The Basics of Photoelectric Controls

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The excess gain a thru-beam sensor pair will ultimately have depends on how well aligned the sensors are, the separation between them, the sensitivity of the Detector Amplifier and the optical beam pattern the sensors exhibit. Every lens generates a different pattern. These patterns are determined by the size, shape, material and quality of the lens, the size and intensity or sensitivity of the source or detector chip and the focal length between chip and lens. A relationship that clarifies the understanding of various patterns is the comparison of radiation patterns to shotgun patterns.

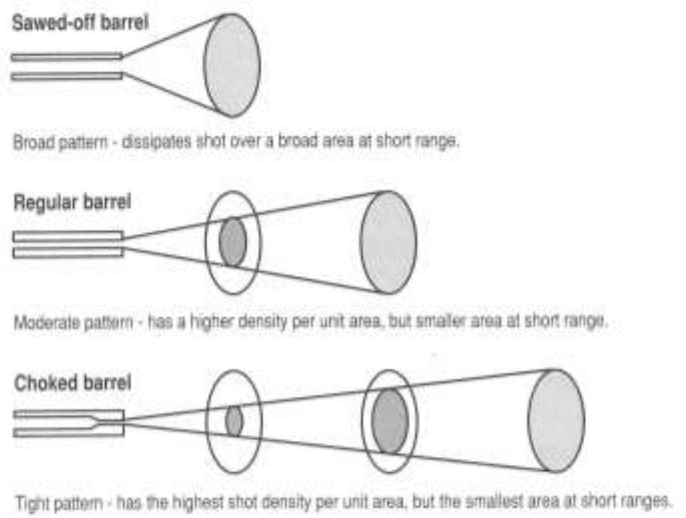

Fig. 23 Comparison of beam patterns to shotgun patterns.

A shotgun barrel's length and choke can be seen as the counterpart of focal length. Similarly, barrel gauge is comparable to chip size and shell load is comparable to radiant power and sensitivity.

If you had a box of shotgun shells in which all the shells were exactly the same, you could get different performance from each shell by putting each in a different style shotgun. If you fired one from a sawed off shotgun, the resulting pattern would be very broad with little appreciable range. If you placed another shell in a regular barreled shotgun, the pattern would be narrower but with much greater range. A third shell could be fired from a shotgun with a choke on it and the pattern would be narrower and the range longer.

(See the Eaton’s Sensing Solutions catalog for a breakdown of sensing fields for specific models)

Diffuse Proximity Performance

Because excess gain in proximity units is dependent on more variables than a thru-beam system, the graphic plot is more complex. Since nearly every proximity sensor has a different combination of lenses and beam angles, nearly every excess gain curve for proximity sensors is different. The excess gain for a proximity sensor is expressed as a ratio between the amount of light received to the amount of light required to trigger the sensor.

Excess Gain = Light Received /Minimum Light Required

Published excess gain curves for proximity sensors are determined using a large Kodak #R-27 90% reflectance test card. The following figures are typical of proximity excess gain curves.

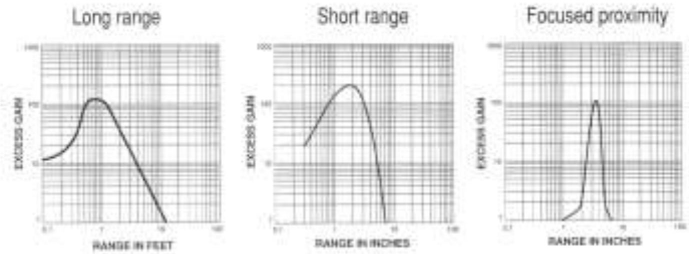

Fig. 24 Excess gain curves for long range, short range and focused proximity photoelectric controls.

Compare the excess gain curves in figure 23. The short range sensor delivers high excess gain over a short sensing distance and then drops off rapidly. This is due to the fact that the source beam and the detector's field of view converge over a short distance from the lenses, so the energy present in the area of coincidence is very high. This makes detecting small or difficult to sense surfaces possible. It also provides you with the ability to ignore objects or surfaces in the near background.

The long range sensor's source beam and detectors field of view are positioned close together on the same axis. This results in maximum convolvement of the source beam and detector field of view out to the maximum range of the sensor. Excess gain peaks several inches out from the sensor then drops off slowly over distance. Optical detection up to 10 feet on a white surface is possible. A clear field of view several feet from the sensor is necessary to prevent latch up or false triggering.

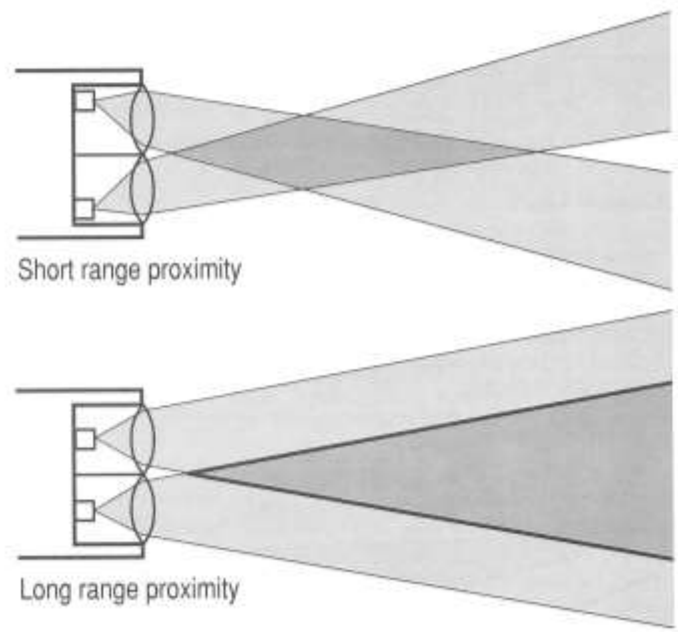

Fig. 25 Short range proximity sensors provide high excess gain at close range without triggering on near background objects. Long range sensors detect objects up to 10 feet away.

In a focused spot proximity sensor the source and detector are positioned behind the lens in order to focus the energy to a point. The source beam and detector field of view converge at the focus point forming a sensing zone about 0.128 inches or smaller in diameter. The excess gain is extremely high at this focused point and drops off very fast on either side of the sensing zone. A focused proximity sensor is excellent for sensing into holes or cavities, for detecting very small objects, or level detection between two surfaces.

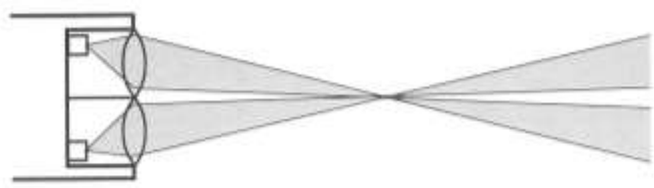

Fig. 26 On a focused spot sensor, the energy is focused to a point out from the lenses, thus forming a detection zone which will be blind at any spot other than the point of focus.

Reflex Performance

Excess gain curves for reflex sensors are similar in appearance to proximity sensors. In this case, excess gain and range are related to the light returned from a retroreflective target. Other than the actual retroreflector type used, the maximum operating range is also dependent on lens geometry and detector amplifier gain. Reflex sensors feature ranges up to 75 feet to a 3 inch retroreflector. As shown in Figure 26 the effective beam is defined as the actual size of the retroreflector surface. The entire reflector must be blocked by the target object before the sensor will recognize a beam blockage and switch its output.

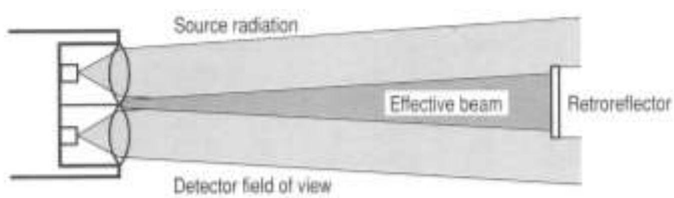

Fig. 27 Beam pattern for a reflex sensor.

Retroreflectors and Reflex Performance

Reflex sensor range and excess gain are dependent on reflector quality. Two types of retroreflector target materials are available, corner cube and embedded glass bead reflectors.

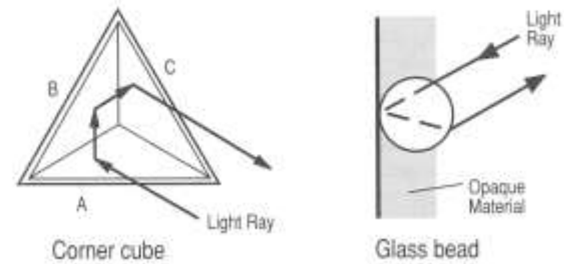

Fig. 28 Corner cube and glass bead retroreflectors.

Corner cube retroreflectors provide the highest signal return to the sensor. Cube style reflectors exhibit 2000 to 3000 times the reflectivity of white paper. When a ray of light strikes one of the three adjoining sides (A) arranged at right angles to each other, the ray is reflected to the second side (B) and then to a third (C) then back to its source in a direction parallel to its original course. Thousands of these cube shapes are molded into a rugged plastic reflector or vinyl material. The fact that the light returned from a corner cube surface is depolarized with respect to the received light makes this the only retroreflec-tor to use with polarized reflex sensors.

Target size affects the maximum sensing range.

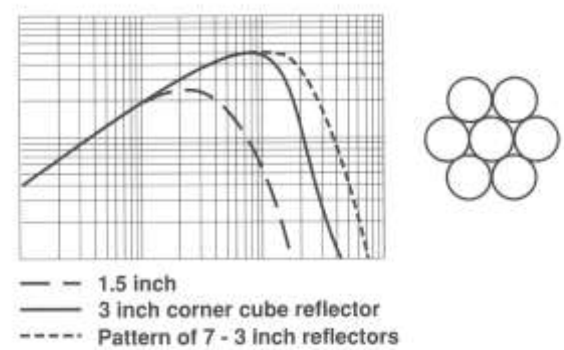

Fig. 29 Reflector areas affect on reflex performance.

Glass bead retroreflectors are available in tape form for use in dispensers for package coding on conveyors and in sheet form which the user can cut to size. The bead style surface is typically rated at 200 to 900 times the reflectivity of white paper. Glass bead type retroreflectors cannot be used with polarized reflex sensors.

Contrast

Contrast measures the ability of a photoelectric control to detect an object. It is expressed as a ratio between excess gain under light conditions and excess gain under dark conditions.

Contrast Ratio = Excess Gain under light conditions / Excess Gain under dark conditions

When applying photoelectric controls, the sensing mode that provides the greatest contrast ratio should be selected. For reliable operation, a ratio of 10:1 is recommended.

Contrast and Sensing Modes

The contrast a thru-beam or reflex sensor perceives is affected by:

- The light transmissivity of an object or surface.
- The size of an object in relation to the effective beam size.

The contrast a proximity sensor perceives is related to the amount of light an object or surface reflects back to the sensor. This reflectivity is affected by:

- How far the object or surface is from the sensor.
- Color or material of the object or surface.
- Size of the object or surface.

The ideal application provides infinite contrast ratio of the detection event. This is the case, for example, when 100% of the beam is blocked in reflex or thru-beam sensing modes, or when nothing is present in the case of proximity sensing modes. Understanding the contrast ratio becomes critical when this situation does not exist, such as detecting semi transparent objects, or when sensing extremely small objects.

For example, a thru-beam sensor is positioned 10 inches apart to detect a semi-transparent plastic bottle moving through the sensing zone. Given that the excess gain at that range equals 100, and the bottle blocks 5% of the light energy and passes 95% of the light, the contrast ratio would be approximately 1 (100/95). This does not meet the 10:1 ratio recommended, and indeed the application would not work. The thru-beam pair is simply too powerful for this application. Note that the high excess gain provided by this thru-beam sensor pair does not offer any advantage in this application.

A focused proximity sensor with the excess gain shown on the chart in figure 30, and positioned 3 to 4 inches from the bottle could provide the high contrast required, and provide excellent back-ground rejection. This product would work better in this application than the thru-beam pair.

In the detection zone 3 to 4 inches from the sensor, the excess gain is 20 to 100. The background will have no affect on the reliability because excess gain = 0.

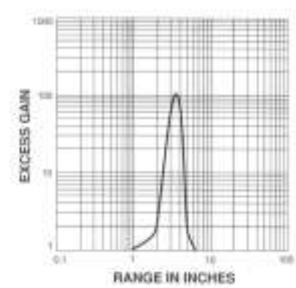

Fig. 30

Photoelectric Control Logic

Photoelectric control logic can be divided into two categories. First, are devices that "condition" the signal between the detector and the output device. Typically, these are logic modules that are mounted inside the photoelectric control and include timing or counting functions. Second, is switch logic. Output devices from two or more controls can be wired in series or parallel providing an output to the load only when the correct combination of controls is energized.

Timing Functions

Timing functions provide a natural extension to the simple sensor by altering the raw sensor signal to make it more useful for controlling local action in response to sensed events. Timing functions "condition" the detection event causing the output signal from the sensor to be stretched, shortened or displaced in time.

Light Operate Versus Dark Operate

In most applications, photoelectric controls generate an output whenever an object is detected. This occurs in one of two modes. If the control generates an output when the photo detector sees light, the control is said to be working in the "Light Operate" mode. If the control generates an output when the photo detector does not see light, the control is said to be working in the "Dark Operate" mode. Light /dark operation is normally selected by a switch mounted inside the control. This is most useful when the sensor is equipped with a single pole output device.

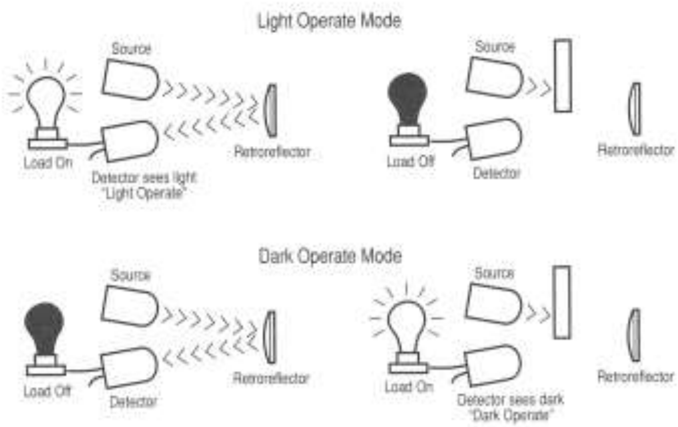

Fig. 31 Demonstration of light operation versus dark opera-tion.

When a photoelectric control is operating without a logic function, an output is generated for the length of time an object is detected. This can be expressed in the following diagram.

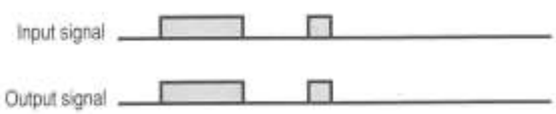

Fig. 32 Diagram showing object detected versus output.

On Delay Logic

On delay logic allows the output signal to turn on only after the object has been detected for a predetermined period of time. The output will turn off immediately after the object is no longer detected. This logic is useful if a sensor must avoid false interruptions from small objects, but detect a large or slow moving object. On delay is useful in bin fill detection, or jam detection since it will not false trigger on the normal flow of objects going past.

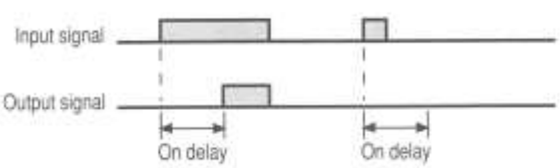

Fig. 33 On delay logic.

Off Delay Logic

Off delay logic holds the output on for a predetermined period of time after an object is no longer detected. The output is turned on as soon as the object is detected. Off delay ensures that the output will not drop out despite short periods of signal loss. If an object is once again detected before the output times out, the output will remain on. Delay off logic is useful in marginal applications susceptible to periodic signal loss such as web detections.

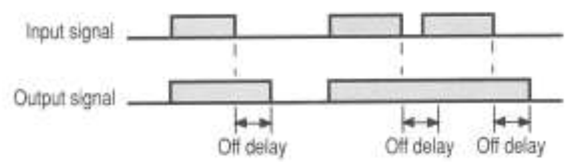

Fig. 34 Off delay logic.

On/Off Delay Logic

On/off delay logic combines on and off delay so the output will be generated only after the object has been detected for a predetermined period of time, and will drop out only after the object has no longer been detected for a predetermined period of time. Combining on and off delay "smooths" the output of the photoelectric control for applications such as jam detection, fill level detection and edge guide.

One-Shot Logic

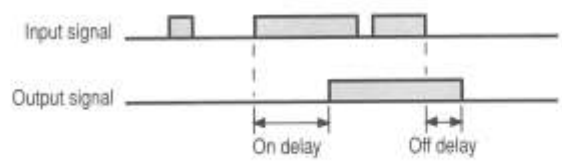

Fig. 35 On/off delay logic

One-shot logic generates an output of predetermined length no matter how long an object is detected. A one shot can be programmed to trigger on the leading or trailing edge of the object detected. A standard one-shot must time out before it can be retriggered. One-shot logic is useful in applications that require an output of specified length, such as an air valve actuating a kicker on a conveyor line.

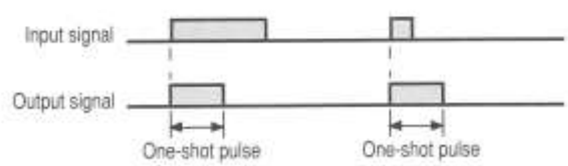

Fig. 36 One-Shot Logic

Retriggerable One-Shot Logic

Just like a standard one-shot, a retriggerable one-shot generates an output of predetermined length whenever an object is detected. A retriggerable one-shot will restart each time an object is detected and will remain triggered as long as a stream of objects are detected before the one-shot times out. A retriggerable one-shot is useful in detecting underspeed conditions in conveyor lines.

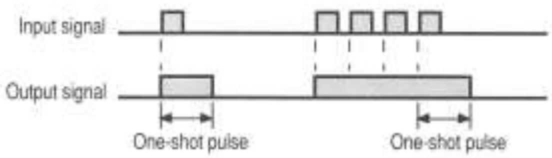

Fig. 37 Retriggerable one-shot logic.

Delayed One-Shot

Delayed one-shot logic combines on delay and one-shot logic. In this function the one-shot feature is delayed for a predetermined period of time after an object has been detected. A delayed one-shot is useful in applications where the photoelectric control cannot be mounted exactly at the site where the action caused by the output device is taking place. Applications include a spray paint booth (the control cannot be mounted inside the booth), high temperature ovens or drying bins.

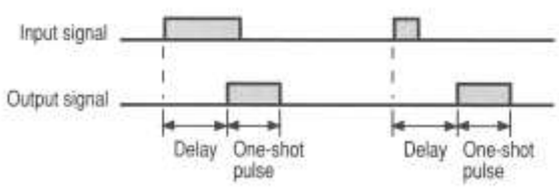

Fig. 38 Delayed one-shot logic.

Underspeed Detection Logic

Underspeed detection logic operates identically to a retriggerable one-shot in that it detects speeds that fall below a certain predetermined level. In addition to this feature, the underspeed detector has a built in latch feature that shuts the system completely down when the speed slows to the predetermined level. This prevents the one-shot from retriggering once it times out, thereby eliminating erratic switching while the motor is winding down.

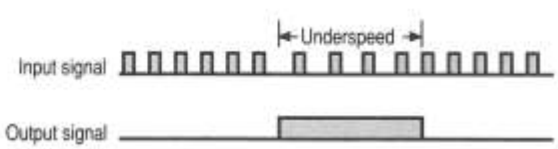

Fig. 39 Underspeed detection logic

Underspeed/Overspeed Detection Logic

This detection logic is capable of detecting overspeed conditions as well as underspeed conditions. An underspeed / overspeed detector counts a predetermined number of objects within a specified length of time. If the system operates either at a higher or lower rate, an output is generated.

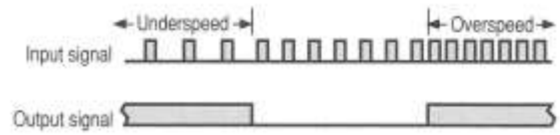

Fig. 40 Overspeed/underspeed detection logic.

Output Devices and Switch Logic

A photoelectric control actively interfaces to the outside world through an output switching device. The load to be energized may be a solenoid or relay coil, counter module, or input card to a programmable controller. Depending on the current requirement, AC or DC operating voltage, and switching speed, an appropriate output device must be selected for best long term performance. Photoelectric con-trols are available with built-in solid state AC, DC or AC /DC switches, as well as with sockets for replaceable output modules for quick repair and system flexibility.

Types of Output Devices and Their Symbols

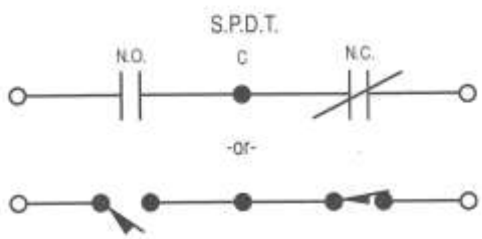

Fig. 41

Relay Devices

A relay is a mechanical switch which is available with a variety of contact configurations. Relays can handle large load currents at high voltages allowing them to directly interface with motors, large solenoids, brakes and ejectors. They can switch either AC or DC loads. Contact life depends on the load current, and frequency of operation. Relays are subject to contact wear and contact resistance build-up. Also, because of contact bounce they can produce erratic results with coun-ters and programmable controller inputs unless the input is filtered. Being mechanical, they can add 10 to 25 mS to a photoelectric's response time.

Since relays are most familiar to factory personnel, and because they provide multiple contacts, relays are the most common output device used with photoelectric sensors.

Features—Mechanical relays
- Switch high currents /voltages
- Multiple contacts
- Switch AC/DC voltages
- Tolerant of momentary short circuits and large inrush currents

Limitations—Mechanical relays
- Slow response time (10-25 mS)
- Contact and mechanical wear
- Contact bounce
- Affected by shock and vibration

Transistor devices (DC switch)

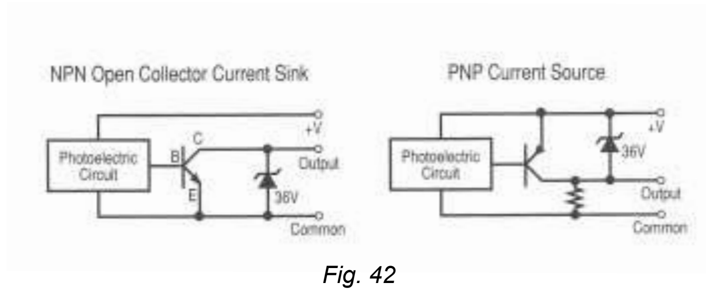

Fig. 42

Transistors are solid state DC switching devices. They are most commonly used in low voltage DC powered photoelectric sensors as the output switch. Two types of transistors are commonly used depending on the switching function. The NPN current sink provides a contact closure to DC common and the PNP current source provides a contact closure to the DC positive rail. A transistor can be thought of as a single pole switch which must be operated within its voltage and maximum current ratings. Any short on the load will immediately destroy a transistor switch.

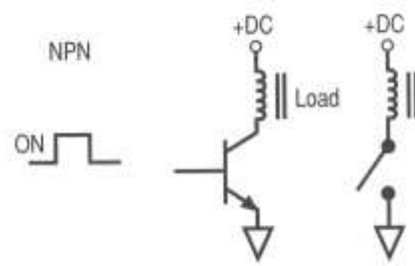

Fig. 43 A transistor can be looked at as a single pole switch.

Switching inductive loads creates voltage spikes many times the control voltage level which would exceed the maximum voltage rating of the transistor. Peak voltage clamps such as zener diodes or transorbs are utilized to protect the output device. Transistor outputs are typically rated to switch loads of 250 mA at 30 VDC maximum.

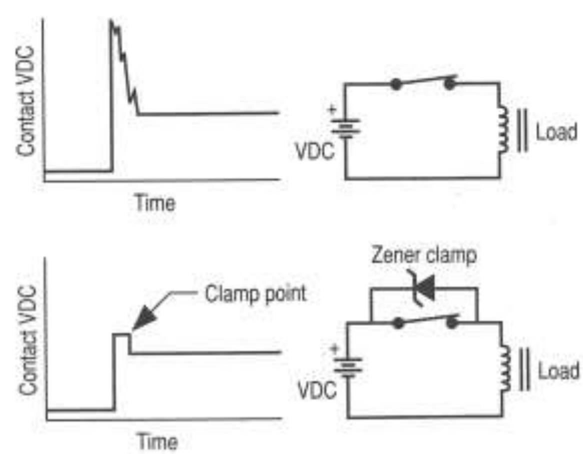

Fig. 44 Action of a Zener diode used to clamp inductive spikes for transistor protection

Features—Transistor switches
- Virtually instantaneous response time
- Low off state leakage and voltage drop
- Infinite life when operated within rated current/voltage
- Not affected by shock/vibration
- Interface direct to TTL and CMOS circuits

Limitations—Transistor switches
- Low current handling
- Cannot tolerate large inrush currents (unless clamped)
- Destroyed by short circuit

Triac Devices

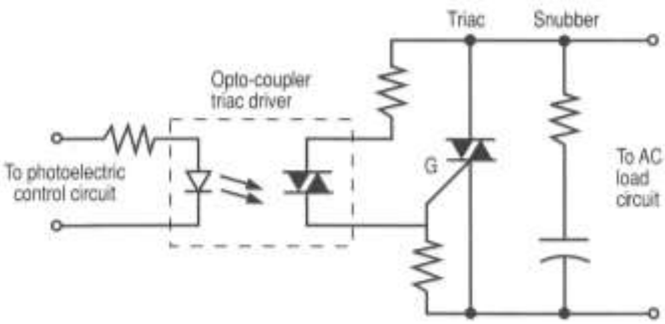

Fig. 45 Optically isolated triac switch

A triac is a solid state device designed to control AC current. Triac switches turn "ON" in less than a microsecond when its gate (control leg) is energized and shuts "OFF" at zero crossing of the AC power cycle. Because a triac is a solid state device, it is not subject to the mechanical limitations of a relay such as contact bounce, pitting and corrosion of contacts, or shock and vibration sensitivity. Switching response time is limited only to the time it takes the 60 Hz AC power to go through one-half cycle.

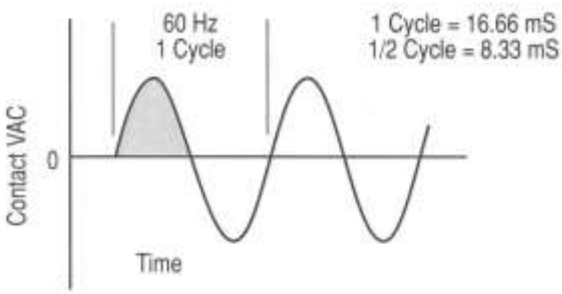

Fig. 46 Triac switches can be turned "ON" at any point in the AC power cycle, "OFF" only at zero crossing.

As long as the triac is used within its rated maximum current and voltage specifications, life expectancy is virtually infinite. Triac devices used with photoelectric sensors generally are rated for 2 A loads or less.

Triacs do have limitations. Like a transistor, shorting the load will destroy a triac. Inductive loads directly connected to the triac or large voltage spikes from other sources can false trigger a triac device. To reduce the effect of these spikes a snubber circuit composed of a resis-tor and capacitor in series is connected across the device. Depending on the maximum load expected to be switched, an appropriate snubbing network to protect the triac must be used. The snubbing network contributes to the "OFF STATE" leakage the load would see. A triac rated for 1 A loads may have 5 mA of "OFF STATE" leakage. This leakage must be taken into account switching loads requiring little current such as inputs to PLC's. In "ON STATE" triacs exhibit about 1.7 VRMS voltage drop.

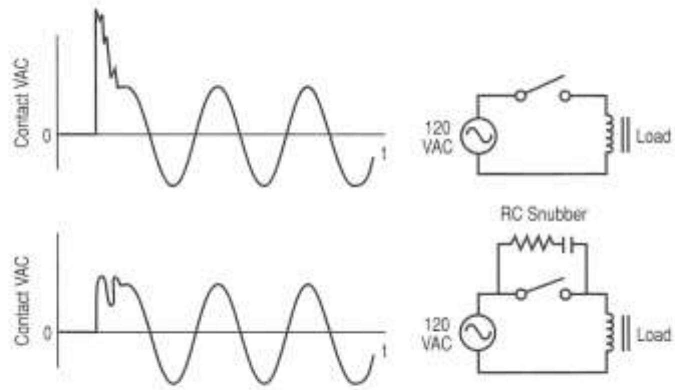

Fig. 47 Use of R.C. snubber networks to reduce triac false triggering by inductive spikes.

Features—Triac switches
- Fast response time (8.33 mS)
- Tolerant of large inrush currents
- Direct interface to counters and programmable controllers
- Infinite life when operated within rated current/voltage
- Not affected by shock/vibration

Limitations—Triac switches
- Can be false triggered by large induced currents
- Snubber network contributes "OFF STATE" leakage
- Destroyed by short circuits

Bilateral FET Device (AC/DC Switch)

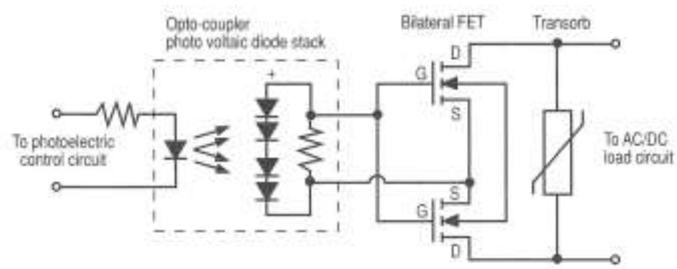

Fig. 48

The FET (Field Effect Transistor) is slated to be the solid state switch of the future because of its near ideal operating characteristics. The voltage applied to the gate controls the conduction resistance between the source and drain. In the "OFF STATE," source to drain resistance is typically hundreds of megohms and only about 1 ohm when "ON." FET switches exhibit no "OFF STATE" leakage and, being resistive devices, do not develop the fixed voltage drop across its terminals like other solid state switch devices. Unlike a triac switch, switching occurs immediately. FET devices are independent of voltage or current phase. FET switches can be configured in circuits which will control AC or DC voltages and will not generate switch induced line noise like relay and triac switches. FET switches cannot tolerate line spikes or large inrush currents. The device must be protected by using a voltage spike clamping device such as a transorb. It shunts voltage spikes which exceed the conduction threshold voltage of the transorb and dissipates the energy as heat.

Features—Bilateral FET switches
• Switch AC or DC voltages
• Low "ON STATE" voltage drop
• Extremely fast response time
• Infinite life when operated within voltage/current ratings
• Interface direct into TTL and CMOS circuits
• Does not self-generate line noise

Limitations—Bilateral FET switches
• Cannot tolerate large inrush currents
• Can be destroyed by line spikes (if not clamped)

Two-wire switch device (AC/DC)

A two-wire photoelectric sensor is composed of 3 main components: the photoelectric sensing head, the power switch base, and the wiring receptacle. The power base assembly is a standard mechanical limit switch style body which houses the sensor power supply, output switch circuit, and socket for plug-in logic modules. As the name implies, it requires only 2 connections just like the standard mechanical limit switch. All electronics are encapsulated in epoxy for electrical insulation of components and to provide vibration and shock resistance.

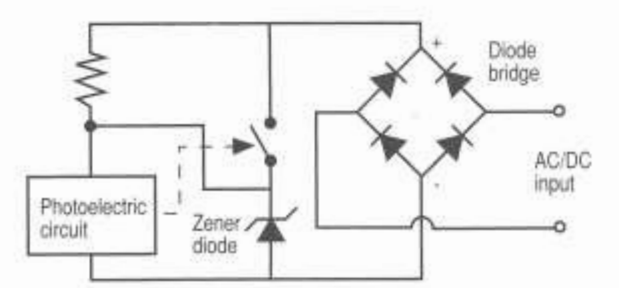

Fig. 49 Two-wire switch circuit

A two-wire electronic switch approximates a mechanical switch with the circuit shown above. When the switch is open the resistor provides a leakage path around the switch to power the photoelectric circuitry. This creates an "OFF STATE" leakage of about 1.7 mA. When the switch is closed the zener diode regulator maintains enough voltage to power the circuitry. The diode bridge converts AC load current to DC for powering the sensor. Two-wire switches "steal" their operat-ing power from the load circuit. This means there will be some leak-age current when the switch is off and about 7 to 9 volts dropped across the switch when it is on. Leakage current must be about 1.7 mA or less to ensure compatibility with programmable controller inputs.

Because very little power is available to operate the control (including LED status indicators, source, detector, switch circuitry, and logic module), large lens surfaces are needed to provide reasonable optical performance and make up for the lack of available operating current. A two-wire photoelectric control compromises optical performance for low "OFF STATE" leakage.

The voltage drop across the switch is cumulative when more than one switch is wired in series with a load. The "OFF STATE" leakage current is cumulative when more than one switch is connected in parallel with a load.

Features-2-wire switch
• Two-wire connection (low wiring cost)
• Familiar wiring and rugged package
• Switch AC or DC loads
• Low leakage current in "OFF STATE"
• Short circuit protection and EMI /RFI immune models available

Limitations-2-wire switch
• Reduced optical performance compared to 3 and 4 wire style sensors
• High "ON STATE" voltage drop across the switch

Logic Function Using Switch Devices

The output devices from two or more photoelectric sensors can be wired together in series or parallel to perform logic functions. It is important to keep in mind when dealing with output device logic that an "ON" condition may represent either object presence or absence. The user has a choice, through selection of light operate or dark operate outputs or a light/dark switch in the control.

The user should also be aware of the possible side effects of these connections dependent on the type of switch used. These side effects include: excessive voltage drop in series connected switches and excessive leakage current in parallel connected switch devices. The load being switched is a determining factor at which point the above effects will interfere with proper operation. Output switches that exhibit the above effects are: triac devices ("OFF STATE" leakage current), and two-wire devices ("OFF STATE" leakage and "ON STATE" voltage drop).

Parallel ("OR" Function)

The term "OR" in binary logic defines the resultant output as being ON if one "OR" more of the inputs is on.

C	B	A	Out
0	0	0	0
0	0	1	1
0	1	0	1
1	0	0	1

0 = Off
1 = On

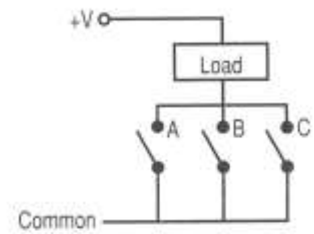

Fig. 50 "OR" function truth table.

The "OR" function is accomplished by connecting switches in parallel. The diagram shows normally open relay contacts. If switch A, B, "OR" C closes, the load will be energized. The switches shown could be any optically isolated solid state switch having both its terminals available for connection including: (A) isolated NPN transistor, (B) isolated bilateral FET, and (C) isolated triac device. "OR" logic functions can also be accomplished using 3-wire type sensors.

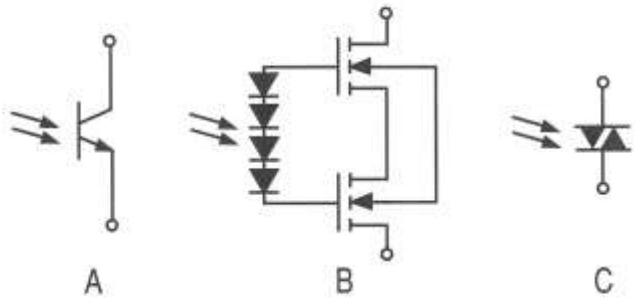

Fig. 51 Symbols of optically isolated solid state switches.

10 to 30 VDC powered sensors employing transistor output switches normally have one leg of the switch connected to DC common (the emitter on NPN transistors), or the positive rail (the emitter on PNP transistors). In this case, NPN current sink outputs may only switch loads in parallel to circuit common and PNP current source outputs may only switch in parallel to the positive DC rail.

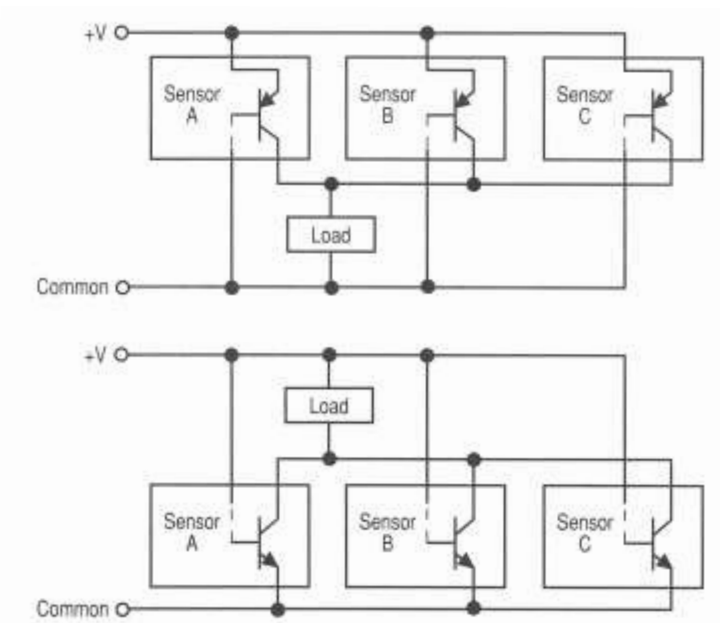

Fig. 52 Current sink and current source "OR" circuits with output devices tied internally to one side of the DC supply line.

Two, three and four-wire AC switches can be connected in an "OR" circuit configuration. Proper wiring techniques recommend only switching the hot side of the line in AC circuits.

When parallel connecting triac switches or two-wire photoelectric sensors, attention should be paid to how much "OFF STATE" leakage current the load will see. The leakage current is summed in parallel connections as shown in the two-wire "OR" circuit, Fig. 54.

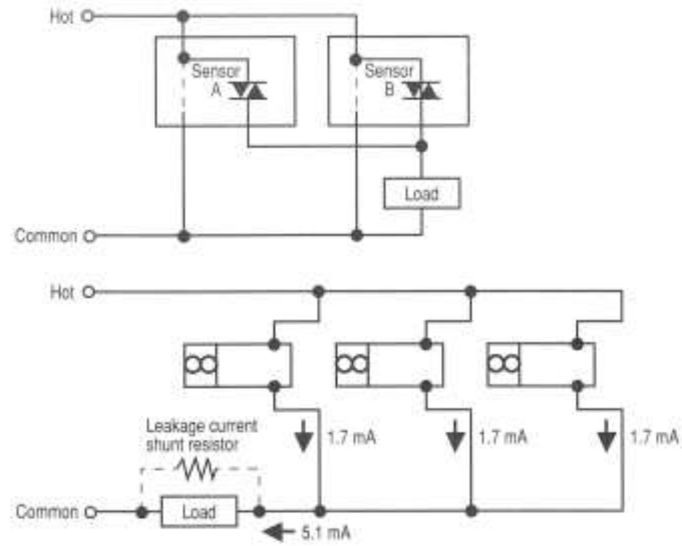

Fig. 53 "OR" circuit utilizing solid state AC switches and the affect of summed leakage currents.

Summed leakage currents equal: (1.7 mA)(3) = 5.1 mA total "OFF STATE" leakage delivered to the load. If the load is effected by the total leakage applied, a shunt resistor can be connected across the load to reduce the leakage seen by the load. This problem is only encountered when switching programmable controller inputs or other high impedance inputs.

Example application utilizing parallel "OR" logic

Two thru-beam sensor systems are positioned to monitor the possible presence of intruders into a building. The output devices from the photoelectric sensors are connected in parallel with each other with normally open contacts as long as the beams are complete. The sensors are set for dark energize. The load to be energized is a solenoid that will release the latch on a cage full of hungry guard dogs.

Series "AND" logic/gating functions

The term "AND" in binary logic defines the resultant output as being ON only when all inputs are ON. This is accomplished by connecting switches in series with the load. This type of circuit is best suited for the application of isolated switch devices not tied to power supply rails with one of their connections, such as a three-wire switch.

B	A	Out
0	0	0
0	1	0
1	0	0
1	1	1

0 = Off
1 = On

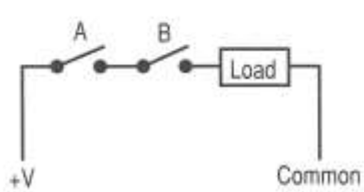

Fig. 54 "AND" function truth table with example series circuit.

When using solid state switches for this function the voltage drop across each switch will reduce the power the load will receive. This is mainly a problem only when utilizing two-wire photoelectrics because of the significant voltage drop (7 to 9 V) they exhibit. Depending on the minimum amount of voltage a load will require to operate properly will determine how many two-wire switches or voltage drops may be connected in series.

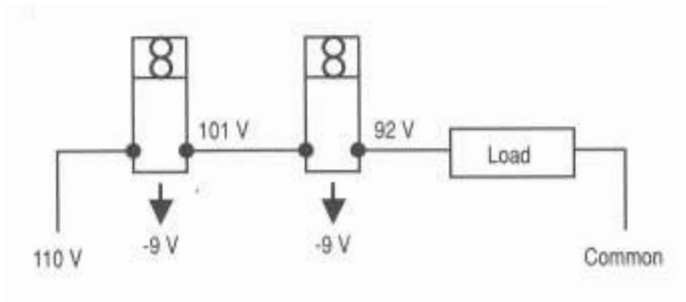

Fig. 55 Some solid state switches can reduce the amount of voltage the load will ultimately see.

"OFF STATE" leakage currents are not cumulative in a series circuit.

The idle state of the switch contacts must be set depending on the sensing mode by programming the light/dark energize switch in the photoelectric sensor.

"AND" Gating function

The logical "AND" configuration is commonly used to perform gating functions. We can use the gating function to perform inspection of fill levels, object placement or presence. The gate sensor usually will employ a one-shot logic module set to trigger on detection of an edge (light/dark, or dark/light). The one-shot will allow a short period of time for the inspection sensor to determine whether the object is OK. If not, the circuit will be completed signaling an alarm, firing a sole-noid for rejection of the object, or shutting down the machine.

Example gating application

A short range proximity sensor is positioned near the neck of a jar. The sensor will be set to energize when the jar is detected. A one-shot logic module inside the proximity sensor is set to trigger on the dark to light transition for a short period of time. The proximity gating sensor's output device is connected in series with a thru-beam sensor switch that is set in light energize mode. The sensors interface to a programmable controller which monitors the inspection system input. Jars with labels will never complete the series circuit so the programmable controller will ignore them. If a jar without a label is detected, the series circuit will be energized for the gate sensors one-shot period signaling the programmable controller to reject the jar at the reject location.

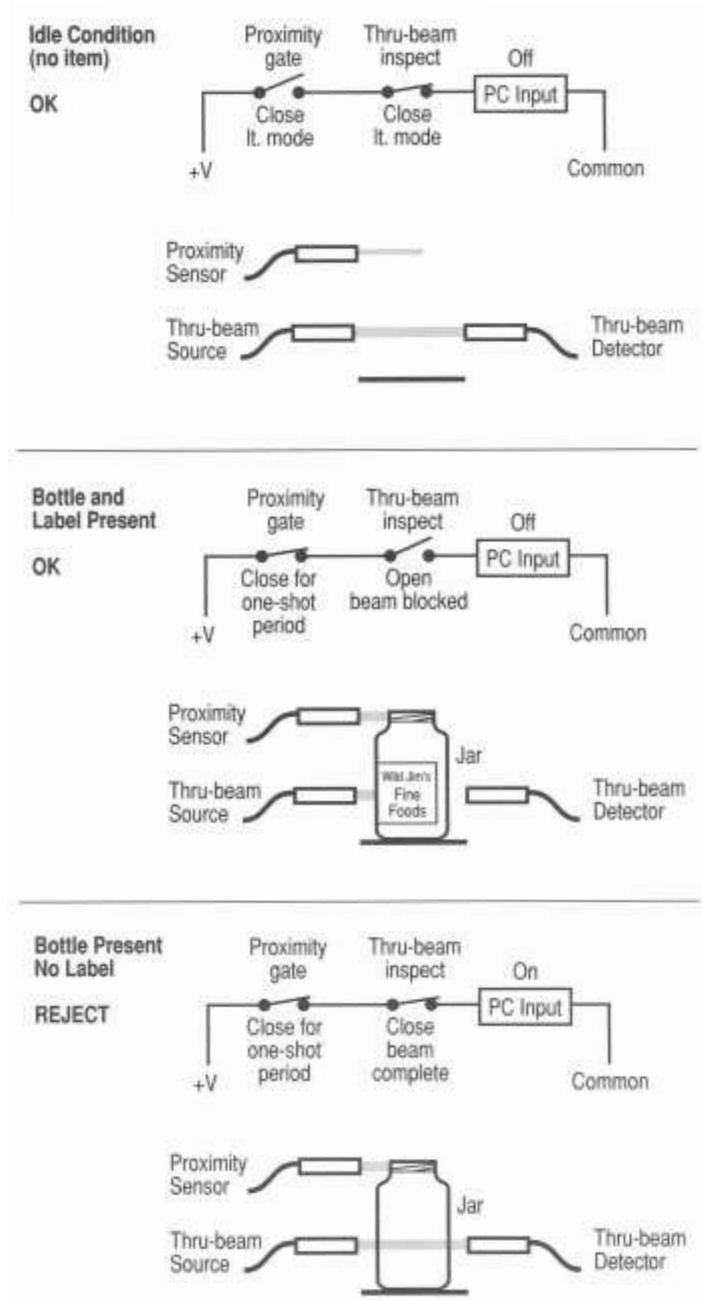

Fig. 56 Using the gating function to inspect jars for presence of labels. System rejects non-labeled items.

Appendix

Speed Conversion Table

feet/minute	inches/minute	inches/second	seconds/inch
0.5	6	0.1	10
1	12	0.2	5
2	24	0.4	2.500
3	36	0.6	1.666
4	48	0.8	1.250
5	60	1.0	1.000
6	72	1.2	0.833
7	84	1.4	0.714
8	96	1.6	0.625
9	108	1.8	0.555
10	120	2.0	0.500
11	132	2.2	0.435
12	144	2.4	0.417
13	156	2.6	0.385
14	168	2.8	0.358
15	180	3.0	0.333
16	192	3.2	0.313
17	204	3.4	0.294
18	216	3.6	0.278
19	228	3.8	0.263
20	240	4.0	0.250
21	252	4.2	0.238
22	264	4.4	0.227
23	276	4.6	0.217
24	288	4.8	0.208
25	300	5	0.200
30	360	6	0.167
40	480	8	0.125
50	600	10	0.100

feet/minute	inches/minute	inches/second	seconds/inch
60	720	12	0.083
70	840	14	0.071
80	960	16	0.063
90	1080	18	0.056
100	1200	20	0.050
125	1500	25	0.040
150	1800	30	0.033
175	2100	35	0.029
200	2400	40	0.025
225	2700	45	0.022
250	3000	50	0.20
275	3300	55	0.018
300	3600	60	0.016
325	3900	65	0.015
350	4200	70	0.014
375	4500	75	0.013
400	4800	80	0.012
450	5400	90	0.011
500	6000	100	0.010
600	7200	120	0.008
700	8400	140	0.007
800	9600	160	0.006
900	10800	180	0.0055
1000	12000	200	0.005
1250	15000	250	0.004
1665	19980	333	0.003
2500	30000	500	0.002
5000	60000	1000	0.001

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