EN

WHITE PAPER

LASER SENSORS

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IPF ELECTRONIC

TABLE OF CONTENTS

1. Introduction 3

2. Classification of laser sensors 3

3. Laser light barriers 4
3.1 Solutions with soiling compensation 5
3.2 Transmitters with test input 6
3.3.1 Coverage-proportional systems 6
3.3.2 Systems with receiver or pixel lines 6

4. Retro-reflective laser sensors 7
4.1 Systems with polarizing filter 7

5. Scanning systems 8

6. Energetic diffuse reflection sensors 9

7. Diffuse reflection sensors with background suppression 10
7.1 Mechanical background suppression 10
7.2 Background suppression by means of diode array 11
7.2.1 Application specialist thanks to special signal evaluation 11
7.3 Background suppression with "time-of-flight" 11

8. Laser distance sensors 12
8.1 Distance measurement with diode array 12
8.2 Distance measurement with time-of-flight 12
8.3 Distance measurement based on phase comparison principle 13
8.4. Laser sensors with special light beam geometries 14

9. Continuous further developments 15

1. INTRODUCTION

Back in 2013, ipf electronic published the white paper "Optical Sensors" in which one of the chapters covered the topic of laser sensors. There is a large selection of such devices and their potential fields of application are extremely diverse. For this area alone, ipf electronic therefore offers around 160 laser sensors in many different versions (status as of 2016). Reason enough to revisit the subject in greater detail in this white paper.

2. CLASSIFICATION OF LASER SENSORS

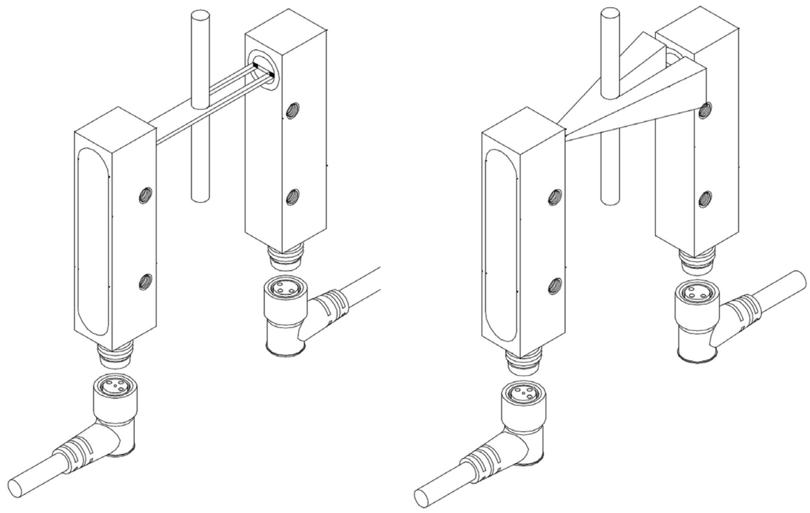
Laser sensors are the preferred choice wherever great demands are placed on resolution, repeat accuracy, reliability, switching frequency, sensing range and operating range. The transmitters of such sensors operate with laser light of class 1 or 2 as defined in EN 60825.

Laser sensors are optical sensors and can therefore be divided into through-beam systems, reflection systems and scanning systems. Through-beam systems include through-beam laser sensors, forked laser light barriers, angular laser light barriers as well as laser measurement systems, whereas the reflection systems category essentially contains only retro-reflective laser sensors. The scanning systems too include laser measurement systems as well as diffuse reflection laser sensors with and without background suppression.

Through-beam systems	Reflection systems	Scanning systems
Through-beam laser sensors	Retro-reflective laser sensors	Diffuse reflection laser sensors with background suppression
Forked/angular laser light barriers		Diffuse reflection laser sensors without background suppression (energetic)
Laser measurement systems		Laser measurement systems

3. LASER LIGHT BARRIERS

Laser light barriers operate with visible, parallel-aligned laser light (collimated laser beam) generated using precision optics and enable extremely large transmitter-receiver distances. With through-beam systems, the position at which the light beam is interrupted is irrelevant because a clearly defined shadow projection of an object to be detected hits the receiver. Therefore, the distance from the measurement object to the transmitter/receiver does not significantly influence the signal. Mutual interference of the sensors themselves only occurs to a limited extent, which means that it is possible to operate several devices together in a confined space.



Unlike conventional light barriers (right), laser light barriers project a clearly defined shadow of an object onto the receiver. (All images: ipf electronic gmbh)

Forked laser light barriers do not require adjustment because the transmitter and receiver form a compact unit. On systems with separate transmitter and receiver too, adjustment is extremely easy due to the visible laser light spot.

Forked laser light barriers such as the **PG800370** are ready for operation immediately because they do not require alignment.

The extremely small diameter of the light spot means that even objects no thicker than a human hair can be detected. Furthermore, apertures and optics ensure uniform light distribution in the laser beam as well as a sharp beam boundary.

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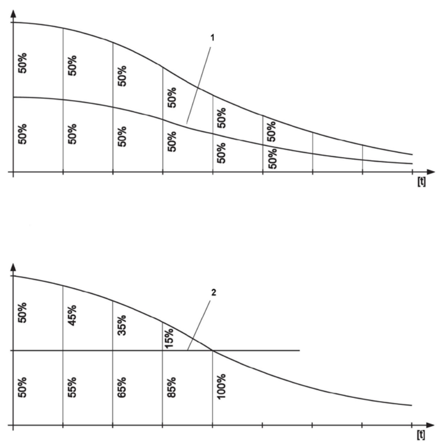
3.1 SOLUTIONS WITH SOILING COMPENSATION

A special feature of laser light barriers is the availability of solutions with soiling compensation for use in harsh environmental conditions. The receivers of these systems have automatic tracking of the internal switching threshold, which prevents shifting of the switching point in the light beam caused by increasing soiling.

Laser system with soiling compensation (top: **PE180122** receiver; bottom: **PS180022** transmitter). For special measuring tasks, the light beam is focused by means of slit diaphragms integrated in the transmitter and receiver.

Functional principle: Soiling of the transmitter or receiver optics leads to signal attenuation which the receiver compensates by lowering the switching threshold or adjusting it according to the respective degree of soiling. For this purpose, when the light barrier is free, the receiver continuously checks the amount of light currently hitting its optics. This current intensity is assumed as 100% light quantity, and 50% of this light quantity is defined as the switching threshold. This method also works because the receiver can make a distinction between gradual soiling of the optics and an object which, in a specific application, passes through the detection range of the light barrier extremely quickly (the light beam is interrupted abruptly).

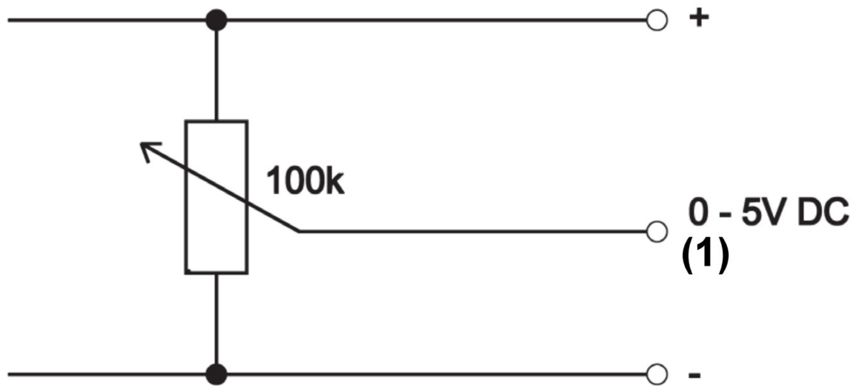


In contrast to a fixed switching threshold (2), dynamic switching threshold tracking (top) (1 = tracked switching threshold) compensates for the degree of soiling of the through-beam barrier. The y-axis represents the degree of coverage.

3.2 TRANSMITTERS WITH TEST INPUT

Various transmitters from the ipf electronic range have a so-called test input. This test input, i.e. an applied voltage signal between 0 und 5V, allows the laser power of the transmitter to be infinitely adjusted between 0 and 100%. If the transmitter is used in combination with a receiver with a fixed switching threshold (e.g. 50%), it is possible to vary the switching point, i.e. the system sensitivity, by adjusting the transmitting power.

The laser transmitter is switched off at an input signal > 5V. For this reason, this input can also be used for function tests on the light barrier because, with the transmitter switched off, a signal change must take place at the switching outputs of the receiver. This function can also be used to switch off the laser in the case of maintenance work. This is normally achieved by simply switching a 24V signal to this input.



Test input circuit (1)

3.3 RECEIVERS WITH ANALOG OUTPUT

In the case of through-beam laser sensors with an analog output on the receiver side, a distinction is made between two functional principles: the so-called coverage-proportional systems and systems with receiver or pixel lines.

3.3.1 COVERAGE-PROPORTIONAL SYSTEMS

With coverage-proportional systems, the light beam bundle projected by the transmitter is mapped to a single receiver element. The receiver converts the amount of light it receives into a corresponding analog signal. This means that the analog signal can be used to determine the degree of coverage or attenuation of the laser light beam. The user can utilize this in two ways: on the one hand, this signal can be used for measurement tasks and, on the other hand, it provides information with regard to the alignment and degree of soiling of the overall system. However, this signal cannot tell us what is causing the laser beam coverage. It is therefore not possible to distinguish whether the light beam coverage is caused by a single item (solid material) or by a structure (perforated tape). It can thus only be used to determine the percentage of coverage.

3.3.2 SYSTEMS WITH RECEIVER OR PIXEL LINES

In the case of systems with receiver or pixel lines, the light beam bundle projected by the transmitter is mapped to multiple receiver elements that are arranged in a line. This so-called pixel line is read out and usually evaluated by a microcontroller. The shadow cast by an object in the light beam is mapped on this receiver line, whereby illuminated and non-illuminated pixels occur, i.e. a pattern which is proportional to the respective object geometry is created on the receiver line. This enables the evaluating controller to determine the structures of the object. From this, data such as the object width or position can then be determined and, depending on the setup, can be output as an electrical measurement signal or an analog signal.

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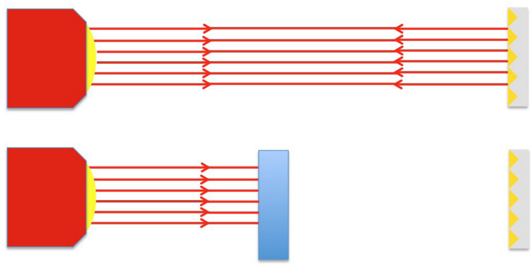
4. RETRO-REFLECTIVE LASER SENSORS



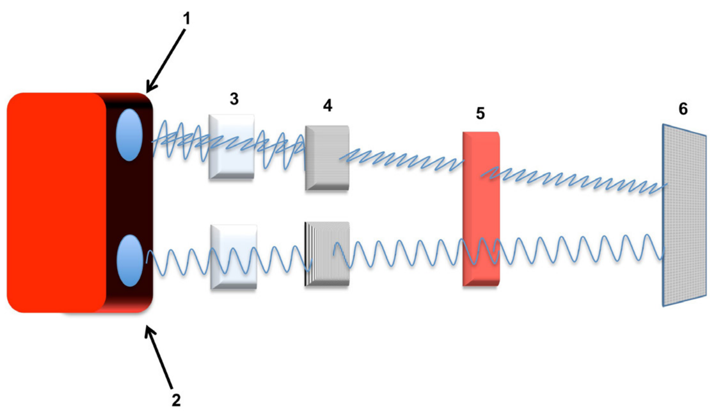
Retro-reflective laser systems require a reflector (right) as a counterpart.

In a retro-reflective laser system, the transmitter and receiver are in the same housing, which means that a reflector (prismatic reflector / retro-reflector) is required as the counterpart. As with through-beam systems, the reflection systems are also based on the interruption of light. This sensor variant can also reliably detect all objects irrespective of their color, shape and surface, whereby extremely large ranges are possible depending on the size of the reflector. Unlike through-beam systems, however, the reflection systems require only one voltage supply at the device end.

The installation requirements for a reflection system are similar to those for a through-beam system. The device in which the transmitter and receiver are housed must be precisely aligned with the reflector. As already pointed out above, the size of the reflector influences the system range and therefore also the sensitivity. Such systems have difficulty detecting transparent objects and, in the case of extremely reflective surfaces such as chrome-plated parts, the devices must be equipped with a polarizing filter. The functional principle of polarizing filters is therefore described below.

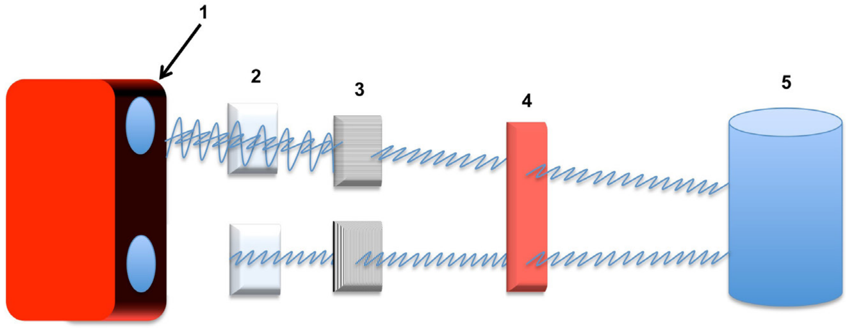
4.1 SYSTEMS WITH POLARIZING FILTER

In physics, the term "polarization" refers to the orientation of the oscillation plane of transversal waves. In this context, "transversal" describes the propagation characteristics of a wave and means that the oscillation occurs perpendicular to its direction of propagation. A polarizing filter is therefore a polarizer for light and influences its axis of oscillation.



Function of a polarizing filter. Only light of a particular axis of oscillation is able to pass through the filter of the transmission optics. This is also the case at the filter on the receiver side. 1 from transmitter, 2 To receiver, 3 Lens, 4 Polarizing filter, 5 Front screen, 6 Reflector

The polarizing filter of the transmission optics allows only light of one axis of oscillation to leave the device. The individual trip elements of the reflector rotate the oscillation plane of the light beam by 90°. Only then can the light reflected by the prismatic reflector pass through the polarizing filter and reach the receiver.

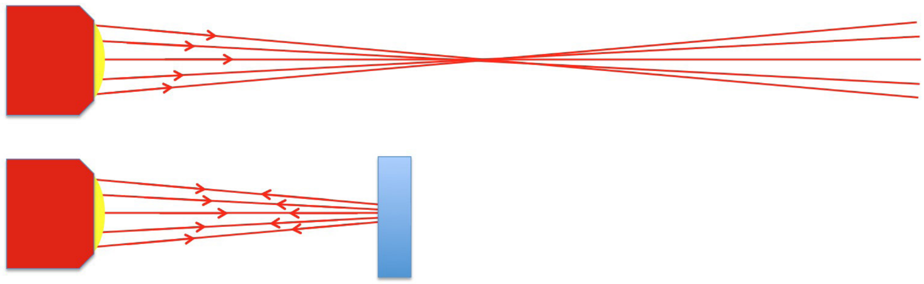


The light reflected by the object cannot pass through the polarizing filter so that the object is reliably detected. 1 from transmitter, 2 Lens, 3 Polarizing filter, 4 Front screen, 5 Reflective object

Reflective or extremely shiny surfaces, however, cannot influence the oscillation plane of the transmitted light beam. The light reflected by the object cannot pass through the polarizing filter in front of the receiver so that the object is reliably detected.

5. SCANNING SYSTEMS

Scanning laser systems integrate the transmitter and receiver in a single device and do not need a counterpart like a reflector as a reference surface because the light beam reflection is evaluated at the object to be detected.



Scanning systems evaluate the light beam reflected by an object.

6. ENERGETIC DIFFUSE REFLECTION SENSORS

Energetic diffuse reflection sensors operate according to the principle of intensity differentiation. For this purpose, a specific amount of light (sensitivity) is set at the sensor usually using a potentiometer. If the amount of light reflected by the object reaches or exceeds this predefined threshold, the device switches on. If only a small amount of light is reflected by the object to be detected (intensity), the sensor does not receive a switching signal.

The design of the system means that energetic diffuse reflection sensors reliably detect all objects that reflect sufficient light, i.e. objects that reflect enough light for the defined switching threshold to be exceeded. As a result, only objects with sufficient reflectivity can be reliably detected. With the same basic sensitivity, material surfaces with a greatly varying degree of reflection can cause the diffuse reflection sensor to have different response behaviors and switching distances. In this case, dark materials can be difficult or impossible to detect in front of light backgrounds because the diffuse reflection sensor receives a strong reflection signal as a result of such backgrounds, which may already exceed the necessarily low switching threshold setting.

A further problem is caused by the surface finish of the objects to be detected. The rougher the surface is, the greater the light scattering will be, which in turn has a detrimental effect on the range and sensitivity of energetic diffuse reflection sensors. Conversely: The smoother the surface is, the better the response behavior of the diffuse reflection sensor will be – always provided that the surface of the object to be detected is at an angle of 90° to the sensor or transmitted signal.

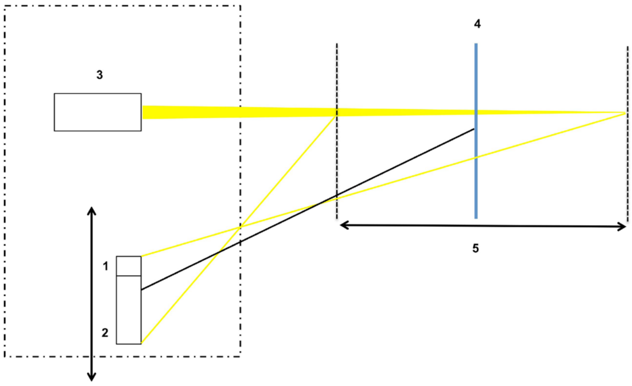
7. DIFFUSE REFLECTION SENSORS WITH BACKGROUND SUPPRESSION

The problems encountered with energetic diffuse reflection sensors are essentially eliminated by diffuse reflection sensors with background suppression. These devices are able to detect materials in their scanning range largely independent of the material's degree of reflection (color, surface). The basis for this functional principle is that the used receiver elements assess the object position from which the incident transmitted light is reflected. This makes it possible to ascertain whether the object is in the selected detection or switching range.

The basic requirement for this is of course that the object's surface can reflect the incident transmitter light to a sufficient degree. The effective sensing range is therefore not dependent on the object to be detected, but rather only on the set sensing distance. This allows an interfering background to be reliably suppressed. This property has resulted in the devices also being referred to as "diffuse reflection sensors with background suppression", a designation which stands for material-independent object detection in the case of scanning systems. From a technical perspective, background suppression can be implemented in laser sensors in many different ways. The following sections explain mechanical background suppression (triangulation principle), implementation using a diode array (electronic background suppression / triangulation) and the "time-of-flight" principle.

7.1 MECHANICAL BACKGROUND SUPPRESSION

The figure below shows the functional principle of mechanical background suppression. Two receivers or diodes (background and foreground diode) are placed next to each other on an adjustable carriage. Depending on which receiver is generating an output signal (determined by the incident reflection light beam), it is possible to say precisely whether or not the object is located within the predefined detection range. On these devices, the detection range can be changed by moving the receiver array. This is done mechanically via a spindle.

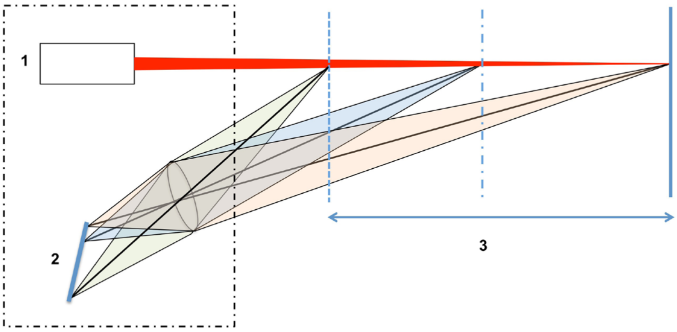


1 Background diode, 2 Foreground diode, 3 Light source, 4 Object, 5 Measuring range

The main advantage of diffuse reflection sensors with mechanical background suppression is their extremely high adjustment accuracy, which enables objects to be detected very reliably irrespective of their color. In contrast, objects in the background are not detected. In the context of dark or rough object surfaces, this can be explained, as with all optical sensors, by the Photometric Distance Law, which is explained in detail in the white paper "Optical Sensors". At the end of the operating range, however, the technical properties of the diffuse reflection sensors described here drop away slightly. In other words, the detection of dark objects or rough material surfaces becomes more difficult and switching point accuracy decreases.

7.2 BACKGROUND SUPPRESSION BY MEANS OF DIODE ARRAY

In the case of background suppression with a diode array, a microcontroller reads out a large number of diodes (128 or more) individually in the array and evaluates the signal. The large number of diodes enables the position and distance of an object to be precisely specified and makes it possible to determine whether the object is in the detection range or not. For this purpose, a teach-in process is used to divide the diode array into two receiver groups for the foreground and background.



1 Laser, 2 Diode array, 3 Measuring range

7.2.1 APPLICATION SPECIALIST THANKS TO SPECIAL SIGNAL EVALUATION

Owing to the integrated microcontroller, laser distance sensors with diode array can become specialists in certain applications. One example is the recognition of extremely flat objects on conveyor belts with a vertical offset, whereby this offset can be greater than the thickness of the component. In most cases, a vertical offset of the belt does not occur abruptly. Instead, the sensor-belt distance changes continuously, similar to a sinusoidal curve. To detect a component, the microcontroller of the special devices compares the recorded distance measurement signal internally and generates a switching signal if the measuring distance suddenly changes. This happens whenever an object on the belt enters the detection range of the sensor. Devices such as the **PT16C031** are available for this type of application. In this context, devices with the described functional principle are an alternative to diffuse reflection sensors with background suppression for which only one limit value can be defined. The use of such diffuse reflection sensors is only recommended in cases where the vertical offset of a conveyor belt is much smaller than the smallest component height that is to be detected.

7.3 BACKGROUND SUPPRESSION WITH "TIME-OF-FLIGHT"

The time-of-flight principle is a propagation time method for object recognition. According to this principle, the position of an object is determined using the propagation time of a light pulse which is emitted from the sensor transmitter, reflected by the object to be detected and finally captured by the receiver. Using the time it takes for the pulsed light to travel from the transmitter to the receiver, it is possible to determine the distance of an object to the sensor and thus ascertain whether the distance information matches the previously taught set-points. If this is the case, the device generates a switching signal which can be processed further in the higher-level control. Here, the range or switching distance is largely independent of the reflection properties of an object's surface. This enables e.g. very dark objects on very light backgrounds to be detected extremely well in cases where such objects still reflect sufficient light. As time-of-flight technology allows extremely small and densely packed optics, this method has certain advantages over the triangulation principle with respect to the installation space required for the sensors because the triangulation principle requires comparatively large receiver optics in order to determine the angle of incidence of the light reflected by an object's surface.

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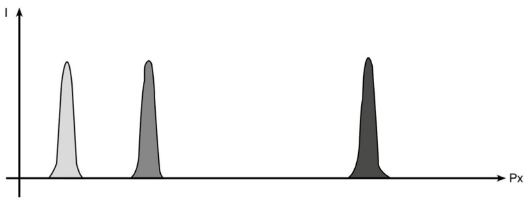
8. LASER DISTANCE SENSORS

Extremely precise measuring laser distance sensors are suitable for distance measurement at a resolution with very fine increments. Such devices are specially designed for measurement processes on small and fast-moving objects. Even objects with frequently changing colors can be reliably measured with these sensors. The following functional principles among others are available for distance measurement: Diode array (pixel lines), time-of-flight and phase comparison measurement.

Laser distance sensors such as the **PT160070** can even detect objects with frequently changing colors.

8.1 DISTANCE MEASUREMENT WITH DIODE ARRAY

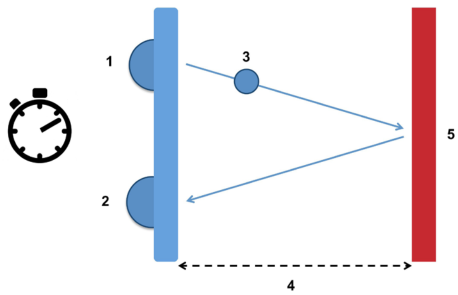
A distance measurement can be carried out using a diode array integrated in the sensor, i.e. a pixel line. The light beam reflected by the object is mapped to the array with the diodes or pixels. In other words, certain diodes of the array capture the light beam, i.e. are hit by the light beam. From the position of this reflection signal relative to the line, it is then possible to determine the distance of the object.



Signal path via the pixel line for three different object distances relative to the device.

8.2 DISTANCE MEASUREMENT WITH TIME-OF-FLIGHT

As an alternative to the solution with integrated diode array as described under 8.1, another measurement principle is used in the case of larger distances. The reason for this is that, as a result of the triangulation principle, measuring accuracy decreases as distances increase. Similar to the functional principle of background suppression with time-of-flight, the propagation time method can also be used for distance measurement. The distance of an object to the sensor is determined using the time it takes for the pulsed light to travel from the transmitter to the receiver. Here, the range is largely independent of the reflection properties of an object's surface.

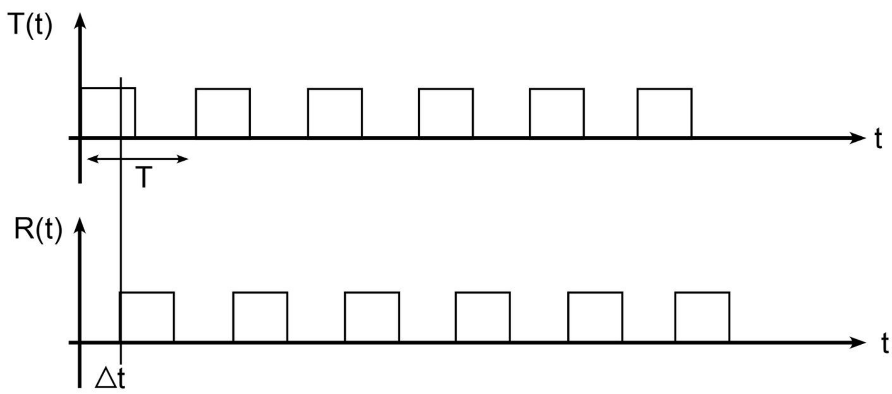


1 Transmitter, 2 Receiver, 3 Photons, 4 Distance, 5 Object. The formula for distance measurement is as follows: measured distance = (propagation time of photons / 2) x speed of light

8.3 DISTANCE MEASUREMENT BASED ON PHASE COMPARISON PRINCIPLE

As a technical alternative to the time-of-flight measurement, the so-called "phase comparison method" can also be used. With this method, the transmitted light source (laser LED) is pulsed at a fixed frequency, i.e. switched on and off in predefined intervals. This gives the transmitted light beam a defined phase position. The pulsed light beam is emitted from the sensor, passes through the space between the sensor and object, is reflected by the object and is captured by the receiving unit integrated in the sensor. The distance traveled by the light beam between the sensor and object causes the received signal to undergo a distance-dependent phase shift. This phase shift is determined in the device and converted into a measurement signal that is proportional to distance.

The laser measurement system **PT900020** performs distance measurement based on the phase comparison principle



The distance traveled by the light beam between the sensor and object produces a distance-proportional phase shift Δt between the transmitted signal T(t) and received signal R(t).

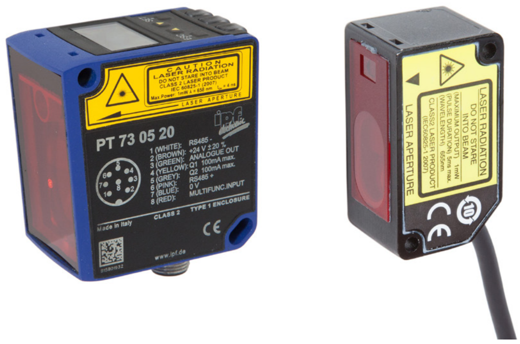
8.4. LASER SENSORS WITH SPECIAL LIGHT BEAM GEOMETRIES

Special sensors with particular light beam geometries have been developed to enable objects with porous or rough surfaces to be detected by diffuse reflection laser sensors. Thanks to a fine, linear light beam, the changing properties of object surfaces have a far lesser effect or no effect whatsoever on the reliability and precision of a distance measurement or component detection using these devices.

Furthermore, to minimize the effects that greatly differing reflection properties or object colors have on measurements, many diffuse reflection laser sensors have an integrated control circuit that regulates the power of the laser diode depending on the reflection properties of an object's surface, i.e. on the quality of the receiver signal. With dark surfaces, the transmitting diode therefore has a high intensity. With light objects, however, the transmitting diode has a lower intensity. In this way, the measurement results can be formed virtually independent of the color of the object. If, despite an increase in power, it is still not possible to obtain a usable received signal (excessive soiling, object does not reflect any light), this is reported via a switching signal output. The user is therefore always provided with a status signal indicating the quality of measured value formation, and can immediately tell if measured value formation is no longer possible. Furthermore, integrated teach options enable the used measuring range to be set to narrower limits within the measuring range configured at the factory, thereby defining a new, individual characteristic curve for current and voltage output.

9. CONTINUOUS FURTHER DEVELOPMENTS

The examples presented in this white paper show just how large the selection of laser sensors with their many different functions is. As such devices are, as mentioned above, particularly well suited for applications in which "conventional" sensors are often unable to deliver the desired results or even fail completely, laser sensors open up new dimensions. At the same time, further development continues unabated. An example of this is the laser distance sensor **PT730520** and the diffuse reflection laser sensors of the **PT44** series, which were first launched by ipf electronic in 2015.



Examples of continuous further development of laser sensors: laser distance sensor PT730520 (left) and diffuse reflection laser sensors of the PT44 series (right).

The laser distance sensor **PT730520** with background and foreground suppression is suitable for positioning tasks over large distances and is based on radiated light technology (time-of-flight principle and phase comparison principle; see page 19 and 20), which means that no reflector is needed. The **PT730520** in its robust zinc diecast housing (IP67) has a high shock resistance up to 30G and is suitable for use e.g. in automated warehouses, freight elevators, production systems, packaging machines, commercial vehicles, for crane positioning, etc.

Thanks to their high measurement repeat accuracy of up to 10µm and a linearity deviation of just ±0.1% of the measuring range end value, the **PT44** diffuse reflection laser sensors are able to detect extremely small objects. These diffuse reflection laser sensors were initially offered with measuring ranges of 25 to 35mm, 35 to 65mm and 65 to 135mm. 2016 then saw the introduction of two new versions with extended measuring ranges of 120 to 280mm and 200 to 600mm. These devices open up further potential fields of use for the diffuse reflection laser sensors with a very small beam diameter of ~50 (**PT440300**) to ~500µm (**PT440304**) in the case of applications where the presence of extremely small objects needs to be checked or where the overlapping of thin materials such as metal plates is to be detected.

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Subject to alteration! Version: October 2019