White Paper

Safety Light Curtains

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Table of contents

1. Introduction

Safety light curtains are indispensable, as they safeguard danger areas at machines, robots or automated systems against unauthorized intervention or entry and thereby contribute to accident prevention.

This white paper pertains to the safety light curtains of the OY32 and OY36 series from ipf electronic, which satisfy safety category 4 and the high Performance Level "e".
The light curtains are designed in accordance with international safety standards, in particular, standards CEI IEC 61496-1: 2004* and CEI IEC 61496-2: 2006*.

The function of safety light curtains is described in the following; discussed in this context is what is to be observed during the installation of such protective systems.
This white paper does not serve as the operating instructions for the devices mentioned above. If you need operating instructions, please contact an application specialist from ipf electronic or download the required documents for the OY32 and OY36 series from the ipf electronic website.

* CEI IEC 61496-1: 2004 - Safety of machinery: Electro-sensitive protective equipment. Part 1: General requirements and tests.

CEI IEC 61496-2: 2006 - Safety of machinery: Electro-sensitive protective equipment.
Part 2: Particular requirements for equipment using active opto-electronic protective devices

2. General functionality

A safety light curtain consists of a transmitter rail and a receiver rail. The LEDs in the transmitter rail emit infrared beams in a temporally defined sequence. This sequential pattern is received by the LEDs of the receiver rail. After a pass (max. 50ms or 140ms), the receiver performs an evaluation on the basis of the preset parameters to determine whether an object is located between the transmitter and receiver rails. If this is the case, the receiver switches its output.
With respect to the beam functions of a safety light curtain, a distinction is made between parallel beam and cross beam. If each emitted light beam is received by only the opposing receiver element, one speaks of parallel beam function. With the cross beam function, each light beam emitted by a transmitting element is received not only by the directly opposing receiver element, but also by the receiver elements located directly above or below. This process alternates. Compared to the parallel beam function, the cross beam function can detect significantly smaller objects within a safety light curtain.

3. Classification of safety light curtains and areas of application

Depending on the operation site or the required safeguarding of the danger area, safety light curtains can be divided into the following three categories:

- Finger protection
- Hand protection
- Body protection

For finger and hand protection, a wide range of models with protected field heights of 150mm to 1800mm are available. Such systems are used, for example, in the danger area of welding robots, uncoiling stations, pallet loading equipment, lathes, impact cutters, press brakes as well as packaging and cutting machines.
The systems for body protection are available with beam spacings of 500mm to 1200mm and are used above all for access guarding in the danger area of transport systems, stackers and packaging machinery.

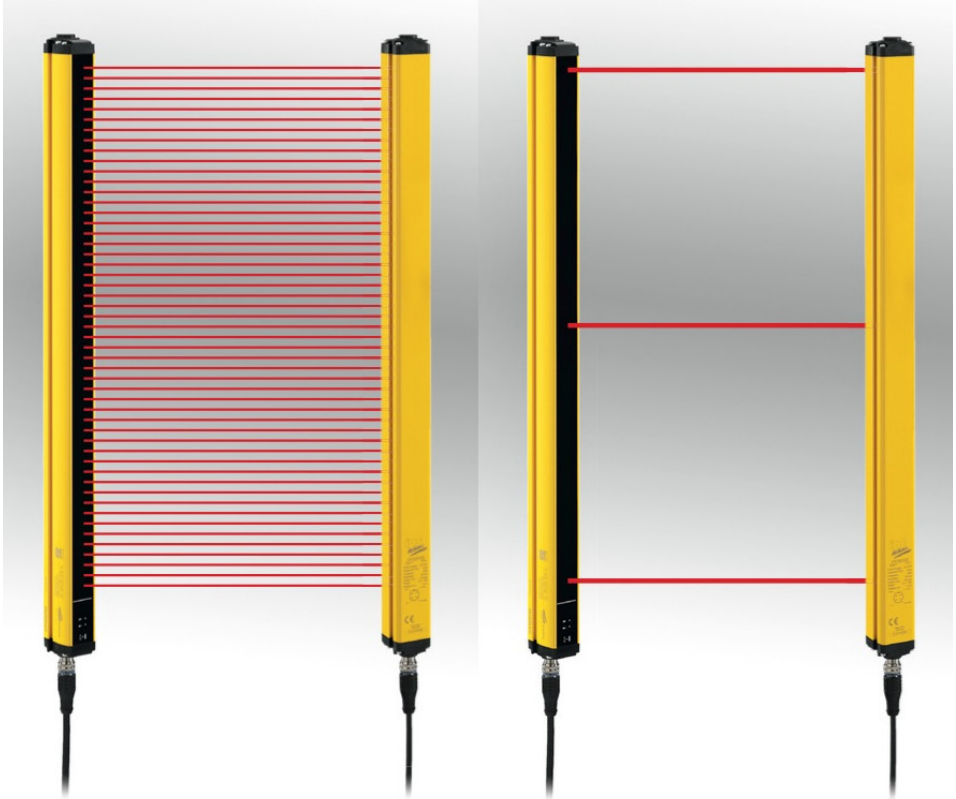


Fig. 1: Safety light curtains for finger protection (left) and body protection (right)

4. Selecting the right protection system

After performing the corresponding hazard assessment, at least three important properties should be taken into account when selecting a safety light curtain:

- Resolution of the protective system
- Height of the protected area
- Minimum safety distance of the system to the danger area

4.1 Resolution of the protective system

Resolution here refers to the minimum size of a matte object with which at least one beam in the scanning range of the system can be interrupted with certainty. The resolution is solely dependent on the geometric properties of the lenses in the devices, the diameter of the individual beams and their distance to one another and is not influenced by the ambient and environmental conditions of the safety light curtain (Fig. 2).

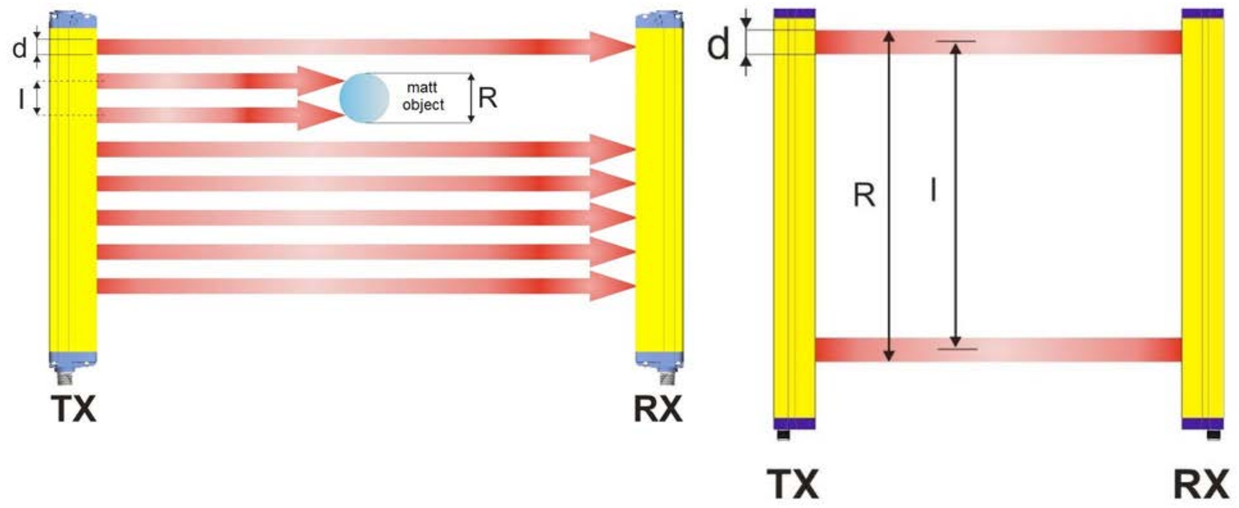


Fig. 2: Resolution refers to the minimum size of a matte object with which at least one beam of the system (left for finger or hand protection, right for body protection) can be interrupted with certainty.

The resolution value "R" is calculated with the following equation:

$$R = l + d$$

Variable "l" stands for the distance between two adjacent optics of the system, while "d" specifies the lens diameter. "TX" stands for transmitter and "RX" for receiver
(see Fig. 2).
The systems for finger protection from ipf electronic have a resolution (R) of 14mm, while the safety light curtains for hand protection feature a resolution of 30mm.
Fig. 3 shows the corresponding values of the systems for body protection.

article-no.	centerline of optics [mm] (l)	number of optics (n)	resolution [mm] (R)	Ø optics [mm] (d)	range [m]
OY360110	500	2	515	15	0.5 … 50
OY360111	400	3	415	15	0.5 … 50
OY360112	300	4	315	15	0.5 … 50
OY360113	400	4	415	15	0.5 … 50

Fig. 3

4.2 Height of the protected area

The protected field height (Hp) is the height of the entire area that is protected by a safety light curtain (Fig. 4).

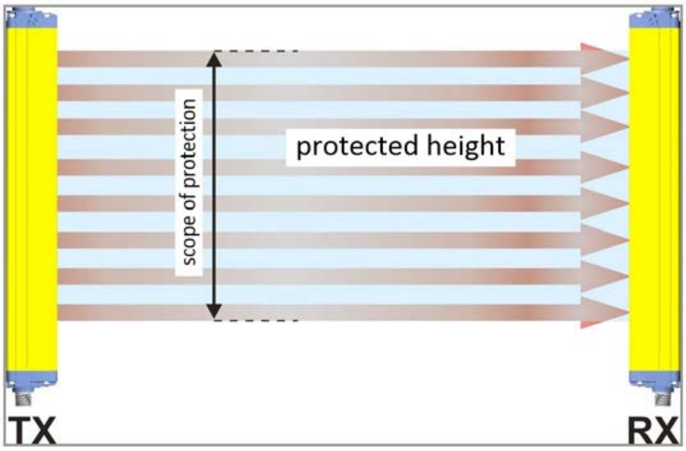
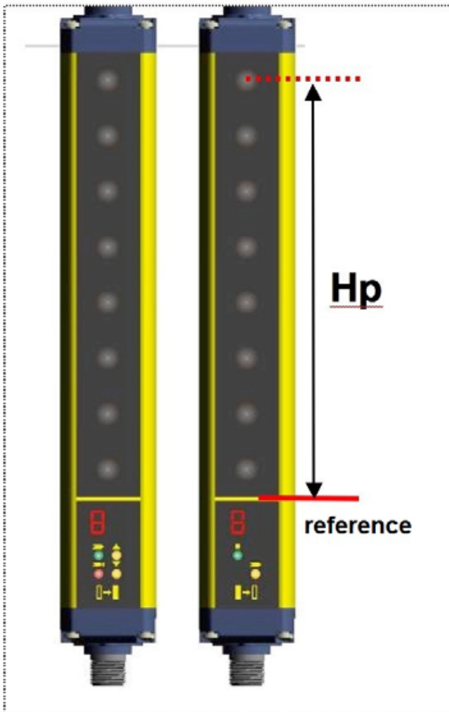


Fig. 4: Protected area for finger and hand protection

For the devices of the OY32 series for finger and hand protection, the height of the protected area is limited by a yellow line on the front screen and the protected field heights (Hp) specified in Fig. 5.



article	height of protected area Hp (mm)
OY320100 / OY320130	150
OY320101 / OY320131	300
OY320102 / OY320132	450
OY320103 / OY320133	600
OY320104 / OY320134	750
OY320105 / OY320135	900
OY320106 / OY320136	1050
OY320107 / OY320137	1200
OY320108 / OY320138	1350
OY320109 / OY320139	1500
OY32010A / OY32013A	1650
OY32010C / OY32013C	1800

OY32010x = resolution 30mm
OY32030x = resolution 14mm

Fig. 5

For body protection, a distinction must be made between the "height of the scanning area" and the "height of the protected area" (Fig. 6). The height of the scanning area is the distance between the top point of the first and the bottom point of the last lens of the safety light curtain. The height of the protected area defines the height that is effectively safeguarded by the safety light curtain in which a non-transparent object reliably interrupts a beam of the light curtain. In this context, the object must have dimensions that are larger than or equal to the resolution of the light curtain. According to the table in Fig. 3, such objects are in the range between 315 and 515mm for the protective systems of the OY36 series.

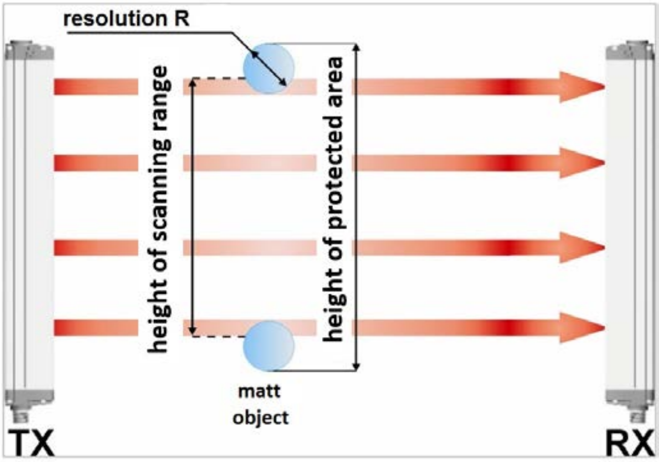


Fig. 6: For body protection, a distinction is to be made between the "height of the scanning area"
and the "height of the protected area".

4.3 Minimum safety distance of the system to the danger area

We now come to the property "minimum safety distance" of safety light curtains.
This is a topic that often raises many questions in connection with the installation of such systems in practice and is, therefore, handled in greater detail at this point.

What does "minimum safety distance" mean? Simply stated: the distance in which a safety light curtain is to be installed in front of a danger area or dangerous system movement. Here, the distance of the system must ensure that an object or body part / body that penetrates the danger area does not come into contact with a dangerous movement of a machine or system (the danger source) before the movement has been fully stopped by the triggering of the safety light curtain or ESPE (electro-sensitive protective equipment) (Fig. 7).

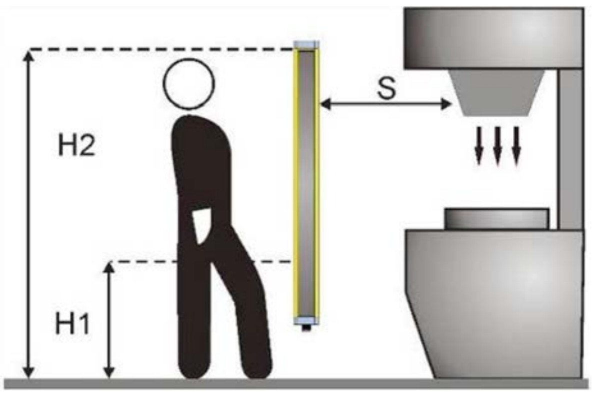


Fig. 7: Protective equipment must have a minimum safety distance (S).

In accordance with directive EN ISO 13855:2010 (Safety of machinery – Positioning of safeguards with respect to the approach speeds of parts of the human body), the distance of a safety light curtain is largely dependent on four factors here.

- **Response time of the ESPE:** the time that passes between the effective interruption of the light beams and the opening of the contacts of the output switching element (OSSD).
  (OSSD: output signal switching device)
- **Stopping time of the machine:** the time that passes between the opening of the contacts of the ESPE and the effective stop of the dangerous machine movement.
- **Resolution of the ESPE**
- **Approach speed:** the speed with which an object that is to be detected
  (e.g., finger, hand or body) approaches the danger area.

4.3.1 Calculation of the minimum safety distance

The minimum safety distance is calculated with the following equation:

$$\mathbf{S = K\,(t_1 + t_2) + C}$$

What the individual variables mean:

S = safety distance in mm
K = approach speed in mm/s
t_1 = response time of the ESPE in seconds

t_2 = stopping time of the machine in seconds
C = additional distance that takes into account the possibility that a body or body part enters the danger area before the safety light curtain triggers

For safety light curtains with a resolution ﬃ 40mm, the equation for C is:

$$\mathbf{C = 8\,(R-14)}$$

R = resolution of the device or safety light curtain according to manufacturer specifications

For safety light curtains with a resolution > 40mm (body protection), the following applies for C:

C = 850mm

4.3.2 Special relevance of the stopping time

As already emphasized further above, the topic of "minimum safety distance" raises many questions in practice, whereby, in connection with the calculation of this distance and – above all – with the estimation of t_2 (the stopping time of a machine or system), estimates are sometimes incorrect. Users of safety light curtains are sometimes of the opinion that a machine comes to an immediate standstill in the event of an emergency stop triggered by the protective device. This is, however, not generally the case. In daily practice, it is not seconds that pass, but rather milliseconds until the system comes to an absolute stop.

This means: each millisecond that passes at a system before it comes to a complete stop increases the required distance to the dangerous machine area or to the dangerous movement.

Here are a few concrete examples:

The resolution of the OY32 safety light curtain from ipf electronic for finger protection is 14mm. For factor C (additional distance), the following result was therefore calculated according to the equation for devices with a resolution ffi 40mm:

8 (14-14) = 0

Because factor C has a value of 0 for finger protection, the variables K (approach speed) and times t_1 and t_2 remain for the calculation of the safety distance, whereby the approach speed is specified with 2m/s (2000mm/s). The sum of the response time of the light curtain t_1 and the machine stopping time t_2, each in milliseconds, is multiplied by two, thereby yielding the distance of the safety light curtain to the danger area.

If a system needs, e.g., 50ms for a complete stop and the used light curtain needs 11ms, the distance of the safety light curtain for finger protection would need to be 122mm. For a machine stopping time of 0.5 seconds (500ms), this already yields a distance of 1.022 millimeters between the protective system and danger source.

It thereby becomes clear that the stopping time of a machine or system has a considerable influence on the minimum safety distance – even though the following exception rule exists for the value K both for systems for finger and hand protection as well as for body protection.

If the calculated distance value is ffi 500mm, K is specified with 2000mm/s (as described above). If the calculated value is > 500mm, however, an approach speed of 1600mm/s may be used for K.

But even when using this rule, the distance of a safety light curtain is still 817.6 millimeters for a stopping time of 0.5 seconds.

Because the variable t_2 (stopping time of the machine) is immensely important for the calculation of the safety distance, it should always be determined with great care with the aid of special measuring instruments and, if necessary, by specialists. Furthermore, the stopping time may change as a result of wear on a machine or system. It is therefore recommended that the measurements be repeated at regular intervals, whereby this is already prescribed by law for some machines and systems.

Safety light curtains with a resolution of > 40mm are used most often to prevent persons from entering danger areas. To prevent climbing over or crawling beneath the protective device, the height of the upper and lower light beam is to be taken into account for systems that are installed vertically (see Fig. 7 on page 9). Starting with the reference plane (e.g., the machine foundation), the upper beam must be positioned at a height of ﬄ 900mm (H2) and the lower beam must be positioned at a height of ﬃ 300mm (H1).

4.3.3 Safety distance with horizontally installed systems

If safety light curtains are to be installed horizontally on a machine due to conditions on-site, the distance between the danger area and the optical beam farthest from this area must be calculated using the following equation:

$$\mathbf{S = 1600\ mm/s\ (t_1 + t_2) + 1200 - 0.4\ H}$$

With the exception of H, the variables used in this equation were already described in detail on pages 9 and 10. Variable H describes the height of the beams above the ground (Fig. 8). This height must not, however, exceed a distance above the ground of 1000mm.

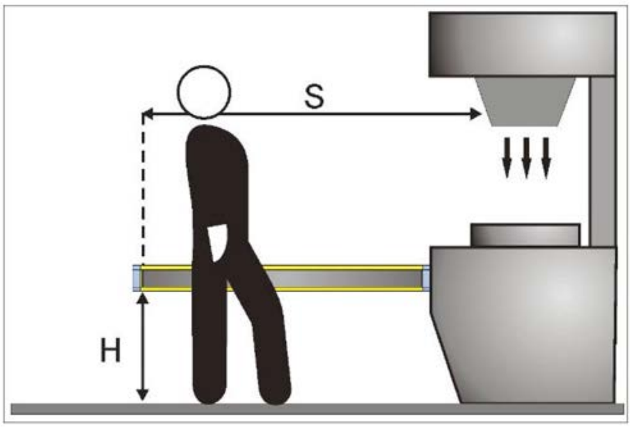


Fig. 8: The height (H) of the beams above the ground must always be less than 1000mm to the ground (e.g., machine foundation) for horizontally installed systems.

As the calculations in Chapter 4.3 show, the minimum safety distance of a safety light curtain to a danger area takes on a central importance. This topic should therefore always be given special attention when installing a system.

5. What else is to be taken into account during installation?

Before discussing other relevant aspects regarding the correct installation of safety light curtains in greater detail, first some general information on the positioning of such systems using illustrative graphics (Figs. 9 and 10).

Fig. 9: Installation of a safety light curtain with resolution for hand protection: incorrect installations are shown on the left, as the person can both reach over the safety light curtain and well as place a hand underneath to enter the danger area without triggering the ESPE.
The correct installation is shown on the right.

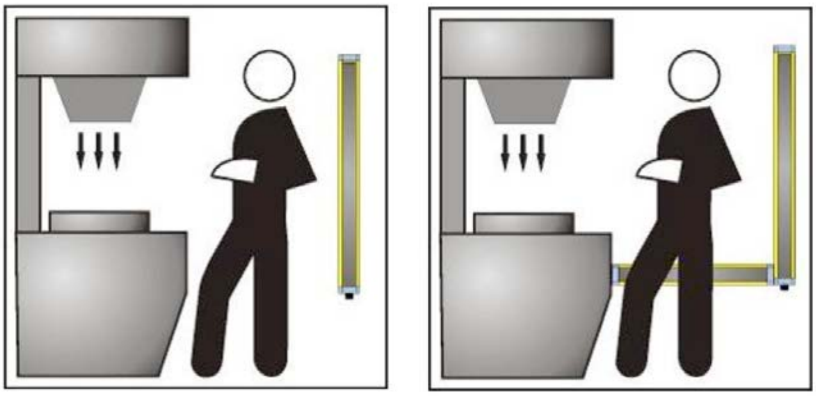


Fig. 10: Installation of a safety light curtain with resolution for body protection: incorrect installations are shown at the left, as the person can pass between the ESPE and the machine to enter the danger area; at the right, a horizontally installed safety light curtain reliably safeguards the danger area.

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5.1 Minimum distance from reflective surfaces

Reflective surfaces that are located near the light beams of safety light curtains can cause passive reflections. This affects the detection of an object within the protected area (Fig. 11).

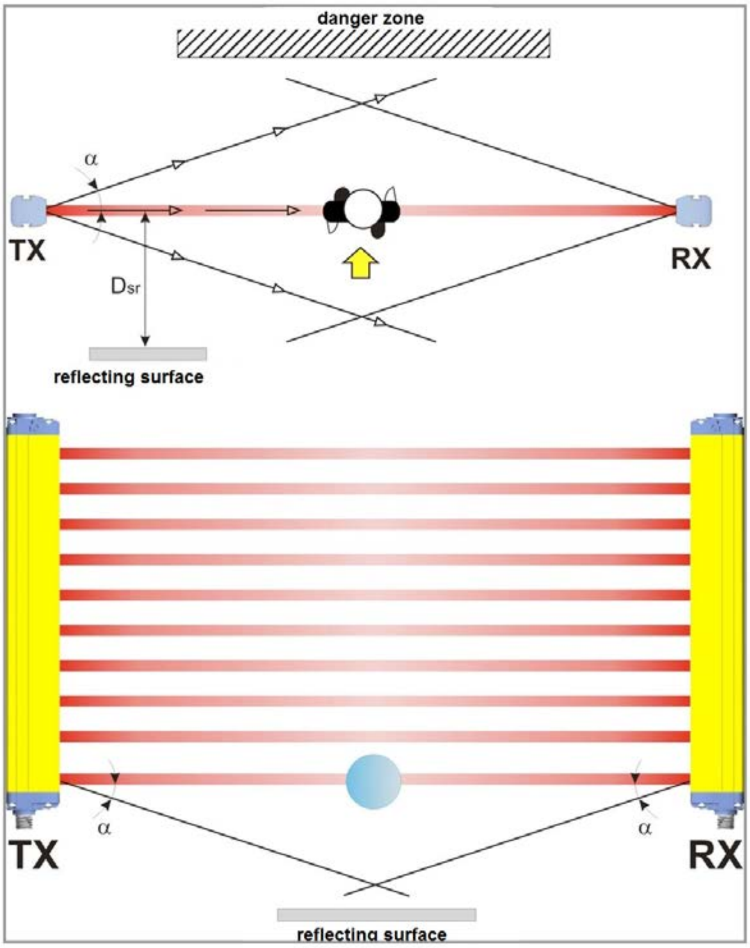


Fig. 11: Reflective surfaces that are located, e.g., above, below or to the side of a beam emitted by an ESPE can affect the detection of an object in the protected area.

For this reason, a correctly oriented safety light curtain must be installed at a minimum distance from reflective surfaces. The minimum distance is dependent on the following factors here:

- the distance between transmitter (TX) and receiver (RX) = range
- the effective angle of beam spread of the ESPE (EAA)

All safety light curtains from ipf electronic satisfy safety category 4 without exception. Therefore, the following applies for these protective devices:

- EAA = 5° ($\alpha = \pm 2.5°$)

Fig. 12 shows how the minimum distance from a reflective surface (D_{sr}) is determined as function of the range.

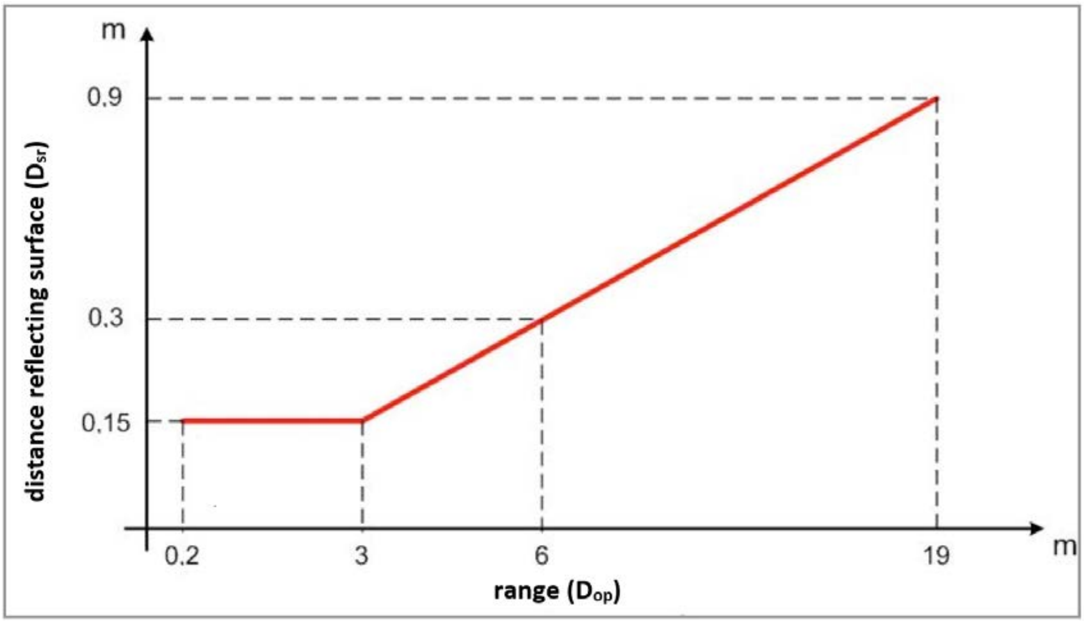


Fig. 12: The equation for calculating D_{sr} for ESPE type 4 is:
D_{sr} (m) = 0.15 for ranges < 3m
D_{sr} (m) = 0.5 x range (m) x tan 2α for ranges ≥ 3m

5.2 Installation of multiple systems next to one another

If it is necessary to install multiple protective systems in directly adjacent areas, it should be ensured that the transmitter of one system does not interfere with the receiver of the other system. For this reason, the potentially interfering transmitter (TX_B) of one system must be positioned so that it is not located within a safety distance (D_{do}) of the axis of the other transmitter/receiver pair (TX_A - RX_A), as shown in Fig. 13.

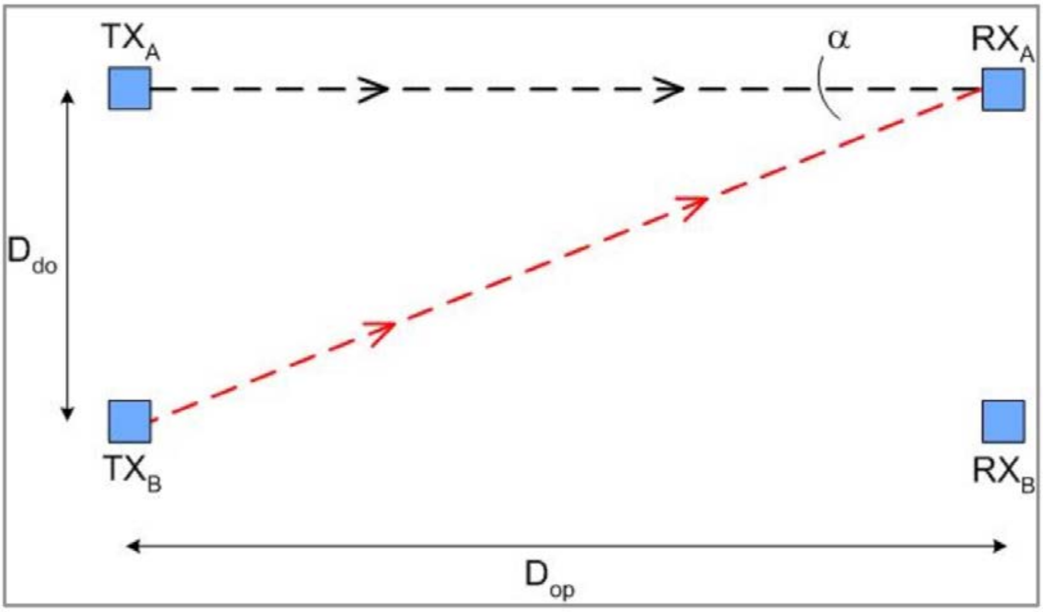


Fig. 13: The minimum distance (D_{do}) is dependent on:

- the range between transmitter (TX_A) and receiver (RX_A)
- the effective angle of beam spread of the ESPE (EAA)

Fig. 14 shows the distance of the interfering transmitter (TX_B) as a function of the range (D_{op}) of the transmitter/receiver pair (TX_A - RX_A).

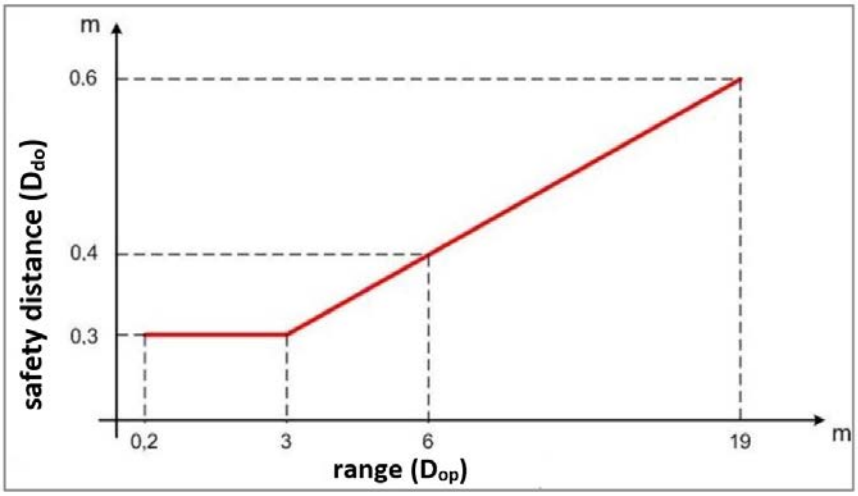


Fig. 14

The following table lists example values of the minimum necessary safety distances during installation with respect to a number of example ranges.

Range (m)	**Minimum distance of the installation (m)**
3	0.30
6	0.50
10	0.65
19	0.80

By taking appropriate measures during the installation of safety light curtains, the possible problem of interference between identical systems can be avoided. A typical case in this context is a number of safety systems arranged adjacent to one another and along a line.
Such configurations are often used where multiple processing machines are arranged adjacent to one another and are protected by safety light curtains. Shown in Fig. 15 are two possible solutions for such cases.

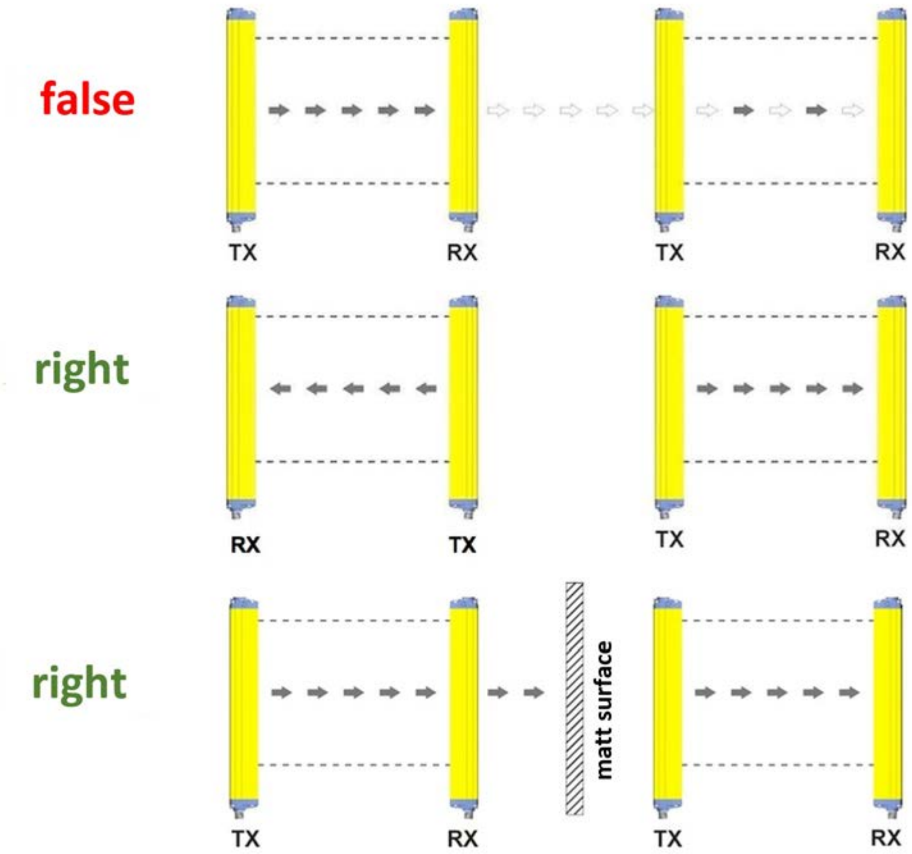


Fig. 15

5.3 Alignment of transmitter and receiver

Transmitter and receiver are always to be arranged parallel to one another, whereby the beams must be at a right angle to the transmitter and receiver surface. The connectors of transmitter and receiver should be oriented in the same direction during mounting. Fig. 16 shows two cases in which the transmitter and receiver are not installed correctly.

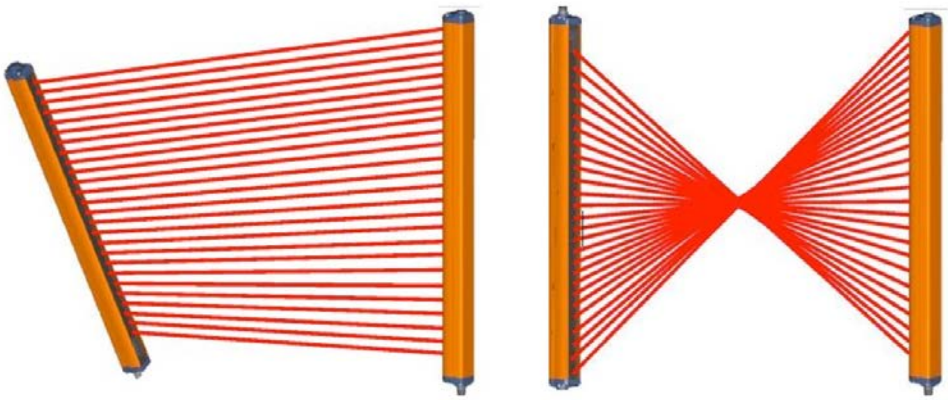


Fig. 16

5.4 Use of deflection mirrors

A danger area that can be accessed from multiple and immediately adjacent sides can be safeguarded with a single safety light curtain through the use of additional deflection mirrors. Fig. 17 shows an example for a solution in which such a danger area is monitored using two deflection mirrors that are installed at an inclination angle of 45° to the beams of the ESPE.

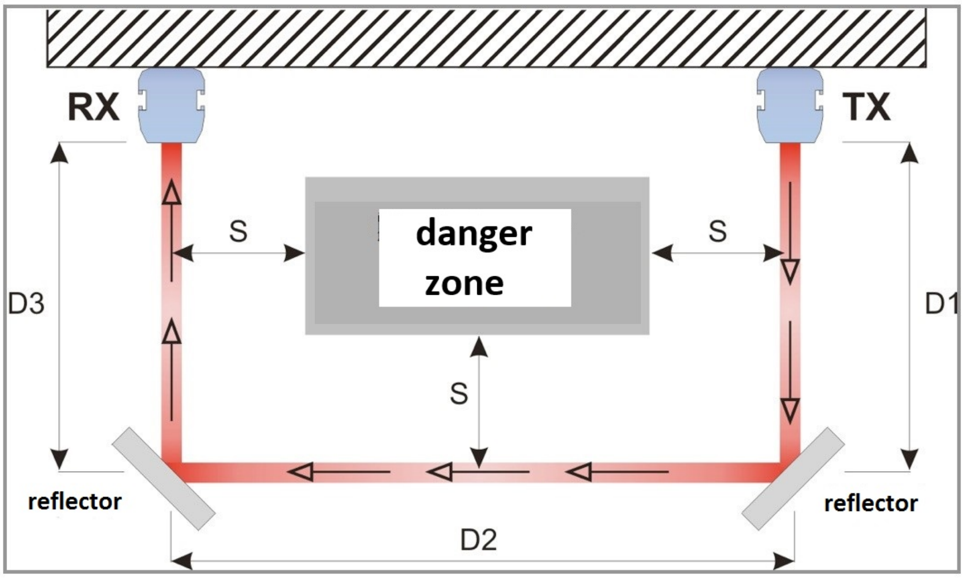


Fig. 17

When using deflection mirrors, a number of precautions are to be observed, however. Special care is to be taken when aligning transmitter and receiver, since even a slight angular displacement of a deflection mirror may put transmitter and receiver out of alignment. For such installations, the use of a laser alignment aid is therefore helpful.

Furthermore, the minimum safety distance must be maintained for all sections of the protective device. The use of a deflection mirror also reduces the effective range of the ESPE by approx. 15%. The use of two or more deflection mirrors results in a further reduction of the range, as is shown in the following table.

Number of mirrors	**Range (14mm)**	**Range (30mm)**
1	5.1m	16.5m
2	4.3m	13.7m
3	3.7m	11.6m

When using deflection mirrors, no more than three mirrors should ever be used per safety device. In addition, these should be checked periodically for soiling, since dust on the reflective mirror surface can result in a drastic decrease in the performance of the protective system.

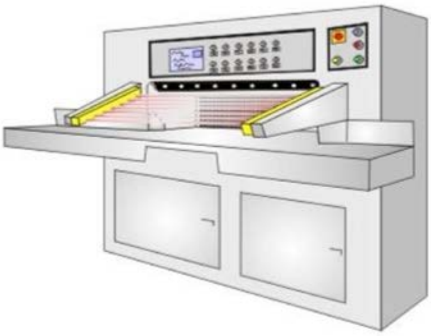
6. Application examples

A number of examples on the use of safety light curtains in a wide range of applications follow.

Automatic drilling machine:
The safety light curtain protects the operator from abrasions when loading or removing the workpieces.

Bending press:
The safety light curtain protects the operator from being crushed between the upper and lower tool and from the workpiece being processed.

Paper cutting machine:
On a machine for paper cutting, the safety device protects the operator from abrasions or cuts on fingers by the cutting knives.



Milling machine:

The protective device prevents hands or other body parts of the operator at a milling machine from being injured by the tool or the machine spindle.