# Capacitive Proximity Sensors
Theory of Operation

Capacitive proximity sensors are similar to inductive proximity sensors. The main difference between the two types is that capacitive proximity sensors produce an electrostatic field instead of an electromagnetic field. Capacitive proximity switches will sense metal as well as nonmetallic materials such as paper, glass, liquids, and cloth.

Sensor Face

Metal or Nonmetal Object

Target
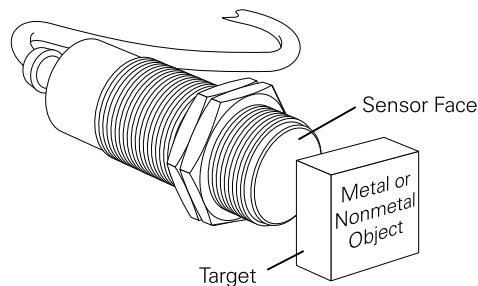
The sensing surface of a capacitive sensor is formed by two concentrically shaped metal electrodes of an unwound capacitor. When an object nears the sensing surface it enters the electrostatic field of the electrodes and changes the capacitance in an oscillator circuit. As a result, the oscillator begins oscillating. The trigger circuit reads the oscillator's amplitude and when it reaches a specific level the output state of the sensor changes. As the target moves away from the sensor the oscillator's amplitude decreases, switching the sensor output back to its original state.

Target

Dielectric Plate

Oscillator

Trigger

Output

Target Absent | Target Present | Target Absent
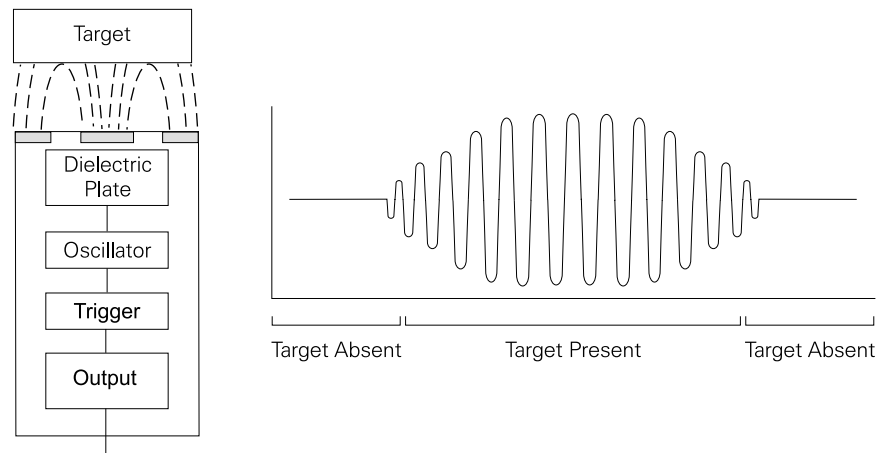
Standard Target and Dielectric Constant

Standard targets are specified for each capacitive sensor. The standard target is usually defined as metal and/or water. Capacitive sensors depend on the dielectric constant of the target. The larger the dielectric number of a material the easier it is to detect. The following graph shows the relationship of the dielectric constant of a target and the sensor's ability to detect the material based on the rated sensing distance (S_r).
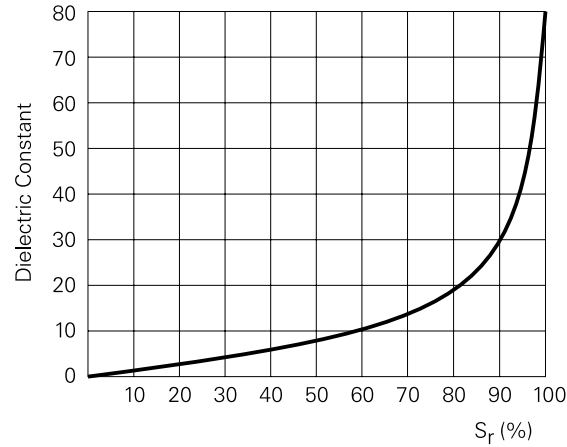

The following table shows the dielectric constants of some materials. If, for example, a capacitive sensor has a rated sensing distance of 10 mm and the target is alcohol, the effective sensing distance (S_r) is approximately 85% of the rated distance, or 8.5 mm.

| Material	Dielectric Constant	Material	Dielectric Constant
Alcohol	25.8	Polyamide	5
Araldite	3.6	Polyethylene	2.3
Bakelite	3.6	Polyproplene	2.3
Glass	5	Polystyrene	3
Mica	6	Polyvinyl Chloride	2.9
Hard Rubber	4	Porcelain	4.4
Paper-Based Laminate	4.5	Pressboard	4
Wood	2.7	Silica Glass	3.7
Cable Casting Compound	2.5	Silica Sand	4.5
Air, Vacuum	1	Silicone Rubber	2.8
Marble	8	Teflon	2
Oil-Impregnated Paper	4	Turpentine Oil	2.2
Paper	2.3	Transformer Oil	2.2
Paraffin	2.2	Water	80
Petroleum	2.2	Soft Rubber	2.5
Plexiglas	3.2	Celluloid	3

Detection Through Barriers

One application for capacitive proximity sensors is level detection through a barrier. For example, water has a much higher dielectric than plastic. This gives the sensor the ability to "see through" the plastic and detect the water.
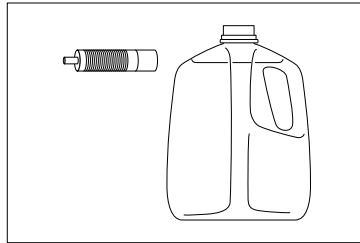

Shielding

All Siemens capacitive sensors are shielded. These sensors will detect conductive material such as copper, aluminum, or conductive fluids, and nonconductive material such as glass, plastic, cloth, and paper. Shielded sensors can be flush mounted without adversely affecting their sensing characteristics. Care must be taken to ensure that this type of sensor is used in a dry environment. Liquid on the sensing surface could cause the sensor to operate.

Sensor Flush Mounted
with Working Surface
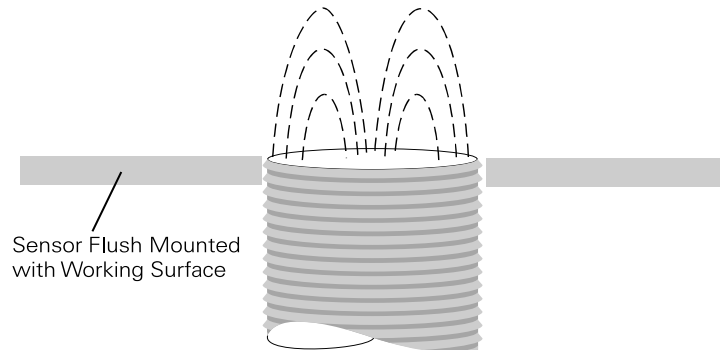
Capacitive Proximity Sensor Family

The 3RG16 product family identifies the Siemens capacitive proximity sensor. Units are available in DC or AC versions. Electronic controls such as SIMATIC® PLCs or relays can be controlled directly with the DC voltage version. In the case of the AC voltage version the load (contactor relay, solenoid valve) is connected with the sensor in series directly to the AC voltage. Sensors are available with two-, three-, and four-wire outputs.
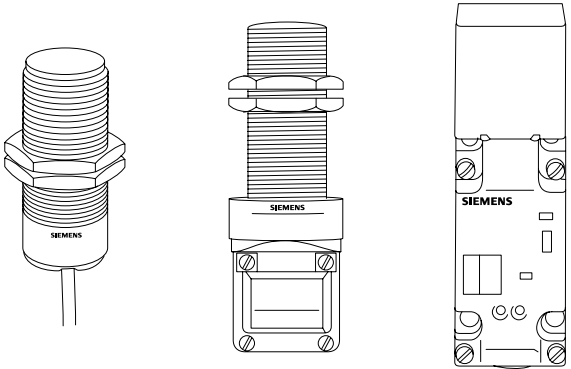
Capacitive Sensor Selection Guide

| Housing Dimension (mm)	Material	Shielded Unshielded	Sn (mm)	Operating Voltage	Wires
18	Plastic	Shielded	5	10-65 VDC	3
30	Metal	Shielded	10	20-250 VAC	3
	Plastic	Shielded	10	20-250 VAC	2
	Metal	Shielded	10	10-65 VDC	4
	Plastic	Shielded	10	10-65 VDC	4
40	Plastic	Shielded	20	20-250 VAC	2
	Plastic	Shielded	20	10-65 VDC	4
40x40 (Limit Switch Style)	Plastic	Shielded	20	20-250 VAC	2
	Plastic	Shielded	20	10-65 VDC	4
20x20 (Flat Pack)	Metal	Shielded	5	10-30 VDC	3

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1) A main difference between an inductive proximity sensor and a capacitive proximity sensor is that a capacitive proximity sensor produces an _____ field.

2) Capacitive proximity sensors will sense _____ material.

3) The larger the _____ constant of a material the easier it is for a capacitive proximity sense to detect.

4) It is easier for a capacitive proximity sensor to detect _____ than porcelain.

   a. teflon
   b. marble
   c. petroleum
   d. paper

5) The maximum rated sensing distance of a capacitive proximity sensor is _____ mm.

Ultrasonic Proximity Sensors
Theory of Operation

Ultrasonic proximity sensors use a transducer to send and receive high frequency sound signals. When a target enters the beam the sound is reflected back to the switch, causing it to energize or deenergize the output circuit.
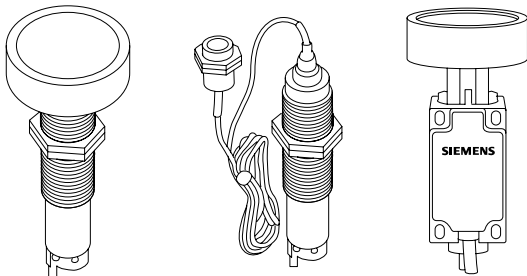
Piezoelectric Disk

A piezoelectric ceramic disk is mounted in the sensor surface. It can transmit and receive high-frequency pulses. A high-frequency voltage is applied to the disk, causing it to vibrate at the same frequency. The vibrating disk produces high-frequency sound waves. When transmitted pulses strike a sound-reflecting object, echoes are produced. The duration of the reflected pulse is evaluated at the transducer. When the target enters the preset operating range, the output of the switch changes state. When the target leaves the preset operating range, the output returns to its original state.

Piezoelectric Ceramic disk   Target

Transmitted Sound Waves   Echo Sound Waves
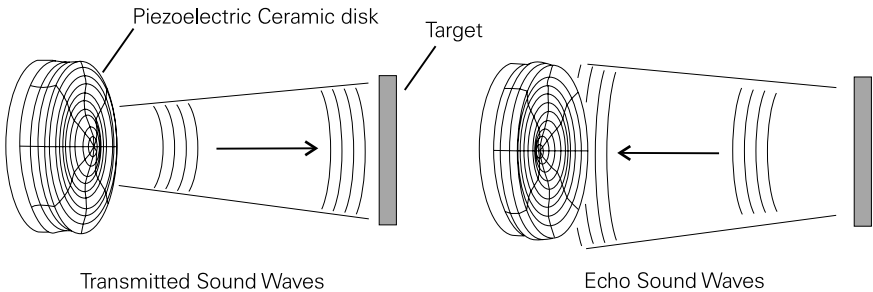
The emitted pulse is actually a set of 30 pulses at an amplitude of 200 Kvolts. The echo can be in microvolts.
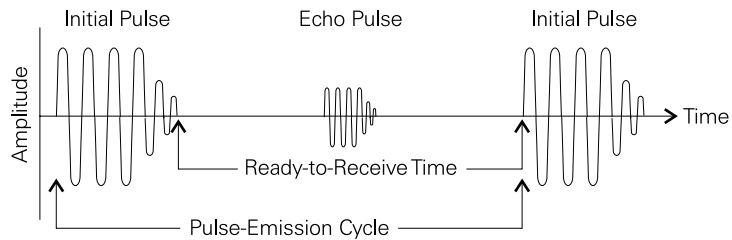

Blind Zone

A blind zone exists directly in front of the sensor. Depending on the sensor the blind zone is from 6 to 80 cm. An object placed in the blind zone will produce an unstable output.
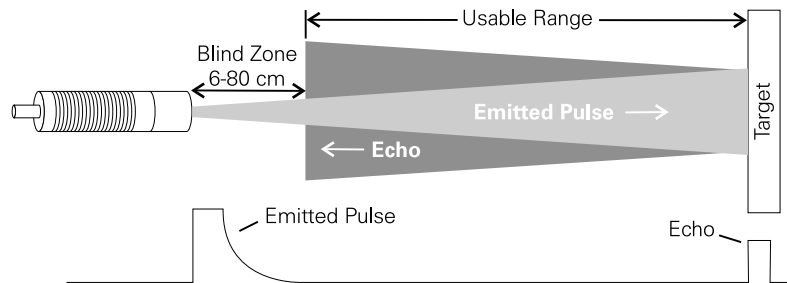

Range Definition

The time interval between the transmitted signal and the echo is directly proportional to the distance between the object and sensor. The operating range can be adjusted in terms of its width and position within the sensing range. The upper limit can be adjusted on all sensors. The lower limit can be adjusted only with certain versions. Objects beyond the upper limit do not produce a change at the output of the sensor. This is known as "blanking out the background".

On some sensors, a blocking range also exists. This is between the lower limit and the blind zone. An object in the blocking range prevents identification of a target in the operating range. There is a signal output assigned to both the operating range and the output range.
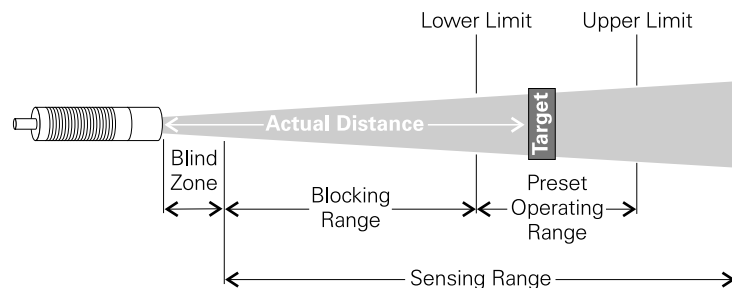
Radiation Pattern

The radiation pattern of an ultrasonic sensor consists of a main cone and several neighboring cones. The approximate angle of the main cone is 5°.
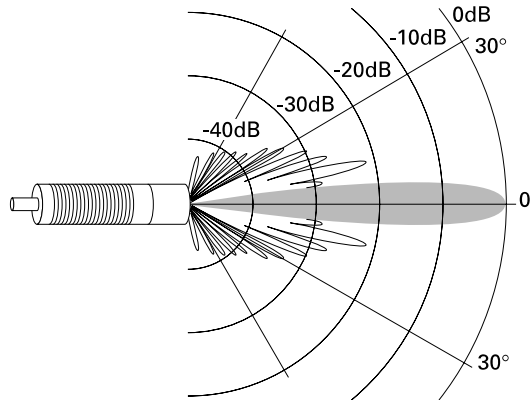

Free Zones

Free zones must be maintained around the sensor to allow for neighboring cones. The following examples show the free area required for different situations.

Parallel Sensors

In the first example, two sonar sensors with the same sensing range have been mounted parallel to each other. The targets are vertical to the sound cone. The distance between the sensors is determined by the sensing range. For example, if the sensing range of the sensors is 6 cm, they must be located at least 15 cm apart.
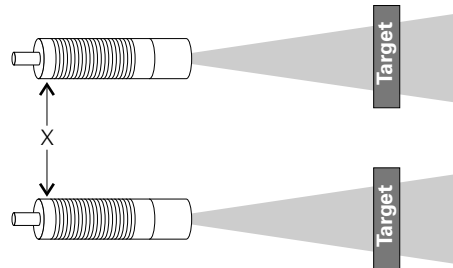
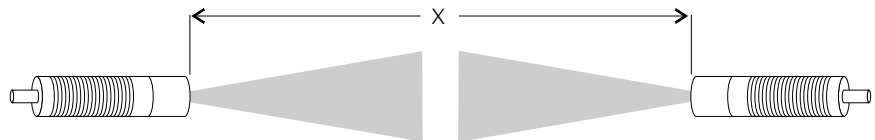| Sensing Range (CM)	X (CM)
6-30	>15
20-130	>60
40-300	>150
60-600	>250
80-1000	>350

Mutual Interference

Mutual interference occurs when sonar devices are mounted in close proximity to each other and the target is in a position to reflect echoes back to a sensor in the proximity of the transmitting sensor. In this case, the distance between sensors (X) can be determined through experimentation.
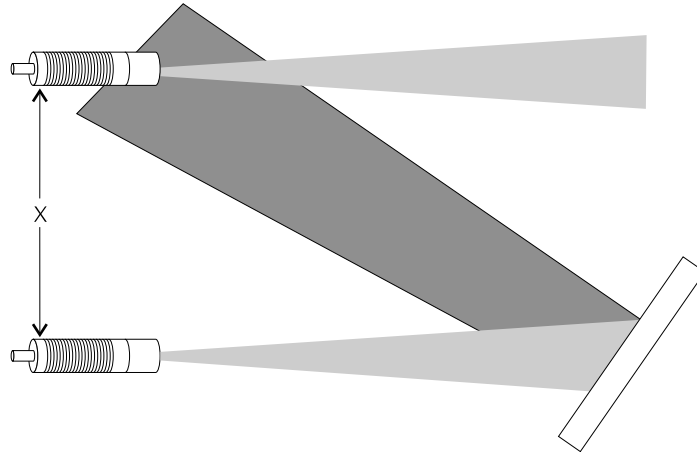
Opposing Sensors

In the following example, two sonar sensors with the same sensing range have been positioned opposite of each other. A minimum distance (X) is required between opposing sensors so that mutual interferance does not occur.

| Sensing Range (CM)	X (CM)
6-30	>120
20-130	>400
40-300	>1200
60-600	>2500
80-1000	>4000

Flat and Irregular Shaped Surfaces

Sonar sensors mounted next to a flat surface, such as a wall or smooth machine face, require less free area than sensors mounted next to an irregular shaped surface.

Flat Surface
Near Free Zone

Irregular Surface
Near Free Zone

X

Y
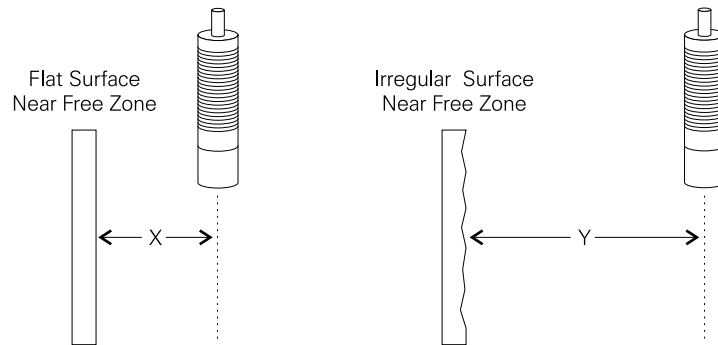
Sensing Range (CM)	X (CM)	Y (CM)
6-130	>3	>6
20-130	>15	>30
40-300	>30	>60
60-600	>40	>80
80-1000	>70	>150

Angular Alignment

The angle of the target entering the sound cone must also be considered. The maximum deviation from the send direction to a flat surface is ±3°.

+3°   -3°
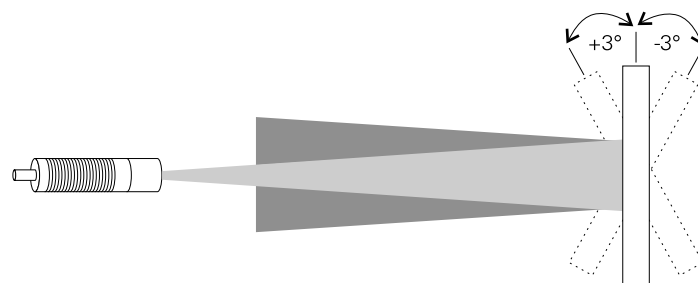
If the angle were greater than 3° the sonic pulses would be reflected away and the sensor would not receive an echo.

>3°
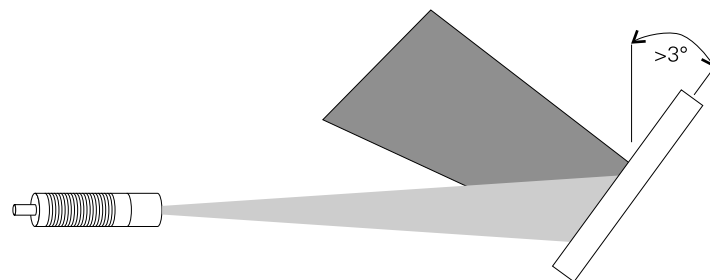
Liquids and Coarse-Grained Materials

Liquids, such as water, are also limited to an angular alignment of 3°. Coarse-grained materials, such as sand, can have an angular deviation as much as 45°. This is because the sound is reflected over a larger angle by coarse-grained materials.

Liquid   Coarse-Grained Material
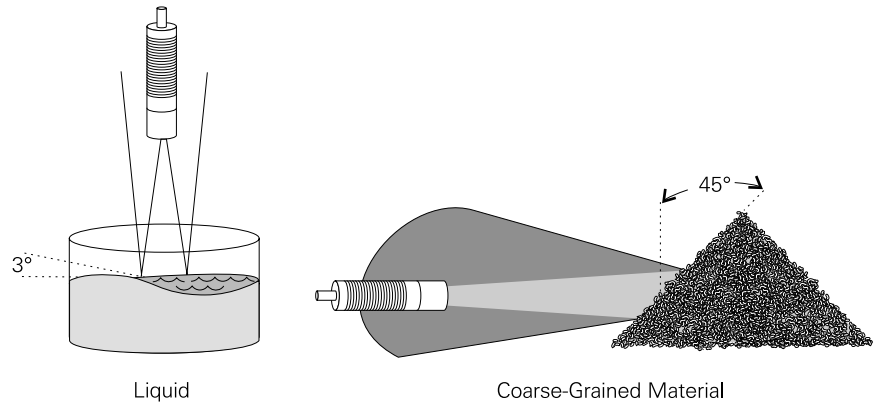
Blanking Out Objects

An object may be located in the vicinity of the sound cone that causes improper operating of the sensor. These objects can be blanked out by using an aperture made of a sound absorbing material such as rock wool. This narrows the sound cone and prevents pulses from reaching the interfering object.


Interferring Object

Target

Aperture

Sound-Absorbing Material
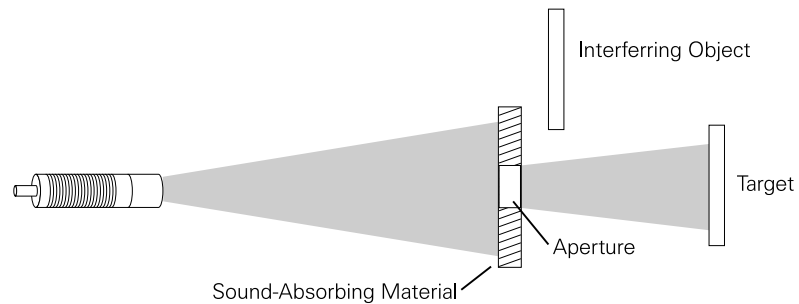
Operating Modes

Sonar sensors can be setup to operate in several different modes: diffuse, reflex, and thru-beam.

Diffuse Mode

This is the standard mode of operation. Objects, traveling in any direction into the operating range of the sound cone, will cause the sensor output to switch states. This mode of operation is similar to a proximity sensor.
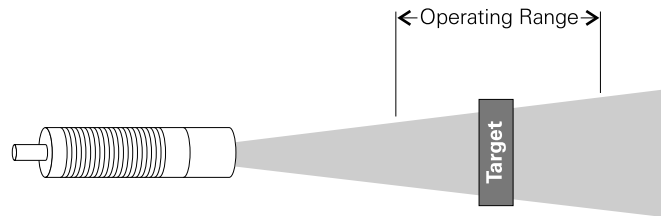
Reflex Mode

The reflex mode uses a reflector located in the preset operating range. The operating range is adjusted for the reflector. The pulses are bounced off the reflector and the echo pulses are returned to the sensor. When a target blocks the echo pulses the output is activated. Typically used in applications where the target is not a good sound absorber.
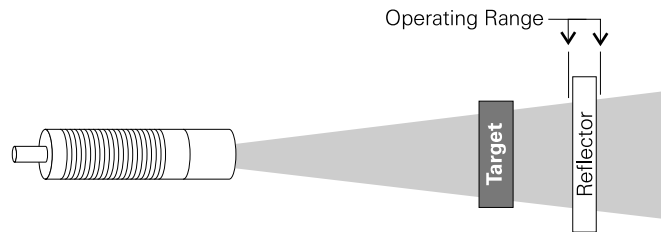
Thru-Beam Mode

Thru-beam sensors consist of a transmitter, which emits ultrasonic pulses, and a receiver. If the beam between the transmitter and the receiver is interrupted the output of the receiver switches state.

Environmental Influences

Sound travel time can be affected by physical properties of the air. This, in turn, can affect the preset operating distance of the sensor.

Condition	Effect
Temperature	Sonic wave speed changes by 0.17%/°K. Most sensors have a compensation adjustment.
Pressure	With normal atmospheric variation of ±5%, sound velocity varies approximately ±0.6%. Sound velocity decreases 3.6% between sea level and 3 km above sea level. Adjust sensor for appropriate operating range.
Vacuum	Sensors will not operate in a vacuum.
Humidity	Sound velocity increases as humidity increases. This leads to the impression of a shorter distance to the target. The increase of velocity from dry to moisture-saturated air is up to 2%.
Air Currents	Wind Speed <50 km/h - No Effect 50 - 100 km/h - Unpredictable Results >100 km/h - No Echo Received by Sensor
Gas	Sensors are designed for operation in normal atmospheric conditions. If sensors are operated in other types of atmospheres, such as carbon dioxide, measuring errors will occur.
Precipitation	Rain or snow of normal density does not impair the operation of a sensor. The transducer surface should be kept dry.
Paint Mist	Paint mist in the air will have no effect, however, paint mist should not be allowed to settle on transducer surface.
Dust	Dusty environments can lower sensing range 25-33%.

Review 5

1) Ultrasonic proximity sensors use high frequency
_____ signals to detect the presence of a target.

2) The blind zone of an ultrasonic proximity sensor can be
from _____ - _____ cm, depending on
the sensor.

3) The approximate angle of the main sound cone of an
ultrasonic proximity sensor is _____ degrees.

4) The free zone between two parallel ultrasonic sensors
with a rated sensing range of 20-130 cm must be
greater than _____ cm.

5) The maximum angle of deviation from the send
direction of an ultrasonic sensor to a flat surface is
_____ degrees.

6) _____ mode is the standard mode of operation
for an ultrasonic sensor.

Ultrasonic Proximity Sensor Family

The ultrasonic proximity sensor family consists of a Thru-Beam sensor, compact range (M18, Compact Range 0, I, II, and III), and modular (Modular Range II) sensors.
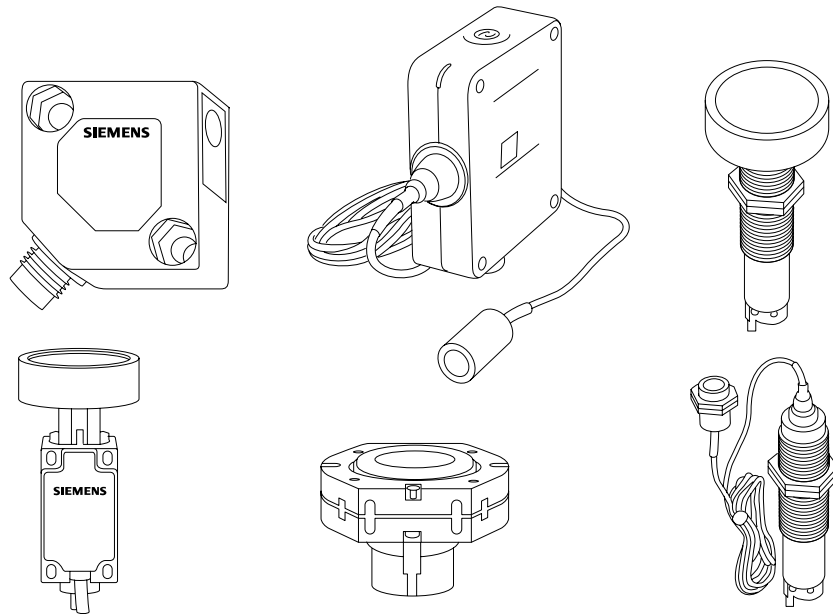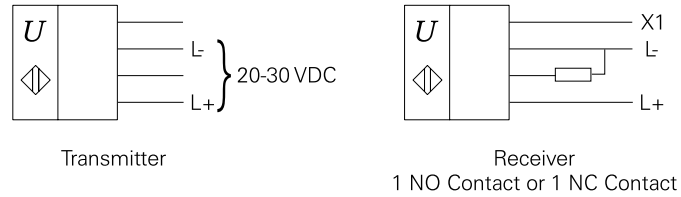

Thru-Beam

Thru-Beam sensors consist of a transmitter and a receiver. The transmitter sends a narrow continuous tone. When a target is positioned between the transmitter and the receiver the tone is interrupted, which causes the output of the receiver to change state. The operating voltage is 20-30 VDC. The switching frequency is 200 Hz at 40 cm sensing distance.

Receiver
Available as NO or NC

Transmitter
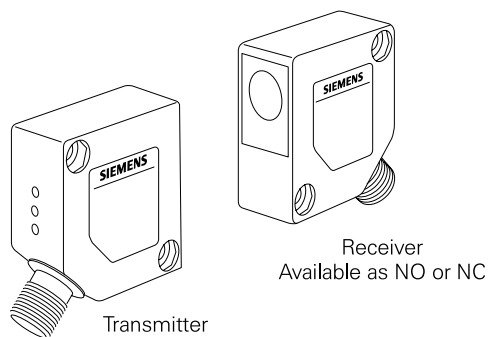
Thru-Beam Receivers

There are two receivers available for the Thru-Beam sensors. Both use a PNP transistor. One receiver provides a normally open (NO) contact and the other provides a normally closed (NC) contact.

Transmitter

Receiver
1 NO Contact or 1 NC Contact

The sensitivity and frequency setting of the Thru-Beam sensors is a function of the X1 connection on the receiver.

| Receiver	Distance (cm)	Switching Frequency (Hz)
X1 Open	5-150	100
X1 to L-	5-80	150
X1 to L+	5-40	200

The minimum size of a detectable object is a function of the distance between the transmitter and the receiver. If the distance between the transmitter and the receiver is less than 40 cm and the minimum gap width between two objects is at least 3 cm, objects of 2 cm or larger will be detected. If the distance between the sensors is less, even gaps of less than 1 mm can be detected. At maximum sensing distance, objects greater than 4 cm will be detected, provided the gap between objects is greater than 1 cm.

Compact Range 0

Compact Range 0 sensors are available with an integrated or an separate transducer. They are configured with a normally open (NO), normally closed (NC) or analog output. These sensors have a cubic shape (88 x 65 x 30 mm). The sensors operate on 18 - 35 VDC and can handle a load up to 100 mA.
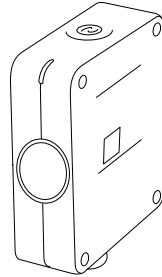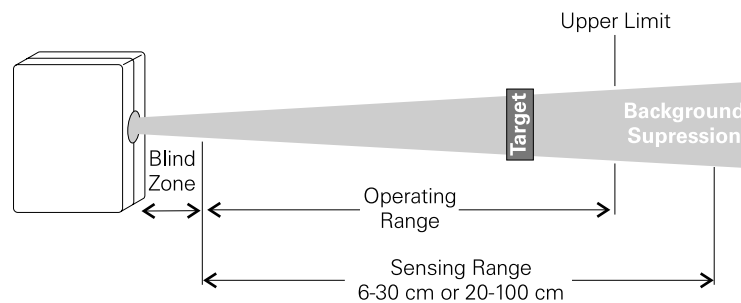

Integrated Transducer
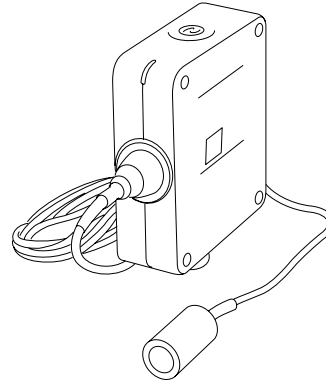
Separate Transducer

Depending on the sensor, the sensing range is either 6 - 30 cm (separate transducer) or 20 - 100 cm (integrated transducer). Switching frequencies vary from 5 Hz to 8 Hz. Compact Range 0 sensors have background suppression. This means the upper limit of the sensing range is adjustable with a potentiometer. Targets within the sensing range but beyond the switching range of the upper limit will not be detected.


Upper Limit

Target

Background Supression

Blind Zone

Operating Range

Sensing Range
6-30 cm or 20-100 cm

Compact Range I

Compact Range I sensors are available with a normally open (NO) or a normally closed (NC) contact. They are also available with two outputs, one normally open (NO) and one normally closed (NC). These sensors have a cylindrical shape (M30 x 150 mm). Several versions are available, including a separate transducer (shown) and a tilting head (not shown). The sensors operate on 20 - 30 VDC and can handle a load up to 200 mA.
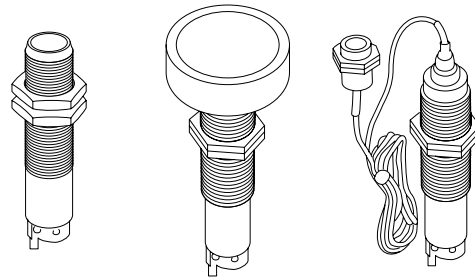
Depending on the sensor the sensing range is either 6 - 30 cm, 20 - 130 cm, 40 - 300 cm, or 60 - 600 cm. Switching frequencies vary from 1 Hz to 8 Hz. Compact Range I sensors have background and foreground suppression. This means the upper and lower limits of the sensing range are adjustable with separate potentiometer. Targets within the sensing range but beyond the switching range of the upper and lower limits will not be detected.
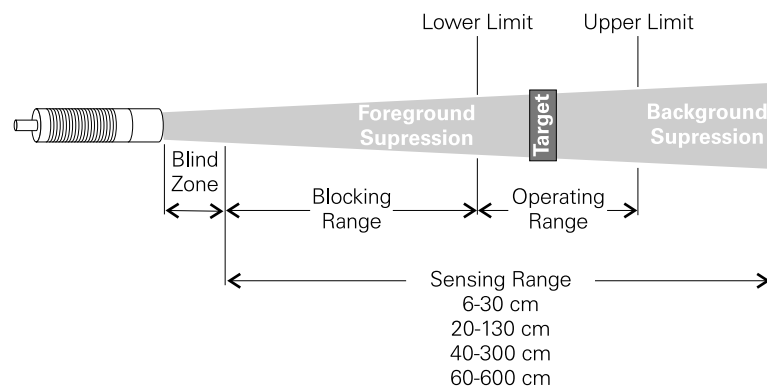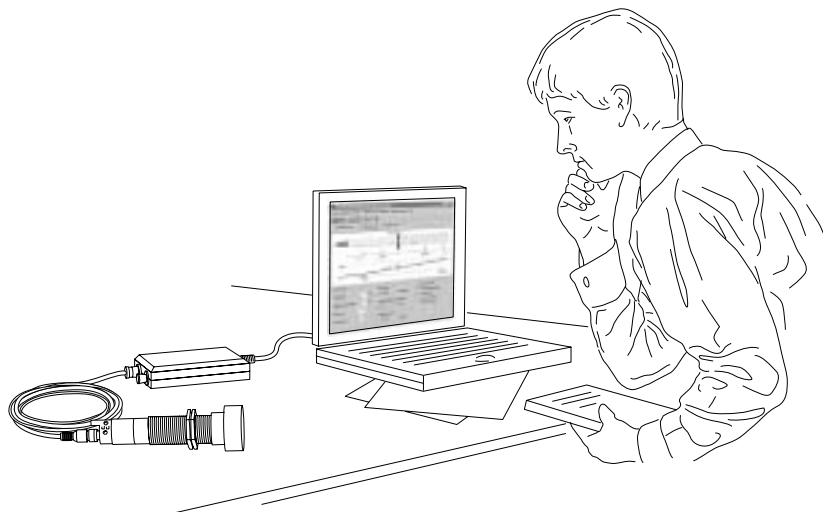
SONPROG

The ultrasonic sensors discussed so far (Thru-Beam, Compact Range 0, and Compact Range I) are either nonadjustable or can be adjusted manually with potentiometers. SONPROG is a computer program, unique to Siemens, that is used to adjust Compact Range II, Compact Range III, and Compact Range M18 sensors.

Sensor	Adjustment
Thru-Beam	None
Compact Range 0	1 Potentiometer
Compact Range I	2 Potentiometers
Compact Range II	SONPROG
Compact Range III	SONPROG
Compact Range M18	SONPROG

With SONPROG sonar sensors can be matched individually to the requirements of a particular application. An interface is connected between the sensor and an RS232 port of a computer. SONPROG can be used to set the following parameters:

- Beginning and end of switching range
- Switching hysteresis
- Beginning and end of analog characteristic
- End of blind zone
- End of sensing range
- NO/NC contacts
- Potentiometer adjustments on sensors on/off

These values can be printed out and stored in a file. They are immediately available when needed. When replacing a sensor, for example, the stored parameters can be easily applied to the new sensor.
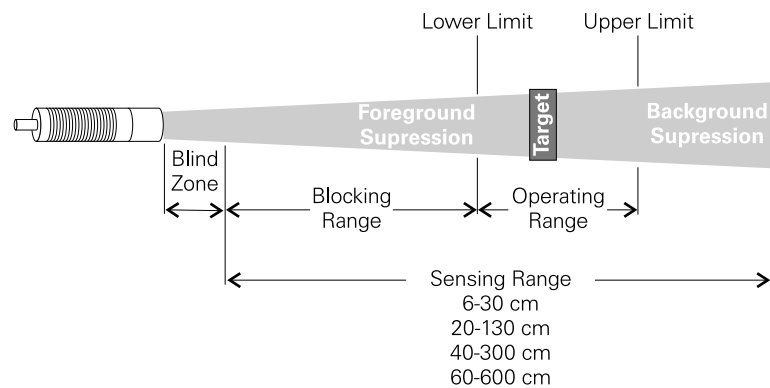
Compact Range II

Compact Range II sensors are similar in appearance to Compact Range I sensors. A major difference is that Compact Range II sensors can be adjusted manually or with SONPROG. They are available with a normally open (NO) or a normally closed (NC) contact. They are also available with two outputs, one normally open (NO) and one normally closed (NC). These sensors have a cylindrical shape (M30 x 150 mm). Several versions are available, including a separate transducer. The sensors operate on 20 - 30 VDC and can handle a load up to 300 mA. Compact Range II sensors can be synchronized to prevent mutual interference when using multiple sensors in close proximity to each other.
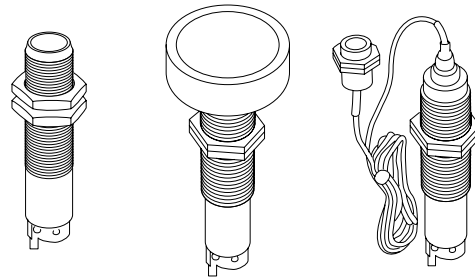

Depending on the sensor the sensing range is either 6 - 30 cm, 20 - 130 cm, 40 - 300 cm, or 60 - 600 cm. Switching frequencies vary from 1 Hz to 8 Hz. Compact Range II sensors have background and foreground suppression.

Compact Range II Analog Version

An analog version of the Compact Range II sensor is available. The analog measurement is converted by the sensor to digital pulses. A counter in LOGO! or a PLC counts the pulses and makes the measurement conversion. If, for example, the switching output of the sensor were set such that 50 Hz was equivalent to 50 cm and the gate time of LOGO! was set for 1 second, LOGO! would be able to accurately convert any frequency to its corresponding distance.
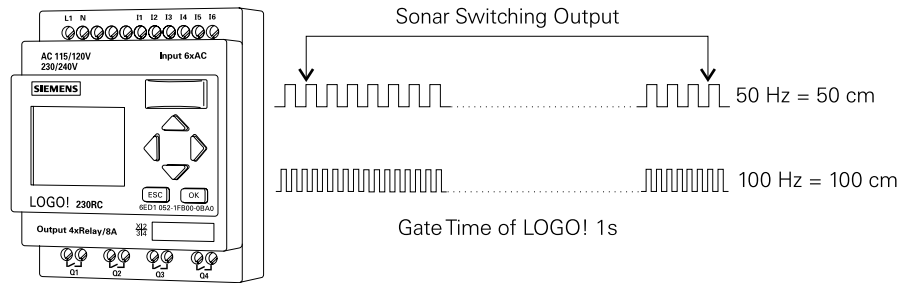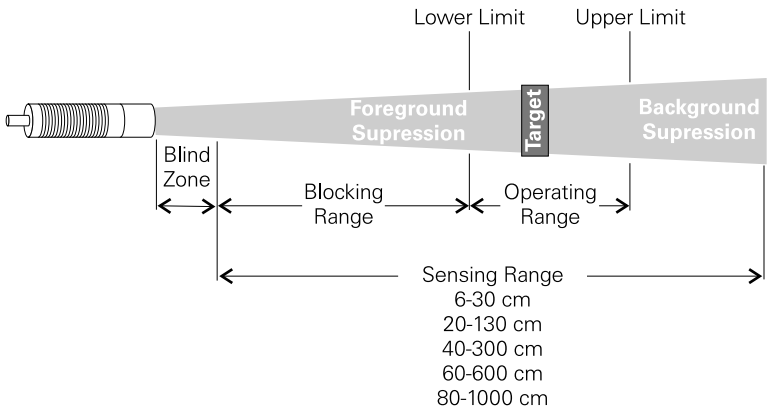

Compact Range III

Like the Compact Range II sensors, Compact Range III sensors can be adjusted manually or with SONPROG. They are available with a normally open (NO) or a normally closed (NC) contact. They are also available with two analog outputs, 0 - 20 mA or 0 - 10 VDC. The sensors operate on 20 - 30 VDC and can handle a load up to 300 mA. Compact Range III sensors can be synchronized to prevent mutual interference when using multiple sensors in close proximity to each other. In addition, they offer an arithmetic mean feature. This is useful for liquid level sensing or other applications where reflection variations can occur. The arithmetic mean feature helps compensate for these variations.
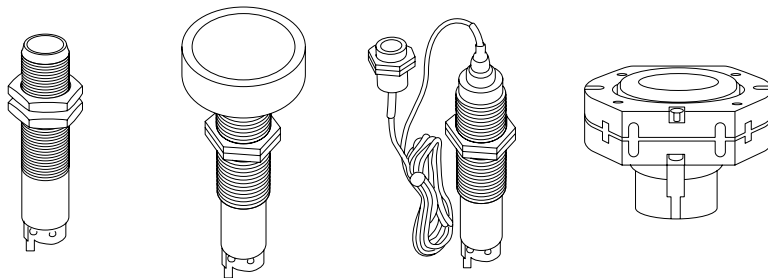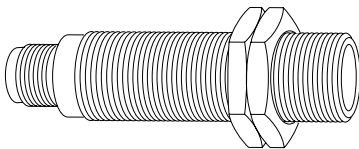
Depending on the sensor, the sensing range is either 6 - 30 cm,
20 - 130 cm, 40 - 300 cm, 60 - 600 cm, or 80 - 1000 cm.
Switching frequencies vary from 0.5 Hz to 5 Hz. Compact
Range III sensors have background and foreground suppression.

Compact Range M18

The small size (M18 x 101 mm) of the Compact Range M18
sensor makes it suited for applications where space is limited.
Compact Range M18 sensors are available with a normally
open (NO) or a normally closed (NC) contact. They are also
available with an analog output (4 - 20 mA, 0 - 20 mA, or 0 - 10
VDC). The sensors operate on 20 - 30 VDC and can handle a
load up to 100 mA.

Depending on the sensor the sensing range is either 5 - 30 cm
or 15 - 100 cm and the switching frequency is either 4 or 5 Hz.
Compact Range M18 sensors have background suppression.
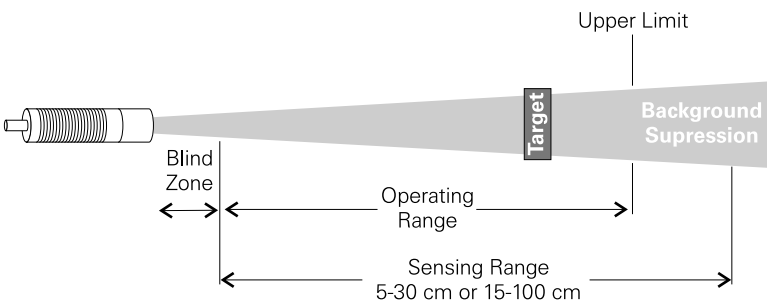
Compact Range with for use with AS-i

Siemens also manufactures ultrasonic sensors for use with AS-i. Four sensing ranges are available: 6 - 30 cm, 20 - 130 cm, 40 - 300 cm, and 60 - 600 cm. The switching frequency varies from 1 to 8 Hz.
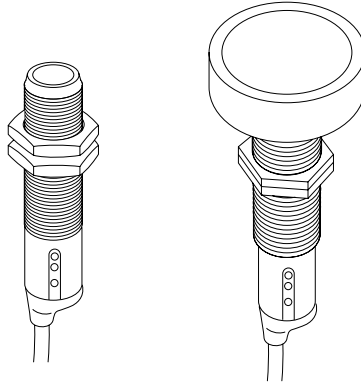

Modular Range II and the Signal Evaluator

The next group of ultrasonic sensors is Modular Range II. The Modular Range II consists of sensors and their corresponding signal evaluator. The signal evaluator is required for Modular Range II sensors. Sensor values are set using buttons on the evaluator. A two-line LCD displays the set values.
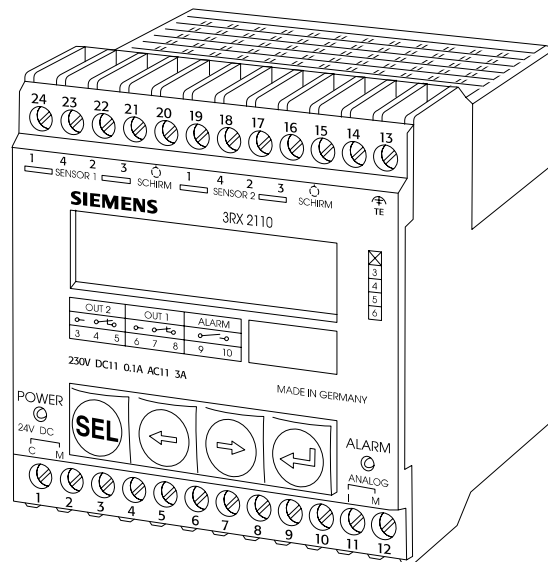
The signal evaluator can operate a maximum of two Modular Range II sensors. It is supplied with a 20 - 30 VDC power supply. It has two switching outputs, one error output, and one analog output.
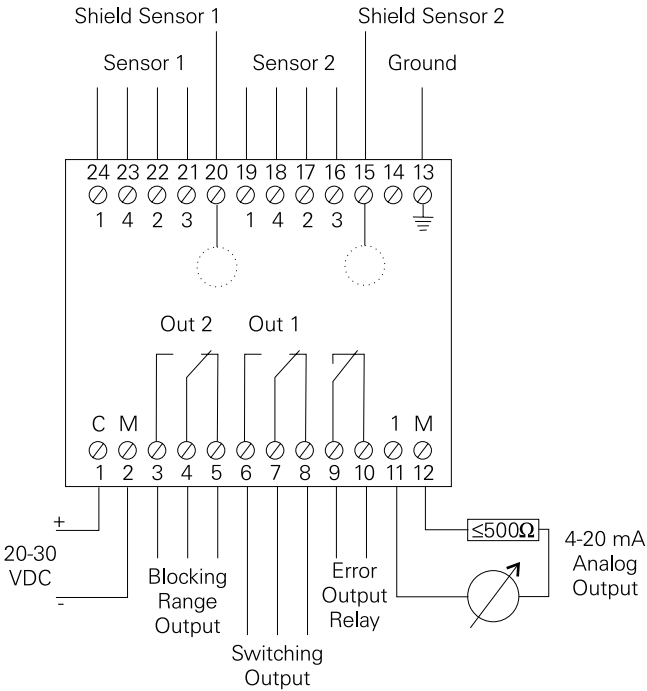

Modular Range II Sensors

Module Range II sensors are available in three versions: cubic sensors, cylindrical sensors, and spherical sensors. They have analog and normally open (NO) or normally closed (NC) outputs. As mentioned earlier, all settings and operations are done with a signal evaluator.
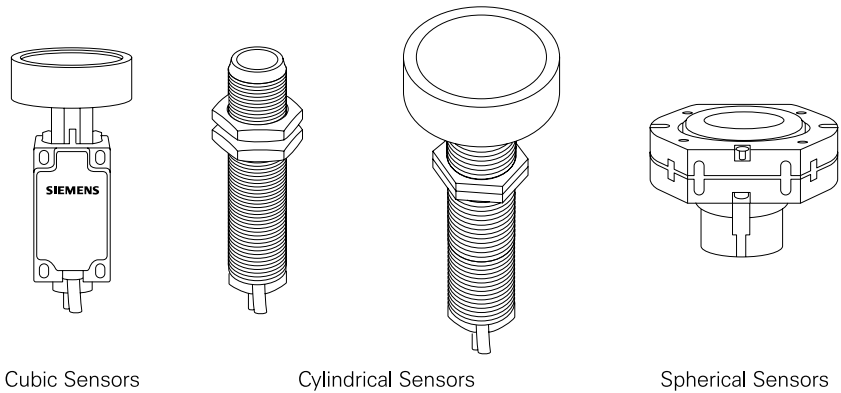
Cubic Sensors   Cylindrical Sensors   Spherical Sensors

Depending on the sensor the sensing range is either 6 - 30 cm, 20 - 130 cm, 40 - 300 cm, 60 - 600 cm, or 80 - 1000 cm. Switching frequencies vary from 1 Hz to 20 Hz. Modular Range II sensors have background and foreground suppression.
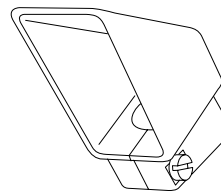

Sensing Range
6-30 cm
20-130 cm
40-300 cm
60-600 cm
80-1000 cm
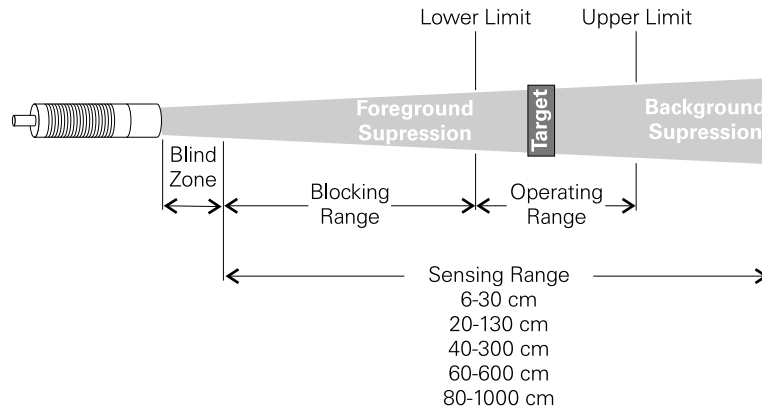
Accessories

An adjusting device with a mounting flange (shown) or bracket (not shown) and a 90° diverting reflector are available for M30 spherical sensors. The adjusting device allows the sensor to be positioned in hard-to-mount areas.
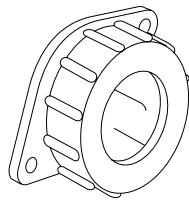
Adjusting Device
Flange Model

90° Diverting Reflector

1) Ultrasonic _____-_____ proximity sensors require a separate transmitter and receiver.

2) If X1 is connected to L+ of a Thru-Beam ultrasonic proximity sensor, the sensing range is _____ to _____ cm.

3) The maximum sensing range of a Compact Range 0 ultrasonic sensor with a _____ transducer is 6 - 30 cm.

4) Compact Range _____ does not offer foreground suppression.

   a. 0
   b. I
   c. II
   d. III

5) _____ is a computer program used to adjust Compact Range II, Compact Range III, and Compact Range M18 ultrasonic sensors.

6) _____ Range II require a signal evaluator.

7) A signal evaluator can operate a maximum of _____ sensors.

   a. 1
   b. 2
   c. 3
   d. 4