Important User Information

Read this document and the documents listed in the additional resources section about installation, configuration, and operation of this equipment before you install, configure, operate, or maintain this product. Users are required to familiarize themselves with installation and wiring instructions in addition to requirements of all applicable codes, laws, and standards.

Activities including installation, adjustments, putting into service, use, assembly, disassembly, and maintenance are required to be carried out by suitably trained personnel in accordance with applicable code of practice.

If this equipment is used in a manner not specified by the manufacturer, the protection provided by the equipment may be impaired.

In no event will Rockwell Automation, Inc. be responsible or liable for indirect or consequential damages resulting from the use or application of this equipment.

The examples and diagrams in this manual are included solely for illustrative purposes. Because of the many variables and requirements associated with any particular installation, Rockwell Automation, Inc. cannot assume responsibility or liability for actual use based on the examples and diagrams.

No patent liability is assumed by Rockwell Automation, Inc. with respect to use of information, circuits, equipment, or software described in this manual.

Reproduction of the contents of this manual, in whole or in part, without written permission of Rockwell Automation, Inc., is prohibited.

Throughout this manual, when necessary, we use notes to make you aware of safety considerations.

| WARNING: | Identifies information about practices or circumstances that can cause an explosion in a hazardous environment, which may lead to personal injury or death, property damage, or economic loss. |
| ATTENTION: | Identifies information about practices or circumstances that can lead to personal injury or death, property damage, or economic loss. Attendees help you identify a hazard, avoid a hazard, and recognize the consequence. |
| IMPORTANT | Identifies information that is critical for successful application and understanding of the product. |
| SHOCK HAZARD: | Labels may be on or inside the equipment, for example, a drive or motor, to alert people that dangerous voltage may be present. |
| BURN HAZARD: | Labels may be on or inside the equipment, for example, a drive or motor, to alert people that surfaces may reach dangerous temperatures. |
| ARC FLASH HAZARD: | Labels may be on or inside the equipment, for example, a motor control center, to alert people to potential Arc Flash. Arc Flash will cause severe injury or death. Wear proper Personal Protective Equipment (PPE). Follow ALL Regulatory requirements for safe work practices and for Personal Protective Equipment (PPE). |
# Table of Contents

**Sensor Application Basics** ........................................... 5  
Contact vs. Non-Contact Technologies ................................ 5  
Discrete vs. Analog Detection ........................................ 6  
Sensor Characteristics/Specifications ................................. 6  
Standards .................................................................... 8  
Agency Approvals .......................................................... 9  
Sensor Selection — A Methodical Approach .......................... 10  

**Outputs & Wiring** ......................................................... 15  
Power Supplies ............................................................. 15  
Output Types ............................................................... 16  
Wiring ....................................................................... 22  
Output Timing and Logic ................................................ 26  

**PHOTOSWITCH Photoelectric Sensors** ............................. 29  
Introduction .................................................................... 29  
Photoelectric Sensor Construction ...................................... 29  
Sensing Ranges ................................................................ 34  
Sensing Modes ............................................................... 39  
Transmitted Beam ............................................................ 40  
Transmitted Beam Advantages and Disadvantages ............... 42  
Typical Transmitted Beam Applications ............................. 43  
Retroreflective and Polarized Retroreflective ....................... 44  
Retroreflective and Polarized Retroreflective Advantages and Disadvantages .......................................... 47  
Typical Retroreflective and Polarized Retroreflective Application ......................................................... 48  
Diffuse ......................................................................... 49  
Diffuse Advantages and Disadvantages .............................. 53  
Fiber Optic Cables .......................................................... 55  

**Inductive Proximity Sensors** .......................................... 61  
Standard Target for Inductive Proximity Sensors ................. 61  
Target Correction Factors for Inductive Proximity Sensors .... 62  
Hysteresis (Differential Travel) ......................................... 62  
Switching Frequency ......................................................... 63  
Ripple ......................................................................... 63  
Mounting Considerations for Weld Field Immune Proximity Sensors .......................................................... 63  
Series Connected Sensors ................................................ 64  
Parallel Connected Sensors .............................................. 65  
TTL Wiring ..................................................................... 66  
PLC Wiring .................................................................... 66  
Shielded vs. Unshielded Inductive Sensors ......................... 67  
Spacing Between Shielded Sensors (Flush?Mountable) and Nearby Metal Surfaces ........................................ 67  
Spacing Between Unshielded Sensors (Nonflush?Mountable) and Nearby Metal Surfaces ............................... 69  
Applications .................................................................. 72  
Top 23 Reasons to Use the 871TM ..................................... 75  

**Ultrasonic Sensing** ......................................................... 77  
Ultrasonic Sensor Construction .......................................... 77
<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensing Range and Effective Beam</td>
<td>78</td>
</tr>
<tr>
<td>Target Considerations</td>
<td>82</td>
</tr>
<tr>
<td>Environmental Considerations</td>
<td>84</td>
</tr>
<tr>
<td>Ultrasonic Advantages and Disadvantages</td>
<td>85</td>
</tr>
<tr>
<td>Typical Applications</td>
<td>86</td>
</tr>
<tr>
<td><strong>Capacitive Proximity Sensors</strong></td>
<td>89</td>
</tr>
<tr>
<td>Shielded vs. Unshielded Capacitive Sensors</td>
<td>90</td>
</tr>
<tr>
<td>Standard Target for Capacitive Proximity Sensors</td>
<td>91</td>
</tr>
<tr>
<td>Environmental Considerations</td>
<td>93</td>
</tr>
<tr>
<td>Capacitive Proximity Advantages and Disadvantages</td>
<td>94</td>
</tr>
<tr>
<td>Typical Applications</td>
<td>95</td>
</tr>
<tr>
<td><strong>Limit Switches</strong></td>
<td>97</td>
</tr>
<tr>
<td>Limit Switch Construction</td>
<td>101</td>
</tr>
<tr>
<td>Limit Switch Advantages and Disadvantages</td>
<td>113</td>
</tr>
<tr>
<td>Typical Applications</td>
<td>115</td>
</tr>
<tr>
<td><strong>Encoders</strong></td>
<td>117</td>
</tr>
<tr>
<td>Incremental Versus Absolute Encoders</td>
<td>118</td>
</tr>
<tr>
<td>Mechanical Installation and Accessories</td>
<td>120</td>
</tr>
<tr>
<td>Applications</td>
<td>122</td>
</tr>
<tr>
<td>Accessories</td>
<td>122</td>
</tr>
<tr>
<td><strong>Connection Systems</strong></td>
<td>125</td>
</tr>
<tr>
<td>Introduction</td>
<td>125</td>
</tr>
<tr>
<td>Choosing the Best Cabling Option for Your Application</td>
<td>126</td>
</tr>
<tr>
<td>Traditional Hardwiring Methods</td>
<td>127</td>
</tr>
<tr>
<td>Wiring Consolidation Using Passive Distribution Boxes</td>
<td>130</td>
</tr>
<tr>
<td>Safety Connection Systems</td>
<td>132</td>
</tr>
<tr>
<td>Systems without Enunciation</td>
<td>132</td>
</tr>
<tr>
<td>Systems with Enunciation</td>
<td>133</td>
</tr>
<tr>
<td>Device Networks</td>
<td>134</td>
</tr>
<tr>
<td>DeviceNet Flat Media Systems</td>
<td>134</td>
</tr>
<tr>
<td>DeviceNet Round Media Solutions</td>
<td>136</td>
</tr>
<tr>
<td>Control Networks</td>
<td>138</td>
</tr>
<tr>
<td>Cable Application — Best Practices</td>
<td>139</td>
</tr>
<tr>
<td>Motion Applications</td>
<td>140</td>
</tr>
<tr>
<td>Bundling and Cable Ties</td>
<td>141</td>
</tr>
<tr>
<td>Cable Jacket Material</td>
<td>142</td>
</tr>
<tr>
<td>Application Compatibility</td>
<td>143</td>
</tr>
<tr>
<td>Selection Criteria</td>
<td>144</td>
</tr>
<tr>
<td>IEC Enclosure Classification</td>
<td>144</td>
</tr>
<tr>
<td>Popular Rockwell Automation Sensor Connectivity with Most</td>
<td>146</td>
</tr>
<tr>
<td>Standard Cordsets and Patchcords</td>
<td></td>
</tr>
<tr>
<td><strong>Radio Frequency Identification (RFID)</strong></td>
<td>149</td>
</tr>
<tr>
<td>System Features</td>
<td>149</td>
</tr>
<tr>
<td>Dual-channel Integrated Architecture Application Diagram</td>
<td>149</td>
</tr>
<tr>
<td><strong>Technical Definitions &amp; Terminology</strong></td>
<td>151</td>
</tr>
</tbody>
</table>
Sensor Application Basics

Industry continually strives to develop products 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:

- PHOTOSWITCH® Photoelectric Sensors
- Inductive Proximity Sensors
- Ultrasonic Proximity Sensors
- Capacitive Proximity Sensors
- Limit Switches

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. Non-Contact 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.

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

- No physical contact is required
- No moving parts to jam, wear, or break (therefore less maintenance)
- 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 non-contact 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 non-contact sensor counts how many have left the painting area and how many have moved on to the curing area. The change to a non-contact 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 effect 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.

![Nominal sensing distance](image)

**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.

![Hysteresis diagram](image)

**Repeatability**

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

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 Electrotechnical 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 Standards Association (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?
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.
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.
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.

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:
Sensor Ratings

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

- 10…30V DC  ·  90…250V AC
- 20…130V DC  ·  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 35 mA
- Ultrasonic 70 mA
- Inductive 15 mA
- Capacitive 15 mA

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.
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...25 ms, 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.
A PNP transistor output is considered a ‘sourcing’ output. The load must be connected between the sensor output and the negative (−) power connection.

Transistors exhibit very low leakage current (measured in μA) and relatively high switching current (typically 100 mA) for easy interface to most DC loads. Response times of sensors with transistor outputs can vary from 2 ms to as fast as 30 μs. 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 30 mA. As a result, FETs are generally more expensive than standard transistor outputs.
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 500 mA 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 1 mA, 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 50/60 Hz AC power sine wave is required to deactivate a TRIAC circuit. For most applications, however, Power MOSFETs provide better output characteristics.
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.

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.

Output strengths and weaknesses

<table>
<thead>
<tr>
<th>Output Type</th>
<th>Strengths</th>
<th>Weaknesses</th>
</tr>
</thead>
</table>

### 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.

![Series connection of 2-wire outputs](image)
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.


**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.

**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.
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.
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 50 ms 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 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.
**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.
Motion detection logic

On/Off Delay

$t_f =$ time target present
$t_o =$ time target absent

Motion detection logic

Copyright © 2017 Rockwell Automation, Inc. All Rights Reserved.
PHOTOSWITCH® Photoelectric Sensors

Introduction

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 25.4 mm (1 in.) 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 standalone 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

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.

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.

![Modulation](image)

The modulation rate or frequency is often in excess of 5 kHz, 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.

![Spectral Response](image)

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

**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 the figure below 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.
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).

**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.

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.

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 76 mm (3 in.) at 3.05 m (10 ft), which can make alignment quite difficult. A sensor with a 3° field of view has a 152 mm (6 in.) spot at 3.05 m (10 ft) making alignment easier.

**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.

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.
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.

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

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 30 μs to 30 ms.

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.

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.

### 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>
<thead>
<tr>
<th>Sensing Mode</th>
<th>Applications</th>
<th>Advantages</th>
<th>Cautions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transmitted Beam</td>
<td>General purpose sensing</td>
<td>• High margin for contaminated environments</td>
<td>• More expensive because separate light source and receiver required, more costly wiring</td>
</tr>
<tr>
<td></td>
<td>Parts counting</td>
<td>• Longest sensing distances</td>
<td>• Alignment important</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Not affected by second surface reflections</td>
<td>• Avoid detecting objects of clear material</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Probably most reliable when you have highly reflective objects</td>
<td></td>
</tr>
<tr>
<td>Retroreflective</td>
<td>General purpose sensing</td>
<td>• Moderate sensing distances</td>
<td>• Shorter sensing distance than transmitted beam</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Less expensive than transmitted beam because simpler wiring</td>
<td>• Less margin than transmitted beam</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Easy alignment</td>
<td>• May detect reflections from shiny objects (use polarized instead)</td>
</tr>
<tr>
<td>Polarized Retroreflective</td>
<td>General purpose sensing of shiny objects</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
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.
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 274 m (900 ft). Transmitted beam application margins can exceed 10,000X at distances of less than 10 m (31 ft). 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 3 m (9.8 ft). 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.

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.

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.

**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**

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.

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.

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
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
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.

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.

![Polarized retroreflective sensing diagram](image)

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 retroreflective 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.

![Retroreflective or polarized retroreflective effective beam alignment](image)

**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 76 mm (3 in.) 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**

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...15 feet.

**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...150 mm (1...6 in.) from the sensor face).

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**
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.

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 216 x 292 mm (8.5 x 11 in.) 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>
<thead>
<tr>
<th>Object</th>
<th>Typical Relative Reflectivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Retroreflective tape</td>
<td>2000</td>
</tr>
<tr>
<td>Polished aluminum (perpendicular)</td>
<td>500</td>
</tr>
<tr>
<td>White paper (reference)</td>
<td>100</td>
</tr>
<tr>
<td>White typing paper</td>
<td>90</td>
</tr>
<tr>
<td>Cardboard</td>
<td>40</td>
</tr>
<tr>
<td>Packaged box (cereal box)</td>
<td>30</td>
</tr>
<tr>
<td>Cut lumber</td>
<td>20</td>
</tr>
<tr>
<td>Black paper</td>
<td>10</td>
</tr>
<tr>
<td>Neoprene</td>
<td>5</td>
</tr>
<tr>
<td>Tire rubber</td>
<td>4</td>
</tr>
<tr>
<td>Black felt</td>
<td>2</td>
</tr>
</tbody>
</table>

 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 an object. The two signals are compared, and the
output will change state upon active detection of the object or the background.

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 an 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.

**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.

![Wide angle diffuse effective beam pattern](image)

**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 midpoint between detection of the object and detection of the background.
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 216 x 279 mm (8.5 x 11 in.) 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.

Diffuse Advantages and Disadvantages

Standard 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.

**Standard 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.

**Fiber Optic Cables**

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. Ideal for sensing small objects, fiber optic cables can be mounted in locations that would otherwise be inaccessible to photoelectric sensors. Other characteristics/advantages of fiber optic sensors include:

- Some glass fiber optic tips have the ability to withstand high temperatures (up to 482°C (900°F))
- Withstand extreme shock and vibration
- Often have the fastest response times
- Immunity to electrical interference (EMI, RFI).

**Fiber Optic Cables—Types**

Fiber optic cables can be made of glass or plastic and categorized as either individual (transmitted beam) or bifurcated (diffuse).

Glass fiber optic cables contain multiple strands of very thin glass fiber that are bundled together in a flexible sheath. Typically more durable than their plastic counterparts, glass fiber optic cables will withstand much higher temperatures; glass fiber optic cables with a stainless steel sheath are rated up to 260°C (500°F). Special glass cables can be obtained with temperature ratings of up to 482°C (900°F). Most glass cables are available with a choice of PVC or
flexible stainless steel sheath. While PVC-sheathed cables are typically less expensive, stainless steel sheathing offers
greater durability and allows the cables to operate in higher temperatures. Glass fibers can be used with infrared or visible
LED light sources.

Light transmission is maximized with a thicker bundle diameter. It is also important to note that attenuation increases as
fiber optic cable length increases. For further details, see the Application Recommendations section on page xxxxx.

Plastic fiber optic cables are constructed of a single acrylic monofilament and, since plastic fibers absorb infrared light,
they are most efficient when used with visible red LED sources. It is recommended that plastic fiber optic cables are used
with visible light sources. Considered less durable than glass cables, plastic fibers are generally less expensive and can be
used in applications where continuous flexing of the cable is required. For that reason, coiled plastic cables are also
available for such applications.

**Selection Process**

1. **Determine the sensing mode**
   - Transmitted beam (two separate cables required)
     - Greater distance from sensing tip to the object
     - Reflectivity of the object is low
     - Generally darker colors reflect less light.
   - Diffuse (one bifurcated cable)
     - Distance from sensing tip to the object is small
     - Reflectivity of the object is high
     - Generally lighter colors reflect more light.

2. **Choose between glass or plastic fiber optic cables**
   - Glass
     - Higher temperature rating (up to 482°C (900°F) possible)
     - Used with infrared or visible red light sources
     - More expensive.
   - Plastic
     - Typically used for visible light sources
     - Lower temperature applications (lower than 70°C (158°F))
     - Less expensive.

3. **Mechanical considerations**
   - Glass has a more restrictive bending radius.
   - Select sensing tip configuration based on mounting space availability
     - Threaded tip versus ferruled
     - Straight tip versus 45° or 90° bend
     - Straight tip with light exiting at 90°.
4. **Select fiber bundle size for the application.**

- The smaller the bundle size, the smaller the light spot size for seeing smaller objects.
- The larger the bundle size, the greater the sensing distance.

5. **Cable length**

- Determine distance from sensor to object including required bending radii
- Longer (custom length) cables have shorter sensing distances due to light loss
  - Light loss is approximately 6% per foot for glass and 3% for plastic
- Use of extended range lens assemblies significantly increases sensing distance.

**Custom Fiber Optic Cables**

Rockwell Automation/Allen-Bradley can provide custom glass fiber optic cables to meet nearly any application requirement.

Typical cable modifications include:

- Custom lengths up to 15.2 m (50 ft)
- Custom temperature ratings up to 482 °C (900 °F) applies to glass fiber optic cables
- Custom configurations including multiple sensing tips
- Custom sensing end tips—nearly any modification is possible
- Reference pages 1-258...1-259 for glass and 1-281...1-282 for plastic.

Note: For more information contact product support at 1.440.646.5800.

| ATTENTION | Fiber optic cables are not recommended for explosion-proof applications in hazardous environments. The fiber optic cable can provide a path for explosive fumes to travel from the hazardous area to the safe area. |

**Sensing Modes**

The standard photoelectric sensors, fiber optic sensors are offered in two sensing modes: transmitted beam and diffuse. Reflective sensing can be accomplished in a diffuse mode or retroreflective mode.

Standard **diffuse** sensing with fiber optic cables is similar to sensing with lensed photoelectrics. When adjusted to maximum sensitivity these sensors, using bifurcated fiber optic cables, can detect extremely small targets.

Individual fiber optic cables may be used for more specialized diffuse mode applications. For instance, aiming the two separate sensing tips of the cables at the target can create sharp cutoff, fixed focus and mechanically convergent sensing modes.
**Bifurcated Cable (Diffuse/Retroreflective)**

![Bifurcated Cable Diagram]

Standard retroreflective sensing is possible with fiber optics, 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.

Transmitted beam sensing, the most reliable sensing mode, requires two individual fiber optic cables. Targets are detected when they break the light path established between the emitter and receiver cables.

**Individual Cable (Transmitted Beam)**

![Individual Cable Diagram]

**Sensing End Tip Selection**

One of the most important decisions to be made when selecting fiber optic cables is the sensing end tip configuration. Among the many considerations:

- Size of the object to be sensed
- Rate of travel of the target object
- Distance to the object
- Mounting options
- Environmental conditions
- Moving parts surrounding the object
- Sensing mode

Based on these factors, there are many sensing tips to select from offering various fiber diameters and arrays, bending radii, threaded and smooth body configurations, etc. The following pages are designed to assist in the selection of the proper sensing end tip for the application. Once a selection has been made, proceed to the fiber optic cables section to select the appropriate fiber optic cable cat. no.

**45FVL/45FSL Light Source Selector Guide for Color Contrast Sensing**

<table>
<thead>
<tr>
<th>Background</th>
<th>Target</th>
</tr>
</thead>
<tbody>
<tr>
<td>White</td>
<td>White</td>
</tr>
<tr>
<td>Yellow</td>
<td>Yellow</td>
</tr>
<tr>
<td>Orange</td>
<td>Orange</td>
</tr>
<tr>
<td>Red</td>
<td>Red</td>
</tr>
<tr>
<td>Green</td>
<td>Green</td>
</tr>
<tr>
<td>Blue</td>
<td>Blue</td>
</tr>
<tr>
<td>Black</td>
<td>Black</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>White</th>
<th>*</th>
<th>B</th>
<th>B</th>
<th>B</th>
<th>R</th>
<th>R</th>
<th>R</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yellow</td>
<td>B</td>
<td>*</td>
<td>G</td>
<td>G</td>
<td>R</td>
<td>R</td>
<td>R</td>
</tr>
<tr>
<td>Orange</td>
<td>B</td>
<td>G</td>
<td>*</td>
<td>G</td>
<td>G</td>
<td>G</td>
<td>R</td>
</tr>
<tr>
<td>Red</td>
<td>B</td>
<td>G</td>
<td>G</td>
<td>*</td>
<td>R</td>
<td>B</td>
<td>R</td>
</tr>
<tr>
<td>Green</td>
<td>R</td>
<td>R</td>
<td>G</td>
<td>R</td>
<td>*</td>
<td>B</td>
<td>G</td>
</tr>
</tbody>
</table>
Blue | R | R | G | B | B | *
---|---|---|---|---|---|---
Black | R | R | R | G | B | *

R = Red; B = Blue; G = Green
* 45CLR ColorSight sensor suggested for shades of same color.
Note: White LED light source can be used selectively in place of red, blue and green.

**Cork Detection with Bifurcated Fiber Optic Cables**

![Diagram of cork detection with bifurcated fiber optic cables]

**Work Piece Detection with Individual Fiber Optic Cables**

![Diagram of work piece detection with individual fiber optic cables]
Inductive Proximity Sensors

Inductive Proximity Sensors

Principles of Operation for Inductive Proximity Sensors

Inductive proximity sensors are designed to operate by generating an electromagnetic field and detecting the eddy current losses generated when ferrous and nonferrous metal target objects enter the field. The sensor consists of a coil on a ferrite core, an oscillator, a trigger-signal level detector and an output circuit. As a metal object advances into the field, eddy currents are induced in the target. The result is a loss of energy and a smaller amplitude of oscillation. The detector circuit then recognizes a specific change in amplitude and generates a signal which will turn the solid-state output “ON” or “OFF.”

A metal target approaching an inductive proximity sensor (above) absorbs energy generated by the oscillator. When the target is in close range, the energy drain stops the oscillator and changes the output state.

Standard Target for Inductive Proximity Sensors
The active face of an inductive proximity switch is the surface where a high-frequency electro-magnetic field emerges.

A standard target is a mild steel square, one mm thick, with side lengths equal to the diameter of the active face or three times the nominal switching distance, whichever is greater.

**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 ferrous-selective sensors will not detect brass, aluminum or copper, while nonferrous selective sensors will not detect steel or ferrous-type stainless steels.

The correction factors listed below can be used as a general guideline. Common materials and their specific correction factors are listed on each product specification page.

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

<table>
<thead>
<tr>
<th>Target Material</th>
<th>Approximate Correction Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mild Steel</td>
<td>1.0</td>
</tr>
<tr>
<td>Stainless Steel</td>
<td>0.85</td>
</tr>
<tr>
<td>Brass</td>
<td>0.50</td>
</tr>
<tr>
<td>Aluminum</td>
<td>0.45</td>
</tr>
<tr>
<td>Copper</td>
<td>0.40</td>
</tr>
</tbody>
</table>

The size and shape of the target may also affect the sensing distance. The following should be used as a general guideline when correcting for the size and shape of a target:

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

**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 is subjected to shock and vibration or when the target is stationary at the nominal sensing distance.
Vibration amplitudes must be smaller than the hysteresis band to avoid chatter.

**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, speed of target and switch type. This indicates the maximum possible number of switching operations per second. The measuring method for determining switching frequency with standard targets is specified by IEC60947-5-2.

**Ripple**

Ripple is the alternating voltage superimposed on the DC voltage (peak to peak) in %. For the operation of DC voltage switches, a filtered DC voltage with a ripple of 10% maximum is required (according to DIN 41755).
Reliable operation is dependent on the strength of the magnetic field and the distance between the current line and the sensor.

**Perpendicular Mounting to the Current Line**

![Diagram of perpendicular mounting]

**Parallel Mounting to the Current Line**

![Diagram of parallel mounting]

Use the following chart or formulas to determine the spacing requirements between the current line and proximity sensor. Select a distance that falls within the safe zone.

- \( H = \frac{I}{2\pi r} \)
- \( B = \frac{H}{0.796} \)
- Gauss = 10\(^{-8}\)B

where:

- \( I \) = welding current (in kA),
- \( H \) = field strength (in kA/m),
- \( B \) = flux (in mT), and
- \( r \) = distance between sensor and current carrying lines (in meters).

**Series Connected Sensors**
Sensors can be connected in series with a load. For proper operation, the load voltage must be less than or equal to the minimum supply voltage minus the voltage drops across the series-connected proximity sensors.

**Wiring Diagram for Series Connected Current Sink Sensors (NPN)**

![Wiring Diagram for Series Connected Current Sink Sensors (NPN)](image)

**Wiring Diagram for Series Connected Current Source Sensors (PNP)**

![Wiring Diagram for Series Connected Current Source Sensors (PNP)](image)

**Parallel Connected Sensors**

Sensors can be connected in parallel to energize a load. To determine the maximum allowable number of sensors for an application, the sum of the maximum leakage current of the sensors connected in parallel must be less than the maximum OFF-state current of the load device.

**ATTENTION**

Care should be taken when designing parallel proximity circuits. If too much leakage current flows into the load it may cause the solid state input to change state or a small relay not to drop out. Sensors connected in parallel do not provide a higher load current capability.

**Wiring Diagram for Parallel Connected Current Sink Sensors (NPN)**

![Wiring Diagram for Parallel Connected Current Sink Sensors (NPN)](image)

**Wiring Diagram for Parallel Connected Current Source Sensors (PNP)**

![Wiring Diagram for Parallel Connected Current Source Sensors (PNP)](image)
**Wiring Diagram for Parallel Connected AC Sensors**

When using sourcing outputs, ground must be floating and cannot be common, or short circuit will result.

**TTL Wiring**

When using sourcing outputs, ground must be floating and cannot be common, or short circuit will result.

**PLC Wiring**

For PLC wiring information for Inductive and Capacitive sensors, refer to publication 871-4.5, June 1996.

THIS PUBLICATION HAS BEEN OBSELETED!!!!
**Shielded vs. Unshielded Inductive Sensors**

*Shielded Sensor*

Shielded construction includes a metal band which surrounds the ferrite core and coil arrangement.

*Unshielded Sensor*

Unshielded sensors do not have this metal band.

**Spacing Between Shielded Sensors (Flush-Mountable) and Nearby Metal Surfaces**

Shielded proximity sensors allow the electro-magnetic field to be concentrated to the front of the sensor face. Shielded construction allows the proximity to be mounted flush in surrounding metal without causing a false trigger.

**Tubular Style**

<table>
<thead>
<tr>
<th>Housing Diameter</th>
<th>Dimension X</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.5 mm</td>
<td>1 mm</td>
</tr>
<tr>
<td>12 mm</td>
<td>2 mm</td>
</tr>
<tr>
<td>18 mm</td>
<td>4 mm</td>
</tr>
<tr>
<td>30 mm</td>
<td>6 mm</td>
</tr>
</tbody>
</table>

\[d = \text{diameter or width of active sensing face}\]
\[Sn = \text{nominal sensing distance}\]

**Limit Switch Style**
**Limit Switch Style (871L and 872L)**

- $d =$ diameter or width of active sensing face
- $\ast$ 802PR-LB or 802PR-XB can be mounted side-by-side.

**Flat Pack Style**

- $d =$ diameter or width of active sensing face
- $S_n =$ nominal sensing distance

**Cube Style (871P VersaCube — 2- & 3-Wire)**

- $d =$ diameter or width of active sensing face

**Cube Style (871P VersaCube — 4-Wire)**
<table>
<thead>
<tr>
<th>Surrounding Metal Thickness</th>
<th>Number of Sides</th>
<th>Orientation</th>
<th>Opening Required</th>
<th>Metal-Free Clear Zone (Each Side)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;3 mm</td>
<td>4</td>
<td>Front sensing face with bracket on back</td>
<td>44x44 mm</td>
<td>4 mm</td>
</tr>
<tr>
<td>3 mm</td>
<td>1, 2, or 3</td>
<td></td>
<td>40x40 mm</td>
<td>None</td>
</tr>
<tr>
<td>≥3 mm</td>
<td>4</td>
<td></td>
<td>41x41 mm</td>
<td>1 mm</td>
</tr>
</tbody>
</table>

\(d = \text{diameter or width of active sensing face}\)

**Spacing Between Unshielded Sensors (Nonflush-Mountable) and Nearby Metal Surfaces**

Longer sensing distances can be obtained by using an unshielded sensor. Unshielded proximity sensors require a metal-free zone around the sensing face. Metal immediately opposite the sensing face should be no closer than three times the rated nominal sensing distance of the sensor.

**Tubular Style**

<table>
<thead>
<tr>
<th>Housing Diameter</th>
<th>Dimension X</th>
</tr>
</thead>
</table>

![Diagram of tubular sensor configurations](http://www.ab.com/en/epub/catalogs/12772/6543185/12041221/12041227/print.html)
<table>
<thead>
<tr>
<th>Diameter</th>
<th>Sensing Distance</th>
</tr>
</thead>
<tbody>
<tr>
<td>8 mm</td>
<td>8 mm</td>
</tr>
<tr>
<td>12 mm</td>
<td>13 mm</td>
</tr>
<tr>
<td>18 mm</td>
<td>20 mm</td>
</tr>
<tr>
<td>30 mm</td>
<td>35 mm</td>
</tr>
</tbody>
</table>

**d** = diameter or width of active sensing face  
**Sn** = nominal sensing distance

**Limit Switch Style**

**Flat Pack Style**

**Cube Style (871P VersaCube — 2- & 3-Wire)**
Cube Style (871P VersaCube — 2- & 3-Wire)

\[ d = \text{diameter or width of active sensing face} \]

- \(3d\) for weld field immune models.

Cube Style (871P VersaCube — 4-Wire)

<table>
<thead>
<tr>
<th>Surrounding Metal Thickness</th>
<th>Number of Sides</th>
<th>Orientation</th>
<th>Metal-Free Clear Zone</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 mm</td>
<td>1</td>
<td>Front sensing face with bracket on back</td>
<td>15 mm protrusion</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Side sensing face with bracket on back</td>
<td>15 mm protrusion ⋆</td>
</tr>
<tr>
<td></td>
<td>2, 3, or 4</td>
<td>Front sensing face with bracket on back</td>
<td>30 mm protrusion</td>
</tr>
</tbody>
</table>

⋆ Sensing distance deviation may be up to -15%.
d = diameter or width of active sensing face

Applications

Machine Tools

Plating Line

Grinding Machines

Wood Industry

Petroleum Industry—Valve Position

Inductive proximity sensor used to detect a foil seasoning bag inside of a cardboard container.

Ferrous selective inductive proximity sensor used to sort ferrous and nonferrous can tops.

Food Industry

Stainless Steel Sheet Welder

On Line Parts Sorting

Railroad Yard Position Sensing

Coolant Resistant Sensing

Up and Downslope Control of Continuous Tube Welder

Nut Placement on Transformer

Closed Barrier Indicator

Detect Presence of Bushing in Piston
Control Presence of Mild Steel Bars in Grate Welding

Elevator Positioning
Rockwell Automation produces rail guide inductive proximity sensors for the positioning of elevator cars. These sensors offer increased accuracy and longer life when compared to typical mechanical switches. They are a cost-effective solution for lowering your repair costs and downtime. Contact your local Rockwell Automation sales office or Allen-Bradley distributor for a proximity sensor tailored to your requirements!

**Top 23 Reasons to Use the 871TM**

Robust Electrical Design
- Your choice of AC/DC, 2-wire or 3-wire DC
- Short circuit protection [ ]
- Overload protection [ ]
- Reverse polarity protection (DC models)
- Radio frequency protection
- Transient noise protection
- False pulse protection
- Epoxy potted for protection against mechanical shock and vibration

Stainless Steel Body
- Superior Strength of Impact and Abrasion Resistance Stainless Steel
- Superior Chemical and Cutting Fluid Resistance
- One Piece Body for Min O.D. Eliminates "Joint" Leaking
- Increased Mounting Torque

LED Lens and Grommet
- Provide Mechanical Seals for Primary Fluid Barrier
- Chemical Resistant

SOOW-A ToughLink™ Cable
- Superior Abrasion and Chemical Resistance
- Cutting Fluid Resistant
- Superior Strength of #18 AWG Conductors and Jacket Materials
- Fire Retardant
- Outdoor Approved
- Plastisol Filled Provides Increased "Fluid Wicking" Resistance

DC and long barrel AC/DC models only.
Ultrasonic Sensing

Ultrasonic 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.

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
Basic Components

Transducer/Receiver

The ultrasonic transducer pulses, sending sound waves 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 25 kHz and 500 kHz. Medical ultrasound units operate at 5 MHz or more. Sensing frequency is inversely proportional to sensing distance. While a 50 kHz sound wave may work to 10 m (33 ft) or more, a 200 kHz sound wave is limited to sensing ranges of about 1 m (3 ft).

Sensing Range and Effective Beam

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

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 or teach button.

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.”

![Spacing of Ultrasonic Sensors](image)

When more than one ultrasonic sensor is in use, some experimentation may be needed to determine optimal spacing for the application. The following values should only be used as a reference:
Sensor Alignment ☆ ‡

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.

☆ Not appropriate for transmitted beam style ultrasonic sensors.
‡ Applicable to certain ultrasonic models utilizing potentiometers.

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

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.
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.

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 Advantages and Disadvantages**

**Ultrasonic Advantages**

1. An ultrasonic 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.

2. 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.

3. 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.

**Ultrasonic 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 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

Distance measurement, height measurement, or work piece positioning

Part presence/absence sensing or glass and clear parts detection
Target temperature affects sensing capabilities

Copyright © 2017 Rockwell Automation, Inc. All Rights Reserved.
Capacitive Proximity Sensors

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 sensor components

The sensor consists of four basic components:

- A capacitive probe or plate
- An oscillator
- A signal level detector
- A solid-state output switching device
- An adjustment potentiometer

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 generate an...
electrostatic field and reacts to changes in capacitance caused when a target enters the electrostatic field. 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.

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 larger the target’s size, the stronger the capacitive coupling between the probe and the target. Materials with higher dielectric constants are easier to detect than those with lower values. The shorter the distance between target and probe, the stronger the capacitive coupling between the probe and the target.

**Shielded vs. Unshielded Capacitive Sensors**
Shielded sensors are constructed with a metal band surrounding the probe. This directs the electrostatic field to the front of the sensor and results in a more concentrated field. Shielded construction allows the sensor to be mounted flush in surrounding material without causing false trigger. Unshielded sensors do not have a metal band. Compensation probes provide increased stability for the sensor.

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 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.

Unshielded capacitive proximity sensors are 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 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.

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.

**Standard Target for Capacitive Proximity Sensors**
As with inductive proximity sensors, the standard target for capacitive sensors is a square piece of mild steel 1 mm (0.04 in.) 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>
<thead>
<tr>
<th>Material</th>
<th>Constant</th>
<th>Material</th>
<th>Constant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acetone</td>
<td>19.5</td>
<td>Perspex</td>
<td>3.2...3.5</td>
</tr>
<tr>
<td>Acrylic Resin</td>
<td>2.7...4.5</td>
<td>Petroleum</td>
<td>2.0...2.2</td>
</tr>
<tr>
<td>Air</td>
<td>1.000264</td>
<td>Phenol Resin</td>
<td>4...12</td>
</tr>
<tr>
<td>Alcohol</td>
<td>25.8</td>
<td>Polyacetal</td>
<td>3.6...3.7</td>
</tr>
<tr>
<td>Ammonia</td>
<td>15...25</td>
<td>Polyamid</td>
<td>5.0</td>
</tr>
<tr>
<td>Aniline</td>
<td>6.9</td>
<td>Polyester Resin</td>
<td>2.8...8.1</td>
</tr>
<tr>
<td>Aqueous Solutions</td>
<td>50...80</td>
<td>Polyethylene</td>
<td>2.3</td>
</tr>
<tr>
<td>Bakelite</td>
<td>3.6</td>
<td>Polypropylene</td>
<td>2.0...2.3</td>
</tr>
<tr>
<td>Benzene</td>
<td>2.3</td>
<td>Polystyrene</td>
<td>3.0</td>
</tr>
<tr>
<td>Carbon Dioxide</td>
<td>1.000985</td>
<td>Polyvinyl Chloride Resin</td>
<td>2.8...3.1</td>
</tr>
<tr>
<td>Carbon Tetrachloride</td>
<td>2.2</td>
<td>Porcelain</td>
<td>4.4...7</td>
</tr>
<tr>
<td>Celluloid</td>
<td>3.0</td>
<td>Powdered Milk</td>
<td>3.5...4</td>
</tr>
<tr>
<td>Cement Powder</td>
<td>4.0</td>
<td>Press Board</td>
<td>2...5</td>
</tr>
<tr>
<td>Cereal</td>
<td>3...5</td>
<td>Quartz Glass</td>
<td>3.7</td>
</tr>
<tr>
<td>Material</td>
<td>Dielectric Constant</td>
<td></td>
<td></td>
</tr>
<tr>
<td>----------------------------------</td>
<td>---------------------</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chlorine Liquid</td>
<td>2.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rubber</td>
<td>2.5...35</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ebonite</td>
<td>2.7...2.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Salt</td>
<td>6.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Epoxy Resin</td>
<td>2.5...6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sand</td>
<td>3.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ethanol</td>
<td>24</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shellac</td>
<td>2.5...4.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ethylene Glycol</td>
<td>38.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shell Lime</td>
<td>1.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fired Ash</td>
<td>1.5...1.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Silicon Varnish</td>
<td>2.8...3.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flour</td>
<td>1.5...1.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Soybean Oil</td>
<td>2.9...3.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Freon R22 &amp; 502 (liquid)</td>
<td>6.11</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Steel</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gasoline</td>
<td>2.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Styrene Resin</td>
<td>2.3...3.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Glass</td>
<td>3.7...10.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sugar</td>
<td>3.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Glycerine</td>
<td>47</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sulphur</td>
<td>3.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Marble</td>
<td>8.0...8.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Teflon</td>
<td>2.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Melamine Resin</td>
<td>4.7...10.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Toluene</td>
<td>2.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Metal</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transformer Oil</td>
<td>2.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mica</td>
<td>5.7...6.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Turpentine Oil</td>
<td>2.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nitrobenzine</td>
<td>36</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Urea Resin</td>
<td>5...8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nylon</td>
<td>4...5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vaseline</td>
<td>2.2...2.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oil Saturated Paper</td>
<td>4.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water</td>
<td>80</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Paraffin</td>
<td>1.9...2.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wood, Dry</td>
<td>2...7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Paper</td>
<td>1.6...2.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wood, Wet</td>
<td>10...30</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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.

![Capacitive sensing through a tank](image)

Each application should be tested. The list of dielectric constants is provided to help 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 electrodes generate a weaker electrostatic field compared to the electrostatic field generated by the sensing electrodes. When contaminants lie directly on the sensor face, both fields (sensing and compensation) are affected. Because the sensing field increases at the same ratio as the compensation field, the sensor will not detect a difference between the two fields and, therefore, will not trigger an output. When a target approaches the sensor, the sensing field is affected, while the compensation field remains unchanged. The sensor detects the difference between the two fields and generates an output.

![Probe Detail](Diagram)

**Capacitive Proximity Advantages and Disadvantages**

**Capacitive Proximity 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

**Capacitive Proximity 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

**Capacitive Proximity Sensors**

*Bulletin 872C and 872CP Capacitive*
Proximity Sensors are designed for non-contact sensing of a wide range of materials. The Bulletin 872C and 872CP Capacitive Sensors can detect non-metal solids and liquids in addition to metal targets. Capacitive sensors can sense the presence of some targets through other materials. Each unit has an adjustable sensing distance and is equipped with an LED to indicate output. They are housed in either plastic or nickel brass cylindrical housing. They are available in 18, 30, 32 mm housing with DVC cable, micro, and pico quick disconnects.

**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
Level sensing in a hopper can be either through a window or embedded in material

Product sensing through packaging

Copyright © 2017 Rockwell Automation, Inc. All Rights Reserved.
Limit Switches

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.”

**Bulletin 802T Limit Switches**

The 802T limit switch is ideal for applications in which heavy-duty pilot ratings, a high degree of versatility and rugged NEMA Type 4 and 13 oil-tight (6P on select rotary shaft models) enclosures are desired, including:

- Conveyor systems
- Transfer machines
- Automatic turret lathes
- Milling and boring machines
- Radial drills

**Bulletin 802M/MC Prewired Limit Switches**

Bulletin 802M and 802MC compact prewired limit switches are factory-sealed to meet the demanding requirements for NEMA Type 4, 4X, 6P and IP67 environments. A large variety of operating heads and levers are available to suit a wide range of applications, especially where the switch may be subject to washdowns, streams of coolant, or occasionally submerged in fluids commonly found on machines or in industrial processes.

**Bulletin 802B Compact, Precision and Small Precision Limit Switches**

The 802B family of limit switches is designed to withstand tough industrial environments. Its compact, rugged enclosure makes the 802B ideal for mounting in areas too small for traditional NEMA-style limit switches. Each model features a die-cast housing for durability as well as industry-standard mounting dimensions.

The compact style housing boasts a prewired 3-meter cable or connector version and triple-sealed construction, giving it NEMA 6 and IP67 enclosure ratings. The precision line offers 5 unique head configurations that can be ordered as side or flange mount. The small precision family offers additional features in an even smaller package, providing a washdown-rated housing with 12 different head configurations.
**Bulletin 440P and 802K International Style Limit Switches**

The 440P and 802A limit switch family offers a full range of international style solutions for both safety and standard sensing applications. The 440P is available in three different body styles: 30 mm metal, 22 mm plastic and 15 mm plastic, with a broad selection of operator types, circuit arrangements and connection options. The 802K is available in a 30 mm metal version. The 440P is ideal for a wide variety of applications including material handling, packaging, elevators, escalators, scissor lifts, industrial trucks and tractors, cranes and hoists, overhead door as well as general safety guarding applications.

The 22 mm plastic body style is available in positive opening action two- and three-circuit models, with seven different operator types:

- Adjustable roller lever
- Adjustable rubber roller lever
- Short lever
- Hinge lever
- Roller plunger
- Dome plunger

The metal body, 30 x 60 mm style is available in positive opening action two- and four-circuit models and seven different operator types:

- Metal roller plunger
- Metal dome plunger
- Metal short lever
- Metal adjustable lever
- Metal rod lever
- Metal spring rod
- Telescopic arm

**Limit Switch Offerings**

<table>
<thead>
<tr>
<th>NEMA Style</th>
<th>Hazardous Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>802T Plug-In</td>
<td>802X/802XR</td>
</tr>
<tr>
<td>802M / MC Factory Sealed</td>
<td>IEC Style</td>
</tr>
<tr>
<td>802T Plug-In Safety (DALS)</td>
<td>440P Small and Large Body</td>
</tr>
<tr>
<td>802B Family</td>
<td>802K Large Body</td>
</tr>
<tr>
<td>802G Gravity Return</td>
<td>Legacy</td>
</tr>
<tr>
<td>802R Sealed Contact</td>
<td>802T NonPlug-In</td>
</tr>
<tr>
<td></td>
<td>801 General Purpose</td>
</tr>
</tbody>
</table>

**Competitive Comparison**

**Bulletin 802 Limit Switches**
- Plug in design — allows for quick, easy installations and repair
- Safety rated contacts in a NEMA housing (802T)
- Superior sealing for wet and washdown applications (802M)
- Corrosion resistant fittings — with stands chemical washdowns (802MC)
- Ideal for safety and sensing applications 440P and 802T DALS

<table>
<thead>
<tr>
<th>Company</th>
<th>Plug-in Offering</th>
<th>Compact Offering</th>
<th>IEC Offering</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rockwell Automation/Allen-Bradley</td>
<td>802T Plug-in</td>
<td>802B Compact Precision, Small Precision</td>
<td>440P Small Plastic, 440P Large Metal, 440P IMP</td>
</tr>
<tr>
<td>Square D/Telemecanique</td>
<td>9007 C Industrial</td>
<td>9007 MS / ML, 9007 XA, XC</td>
<td>Osiswitch</td>
</tr>
<tr>
<td>Omron</td>
<td>D4A series</td>
<td>D4C, ZC, ZE, ZV</td>
<td>D4N &amp; D4BN</td>
</tr>
<tr>
<td>Honeywell / Microwswitch</td>
<td>HDLS series</td>
<td>914/924 CE Compact, SL1 Precision</td>
<td>GLS DIN &amp; GLS MIN - DIN</td>
</tr>
<tr>
<td>Cutler - Hammer</td>
<td>E50 Heavy - Duty Modular</td>
<td>E47 Precision &amp; Compact Prewind</td>
<td>E49 Compact &amp; Miniature DIN</td>
</tr>
</tbody>
</table>

Copyright © 2017 Rockwell Automation, Inc. All Rights Reserved.
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.

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.

**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.
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.

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

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

**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.

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 the figure below.
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.

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.

**Note:** Pretravel occurs before contact movement.
Contact arrangement diagram for slow make and break switch

Point where direct opening mechanism engages.

Trip and Reset Point for Contacts 23-24

Maximum Travel

Terminal Numbers

11-12

23-24

Unshaded areas show positions at which each contact is open.

Shaded areas show positions at which each contact is closed.

Actuator positions are shown in millimeters or inches for push style switches.

Copyright © 2017 Rockwell Automation, Inc. All Rights Reserved.
Limit Switch Advantages And Disadvantages

Limit Switch Advantages and Disadvantages

Limit Switch 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 (5 A at 24V DC or 10A at 120V AC typical vs. less than 1 A 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

Limit Switch 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

Position verification
End-of-travel Limit Switch for Part Detection

Limit Switch for Conveyor Misalignment Indication

Counting and parts detection
Encoders

To solve positioning problems in automation, lengths and angles need to be measured as accurately as possible. Encoders can electronically monitor the position of a rotating shaft to measure information such as position, distance, and speed.

Encoders can have various outputs and they can be incremental or absolute.

How an encoder works

The simplified diagram below identifies major encoder components. An encoder consists of a light source, optical disk, and a light source receiver. As the shaft rotates, the optical disk passes and breaks the light beam. The light receiver and associated electronic circuitry converts the on/off light states into an electrical signal as shown in the encoder voltage graph below.

Basic Encoder Components
**Incremental Versus Absolute Encoders**

**Incremental Encoders**

The graphic below shows the code disk for an incremental encoder. Incremental encoders generate a series of pulses as they move and provide relative values. Incremental encoders provide speed and distance feedback. They are typically simple and inexpensive. Incremental encoders provide relative position information.

**Incremental Outputs**
**Absolute Encoders**

An absolute encoder has a unique digital output for each shaft position that provides true, or absolute, position regardless of power interruptions. The code disk for an absolute encoder uses an absolute track with straight binary, binary coded decimal, or gray code to provide absolute position data. Upon a loss of power, the encoder will provide the correct absolute position when power is restored. Absolute encoders are used for packaging machines, robotics, lead/ball screw, and pick and place applications, to name a few. Gray code provides the most reliable high speed positioning at the lowest cost.

**Absolute Code Disk with Grey Code**

<table>
<thead>
<tr>
<th>Binary Coded Decimal</th>
<th>Natural Binary</th>
<th>Grey Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 0000</td>
<td>0 0000</td>
<td>0 0000</td>
</tr>
<tr>
<td>0 0001</td>
<td>0 0001</td>
<td>0 0001</td>
</tr>
<tr>
<td>0 0010</td>
<td>0 0010</td>
<td>0 0011</td>
</tr>
<tr>
<td>0 0011</td>
<td>0 0011</td>
<td>0 0010</td>
</tr>
<tr>
<td>0 0100</td>
<td>0 0100</td>
<td>0 0110</td>
</tr>
<tr>
<td>0 0101</td>
<td>0 0101</td>
<td>0 0111</td>
</tr>
<tr>
<td>0 0110</td>
<td>0 0110</td>
<td>0 0101</td>
</tr>
<tr>
<td>0 0111</td>
<td>0 0111</td>
<td>0 0100</td>
</tr>
<tr>
<td>0 1000</td>
<td>0 1000</td>
<td>0 1100</td>
</tr>
<tr>
<td>0 1001</td>
<td>1 1001</td>
<td>1 1101</td>
</tr>
<tr>
<td>1 0000</td>
<td>0 1010</td>
<td>0 1111</td>
</tr>
<tr>
<td>1 0001</td>
<td>0 1011</td>
<td>0 1110</td>
</tr>
<tr>
<td>1 0010</td>
<td>0 1100</td>
<td>0 1010</td>
</tr>
</tbody>
</table>
Latch, Direction, and Reset Features

- Latch is required for natural binary or binary coded decimal outputs to prevent erroneous readings while the shaft is turning.
- Wire the encoder for counting up or down with either CW or CCW rotation of shaft.
- Zero reference is an output signal which is produced once per revolution. It is used to identify a home position or a reset point. This provides a time savings when commissioning a machine.

Single-turn versus Multi-turn

In a single turn encoder, the output codes are repeated for every revolution of the encoder shaft. There is no mechanism to indicate whether the encoder had made one revolution or several revolutions. All that is output is the relative position. In a multi turn absolute encoder, the output is unique for each shaft position through every rotation up to x number of revolutions.

Single turn absolute encoders are used when full range of positioning in the application is not greater than one full revolution (360 degrees) of the encoder shaft - an example is rotary table positioning.

Multi turn absolute encoders are used when a full range of positioning in the application requires multiple turns of the encoder shaft - an example of this is lead and ball screw applications.

Resolution

The resolution of the encoder is dependent on the number of tracks on the code disk. Each track requires a wire (pin connection) for the output signal for that bit. Ten-bit resolution is 1024 counts per turn.

Example: 2 to the 10th = 1024

Mechanical Installation and Accessories

Several housing sizes are available to accommodate the physical constraints of an application installation as well as allowing for more precise resolutions.

Hollow shaft encoders are shaft-less by design and mount of the shaft of a connected device, such as a motor. Advantages of hollow shaft mounting include reduced mounting depth, reduced installation cost, and flexible coupling and mounting plates are not required.
Mounting types include square flange and English or metric servo in three and four hold mounting patterns.

Radial versus Axial Mounting

Radial refers to the direction perpendicular to the encoder shaft. Axial refers to the direction parallel to the encoder shaft.
Applications

Incremental encoder

Incremental encoder output provides relative position of the shaft - external electronics such as counters are required to accumulate data to determine position, speed, and direction. Incremental encoder output provides relative position of the shaft - external electronics such as counters are required to accumulate data to determine position, speed and direction. Use when retention of position data is not required upon power loss. Incremental encoders are used for velocity control, point to point applications and sequencing.

Absolute encoder

Absolute encoders provide the absolute angle position of the shaft. Use an absolute encoder when position data must be retained on loss of power. Typical applications include: packaging machines, robotics, lead/ball screw, rotary table positioning, pick and place, or component insertion.

Application Tips/Summary

- Differential Line driver outputs provide the most reliable signals for incremental encoders
- Grey code output is the most reliable code type for absolute encoders
- Low capacitance cable is recommended for cable lengths greater than 150 feet to prevent signal distortion.
- Servo flange mounting permits easy adjustment of the encoder during installation.
- Encoder resolution can sometimes be enhanced through pulse multiplication at the PLC, controller or counter.

Accessories
**Couplings**

Rigid couplings will cause a failure to the bearings in the encoder or to the motor. Flexible couplings should always be used to compensate for parallel misalignment.

Parallel misalignment is the maximum amount of distance between the center lines of the coupled shafts. Rigidly coupling the encoder shaft to the machine shaft will cause premature failure in the bearings of the encoder.

Rockwell Automation provides a variety of prewired cable assemblies, mating connectors, flexible couplings, measuring wheels, servo clamps, and mounting brackets.
Connection Systems

Introduction

"On-Machine" is a control design philosophy that moves the industrial controls and hardware closer to the application or on the machine while minimizing the number of components in the cabinet. Although many of these controls have always been on the machine, such as sensors, push buttons, tower lights, and connection systems, the complete On-Machine strategy involves taking controls that are traditionally found in an enclosure and moving them out to the application as well.

Although the world outside the enclosure may not seem appropriate for many of today's panel-based industrial controls, the ideal On-Machine component has several key features to enable this migration. Its housing is typically “hardened” to IP67 enclosure standards in order to withstand the harsh environments often found on the factory floor. It tends to be modular and compact in design, with plug-and-play electronic capabilities to ease installation and setup. It can be used as part of a flexible communication network including both standard and intelligent devices.

On-Machine solutions are also connectorized for quick system assembly using IP67 connection systems instead of traditional wiring in conduit.

The obvious benefit of moving products out of an enclosure and putting them directly on the machine is the reduced panel space required for an On-Machine system. Secondly, the wiring system is greatly simplified because many connections between components can reside on the machine instead of running back and forth between enclosures. Although the purchase cost of individual components may be slightly higher, the reduction in wiring complexity is so substantial that the decreased wiring time and conduit installation costs make the overall solution more economical.

The end result: the larger and more complex the machine, the greater the potential savings during assembly. A recent study by a consortium of European manufacturers and machine tool technology groups concluded that On-Machine assembly costs are up to 30% less than conventional methods.

The features afforded by On-Machine components result in many other benefits, such as decreased systems troubleshooting and repair time as well as enhanced control system reliability—with prewired connection there is less manual wiring, resulting in reduced wiring errors and fewer wiring points to check. Plus, the plug-together connectorized components can often be installed by less technically-trained personnel, providing more flexibility with the workforce. Using plug-and-play components even simplifies design effort and engineering documentation.

On-Machine architectures also reduce the need for maintenance technicians and operators to access a control panel every time they have to check a connection or make an adjustment. Instead, they can efficiently isolate problems and replace a starter or I/O locally, rather than sorting through a complex panel. This gets the machine up and running again both faster and safer.

Startup and commissioning time also are critical, and On-Machine solutions can reduce both considerably. Due to the modularity and simplified connectivity of components, On-Machine designs allow OEMs to more cost efficiently build a machine at their site, pretest it, and then disassemble it for transport to an end user’s plant.

Equally important for end users is the flexibility of being able to relocate equipment and make additions with relative ease.

The On-Machine approach also allows OEMs to provide standard product offerings once considered to be custom applications. In the material handling industry, for example, conveyors once sold as large customized systems can now be sold in standard ten-foot sections. This allows for reduced OEM engineering, quicker delivery times, and increased flexibility for the end user.
The migration to the On-Machine approach, like most industrial innovations, will be driven by economics as companies continue to refine their understanding of true assembly and installation costs. OEMs and end users will see different cost advantages depending on their particular industry and equipment environment.

The ability of these solutions to reduce wiring and system costs, improve Mean Time to Repair (MTTR), enhance control system reliability, increase productivity, and promote flexibility will make On-Machine solutions a common strategy for reducing costs and increasing reliability of both OEM and end user control systems.

Choosing the Best Cabling Option for Your Application

With the variety of cabling options available, it is crucial to determine which On-Machine solution best suits the application based on several considerations. Use the process outlined below as a guideline to selecting the best On-Machine solution for your needs.

1. **Number, Location, and Concentration of Field Devices.** If there are only a few devices, a simple hard wired solution may be the simplest and most cost-effective solution. However, in the case of machines with relatively high device counts, a connector-based solution could prove to be the easiest to apply and troubleshoot. Those applications with high I/O counts and devices concentrated in key areas may best benefit from the same connectorized solution, but with local hardened I/O blocks. And ultimately, for installations with many devices distributed over distances, a network approach may prove most suitable.

2. **Environment.** What is the environment your field devices—and therefore the cabling system—will be exposed to? Applications where washdowns or corrosive materials are common will require all devices and the associated cabling to be IP67-rated or have stainless steel hardware, respectively. On the other hand, for machines installed in relatively clean, less severe environments, open-style connectors and terminal blocks may be appropriate. If temperature extremes are an issue, the need for high- or low-temperature control components may dictate the selection of a wiring solution.

3. **Machine Sections and Their Locations.** Large machines built in sections and disassembled for shipment only to be reassembled on site generally need modular wiring solutions. Plug-and-play wiring systems allow for the simplest commissioning/recommissioning of the control system on the plant floor, with minimal marshalling and wiring errors.

4. **Sensors - Connection Systems**
Standard vs. Networked Solutions. While standard wiring solutions can just satisfy about every need and address the bulk of industrial control applications, there are instances where system feedback and enhanced diagnostics are a must. In these cases, networks such as ControlNet and DeviceNet, which both have their own topographies and media types, must be considered.

5. Safety vs. Nonsafety Installations. When installing a machine safety system, there are special wiring practices and configurations that must be employed. The Rockwell Automation/Allen-Bradley Safety Connection System is a connector-based system designed specifically for safety applications.

6. Special Considerations. Upon choosing the best On-Machine wiring scheme, it is important to take other characteristics into account for the cabling components. Component selection and installation may be impacted by the need for high-flex cable in motion applications, device connection options, routing paths, and available space, among other factors.

Traditional Hardwiring Methods

A hardwired system consists of fixed wiring from the devices routed through a cable gland and into terminal connections within the cabinet. At the device, connections may be via terminals as well; in the event of devices with built-in connectors, field attachable connectors may be employed.

Benefits

- A simple solution—requires few parts
- Since no cable lengths are specified, requires little pre-engineering
- A good solution for small machines and/or low device counts

Limitations
• Time-consuming installation and commissioning
• Prone to wiring errors
• Considerable down time and difficult component replacement in the event of failure

**Introduction of Quick-Disconnect Cabling at Field Device**

This system is characterized by fixed wiring from terminal blocks through a cable gland at the cabinet, out to connector-based field devices.

**Benefits**

• A simple solution—requires few parts
• Limited specification of cable lengths, requires some pre-engineering
• Devices can be placed and mounted prior to wiring installation

**Limitations**

• Time-consuming installation and commissioning at the cabinet
• Prone to wiring errors within the cabinet
• Longer down time and difficult component replacement in the event of cable failure
**Introduction of Quick-Disconnect Cabling at Both Ends**

In this case, connector-based devices are interfaced with the panel via a quick-connect receptacle. Inside the panel, however, the receptacle is hardwired to terminal connections.

**Benefits**

- Easy replacement and reduced down time in event of field device or cable failure
- Highly modular design
- Eliminates wiring errors outside cabinet
- Less time for installation and commissioning outside cabinet

**Limitations**

- More complex to engineer
- Potentially higher number of parts
- Time consuming installation and commissioning inside cabinet
- Prone to wiring errors in cabinet
Quick-disconnect connector

**Wiring Consolidation Using Passive Distribution Boxes**

Here, the field devices are interfaced with a distribution box. All connections between the devices and the box are of the quick-connect type. The distribution box is then routed through a cable gland at the cabinet and hard wired into terminals.

**Benefits**

- Simplifies, neatens and consolidates field device wiring
- Minimal time to repair (MTTR) in event of field device failure
- Eliminates wiring errors outside cabinet
- Reduced installation and commissioning time outside cabinet
- More modular approach, allows replacement of shorter runs upon cable failure

**Limitations**

- More complex to engineer
- Potentially higher number of parts
- Time consuming in-cabinet installation and commissioning
- Potential remains for wiring errors in cabinet
Wiring Consolidation With Modular Components Outside Panel

This system is almost identical to the previous example, but with a quick-connect cable between the distribution box and cabinet. The cabinet receptacle is then hard wired to terminals on the panel.

Benefits

- Simplifies, neatens and consolidates field device wiring
- Minimal time to repair (MTTR) in event of field device or cable failure
- Eliminates wiring errors outside cabinet
- Reduced installation and commissioning time outside cabinet
- Even more modular—facilitates replacement of shorter runs upon cable failure, simplifies swap out of failed distribution boxes or main cable

Limitations

- More complex to engineer
- Potentially higher number of parts
- Time consuming in-cabinet installation and commissioning
- Potential remains for wiring errors in cabinet
**Safety Connection Systems**

Allen-Bradley Guardmaster Safety Connection Systems are complete wiring solutions dedicated to machine safety. These quickdisconnect based systems are specifically intended for use with dry-contact safety switches, and offer flexible and reliable connections between safety interlocks, E-stops, cable pull switches, and safety relays.

Safety Connection Systems layouts are available with or without enunciation capabilities, allowing the user the option of direct feedback for the status of individual switches in the system. Enunciation systems utilize an auxiliary contact as input to tower lights, audible alarms, PLC input cards, etc.

**Systems without Enunciation**

As illustrated below, wiring systems for applications not requiring enunciation use a combination of patchcords, shorting plugs, safety wired distribution boxes and T-ports for series wiring of safety circuits. Distribution boxes for such an application are dual channel models with 2 NC or 1 NC + 1 NO contact configurations. Note that shorting plugs must be used on all unused ports for the system to operate.

**Benefits**

- Reduced installation cost and easy system expansion
- Simplified troubleshooting
- Modularity
- Provide for Safety PLC input expansion
- Support systems up to Category 3 (per EN954-1)

**Limitations**

- Suitable for dry-contact switches only—no light curtains, safety mats or pressure sensitive safety edges
- No feedback from individual switches
**Systems with Enunciation**

As shown in the illustration below, system layouts with enunciation require patchcords, shorting plugs, and distribution boxes, which allow for series wiring of the safety circuits while providing a separate circuit for enunciation. Distribution boxes are offered for these applications in several contact configurations: dual channel with 2 N.C., dual channel with 1 N.C. + 1 N.O. or single channel with 1 N.C. Each type also provides a N.O. auxiliary contact that is interfaced with the enunciation device to provide visual or audible alarm indication. In addition, LEDs on the distribution boxes assist in the troubleshooting of this system. Again, note that shorting plugs must be used on all unused ports for the system to operate.

**Benefits**

- Reduced installation cost and easy system expansion
- Simplified troubleshooting and replacement of components
- Modularity
- Feedback from individual switches
- Support systems up to Category 3 (per EN954-1)

**Limitations**

- Suitable for dry-contact switches only—no light curtains, safety mats or pressure sensitive safety edges
**Device Networks**

DeviceNet is an open communication network designed to connect factory floor devices such as photoelectric sensors, inductive proximity sensors, motor starters, drives, valve manifolds, and simple operator interfaces together without interfacing through an I/O system. It increases the amount and rate of information flowing from plant floor devices to control systems, and has the potential to substantially reduce wiring costs.

The DeviceNet network consists of a cabling system that provides both power and communication to nodes. Like the previous examples, the options range from fully hard wired networks to completely connector-based systems. Below are examples designed to showcase the various media types, their features and limitations—each, in reality, is capable of supporting the same types of connections as their non-network counterparts.

**Device Flat Media Systems**

**KwikLink™ General Purpose Media**

Utilizing the same flat cable design pioneered by Rockwell Automation with the introduction of the original KwikLink system, KwikLink general purpose connectors combine the flexibility and simplicity of their predecessor in a low profile, OEM-friendly package.

**Benefits**

- Optimal plug-and-play capability offers drastic reduction in labor, materials, and installation costs
- Devices can be added anywhere along the trunk—no need for predetermined cable lengths
- Modular, snap-on connectors eliminate cutting and stripping of cables
- Wide range of components, cable types, and accessories provides optimal system flexibility

- Keyed cable and snap-on connectors prevent wiring errors
- Ideal solution for less demanding industrial applications
- Class 2 cable—even more flexible than previous flat cable—makes cable routing even easier
Limitations

- Maximum trunk line distance of 420 m (1378 ft)
- Single-use connectors cannot be moved or removed once applied

DeviceNet Flat Media Systems

KwikLink Heavy Duty Media

The KwikLink physical media system consists of flat trunk cable and snap-on modular connectors which can be placed anywhere along the trunk. Devices are then interfaced with the trunk via special patchcords, distribution boxes and I/O blocks.

Benefits

- Optimal plug-and-play capability offers drastic reduction in labor, materials, and installation costs
- Devices can be added anywhere along the trunk—no need for predetermined cable lengths
- Modular, snap-on connectors eliminate cutting and stripping of cables
- Wide range of components, cable types, and accessories provides optimal system flexibility

- Keyed cable and snap-on connectors prevent wiring errors
- Heavy duty connectors and cable allow for use in harsh environments

Limitations
• Maximum trunk line distance of 420 m (1378 ft)
• Single-use connectors cannot be moved or removed once applied

DeviceNet Round Media Solutions
Thick Trunk
This round media thick trunk system is based on the use of “thick cable” for DeviceNet. Allen–Bradley thick trunk cable allows maximum trunk line distance and is the original DeviceNet system configuration. A full range of rugged, durable Allen–Bradley DeviceNet components are available for use in thick trunk systems. Although typically used as trunkline only, thick cable can also be used for drops to field devices.

Benefits
• Allows for greatest trunkline distance: 500 m (1640 ft)
• Simplified troubleshooting and replacement of components
• Reduced installation cost and easy system expansion
• PVC cable jacket offers good oil and chemical resistance
• Shielded cable provides optimal resistance to noise

Limitations
• More rigid cable than flat and thin cable counterparts
• Shielded cable makes cutting and stripping of cable time consuming in hardwired networks

DeviceNet Round Media Solutions

Thin Trunk

The following round media thin trunk system is based on the use of “thin cable” for DeviceNet. Here, the thin cable typically used for drops to field devices is used as the main trunkline as well. The use of thin cable reduces maximum trunk line distances but allows for a more compact and cost effective installation for some applications. And like the thick trunk system, a wide variety of rugged, durable Allen-Bradley DeviceNet components are also available for use in thin trunk systems.

Benefits

• Simplified troubleshooting and replacement of components
• Reduced installation cost and easy system expansion
• Allows for a more compact DeviceNet installation
• TPE cable jacket offers additional chemical resistance for harsh applications
• Shielded cable provides optimal resistance to noise

Limitations

• At 100 m (328 ft), offers the shortest maximum trunkline length
• Shielded cable makes cutting and stripping of cable time consuming in hardwired networks
Control Networks

The ControlNet network is an open, state-of-the-art control network that meets the demands of real-time, high-throughput applications. ControlNet uses the proven Common Industrial Protocol (CIP) to combine the functionality of an I/O network and a peer-to-peer network providing high-speed performance for both functions.

The ControlNet network provides deterministic, repeatable transfers of all mission-critical control data in addition to supporting transfers of non-time-critical data. I/O updates and controller-to-controller interlocking always take precedence over program uploads and downloads and messaging.

ControlNet IP67 Media

Rockwell Automation offers a variety of ControlNet media options; the decision on which media type to use is based on the environmental factors associated with your application and installation site. A typical ControlNet network consists of one or more of the following: trunk cables, taps, repeaters, terminators, and bridges. The ControlNet IP67 media system offers a modular, rugged version of taps and connectors for high vibration or IP67 type environments.

Benefits

- Variety of media options for a wide range of application needs, including fiber or coaxial media types.
- Threaded connection media type resists vibration and fluid ingress, allowing ControlNet architectures to be implemented in aggressive environments.
- Redundant media option increases network uptime.
- Passive media maximizes reliability and minimizes media failures when compared to active media components.
- High-flex cable option is well suited for applications involving constant stress attributed to robotic motion and frequent connection/ disconnection.

Limitations

- Field attachable connectors rely on installation technique for both electrical and mechanical integrity.
• Thread-on connectors require additional time to install versus quarter turn bayonet versions.

Cable Application—Best Practices

The following are examples of common wiring problems and best practices that will help prevent them. Taking these suggestions into consideration can help ensure reliable operation, extend the system life cycle and ultimately reduce costs attributed to downtime and repeated cable replacement.

Bend Radius—Fixed and Moving Applications

Allowing for adequate bend radius is pivotal in increasing the life of the cable. When sufficient bend radius is provided, the cable can more effectively absorb the energy of the bend over a greater portion of the overall cable length.
Stress Relief—Cable Gland and Connectors

Ample stress relief at connections is another key to extended cable life. Building a sufficient stress loop into your cable installations can prevent undue stress on the cable at or close to the connector. Built-in overmolded stress relief such as that found on Rockwell Automation patchcords and cordsets offers additional protection from failures at the connector.

Motion Applications

When one or both of the connections are in motion, extra cable length should be designed into the system to prevent stress on the cable and connectors. In this instance, cable loops (open or closed), coiled cables or C-tracks are the best solution.
Bundling and Cable Ties

When applying cable ties to any installation, care should be taken so the ties do not pinch or compress the cable(s) in any way. Correct use of cable ties permits movement without placing undue stress on the cable(s); appropriate bundling technique should allow for relatively free movement of the cables within the bundle.
**Cornering**

For cables run along corners, tie-downs should be applied in such a way as to prevent extra stress on the cable. Avoid the use of outside cornering as the corner itself is a potential pinch point.

**Cable Jacket Material**

<table>
<thead>
<tr>
<th>Cable Type</th>
<th>General Positioning</th>
<th>Sample Cat. No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>PVC Cable</td>
<td>Cost effective, general purpose cable</td>
<td>889D-F4AC-2</td>
</tr>
<tr>
<td>PUR Cable</td>
<td>Well suited for oil-based solutions and flex applications</td>
<td>889D-F4UC-2</td>
</tr>
<tr>
<td>TPE Cable</td>
<td>The all-around automotive solution (weld, flex, fluids)</td>
<td>889D-F4HJ-2</td>
</tr>
<tr>
<td>ToughLink Cable</td>
<td>Heavy-duty construction for the most rugged environments</td>
<td>889D-F4HC-2</td>
</tr>
<tr>
<td>ToughWeld Cable</td>
<td>Best suited for weld slag resistance</td>
<td>889D-F4WE-2</td>
</tr>
</tbody>
</table>

**Positioning Tables**
### Application Compatibility

#### General Properties

<table>
<thead>
<tr>
<th></th>
<th>PVC</th>
<th>PUR</th>
<th>TPE</th>
<th>ToughLink</th>
<th>ToughWeld</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weld slag resistance</td>
<td>F</td>
<td>F</td>
<td>G-E</td>
<td>F</td>
<td>F</td>
</tr>
<tr>
<td>Sub-zero temperature flexibility</td>
<td>F</td>
<td>G-E</td>
<td>G</td>
<td>E</td>
<td>F-G</td>
</tr>
<tr>
<td>Constant bending and flexing</td>
<td>F</td>
<td>E</td>
<td>E</td>
<td>F-G</td>
<td>F</td>
</tr>
<tr>
<td>Abrasion resistance</td>
<td>G</td>
<td>E</td>
<td>G</td>
<td>G</td>
<td>G</td>
</tr>
<tr>
<td>Ozone resistance</td>
<td>E</td>
<td>E</td>
<td>E</td>
<td>E</td>
<td>E</td>
</tr>
<tr>
<td>Sunlight and weathering</td>
<td>E</td>
<td>G</td>
<td>G</td>
<td>E</td>
<td>E</td>
</tr>
</tbody>
</table>

#### General Chemicals

<table>
<thead>
<tr>
<th></th>
<th>PVC</th>
<th>PUR</th>
<th>TPE</th>
<th>ToughLink</th>
<th>ToughWeld</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alcohols—very mild diluted (less than 3% concentration)</td>
<td>E</td>
<td>G</td>
<td>E</td>
<td>E</td>
<td>E</td>
</tr>
<tr>
<td>Acids—very mild diluted less than 3% concentration</td>
<td>E</td>
<td>G</td>
<td>E</td>
<td>E</td>
<td>E</td>
</tr>
</tbody>
</table>

* Best flex-rated cable for pico applications. For DC micro flex-rated cable use TPE.
<table>
<thead>
<tr>
<th>Compound</th>
<th>PVC</th>
<th>PUR</th>
<th>TPE</th>
<th>ToughLink</th>
<th>ToughWeld</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alkalis—strong up to 50% concentration</td>
<td>E</td>
<td>P-F</td>
<td>E</td>
<td>G</td>
<td>E</td>
</tr>
<tr>
<td>Bleach</td>
<td>E</td>
<td>P-F</td>
<td>E</td>
<td>E</td>
<td>E</td>
</tr>
<tr>
<td>Oils, greases</td>
<td>G-E</td>
<td>E</td>
<td>E</td>
<td>G-E</td>
<td>E</td>
</tr>
<tr>
<td>Solvents, volatile (acetone, toluene, MEK)</td>
<td>P-F</td>
<td>P-F</td>
<td>P-F</td>
<td>P-F</td>
<td>P-G</td>
</tr>
<tr>
<td>Solvent oils (distilled mineral oils C5-C20, citrus oil)</td>
<td>P-F</td>
<td>G</td>
<td>P-F</td>
<td>P-F</td>
<td>G</td>
</tr>
<tr>
<td>Water (submerged)</td>
<td>E</td>
<td>G</td>
<td>E</td>
<td>E</td>
<td>E</td>
</tr>
</tbody>
</table>

**By Industry**

<table>
<thead>
<tr>
<th>Industry</th>
<th>PVC</th>
<th>PUR</th>
<th>TPE</th>
<th>ToughLink</th>
<th>ToughWeld</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metalworking Oils/Coolants</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diluted with water</td>
<td>G</td>
<td>G</td>
<td>E</td>
<td>G</td>
<td>E</td>
</tr>
<tr>
<td>Waterless, oil-based</td>
<td>G</td>
<td>E</td>
<td>E</td>
<td>G</td>
<td>E</td>
</tr>
<tr>
<td>Food and Beverage</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Food/beverage industry soils (oils, fats, fruits, juices, vegetables, dairy, tomatoes, wine, vinegar)</td>
<td>G</td>
<td>G</td>
<td>E</td>
<td>G</td>
<td>E</td>
</tr>
<tr>
<td>Food/beverage industry chemicals (chlorinated alkaline cleaners, acidic mineral cleaners, detergents, sanitizers, convey or lubricants)</td>
<td>E</td>
<td>G</td>
<td>E</td>
<td>E</td>
<td>E</td>
</tr>
<tr>
<td>Automotive Fluids</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Antifreeze (ethylene glycol)</td>
<td>E</td>
<td>G</td>
<td>E</td>
<td>G</td>
<td>E</td>
</tr>
<tr>
<td>Fuels (gasoline, diesel, kerosene)</td>
<td>G</td>
<td>E</td>
<td>G</td>
<td>G</td>
<td>G</td>
</tr>
<tr>
<td>Motor, transmission (ATF), axle oils, power steering fluid</td>
<td>G</td>
<td>E</td>
<td>E</td>
<td>G</td>
<td>E</td>
</tr>
<tr>
<td>Brake fluids (many different types available)</td>
<td>P-G</td>
<td>P-G</td>
<td>P-G</td>
<td>P-G</td>
<td>P-G</td>
</tr>
</tbody>
</table>

P=Poor, F=Fair, G=Good, E=Excellent

**Enclosure Selection Criteria**

**Enclosures for Nonhazardous Locations**

<table>
<thead>
<tr>
<th>For a Degree of Protection Against:</th>
<th>Designed to Meet Tests No.</th>
<th>Type</th>
<th>For Indoor Use</th>
<th>For Outdoor Use</th>
<th>Indoor or Outdoor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Incidental contact with enclosed equipment</td>
<td>6.2</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Falling dirt</td>
<td>6.2</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Rust</td>
<td>6.8</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Circulating dust, lint, fibers and flyings†</td>
<td>6.5.1.2 (2)</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Windblown dust</td>
<td>6.5.1.1 (2)</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Falling liquids and light splashing</td>
<td>6.3.2.2</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Rain (Test evaluated per 6.4.2.1)</td>
<td>6.4.2.1</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Rain (Test evaluated per 6.4.2.2)</td>
<td>6.4.2.2</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Snow and sleet</td>
<td>6.6.2.2</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Hosedown and splashing water</td>
<td>6.7</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Occasional prolonged submersion</td>
<td>6.11 (2)</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Oil and coolant seepage</td>
<td>6.3.2.2</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oil or coolant spraying and splashing</td>
<td>6.12</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Corrosive agents 6.9

⋆ See below for abridged description of NEMA enclosure test requirements. Refer to NEMA Standards Publication No. 250 for complete test specifications.
† Non-hazardous materials, not Class III ignitable or combustible.

Selection Criteria

Enclosures for Hazardous Locations (Division 1 or 2)§

<table>
<thead>
<tr>
<th>For a Degree of Protection Against Atmospheres Typically Containing:♣</th>
<th>Designed to Meet Tests∆</th>
<th>Class (National Electrical Code)</th>
<th>7, Class I Group</th>
<th>9, Class II Group</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acetylene</td>
<td>Explosion Test</td>
<td>I</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Hydrogen, Manufactured Gas</td>
<td>Hydrostatic Test</td>
<td></td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Diethyl Ether, Ethylene, Hydrogen Sulfide</td>
<td>Temperature Test</td>
<td></td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Acetone, Butane, Gasoline, Propane, Toluene</td>
<td></td>
<td></td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Metal dusts and other combustible dusts with resistivity of less than 10^6 Ω-cm</td>
<td>Dust Penetration Test</td>
<td>II</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Carbon black, charcoal, coal or coke dusts with resistivity between 10^2...10^8 Ω-cm</td>
<td>Temperature Test with Dust Blanket</td>
<td></td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Combustible dusts with resistivity of 10^5 Ω-cm or greater</td>
<td></td>
<td></td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Fibers, flyings</td>
<td>♦</td>
<td>III</td>
<td>✓</td>
<td>✓</td>
</tr>
</tbody>
</table>

§ For indoor locations only, unless cataloged with additional NEMA Type enclosure number(s) suitable for outdoor use as shown in the table on NEMA Enclosures. 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.

♣ 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.

∆ For complete requirements, refer to UL Standard 698, compliance with which is required by NEMA enclosure standards.

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

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 table on this page indicates the general degree of protection—refer to the Abridged Descriptions of IEC Enclosure Test Requirements starting below. For complete test requirements refer to IEC 60259.

First Numeral☆

Protection of persons against access to hazardous parts and protection against penetration of solid foreign objects.

0 Non-protected
1 Back of hand; objects greater than 50 mm in diameter
3 Finger; objects greater than 12.5 mm in diameter
5 Tools or objects greater than 2.5 mm in diameter
7 Tools or objects greater than 1.0 mm in diameter
9 Dust-protected (dust may enter during specified test but must not interfere with operation of the equipment or impair safety)
11 Dusttight (no dust observable inside enclosure at end of test)

Second Numeral☆

Protection against ingress of water under test conditions specified in IEC 60259.

0 Non-protected
2 Vertically falling drops of water
4 Vertically falling drops of water with enclosure tilted 15°
6 Spraying water
8 Splashing water
10 Water jets
12 Powerful water jets
13 Temporary submersion
14 Continuous submersion
Example: IP41 describes an enclosure that is designed to protect against the entry of tools or objects greater than 1 mm 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.

⋆ The IEC standard permits use of certain supplementary letters with the characteristic numerals. If such letters are used, refer to IEC 60259 for the explanation.

### Popular Rockwell Automation Sensors Connectivity with Most Standard Cordsets & Patchcords

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>42xx-xxxx-F4</td>
<td>4-Pin DC Micro (M12)</td>
<td>889D-F4AC-‡</td>
<td>45xx-xxxxx-D5</td>
<td>5-Pin DC Micro (M12)</td>
<td>889D-F5AC-‡</td>
</tr>
<tr>
<td>42xx-xxxx-G3</td>
<td>3-Pin AC Micro (Dual Key)</td>
<td>889R-F3EAA-‡</td>
<td>45xx-xxxxx-F4</td>
<td>4-Pin DC Micro (M12)</td>
<td>889D-F4AC-‡</td>
</tr>
<tr>
<td>42xx-xxxx-G4</td>
<td>4-Pin AC Micro (Dual Key)</td>
<td>889R-F4EA-‡</td>
<td>802B-xxxxxx-D4</td>
<td>4-Pin DC Micro (M12)</td>
<td>889D-F4AC-‡</td>
</tr>
<tr>
<td>42xx-xxxx-P3</td>
<td>3-Pin Pico (M8)</td>
<td>889P-F3AB-‡</td>
<td>802B-xxxxxxx-R4</td>
<td>4-Pin AC Micro (Dual Key)</td>
<td>889R-F4EAA-‡</td>
</tr>
<tr>
<td>42xx-xxxx-P4</td>
<td>4-Pin Pico (M8)</td>
<td>889P-F4AB-‡</td>
<td>836E-Dx1xxxx-D4</td>
<td>4-Pin DC Micro (M12)</td>
<td>889D-R4AC-‡</td>
</tr>
<tr>
<td>42xx-xxxx-Y4</td>
<td>4-Pin Pico (M8)</td>
<td>889P-F4AB-‡</td>
<td>837E-Dx1xxxxa-D4</td>
<td>4-Pin DC Micro (M12)</td>
<td>889D-R4AC-‡</td>
</tr>
<tr>
<td>42xx-xxxx-D5</td>
<td>5-Pin DC Micro (M12)</td>
<td>889D-F5AC-‡</td>
<td>871xx-xxxxxxxxx-R5</td>
<td>5-Pin AC Micro (Dual Key)</td>
<td>889R-F5EAA-‡</td>
</tr>
<tr>
<td>42xx-xxxx-N5</td>
<td>5-Pin Mini</td>
<td>889N-F5AF-‡</td>
<td>871xx-xxxxxxxx-N4</td>
<td>4-Pin Mini</td>
<td>889N-F4AF-‡</td>
</tr>
<tr>
<td>42Cx-xxxx-D4</td>
<td>4-Pin DC Micro (M12)</td>
<td>889D-F4AC-‡</td>
<td>871xx-xxxxxxx-N3</td>
<td>3-Pin Mini</td>
<td>889N-F3ECA-‡</td>
</tr>
<tr>
<td>42CRC-xxxx</td>
<td>5-Pin AC Micro (Dual Key)</td>
<td>889R-F5ECA-‡</td>
<td>871xx-xxxxxxx-R3</td>
<td>3-Pin AC Micro (Dual Key)</td>
<td>889R-F3EAA-‡</td>
</tr>
<tr>
<td>42GDx-9xx0-QD</td>
<td>4-Pin DC Micro (M12)</td>
<td>889D-F4AC-‡</td>
<td>871xx-xxxxxxx-3</td>
<td>3-Pin Pico (M8)</td>
<td>889P-F3AB-‡</td>
</tr>
<tr>
<td>42GDx-9xx0-QD1</td>
<td>4-Pin Mini</td>
<td>889N-F4AF-‡</td>
<td>871C-DxxMaxxx-D4</td>
<td>4-Pin DC Micro (M12)</td>
<td>889D-F4LC-‡</td>
</tr>
<tr>
<td>42GDx-9xx4-QD</td>
<td>5-Pin Mini</td>
<td>889N-F5AF-‡</td>
<td>871C-DxxMaxxx-D4</td>
<td>4-Pin DC Micro (M12)</td>
<td>889D-F4AC-‡</td>
</tr>
<tr>
<td>42GDx-9xx5-QD</td>
<td>5-Pin Mini</td>
<td>889N-F5AF-‡</td>
<td>871D-xxxxxxx-xxxx</td>
<td>4-Pin DC Micro (M12)</td>
<td>889D-F4HJ-‡</td>
</tr>
<tr>
<td>42GRx-9xx0-QD1</td>
<td>4-Pin Mini</td>
<td>889N-F4AF-‡</td>
<td>871F-Dxxx-xxxxxx-D4</td>
<td>4-Pin DC Micro (M12)</td>
<td>889D-F4AC-‡</td>
</tr>
<tr>
<td>42GRx-9xx0-QD1</td>
<td>4-Pin Mini</td>
<td>889N-F5AF-‡</td>
<td>871F-Nxxxx-xxxxxx-D4</td>
<td>4-Pin DC Micro (M12)</td>
<td>889D-F4AC-‡</td>
</tr>
<tr>
<td>42GRx-9xx1-QD</td>
<td>5-Pin Mini</td>
<td>889N-F4AF-‡</td>
<td>871F-Nxxxx-xxxxxx-D4</td>
<td>4-Pin DC Micro (M12)</td>
<td>889D-F4HJ-‡</td>
</tr>
<tr>
<td>42GRx-9xx3-QD</td>
<td>4-Pin AC Micro (Dual Key)</td>
<td>889R-F4EAA-‡</td>
<td>871F-Pxxxxxx-xxxx</td>
<td>4-Pin DC Micro (M12)</td>
<td>889D-F4AC-‡</td>
</tr>
<tr>
<td>42GRx-9xx3-QD1</td>
<td>4-Pin AC Micro (Dual Key)</td>
<td>889R-F4EAA-‡</td>
<td>871F-Pxxxxxx-xxxx</td>
<td>4-Pin DC Micro (M12)</td>
<td>889D-F4AC-‡</td>
</tr>
<tr>
<td>42GRx-90x0-QD</td>
<td>4-Pin DC Micro (M12)</td>
<td>889D-F4AC-‡</td>
<td>871F-PWxxxxxx-D4</td>
<td>4-Pin DC Micro (M12)</td>
<td>889D-F4HJ-‡</td>
</tr>
<tr>
<td>42GRx-92x0-QD</td>
<td>4-Pin DC Micro (M12)</td>
<td>889D-F4AC-‡</td>
<td>871L-xxxxxxx-D4</td>
<td>4-Pin DC Micro (M12)</td>
<td>889D-F4AC-‡</td>
</tr>
<tr>
<td>42GRx-95x0-QD</td>
<td>4-Pin DC Micro (M12)</td>
<td>889D-F4LC-‡</td>
<td>871P-Dxxxxxx-D4</td>
<td>4-Pin DC Micro (M12)</td>
<td>889D-F4AC-‡</td>
</tr>
<tr>
<td>42GRx-9xx2-QD</td>
<td>5-Pin Mini</td>
<td>889N-F5AF-‡</td>
<td>871P-Dxxxxxx-D4</td>
<td>4-Pin DC Micro (M12)</td>
<td>889D-F4AC-‡</td>
</tr>
<tr>
<td>42GRx-9xx2-QD1</td>
<td>4-Pin Mini</td>
<td>889N-F4AF-‡</td>
<td>871P-NWxxxxxx-D4</td>
<td>4-Pin DC Micro (M12)</td>
<td>889D-F4HJ-‡</td>
</tr>
<tr>
<td>42GRx-9xx2-QD</td>
<td>5-Pin Mini</td>
<td>889N-F5AF-‡</td>
<td>871P-NWxxxxxx-D4</td>
<td>4-Pin DC Micro (M12)</td>
<td>889D-F4HJ-‡</td>
</tr>
<tr>
<td>42GRx-9xx3-QD</td>
<td>5-Pin Mini</td>
<td>889N-F5AF-‡</td>
<td>871R-xxxxxxx-D4</td>
<td>4-Pin DC Micro (M12)</td>
<td>889D-F4AC-‡</td>
</tr>
<tr>
<td>42GRx-9xx3-QD1</td>
<td>4-Pin AC Micro (Dual Key)</td>
<td>889R-F4EAA-‡</td>
<td>871T-Mxxxxxx-D4</td>
<td>4-Pin DC Micro (M12)</td>
<td>889D-F4AC-‡</td>
</tr>
<tr>
<td>42GRx-9xx4-QD</td>
<td>4-Pin AC Micro (Dual Key)</td>
<td>889R-F4EAA-‡</td>
<td>871T-MMxxxxxx-D4</td>
<td>4-Pin DC Micro (M12)</td>
<td>889D-F4AC-‡</td>
</tr>
<tr>
<td>42GRx-9xx5-QD</td>
<td>5-Pin Mini</td>
<td>889N-F5AF-‡</td>
<td>871T-MDxxxxxx-D4</td>
<td>4-Pin DC Micro (M12)</td>
<td>889D-F4AC-‡</td>
</tr>
<tr>
<td>42GRx-9xx5-QD1</td>
<td>4-Pin Mini</td>
<td>889N-F4AF-‡</td>
<td>871T-MDxxxxxx-D4</td>
<td>4-Pin DC Micro (M12)</td>
<td>889D-F4AC-‡</td>
</tr>
<tr>
<td>42GRx-9xx6-QD</td>
<td>5-Pin Mini</td>
<td>889N-F5AF-‡</td>
<td>871TM-xxxxxx-D4</td>
<td>4-Pin DC Micro (M12)</td>
<td>889D-F4AC-‡</td>
</tr>
<tr>
<td>42GRx-9xx6-QD1</td>
<td>4-Pin Mini</td>
<td>889N-F4AF-‡</td>
<td>871TM-xxxxxx-D4</td>
<td>4-Pin DC Micro (M12)</td>
<td>889D-F4AC-‡</td>
</tr>
<tr>
<td>42GTx-9xx0-QD</td>
<td>4-Pin DC Micro (M12)</td>
<td>889D-F4AC-‡</td>
<td>871TM-xxxxxx-D4</td>
<td>4-Pin DC Micro (M12)</td>
<td>889D-F4AC-‡</td>
</tr>
<tr>
<td>42GTx-9xx0-QD1</td>
<td>4-Pin Mini</td>
<td>889N-F4AF-‡</td>
<td>871TM-xxxxxx-D4</td>
<td>4-Pin DC Micro (M12)</td>
<td>889D-F4AC-‡</td>
</tr>
<tr>
<td>42GTx-9xx1-QD</td>
<td>5-Pin Mini</td>
<td>889N-F5AF-‡</td>
<td>871TM-xxxxxx-D4</td>
<td>4-Pin DC Micro (M12)</td>
<td>889D-F4AC-‡</td>
</tr>
<tr>
<td>42GTx-9xx2-QD</td>
<td>5-Pin Mini</td>
<td>889N-F5AF-‡</td>
<td>871TM-xxxxxx-D4</td>
<td>4-Pin DC Micro (M12)</td>
<td>889D-F4AC-‡</td>
</tr>
<tr>
<td>42GTx-9xx3-QD</td>
<td>4-Pin Mini</td>
<td>889N-F4AF-‡</td>
<td>871Z-xxxxxxx-D4</td>
<td>4-Pin DC Micro (M12)</td>
<td>889D-F4HJ-‡</td>
</tr>
<tr>
<td>Part Number</td>
<td>Description</td>
<td>Connector Type</td>
<td>Cable Length</td>
<td>Part Number</td>
<td>Description</td>
</tr>
<tr>
<td>-------------</td>
<td>----------------------------------</td>
<td>--------------------</td>
<td>--------------</td>
<td>-------------</td>
<td>----------------------------------</td>
</tr>
<tr>
<td>42GTx-9xx3-QD1</td>
<td>4-Pin AC Micro (Dual Key)</td>
<td>889R-F4AEA- *</td>
<td>872xx-xxxxxx-N3</td>
<td>3-Pin Mini</td>
<td>889N-F3AF-†</td>
</tr>
<tr>
<td>42GTGx-10xxx-QD</td>
<td>5-Pin DC Micro (M12)</td>
<td>889D-F5AC- *</td>
<td>872xx-xxxxxx-N4</td>
<td>4-Pin Mini</td>
<td>889N-F4AF-‡</td>
</tr>
<tr>
<td>42GTGx-10xxx-QD1</td>
<td>5-Pin Mini</td>
<td>889N-F5AF-‡</td>
<td>872xx-xxxxxx-P3</td>
<td>3-Pin Pico (M8)</td>
<td>889P-F3AB- *</td>
</tr>
<tr>
<td>42KB-xxxxxx-Y3</td>
<td>3-Pin Pico (M8)</td>
<td>889P-F3AB- ‡</td>
<td>872xx-xxxxxx-R3</td>
<td>3-Pin AC Micro (Dual Key)</td>
<td>889R-F3AE- *</td>
</tr>
<tr>
<td>42MTB-5000QD5-1</td>
<td>5-Pin Mini</td>
<td>889N-F5AF-‡</td>
<td>872x-xxxxxx-D4</td>
<td>4-Pin DC Micro (M12)</td>
<td>889D-F4AC- *</td>
</tr>
<tr>
<td>42MTB-5004QD4-1</td>
<td>4-Pin Mini</td>
<td>889N-F4AF-‡</td>
<td>873E-xxxxxx-F4</td>
<td>4-Pin DC Micro (M12)</td>
<td>889D-F4AC- *</td>
</tr>
<tr>
<td>42Smx-7xxx-QD</td>
<td>4-Pin DC Micro (M12)</td>
<td>889D-F4AC- *</td>
<td>873P-Dxxxx1-D5</td>
<td>4-Pin DC Micro (M12)</td>
<td>889D-F4AC- *</td>
</tr>
<tr>
<td>42Sr-6xx2-QD</td>
<td>4-Pin DC Micro (M12)</td>
<td>889D-F4AC- *</td>
<td>873P-Dxxxx-D4</td>
<td>4-Pin DC Micro (M12)</td>
<td>889D-F4AC- *</td>
</tr>
<tr>
<td>42Sr-6xx3-QD</td>
<td>4-Pin DC Micro (M12)</td>
<td>889D-F4AC- *</td>
<td>873P-Dxxxx-F4</td>
<td>4-Pin DC Micro (M12)</td>
<td>889D-F4AC- *</td>
</tr>
<tr>
<td>42Sr-6xx4-QD</td>
<td>4-Pin AC Micro (Dual Key)</td>
<td>889R-F4AEA- *</td>
<td>873P-Dxxxx5-D5</td>
<td>5-Pin DC Micro (M12)</td>
<td>889D-F5AC- *</td>
</tr>
<tr>
<td>42Sr-6xx5-QD</td>
<td>4-Pin AC Micro (Dual Key)</td>
<td>889R-F4AEA- *</td>
<td>875xx-xxxxxx-D4</td>
<td>4-Pin DC Micro (M12)</td>
<td>889D-F4AC- *</td>
</tr>
<tr>
<td>42Sr-6xx6-QD</td>
<td>4-Pin AC Micro (Dual Key)</td>
<td>889R-F4AEA- *</td>
<td>875xx-xxxxxx-R3</td>
<td>3-Pin AC Micro (Dual Key)</td>
<td>889R-F3AE- *</td>
</tr>
<tr>
<td>42Sr-6xx7-QD</td>
<td>4-Pin AC Micro (Dual Key)</td>
<td>889R-F4AEA- *</td>
<td>875xx-xxxxxx-P3</td>
<td>3-Pin Pico (M8)</td>
<td>889P-F3AB- *</td>
</tr>
<tr>
<td>45xxx-xxxx-P4</td>
<td>4-Pin Pico (M8)</td>
<td>889P-F4AB- *</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Replace symbol with 1 (1 m), 2 (2 m), 5 (5 m), or 10 (10 m) for standard cable lengths.
‡ Replace symbol with 1 (1 m), 2 (2 m), 3 (3 m), 4 (4 m), 5 (5 m) or 6 (6 m) for standard lengths.
Radio Frequency Identification (RFID)

Allen-Bradley industrial RFID system consists of three key components:

- **Communication Interfaces**: To either a network or controller.
- **Transceivers**: At each point or station in the manufacturing process where identification or the reading/writing of information is desired.
- **RFID Tags**: One for each item, pallet, tote, or transport fixture used in the application.

**System Features**

- 1- and 2-channel EtherNet/IP™ interface offered
- Embedded switch, with Device Level Ring (DLR)
- Rugged transceiver styles designed for industrial locations
- 13.56 MHz high frequency technology ideal for light industrial applications
- Tag memory options: 128 B, 64 B, 256 B, and 2 KB
- Read/write speeds up to 625 B/s
- Different tag styles with sensing distances of up to 7.3 in. (185 mm)
- Reusable Rislan® tags assure long life and reliable performance in harsh environments
- AOP and AOI available

**Dual-Channel Integrated Architecture Application Diagram**
Technical Definitions & Terminology

5PY: A type of analog DC tachometer with a specific bolt pattern.

**AC Coupled Amplifier:** An amplifier in which only pulsed (AC) signals are amplified and direct (DC) signals are ignored. (Direct signals generated by sunlight, heat sources and other.)

**Active Face:** Portion of the sensor from which the electromagnetic field or ultrasonic pulse emanates.

**Actuator:** A switch mechanism that when moved as intended, operates the switch contacts. This mechanism transmits the applied force from the actuating device...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 Resetting 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 target in which a maximum signal strength is obtained.

**Ambient Light:** Illumination of a Receiver not generated by its Light Source.

**Analog:** Electronic circuit with a current or voltage output signal that varies as a function of the light intensity received by the photodetector.

**Angstrom:** Unit of measurement used to determine the wavelength of light. 10 Angstrom (Å) is equal to 1 nanometer (nm).

**Angular Acceleration:** The rate of change of angular velocity usually expressed in radians per second squared.

**Angular Misalignment:** The maximum amount of angle between the coupled shafts.

**Attenuation:** The reduction of signal strength. An example is when light travels through a fiber optic cable. The degree of attenuation depends on the fiber material and on the total length of the fiber optic cable.

**Axial:** The direction parallel to the encoder shaft.

**Axial Approach:** The approach of the target with its center maintained on the reference axis.
Axial Compliance: The maximum amount of machine shaft end play.

Axial Load: The maximum amount of force that may be applied to an encoder shaft in a direction parallel to the shaft.

Bifurcated: A fiber optic bundle that divides in two legs, forming a Y.

Blind Shaft: A hollow shaft encoder which is covered on one end so that the accepted shaft cannot exceed a maximum length. See also “Hollow Shaft” and “Through Shaft.”

Binary: A number system using 2 as its base (1, 2, 4, 8, 16, 32, …).

Binary Coded Decimal (BCD): A number system where decimal numbers 0 through 9 are represented by 4 binary bits (8, 4, 2, 1).

Bit: An abbreviation for binary digit.

C...D

Channel: An incremental encoder output signal. A dual channel encoder has two outputs.

Complementary Output: Output circuit with a dual output device such that when one output is energized the other output is de-energized (similar to SPDT contact).

Complementary Outputs: (N.O. & N.C.) A proximity sensor that features both normally open and normally closed outputs, which can be used simultaneously.

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.

Counts Per Turn: Sometimes referred to as Pulses Per Revolution (PPR), the total number of positions in 360 degrees of shaft rotation.

Current Consumption: The current consumed by the proximity switch when the output device is in the off condition.

Current Sinking: An output type where signal current flows from the load into the encoder.

Current Sourcing: An output type where signal current flows from the encoder into the load.

Damping Material: Material which causes a decrease in the strength of the electromagnetic or electrical field produced by the sensing coil.

Dark Operate: A dark operate sensor energizes an output when the light intensity on the photodetector has sufficiently decreased.
Data: Factual measurement information transmitted by an encoder either in parallel or serial form.

Decades: In BCD a decade is comprised of 4 bits (1, 2, 4, 8) representing one decimal place (units, tens, hundreds, etc.).

Diagnostic: Advanced warning of loss in signal strength due to misalignment, dust and more, prior to loss of control output signal.

Differential: In digital logic terms a pair of outputs exactly opposite 0, 1, or 180 degrees out of phase.

Differential Line Driver: A type of output driver using two signal lines per encoder channel. When used with a differential line receiver, longer cable lengths and higher noise immunity can be provided.

Differential Travel (Hysteresis): The distance between the operating point and the release point. 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 resetting position, or the distance between the operating point and the release point.

Diffuse Reflection (Proximity): A photoelectric sensing method in which the light emitted by the Light Source hits the target surface and is then diffused from the surface in all directions.

Digital Output: An output circuit with only two operating states that are either “On” or “Off.” These operating states often are called “Hi” or “Low.”

Dual Output: Sensor which has two outputs which may be complementary or may be of a single type (i.e. two normally open or two normally closed).

Duty Cycle: The ratio of the logic “1” level to the total period of one cycle.

Dwell-Time: The adjustable or fixed time length of an output pulse, independent of input signal duration.

E...H

Effective Operating Distance: (Sr) The operating distance of an individual proximity switch measured at stated temperature, voltage, and mounting condition.

End Play: The amount of axial shaft movement with a specified amount of axial load applied.

Excess Gain: See Operating Margin.

False Pulse: An undesired change in the state of the output of the proximity switch that lasts for more than two milliseconds.

False Pulse Protection: Circuitry designed to avoid false pulses during Power on or Power down action.

Ferrule: Tip or Termination of a fiber optic cable.
Field of View: The region that is illuminated by the Light Source and that can be seen by the Receiver. Field of View is expressed in degrees but is three dimensional.

Flange: A square mounting configuration for rotary encoders and resolvers.

Flush Mounting: A shielded proximity sensor which can be flush mounted in metal up to the plane of the active sensing face.

Free Zone: The area around the proximity switch which must be kept free from any damping material.

Frequency Response: The maximum frequency at which all parameters are still in specification.

Gating: The provision to apply an external signal to a sensor in order to prevent undesirable operation.

Grey Code: A binary code in which only one bit of the binary word changes for each sequential number or position.

Heavy Duty: Encoders with higher shaft loading characteristics are considered heavy duty.

High Performance: Encoders with high frequency response and resolution are considered high performance.

Hollow Shaft: A shaftless encoder design which mounts on the shaft of a connected device such as a motor. See also “Blind Shaft” and “Through Shaft.”

Hysteresis: The distance between the operating point and the release point.

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 sensors active 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.

IP66 (IEC 529): Provides a degree of protection against dust, and water projected in powerful jets from any direction.

Impedances: Impedances, expressed in ohms, are usually specified in rectangular form as R + jX where R is the sum of the DC and AC resistive components and X is the reactive component.

Index: An output signal, also known as a zero marker, which is produced once per revolution. It is used to identify a home position or a reset point.

Infrared: Invisible Light Radiation starting at a wavelength of 690 nanometer (or 6900 Angstrom) and longer.

Input Current: The current required to power the internal circuitry of the encoder.

Intrinsic Safety: A design technique applied to electrical equipment and wiring for hazardous locations. It is
based on limiting electrical and thermal energy to a level below that required to ignite hazardous atmospheric mixtures.

**Isolated Output**: An output that is optically separated from the input and other output and independent of the other output to a specified level.

**Isolation Voltage**: Maximum rated voltage between isolated outputs or input and output.

**LED (Light Emitting Diode)**: Semi-conductor that generates monochromatic light when current flows in the conductive direction. An LED is the standard Light Source for most photoelectric sensors.

**Lateral Approach**: The approach of the target perpendicular to the reference axis.

**Leakage Current**: Small current flowing through a solid state output when in the Off State.

**Leakage Current**: Current which flows through the output when the output is in an “off” condition or de-energized. This current is necessary to supply power to the electronics of the sensor.

**Light Operate**: A light operate sensor energizes an output when the light intensity on the photodetector has sufficiently increased.

**Load**: A term used to describe the device to which encoder signals are applied.

**M...N**

**Maximum Inrush Current**: The maximum current level at which the proximity sensor can be operated for a short period of time.

**Maximum Load Current**: The maximum current level at which the proximity sensor can be continuously operated.

**Maximum Working Speed**: A maximum speed allowed for operation for most applications. Shaft loading must be minimized. Some specifications may not be met. See also “Operating Speed.”

**Maximum Working Temperature**: A maximum temperature allowed for operation for most applications. Some specifications may not be met. Also see “Operating Temperature.”

**Minimum Load Current**: The minimum amount of current required by the sensor to maintain reliable operation.

**Moment of Inertia**: The sum of the products formed by multiplying the mass of each element of a figure by the square of its distance from an axis.

**NEMA Type 1**: Type 1 enclosures are intended to provide protection against incidental contact with dirt, dust, lint, fibers, and other nonliquid contaminants.

**NEMA Type 4**: Type 4 enclosures are intended for indoor or outdoor use primarily to provide a degree of protection against windblown dust and rain, splashing water and hose directed water. They are not intended to
provide protection against conditions such as internal condensation or internal icing.

NPN: The sensor switches the load to the negative terminal. The load should be connected between the sensor output and positive terminal.

Nanometer (nm): 1 Nanometer is equal to 10⁻⁹ meter.

Noise: Presence of undesirable voltage, current, or light that may cause the sensor to malfunction.

Nonferrous Metal: Any metal which does not contain iron.

Normal Contact Position: The position of the contacts when no operating force is applied.

Normally Closed: Output opens when an object is detected in the active switching area.

Normally Open: Output closes when an object is detected in the active switching area.

Nosepiece: The housing that holds the shaft, bearings, and shaft seal.

Null Voltage: The residual voltage remaining when the in-phase component of the output voltage is zero.

O...P

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: Between 0 and 81% of the rated operating distance for inductive proximity switches.

Operating Distance, Rated: The operating distance specified by the manufacturer and used as a reference value. Also known as nominal sensing distance.

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: The ratio of electrical signal available at a given sensing range to the minimum signal required to trigger the amplifier and output.

Operating Mode: See “Light Operate” and “Dark Operate.”

Operating Speed: The maximum shaft RPM allowed at which all specifications are met. See also “Maximum Working Speed.”

Operating Temperature: The maximum temperature allowed at which all specifications are met.

Operating Torque: The torque that must be applied to the actuator to cause the movable contacts to move to the operated contact position.
**Optical Crosstalk:** Optical Crosstalk occurs when a photoelectric receiver responds to the signal from an adjacent emitter. Crosstalk can usually be resolved by repositioning the sensors.

**Overtravel:** The movement of the actuator beyond the contact operating position.

**PNP:** The sensor switches the load to the positive terminal. The load should be connected between the sensor output and negative terminal.

**Parallel Misalignment:** The maximum amount of distance between the center lines of the coupled shafts.

**Photoelectric Sensor:** Electronic device recognizing changes in light intensity and converting these changes into a change in output state.

**Pretravel** (Travel to the operate contacts): Travel to operate the contacts from the actuator free position.

**Programmable Output:** (N.O. or N.C.) 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. Also known as selectable output.

**Pulse:** A sudden fast change of a normally constant or relatively slow changing value such as voltage, current or light intensity.

**Pulses Per Revolution** (PPR): See counts per turn.

**Push-Pull:** A type of single-ended output driver capable of sinking and sourcing current. Also known as Totem-Pole.

**Q...S**

**Quadrature:** Separation in phase by 90°. Used on incremental encoders to denote the direction of motion.

**Radial:** The direction perpendicular to the encoder shaft.

**Radial Load:** The maximum amount of force that may be applied to an encoder shaft in a perpendicular direction.

**Radial Play:** The amount of shaft radial movement with specified radial load.

**Radian:** An arc in any circle, equal in length to the radius of the same circle.

**Repeatability:** The variation of the effective operating distance measured at room temperature and constant supply voltage. It is expressed as a percentage of the sensing distance.

**Residual Voltage:** The voltage across the sensor output while energized and carrying maximum load current.

**Resolution:** The measure of the smallest change of input that the encoder can detect.

**Response Time:** The sum of the time needed for a string of electronic circuits to translate a change in light into a change of output status.
**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 %:** The percentage of alternating component left on a DC signal after rectifying. Measured peak to peak of the alternating component and compared to the DC signal value.

**Ripple:** The variance between peak-to-peak values in DC voltage. It is expressed in percentage of rated voltage.

**Rise Time (10% Levels):** The time required for an analog voltage or current output value to rise from 10% of its maximum value to 90% of its maximum value.

**Running Torque:** The torque required to keep a shaft rotating at constant velocity, typically measured in inch-ounces.

**Sensing Distance:** The distance at which an approaching target activates (changes state of) the proximity output.

**Sensing Range:** The sensing range is the distance within which the sensor will detect a target under fluctuations of temperature and voltage.

**Sensitivity:** The output voltage expressed as a function of the shaft angle in millivolts/degree.

**Servo:** A circular mounting configuration that allows for rotation of the encoder for purposes of alignment. Also a common term for a small electric motor.

**Shaft Loading:** The maximum amount of force that may be applied to an encoder shaft typically expressed in pounds (Newtons).

**Shaft Runout:** The amount of radial movement when spinning.

**Shielded:** Sensor which can be flush mounted in metal up to the plane of the active sensing face.

**Shock:** A transient motion which is capable of exciting mechanical resonances.

**Short Circuit Protection:** (SCP) Sensor protected from damage when a shorted condition exists for an indefinite or defined period of time.

**Single-Ended:** An output referenced to common which uses only one signal line for data transmission.

**Sink (Current):** Transistor output that requires the current to flow from positive (+) through the load and then through the output to negative (-). A current sink output uses an NPN Transistor.

**Sinking:** See NPN.

**Size 15:** Encoders with a nominal diameter of 1.5 inches (1.625 inch encoders are also classified as size 15).
Size 20: Encoders with a nominal diameter of 2.0 inches.

Size 25: Encoders with a nominal diameter of 2.5 inches.

Slew Speed: The maximum velocity an encoder may be operated without physical damage to the unit.

Slow Make-Slow Break: A type of contact structure with no overcenter mechanism. Contacts move at a speed directly proportional to the speed of operation of the actuator. Contacts may touch with little contact pressure.

Snap Action: In this type of contact structure, movement of the actuator applies force to an overcenter mechanism, which creates a fast change in contact state once the overcenter position has been exceeded.

Snap Action/IEC Positive 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 has not opened with the snap action mechanism. This helps to ensure opening of even a welded contact. For example, if a contact has a snap action operating point at 40° rotary movement, the direct opening action point may be at 60° or more. No direct opening action forces are applied to the N.O. contact.

Source (Current): Transistor output that requires the current to flow from positive ( + ) through the output and then through the load to negative ( - ). A current source output uses a PNP transistor.

Sourcing: See PNP.

Starting Torque: The torque required to start a shaft rotating, typically measured in inch-ounces.

Switching Frequency: The maximum number of times per second the sensor can change state (ON and OFF) usually expressed in Hertz (Hz). As measured in DIN EN 50010.

Symmetry: The ratio of the logic “1” level to the total period of one cycle.

Synchronous Serial Interface or SSI: A serial communication protocol often used to translate parallel absolute encoder data. Advantages of SSI over parallel wiring include reduced wire count and better noise immunity.

T...Z

Target: Object which activates the sensor.

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.

Through Shaft: A hollow shaft encoder which is open on both ends so that the accepted shaft length is unlimited. For example, a through shaft encoder allows a motor shaft to protrude through it. See also “Blind Shaft” and “Hollow Shaft.”

Total or Maximum Travel: The sum of the pretravel and the overtravel.
**Transformation Ratio**: The ratio of the output voltage to the input voltage when the output is at maximum coupling.

**Transmitted Beam**: A sensing mode where the Light Source and the Receiver are opposite each other and where the target breaks the beam.

**Two-Wire Proximity Switch**: A proximity sensor which switches a load connected in series to the power supply. Power for the proximity switch is obtained through the load at all times.

**Unshielded**: Sensors which have longer sensing distances and a wider magnetic field but are sensitive to surrounding metal.

**Vibration**: The periodic change in displacement with respect to a fixed reference.

**Voltage Drop**: The maximum voltage drop across a conducting sensor.

**Wavelength**: Distance traveled by light while completing one complete sine-wave. Is expressed in nanometers (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.

**Zero Reference**: An output signal which is produced once per revolution. It is used to identify a home position or a reset point.
Rockwell Automation Support

Use the following resources to access support information.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct Dial Codes</td>
<td>Find the Direct Dial Code for your product. Use the code to route your call directly to a technical support engineer.</td>
<td><a href="http://www.rockwellautomation.com/global/support/direct-dial.page">http://www.rockwellautomation.com/global/support/direct-dial.page</a></td>
</tr>
</tbody>
</table>

Documentation Feedback

Your comments will help us serve your documentation needs better. If you have any suggestions on how to improve this document, complete the How Are We Doing? form at http://literature.rockwellautomation.com/idc/groups/literature/documents/du/ra-du002_-en-e.pdf.

Rockwell Otomasyon Ticaret A.Ş., Kar Plaza İş Merkezi E Blok Kat:6 34752 İçerenköy, İstanbul, Tel: +90 (216) 5698400

www.rockwellautomation.com

Power, Control and Information Solutions Headquarters

Americas: Rockwell Automation, 1201 South Second Street, Milwaukee, WI 53204-2496 USA, Tel: (1) 414.382.2000, Fax: (1) 414.382.4444
Europe/Middle East/Africa: Rockwell Automation NV, Pegasus Park, De Kiezelstraat 12a, 1831 Diegem, Belgium, Tel: (32) 2 663 0600, Fax: (32) 2 663 0640
Asia Pacific: Rockwell Automation, Level 14, Core F, Cyberport 3, 100 Cyberport Road, Hong Kong, Tel: (852) 2887 4788, Fax: (852) 2508 1846

Publication C117-RM001A-EN-P - February 2017

Copyright © 2017 Rockwell Automation, Inc. All rights reserved. Printed in the U.S.A.