Photoelectric sensors are used in many applications and industries to provide accurate detection of objects without physical contact.

In its most basic form, a photoelectric sensor can be thought of as a “limit switch-like” device, where the mechanical actuator or lever arm function is replaced by a beam of light.

Photoelectric sensors operate by sensing a change in the amount of light that is either reflected or blocked by an object to be detected (target). The change in light could be the result of the presence or absence of the target, or as the result in a change of the size, shape, reflectivity or color of a target.

A photoelectric sensor can be used in applications to sense targets at distances from less than 5mm (0.2in) to over 250m (820ft).

Successful sensing with a photoelectric sensor requires that the object to be detected (target) causes a sufficient change of light level detected by the sensor and that the user has a clear understanding of the sensing requirements.

The following must be clearly understood:

- The sensing requirements,
- The sensing environment, and
- The capabilities and limitations of the photoelectric sensor.

Be prepared to answer the following questions:

- What is the size, shape and/or opacity of the object to be detected?
- Does the object to be detected have any reflective properties?
- What response time is required of the sensor?
- What mounting configuration is required for the sensor? Are there position or physical restraints to consider?
- What is the frequency of operation and what requirement does the operating rate impose on the output device?
- What are the load requirements, such as voltage, current, load impedance?
- What voltage and current supply are available to operate the sensor?
- What is the ambient temperature surrounding the photoelectric sensor?
- Are there other environmental conditions such as dirt or high humidity that are unique to the area surrounding the photoelectric sensor?

There are a vast number of photoelectric sensors to choose from. Each offers a unique combination of sensing performance, output characteristics and mounting options. Many sensors also offer unique embedded logic or device networking capabilities.

This introduction will help you select the optimal photoelectric sensor for each application.

Basic Concepts and Components

There are four basic components to any photoelectric sensor:

- Light source
- Light detector
- Lenses
- Output switching device

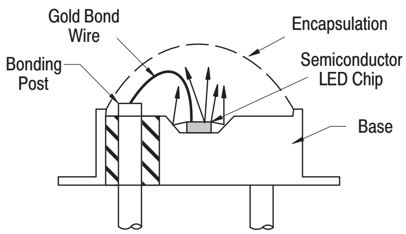
Light Source

A light emitting diode (LED) is a solid-state semiconductor that emits light when current is applied. *Figure 1* shows the construction of an LED. LEDs are made to emit specific wavelengths or colors of light. Infrared, visible red, green, and blue LEDs are used as the light source (emitter) in most photoelectric sensors.

Different LED colors offer different desirable characteristics. Infrared LEDs are the most efficient, they generate 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.

Figure 1
LED Light-Emitting Diode



Visible red, blue, and yellow LEDs are also used in special applications where specific colors or color contrasts must be detected. These LEDs are also used as status indicators on photoelectric sensors.

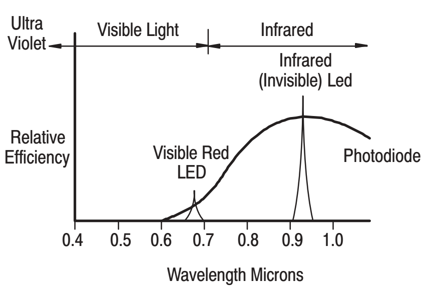
LEDs are rugged and reliable components, making them ideal for use in photoelectric sensors. They operate over a wide temperature range and are very resistant to damage from shock and vibration.

Light Detector

A photodetector is the component used to detect the light source. A photodiode or phototransistor is a robust solid-state component that provides a change in conducted current depending on the amount of light detected.

Photodetectors are more sensitive to certain wavelengths of light. The spectral response of a photodetector determines its sensitivity to different wavelengths in the light spectrum. To improve sensing efficiency, the LED and photodetector are often spectrally matched. An example is shown in *Figure 2*.

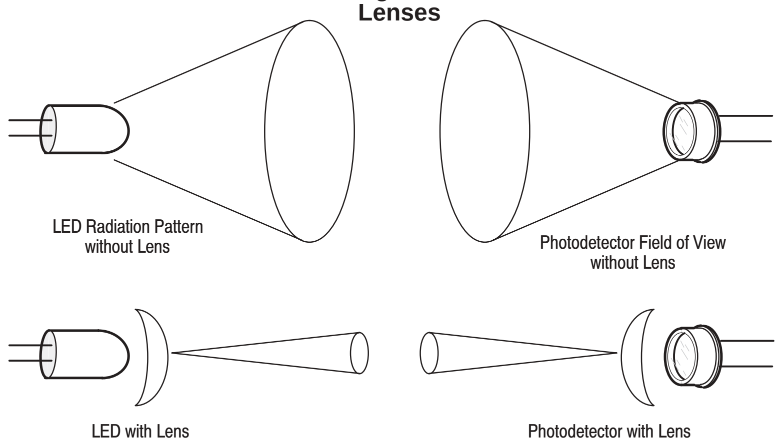
Figure 2
Spectral Response



The invisible (infrared) LED is a spectral match for this silicon phototransistor, and has much greater efficiency than a visible (red) LED.

The photodetector and associated circuitry are referred to as the receiver.

Figure 3
Lenses



Lens

LEDs typically emit light and photodetectors are sensitive to light over a broad area. Lenses are used with LED light sources and photodetectors to narrow this area. As the area is narrowed, the range of the LED or photodetector increases. As a result, lenses also increase the sensing distance of photoelectric sensors (see *Figure 3*).

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

Some photoelectric sensors are optimized for extra sensing distance. The light beam (or field of view) emitted by 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.

Output Device

Once a sufficient change of light level is detected, the photoelectric sensor switches an output device to provide an interface to machine logic. Many types of discrete and variable (analog) outputs are available, each with particular strengths and weaknesses. Refer below to “Output Devices” for information about each type.

Margin

Margin (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 example:

- 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.

LED Modulation

The amount of light generated by the LED in the light source 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 an upper limit 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, see *Figure 4*.

Figure 4
Modulation

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

Synchronous Detection

The receiver is designed to detect a pulsed light source 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.

Synchronous detection is only possible when the light source and receiver are in the same housing, which is true for all sensing modes except transmitted beam as explained below.

Photoelectric Sensing Modes

Different methods of sensing are referred to as sensing modes. There are three basic types:

- Transmitted beam (sometimes called through-beam or thru-beam)
- Retroreflective (sometimes referred to as reflex)
- Diffuse (also known as proximity)
- While many applications can be handled by any of these sensing modes, each offers specific strengths and weaknesses to consider. These strengths and weaknesses are summarized in *Table 1.*

Transmitted Beam

In this mode (*Figure 5*) the light source and receiver are contained in separate housings. These two units are positioned opposite each other so that the light from the light source shines directly on the receiver. Targets must break (block) the beam between light source and receiver.

Figure 5
Transmitted Beam Sensing

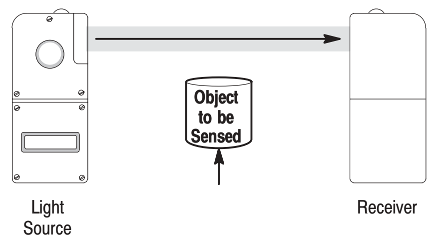


Table 1
Photoelectric Sensing Modes Advantages and Cautions

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 of 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 • Ease of 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 backgrounds that are close to the object.	• Access to both sides of the object not required • Provides some protection against sensing of close backgrounds • Detects objects regardless of color within specified distance	• Only useful for very short distance sensing • Not used with backgrounds close to object
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 targets 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 distance sensing

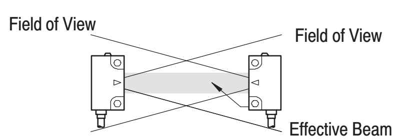
Transmitted beam sensors provide the longest sensing distances and the highest level of operating margin. For example, PHOTOSWITCH® Series 4000B Transmitted Beam sensors are capable of sensing distances of up to 274m (900ft).

Transmitted beam application margins at ranges of less than 10m (3.1ft) can exceed 10,000X. For this reason, transmitted beam is the best sensing mode when operating in very dusty or dirty industrial environments.

Another example: Series 9000 Transmitted Beam photoelectric sensors offer 300X margin at a sensing distance of 3m (9.8ft). At this distance, these sensors will continue to operate even if 99.67% of the combined lens area of the light source and receiver is covered with contamination.

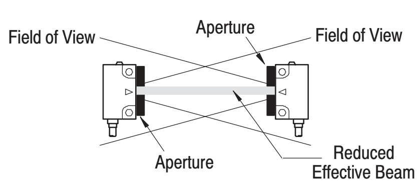
The "effective beam" of a transmitted beam sensor is equivalent to the diameter of the lens on the light source and receiver (*Figure 6*). Reliable detection occurs when the target is opaque and breaks at least 50% of the effective beam.

Figure 6
Effective Beam



Detection of objects smaller than the effective beam can best be achieved by reducing the beam diameter through means of apertures placed in front of the light source and receiver (*Figure 7*). Apertures are available for most 42KL, 42KB and 42EF transmitted beam sensors. Some users have created their own apertures for other sensor families.

Figure 7
Effective Beam with Apertures



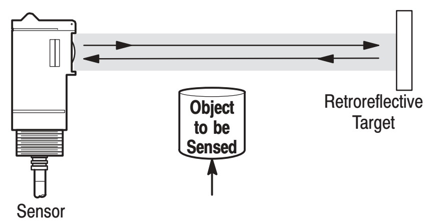
The most reliable transmitted beam applications have a very high margin when the target is absent, and a margin of zero (or close to zero) when the target is present.

Transmitted beam sensing may not be suitable for detection of translucent or transparent targets. The high margin levels allow the sensor to "see through" these targets. While it is often possible to reduce the sensitivity of the receiver, retroreflective or diffuse sensing may provide a better solution.

Retroreflective

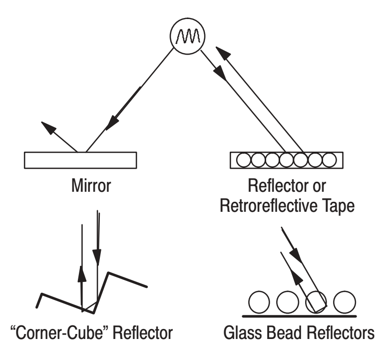
Retroreflective (reflex) is the most popular sensing mode. A retroreflective sensor contains both the light source and receiver in one housing. The light beam emitted by the light source is reflected by a special reflective object and detected by the receiver. The target is detected when it breaks this light beam (*Figure 8*).

Figure 8
Retroreflective Sensing



Special reflectors or reflective tapes are used for retroreflective sensing. Unlike mirrors or other flat reflective surfaces, these reflective objects 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 the sensing system (see *Figure 9*).

Figure 9
Retroreflective Materials



A wide selection of reflectors and reflective tapes are available.

The maximum available sensing distance of a sensor and reflector will depend in part upon the efficiency of the reflector or reflective tape. These reflective materials are rated with a reflective index (refer to page 1–386).

The PHOTOSWITCH standard 78mm (3in) diameter round reflector (catalog number 92–39) is used to determine the maximum sensing distance of most PHOTOSWITCH sensors.

The 92–39 reflector has a reflective index of 100. The 92–99 reflective tape has a reflective index of 77 meaning that it will reflect only 77% as much light as a 92–39 reflector.

Retroreflective sensors are easier to install than transmitted beam sensors. Only one sensor housing must be installed and wired. However, margins when the target 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 targets must be sensed. Reflections from the target itself may be detected. It may be possible to orient the sensor and reflector or reflective tape so that the shiny target reflects light away from the receiver. However, for most applications with shiny targets, *polarized retroreflective* sensing offers a better solution.

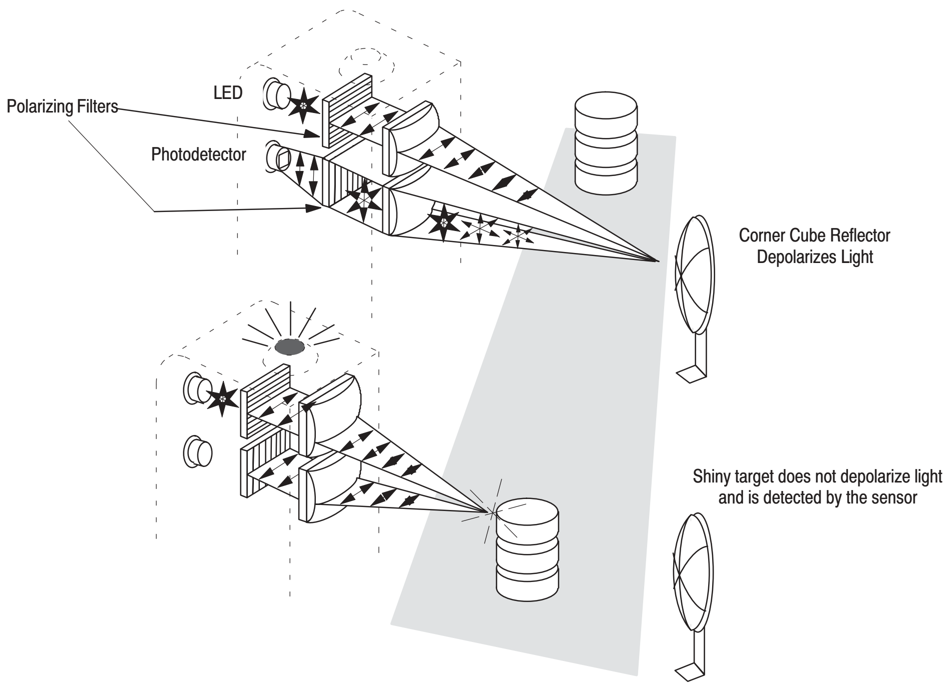
Polarized retroreflective sensors contain polarizing filters in front of the light source and receiver. These filters are perpendicular or 90° out of phase with each other (*Figure 10*).

The sensor cannot see light reflected by most targets. The reflected polarized light cannot pass through the polarizing filter located in front of the receiver.

Reflectors depolarize reflected light. Some of the reflected depolarized light can pass though the polarizing filter in front to the receiver and can be detected by the sensor.

In summary, the sensor can "see" the reflection from a reflector, and it cannot "see" the reflection from most shiny targets.

Figure 10
Polarized Retroreflective Sensing



Polarized retroreflective sensors offer 30%–40% shorter range (and less margin) than standard retroreflective sensors. Instead of infrared LEDs, polarized retroreflective sensors must use a less efficient visible light source (typically a visible red LED). There are additional light losses caused by the polarizing filters.

Polarized sensors will 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 that are detected by the receiver when it is wrapped in clear plastic film. In the latter case, the shiny object becomes the "second surface" behind the plastic wrap. Other sensing modes must be considered for these applications.

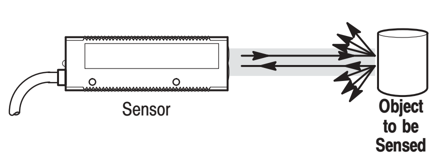
All standard reflectors depolarize light and are suitable for polarized retroreflective sensing. However, most reflective tapes do not depolarize light and are suitable only for use with standard retroreflective sensors. Specially constructed reflective tapes for polarized retroreflective sensing are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

Diffuse

Transmitted beam and standard or polarized retroreflective sensing creates a beam of light between light source and receiver or between sensor and reflector. Access to opposite sides of the target is required.

Sometimes it is difficult, or even impossible, to obtain access on both sides of a target. In these applications, it is necessary to point the light source directly at the target. Light is scattered by the surface at all angles and a small portion is reflected back to be detected by the receiver contained in the same housing. This mode of sensing is called diffuse or proximity (see *Figure 11*).

Figure 11
Diffuse Sensing



A sensing mode in which light strikes an object surface, is diffused from the surface at all angles and detected by the sensor.

There are a number of different types of diffuse sensing. The simplest, *standard diffuse*, is discussed here. Other types, sharp cutoff diffuse, fixed focus diffuse, wide angle diffuse, and background suppression diffuse, are explained in later sections.

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

Target reflectivity can vary widely. Relatively shiny surfaces may reflect most of the light *away* from the receiver, making detection very difficult. The sensor face must be parallel with these types of target surfaces.

Very dark, matte objects may absorb most of the light and reflect very little for detection. These targets 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 calibrated diffuse target. Allen-Bradley uses a 216mm (8.5in) x 292mm (11in) sheet of white paper that has been specially formulated to be 90% reflective—meaning that 90% of the light energy from the light source will be reflected by the paper.

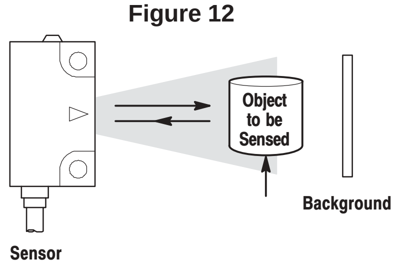
"Real world" diffuse targets are often considerably less reflective, as shown in *Table 2*.

Table 2

Target	Typical Relative Reflectivity
Polished aluminum	500
White paper (reference)	100
White typing paper	90
Cardboard	40
Cut lumber	20
Black paper	10
Neoprene	5
Tire rubber	4
Black felt	2

Detecting targets positioned close to reflective backgrounds can be particularly challenging. It may be impossible to adjust the sensor to obtain sufficient margin from the target without detecting, or coming close to detecting, the background (*Figure 12*). Other types of diffuse sensing may be more appropriate.

Figure 12



Sharp Cutoff Diffuse

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

Note that 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.

An even better solution is provided by background suppression diffuse sensors.

Background Suppression Diffuse

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

In simple terms, background suppression sensing can allow the sensor to ignore the presence of a very reflective background almost directly behind a dark, less-reflective target. For many applications, it is the ideal diffuse sensing mode. However, background suppression sensors are more complex, and therefore more expensive than other diffuse sensors.

Fixed Focus Diffuse

In a fixed focus (convergent beam) sensor, the light 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 targets. 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 target 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.

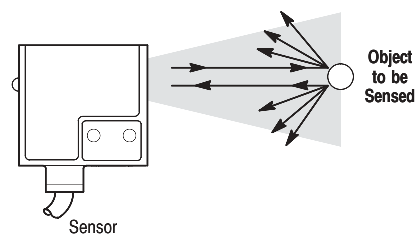
Wide Angle Diffuse

Wide angle diffuse sensors project the light source and detection area of the receiver over a wide area (*Figure 13*).

These sensors are ideal for two applications:

- 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 targets.

Figure 13
Wide Angle Diffuse



Fiber Optics

Fiber optic sensors permit the attachment of "light pipes" called fiber optic cables. Emitted light from the light source is transmitted 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).

Both glass and plastic are used as transparent materials to create fiber optic cables.

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 plastic fiber optic cables. Glass cables will withstand much higher temperatures. Standard Allen-Bradley glass fiber optic cables with a stainless steel sheath rated up to 260°C (500°F). Special order 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

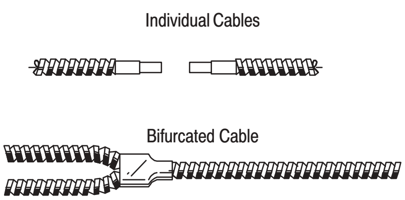
Plastic

Plastic fiber optic cables are typically constructed of a single acrylic monofilament. There is no protective sheathing, making plastic fiber optic cables less durable, but typically less expensive than glass cables.

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

Fiber optic cables are available in *individual* or *bifurcated* configurations (*Figure 14*).

Figure 14
Fiber Optic Cables



Two individual cables are used for transmitted beam sensing. Some individual cables are packaged separately, others are sold in packages of two. Order carefully to receive two cables.

Bifurcated cables are used for diffuse or retroreflective sensing modes. Standard diffuse sensing with fiber optic cables are similar to sensing with lensed photoelectric sensors.

Retroreflective sensing is possible with either reflectors or reflective tapes. Polarized retroreflective sensing is not possible. In some applications it will be necessary to reduce the sensitivity of the sensor to prevent diffuse detection of the target.

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.

Comparison of Fiber Optic Cables

	Glass	Plastic
Construction	Thin glass strands bundled in stainless steel or PVC sheath	Single acrylic monofilament
Temperature Range	–40°C (–40°F) to 260°C (500°F) with stainless steel sheath. Special order up to 480°C (900°F).	–30°C (–20°F) to 70°C (158°F)
Durability	Very durable	Adequate for many applications
Continuous Flexing	Will quickly break glass fibers	Will work very well, coiled versions available
Light Source	Visible or infrared OK	Must use visible light
Range	Can be longer range because of larger diameter	Adequate for many applications

A wide selection of fiber optic cables is available and many special configurations can be obtained.

Clear Object Detection

Clear materials present a unique application challenge for photoelectric sensors. Most clear objects and films provide insufficient contrast to be reliably detected using general purpose retroreflective or polarized retroreflective sensors. Various forms of diffuse sensing do not offer a preferred solution because the exact location of the clear target cannot be detected.

Rockwell Automation/Allen-Bradley offers ClearSight™ photoelectric sensors that are specifically designed for clear object and clear film sensing applications. These modified polarized retroreflective sensors contain special optical assemblies designed to optimize the amount of contrast generated by clear objects and films. Special electronics and software features further enhance sensing reliability.

For detailed information about solving the challenges of clear object detection, refer to the white paper “Clear Object Detection Using Photoelectric Sensors,” publication 42–8.0.

Photoelectric Sensor Specifications

Light/Dark Operate Output

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.

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.

Maximum Sensing Distance

This specification refers to the sensing distance from:

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

This sensing distance is guaranteed by the manufacturer. PHOTOSWITCH photoelectric sensors are conservatively rated; the actual available sensing distance will typically exceed this specification.

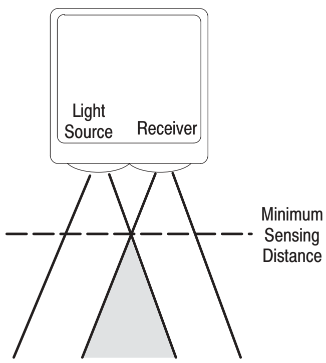
Note that this distance is specified at a margin of 1X, meaning that just enough light from the light source will be detected by the receiver to change the state of the output.

Most industrial environments will create contamination on the sensor lenses and reflectors or targets. Sensors should be applied at shorter distances to increase the margin to an acceptable value and enhance application reliability.

Minimum Sensing Distance

Many retroreflective, polarized retroreflective, and diffuse (most types) sensors have a small "blind" area near the sensor (*Figure 15*). Reflectors, reflective tapes, or diffuse targets should be located further away from the sensor than this minimum sensing distance for reliable operation.

Figure 15
Blind Area



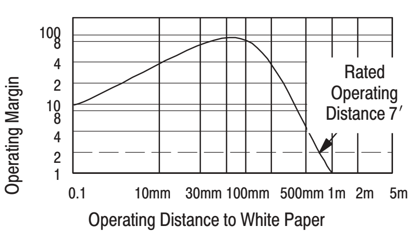
Typical Response Curve

The catalog pages for most PHOTOSWITCH photoelectric sensors contain a curve that shows what the typical margin will be depending on sensing distance.

A margin of at least 2X is generally recommended for industrial environments.

Figure 16 shows an example curve for a diffuse sensor. The maximum sensing range (margin=1X) of this sensor is 1m (39.4in) to a specified white paper target. A margin of 4X can be achieved at approximately half that distance, or 500mm (19.7in).

Figure 16
Margin



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 target is no longer detected by the sensor.

For most sensors, the response time is a single specification for both the ON time and OFF time. For other sensors, two different values may be given.

Response times are dependent on sensor design and choice of output device. Slower sensors usually offer longer sensing ranges. Very fast sensors typically have shorter sensing ranges. PHOTOSWITCH photoelectric sensors response times vary from 30µs to 30ms.

Field of View

For most photoelectric sensors, the light beam from the light source and the area of detection in front of the receiver project away from the sensor in a conical shape. Field of view is a measurement (in degrees) of this conical area.

The Field of View is a useful specification to determine the available sensing area at a fixed distance away from a photoelectric sensor.

Refer to *Figure 17* for this example. The 42SRU-6002 retroreflective sensor has a 3° field of view. The figure shows that at a sensing distance of 3.0m (10ft) the detection area will be a circle that is approximately 168mm (6.6in) diameter (56mm or 2.2in per degree).

Sensors with a wide field of view typically have shorter sensing distances. However, a wider field of view can make alignment easier.

Beam Patterns

Beam patterns are included for several lines of Allen-Bradley photoelectric sensors to help predict the performance of these sensors in a variety of applications. A beam pattern is defined as the sensing area for a photoelectric sensor. It is the pattern generated by comparing the response of the receiver to the emitted signal over the operating distance of the sensor.

All beam patterns are drawn in two dimensions and are assumed to be symmetrical in all planes about the optical axis of the sensor. The maximum operating margin is located at the optical axis and decreases towards the outer boundary of the beam pattern.

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, fog, etc. will decrease the sensing area and operating range of the sensor.

Transmitted 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.

Retroreflective Beam Patterns

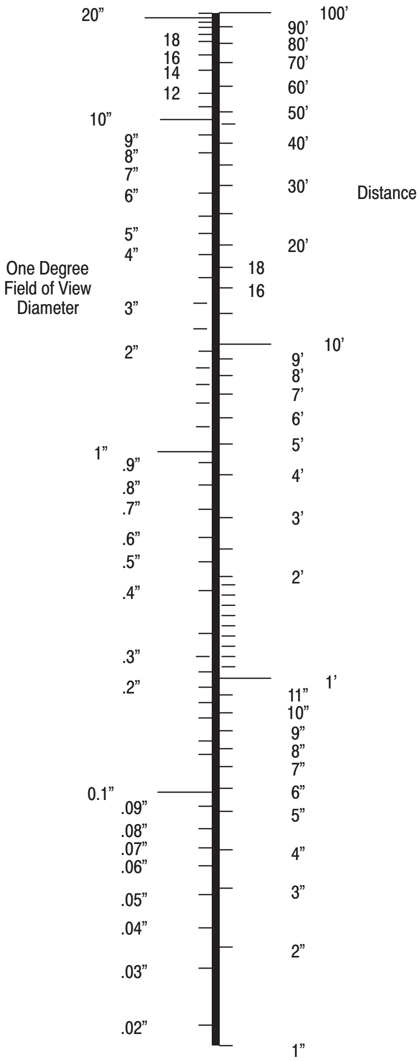
Beam patterns for retroreflective and polarized retroreflective sensors represent the boundary within which the sensor will respond to a retroreflective target as it passes by the sensors optics. The retroreflective target is held perpendicular to the sensor's optical axis while the beam diameter is plotted. The model 92–39 76mm 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.

Diffuse, Sharp Cutoff, and Background Suppression Beam Patterns

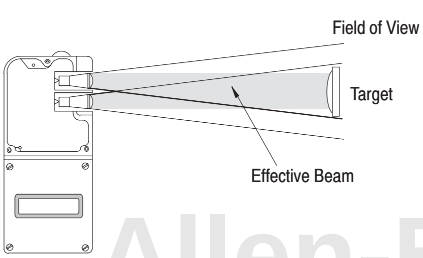
The beam pattern for a diffuse sensor represents the boundary within which the edge of a white reflective target that will be detected as it passes by the sensor. Diffuse beam patterns are generated using a 90% reflective sheet of 216mm x 279mm ($8^1/_2$in x 11in) white paper held perpendicular to the sensor's optical axis. The sensing area will be 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 targets with surfaces that are not perpendicular to the sensor's optical axis will also significantly decrease sensor response.

Figure 17
Field of View Diameter vs. Distance



It is important to note that the effective size of the beam of the retroreflective control is equal to the size of the retroreflective target. Additional reflective targets in the field of view will increase the excess gain and operating distance, if the field of view is bigger than the initial target as depicted in (*Figure 18*).

Figure 18
Retroreflective Sensors



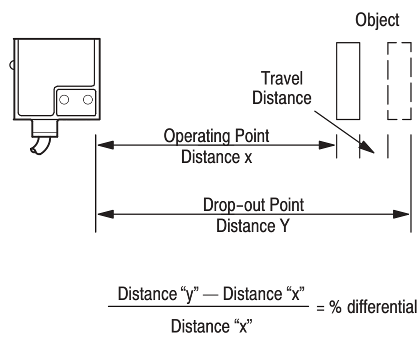
Hysteresis

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.

An example is shown in *Figure 19*. As the target moves toward the sensor, it will be detected at distance X. As it then moves away from the sensor, it will still be detected until it gets to distance Y.

Figure 19
Hysteresis



The high hysteresis in most photoelectric sensors is useful for detecting large opaque objects in retroreflective, polarized retroreflective and transmitted beam applications. In diffuse applications a large difference in reflected light from target and background also allows the use of high hysteresis sensors.

Low hysteresis requires smaller changes in light level. The Series 10,000 and 42FT allow selection of low hysteresis for these applications.

Aligning a Photoelectric Sensor

Proper alignment of the sensor will create a more rugged sensing solution that requires less maintenance.

Retroreflective or Polarized Retroreflective

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

Diffuse (all types)

Aim the sensor at the target. Pan the sensor up and down, left and right to center the beam on the target.

Reduce the sensitivity just until the target is no longer detected and note the position of the sensitivity adjustment.

Remove the target and increase the sensitivity until the background is detected. Adjust the sensitivity to the mid point between detection of the target and detection of the background.

Transmitted Beam

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

Table 3

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
FET *AC or DC switching*	• Very low leakage current • Fast switching speed	• Low output current
Power MOSFET *AC or DC switching*	• Very low leakage current • Fast switching speed	• Moderately high output current
TRIAC *AC switching only*	• High output current	• Relatively high leakage current • Slow output switching
NPN or PNP Transistor *DC switching only*	• Very low leakage current • Fast switching speed	• No AC switching

Digital Output Devices

Once the sensor has detected the target, an output device switches the electrical power in the user's control circuit. The output is either ON or OFF, making the sensor a digital device.

There are many types of outputs available, each with different benefits and weaknesses. The types available with Allen-Bradley PHOTOSWITCH photoelectric sensors are described below, and summarized in *Table 3*.

Electromechanical Relay

An electromechanical relay (or simply "relay") offers a reliable, positive means of switching electrical energy. Its major advantages are high switching current and electrical isolation from the sensor power source.

Because of the electrical isolation from the power source of the sensor, and due to the absence of leakage current, relays from multiple sensors can readily be connected in series and/or parallel.

Contact ratings will vary from 1A to 5A at 120/240V AC 50/60Hz resistive, depending on the sensor selected.

There are a number of different contact arrangements available:

- SPST—Single pole, single throw
- SPDT—Single pole, double throw
- DPDT—Double pole, double throw

Relays have a finite life span, typically measured in millions of operations. Inductive loads can shorten the life span considerably. Solid-state outputs should be considered for applications that require frequent switching by the sensor.

Response times of relays are typically 15–25ms, much slower than most solid state outputs.

FET

The FET (Field Effect Transistor) is a solid-state device that provides for fast switching of AC or DC power and very low leakage current. Its switching current is limited. The FET output on the Series 4000B switches only 30mA of current.

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 switching current capacity.

The Power MOSFET used in Series 6000 and Series 9000 sensors can switch up to 300mA of current.

TRIAC

A TRIAC is a solid-state output device designed for AC switching only. TRIACs offer high switching current, making them suitable for connection to large contactors and solenoids.

TRIACs exhibit much higher leakage current than FETs and Power MOSFETs. Leakage current from TRIACs can exceed 1mA, making them unsuitable as input devices for programmable controllers and other solid-state inputs. A zero crossing of the 50/60Hz AC power cycle is required to activate a TRIAC, meaning that the minimum response time is 8.3ms.

For most applications, Power MOSFETs provide better output characteristics.

NPN/PNP Transistor

Transistors are the typical solid-state output device for low voltage DC sensors.

A sensor with an NPN transistor output device has a sinking output. The load must be connected between the sensor output and the **(+)** power connection.

A sensor with a PNP transistor output device has a sourcing output. The load must be connected between the sensor output and the **(–)** power connection.

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.

Analog Output

Analog sensors provide an output that is proportional, or inversely proportional, to the quantity of light seen by the receiver.

Series 5000 analog output sensors provide a selectable voltage or current output that is proportional or inversely proportional to the amount of light detected by the receiver.

Timing and Logic

Photoelectric sensors are somewhat unique among presence sensors because many offer timing or logic functions. These functions may be available in special versions of the sensors, or in plug-in modules.

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) such as the 42FB and 42FT 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.

One-Shot

One-shot logic provides a single pulse output regardless of the speed that 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—provides a pulse each time a target moves past the sensor that is sufficiently long to allow other slower logic to respond.
- In slower 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.

Delayed One-Shot

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

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.