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WHITEPAPER
CAPACITIVE SENSORS

Author: Dipl.-Ing. Christian Fiebach
Executive Manager ipf electronic gmbh

Dipl.-Ing. Volker Grefe
Strategic Product Management
ipf electronic gmbh

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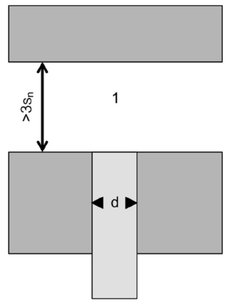
TABLE OF CONTENTS

1. INTRODUCTION

One of the main intentions for the development of capacitive sensors was basically to obtain device solutions that can be handled in applications similar to inductive sensors, but are also able to detect non-metallic materials such as wood, plastic and also liquids without contact. Capacitive sensors are mainly used for presence control or position detection of objects. In addition, such sensors can be used for filling level control, whereby this is also possible through container walls (more on this topic on page 6). Capacitive sensors are wear-free, do not require maintenance and have a service life that is independent of the switching frequency. They do not require any actuating force and operate without contact and do not exhibit contact bounce due to their electronic design. Such devices can be used to directly control electronic circuits as well as PLCs, relays and contactors.

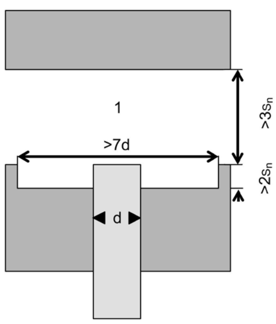
2. CLASSIFICATION OF CAPACITIVE SENSORS

A distinction must be made between flush mounting and non-flush mounting. With flush mounting, the sensor can be integrated up to the active surface in a metal or other potentially influencing material without changing its properties. The distances specified for the devices must be observed in this case. Sensors for flush mounting are particularly suitable for detecting solid bodies or liquid levels, e.g. through container walls that are not made of metal.



With flush mounting, the sensor can be integrated into the carrier material up to the active surface (1 = free zone).
(All images: ipf electronic gmbh)

For non-flush mountable capacitive sensors, a free zone must be provided around the sensor, which must also be maintained to the opposite material for all devices. The specified distances must also be observed for these sensors. Non-flush mountable devices are particularly recommended for applications in which a medium comes into contact with the active surface of the sensor, e.g. filling level detection of bulk solids, pastes or liquids.



With non-flush mountable sensors, a free zone (1) around the device must be maintained.

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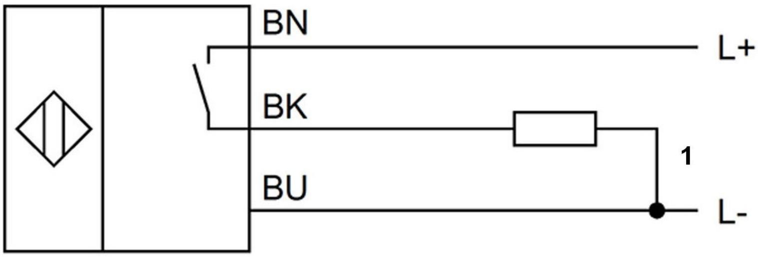
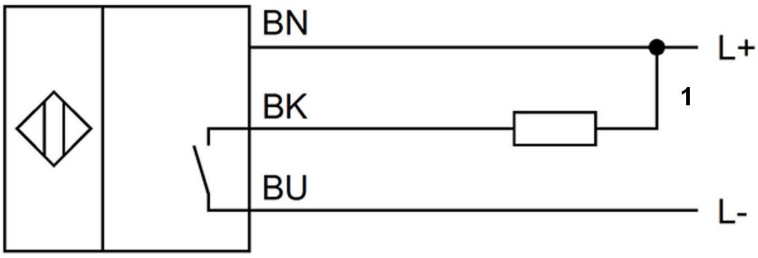
2.1 OUTPUT CIRCUIT

With the DC voltage devices of capacitive sensors, a distinction is made between PNP and NPN output circuits, with the PNP output circuit being the standard. Here, the output stage of the sensor contains a PNP transistor which switches the load against the positive operating voltage (+UB). The load is connected between the output and the negative operating voltage (0V). Similarly, in an NPN output circuit, the output stage of a sensor contains an NPN transistor that switches the load against the negative operating voltage (0V). The load is connected between the output and the positive operating voltage (+UB).



In the PNP output circuit, the transistor switches the load (1) against the positive operating voltage (+UB).



Accordingly, in an NPN output circuit, the output stage of a sensor contains a transistor that switches the load (1) against the negative operating voltage (0V).

2.2 OUTPUT FUNCTION

The switching function at the output is comparable with mechanical contacts.

Normally open contact (NO): Object or medium in the area of the active switching zone-output switched through.
Normally closed contact (NC): Object or medium in the area of the active switching zone-output blocked.

3. FUNCTIONALITY OF CAPACITIVE SENSORS

The active surface of a capacitive sensor consists of two concentrically arranged metallic electrodes (opened plate capacitor). If a metallic or non-metallic object approaches the active surface, it changes the electric field in front of the electrode surfaces. This change is converted into a switching signal via an evaluation circuit.

3.1 SWITCHING DISTANCES, PERMITTIVITY AND SWITCHING HYSTERESIS

The distance to the sensor surface at which a material or medium causes a change in the switching state is called the sensing distance. Capacitive sensors achieve the greatest switching distances with ferromagnetic materials (steel, iron) and water. With other materials, the achievable sensing distance is lower. This material influence on the sensing distance is described by material-specific reduction factors.

The following applies: Material-dependent operating distance = nominal operating distance x reduction factor for the respective material. The nominal operating distance is a parameter for grouping the sensors. It does not take into account specimen scattering and external influences such as temperature or voltage fluctuations. The distance is specified at which the standard measuring plate approaching the active surface of the sensor causes a change in state of the switching output. The standard measuring plate is made of FE360 steel, is 1mm thick, square, grounded and has a smoothed surface. The edge length of the standard measuring plate corresponds to the diameter of the active area of a capacitive proximity switch.

The material-specific reduction factor of a capacitive sensor depends on the relative permittivity εr for a given material. The relative permittivity εr describes the permeability of a material to electric fields. In general, capacitive sensors detect products with a relative permittivity εr > 1.5. The constant depends on several factors such as temperature. Therefore, data on specific products are to be understood as merely exemplary. As already mentioned in the introduction, level sensing with capacitive proximity switches through container walls is possible, but these must only be made of non-metallic materials. In addition, the relative permittivity εr of the medium to be detected must be greater by a factor of about 5. An overview of various materials and their influence on the sensing distance of capacitive sensors is shown on page 7.

As a rule, the sensing distance of capacitive sensors can be adjusted with a potentiometer. Provided that the environmental influences are constant, it is possible to adjust the range or sensitivity up to the specified maximum value. In the case of fluctuating environmental influences, the maximum value must not be exhausted, as the environmental influences (e.g. temperature) affect the response behavior and could lead to malfunctions if the maximum setting is used.

Material	**εr**	**Switching distance in %**	**Reduction factor**
Steel FE360	conducts	100	1
Salt water	80	100	1
Marble	8	65	0.65
Porcelain	4-5	50	0.5
PE	2.3	10	0.1
Oil	2.2	10	0.1
Wood	2-7	10-60	0.1-0.6

The specified switching distance of capacitive proximity switches refers to precisely defined measuring conditions. Other measuring arrangements or materials generally result in reduced switching distances. The specifications listed in the table are to be regarded as guide values and are therefore non-binding.

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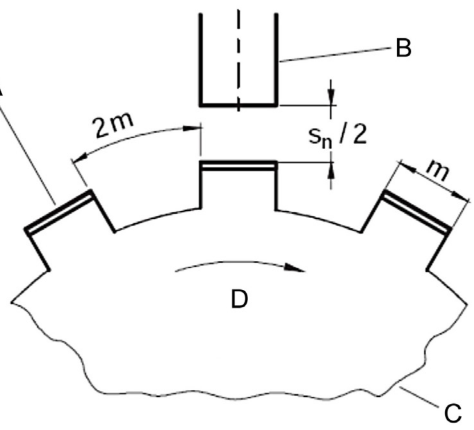
In the context of the previous explanations, the switching hysteresis describes the path difference between the switch-on point when a material approaches the sensor head and the switch-off point when the material moves away from the sensor again, with the switch-on point being closer to the sensor than the switch-off point. This built-in hysteresis prevents the switching output from rocking back and forth when an object is at the limit of the sensing range and subject to mechanical vibration.

The maximum switching frequency of capacitive sensors, in turn, specifies the maximum permissible number of pulses per second at a constant pulse-pause ratio of 1 : 2 and half the nominal switching distance. This switching frequency is also determined with a standard measuring plate. The maximum possible switching operations per second thus set limits to the switching frequency. Therefore, a compromise must be made between the size of the proximity switch and the switching frequency when selecting the correct capacitive proximity switch.



A: measuring plate, B: proximity switch, C: disk, D: non-conductive material

3.2 SERIES CONNECTION AND PARALLEL CONNECTION
The series connection of 3-wire PNP sensors is operationally safe only via a logical AND element, e.g. the **VL250100**. When 3-wire PNP sensors are connected in parallel, the internal resistance of the sensor connected through affects the remaining initiators. Therefore, decoupling diodes must be inserted in the outputs. As an aid to parallel connection, a logical OR element can be used, e.g. the **VL250120**.

3.3 TIGHTENING TORQUES

To avoid damage when installing the proximity switches, the tightening torques specified below must not be exceeded.

	Housing material				
	Stainless steel	**Brass nickel plated/ chrome plated**	**PTFE**	**PPO**	**PA 6.6**
M5	1.5 Nm	-	-	-	-
M8	4.5 Nm	-	-	-	-
M12	15 Nm	10 Nm	0.2 Nm	1 Nm	1 Nm
M18	40 Nm	28 Nm	0.5 Nm	3 Nm	1.7 Nm
M22	50 Nm	32 Nm	1.4 Nm	10 Nm	6 Nm
M30	150 Nm	82 Nm	2.5 Nm	8 Nm	8 Nm
M32	180 Nm	110 Nm	3 Nm	13 Nm	13 Nm

3.4 ACTIVE SWITCHING ZONE/ACTIVE AREA

The active switching zone is the space in front of the active area where the proximity switch reacts to the approach of objects, i.e. changes the switching state of the output.

3.5 REVERSE POLARITY AND SHORT CIRCUIT PROTECTION (DC DEVICES)

As internal protection, the reverse polarity protection prevents destruction of the proximity switch if the connecting leads are inadvertently reversed. Due to the short-circuit protection (DC devices), proximity switches are not destroyed in case of overcurrent.

4. CABLE ROUTING

When installing capacitive sensors, some important things must be observed with regard to the routing of the connections. For example, the connecting cables of capacitive proximity switches should never be laid in a cable duct parallel to cables through which inductive loads are switched (e.g. contactor coils, solenoid valves, motors, etc.) or which carry the currents of electronic motor drives. The cable lengths should also be kept as short as possible. Shielded or twisted cables are recommended, especially for longer cable lengths > 5m. To reduce interference, it is also advisable to maintain a distance of > 100mm from the interfering line.

5. WHICH CAPACITIVE SENSORS ARE AVAILABLE?

The selection of capacitive sensors is very large. In general, a distinction can be made between devices in cylindrical form, with and without thread, in metal or plastic housings, and devices for level applications (the design of which is usually adapted to the respective application). In addition, there are special versions, e.g. for ambient temperatures above +80 °C or-25 °C, solutions with Teflon housings as well as devices that have been specially developed for hose and tube mounting.

Special designs of capacitive sensors with Teflon housing as well as developments for hose and tube mounting.

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5.1 TYPICAL APPLICATIONS OF CAPACITIVE SENSORS

A typical application of capacitive proximity switches is the positioning or counting of objects, containers or packaging, to name a few examples. In addition, such devices are used for level sensing of pasty, solid and liquid media. Capacitive sensors also have the great advantage that they react very well to all conceivable metals. In the past, the devices were therefore used in particular in the detection of non-ferrous metals, e.g. for the detection of thin copper wires in the electronics industry. However, in such applications, care must be taken to avoid deposits of material residues, such as metal abrasion, on the active sensor surface, since the sensors then also generate a switching signal. The range of applications for capacitive sensors is thus very versatile. The range of products offered by ipf electronic in this product area is therefore correspondingly broad. In the following, some capacitive sensors with standard sensing distance and device solutions for special environmental conditions are presented.

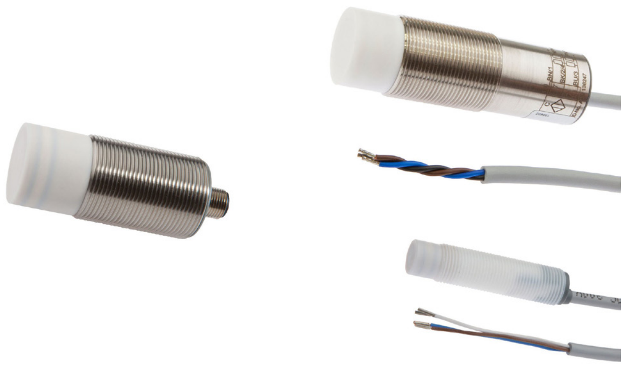
5.2 CAPACITIVE SENSORS WITH NORM SWITCHING DISTANCE

The portfolio of capacitive sensors with standard sensing distance (sensing distances from 0.8mm to 120mm) from ipf electronic covers sizes (diameter) from 6.5mm (round) to 100mm (round). The sensors are available with and without thread as well as cuboid solutions. The proximity switches, which are suitable for flush as well as non-flush mounting, have an active surface made of plastic and can be used in a temperature range from-25°C to +70°C.

Selection of capacitive sensors with standard sensing distance with a diameter from 6.5mm to 100mm.

5.3 CAPACITIVE SENSORS FOR PARTICULARLY DEMANDING ENVIRONMENTS

In addition to an extended operating temperature range from-25° C to over +80° C, the device solutions for special environmental conditions have, for example, a high level of tightness and are resistant to alkalis or acids. These proximity switches are available in sizes from 4mm (round) to 35mm (round) and with or without thread. The switching distances of the flush and non-flush mountable device variants range from 2mm to 40mm. The active surface is made of plastic or Teflon.



Capacitive sensors for harsh environmental conditions.

6. GLOSSARY

The following explanation of some of the technical terms and variables used in this white paper.

Relative permittivity εr:	Describes the permeability of a material to electric.
Specimen scattering:	Deviations from a reference value with regard to a characteristic property of a component or technical device in series production.
Bouncing:	Bouncing is a mechanically triggered interference effect in electromechanical switches that causes an unintentional, brief, multiple opening and closing of a contact.
Nominal switching distance (Sn):	The distance at which the standard measuring plate approaching the active face of a sensor causes a change of state of the switching output.
Norm measuring plate	A 1mm thick, square and grounded plate made of FE360 steel, the surface of which is smoothed. The edge length of the standard plate corresponds to the diameter of the active area of a capacitive sensor.
Plate capacitor (capacitor):	Consists in principle of two electrically conductive surfaces (electrodes) separated by an insulating material (dielectric). As a passive electrical component, a capacitor can store electrical charge and the correlating energy in an electrical field in a DC circuit. The stored charge per voltage is called electrical capacitance.
PNP-/NPN output circuit:	For detailed explanations see chapter 2.1
Reduction factor:	In the context of capacitive sensors, the factor of a material multiplied by the nominal sensing distance of a device to obtain the sensing distance (see table on page 7).
Switching distance:	Distance of the sensor surface at which a material or medium causes a change in the switching state.
Switching frequency (max.):	For capacitive sensors, specifies the maximum permissible number of pulses per second with a constant pulse-pause ratio of 1 : 2 at half the nominal switching distance. This switching frequency is also determined with the standard measuring plate.
Switching hysteresis:	Describes the difference in travel between the switch-on point when a material approaches the sensor head and the switch-off point when the material moves away from the sensor head again, with the switch-on point being closer to the sensor than the switch-off point. The switching hysteresis prevents the switching output from toggling back and forth when an object is at the limit of the detection range and is subject to mechanical vibrations.

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