as 50% more sensing range than a shielded sensor of the same size. Because of the larger sensing range, difficult targets may be easier to detect using unshielded sensors.

Figure 4.6: Unshielded Construction Coil and Core Assembly



Unshielded sensors cannot be mounted flush in metal. To avoid a false trigger, unshielded sensors must be mounted with a metal-free zone around the sensing face.

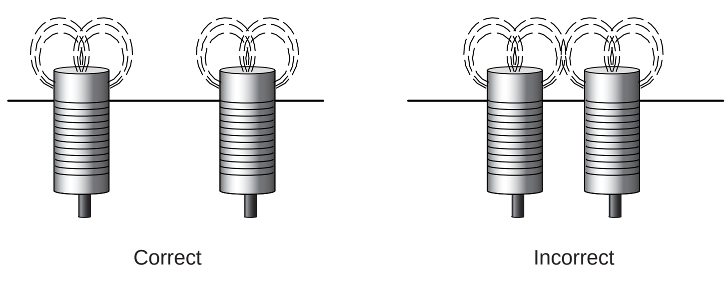
Figure 4.7: Unshielded Construction Mounted with a Metal-Free Zone



Spacing Considerations

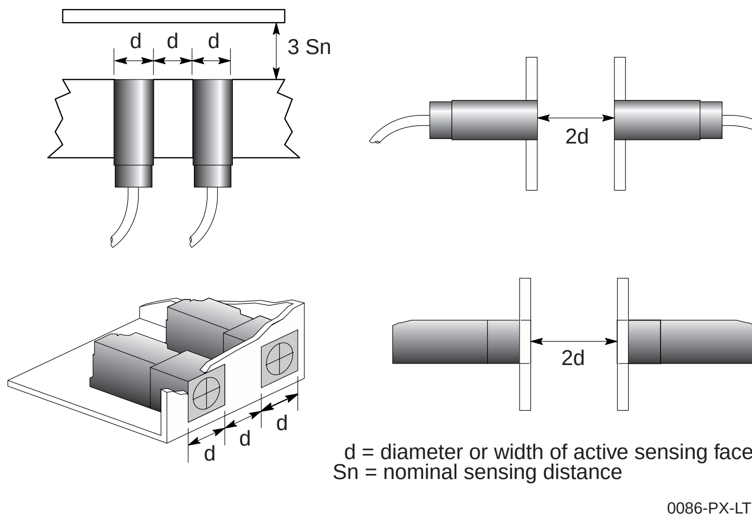
The diameter of the sensing coil determines spacing between sensors. Unshielded sensors must be placed further apart than shielded sensors because their sensing fields plume out laterally from the sensor face and will give false readings if overlapped.

Figure 4.8: Spacing of Unshielded Sensors



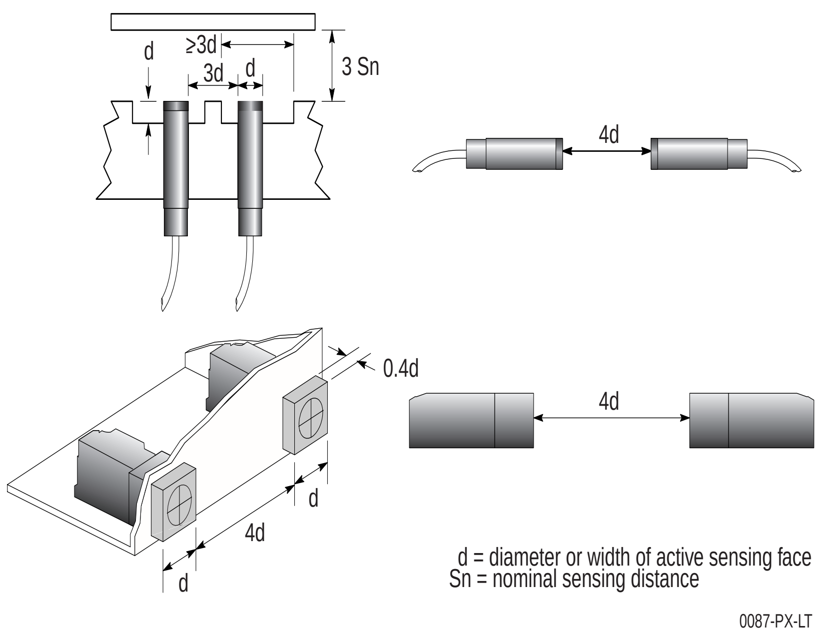
Spacing requirements for specific sensors vary. Shielded sensors, however, generally require a distance of one diameter of the sensing face between adjacent sensors and two diameters of sensing face between sensors mounted face-to-face.

Figure 4.9:
Adjacent and Face-to-Face Shielded Sensor Spacing Guidelines



Unshielded sensors generally require spacings of three diameters of the sensing face between adjacent sensors and four diameters of the sensing face when mounted face-to-face.

Figure 4.10:
Adjacent and Face-to-Face Unshielded Sensor Spacing Guidelines



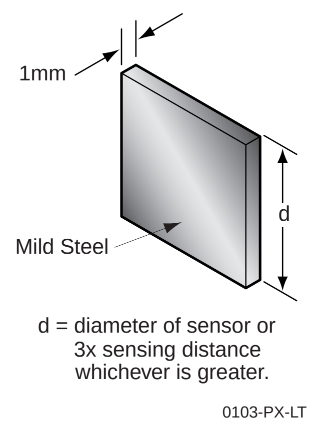
Target Considerations

The operating distance of an inductive proximity sensor varies for each target and application. The ability of a sensor to detect a target is determined by the material of the metal target, its size and its shape.

Sensing Range vs. Material and Size of Target

The sensor's Rated Operating Distance (S_n) is a conventional quantity used to designate the distance at which a standard target approaching the sensor face causes the output signal to change. A standard target is defined as a square piece of mild steel 1mm (0.04") thick, with side lengths equal to the diameter of the sensing face or three times the rated operating distance, whichever is greater.

Figure 4.11:
Standard Target for Inductive Proximity Sensors

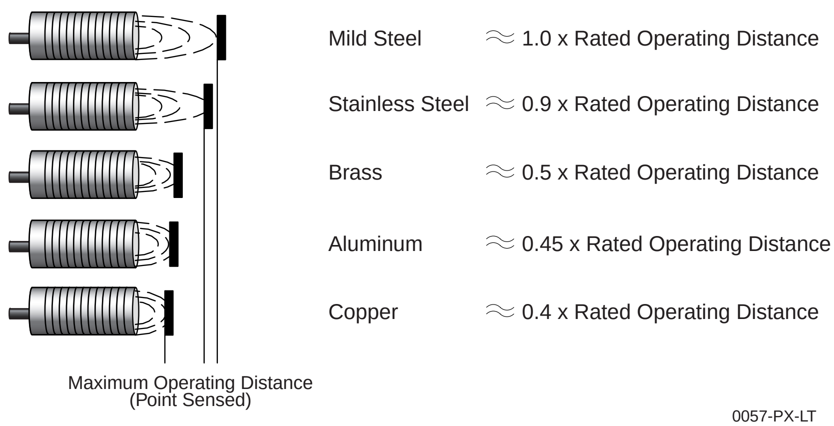


The rated operating distance for a standard mild steel target is used as a reference point. In typical applications, the operating distance is affected not only by the composition of the target, but also by its size and shape. The rated operating distance of a standard mild steel target must be multiplied by a correction factor to determine the rated operating distance for other types of metals.

Effects of the Material of the Target

Typical correction factors for different metals are shown in the following figure.

Figure 4.12:
Typical Correction Factors



Target Correction Factors for Inductive Proximity Sensors

To determine the sensing distance for materials other than the standard mild steel, a correction factor is used. The composition of the target has a large effect on sensing distance of inductive proximity sensors. If a target constructed from one of the materials listed is used, multiply the nominal sensing distance by the correction factor listed in order to determine the nominal sensing distance for that target. Note that nonferrous-selective sensors will not detect steel or ferrous-type stainless steels. Likewise, ferrous selective sensors will not detect non-iron metals.

The correction factors listed below are provided for reference only. Consult the product specification sheet for the sensor you intend to use. Common materials and their specific correction factors are listed on each product specification page.

(Nominal Sensing Range) x (Correction Factor) = Sensing Range

Table 4.1: Correction Factors

Target Material	Approximate Correction Factor
Mild Steel	1.0
Stainless Steel	0.85
Brass	0.50
Aluminum	0.45
Copper	0.40

Effects of Target Size and Shape

The size and shape of the target also need to be considered when choosing an inductive proximity sensor. The following should be used as general guidelines when correcting for target size and shape:

- Flat targets are preferable
- Rounded targets may reduce the operating distance
- Nonferrous materials usually reduce the operating distance for all-metal sensing models
- Targets smaller than the sensing face typically reduce the operating distance
- Targets larger than the operating face may increase the sensing distance
- Foils may increase the operating distance

The rated operating distance does not take into consideration manufacturing tolerances or variations due to external conditions such as voltage or temperature. Allowing for these factors, the actual operating distance of a particular sensor can vary up to ±20% from the rated operating distance.

All Metal, Ferrous and Nonferrous Selection

All metals responsive sensors or standard inductive proximity sensors detect any metal placed in front of the sensor face. A ferrous (any metal containing iron) selective sensor ignores brass, aluminum, or copper while a nonferrous (any metal that does not contain iron) sensor ignores steel or ferrous-type stainless steels.

Ferrous and nonferrous selective sensors can be very powerful in applications where the sensor is required to sense one metal while ignoring another. For example, when machining a piece of aluminum, a ferrous selective sensor can be used to sense the hardened steel cutting tool while ignoring the aluminum block and the aluminum chips created during the machining process.

Nonferrous selective sensors also allow up to 400% more sensing range to nonferrous materials than all metals (standard) models. There are no correction factors; all nonferrous metals are sensed at the full rated operating distance.

Object Motion

The objects being sensed may approach a proximity switch either across the active sensing face (reference axis) or approach/recede from the sensing face.

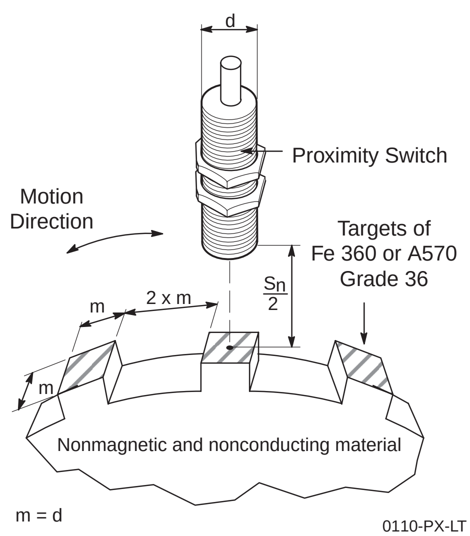
Lateral Approach

In most applications, the reliability of the sensor is increased when the object crosses in front of the active face. This is due to a more controlled sensing face to object distance. When using this sensing mode, a critical consideration should be switching frequency or response speed. Switching frequency is assumed to be the time to change the output state from normal to changed to normal states.

Switching Frequency

The switching frequency is the maximum speed at which a sensor will deliver discrete individual pulses as the target enters and leaves the sensing field. This value is always dependent on target size, distance from sensing face, and speed of target. The switching frequency indicates the maximum possible number of switching operations per second. The measuring method for determining rated switching frequency with standard targets is specified by DIN IEC 60947-5-2. Any changes in target size or material will influence actual switching frequency response.

Figure 4.13:
Switching Frequency



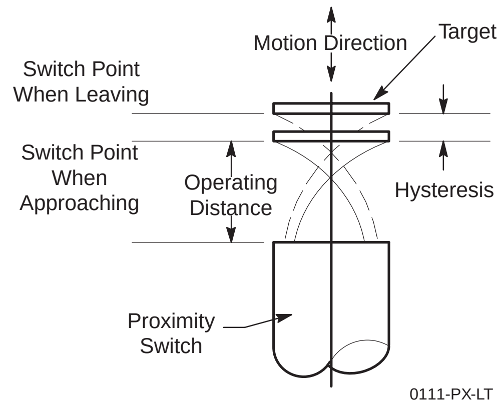
Direct (Radial) Target Approach

When the target approaches a proximity sensor directly towards the face, reliability can be improved by considering the effects of hysteresis. Note that switching frequency should also be considered in direct object approach.

Hysteresis (Differential Travel)

The difference between the operate and the release points is called hysteresis or differential travel. The amount of target travel required for release after operation must be accounted for when selecting target and sensor locations. Hysteresis is needed to help prevent chattering (turning on and off rapidly) when the sensor and/or target is subjected to shock and vibration. Vibration amplitudes must be smaller than the hysteresis band to avoid chatter.

Figure 4.14:
Hysteresis



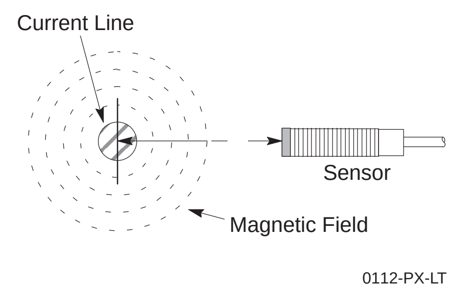
Weld Field Immune

In certain applications such as welding, soldering, inductive heating, and others, high electromagnetic fields are present. The circuitry of proximities can be altered to increase their resistance to the effects of these electromagnetic fields. Below are mounting considerations that must be considered in these applications.

Mounting Considerations for Weld Field Immune Proximities

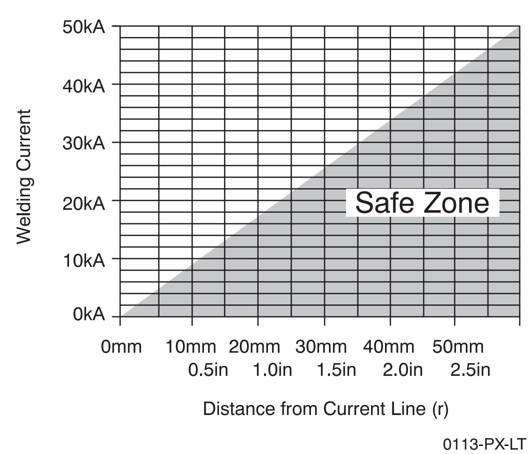
Reliable operation is dependent on the strength of the magnetic field and the distance between the current line and the sensor.

Figure 4.15:
Perpendicular Mounting to the Electromagnetic Field Axis



Given the amperage that is generating the weld field on the chart below, the minimum distance the sensor must be separated from the weld field current is plotted on the horizontal axis (r). A distance within the safe zone will enhance the reliability of the sensor.

Figure 4.16:
Weld Field Immunity



Inductive Proximity Advantages and Disadvantages

Advantages

The advantages of inductive proximity sensors include:

1. Not affected by moisture
2. Not affected by dusty/dirty environments
3. No moving parts/no mechanical wear
4. Not color dependent
5. Less surface dependent than other sensing technologies
6. No blind zone

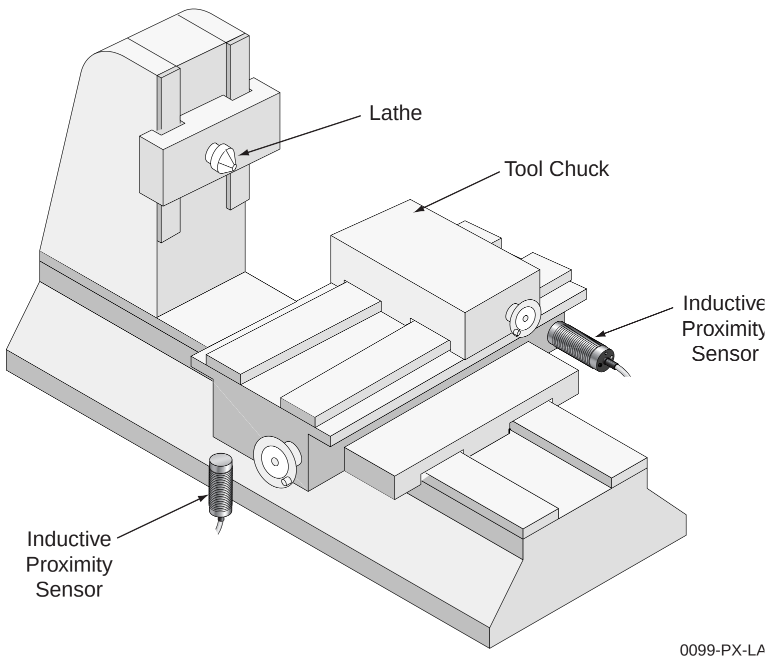
Disadvantages

The cautions of inductive proximity sensors include:

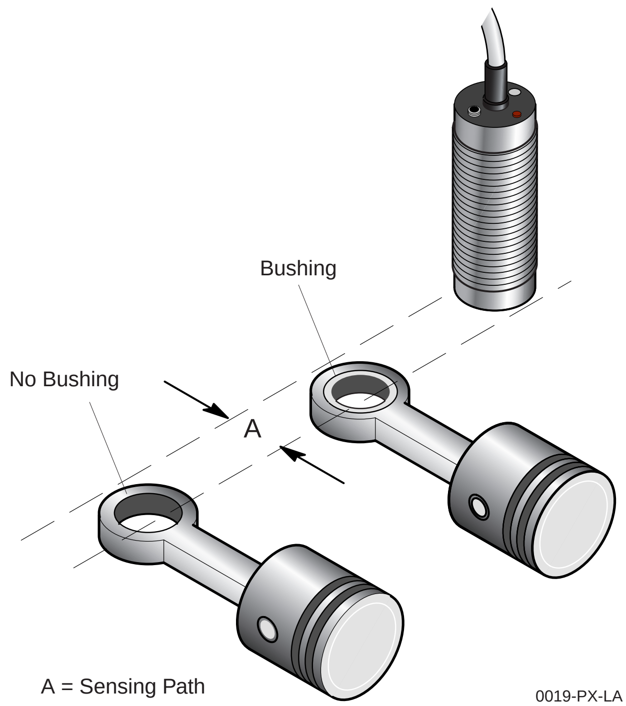
1. Only sense the presence of metal targets
2. Operating range is shorter than other available sensing technologies
3. May be affected by strong electromagnetic fields

Typical Applications

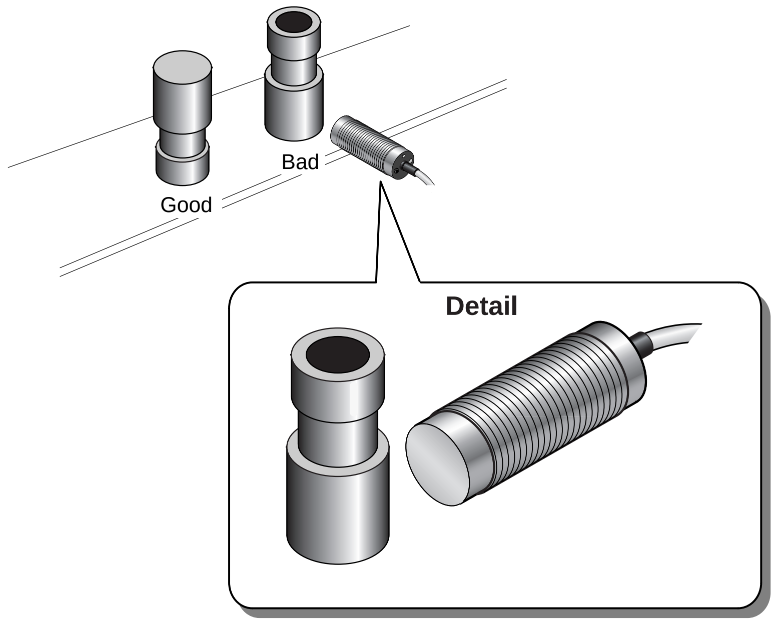
Example 4.1:
Machine Tools



Example 4.2:
Detect Presence of Bushing in Piston



Example 4.3:
On-Line Parts Sorting



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5

Capacitive Proximity Sensing

Capacitive sensing is a noncontact technology suitable for detecting metals, nonmetals, solids, and liquids, although it is best suited for nonmetallic targets because of its characteristics and cost relative to inductive proximity sensors. In most applications with metallic targets, inductive sensing is preferred because it is both a reliable and a more affordable technology.

Capacitive proximity sensors are similar in size, shape, and concept to inductive proximity sensors. However, unlike inductive sensors which use induced magnetic fields to sense objects, capacitive proximity sensors react to alterations in an electrostatic field. The probe behind the sensor face is a capacitor plate. When power is applied to the sensor, an electrostatic field is generated that reacts to changes in capacitance caused by the presence of a target. When the target is outside the electrostatic field, the oscillator is inactive. As the target approaches, a capacitive coupling develops between the target and the capacitive probe. When the capacitance reaches a specified threshold, the oscillator is activated, triggering the output circuit to switch states between ON and OFF.

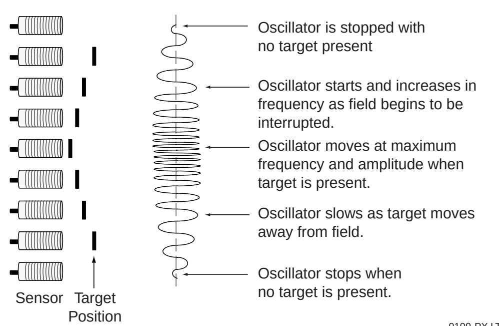


Figure 5.1: Capacitive Proximity Operation

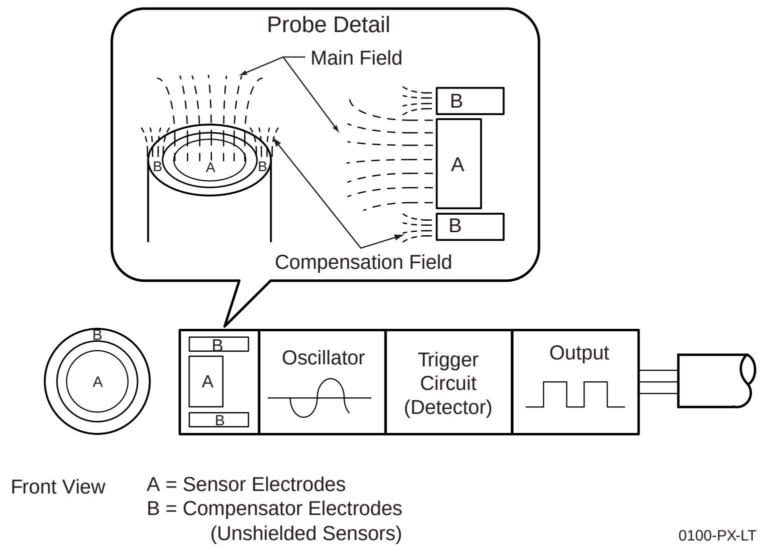
The ability of the sensor to detect the target is determined by the target's size, dielectric constant and distance from the sensor. The dielectric constant is a material property. All materials have a dielectric constant. Materials with higher dielectric constants are easier to detect than those with lower values. Refer to "Dielectric Constants" on page 5-5 for more information. The larger the target's size or dielectric constant, the stronger the capacitive coupling between the probe and the target. The shorter the distance between target and probe, the stronger the capacitive coupling between the probe and the target.

Capacitive Proximity Sensor Construction

The sensor consists of four basic components:

- Capacitive probe or plate
- Oscillator
- Signal level detector
- Solid-state output switching device
- Adjustment potentiometer

Figure 5.2:
Capacitive Sensor Components



Basic Components

Capacitive Probe or Plate

The capacitive probe radiates an electrostatic field which generates capacitive coupling between the probe and a target material entering the field.

Oscillator

The oscillator supplies electrical energy to the capacitive probe/plate.

Trigger Circuit

The trigger circuit detects changes in the amplitude of oscillation. The changes occur when a target enters or leaves the electrostatic field radiating from the sensor.

Solid-State Output Switching Device

Once a sufficient change in the electrostatic field is detected, the solid-state output generates an electrical signal to be interpreted by an interface device such as a programmable logic controller (PLC). This signal indicates the presence of a target in the sensing field.

Adjustment Potentiometer

Turning the potentiometer clockwise increases sensitivity; turning it counterclockwise decreases sensitivity.

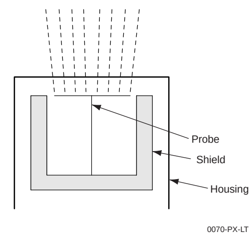
Shielded vs. Unshielded Construction

Each capacitive sensor can be classified as having either a shielded or unshielded construction.

Shielded Probe

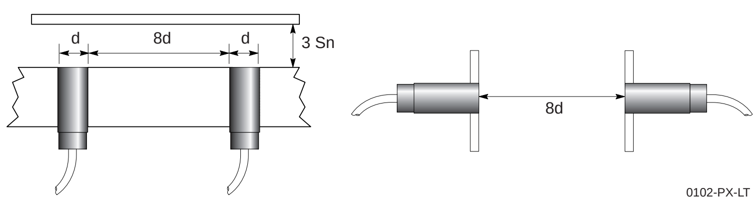
Shielded sensors are constructed with a metal band surrounding the probe. This helps to direct the electrostatic field to the front of the sensor and results in a more concentrated field.

Figure 5.3:
Shielded Probe



Shielded construction allows the sensor to be mounted flush in surrounding material without causing false trigger.

Figure 5.4:
Shielded Sensors
Flush Mounted

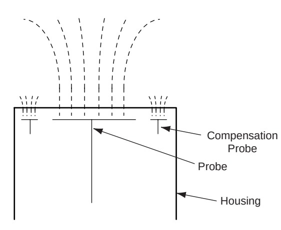


Shielded capacitive proximity sensors are best suited for sensing materials with low dielectric constants (difficult to sense) as a result of their highly concentrated electrostatic fields. This allows them to detect targets that unshielded sensors cannot.

Unshielded Probe

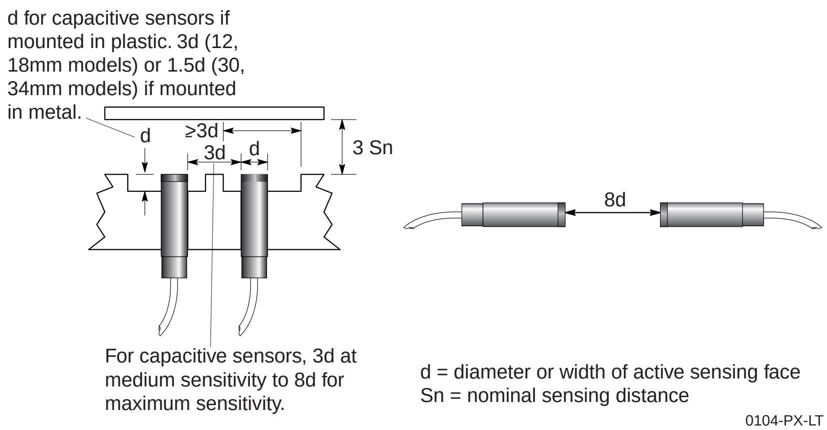
Unshielded sensors do not have a metal band surrounding the probe and hence have a less concentrated electrostatic field. Many unshielded models are equipped with compensation probes which provide increased stability for the sensor. Compensation probes are discussed later in this section.

Figure 5.5:
Unshielded Probe



Unshielded capacitive sensors are also more suitable than shielded types for use with plastic sensor wells, an accessory designed for liquid level applications. The well is mounted through a hole in a tank and the sensor is slipped into the well's receptacle. The sensor detects the liquid in the tank through the wall of the sensor well.

Figure 5.6:
Unshielded Construction Mounted Above Metal



The electrostatic field of an unshielded sensor is less concentrated than that of a shielded model. This makes unshielded capacitives well suited for detecting high dielectric constant (easy to sense) materials or for differentiating between materials with high and low constants. For certain target materials, unshielded capacitive proximity sensors have longer sensing distances than shielded versions.

Unshielded models equipped with a compensation probe are able to ignore mist, dust, small amounts of dirt and fine droplets of oil or water accumulating on the sensor. The compensation probe also improves the sensor's resistance to variations in ambient humidity.

Target Considerations

As with inductive proximity sensors, the standard target for capacitive sensors is a square piece of mild steel 1mm (0.04") thick with side lengths equal to the diameter of the active face or three times the nominal switching distance, whichever is greater. The standard target is grounded per IEC test standards; however, a target in a typical application does not need to be grounded to achieve reliable sensing.

Dielectric Constants

Materials with higher dielectric constant values are easier to sense than those with lower values. For example, water and air are dielectric extremes. A capacitive proximity sensor would be very sensitive to water, with a dielectric constant of 80, which makes it ideal for applications such as liquid level sensing. The same sensor, however, would not be sensitive to air, with a dielectric constant of 1. Other target items would fall within the sensitivity range, such as wet wood, with a dielectric constant between 10 and 30, and dry wood, between 2 and 6.

A partial listing of dielectric constants for some typical industrial materials follows. For more information, refer to the *CRC Handbook of Chemistry and Physics (CRC Press), the CRC Handbook of Tables for Applied Engineering Science (CRC Press),* or other applicable sources.

Table 5.1: Dielectric Constants of Common Industrial Materials

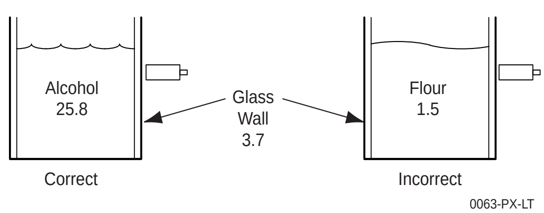
Material	Constant	Material	Constant
Acetone	19.5	Perspex	3.2-3.5
Acrylic Resin	2.7-4.5	Petroleum	2.0-2.2
Air	1.000264	Phenol Resin	4-12
Alcohol	25.8	Polyacetal	3.6-3.7
Ammonia	15-25	Polyamide	5.0
Aniline	6.9	Polyester Resin	2.8-8.1
Aqueous Solutions	50-80	Polyethylene	2.3
Bakelite	3.6	Polypropylene	2.0-2.3
Benzene	2.3	Polystyrene	3.0
Carbon Dioxide	1.000985	Polyvinyl Chloride Resin	2.8-3.1
Carbon Tetrachloride	2.2	Porcelain	4.4-7
Celluloid	3.0	Powdered Milk	3.5-4
Cement Powder	4.0	Press Board	2-5

Table 5.1: Dielectric Constants of Common Industrial Materials

Material	Constant	Material	Constant
Cereal	3-5	Quartz Glass	3.7
Chlorine Liquid	2.0	Rubber	2.5-35
Ebonite	2.7-2.9	Salt	6.0
Epoxy Resin	2.5-6	Sand	3-5
Ethanol	24	Shellac	2.5-4.7
Ethylene Glycol	38.7	Shell Lime	1.2
Fired Ash	1.5-1.7	Silicon Varnish	2.8-3.3
Flour	1.5-1.7	Soybean Oil	2.9-3.5
Freon R22 & 502 (liquid)	6.11	Steel	
Gasoline	2.2	Styrene Resin	2.3-3.4
Glass	3.7-10	Sugar	3.0
Glycerine	47	Sulphur	3.4
Marble	8.0-8.5	Teflon	2.0
Melamine Resin	4.7-10.2	Toluene	2.3
Metal		Transformer Oil	2.2
Mica	5.7-6.7	Turpentine Oil	2.2
Nitrobenzine	36	Urea Resin	5-8
Nylon	4-5	Vaseline	2.2-2.9
Oil Saturated Paper	4.0	Water	80
Paraffin	1.9-2.5	Wood, Dry	2-7
Paper	1.6-2.6	Wood, Wet	10-30

Materials with high dielectric constants may be sensed through the walls of containers made with materials with lower dielectric constants. An example is the detection of alcohol or flour through a glass wall. The alcohol would be detected through the glass while the flour would not.

Fig. 5.6: Capacitive Sensing Through a Tank



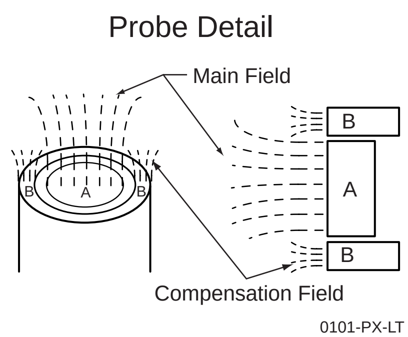
Each application should be tested. The list of dielectric constants is provided to help you determine the feasibility of an application. The values shown will vary depending on the size and density of the target material.

Environmental Considerations

Any material entering a capacitive sensor's electrostatic field can cause an output signal. This includes mist, dirt, dust, or other contaminants on the sensor face.

The use of the compensation electrodes in the probe helps to stabilize an unshielded sensor. The compensation field does not extend far from the sensor. When the target enters the sensing field the compensation field is unchanged. When contaminants lie directly on the sensor face, both fields (sensor and compensation) are affected. The sensor does not see this change in capacitance and therefore does not produce an output because the capacitance of the sensor increased at the same ratio as the compensation capacitance.

Figure 5.7: Compensation Probe Operation



Capacitive Proximity Advantages and Disadvantages

Advantages

The advantages of capacitive proximity sensors include:

1. Detects metal and nonmetal, liquids and solids
2. Can “see through” certain materials (product boxes)
3. Solid-state, long life
4. Many mounting configurations

Disadvantages

The disadvantages of capacitive proximity sensors include:

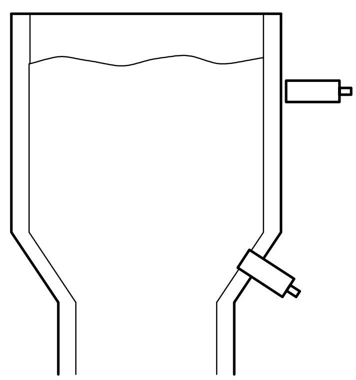
1. Short (1 inch or less) sensing distance varies widely according to material being sensed
2. Very sensitive to environmental factors—humidity in coastal/water climates can affect sensing output
3. Not at all selective for its target—control of what comes close to the sensor is essential

Typical Applications

1. Liquid level sensing
   - Sensing through a sight glass to watch liquid level, such as batter for food processing or ink for printing applications
   - Insertion through sealed tubes into drums or holding tanks for chemicals or aqueous solutions
2. Product filling lines
   - Bottling applications, such as shampoo
   - Full-case detection to ensure that a container has the required number of products
   - Checking material levels, such as cereal in boxes
3. Plastic parts detection
   - Plastics on product packages, such as spouts on laundry detergent boxes
   - Plastic materials within a hopper
4. Pallet detection for materials handling
5. Irregularly shaped products
   - Objects randomly oriented on conveyor belt
   - Highly textured objects

Example 5.1:

Level Sensing in a Hopper Can Be Either Through a Window or Embedded in Material



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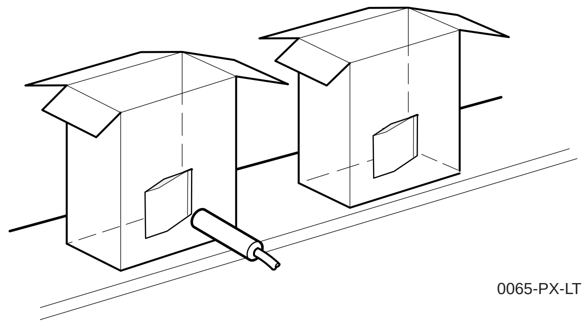
Example 5.2:
Product Sensing Through Packaging



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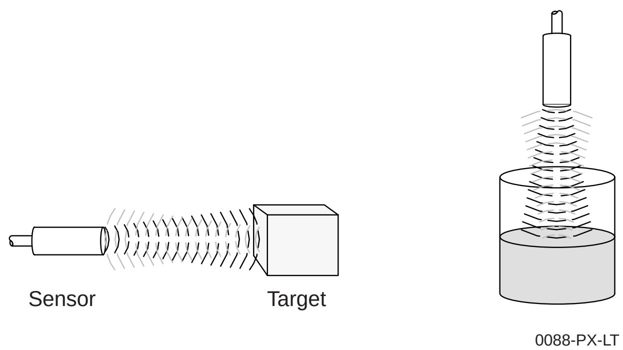
6

Ultrasonic Proximity Sensing

Ultrasonic sensors emit a sound pulse that reflects off of objects entering the wave field. The reflected sound, or "echo" is then received by the sensor. Detection of the sound generates an output signal for use by an actuator, controller, or computer. The output signal can be analog or digital.

Figure 6.1:
Soundwaves Echoing Off of Solid and Liquid Targets



Ultrasonic sensing technology is based on the principle that sound has a relatively constant velocity. The time for an ultrasonic sensor's beam to strike the target and return is directly proportional to the distance to the object. Consequently, ultrasonic sensors are used frequently for distance measurement applications such as level control.

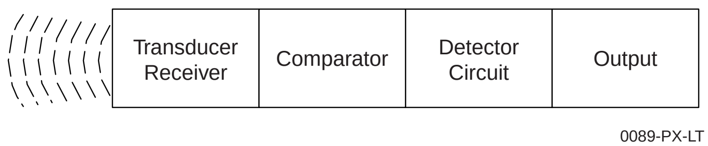
Ultrasonic sensors are capable of detecting most objects—metal or nonmetal, clear or opaque, liquid, solid, or granular—that have sufficient acoustic reflectivity. Another advantage of ultrasonic sensors is that they are less affected by condensing moisture than photoelectric sensors. A downside to ultrasonic sensors is that sound absorbing materials, such as cloth, soft rubber, flour and foam, make poor target objects.

Ultrasonic Sensor Construction

There are four basic components of an ultrasonic proximity sensor:

- Transducer/receiver
- Comparator
- Detector circuit
- Solid-state output

Figure 6.2:
Ultrasonic Proximity Sensor Components



Basic Components

Transducer/Receiver

The ultrasonic transducer pulses, sending soundwaves outward from the face of the sensor. The transducer also receives echoes of those waves as reflected off an object.

Comparator and Detector Circuit

When the sensor receives the reflected echo, the comparator calculates the distance by comparing the emit-to-receive timeframes to the speed of sound.

Solid State Output Switching Device

The solid state output generates an electrical signal to be interpreted by an interface device like a programmable logic controller (PLC). The signal from digital sensors indicates the presence or absence of an object in the sensing field. The signal from analog sensors indicates the distance to an object in the sensing field.

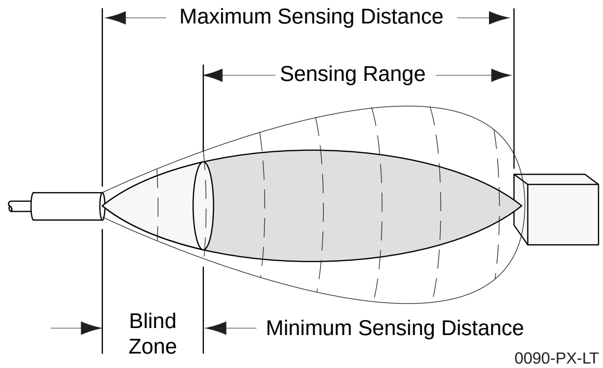
Sensing Frequency

In general, industrial sensors operate between 25kHz and 500kHz. Medical ultrasound units operate at 5MHz or more. Sensing frequency is inversely proportional to sensing distance. While a 50kHz soundwave may work to 10m (33ft) or more, a 200kHz soundwave is limited to sensing ranges of about 1m (3ft)..

Sensing Range and Effective Beam

The sensing range of an ultrasonic sensor is the area between the minimum and the maximum sensing limits.

Figure 6.3:
Ultrasonic Sensing Distance



Minimum Sensing Distance

Ultrasonic proximity sensors have a small unusable area near the face of the sensor. If the ultrasonic beam leaves the sensor, strikes the target, and returns before the sensor has completed its transmission, the sensor is unable to receive the echo accurately. This unusable area is known as the blind zone.

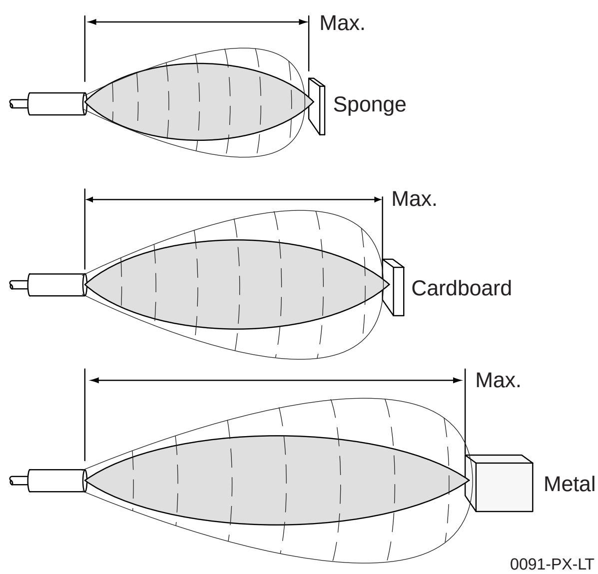
The outer edge of the blind zone is the minimum distance an object can be from the sensor without returning echoes that will be ignored or misread by the sensor.

Maximum Sensing Distance

Target size and material determine the maximum distance at which the sensor is capable of seeing the object. The harder an object is to detect, the shorter the maximum sensing distance can be.

Materials that absorb sound—foam, cotton, rubber, etc.—are more difficult to detect than acoustically reflective materials, like steel, plastic, or glass. If detected at all, these absorbent materials can limit maximum sensing distance.

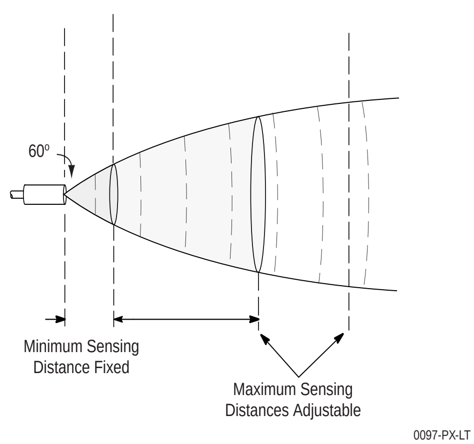
Figure 6.4:
Sensing Range with Maximum Sensitivity



Effective Beam

When the transducer vibrates, it emits ultrasonic pulses that propagate in a cone-shaped beam. This cone can be adjusted, usually via potentiometer, to widen or extend the sensing range.

Figure 6.5:
Effective Beam



Manufacturers provide guidelines for the sensitivity characteristics of their sensors. Some experimentation is required to determine the maximum sensing distance in any given application.

Background Suppression and Nontarget Objects

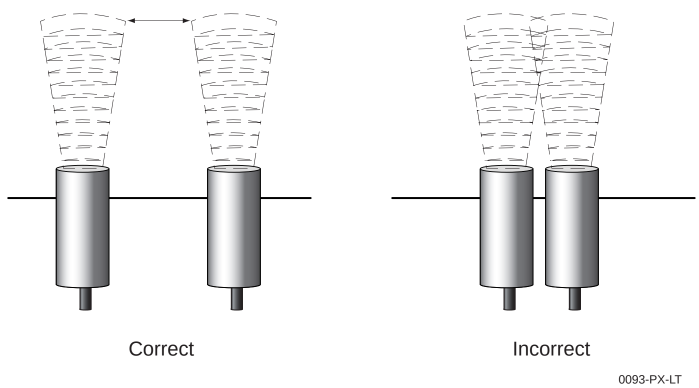
Some analog models offer a background suppression feature which allows the sensor to ignore all objects beyond a specified distance. This distance is set by the user at installation by adjusting a potentiometer.

Nontarget objects in the sensing field can be hidden from the sensor by covering them with sound-absorbent material or by positioning them so that their echoes are reflected away from the sensor.

Spacing Considerations

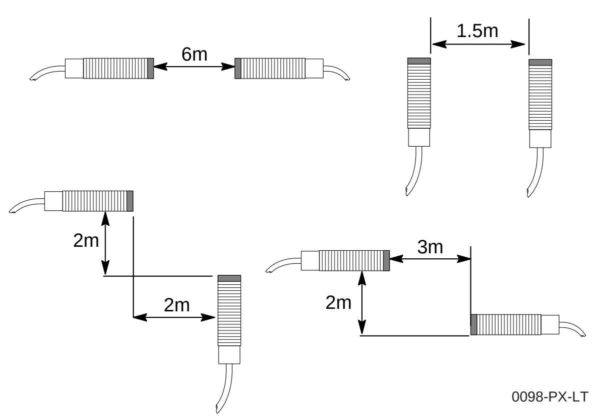
Spacing between sensors is determined by their beam angles. The sensors must be spaced so they do not interfere with each other. This interference is sometimes called “crosstalk.”

Figure 6.6:
Spacing of Ultrasonic Sensors



When more than one ultrasonic sensor is in use, the following spacings can be used as a guide:

Figure 6.7:
Spacing Guidelines



Sensor Alignment[1]

Aim the sensor at the target. Slowly turn the potentiometer until the LED illuminates, indicating target presence. Adjust the angle of the sensor to maximize the brightness of the LED.

If an analog sensor detects objects behind the desired target, turn the potentiometer to suppress the background objects, but not so far that the sensor no longer detects the target.

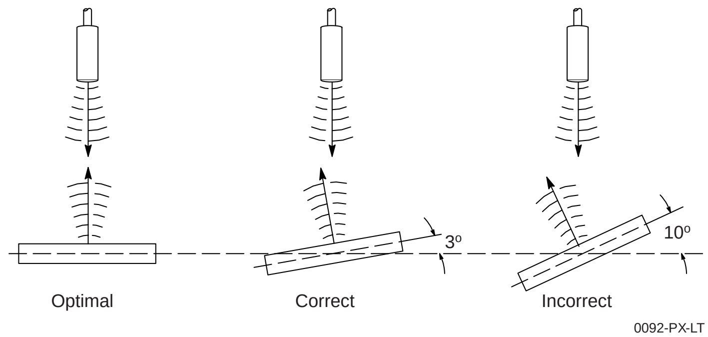
To set the sensing distance of a discrete sensor, adjust the potentiometer until the LED turns off while the target is not present. Next replace the target, and slowly turn the potentiometer until the LED turns back on.

[1] Not appropriate for transmitted beam style ultrasonic sensors.

Target Considerations

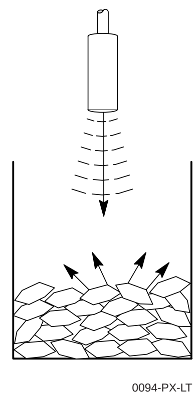
Generally, ultrasonic proximity sensors are affected less by target surface characteristics than are diffuse mode photoelectrics; however, they require the transducer face be within 3° of parallel to smooth, flat target objects.

Figure 6.8:
Smooth Flat Targets Require Precise Sensor Alignment



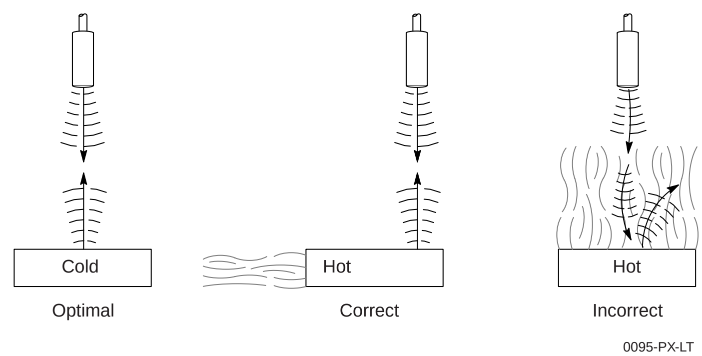
When sensing the sound-scattering surfaces of irregularly shaped targets, the approach angle becomes less critical.

Figure 6.9:
Irregular Targets Require Less Precision



The surface temperature of a target can also influence the sensing range. Radiated heat from high temperature targets distorts the sound beam, leading to shortened sensing range and inaccurate readings.

Figure 6.10:
Target Temperature Affects Sensing Capabilities



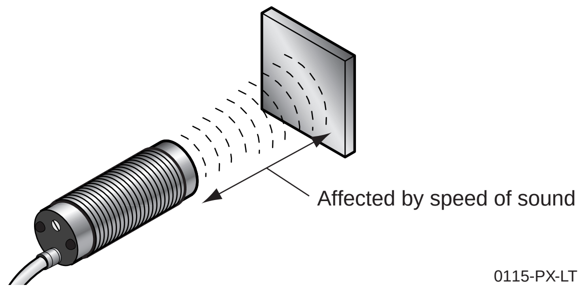
Target Size

The smaller the target the more difficult to detect.

Target-to-Sensor Distance

The further a target is away from the sensor, the longer it takes the sensor to receive the echo.

Figure 6.11:
Target to Sensor Distance



Environmental Considerations

Ambient Noise

Ultrasonic sensors have noise suppression circuitry that allows them to function reliably in noisy environments.

Air Pressure

Normal atmospheric pressure changes have little effect on measurement accuracy; however, ultrasonic sensors are not intended for use in high or low air pressure environments as pressure extremes may physically damage the transducer or the sensor face.

Air Temperature

The velocity of sound in air is temperature dependent. An increase in temperature causes a slowing of the speed of sound and, therefore, increases the sensing distance.

Air Turbulence

Air currents, turbulence and layers of different densities cause refraction of the sound wave. An echo may be weakened or diverted to the extent that it is not received at all. Sensing range, accuracy, and stability can deteriorate under these conditions.

Protective Measures

In wet applications, the sensor should not be mounted in such a way that standing water or other fluids can rest on the sensing face. In general, to maintain operating efficiency, care must be taken to prevent solid or liquid deposits from forming on the sensor face.

The sensor's face can also be vulnerable to aggressive acid or alkaline atmospheres.

Ultrasonic Proximity Advantages and Disadvantages

Advantages

1. Ultrasonic proximity sensors are able to sense large targets up to 15m (49ft) away.
2. An ultrasonic proximity sensor's response is not dependent upon the surface color or optical reflectivity of the object. For example, the sensing of a clear glass plate, a brown pottery plate, a white plastic plate, and a shiny aluminum plate is the same.
3. Ultrasonic sensors with digital (ON/OFF) outputs have excellent repeat sensing accuracy. It is possible to ignore immediate background objects, even at long sensing distances because switching hysteresis is relatively low.
4. The response of analog ultrasonic sensors is linear with distance. By interfacing the sensor to an LED display, it is possible to have a visual indication of target distance. This makes ultrasonic sensors ideal for level monitoring or linear motion monitoring applications.

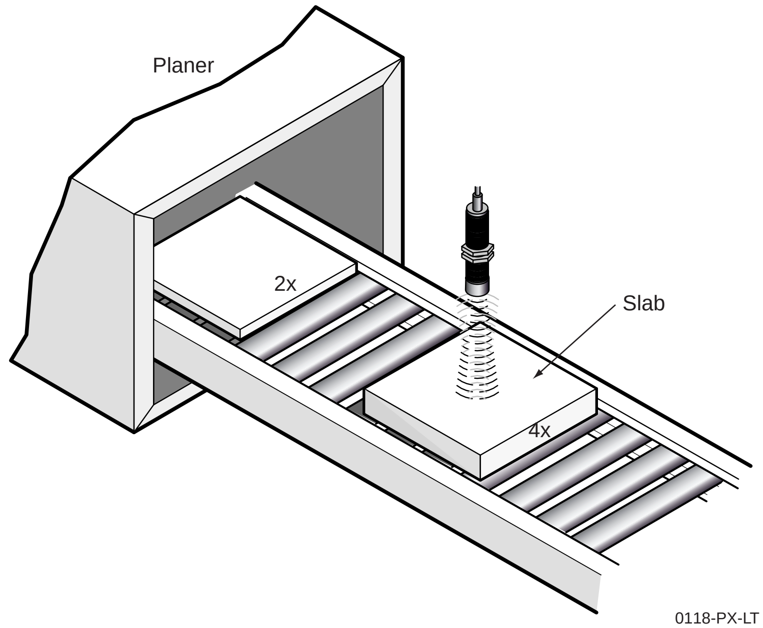
Disadvantages

1. Ultrasonic sensors must view a surface (especially a hard, flat surface) squarely (perpendicularly) to receive ample sound echo. Also, reliable sensing requires a minimum target surface area, which is specified for each sensor type.
2. While ultrasonics exhibit good immunity to background noise, these sensors are still likely to falsely respond to some loud noises, like the "hissing" sound produced by air hoses and relief valves.
3. Proximity style ultrasonic sensors require time for the transducer to stop ringing after each transmission burst before they are ready to receive returned echoes. As a result, sensor response times are typically slower than other technologies at about 0.1 second. This is generally not a disadvantage in most level sensing and distance measurement applications. Extended response times are even advantageous in some applications. Transmitted beam style ultrasonic sensors are much faster with response times on the order of 0.002 or 0.003 seconds.
4. Ultrasonic proximity sensors have a minimum sensing distance.
5. Changes in the environment, such as temperature, pressure, humidity, air turbulence, and airborne particles affect ultrasonic response.
6. Targets of low density, like foam and cloth, tend to absorb sound energy; these materials may be difficult to sense at long range.
7. Smooth surfaces reflect sound energy more efficiently than rough surfaces; however, the sensing angle to a smooth surface is generally more critical than to a rough surface.

Typical Applications

Example 6.1:

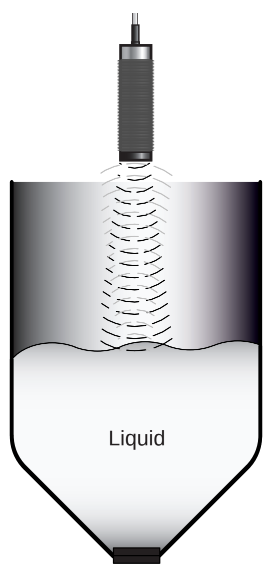
Distance Measurement, Height Measurement, or Work Piece Positioning



0118-PX-LT

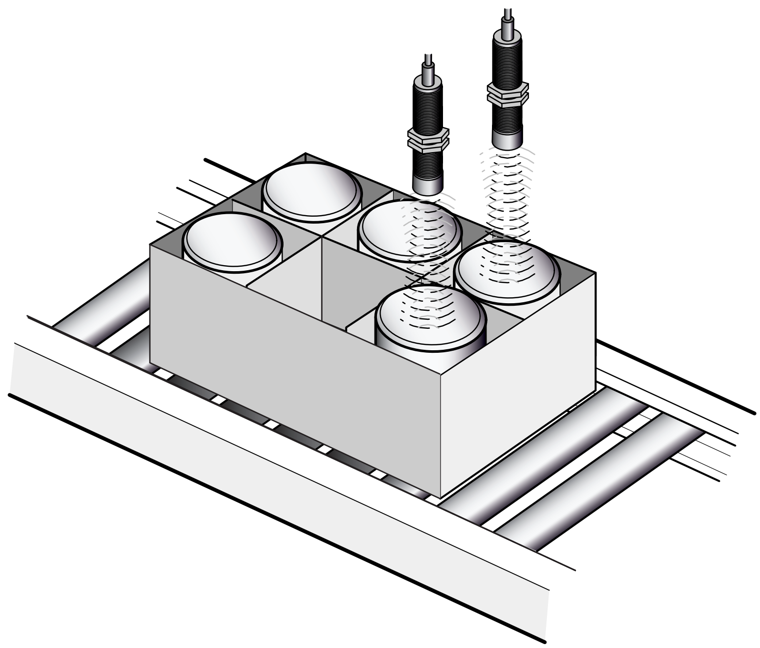
Example 6.2:

Level Control in Tanks (Granular/Liquid)



0119-PX-LT

Example 6.3:
Part Presence/Absence Sensing or Glass and Clear Parts Detection



0117-PX-LT

7

Photoelectric Sensors

In its most basic form, a photoelectric sensor can be thought of as a switch where the mechanical actuator or lever arm function is replaced by a beam of light. By replacing the lever arm with a light beam the device can be used in applications requiring sensing distances from less than 2.54cm (1in) to one hundred meters or more (several hundred feet).

All photoelectric sensors operate by sensing a change in the amount of light received by a photodetector. The change in light allows the sensor to detect the presence or absence of the object, its size, shape, reflectivity, opacity, translucence, or color.

Photoelectric sensors provide accurate detection of objects without physical contact. There is a vast number of photoelectric sensors from which to choose. Each offers a unique combination of sensing performance, output characteristics and mounting options. Many sensors also offer embedded logic or device networking capabilities that allow them to perform stand-alone in applications that would otherwise require external logic circuitry or a programmable controller.

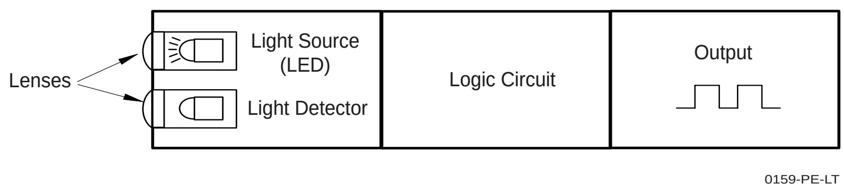
Photoelectric Sensor Construction

A light source sends light toward the object. A light receiver, pointed toward the same object, detects the presence or absence of direct or reflected light originating from the source. Detection of the light generates an output signal for use by an actuator, controller, or computer. The output signal can be analog or digital. Some sensors modify the output with timing logic, scaling, or offset adjustments.

A photoelectric sensor consists of five basic components:

- Light source
- Light detector
- Lenses
- Logic circuit
- Output

Figure 7.1:
Photoelectric Sensor Components

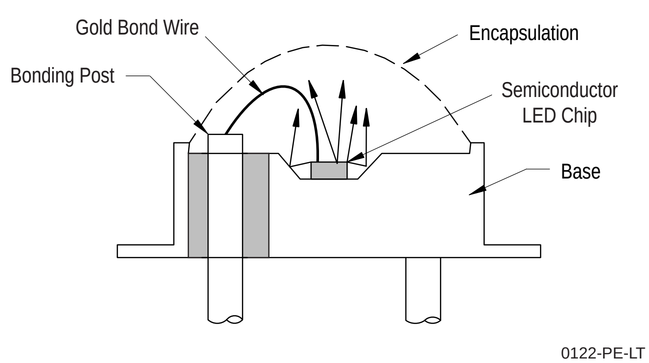


Basic Components

Light Source

Most photoelectric sensors use a light emitting diode (LED) as the light source. An LED is a solid-state semiconductor that emits light when current is applied. LEDs are made to emit specific wavelengths, or colors, of light. Infrared, visible red, green, and blue LEDs are used as the light source in most photoelectric sensors. The LED and its associated circuitry are referred to as the emitter.

Figure 7.2:
LED (Light Emitting Diode) Construction



Different LED colors offer different desirable characteristics. Infrared LEDs are the most efficient, generating the most light and the least heat of any LED color. Infrared LEDs are used in sensors where maximum light output is required for an extended sensing range.

In many applications, a visible beam of light is desirable to aid setup or confirm sensor operation. Visible red is most efficient for this requirement. Visible red, blue, and yellow LEDs are used in applications where specific colors or contrasts must be detected. These LEDs are also used as status indicators on photoelectric sensors.

More recently, laser diodes have also been used as photoelectric light sources. Laser light sources have unique characteristics including:

- Emitted light of a consistent wavelength (color)
- Small beam diameter
- Longer range

Laser sources tend to be more costly than LED light sources. In addition, the small beam size of emitted laser light, although extending the maximum sensing distance potential, may be more easily interrupted by airborne particles. Installers must guard against improper exposure to the laser beam, following typical safety procedures.

Rugged and reliable, LEDs are ideal for use in photoelectric sensors. They operate over a wide temperature range and are very resistant to damage from shock and vibration.

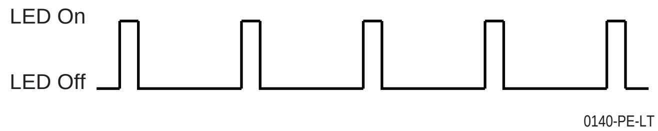
LED Modulation

One of the greatest advantages of an LED light source is its ability to be turned on and off rapidly. This allows for the pulsing or modulation of the source.

The amount of light generated by an LED is determined by the amount of current it is conducting. To increase the range of a photoelectric sensor, the amount of current must be increased. However, LEDs also generate heat. There is a maximum amount of heat that can be generated before an LED is damaged or destroyed.

Photoelectric sensors rapidly switch on and off or modulate the current conducted by the LED. A low duty cycle (typically less than 5%) allows the amount of current, and therefore the amount of emitted light, to far exceed what would be allowable under continuous operation.

Figure 7.3: Modulation

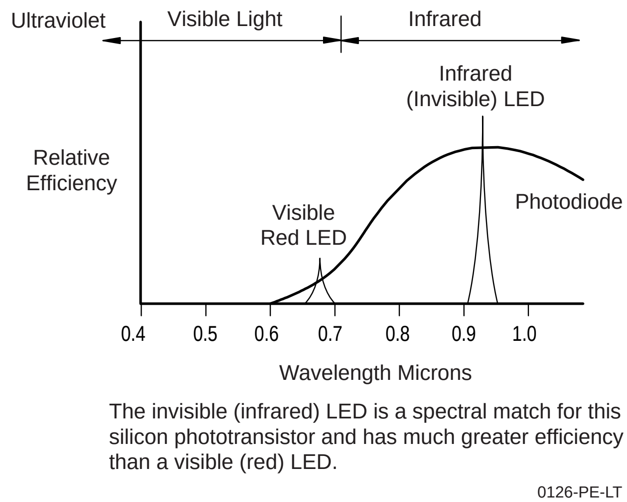


The modulation rate or frequency is often in excess of 5kHz, much faster than can be detected by the human eye.

Light Detector

The light detector is the component used to detect the light from the light source. The light detector is composed of a photodiode or phototransistor. It is a solid-state component that provides a change in conducted current depending on the amount of light detected. Light detectors are more sensitive to certain wavelengths of light. The spectral response of a light detector determines its sensitivity to different wavelengths in the light spectrum. To improve sensing efficiency, the LED and light detector are often spectrally matched. The light detector and its associated circuitry are referred to as the receiver.

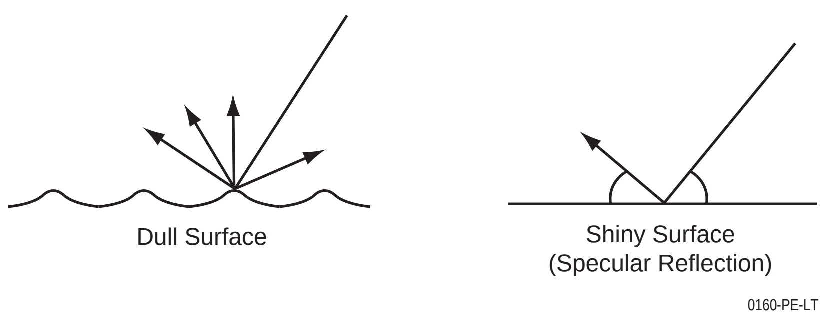
Figure 7.4:
Spectral Response



The surfaces of most objects have at least a small amount of reflectivity. Dull surfaces are rough and tend to reflect light in many directions. Smooth polished surfaces tend to direct light consistently in the same direction, producing the visual effects of mirror reflections and glare. This is generally known as specular reflection. The angle of specular light reflection is the same as the angle of the originating light.

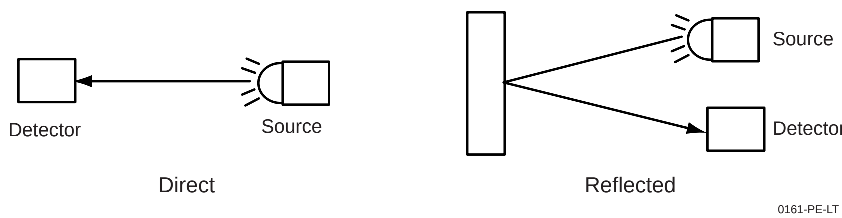
The amount and type of reflectivity of target objects is an important application consideration to be discussed later.

Figure 7.5:
Light Reflected from Dull (Rough) and Shiny (Smooth) Surface



In a photoelectric sensor, the photodetector can receive light directly from the source or from reflections.

Figure 7.6:
Direct and Specular Detection



Logic Circuit

The sensor logic circuit provides the necessary electronics to modulate the LED, amplify the signal from the detector, and determine whether the output should be activated.

Output Device

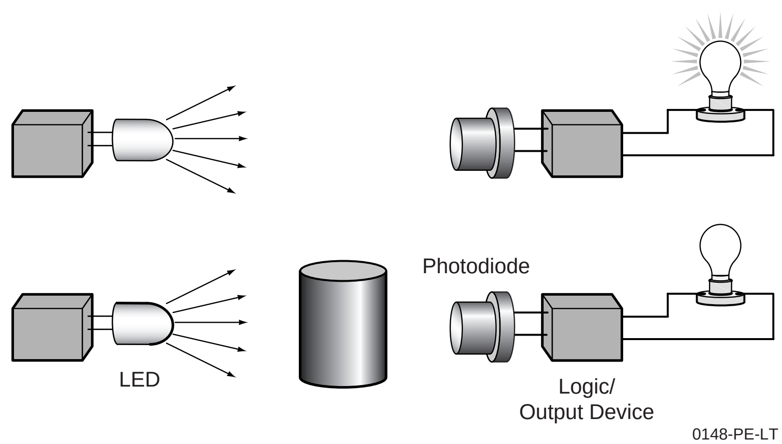
Once a sufficient change of light level is detected, the photoelectric sensor switches an output device. Many types of discrete and analog outputs are available, each with particular strengths and weaknesses (discussed in Outputs & Wiring section).

Basic Circuit

Photoelectric sensors can be housed in separate source and receiver packages or as a single unit.

In Figure 7.7 the photodiode activates the output when light is detected. When an object breaks the beam of light between the source and receiver, the output turns off.

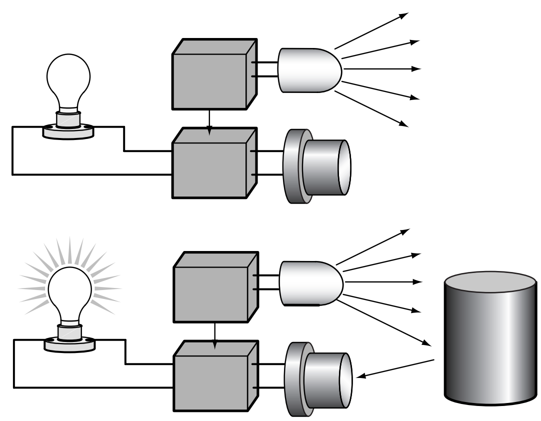
Figure 7.7:
Source-Receiver Basic Circuit



In Figure 7.8 the source, receiver, and logic have been placed in the same housing. The output is activated when the light is reflected off an object back to the receiver. When the target object is present the output turns on.

Having the source, receiver, and logic in the same package makes it easier to design a control that limits interference (sensing other sources of modulated light).

Figure 7.8:
Self Contained
Basic Circuit



Synchronous Detection

The receiver is designed to detect pulsed light from a modulated light source. To further enhance sensing reliability, the receiver and light source are synchronized. The receiver watches for light pulses that are identical to the pulses generated by the light source.

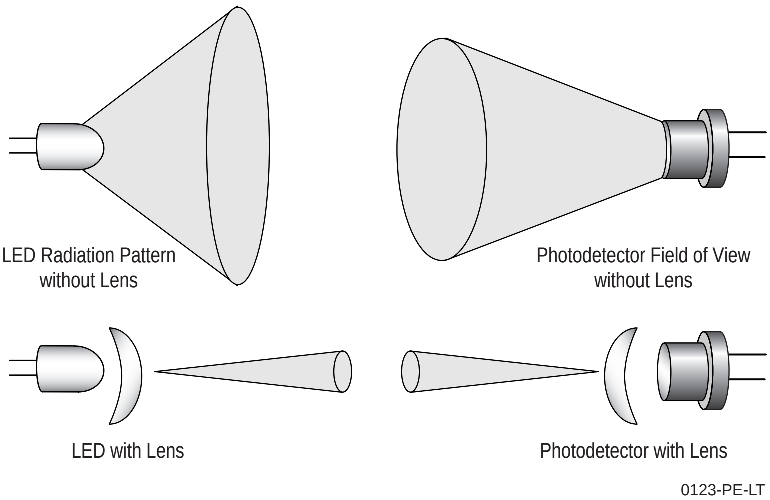
Synchronous detection helps a photoelectric sensor to ignore light pulses from other photoelectric sensors nearby or from other pulsed light sources, such as fluorescent lights. Fluorescent lights, using high frequency inverter type ballasts, require additional precautions.

Synchronous detection is most commonly found when the light source and receiver are in the same housing for all sensing modes except transmitted beam. Separate controls are also typically not capable of synchronous detection.

Lenses

LEDs typically emit light and photodetectors are sensitive to light over a wide area. Lenses are used with LED light sources and photodetectors to narrow or shape this area. As the area is narrowed, the range of the LED or photodetector increases. As a result, lenses increase the sensing distance of photoelectric sensors.

Figure 7.9:
LED and Photodetector With and Without Lenses



The light beam from an LED and lens combination is typically conical in shape. In most sensors, the area of the cone increases with distance.

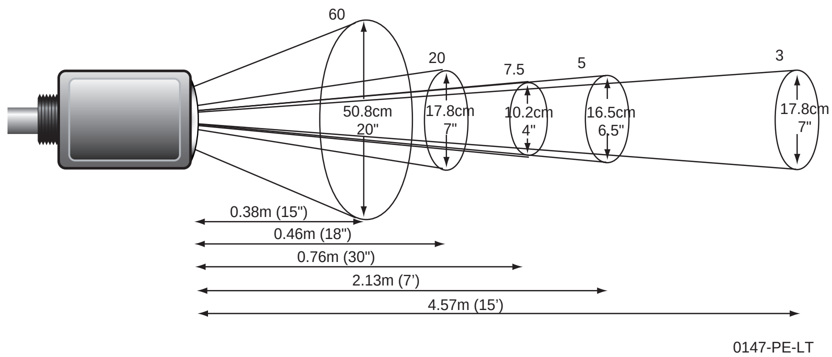
Laser light sources, however, are narrow and parallel. The laser beam tends to diverge only slightly toward its maximum sensing distance.

Sensing Ranges

Field of View

Some photoelectric sensors are optimized for longer sensing distance. The field of view of these sensors is fairly narrow; however, alignment can be difficult if the field of view is too narrow. Other photoelectric sensors are designed for detection of objects within a broad area. These sensors have a wider field of view but a shorter overall range.

Figure 7.10:
Field of View vs Relative Sensing Distance

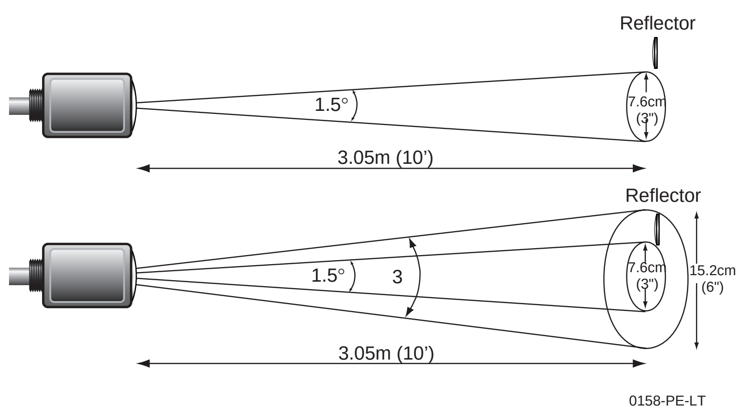


The field of view can be described like a garden hose with a nozzle on the end. As the spray is adjusted, a longer range is achieved using a narrow spray/beam. When the spray/beam is widened the maximum distance decreases.

A typical field of view ranges from 1.5° to 7° for maximum distance and ease of alignment. Sensors with beams greater than 40° are generally referred to as “wide angle.” Sensors with beams that converge are typically referred to as “fixed focus.”

A sensor with a 1.5° field of view has a spot size of 7.6cm (3in) at 3.05m (10ft), which can make alignment quite difficult. A sensor with a 3° field of view has a 15.2cm (6in) spot at 3.05m (10ft) making alignment easier.

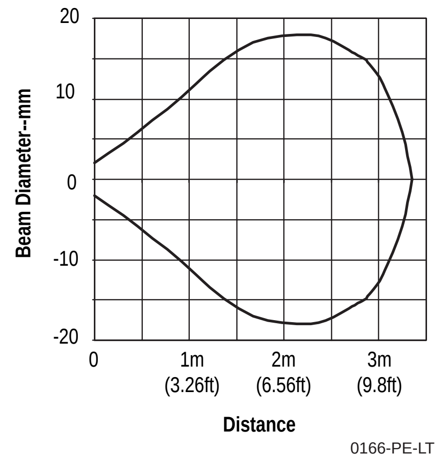
Figure 7.11:
Field of View vs Ease of Alignment



Beam Patterns

Most sensors do not have a perfectly shaped field of view based on varying optical characteristics. Therefore, the general operation of a sensor can be more accurately characterized by a beam pattern.

Figure 7.12:
Beam Pattern



This beam pattern indicates that a reflective target can be detected within the area shown. The area is assumed to be conical 360°. A target outside this area will be ignored. Note that the horizontal and vertical axes can have different scales.

While the field of view specification can be used to estimate sensor performance, beam patterns are much more accurate and should be used if available.

All beam patterns are generated under clean sensing conditions with optimal sensor alignment. The beam pattern represents the largest typical sensing area and should not be considered exact. Dust, contamination, and fog decrease the sensing area and operating range of the sensor.

Effective Beam

The effective beam of a photoelectric sensor is the light from the emitter lens to the receiver lens. The effective beam's size and shape are affected by sensing mode.

Maximum Sensing Distance

This specification refers to the sensing distance from:

- Sensor to reflector in retroreflective and polarized retroreflective sensors
- From sensor to standard target in all types of diffuse sensors
- Light source to receiver in transmitted beam sensors

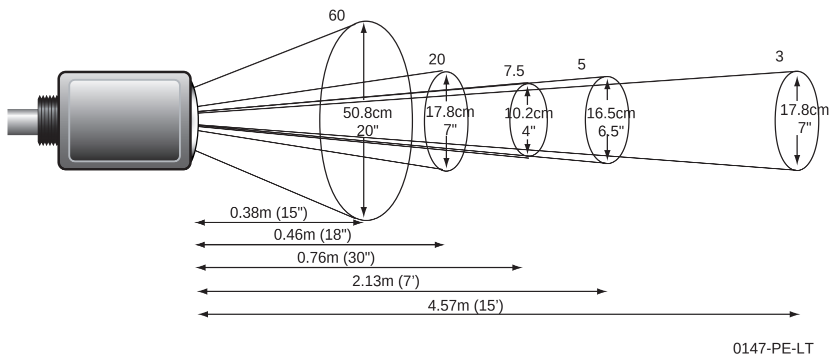
Most industrial environments create contamination on the sensor lenses, reflectors, and targets. These environments may also create suspended contaminants such as steam, flyings, or spray. Sensors should be applied at shorter distances to increase operating margin to an acceptable value and enhance application reliability.

Sensing distance is guaranteed by the manufacturer; therefore, many photoelectric sensors are conservatively rated. The actual available sensing distance can exceed this specification.

Minimum Sensing Distance

Many retroreflective, polarized retroreflective, and diffuse sensors have a small "blind" area near the sensor. Reflectors, reflective tapes, or diffuse targets should be located outside the minimum sensing distance for reliable operation.

Figure 7.13:
Sensing Distance



Margin

Margin (also known as operating margin, excess gain) is an important concept to understand when applying photoelectric sensors. The amount of maintenance required for a photoelectric sensing application can be minimized by obtaining the best margin levels for that application.

Margin is a measurement of the amount of light from the light source that is detected by the receiver. Margin is best explained by the following examples:

- A margin of zero occurs when none of the light emitted by the light source can be detected by the light detector.
- A margin of one is obtained when just enough light is detected to switch the state of the output device (from OFF to ON or from ON to OFF).
- A margin of 20 is reached when 20 times the minimum light level required to switch the state of the output device is detected.

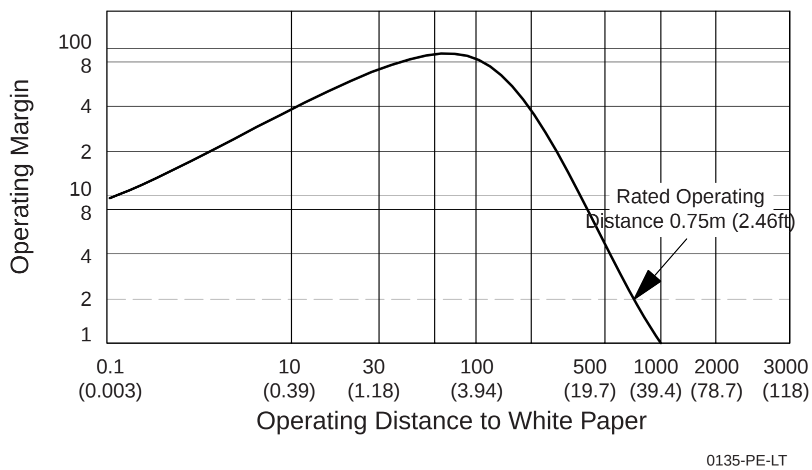
Margin is defined as:

$$\frac{\text{Actual amount of light detected}}{\text{Minimum amount required to change the output device state}}$$

and is usually expressed as a ratio or as a whole number followed by "X." A margin of 6 may be expressed as 6:1 or as 6X.

The catalog pages for most sensors contain a curve that shows what the typical margin is depending on sensing distance. A margin of at least 2X is generally recommended for industrial environments. Operating margins of 10x or more are desirable in heavily contaminated environments.

Figure 7.14:
Typical Response Curve for a Diffuse Sensor—mm (in)



The maximum sensing range of this sensor is 1m (39.4in) to a standard target. A margin of 4X can be achieved at approximately half that distance, or 500mm (19.7in).

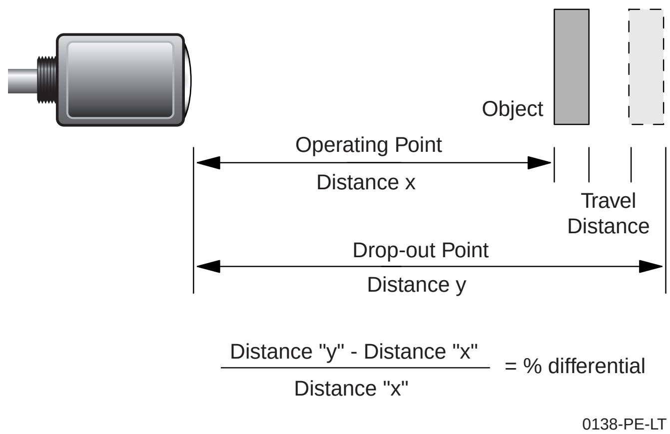
Hysteresis

Photoelectric sensors exhibit hysteresis (or differential).

The hysteresis of a photoelectric sensor is the difference between the distance when a target can be detected as it moves towards the sensor and the distance it has to move away from the sensor to no longer be detected.

As the target moves toward the sensor, it is detected at distance X. As it then moves away from the sensor, it is still detected until it gets to distance Y.

Figure 7.15:
Hysteresis



The high hysteresis in most photoelectric sensors is useful for detecting large opaque objects in retroreflective, polarized retroreflective, and transmitted beam applications. The high hysteresis typically is unaffected by inconsistent object position within the effective beam. In diffuse applications, a large difference in reflected light from object and background also allows the use of high hysteresis sensors.

Low hysteresis requires smaller changes in light level. Some photoelectric sensors are designed to allow selection of low hysteresis for these types of applications. Low hysteresis sensors are most commonly used to detect clear objects, low contrast registration marks, and objects that do not break the entire effective beam.

Response Time

The response time of a sensor is the amount of time that elapses between the detection of a target and the change of state of the output device from ON to OFF or from OFF to ON. It is also the amount of time it takes for the output device to change state once the sensor no longer detects the target.

For most sensors, the response time is a single specification for both the ON time and OFF time.

Response times are dependent on sensor design and choice of output device. Slower sensors usually offer long sensing ranges; very fast sensors typically have shorter sensing ranges. Photoelectric sensors' response times vary from 30µs to 30ms.

Response time of a sensor must be considered in relation to the speed an object passes through the effective beam. Extremely fast machine or object movement may prevent a sensor from responding quickly enough to activate its output.

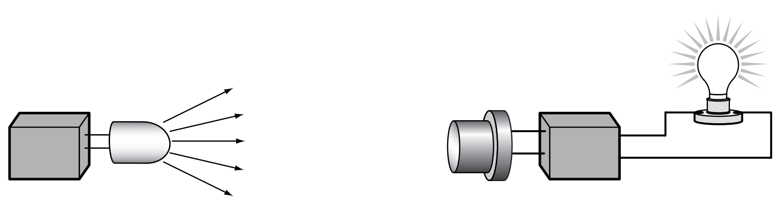
Light/Dark Operate

The terms light operate and dark operate are used to describe the action of a sensor output when a target is present or absent.

A light operate output is ON (energized, logic level one) when the receiver can "see" sufficient light from the light source.

For transmitted beam and retroreflective sensing, a light operate output is ON when the target is absent and light can travel from the light source to the receiver. For diffuse sensing (all types), the output is ON when the target is present and reflecting light from the light source to the receiver.

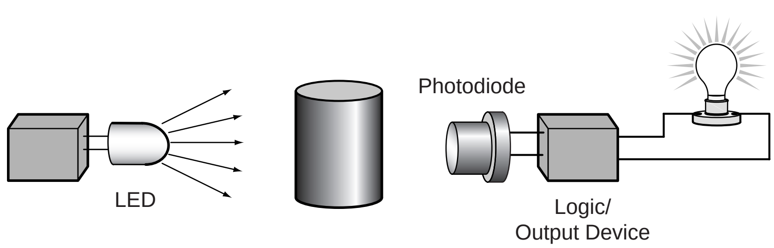
Figure 7.16:
Light Operate



A dark operate output is ON (energized, logic level one) when the receiver cannot "see" the light from the light source.

For transmitted beam and retroreflective sensing, a dark operate output is ON when the target is present and light from the light source is blocked and cannot reach the receiver. For diffuse sensing (all types), a dark operate output is ON when the target is absent.

Figure 7.17:
Dark Operate



Sensing Modes

An important part of any sensor application involves selecting the best sensing mode for the application. There are three basic types of sensing modes in photoelectric sensors: Transmitted Beam, Retroreflective and Diffuse.

Each sensing mode offers specific strengths and weaknesses to consider. The best mode is the one that provides the most reliability for each specific application. This reliability is measured by the ability of the sensor to provide the greatest amount of sensing signal differential between the presence and absence of an object while maintaining enough extra margin to comfortably overcome any contaminates or environmental factors in the sensing area.

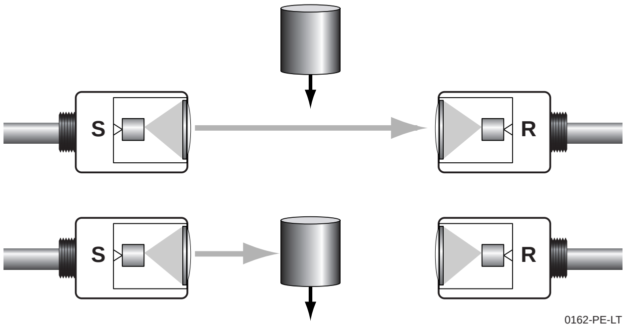
Table 7.1: Photoelectric Sensing Modes Advantages and Cautions

Sensing Mode	Applications	Advantages	Cautions
Transmitted Beam	General purpose sensing Parts counting	• High margin for contaminated environments • Longest sensing distances • Not affected by second surface reflections • Probably most reliable when you have highly reflective objects	• More expensive because separate light source and receiver required, more costly wiring • Alignment important • Avoid detecting objects of clear material
Retroreflective	General purpose sensing	• Moderate sensing distances • Less expensive than transmitted beam because simpler wiring • Easy alignment	• Shorter sensing distance than transmitted beam • Less margin than transmitted beam • May detect reflections from shiny objects (use polarized instead)
Polarized Retroreflective	General purpose sensing of shiny objects	• Ignores first surface reflections • Uses visible red beam for ease of alignment	• Shorter sensing distance than standard retroreflective • May see second surface reflections
Standard Diffuse	Applications where both sides of the object cannot be accessed	• Access to both sides of the object not required • No reflector needed • Ease of alignment	• Can be difficult to apply if the background behind the object is sufficiently reflective and close to the object
Sharp Cutoff Diffuse	Short-range detection of objects with the need to ignore close distance backgrounds	• Access to both sides of the object not required • Provides protection against sensing of close backgrounds • Detects objects regardless of color within specified distance	• Only useful for very short distance sensing
Background Suppression Diffuse	General purpose sensing Areas where you need to ignore backgrounds that are close to the object	• Access to both sides of the target not required • Ignores backgrounds beyond rated sensing distance regardless of reflectivity • Detect objects regardless of color at specified distance	• More expensive than other types of diffuse sensors • Limited maximum sensing distance
Fixed Focus Diffuse	Detection of small objects Detects objects at a specific distance from sensor Detection of color marks	• Accurate detection of small objects in a specific location	• Very short distance sensing • Not suitable for general purpose sensing • Object must be accurately positioned
Wide Angle Diffuse	Detection of objects not accurately positioned Detection of very fine threads over a broad area	• Good at ignoring background reflections • Detecting objects that are not accurately positioned • No reflector needed	• Short distance sensing
Fiber Optics	Allows photoelectric sensing in areas where a sensor cannot be mounted because of size or environment considerations	• Glass fiber optic cables available for high ambient temperature applications • Shock and vibration resistant • Plastic fiber optic cables can be used in areas where continuous movement is required • Insert in limited space • Noise immunity • Corrosive areas placement	• More expensive than lensed sensors • Short-range sensing

Transmitted Beam

In this sensing mode, the light source and receiver are contained in separate housings. The two units are positioned opposite each other so the light from the source shines directly on the receiver. The beam between the light source and the receiver must be broken for object detection.

Figure 7.18:
Transmitted Beam Sensing

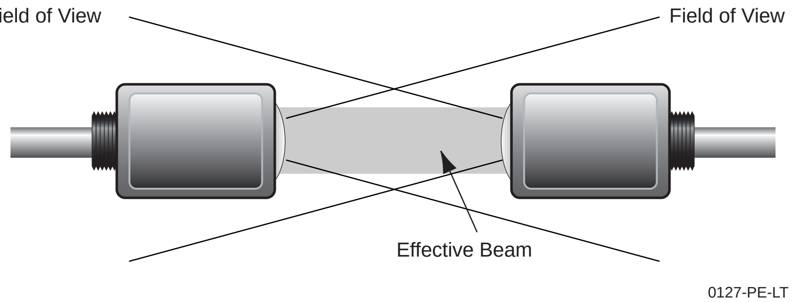


Transmitted beam sensors provide the longest sensing distances and the highest level of operating margin. For example, some sensors are capable of sensing distances of up to 274m (900ft). Transmitted beam application margins can exceed 10,000X at distances of less than 10m (31ft). For this reason, transmitted beam is the best sensing mode for operating in very dusty or dirty industrial environments. Some photoelectric sensors offer 300X margin at a sensing distance of 3m (9.8ft). At this distance, these sensors continue to operate even if up to 99% of the combined lens area of the emitter and receiver is covered with contamination.

Achieving an Optimal Effective Beam

A transmitted beam sensor's effective beam is equivalent to the diameter of the lens on the emitter and receiver. Reliable detection occurs when the object is opaque and breaks at least 50% of the effective beam.

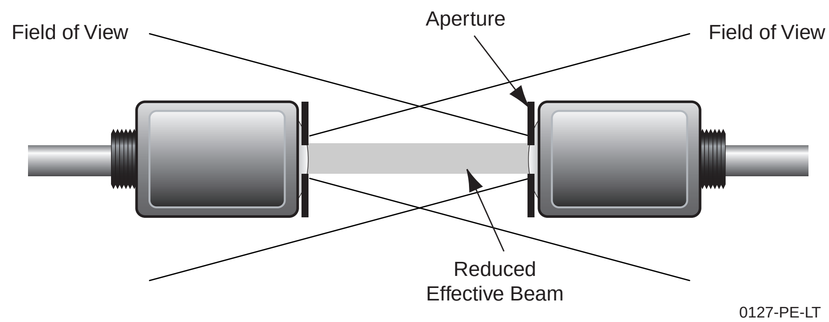
Figure 7.19:
Effective Beam



Note: The 50% used here is as an example. The percentage of the effective beam that has to be broken in order to trigger the output is determined by the sensitivity and hysteresis of the sensor.

Detection of objects smaller than 50% of the beam is achieved by reducing the beam diameter through means of apertures placed in front of the emitter, receiver, or both.

Figure 7.20: Effective Beam with Apertures



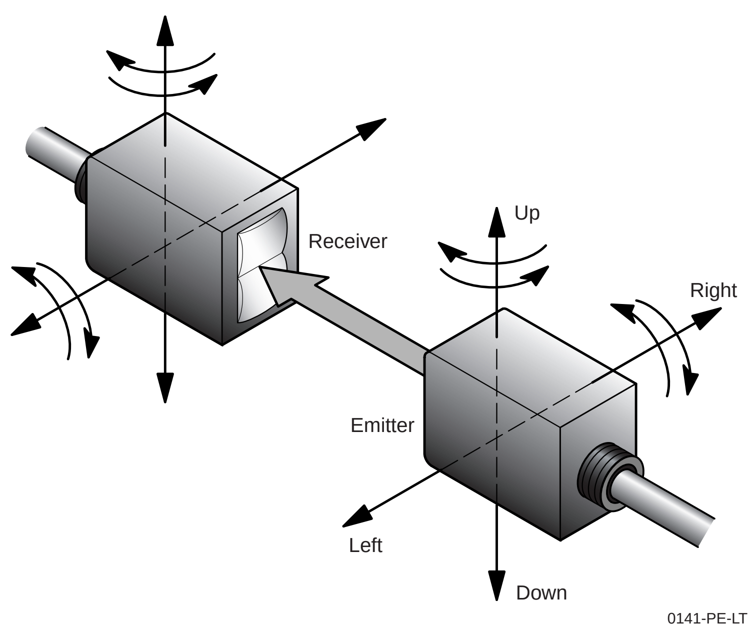
The most reliable Transmitted Beam applications have a very high margin when the object is absent, and a margin of zero (or close to zero) when the object is present.

Sensor Alignment

Sensor alignment is obtained using the following steps:

1. Aim the receiver at the light source.
2. Slowly pan the receiver left until the light source is no longer detected.
3. Note this position, then slowly scan the receiver to the right and note when the reflector is no longer detected.
4. Center the receiver between these two positions, then pan it up and down to center it in the vertical plane.

Figure 7.21: Transmitted Beam Sensor Alignment



Beam Patterns

The beam pattern for a transmitted beam sensor represents the boundary where the receiver effectively receives the signal of the emitter, assuming there is no angular misalignment. Angular misalignment between the emitter and receiver will decrease the size of the sensing area. Beam patterns for transmitted beam sensors are useful for determining the minimum spacing required between adjacent transmitted beam sensor pairs to prevent optical crosstalk from one pair of sensors to the next.

Transmitted Beam Advantages and Disadvantages

Advantages

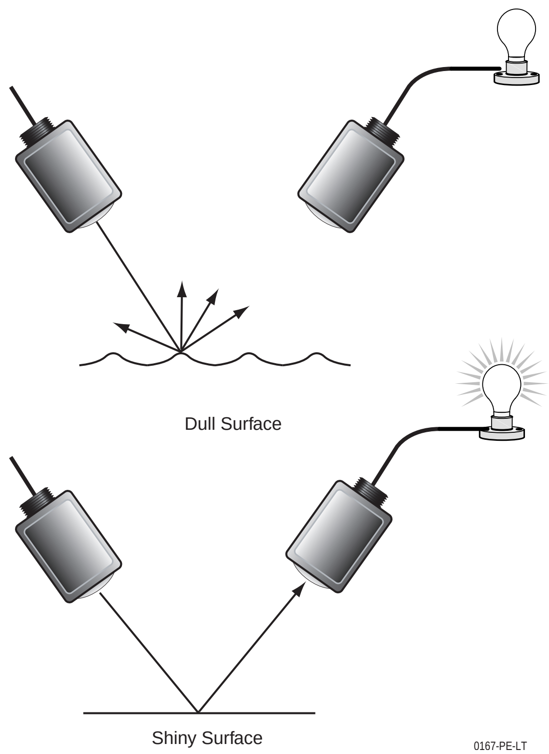
The advantages of transmitted beam sensing are:

1. A general rule of thumb is to use transmitted beam photoelectric sensors wherever possible.

   As long as the object to be detected completely blocks the opposed light beam, the use of transmitted beam photoelectric sensors will always result in the most reliable photoelectric sensing system. (An inductive proximity sensor becomes a first choice for sensing of metal objects that pass close enough to the sensor for reliable detection.)
2. Because of their well-defined effective beam, transmitted beam sensors are usually the most reliable for accurate parts counting.
3. Use of transmitted beam sensors eliminates the variable of surface reflectivity or color.
4. Transmitted beam sensors offer the highest margin.
5. Because of their ability to sense through heavy dirt, dust, mist, condensation, oil, and film, transmitted beam sensors allow for the most reliable performance before cleaning is required and, therefore, offer a lower maintenance cost.
6. Small part or precise position sensing detection (using small apertures or fiber optics).
7. Detection of opaque solids or liquids inside translucent or transparent containers. Transmitted beam sensors can sometimes be used to “beam through” thin-walled boxes or containers to detect the presence, absence, or level of the product inside.
8. A pair of transmitted beam sensors may be positioned to mechanically converge at a point ahead of the sensor. This type of configuration usually results in more depth-of-field as compared to sharp cutoff (convergent beam) diffuse sensors. High-powered emitter-receiver pairs may be configured for long-range mechanical sharp-cutoff sensing.
9. One specialized use of a mechanically converged emitter and receiver pair is to detect the difference between a shiny and a dull surface based on specular reflection. A shiny surface returns emitted light to a receiver if the two units are mounted at equal and opposite angles to the perpendicular to the shiny surface. This light is diffused by any nonreflective surface that covers or replaces the shiny surface. A common example is sensing the presence of cloth (dull surface) on a steel sewing machine table (shiny surface). Specular reflection is also used to

monitor or inspect the orientation or the surface quality of a shiny part.

Figure 7.22:
Specular Reflection



Disadvantages

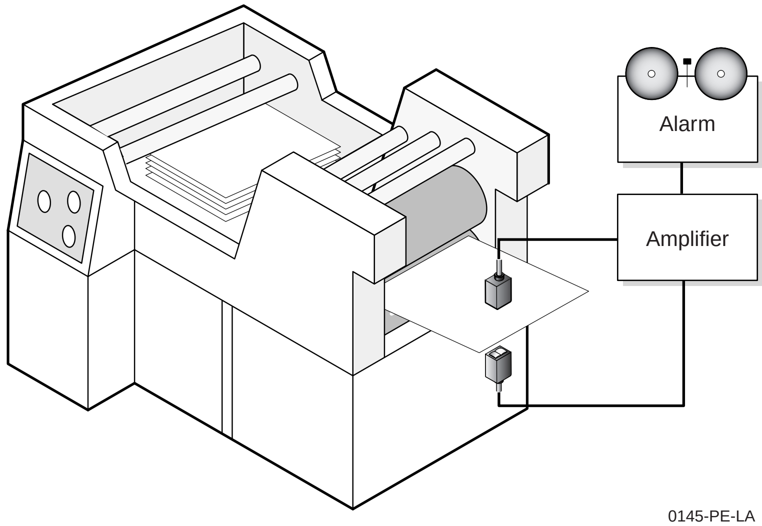
The cautions of transmitted beam sensors are:

1. When used at close range some transmitted beam pairs have so much margin they tend to see through thin opaque materials (paper, cloth, plastics). It becomes difficult to set a sensitivity control operating point because of too much margin. To correct this problem, their signal may need to be mechanically attenuated by the addition of apertures over the lenses.
2. Very small parts that do not interrupt at least 50% of the effective beam can be difficult to reliably detect. Apertures, lenses, or fiber optics can all be used to define the effective beam more critically for reliable detection.

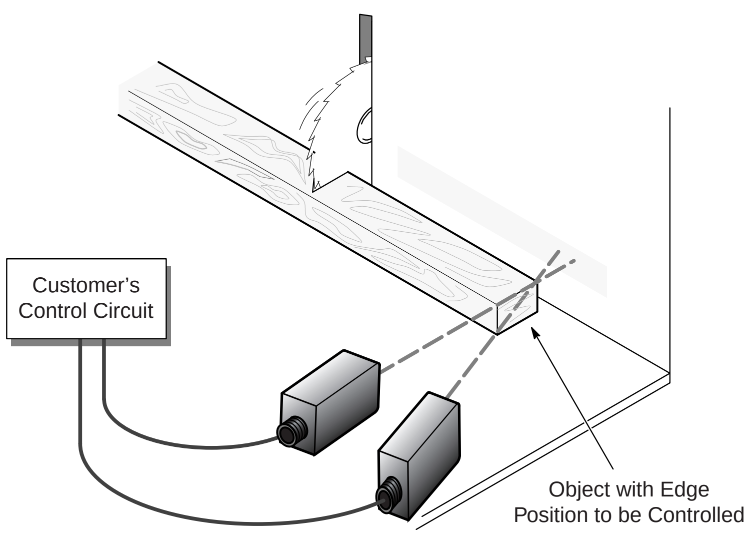
   Note: The use of apertures will reduce a sensor's margin. Alignment will become more difficult.
3. Transmitted beam sensing may not be suitable for detection of translucent or transparent objects. The high margin levels allow the sensor to "see through" these objects. While it is often possible to reduce the sensitivity of the receiver, sensors designed to detect clear objects, such as photoelectric sensors or ultrasonic sensors, are available for optimal clear object detection.

Typical Transmitted Beam Applications

Example 7.1:
Double Sheet Detection



Example 7.2:
Mechanically Convergent Edge Detection

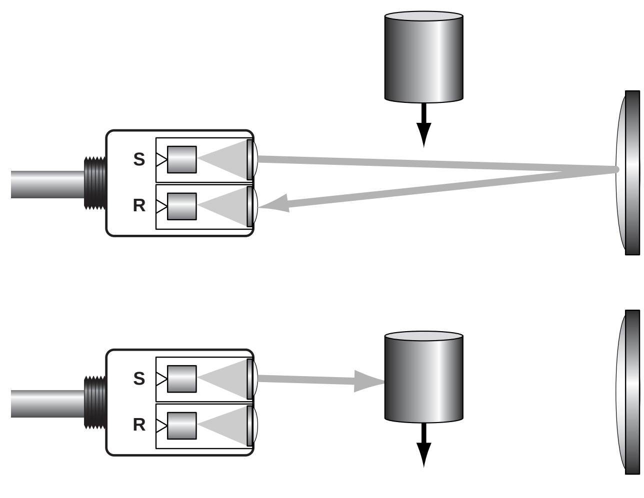


Retroreflective and Polarized Retroreflective

Retroreflective and polarized retroreflective are the most commonly used sensing modes. A retroreflective sensor contains both the emitter and receiver in one housing. The light beam from the emitter is bounced off a reflector (or a special reflective material) and detected by the receiver. The object is detected when it breaks this light beam.

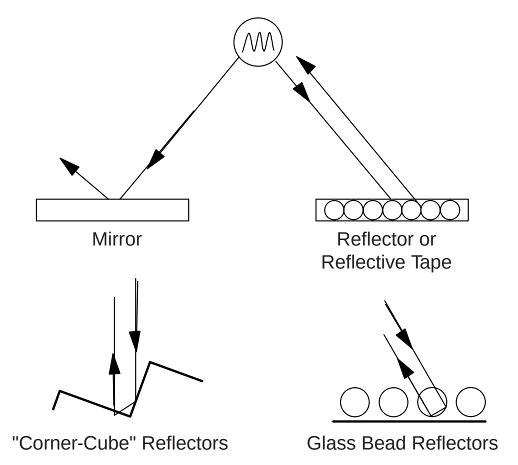
Retroreflective

Figure 7.23:
Retroreflective Sensing



Special reflectors or reflective tapes are used for retroreflective sensing. Unlike mirrors or other flat reflective surfaces, these reflective materials do not have to be aligned perfectly perpendicular to the sensor. Misalignment of a reflector or reflective tape of up to 15° will typically not significantly reduce the margin of a sensor.

Figure 7.24:
Retroreflective Materials



A wide selection of reflectors is available. The maximum available sensing distance of a retroreflective sensor depends in part upon both the size and the efficiency of the reflector. These materials are rated with a reflective index. (See the manufacturer's catalog or documentation to determine the appropriate rating.) For the most reliable sensing, it is recommended that the largest reflector available be used.

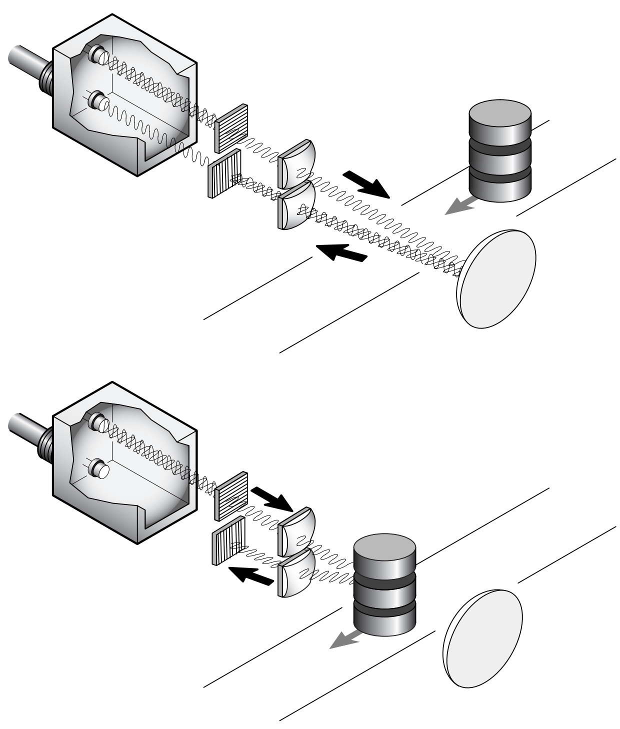
Retroreflective sensors are easier to install than transmitted beam sensors because only one sensor housing is installed and wired. Margins, when the object is absent, are typically 10 to 1000 times lower than transmitted beam sensing, making retroreflective sensing less desirable in highly contaminated environments.

Caution must be used when applying standard retroreflective sensors in applications where shiny or highly reflective objects must be sensed. Reflections from the object itself may be detected. It may be possible to orient the sensor and reflector or reflective tape so the shiny object reflects light away from the receiver; however, for most applications with shiny objects, polarized retroreflective sensing offers a better solution.

Polarized Retroreflective

Polarized retroreflective sensors contain polarizing filters in front of the emitter and receiver that orient light into a single plane. These filters are perpendicular or 90° out of phase with each other.

Figure 7.25:
Polarized Retroreflective Sensing



The light beam is polarized as it passes through the filter. When polarized light is reflected off an object, the reflected light remains polarized. When polarized light is reflected off a depolarizing reflector, the reflected light is depolarized.

The receiver can only detect reflected light that has been depolarized. Therefore, the receiver cannot see (receive) light from reflective objects that did not depolarize the light. The sensor can “see” a reflection from a reflector, and it cannot “see” a reflection from most shiny objects.

All standard reflectors depolarize light and are suitable for polarized retroreflective sensing; however, most reflective tapes do not depolarize light and are suitable only for use with standard retroreflective sensors. Specially constructed reflective tapes for polarized retroreflective sensing are available. Look for reflective tapes specifically identified as suitable for use with polarized retroreflective sensors.

Use caution when applying polarized retroflective in applications where stretch or shrink wrap is used. Polarized sensors only ignore “first surface” reflections from an exposed reflective surface. Polarized light is depolarized as it passes through most plastic film or stretch wrap; therefore, a shiny object may create reflections when it is wrapped in clear plastic film that are detected by the receiver. In the latter case, the shiny object becomes the “second surface” behind the plastic wrap. Other sensing modes must be considered for these applications.

Sensor Alignment

Sensor alignment is obtained using the following steps:

1. Aim the sensor at the reflector (or reflective tape).
2. Slowly pan the sensor left until the reflector is no longer detected.
3. Note this position, then slowly move the sensor to the right and note when the reflector is no longer detected.
4. Center the sensor between these two positions, then pan it up and down to center it in the vertical plane.

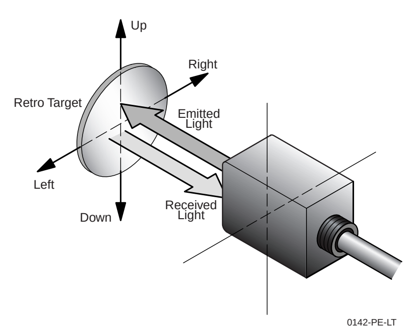


Figure 7.26: Retroreflective or Polarized Retroreflective Effective Beam Alignment

Beam Patterns

Beam patterns for retroreflective and polarized retroreflective sensors represent the boundaries the sensor will respond within as a retroreflective target passes by the sensor's optics. The retroreflective target is held perpendicular to the sensor's optical axis while the beam diameter is plotted. Generally, a 76mm (3in) diameter retroreflective target is used to generate retroreflective beam patterns unless otherwise noted.

For reliable operation, the object to be sensed must be equal to or larger than the beam diameter indicated in the beam pattern. A smaller retroreflective target should be used for accurate detection of smaller objects.

Retroreflective and Polarized Retroreflective Advantages and Disadvantages

Advantages

The advantages of retroreflective sensors include:

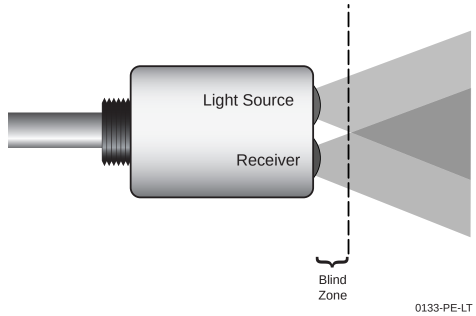
1. When sensor wiring is possible from only one side; a general rule of thumb is to use a retroreflective or polarized retroreflective sensor instead of transmitted beam if the opposite side allows a reflector to be mounted.
2. Polarized retroreflective should be selected instead of standard retroreflective wherever possible for the best application reliability.
3. Polarized retroreflective sensors avoid sensing shiny objects. Polarized retroreflective sensing is the most popular sensing mode in conveyor applications. These applications offer objects that are large (boxes, cartons, manufactured parts), a relatively clean environment, and sensing ranges of 2 to 15 feet.

Disadvantages

The cautions of retroreflective and polarized retroreflective sensors include:

1. Retroreflective sensors have a shorter sensing distance than transmitted beam.
2. Polarized retroreflective sensors offer a 30%-40% shorter sensing distance (and less margin) than standard retroreflective sensors. Instead of Infrared LEDs, polarized retroreflective sensors must use a less efficient visible emitter (typically a visible red LED). The polarizing filters cause additional light losses.
3. Avoid using retroreflective and polarized retroreflective sensors for precise positioning control or detecting small parts because it is usually difficult to create a small effective beam. The beam can be decreased by the use of apertures if required.
4. Most retroreflective and polarized retroreflective sensors are optimized for long distance sensing and have a blind zone at closer distance (typically 25-150mm (1-6 inch) from the sensor face).

Figure 7.27:
Retroreflective Sensing with Blind Spot Indicated

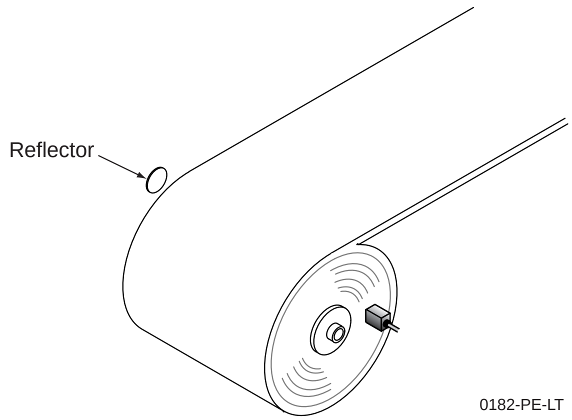


5. The efficiency of different reflective target materials varies widely. Care should be taken to reference the manufacturer's reflectivity index for these materials.
6. Retroreflective and polarized retroreflective sensors will not effectively sense second surface reflections.
7. Avoid detection of translucent or transparent materials. Instead use specially designed clear object/polarized sensors.

Typical Retroreflective and Polarized Retroreflective Application

Example 7.1:

Residual Roll Detection

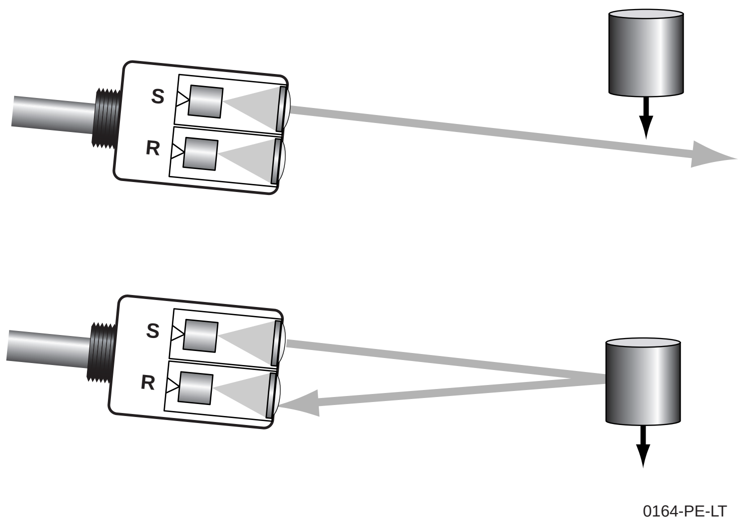


Diffuse

Transmitted beam and retroreflective sensing create a beam of light between the emitter and receiver or between the sensor and reflector. Access to opposite sides of the target object is required.

Sometimes it is difficult, or even impossible, to obtain access on both sides of an object. In these applications, it is necessary to detect a reflection directly from the object. The object's surface scatters light at all angles; a small portion is reflected toward the receiver. This mode of sensing is called diffuse sensing.

Figure 7.28:
Diffuse Sensing



The goal of diffuse sensing is to obtain a relatively high margin when sensing the object. When the object is absent, reflections from any background should represent a margin as close to zero as possible.

Object and background reflectivity can vary widely. This application challenge is most important when using diffuse sensing.

- Relatively shiny surfaces may reflect most of the light away from the receiver, making detection very difficult. The sensor face must be perpendicular with these types of object surfaces.
- Very dark, matte objects may absorb most of the light and reflect very little for detection. These objects may be hard to detect unless the sensor is positioned very close.

The specified maximum sensing distance of a photoelectric sensor is determined using a standardized target. Many manufacturers use a 216mm (8.5in) x 292mm (11in) sheet of white paper specially formulated to be 90% reflective. This means the paper will reflect 90% of the light energy from the light source.

"Real world" diffuse objects are often considerably less reflective, as shown in this table.

Table 7.2: Typical relative reflectivity of sample objects

Object	Typical Relative Reflectivity
Retroreflective tape	2000
Polished aluminum (perpendicular)	500
White paper (reference)	100
White typing paper	90
Cardboard	40
Packaged box (cereal box)	30
Cut lumber	20
Black paper	10
Neoprene	5
Tire rubber	4
Black felt	2

Detecting objects positioned close to reflective backgrounds can be particularly challenging. It may be impossible to adjust a standard diffuse sensor to obtain sufficient margin from the object without detecting, or coming close to detecting, the background. Other types of diffuse sensing may be more appropriate.

There are a number of different types of diffuse sensing, the simplest is standard diffuse. Others include sharp cutoff diffuse, background suppression diffuse, fixed focus diffuse, and wide angle diffuse.

Sharp Cutoff Diffuse

Sharp cutoff diffuse sensors are designed so the light beam from the emitter and the area of detection of the receiver are angled towards each other. Therefore, makes these sensors more sensitive at short distance, and less sensitive at longer distance. This can provide more reliable sensing of objects that are positioned close to reflective backgrounds.

This sensing mode provides some degree of improvement over standard diffuse sensing when a reflective background is present; however, a background that is very reflective may still be detected.

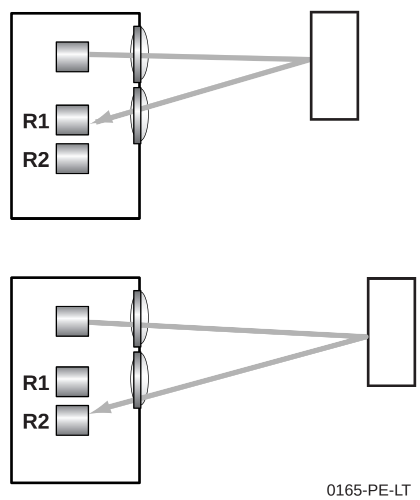
Background Suppression Diffuse

For the most difficult applications, background suppression diffuse sensors can provide an even better solution than standard diffuse or sharp cutoff diffuse.

Background suppression allows the sensor to ignore a very reflective background almost directly behind a dark, less reflective object. For many applications, it is the ideal diffuse sensing mode; however, background suppression sensors are more complex and, therefore, more expensive than other diffuse models.

Background suppression sensors use sophisticated electronics and optics to actively sense both the object and the background instead of attempting to ignore the background behind a object. The two signals are compared, and the output will change state upon active detection of the object or the background.

Figure 7.29:
Background Suppression Diffuse Effective Beam Pattern



If the object is located between the focal plane and the receiver, the beam falls on receiver R1. If the object is moved out of the focal plane, the beam falls on receiver R2. The signal from R2 is then electronically suppressed.

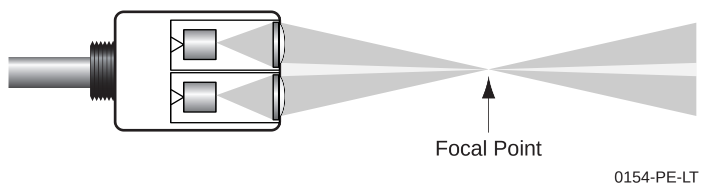
Fixed Focus Diffuse

In a fixed focus sensor, the beam from the light source and the detection area of the receiver are focused to a very narrow point (focal point) at a fixed distance in front of the sensor. The sensor is very sensitive at this point and much less sensitive before and beyond this focal point.

Fixed focus sensors have three primary applications:

- Reliable detection of small objects. Because the sensor is very sensitive at the focal point, a small target can be readily detected.
- Detection of objects at a fixed distance. As a fixed focus sensor is most sensitive at the focal point, it can be used in some applications to detect a object at the focal point and ignore it when it is in front of or behind the focal point.
- Detection of color printing marks (color registration mark detection). In some applications, it is important to detect the presence of a printing mark on a continuous web of wrapping material. A fixed focus sensor with a specific visible light source color (typically red, green or blue) may be selected to provide the greatest sensitivity to the mark.

Figure 7.30:
Fixed Focus Diffuse
Effective Beam Pattern



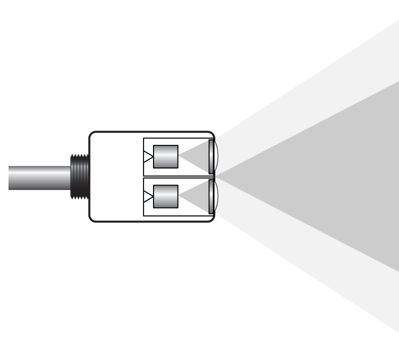
Wide Angle Diffuse

Wide angle diffuse sensors project the light source and detection area of the receiver over a wide area. Typical applications for wide angle sensors are:

Thread detection. A wide angle diffuse sensor can detect the presence of extremely thin strands of thread or other material positioned close to the sensor. The presence or absence (thread break) of the thread can be reliably detected even when the thread moves from side to side in front of the sensor.

Ignoring holes or imperfections in targets. Because wide angle diffuse sensors can sense over a broad area, they can ignore small holes or imperfections in diffuse objects, detecting products not accurately positioned.

Figure 7.31:
Wide Angle Diffuse
Effective Beam Pattern

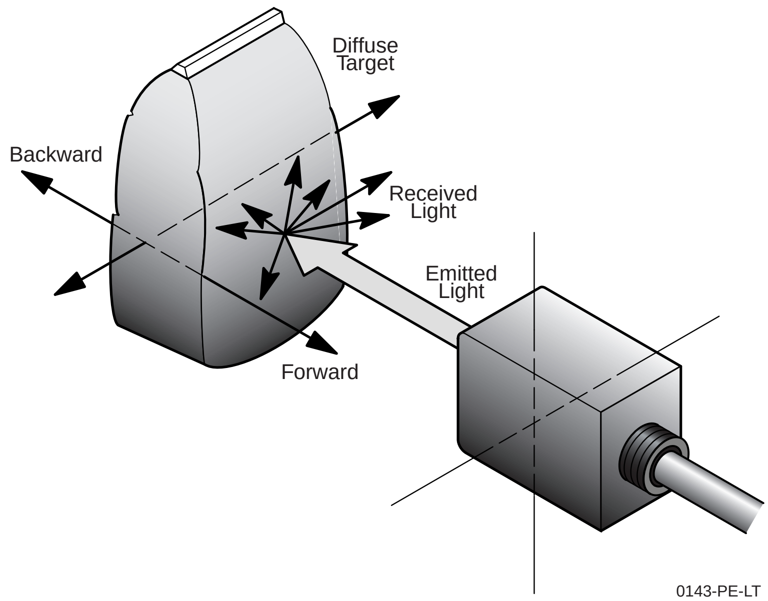


Aligning Diffuse Sensors

Sensor alignment is obtained using the following steps:

1. Aim the sensor at the object.
2. Pan the sensor up and down, left and right to center the beam on the object.
3. Reduce the sensitivity until just the object is no longer detected and note the position of the sensitivity adjustment.
4. Remove the object and increase the sensitivity until the background is detected.
5. Adjust the sensitivity to the mid point between detection of the object and detection of the background.

Figure 7.32:
Diffuse (all types)
Sensor Alignment



Diffuse, Sharp Cutoff and Background Suppression Beam Patterns

The beam pattern for a diffuse sensor represents the boundary within which the edge of a white reflective target will be detected as it passes by the sensor. Diffuse beam patterns are generated using a 90% reflective sheet of 216mm x 279mm (81/2in x 11in) white paper held perpendicular to the sensor's optical axis. The sensing area is smaller for materials that are less reflective and larger for more reflective materials. Smaller objects may decrease the size of the beam pattern of some diffuse sensors at longer ranges. Diffuse objects with surfaces that are not perpendicular to the sensor's optical axis will also significantly decrease sensor response.

Advantages and Disadvantages

Advantages

Diffuse

The advantages of standard diffuse sensors include:

1. Applications where the sensor-to-object distance is from a few inches to a few feet and when neither transmitted beam nor retroreflective sensing is practical.
2. Applications that require sensitivity to differences in surface reflectivity and monitoring of surface conditions that relate to those differences in reflectivity are important.

Sharp Cutoff

The advantages of sharp cutoff sensors include:

1. Sharp cutoff sensors may be used to detect the fill level of materials in an open container. Generally in these types of applications the surface to be sensed is too unstable or the opening is too small to allow use of an ultrasonic proximity detector.

Background Suppression

The advantages of background suppression sensors include:

1. Highly reflective background objects may be ignored because background suppression sensors have a defined cutoff point at the far end of their range.
2. Background suppression can be used to verify the presence of a part that is directly ahead or on top of another reflective surface.
3. Diffuse mode sensing of many surfaces with very low reflectivity is possible because the available margin, inside the fixed sensing field, is usually high.

Fixed Focus

The advantages of fixed focus sensors include:

1. The effective beam of most fixed focus sensors is well defined, especially at the focal point. It is a good second choice, after transmitted beam, for accurate position sensing of edges that travel through the focal point perpendicular to beam.
2. Fixed focus can be used to detect the presence or absence of a small part, such as a screw in an assembly.
3. Visual spot makes it easier to focus exactly.
4. Color registration (color mark) sensing can be achieved with fixed focus sensors using appropriate color LED emitter.

Wide Angle

The advantages of wide angle sensors include:

1. Wide angle sensors do not exhibit the "blind spot" that standard diffuse sensors have for small objects at close range.
2. Wide angle sensors often may be used successfully in areas where there is a background object that lies just beyond the sensor's range. These sensors run out of margin very rapidly with increasing range.
3. Reliably sense shiny round objects, such as cans, and are tolerant of shiny surfaces that vibrate, such as metal foil webs, because wide angle diffuse sensors are not sensitive to the angle of view to a specular surface.

Disadvantages

Diffuse

The cautions of diffuse sensors include:

1. **Reflectivity:** The response of a diffuse sensor is dramatically influenced by the surface reflectivity of the object to be sensed. The performance of diffuse mode (and all proximity mode) sensors is referenced to a 90% reflectance Kodak white test card. Any material may be ranked for its relative reflectivity as compared to this reference.
2. **Shiny surfaces:** Diffuse sensors use lenses that maximize sensing distance by collimating its light. Therefore, shiny objects that are at a nonperpendicular angle may be difficult to detect.
3. **Small part detection:** Diffuse sensors have less sensing distance when used to sense objects with small reflective area. Also, the lensing of most diffuse mode sensors creates a "blind spot" for small parts that pass close to the lens. When transmitted beam sensors cannot be used, small parts that pass at a fixed distance from the sensor should be sensed using a fixed focus sensor. Small parts that pass the sensor at random (but close) distances may be sensed with a wide angle sensor.
4. Most diffuse mode sensors are less tolerant to the contamination around them and lose their margin very rapidly as dirt and moisture accumulate on their lenses.
5. Where accurate counting is essential, diffuse sensing can be problematic, therefore, diffuse mode sensors are a poor choice for applications that require accurate counting of parts. They are particularly unreliable for sensing irregular surfaces, glass or shiny objects, small parts, or parts that pass the sensor at various distances.
6. Backgrounds that may vary or are more reflective than the object may require background suppression or sharp cutoff sensors.

Sharp Cutoff

1. **Sensing reliability:** Fixed focus sensors require that the surface to be detected pass at (or close to) the focus distance from the sensor lens. Avoid use of fixed focus sensors for detection of objects that pass at an unpredictable distance from the sensor.

Background Suppression

1. **Shiny surfaces:** The beam angle to a specular (shiny) surface may affect the location of a background suppression sensor's cutoff point.
2. Objects may have to pass through the sensor's effective beam perpendicular to the emitter/receiver lens plane to be used in higher speed applications.

Fixed Focus

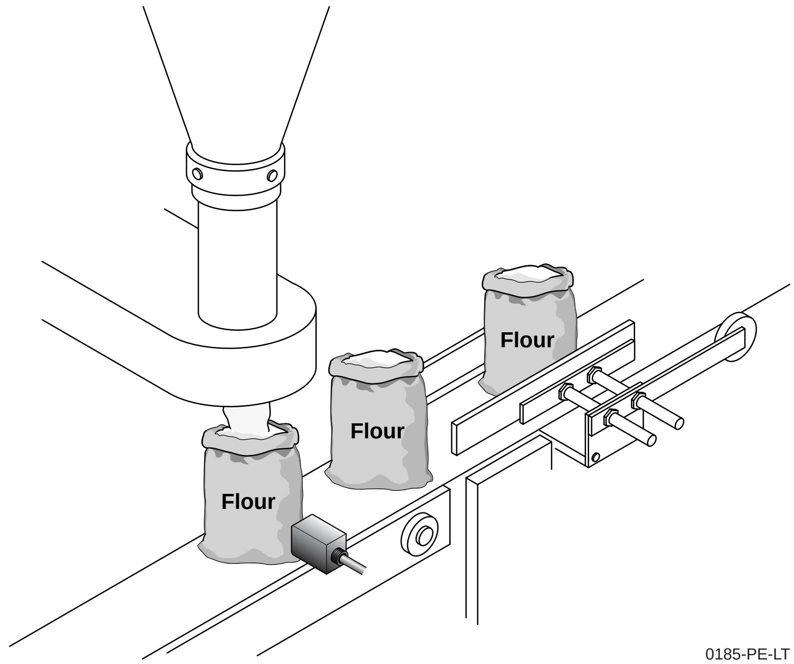
1. Focal point is well defined, resulting in very excellent detection at that focal point and little detection before or after the focal point.

Wide Angle

1. Objects that are off to the side of the sensor may be sensed because the field of view is extremely wide.
2. Care should be taken when mounting to make sure the sensor is not recessed into a mounting hole.

Typical Diffuse Application

Example 7.1:
Package Detection



Fiber Optics

Fiber optic sensors permit the attachment of “light pipes” called fiber optic cables. Light emitted from the source is sent through transparent fibers in the cables and emerges at the end of the fiber. The transmitted or reflected beam is then carried back to the receiver through different fibers.

Fiber optic cables can be mounted in locations that would otherwise be inaccessible to photoelectric sensors. They can be used where there is a high ambient temperature and in applications where extreme shock and vibration or continuous movement of the sensing point is required (as described below). Fiber optic cables may also be used to sense small objects. Fiber optic sensors may have the fastest response.

Fiber optic cables can be configured to operate in all the sensing modes: transmitted beam, retroreflective and the various diffuse modes.

Figure 7.33:
Individual Fiber Optic Cables

Two individual cables are used for transmitted beam sensing. Again, this type of sensing mode is the most reliable.

Bifurcated fiber optic cables are used for retroreflective or diffuse sensing modes.

Figure 7.34:
Bifurcated Fiber Optic Cable

Standard retroreflective sensing is possible, but polarized retroreflective sensing is not. In some applications, it will be necessary to reduce the sensitivity of the sensor to prevent diffuse detection of the target.

Standard diffuse sensing with fiber optic cables is similar to sensing with lensed photoelectrics. With maximum sensitivity these sensors, using bifurcated fiber optic cables, will detect the many small targets. Another method of diffuse fiber optic sensing is to use individual fiber optic cables. The sharp cutoff, fixed focus, and mechanically convergent sensing modes can be created by aiming the sensing tips of the cables at the target.

More difficult applications may benefit from optional lenses that can be attached to various sensing tip configurations. These lenses “tighten” the emitted or received light beam, enabling either longer distance or smaller object sensing.

Both glass and plastic are used in fiber optic cables. Glass fibers can be used with infrared or visible LEDs. Plastic fibers absorb infrared light and therefore are most efficient when used with visible red LEDs.

Glass

Glass fiber optic cables contain multiple strands of very thin glass fiber that are bundled together in a flexible sheath.

Glass fiber optic cables are typically more durable than their plastic counterparts. Glass cables will withstand much higher temperatures; glass fiber optic cables with a stainless steel sheath are rated up to 260°C (500°F). Special cables can be obtained with temperature ratings of up to 480°C (900°F).

Most glass cables are available with a choice of PVC or flexible stainless steel sheath. PVC-sheathed cables are typically less expensive. Stainless steel sheathing adds even greater durability and allows the cables to operate at higher temperatures.

Plastic

Plastic fiber optic cables are typically constructed of a single acrylic monofilament. They are less durable, but typically less expensive than glass cables.

Plastic fibers can be used in applications where continuous flexing of the cable is required. Coiled plastic cables are also available for these applications.

Fiber Optic Advantages and Disadvantages

Advantages

The advantages of fiber optics include:

1. Ability to tolerate extreme ambient conditions with remote mounted electronics.
2. Excellent for small object sensing applications.
3. Easily mounted into restricted access areas.
4. Fiber sensing tips can be arranged or focused to emulate most sensing modes.

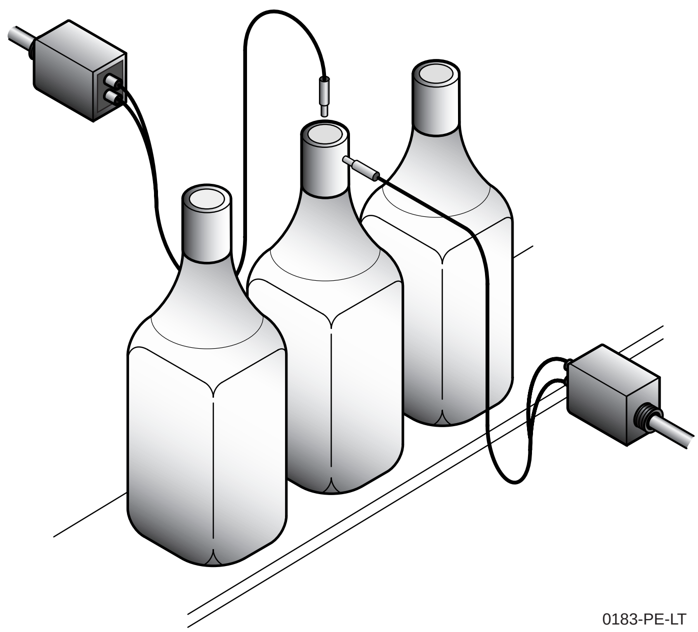
Disadvantages

The cautions of fiber optics include:

1. Plastic fibers work best with visible red sensors.
2. Glass fibers may be damaged by frequent or extreme cable movement.
3. Have very limited sensing range.
4. Ambient contamination may cause severe sensing reliability issues.

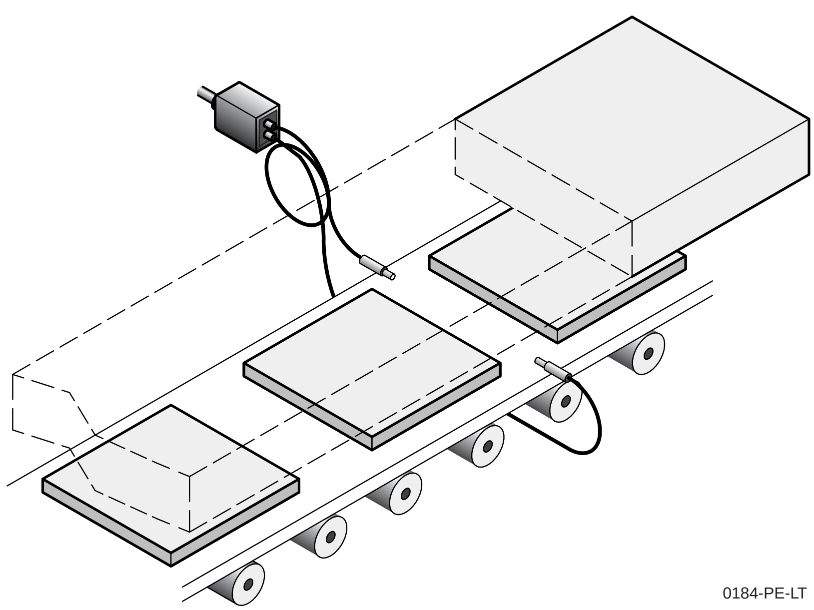
Typical Fiber Optic Applications

Example 7.1:
Cork Detection with Bifurcated Fiber Optic Cable



0183-PE-LT

Example 7.2:
Work Piece Detection with Individual Fiber Optic Cables



0184-PE-LT

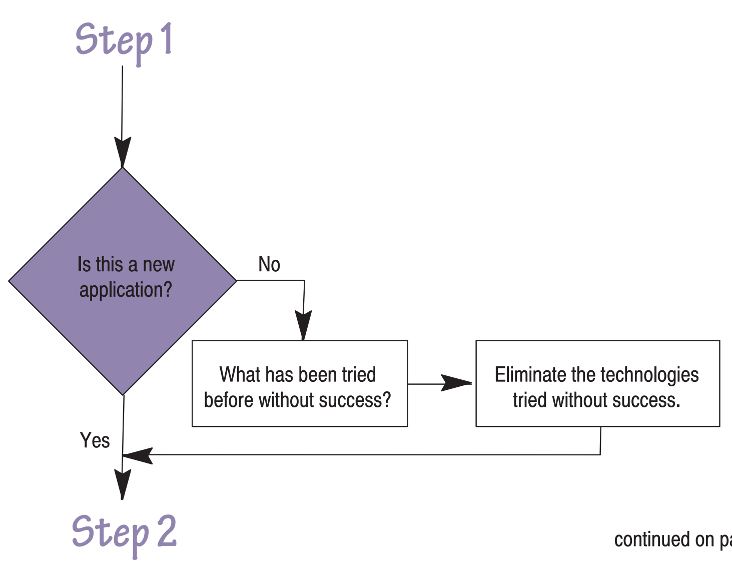
Sensor Selector

The following process addresses important questions that will help you identify the right sensor for your application.

Selecting the Technology

Before you start:

- The experience and sensor knowledge of the customer can eliminate some selections up front.
- Do not advise technology that the user or installer cannot properly set up.
- What is the application? Start with a complete description.



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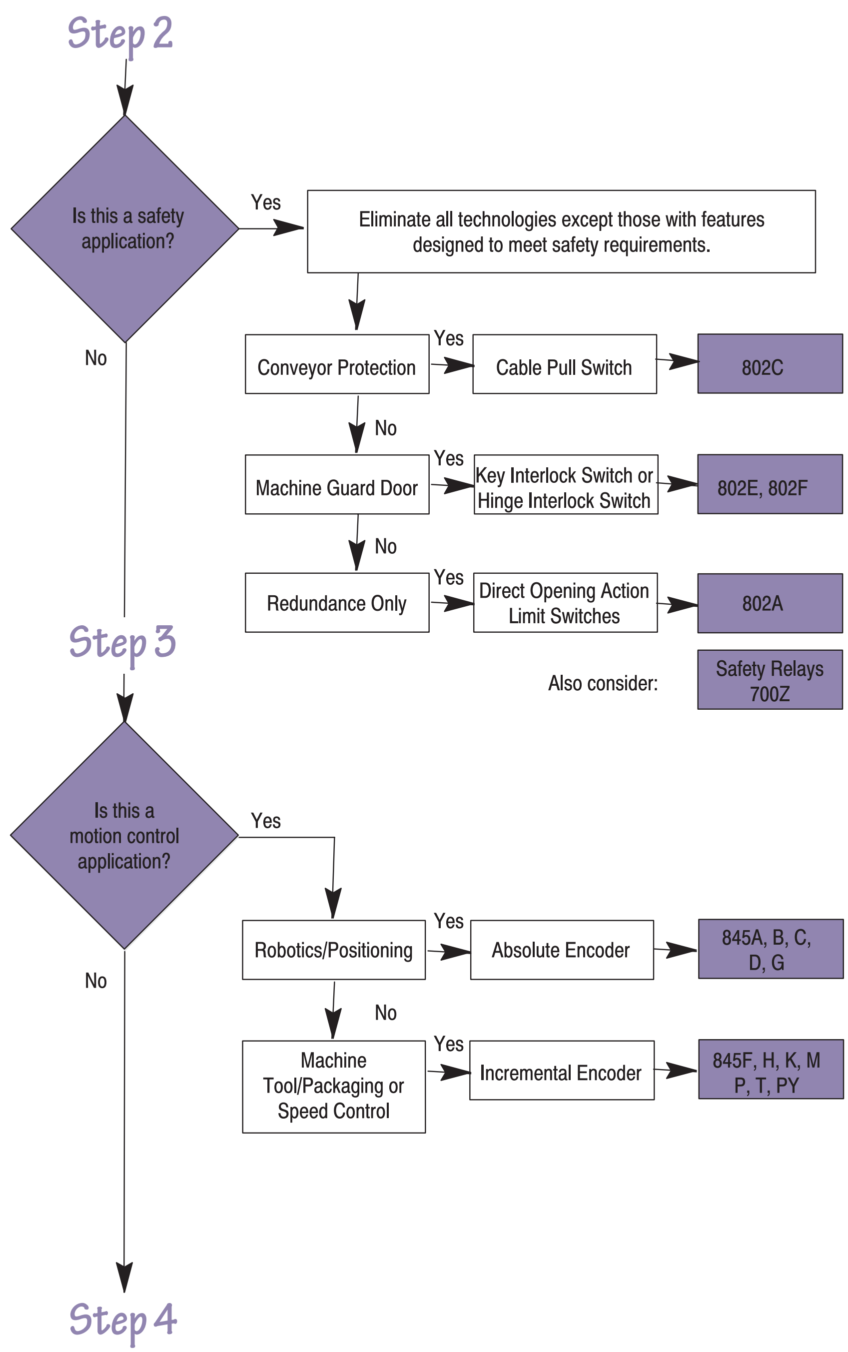

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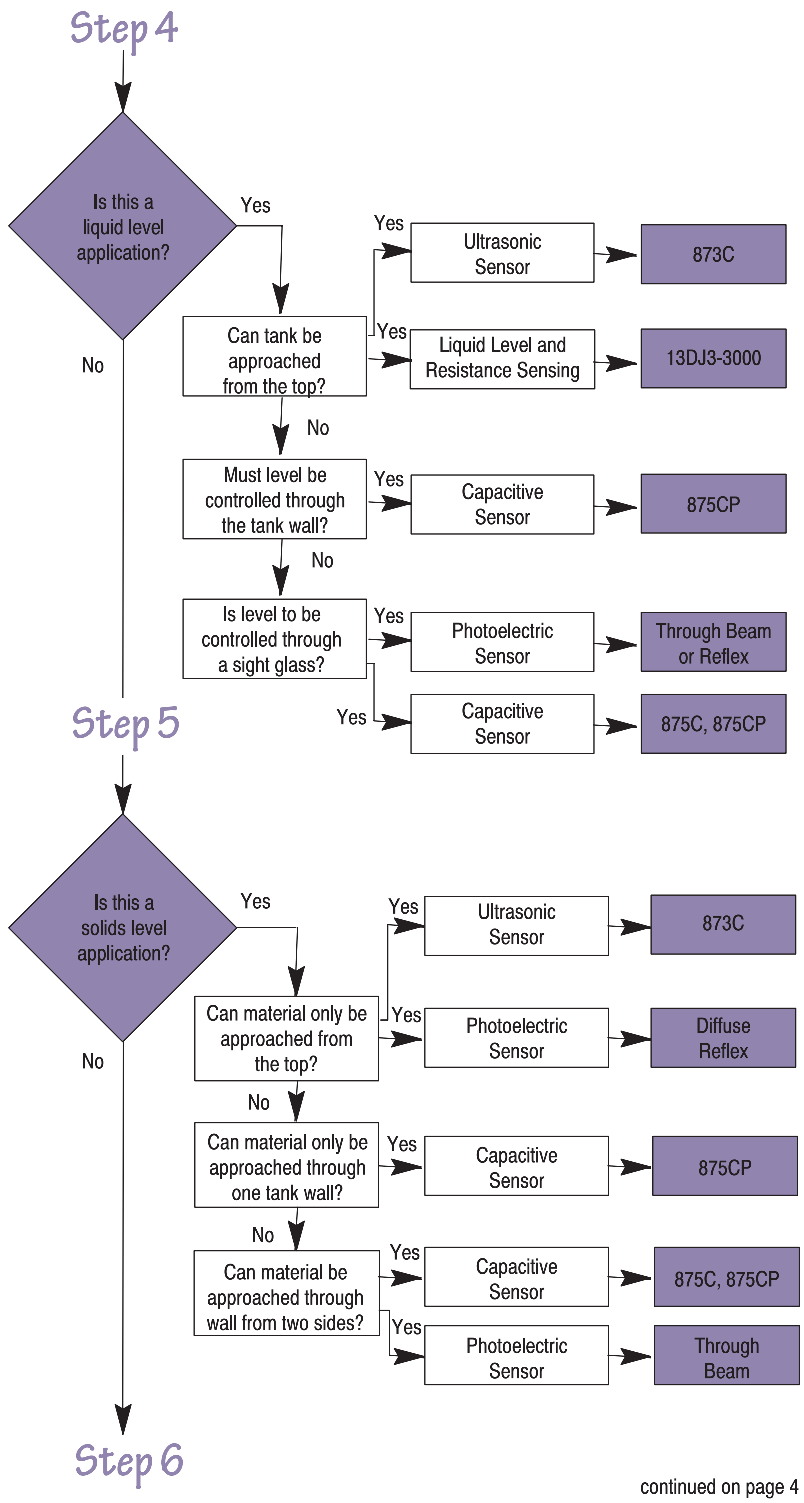

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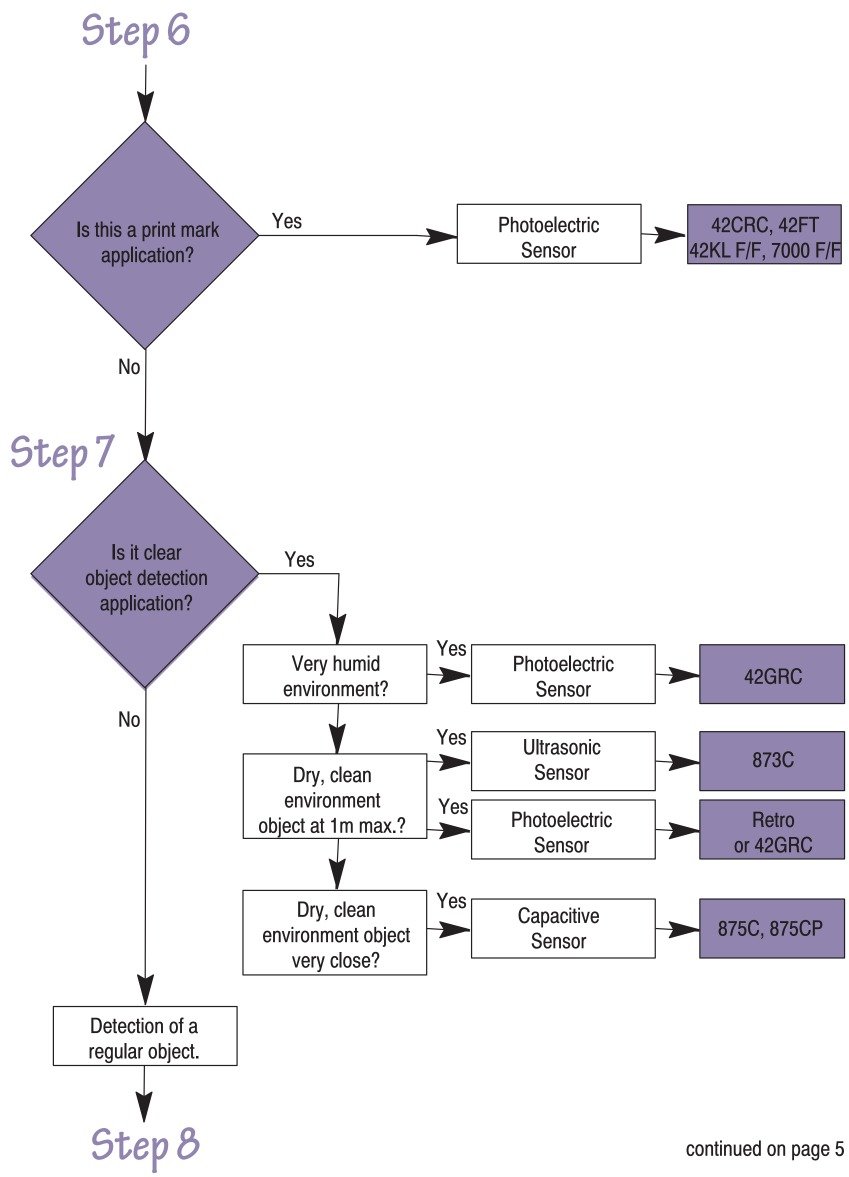

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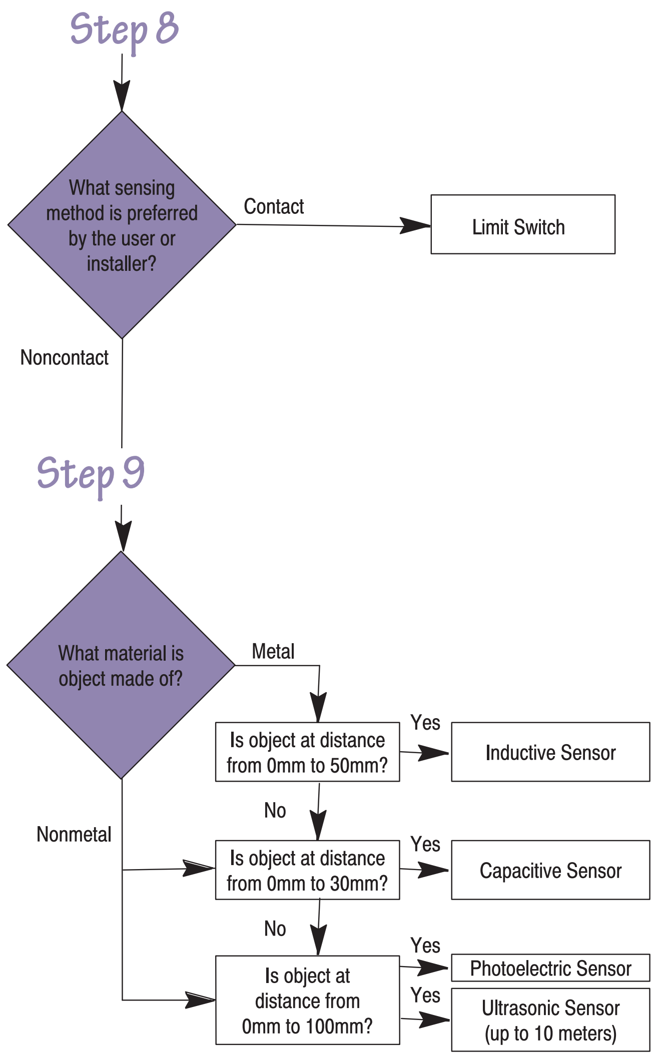


From here on, the selection of technology will depend on the characteristics of the object and on its detectability by the sensing technology.

Rockwell Automation

Sensor Solution Selector

Copy this form and fax it to:
Allen-Bradley Product Support Center: 978/446-3212

Name: ______________________________ Company: ____________________________
Phone: ______________________________ Address: ____________________________
Best Time to Call: ____________________ City: ____________ ST: _______ Zip: _____
Fax: ______________________________
1) Target Object: _____________________ How Oriented? ________________________
2) Color(s): _________________________
3) Texture(s): ________________________ Reflective? ___________________________
4) Speed: ____________________________ Objects/min ft/sec Other ___________
(Circle one)
5) How close can the sensor be to the object? ______________________________
6) Where can the sensor be placed? Above Below 1-Side 2-Sides
7) What do we want to do?
(DIAGRAM)
_____ hold thickness to ± ____________ inches mm.
_____ locate _______ to ± ____________ inches mm.
_____ determine presence of a ________ size object.
_____ thickness/depth/distance to ± ________ resolution.
_____ count a _______________ size object.
_____ other ______________________________________

8) Why is this important? ____
____
9) Other solutions previously tried? _____________________________________
____
10) Environment (dust, high/low temp, corrosion, chemicals, water, etc.) ____________
____
11) Are there any size restrictions on the sensor? __________________________
12) What power sources are available? ____________ 120V AC ____________ 24V DC
13) Is a time delay function required? _____________________________________
14) Any other relevant information? ______________________________________
____

B

IEC & NEMA Enclosures

IEC Enclosures

Degree of Protection

IEC Publication 529 describes standard Degrees of Protection that enclosures of a product are designed to provide when properly installed.

Summary

The publication defines degrees of protection with respect to:

- Persons
- Equipment within the enclosure
- Ingress of water

It does **not** define:

- Protection against risk of explosion
- Environmental protection (e.g. against humidity, corrosive atmospheres or fluids, fungus or the ingress of vermin)

Note: The IEC test requirements for Degrees of Protection against liquid ingress refer only to water. Those products in this catalog, which have a high degree of protection against ingress of liquid, in most cases include Nitrile seals. These have good resistance to a wide range of oils, coolants and cutting fluids. However, some of the available lubricants, hydraulic fluids and solvents can cause severe deterioration of Nitrile and other polymers. Some of the products listed are available with seals of Viton or other materials for improved resistance to such liquids. For specific advice on this subject refer to your nearest Allen-Bradley Sales Office.

IEC Enclosure Classification

The degree of protection is indicated by two letters (IP) and two numerals. International Standard IEC 529 contains descriptions and associated test requirements that define the degree of protection each numeral specifies. The following table indicates the *general* degree of protection — refer to Abridged Descriptions of IEC Enclosure Test Requirements below. **For complete test requirements refer to IEC 529.**

Table 7.3: IEC Enclosure Classification

First Numeral ❶		Second Numeral ❶	
Protection of persons against access to hazardous parts and protection against penetration of solid foreign objects.		Protection against ingress of water under test conditions specified in IEC 529.	
0	Nonprotected	**0**	Nonprotected
1	Back of hand; objects greater than 50mm in diameter	**1**	Vertically falling drops of water
2	Finger; objects greater than 12.5mm in diameter	**2**	Vertically falling drops of water with enclosure tilted 15°
3	Tools or objects greater than 2.5mm diameter	**3**	Spraying water
4	Tools or objects greater than 1.0mm in diameter	**4**	Splashing water
5	Dust-protected (dust may enter during specified test but must not interfere with operation of the equipment or impair safety	**5**	Water jets
6	Dust-tight (no dust observable inside enclosure at end of test)	**6**	Powerful water jets
		7	Temporary submersion
		8	Long-term submersion
Example: IP**41** describes an enclosure that is designed to protect against the entry of tools or objects greater than 1mm in diameter and to protect against vertically dripping water under specified test conditions.			
Note: All first numerals and second numerals up to and including characteristic numeral **6**, imply compliance also with the requirements for all lower characteristic numerals in their respective series (first or second). Second numerals **7** and **8** do **not** imply suitability for exposure to water jets (second characteristic numeral **5** or **6**) unless dual coded; e.g., **IP_5/IP_7**.			
❶ The IEC standard permits use of certain supplementary letters with the characteristic numerals. If such letters are used, refer to IEC 529 for the explanation.			

Abridged Descriptions of IEC Enclosure Test Requirements

(Refer to IEC 529 for complete test specifications — e.g., test apparatus configuration; tolerances; etc.)

Tests for Protection Against Access to Hazardous Parts (first characteristic numeral)

The first characteristic numeral of the IP number indicates compliance with the following tests for the degree of protection against access to hazardous parts. It also indicates compliance with tests as shown in the next section for the degree of protection against solid foreign objects.

The protection against access to hazardous parts is satisfactory if *adequate clearance* is kept between the specified access probe and hazardous parts. For voltages less than 1000V AC and 1500V DC, the access probe must not touch the hazardous live parts. For voltages exceeding 1000V AC and 1500V DC, the equipment must be capable of withstanding specified dielectric tests with the access probe in the most unfavorable position.

IP0_ — No test required.

IP1_ — A rigid sphere 50mm in diameter shall not completely pass through any opening. Force = 50 N.

IP2_ — A jointed test finger 80mm long and 12mm in diameter may penetrate to its 80mm length, but shall have adequate clearance as specified above, from hazardous live parts, in every possible position of the test finger as both joints are bent through an angle up to 90°. Force = 10 N.

IP3_ — A test rod 2.5mm in diameter shall not penetrate and adequate clearance shall be kept from hazardous live parts (as specified above). Force = 3 N.

IP4_ — A test wire 1mm in diameter shall not penetrate and adequate clearance shall be kept from hazardous live parts. Force = 1 N.

IP5_ — A test wire 1mm in diameter shall not penetrate and adequate clearance shall be kept from hazardous live parts. Force = 1 N.

IP6_ — A test wire 1mm in diameter shall not penetrate and adequate clearance shall be kept from hazardous live parts. Force = 1 N.

Tests for Protection Against Solid Foreign Objects (first characteristic numeral).

For first numerals **1**, **2**, **3** and **4** the protection against solid foreign objects is satisfactory if the full diameter of the specified probe does not pass through any opening. Note that for first numerals **3** and **4** the probes are intended to simulate foreign objects which may be spherical. Where shape of the entry path leaves any doubt about ingress or a spherical object capable of motion, it may be necessary to examine drawings or to provide special access for the object probe. For first numerals **5** and **6** see test descriptions below for acceptance criteria.

IP0_ — No test required.

IP1_ — The full diameter of a rigid sphere 50mm in diameter must not pass through any opening at a test force of 50 N.

IP2_ — The full diameter of a rigid sphere 12.5mm in diameter must not pass through any opening at a test force of 30 N.

IP3_ — A rigid steel rod 2.5mm in diameter must not pass through any opening at a test force of 3 N.

IP4_ — A rigid steel wire 1mm in diameter must not pass through any opening at a test force of 1 N.

IP5_ — The test specimen is supported inside a specified dust chamber where talcum powder, able to pass through a square-meshed sieve with wire diamter 50mm and width between wires 75mm, is kept in suspension.

Enclosures for equipment subject to thermal cycling effects (category 1) are vacuum pumped to a reduced internal pressure relative to the surrounding atmosphere: maximum depression = 2 kPa; maximum extraction rate = 60 volumes per hour. If extraction rate of 40 to 60 volumes/hr. is obtained, test is continued until 80 volumes have been drawn through or 8 hr. has elapsed. If extraction rate is less than 40 volumes/hr. at 20 kPa depression, test time = 8 hr.

Enclosures for equipment not subject to thermal cycling effects **and** designated category 2 in the relevant product standard are tested for 8 hr. without vacuum pumping.

Protection is satisfactory if talcum powder has not accumulated in a quantity or location such that, as with any other kind of dust, it could interfere with the correct operation of the equipment or impair safety; and no dust has been deposited where it could lead to tracking along creepage distances.

IP6_ — All enclosures are tested as category 1, as specified above for **IP5_**. The protection is satisfactory if no deposit of dust is observable inside the enclosure at the end of the test.

Tests for Protection Against Water (second characteristic numeral)

The second characteristic numeral of the IP number indicates compliance with the following tests for the degree of protection against water. For numerals **1** through **7**, the protection is satisfactory if any water that has entered does not interfere with satisfactory operation, does not reach live parts not designed to operate when wet, and does not accumulate near a cable entry or enter the cable. For second numeral **8** the protection is satisfactory if no water has entered the enclosure.

IP_0 — No test required.

IP_1 — Water is dripped onto the enclosure from a “drip box” having spouts spaced on a 20mm square pattern, at a “rainfall” rate of 1mm/min. The enclosure is placed in its normal operating position under the drip box. Test time = 10 min.

IP_2 — Water is dripped onto the enclosure from a “drip box” having spouts spaced on a 20mm square pattern, at a “rainfall” rate of 3mm/min. The enclosure is placed in 4 fixed positions tilted 15° from its normal operating position, under the drip box. Test time = 2.5 min. for each position of tilt.

IP_3 — Water is sprayed onto all sides of the enclosure over an arc of 60° from vertical, using an oscillating tube device with spray holes 50mm apart (or a hand-held nozzle for larger enclosures). Flow rate, oscillating tube device = 0.07 l/min. per hole x number of holes; for hand-held nozzle = 10 l/min. Test time, oscillating tube = 10 min.; for hand-held nozzle = 1 min./m^2 of enclosure surface area, 5 min. minimum.

IP_4 — Same as test for **IP_3** except spray covers an arc of 180° from vertical.

IP_5 — Enclosure is sprayed from all practicable directions with a stream of water at 12.5 l/min. from a 6.3mm nozzle from a distance of 2.5 to 3m. Test time = 1 min./m^2 of enclosure surface area to be sprayed, 3 min minimum.

IP_6 — Enclosure is sprayed from all practicable directions with a stream of water at 100 l/min. from a 12.5mm nozzle from a distance of 2.5 to 3m. Test time = 1 min./m^2 of enclosure surface area to be sprayed, 3 min. minimum.

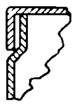
IP_7 — Enclosure is immersed in water in its service position for 30 min. Lowest point of enclosures less than 850mm tall = 1000mm below surface of water. Highest point of enclosures more than 850mm tall = 150mm below surface of water.

IP_8 — Test conditions are subject to agreement between manufacturer and user, but shall be at least as severe as those for **IP_7**.

NEMA Enclosures

Specify the Correct Enclosure for Your Motor Controls

Type 1 General Purpose Surface Mounting



Type 1 enclosures are intended for indoor use primarily to provide a degree of protection against contact with the enclosed equipment in locations where unusual service conditions do not exist. The enclosures are designed to meet the rod entry and rust-resistance design tests. Enclosure is sheet steel, treated to resist corrosion.

Type 1 Flush Mounting

Flush mounted enclosures for installation in machine frames and plaster wall. These enclosures are for similar applications and are designed to meet the same tests as Type 1 surface mounting.

Type 3

Type 3 enclosures are intended for outdoor use primarily to provide a degree of protection against windblown dust, rain and sleet; and to be undamaged by the formation of ice on the enclosure. They are designed to meet rain❶, external icing❷, dust, and rust-resistance design tests. They are not intended to provide protection against conditions such as internal condensation or internal icing.

Type 3R

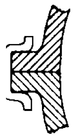
Type 3R enclosures are intended for outdoor use primarily to provide a degree of protection against falling rain, and to be undamaged by the formation of ice on the enclosure. They are designed to meet rot entry, rain❸, external icing❷, and rust-resistance design tests. They are not intended to provide protection against conditions such as dust, internal condensation, or internal icing.

Type 4

Type 4 enclosures are intended for indoor or outdoor use primarily to provide a degree of protection against windblow dust and rain, splashing water, and hose-directed water; and to be undamaged by the formation of ice on the enclosure. They are designed to meet hosedown, dust, external icing❷, and rust-resistance design tests. They are not intended to provide protection against conditions such as internal condensation or internal icing. Enclosures are made of heavy gauge stainless steel, cast aluminum or heavy gauge sheet steel, depending on the type of unit and size. Cover has a synthetic rubber gasket.

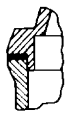
❶ Evaluation criteria: No water has entered enclosure during specified test.
❷ Evaluation criteria: Undamaged after ice that built up during specified test has melted (Note: **Not required to be operable while ice-laden.).**
❸ Evaluation criteria: No water shall have reached live parts, insulation or mechanisms.

Type 3R, 7 & 9 Unilock Enclosure for Hazardous Locations



This enclosure is cast from "copper-free" (less then 0.1%) aluminum and the entire enclosure (including interior and flange areas) is bronze chromated. The exterior surfaces are also primed with a special epoxy primer and finished with an aliphatic urethane paint for extra corrosion resistance. The V-Band permits easy removal of the cover for inspection and for making field modifications. This enclosure meets the same tests as separate Type 3R, and Type 7 and 9 enclosures. For Type 3R application, it is necessary that a drain be added.

Type 4X Nonmetallic, Corrosion-Resistant Fiberglass Reinforcement Polyester



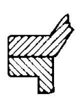
Type 4X enclosures are intended for indoor or outdoor use primarily to provide a degree of protection against corrosion, windblown dust and rain, splashing water, and hose-directed water; and to be undamaged by the formation of ice on the enclosure. They are designed to meet the hosedown, dust, external icing❷, and corrosion-resistance design tests. They are not intended to provide protection against conditions such as internal condensation or internal icing. Enclosure is fiberglass reinforced polyester with a synthetic rubber gasket between cover and base. Ideal for such industries as chemical plants and paper mills.

Type 6P

Type 6P enclosures are intended for indoor or outdoor use primarily to provide a degree of protection against the entry of water during prolonged submersion at a limited depth; and to be undamaged by

the formation of ice on the enclosure. They are designed to meet air pressure, external icing ❷, hosedown and corrosion-resistance design tests. They are not intended to provide protection against conditions such as internal condensation or internal icing.

Type 7 For Hazardous Gas Locations Bolted Enclosure



Type 7 enclosures are for indoor use in locations classified as Class I, Groups C or D, as defined in the National Electrical Code. Type 7 enclosures are designed to be capable of withstanding the pressures resulting from an internal explosion of specified gases, and contain such an explosion sufficiently that an explosive gas-air mixture existing in the atmosphere surrounding the enclosure will not be ignited. Enclosed heat generating devices are designed not to cause external surfaces to reach temperatures capable of igniting explosive gas-air mixtures in the surrounding atmosphere. Enclosures are designed to meet explosion, hydrostatic, and temperature design tests. Finish is a special corrosion-resistant, gray enamel.

Type 9 For Hazardous Dust Locations

Type 9 enclosures are intended for indoor use in locations classified as Class II, Groups E, F, or G, as defined in the National Electrical Code. Type 9 enclosures are designed to be capable of preventing the entrance of dust. Enclosed heat generating devices are designed

❷ Evaluation criteria: Undamaged after ice that built up during specified test has melted (Note: **Not required to be operable while ice-laden.).**

not to cause external surfaces to reach temperatures capable of igniting or discoloring dust on the enclosure or igniting dust-air mixtures in the surrounding atmosphere. Enclosures are designed to meet dust penetration and temperature design tests, and aging of gaskets. The outside finish is a special corrosion-resistant gray enamel.

Type 12

Type 12 enclosures are intended for indoor use primarily to provide a degree of protection against dust, falling dirt, and dripping noncorrosive liquids. They are designed to meet drip❶, dust, and rust-resistance tests. They are not intended to provide protection against conditions such as internal condensation.

Type 13

Type 13 enclosures are intended for indoor use primarily to provide a degree of protection against dust, spraying of water, oil, and noncorrosive coolant. They are designed to meet oil exclusion and rust-resistance design tests. They are not intended to provide protection against conditions such as internal condensation.

Enclosures

Refer to the brief descriptions below for the various types of enclosures offered by Rockwell Automation/Allen-Bradley. For definitions, descriptions and test criteria, see National Electrical Manufacturers Association (NEMA) Standards Publication No. 250. Also see individual product listings within the Rockwell Automation/Allen-Bradley catalog for available enclosure types and for any additional information relating to these descriptions.

Note: Enclosures do not normally protect devices against conditions such as condensation, icing, corrosion or contamination that may occur within the enclosure or enter via the conduit or unsealed openings. Users must make adequate provisions to safeguard against such conditions and satisfy themselves that the equipment is properly protected.

❶ Evaluation criteria: No water has entered enclosure during specified test.

Selection Criteria

Table 7.4: Enclosures for Nonhazardous Locations

For a Degree of Protection Against:	Designed to Meet Tests No. ❶	Type							
		For Indoor Use			Outdoor Use		Indoor or Outdoor		
		1	12	13	3R	3	4	4X	6P
Incidental contact with enclosed equipment	6.2	√	√	√	√	√	√	√	√
Falling dirt	6.2	√	√	√	√	√	√	√	√
Rust	6.8	√	√	√	√	√	√	√	√
Circulating dust, lint, fibers and flyings ❷	6.5.1.2 (2)		√	√		√	√	√	√
Windblown dust	6.5.1.1 (2)					√	√	√	√
Falling liquids and light splashing	6.3.2.2		√	√		√	√	√	√
Rain (Test evaluated per 5.4.2.1)	6.4.2.1				√	√	√	√	√
Rain (Test evaluated per 5.4.2.2)	6.4.2.2					√	√	√	√
Snow and sleet	6.6.2.2				√	√	√	√	√
Hosedown and splashing water	6.7						√	√	√
Occasional prolonged submersion	6.11 (2)								√
Oil and coolant seepage	6.3.2.2		√	√					
Oil or coolant spraying and splashing	6.12			√					
Corrosive agents	6.9				√	√		√	√

❶ See below for abridged description of NEMA enclosure test requirements. Refer to NEMA Standards Publication No. 250 for complete test specifications.
❷ Nonhazardous materials, not Class III ignitable or combustible.

Abridged Description of NEMA Enclosure Test Requirements

6.2 **Rod Entry Test—**A 1/8in diameter rod must not be able to enter enclosure except at locations where nearest live part is more than 4in from an opening — such opening shall not permit a 1/2in diameter rod to enter.

6.3 **Drip Test—**Water is dripped onto enclosure for 30 minutes from an overhead pan having uniformly spaced spouts, one every 20sq in of pan area, each spout having a drip rate of 20 drops per minute. Evaluation 6.3.2.2: No water shall have entered enclosure.

6.4 **Rain Test—**Entire top and all exposed sides are sprayed with water at a pressure of 5 psi from nozzles for one hour at a rate to cause water to rise 18in in a straight–sided pan beneath the enclosure. Evaluation 6.4.2.1: No water shall have reached live parts, insulation or mechanisms. Evaluation 6.4.2.2: No water shall have entered enclosure.

6.5.1.1 (2) **Outdoor Dust Test (Alternate Method)—** Enclosure and external mechanisms are subjected to a stream of water at 45 gallons per minute from a 1in diameter nozzle, directed at all joints from all angles from a distance of 10 to 12ft. Test time is 48 seconds times the test length (height + width + depth of enclosure in ft), or a minimum of 5 minutes. No water shall enter enclosure.

6.5.1.2 (2) **Indoor Dust Test (Alternate Method)—**Atomized water at a pressure of 30 psi is sprayed on all seams, joints and external operating mechanisms from a distance of 12 to 15in at a rate of three gallons per hour. No less than five ounces of water per linear foot of test length (height + length + depth of enclosure) is applied. No water shall enter enclosure.

6.6 **External Icing Test—**Water is sprayed on enclosure for one hour in a cold room (2×C); then room temperature is lowered to approximately –5×C and water spray is controlled so as to cause ice to build up at a rate of 1/4in per hour until 3/4in thick ice has formed on top surface of a 1in diameter metal test bar, then temperature is maintained at –5×C for 3 hours. Evaluation 6.6.2.2: Equipment shall be undamaged after ice has melted (external mechanisms not required to be operable while ice–laden).

6.7 **Hosedown Test—**Enclosure and external mechanisms are subjected to a stream of water at 65 gallons per minute from a 1in diameter nozzle, directed at all joints from all angles from a distance of 10 to 12ft. Test time is 48 seconds times the test length (height + width + depth of enclosure in ft), or a minimum of 5 seconds. No water shall enter enclosure.

6.8 **Rust Resistance Test (Applicable only to enclosures incorporating external ferrous parts)—**Enclosure is subjected to a salt spray (fog) for 24 hours, using water with five parts by weight of salt (NaCI), at 35×C, then rinsed and dried. There shall be no rust except where protection is impractical (e.g. machined mating surfaces, sliding surfaces of hinges, shafts, etc.).

6.9 **Corrosion Protection—**Sheet steel enclosures are evaluated per UL 50, Part 13 (test for equivalent protection as G–90 commercial zinc coated sheet steel). Other materials per UL 508, 6.9 or 6.10.

6.11 (2) **Air Pressure Test (Alternate Method)—**Enclosure is submerged in water at a pressure equal to water depth of six ft, for 24 hours. No water shall enter enclosure.

6.12 **Oil Exclusion Test—**Enclosure is subjected to a stream of test liquid for 30 minutes from a 3/8in diameter nozzle at two gallons a minute. Water with 0.1% wetting agent is directed from all angles from a distance of 12 to 18in, while any externally operated device is operated at 30 operations per minute. No test liquid shall enter the enclosure.

Selection Criteria

Table 7.5: Enclosures for Nonhazardous Locations

For a Degree of Protection Against Atmospheres Typically Containing: ❸	Designed to Meet Tests No. ❷	Class (National Electrical Code)	Type						
			7, Class I Group				9, Class II Group		
			A	B	C	D	E	F	G
Acetylene	Explosion Test Hydrostatic Test Temperature Test	I	√						
Hydrogen, Manufactured Gas		I	√	√					
Diethyl Ether, Ethylene, Hydrogen Sulfide		I			√				
Acetone, Butane, Gasoline, Propane, Toluene		I			√	√			
Metal dusts and other combustible dusts with resistivity of less than 10^5 ohm-cm.	Dust Penetration Test Temperature Test with Dust Blanket	II					√		
Carbon black, charcoal, coal or coke dusts with resistivity between 10^2-10^8 ohm-cm.		II						√	
Combustible dusts with resistivity of 10^5 ohm-cm or greater.		II							√
Fibers, flyings	❹	III							√

❶ For indoor locations only unless cataloged with additional NEMA Type enclosure number(s) suitable for outdoor use as shown in table on page General–12. Some control devices (if so listed in the catalog) are suitable for **Division 2 hazardous location use in enclosures for nonhazardous locations. For explanation of CLASSES, DIVISIONS and GROUPS, refer to the National Electrical Code.**Note: Classifications of hazardous locations are subject to the approval of the authority having jurisdiction. Refer to the National Electrical Code.

❷ See abridged description of test requirements below. For complete requirements, refer to UL Standard 698, compliance with which is required by NEMA enclosure standards.

❸ For listing of additional materials and information noting the properties of liquids, gases and solids, refer to NFPA 497M–1991, Classification of Gases, Vapors, and Dusts for Electrical Equipment in Hazardous (Classified) Locations.

❹ UL 698 does not include test requirements for Class III. Products that meet Class II, Group G requirements are acceptable for Class III.

Abridged Description of UL Standard 698 Test Requirements

Explosion Test—During a series of tests in which gas-air mixtures of the specific gas, over its range of explosive concentrations, are ignited inside the enclosure, the enclosure shall prevent the passage of flame and sparks capable of igniting a similar gas-air mixture surrounding the enclosure. In addition, there shall be no mechanical damage to enclosed electrical mechanisms or the enclosure.

Hydrostatic Test—The enclosure shall withstand for 1 minute a hydrostatic test based on the maximum internal explosion pressure developed during the explosion tests, as follows: cast metal, four times the explosion pressure without rupture or permanent deformation; fabricated steel, twice the explosion pressure without permanent deformation and three times the explosion pressure without rupture. Exception: Hydrostatic tests may be omitted if calculations show safety factor of five to one for cast metal and four to one for fabricated steel.

Temperature Test—The enclosed device is subjected to a temperature test to determine maximum temperature at any point on the external surface. The device must be marked with a temperature code based on the result only if the temperature exceeds +100°C (+212°F).

Dust Penetration Test—The device is operated at full rated load until equilibrium temperatures are attained, then allowed to cool to ambient (room) temperature, through six heating and cooling cycles covering at least 30 hours, while continuously exposed to circulating dust of specified properties in a test chamber. No dust shall enter the enclosure.

Temperature Test with Dust Blanket—This test is conducted as described for the Dust Penetration test except that the recirculating dust nozzles are positioned so that the dust is not blown directly on the device under test. The device is operated at full rated load (and under abnormal conditions for equipment subject to overloading) until equilibrium temperatures are attained. Dust in contact with the enclosure shall not ignite or discolor from heat, and the exterior temperatures based on +40°C (+104°F) ambient shall not exceed:

Table 7.6: Temperature Test Guidelines

Group	Normal Operation	Abnormal Operation
E	+200°C (+392°F)	+200°C (+392°F)
F	+150°C (+302°F)	+200°C (+392°F)
G	+120°C (+248°F)	+165°C (+329°F)

C Glossary

A

active face	See sensing face.
actuator	A switch mechanism that when moved as intended, operates the switch contacts. This mechanism transmits the applied force from the actuating device to the contact block, causing the contacts to operate.
actuator free position	The initial position of the actuator when there is no external force (except gravity) applied to the actuator.
actuator operating position	The position of the actuator when the contacts operate.
actuator reset position	The position of the actuator at which the contacts move from the operated position to the “normal” position.
alignment	Positioning of light source and receiver, reflector, or object so the maximum amount of the emitted light energy reaches the receiver’s photodetector.
alternating current (AC)	A sinusoidal current rated at a given frequency, usually 50Hz or 60Hz.
ambient	The environmental conditions in a sensing area (temperature, light level, humidity, air contamination).
ambient light	Illumination of a receiver that its light source does not generate, or light from an external source in addition to light radiated by the source of the photoelectric device onto the device’s detector.

Ampère (A)	A unit of measurement of electric current. One Volt across one Ohm of resistance causes a current flow of one Ampère. One Ampère is equal to 6.28 x 10^{18} electrons passing a point in one second.
analog output	A sensor output that varies over a range of voltage (or current) and is proportional to some sensing parameter (as opposed to a digital output). The output on an analog photoelectric sensor is proportional to the strength of the received light signal. The output of an analog ultrasonic proximity sensor is proportional to the distance from the sensor to the object that is returning the sound echo.
AND logic	A logic function in which two or more inputs wired in series must be closed to energize the output.
angular reflection scanner	A photoelectric proximity switch in which the optical axes of the light sender and light receiver form an angle (DIN 440 30).
anode	The positive electrode of a device. See diode.
anti-glare filter	See polarizing filter.
ANSI	American National Standards Institute, a body which promotes standards for the industry in North America.
aperture	The size of a lens opening or a mechanical part/external cap attached to a lens that restricts the size of a lens opening, therefore, limiting the size of the effective beam.
attenuation	The reduction of signal strength or loss or reduction of beam intensity resulting from environmental factors, such as dust, dirt, humidity, steam, or other contaminants in the sensing area.
autocollimation	Reflecting principle in which a light beam striking a reflector is reflected parallel to itself.
axial approach	The approach of the target with its center maintained on the reference axis. See reference axis.

B

background suppression sensing	A diffuse photoelectric sensing mode with a defined range limit, used in areas where a reflective background is close to the object.
barrier	See intrinsic safety barrier.
beam-break	See transmitted beam.
beam pattern	A sensor's light dispersion shown graphically.
bending radius	See minimum bending radius.
bifurcated fiber (optic)	A fiber optic assembly that is branched to combine emitted light with received light in the same assembly.
bipolar output	See complementary output.
blind zone	The minimum distance between an object and a sensor in order for the sensor to be able to detect the object.
break	To open an electrical circuit. See normally closed (N.C.).
burn-through	The ability of transmitted beam sensors to "see" through paper, thin cardboard, opaque plastics, and materials of similar optical density.

C

capacitive sensor	Capacitive proximity sensors are triggered by a change in the surrounding electrostatic field. The transducer of a capacitive sensor is configured to act as the plate of a capacitor. The dielectric property of any object present in the sensing field increases the capacitance of the transducer circuit and, in turn, changes the frequency of an oscillator circuit. A detector circuit senses this change in frequency and signals the output to change state.
cascade	To combine logic circuitry to get more complex logic or timing control. (Inputs and outputs are wired in series.)

CENELEC — The European Committee for Electrotechnical Standardization. Responsible for the development of standards covering dimensional and operating characteristics of control components. Similar in nature to ANSI.

chatter — Continuously switch on and off, instead of stable contact closure or opening.

collimation — See autocollimation.

complementary output —

1. Output circuit with dual output devices where one output is normally open and the other is normally closed or de-energized. Output that can be both light operated and dark operated. Also known as 4-wire DC controls.
2. The dual output configuration of a DC sensing device where one output switch is a sinking device (NPN transistor) and the other output switch is a sourcing device (PNP transistor).

component system — See separate controls.

contact bounce — When the contact pair closes, the contacts make and break several times before a stable closed condition is established. Contact bounce is *not* a characteristic of solid-state switch contacts.

continuous load current — The maximum current level allowed to continuously flow through the sensor output in the ON state.

contrast (optical) — See fixed focus.

control base — Unit remote from light source/photoreceiver (or proximity sensor) in which amplification and conditioning or the input signal takes place. Usually contains a power supply and an output device.

convergent beam sensing mode — See margin.

corner-cube reflector — See retroreflector.

correction factors — Suggested multiplication factors taking into account variations in the target material composition. When figuring actual sensing distance this factor should be multiplied with the nominal sensing distance.

crosstalk (acoustical) (electrical) (optical)

Acoustical: occurs when an ultrasonic sensor responds to the signal from an adjacent ultrasonic sensor. Can often be minimized by installing baffles between the sensors and/or extension tubes ahead of the sensing face.

Electrical: occurs in modulated photoelectrics when the modulated emitter signal couples directly onto the receiver lead wires, which results in a "lock-on" condition of the output circuitry.

Optical: occurs when a photoelectric receiver responds to light from an adjacent emitter.

CSA

Abbreviation for Canadian Standards Association. A testing agency. "CSA certified" are products type tested and approved by the Canadian Standards Association as meeting Canadian electrical and safety codes.

current consumption

The amount of current required to power a sensor or control excluding its load.

current sinking

See sinking.

current sourcing

See sourcing.

D

dark operate mode (D.O. or D/O)

The program mode of a photoelectric sensor in which the output circuit energizes (or delay logic begins) when light intensity on the photodetector has sufficiently decreased below the threshold of the photodetector.

delay logic

A timing function which alters an output's response.

delayed one-shot

Timing logic in which an input signal initiates an adjustable delay period, at the end of which the output pulses for an adjustable pulse ("hold") time. The input signal may be either momentary or maintained. No further action occurs until the input signal is removed and then re-applied, at which time the sequence begins again.

depth-of-field

See maximum sensing distance.

diagnostic	Advanced warning signal of potential loss of control output due to ambient changes.
differential, switching	See hysteresis.
differential travel (travel to reset contacts)	The angle or distance through which the actuator moves from the contact operating position to the actuator free position, or the distance between the operating point and the release point. See hysteresis.
diffuse sensing mode	A photoelectric proximity sensing mode in which the light from the emitter strikes a surface of an object at some arbitrary angle and is detected when the receiver captures some small percentage of the diffused light. Also called the "direct reflection mode" or the photoelectric "proximity mode."
digital output	An output circuit or sensor output with only two operating states, either "ON" or "OFF." These operating states often are called "Hi" or "Low."
DIN	"Deutsches Institute für Normung." German committee for standardization.
diode	A two-layer semiconductor that allows current to flow in only one direction and inhibits current flow in the other direction.
direct current (DC)	A current that flows only in one direction through a circuit. As ordinarily used, the term designates a practically nonpulsating current.
direct opening action contacts	Achievement of contact separation as the direct result of a specified movement of the switch actuator through nonresilient members.
direct scan	See transmitted beam.
double break contacts	Contacts which break the circuit in two places.
DPDT relay	Abbreviation for "Double-Pole Double-Throw." A relay with two single-pole double-throw contacts operated simultaneously by a single action. See SPDT.
drift	A change in operate point.

dual output — See complementary output.

dwell-time — The adjustable or fixed time length of an output pulse, independent of input signal duration.

E

ECKO — See Eddy Current Killed Oscillator principle.

eddy currents — Currents induced on the surface of a conducting mass by the rate of change in magnetic flux.

Eddy Current Killed Oscillator principle — Proximity sensors are generally constructed with four main elements: a coil and ferrite core assembly, an oscillator, a convertor/detector, and an output device. The oscillator creates a radio frequency field that is shaped and defined by the coil and core. As a target is placed in this field, eddy currents are generated in the surface of the target. The oscillator, being a limited power device, will lower (kill) its amplitude as the eddy currents are generated. The convertor/detector rectifies the AC signal to DC and compares it to a preset value. The output is triggered when a difference in value is measured.

effective beam — The portion of a beam that must be sufficiently interrupted for an object to be reliably sensed.

electromagnetic interference (EMI) — Electrical noise that may interfere with proper operation of sensors, programmable logic controllers, counters, data recorders, and other sensitive electronic equipment. Common sources of EMI include lighting fixtures and controls, motors, generators, and contactors.

embeddable — See shielded sensor.

emitter (photoelectric) — The light source within any photoelectric sensor (LED, incandescent bulb, laser diode).

enclosure rating — Classification of the protection of electrical equipment from electric shock, foreign bodies, and water.

excess gain — See margin.

explosion-proof	Hazardous location term that refers to explosion containment.

F

Factory Mutual Research (FM)	Organization that tests and approves products for use in hazardous areas.
false pulse	Unwanted change of state of the output usually occurring during power on or power down action.
false pulse protection	Circuitry designed to avoid false pulses during power on or power down action or to disable the output of a sensor or sensing system until the power supply circuit has time to stabilize at the proper voltage level.
ferrous	Composed of and/or containing iron. Exhibits magnetic characteristics.
ferrule	Tip of a fiber optic cable.
FET (Field Effect Transistor)	Semiconductors used as an output based on their ability to switch either AC or DC, their low on-state voltage drop, and their low off-state leakage current. Not tolerant of inrush current typical of inductive loads.
fiber optics	Transparent fibers of glass or plastic used for conducting and guiding light energy. Used in photoelectrics as "light pipes" to conduct sensing light into and out of a sensing area.
field of view	The region that the light source illuminates and that the receiver sees. This refers to the area of response of a photoelectric sensor (receiver). Field of View is expressed in degrees but is three dimensional, represented as a conical shape.
filter	Optical filters that let through light waves in particular wavelength ranges and block other wavelength ranges.
fixed focus sensing mode	A special variation of diffuse mode photoelectric sensing that uses additional optics to create a small, intense, and well defined image at a fixed distance from the front surface of the sensor lens. Fixed focus sensing is the first choice for

photoelectric sensing of small objects that remain within the sensor's depth of field.

flush mounting See shielded sensor.

flux, magnetic The lines of force in a magnetic field generated by an inductive coil.

free zone The area around the proximity switch which must be kept free from any damping material, such as metal that will adversely effect sensor's reliable target detections.

G

gain adjustment See sensitivity adjustment.

gate A circuit, having one output, that only actuates when a specific combination of input events is achieved.

gating The provision to apply an external signal to a sensor to prevent undesirable operation.

glass fiber optics See fiber optics.

ground A conducting path, between an electric circuit and the earth. In power distribution systems it refers to earth ground. Refers to conduit or machine frame ground. In electronic systems, it refers to the electronic chassis or enclosure ground or to DC common (voltage references to the negative side of a DC power supply.)

H

hermetic seal An air-tight seal. In photoelectrics, the lens assemblies of some sensors have hermetic seals to exclude the entrance of air and water behind the lens, thereby preventing fogging of the inner surface of the lens. In limit switches are hermetic seal contacts prevent contact surface contamination.

Hertz (Hz) The international unit of frequency, equal to one cycle per second.

holding current — The current drawn by a load while it is energized. Also called "sealed current" of a load.

hysteresis — The difference in percentage of the nominal sensing distance between the operate (switch on) and release point (switch off) when the target is moving away from the sensor's face. Without sufficient hysteresis a proximity sensor will "chatter" (continuously switch on and off) when there is significant vibration applied to the target or sensor.

I

IEC — The International Electrotechnical Commission, headquartered in Geneva, Switzerland. This organization writes and distributes recommended safety and performance standards for electrical products and components.

impedance — The opposition in an electric circuit to the flow of alternating current (AC) at a given frequency. Impedance consists of resistance, inductive reactance, and capacitive reactance. It is measured in Ohms.

individual fiber (optic) — A fiber optic assembly having one control end and one sensing end.

inductance — The property of an electric circuit whereby an electromotive force (emf) is induced in it by a change of current in itself or in a neighboring circuit.

inductive load — Electrical devices generally made of coiled wire to create a magnetic field to, in turn, produce mechanical work when energized. Inductive loads exhibit inrush of current when energized that can be many times the steady state holding current. When de-energized, the magnetic field collapses, generating a high voltage transient. This transient can cause arcing across mechanical switching contacts or can cause damage to solid-state contacts. Examples of inductive loads include motors, solenoids, and relays. See transient.

inductive proximity sensor — Sensors with an oscillator and coil that radiate an electromagnetic field that induces eddy currents on the surface of metallic objects approaching the sensor face. Typically, the eddy currents dampen the oscillator energy. This energy loss is sensed as a voltage drop, that causes a

	change in the sensor's output state. Often called a "proximity sensor."
infrared	Invisible light energy starting at a wavelength of 690 nanometer and longer. Infrared LEDs are used as an emitter type in photoelectric sensors. See LED (Light Emitting Diode).
input	The signal applied to a circuit to indicate either the status of machine or process, or used to initiate controlled actions.
inrush current	The initial surge of current through a load when power is first applied. Inrush current to an inductive load (solenoid, contactor) can be up to 20 times the holding current.
interrogate	See gate.
intrinsic safety	A design technique applied to electrical equipment (sensors and switches) and wiring for hazardous locations. The technique involves limiting electrical and thermal energy to a level below that required to ignite a specific hazardous atmosphere.
intrinsic safety barrier	A protective component designed to limit the voltage and current in a hazardous area. The barrier functions outside of the hazardous location to divert abnormal energy to ground.
IP rating	A rating system established by IEC standard 529 that defines the suitability of sensor and sensor system enclosures for various environments. Similar to NEMA ratings for enclosures.
isolated output	An output optically and/or electrically separated from the rest of the control system.

K

L

laser	An active electron device that converts input power into a narrow, intense beam of visible or infrared light. Term derived from "Light Amplification by Stimulated Emission Radiation."

laser diode	A silicon-based miniature electronic laser light source.
latch (latching logic)	A logic function in which an input signal locks “on” the output. The output remains “on” until a signal is applied as a second input to reset the latch.
lateral approach	The approach of the target perpendicular to the reference axis. See reference axis.
LED (Light Emitting Diode)	A solid state “light” source that generates various colors of light.
leakage current	The small amount of undesirable current inherent in solid-state switches when they are in the “off” state. Becomes important if the resultant “off-stage” voltage across the load being switched is too high for the load to de-energize.
lens	The optical component of a photoelectric sensor that focuses emitted light rays and/or focuses light rays upon the receiver.
light emitting diode	See LED (Light Emitting Diode).
light frequency	Frequency of modulated light.
light operate mode (L.O. or L/O)	The program mode for a photoelectric sensor in which the output energizes (or delay logic begins) when the light intensity on the photodetector has sufficiently increased.
linear output	The output of an analog sensor that has a straight-line relationship to a sensing parameter i.e., sensing distance.
line voltage	Typical AC control power from 100V to 250V AC.
load	A general term for a device or a circuit that draws power when switched by another device or circuit.
load current	The maximum amount of current that a sensor will switch through its load.
logic	The modification of an input signal that produces delayed, pulsed, latched, or other output response.
logic level	Refers to the state of an input to or an output from a digital circuit (not applicable to analog circuits). It is always at one of only two possible voltages: “low” is a voltage usually less than

2 volts measured with respect to ground; and "high" is a voltage of some nominal level, usually within 2 volts of the positive supply.

logic module — A sensing system accessory that interprets one or more input signals from sensors and modifies those input signals for control of a process.

M

margin indication — An LED used to signal adequate light intensity or a warning of inadequate light intensity.

maintained contact switch — Contacts remain closed after release of actuator until reset.

make — To close or establish an electrical circuit. See normally open (N.O.).

margin — A measurement of light reaching the photodetector over the minimum light required to operate the sensor's amplifier by crossing its threshold level. The calculation is expressed as a whole number ratio. In equation form:

$$\text{Margin} = \frac{\text{Light energy reaching the receiver}}{\text{Amplifier threshold}}$$

Margin, plotted versus sensing distance, is used to predict the reliability of a photoelectric with consideration for ambient conditions. Optimizing margin increases the reliability of the sensor.

maximum load current — The maximum amount of current that can flow through a sensor and not cause sensor failure.

maximum inrush current — The maximum current level at which the sensor can be operated for a short period of time.

maximum operating distance — See maximum sensing distance.

maximum sensing distance — The longest distance at which a sensor can detect a target under optimal conditions.

maximum travel	See total travel.
mechanical convergence	A separate emitter and receiver pair is angled toward a common point, at a desired distance from the controls.
microsecond	One millionth of a second. 1 microsecond = 0.000001 second. Abbreviated: µs.
millisecond	One thousandth of a second. 1 millisecond = 0.001 second. Abbreviated: ms.
minimum bending radius	The minimum radius a fiber optic bundle can withstand without breaking the fibers.
minimum load current	The minimum amount of current a sensor requires to maintain reliable operation.
minimum operating distance	See minimum sensing distance.
minimum sensing distance	The lower limit of the specified sensing range of an ultrasonic or photoelectric sensor.
modulated light source	An LED that emits pulsed light, permitting a photoelectric sensor to ignore ambient light.
momentary switch	A switch with contacts that return from operated condition to normal condition when actuating force is removed.
MOV (metal oxide varistor)	A component designed to protect solid-state output devices and electronic equipment from damage.

N

N.C.	See normally closed (N.C.).
N.O.	See normally open (N.O.).
NPN output	See sinking.
nanometer (nm)	Unit of length used to specify the wavelength of light energy. 1nm = 0.00000001 meter (10^{-9} meter). Some typical

wavelengths: red LEDs are 650nm, green LEDs are 560nm, infrared LEDs are 880 or 940nm.

NEMA	National Electrical Manufacturers Association. NEMA defines standards for electrical control components in the United States.
noise (electrical)	Undesirable energy which causes devices to operate erratically.
nominal sensing distance	The nominal sensing distance is measured from the face of the sensor to the nearest point of the target. Steel is used as the standard target when nominal sensing distance is stated.
non-embeddable	See unshielded.
nonferrous metal	Any metal which does not contain iron, or shows no magnetic tendencies.
non-incendive	Inability under normal operation to ignite a hazardous mixture.
normal contact position	The position of the contacts when no operating force is applied.
normally closed (N.C.)	Output "opens" in actuated state; output is "closed" in rest (normal) state.
normally high	See normally closed.
normally low	See normally open.
normally open (N.O.)	Output "closes" in actuated state; output is "open" in rest (normal) state.
nor logic	A circuit, where no inputs are closed, and yet, the output is energized.

O

off delay	Timing logic in which the output energizes immediately when an input signal is present. The off-delay timing begins at the trailing edge of the input signal, keeping the output energized. If a new input signal is received during the off-

delay timing, the timer is reset, and the off-delay period begins again at the trailing edge of the new input signal. The output de-energizes after removal of input and trailing edge triggered timer expires.

off state current See leakage current.

Ohm Unit of measurement for resistance and impedance. The resistance through which a current of one Ampère will flow when one Volt is applied.

Ohm's law E = I x R. Current (I) is directly proportional to Voltage (E) and inversely proportional to total resistance (R) of a circuit.

on delay Timing logic in which timing begins at the leading edge of an input signal, but the output is energized only after the preset on-delay time has elapsed. The output ceases immediately at the trailing edge of the input signal. If the input signal is not present for the on-delay time period, no output occurs. If the input signal is removed momentarily and then re-established, the on-delay timing starts over again from the beginning.

on delay one-shot Timing logic that combines on delay and one-shot timing into a single function. The input signal must be present for at least the time of the on-delay in order for a timed one-shot pulse to occur. See one-shot.

one-shot Timing logic in which a timed output pulse begins at the leading edge of an input signal. The pulse is always of the same duration, regardless of the length of the input signal. The output cannot re-energize until the input signal is removed and then re-applied.

on/off delay Timing logic that combines on delay and off delay timing into a single function.

opaque A term used to describe a material that blocks the passage of light energy. "Opacity" is the relative ability of a material to obstruct the passage of light.

open-collector A term used to describe the NPN or PNP output of a DC device, where the collector of the input transistor is not connected to any other part of the output circuit except through a diode for protection. See sinking (NPN output), sourcing (PNP output).

operating contact position	The position to which the contacts move when the actuator is deflected to or beyond the actuator operating position.
operating distance, assured	See sensing distance, nominal.
operating distance, rated	See sensing distance, nominal.
operating force	The straight line force in the designed direction applied to the switch actuator to cause the contacts to move to the operated position.
operating margin	See margin.
operating mode	Refers to the specific intensity level (either light or dark) that initiates a photoelectrics output circuit. See light operate mode (L.O. or L/O), dark operate mode (D.O. or D/O).
operating temperature	Actual range over which sensors can be operated. Usage outside the temperature limits will result in loss of stability, change in operate point, and possible permanent damage to the sensor. Nominal sensing distance is determined at 25°C.
operating torque	The torque that must be applied to the actuator to cause the moving contact to move to the operated contact position.
opposed sensing mode	See transmitted beam.
optical crosstalk	When a photoelectric receiver responds to the signal from an adjacent emitter.
optical power	Power or intensity of the projected light available from a particular emitter; beam intensity.
OR logic	A logic function in which the presence of any defined input condition causes a load to energize (A or B or C = output). Usually created by wiring all outputs in parallel to a load.
oscillation	A periodic change in a variable, such as in the wave amplitude of an alternating current.
output	An electrical device, either solid state or contact, that directs power to actuate a load or provide system status indication.

overload protection	The ability of a sensor to withstand load currents between continuous load rating and a short-circuit condition with no damage.
over travel	The movement of the actuator beyond the contact operating position.

P

PNP output	See sourcing.
parallel circuit	A circuit in which current has two or more paths to follow.
passive pull-up	See pull-up resistor.
photodiode	A semiconductor diode in which the reverse current varies with illumination. Characterized by linearity of its output over several magnitudes of light intensity, very fast response time, and wide range of color response.
photoelectric sensor	A device recognizing changes in light intensity which energizes an output circuit.
photoelectric transducer	See photodiode.
plastic fiber optics	See fiber optics.
polarized light	Light that has all component waves in the same orientation. Natural light is made up of waves having a variety of orientations. Photoelectric sensors with polarizing filters emit and detect light waves of a specific polarization while rejecting unwanted light of other polarizations.
polarizing filter	A plastic sheet that orients most light passing through it into a single plane.
power dissipation	The amount of power consumed and converted to heat in normal operation (watts/milliwatts (DC) or Volt-Amps (AC)).
power indicator	An indicator (usually an LED) that signals that the operating voltage is applied to a sensor.

precision snap-action switch — An electromechanical switch having predetermined and accurately controlled characteristics and having a spring-loaded quick make and break contact action.

pretravel — Travel to operate the contacts from the actuator free position.

programmable output — Output which can be changed from N.O. to N.C. or N.C. to N.O. by way of a switch or jumper wire.

proximity sensing mode — See diffuse sensing mode.

proximity sensor — A device used to sense the closeness of an object by using the object as the target. Proximity sensing methods include:

1. Inductive (metal sensing),
2. Capacitive, and
3. Ultrasonic

Photoelectrics, operating in diffuse mode, can be considered proximity sensors.

pull-down resistor — A resistor connected across the output of a device or circuit to hold the output equal to or less than zero. Usually connected to a negative voltage or ground.

pull-up resistor — A resistor connected to the output of a device to hold that output voltage higher than the input transition level. Usually a resistor connected between the output of a sinking (NPN) device and the positive supply voltage of a logic gate.

pulse — A sudden fast change of a normally constant or relatively slow changing value such as voltage, current or light intensity. A pulse is characterized by a rise and fall and has a finite duration.

R

radio frequency interference (RFI) — Interference caused by electromagnetic radiation at radio frequencies to sensitive electronic circuitry. RFI may originate from radio control equipment, stepper motor controls, CRTs, computers, walkie-talkies, public service communications, commercial broadcast stations, or a variety of other sources. RFI occurs most often at a specific frequency or within a specific range of frequencies. As a result, one electronic instrument may be radically affected by the presence of RF interference, while another similar instrument in the same area may appear completely immune.

range See sensing range.

rate sensor Timing logic in which overspeed or underspeed conditions are sensed by a circuit that continuously monitors and calculates the time between input signals, and compares that time with a preset reference.

receiver An electronic component, sensitive to light intensity or ultrasonic waves, that is combined with associated circuitry and output devices.

rectifier A device that converts alternating current into direct current.

red light Visible light in the red range between 600 and 780nm. Red LEDs emit in the red-light range with a wavelength of 630 to 690nm.

reference axis A perpendicular axis passing through the center of the sensor face.

reflection The return of light striking the boundary between two media. Regular or specular reflection is reflection in which the light is returned in only one direction. If it is scattered in a number of directions, the reflection is called "diffuse."

reflectivity (relative) An efficiency measurement of any material surface as a reflector of light, as compared to a Kodak white test card that is arbitrarily rated at 90% reflectivity. Relative reflectivity is of great importance in photoelectric diffuse modes where the more reflective an object is, the easier it is to sense.

reflector See retroreflector.

reflex See retroreflective mode.

refraction The "bending" of light rays as they pass through the boundary from a medium having one refractive index into a medium with a different refractive index. For example, as from air into water or from air into glass or plastic.

registration mark	Typically a contrasting mark, printed on packaging material. This mark is used as the cutoff reference point in wrapping, bagging, and crimping applications.
remote sensor	The optical components of a separate photoelectric sensor that are positioned separate from the power, output, and associated circuitry.
repeat-cycle timer	Logic function where an output is cycled through specific on and specific off time durations as long as the input is present.
repeatability	The repeat accuracy of a sensor's operating distance measured at standardized test temperature and constant voltage.
resistance	The opposition to the flow of electric current. That property of a material that impedes electrical current and results in the dissipation of power in the form of heat. Resistance is measured in Ohms.
resistor	A device that restricts the flow of electrons in an electric circuit.
response time	The time required for the output of a sensor to respond to a change of the input signal. Response time of a sensor becomes extremely important when detecting small objects moving at high speed. Narrow gaps between adjacent objects also must be considered when verifying that sensor response is fast enough for an application. Required Sensor Response Time = Apparent object (gap) size as it passes the sensor Velocity of the object as it passes the sensor. Also known as response speed. See switching frequency.
retriggerable	One of two types of one-shot timing logic. The output pulse of a retriggerable one-shot is restarted with the re-occurrence of every input. The output will remain "on" as long as the time between consecutive inputs is shorter than the one-shot pulse time.
retroreflective sensing mode	A sensor, containing emitter and receiver, that establishes a light beam between a retroreflector and itself. An object is "sensed" when it interrupts this beam.

retroreflector — A standard target used to return the emitted light directly back to the sensor. The most efficient type have corner-cube geometry. Reflective tapes use glass beads or smaller, less efficient corner-cubes.

reverse polarity protection — A circuit that uses a diode to avoid damage to the control in case the polarity of the power supply is accidentally reversed.

ripple — An AC voltage component on the output of a DC power supply. The alternating component of voltage from a rectifier or generator. A slight fluctuation in the intensity of a steady current. Usually expressed as a percentage of the supply voltage. Ripple may be suppressed ("smoothed") with capacitor filtering. Most DC-only devices require less than about 10% ripple for reliable operation.

rise time (10% levels) — The time required for an analog voltage or current output value to rise from a low to high level.

S

saturation voltage — See voltage drop.

scan technique — See sensing mode.

scanner — See photoelectric sensor.

scanning distance — See sensing distance.

selectable output — See programmable output.

self-contained control — A photoelectric or proximity control in which control sensing, signal conditioning, and output occur in a single device.

semiconductor — An electronic component material whose resistance varies when exposed to fluctuating energy levels.

sensing distance — The distance between the sensor and a standard target at which the sensor will effectively and reliably detect the target.

sensing distance, nominal — See nominal sensing distance.

sensing end	The end of any fiber optic cable at which objects to be sensed are located. See bifurcated fiber (optic), individual fiber (optic).
sensing face	A surface of the proximity sensor parallel to the target, from which operating distance/range is measured, along the reference axis.
sensing mode	The arrangement of components (emitters, receivers, reflectors, etc.) in a sensing application.
sensing range	**Transmitted beam mode**: the distance from the emitter to the receiver. **Retroreflective mode**: the distance from the sensor to the retroreflector. **Diffuse mode**: the distance from the sensor to the object being sensed. See transmitted beam mode, retroreflective mode, diffuse mode.
sensitivity adjustment	An adjustment that determines the sensor's ability to discriminate between different levels of light or ultrasonic waves. Sometimes called the "gain adjustment."
separate controls	A system in which sensors are remote from power supply, amplifier, logic device, and output switching device.
series circuit	A circuit in which current has only one path to follow.
series operation	See AND logic.
shielded sensor	Sensor which can be flush mounted in metal up to the plane of the sensing face and that "senses" only to the front of its face.
short circuit protection	The ability of a solid-state output device or circuit to endure operation in a shorted condition indefinitely or for a defined period of time with no damage.
signal ratio	Broadly, the comparison of light seen by a light detector when the beam is blocked, to the light seen when the beam is not blocked. See margin.
signal strength indicator	See margin indication.
sinking	The output of a DC device that switches ground (DC common) to a load. The load is connected between the output of the

device and the positive side of the power supply. The switching component is usually an open collector NPN transistor with its emitter tied to the negative side of DC supply voltage.

skew angle
Used when mounting retroreflective and diffuse sensors to optimize sensing conditions.

Diffuse mode: it reduces background reflections; sensor is angled so its beam strikes background at an angle other than 90°.

Retroreflective mode: skewing is done to reduce the amount of light reflected directly back by the object; sensor and reflector are angled so beam strikes at angle other than 90°.

slow make–slow break
A type of contact; force is applied to operate the contacts without any overcenter mechanism. Contacts move at a speed directly related to the speed of operation of the actuator. Contact force is directly related to the amount of contact movement. Contacts may touch with little contact pressure.

snap action
A rapid motion of contacts from one position to another position. The motion is a constant and is independent from the speed with which the switch actuator is moved. Contact pressure is stable due to spring tension.

snap action/IEC direct opening action
This contact structure is very similar to the snap action contact with one addition, continued operation of the operating mechanism beyond the normal snap action position applies force directly to the normally closed (N.C.) contact, if it does not open with the snap action mechanism. This force is applied after the overcenter mechanism. For example, if a contact has a snap action operating point at 40° rotary movement, the direct opening action point may be in the area of 60° or more. No direct opening action forces are applied to the N.O. contact as it changes from an operated closed state to its normal state.

solid state
Circuits and components using semiconductors without moving parts. Example: transistors, diodes, etc.

sourcing
The output of a DC device that switches positive DC to a load. The load is connected between the output of the device and the ground (DC common) side of the power supply. The switching component is usually an open collector PNP

transistor with its emitter tied to the positive side of the supply voltage.

span — Used to describe the maximum voltage or current in an analog output range. Analog sensors have an adjustment for setting the span value.

specular sensing mode — A photoelectric sensing mode where an emitter and a receiver are mounted at equal and opposite angles from the perpendicular to a highly reflective (mirror-like) surface. The distance from the shiny surface to the sensors must remain constant.

spectral sensitivity — A photodetector's ability to "see" the different wavelengths (color) of light.

SPDT — Single Pole Double Throw: a set of contacts of which one is "open" when the other is "closed."

SPST — Single Pole Single Throw: relay with a single contact that is either normally open or normally closed.

standard target — See target.

status indicator — An LED used to signal that the sensor has switched state.

supply current — The amount of current necessary to maintain operation of a photoelectric sensor, proximity sensor, or control base. Sometimes referred to as "current consumption."

supply voltage — The range of power required to maintain proper operation of a photoelectric sensor, proximity sensor, or control base.

switching frequency — The maximum number of times per second the sensor can change state (ON and OFF). Usually expressed in Hertz (Hz).

switching threshold — See threshold.

T

target —

1. Standardized object used to establish sensing range capabilities of sensor.
2. Also, the part or piece being detected.

thermal drift chart	A chart illustrating sensor operating variance due to changes in temperatures.
three-wire proximity switch	An AC or DC proximity sensor with three leads, two of which supply power and a third that switches the load.
threshold	The voltage in a photoelectric control circuit that causes the output of the sensor to change state. This voltage level is directly related to the amount of light that has reached the photoelectric receiver. The threshold is the value of received signal representing a margin of 1x. The sensitivity control (where one is available) adjusts the threshold voltage level.
through-beam sensing mode	See transmitted beam.
time delay before availability	See false pulse protection.
total travel	The sum of the pretravel and the overtravel.
transducer	A device that converts energy of one form into another form. Used where the magnitude of the applied energy is converted into a signal that varies proportionately to the applied energy's variations.
transient	A very short pulse of voltage (or current) that is many times larger in magnitude than the supply voltage. Transients are usually caused by the operation of a heavy resistive load or of any size inductive load like motors, contactors, and solenoids.
transient protection	Circuitry to guard against spikes induced on the supply lines by inductive sources, such as heavy motors or solenoids turning on and off.
transistor	A tiny chip of crystalline material, usually silicon, that amplifies or switches electric current.
translucent	Term used to describe materials that allow light to pass through.
transmission	Passage of light through a medium. If the light is scattered, it is "diffuse transmission."

transmitted beam — A photoelectric sensing mode in which the emitter and receiver are positioned opposite each other so the light from the emitter shines directly at the receiver. An object then breaks the light beam established between the two.

triac — A solid-state switching element used for AC control voltage. Typically has low current capacity and high leakage current.

trigger — A pulse used to initiate control signal switching through the appropriate circuit paths.

two-wire sensor — A sensor designed to wire in series with its load, exactly like a limit switch. A 2-wire sensor with a solid-state output remains powered when the load is "off" by a residual "leakage current" that flows through the load.

U

UL — Underwriter's Laboratories, Inc., a nonprofit organization that establishes, maintains, and operates laboratories for the examination and testing of devices, systems, and materials primarily for safety. Compliance is indicated by their listing mark on the product.

ultrasonic — Sound energy at frequencies just above the range of human hearing, above 20kHz.

unshielded — Sensors which have longer sensing distances and a wider magnetic field but are sensitive to surrounding metal.

V

Volt — The unit of potential or electromotive force. Commonly abbreviated as V.

voltage — Term used to designate the electrical energy differential that exists between two points and is capable of producing a flow of current when a closed path is connected between the two points.

voltage drop — The voltage that occurs across a solid-state device when its output is driving a load, or the voltage that exists across each element of a series circuit. The magnitude of the voltage drop is dependent upon the circuit demand of the load.

W

waveform A geometric shape as obtained by displaying a characteristic of voltage or current as a function of time. AC line voltage produces a sine wave shape.

wavelength Distance traveled by light while completing one complete sine wave. Is expressed in nanometer (nm). Each color has a specific wavelength.

weld field immunity (WFI) The ability of a sensor not to false trigger in the presence of strong electromagnetic fields.

white paper response A calibration procedure performed on retroreflective sensors to eliminate all response to white paper with 90% reflectance.

wide angle diffuse A photoelectric sensing mode where the lenses spread the emitted/received light over a large area. The angle of these lenses is typically 60° or greater. The sensor's maximum range is reduced, but allows for small object sensing in a wide field of view.

Z

zener diode An electronic component used as a voltage regulator based on its energy dissipation characteristics and ability to stop reverse flow.