Baumer Guideline for Switching Outputs

Scope

This document describes the functionality of switching outputs, such as PNP or NPN. It is intended to provide support for the correct selection, parameterization and implementation of sensors with binary signals.

The information given must not be understood as a specification and Baumer does not assume any responsibility for the information provided.

Contents

1 Abstract

1.1 General information

Sensors with switching outputs or binary signals are primarily known for point level detection, as pressure switches, flow monitors or thermostats. However, continuously measuring sensors can also include switching outputs to provide additional information or to take over control tasks. In a broader sense, binary signals can also output information in the form of frequency, pulse width modulation (PWM), pulse summation for flow rates, etc. IO-Link, which is based on a switching output, can transmit information in both directions in various operating modes. The guide is therefore not limited to purely binary measuring sensors, but also deals with the topic of physical interfaces that can only assume binary logic states, e.g. 0 V and 24 V or "0" or "1".

1.2 Logical states

A distinction is made between two logical states:

- **inactive** Normal condition, e.g. no medium detected, pressure ok or no error
- **Active** Triggered or critical condition, e.g. medium detected, pressure too high or alarm

The exact definition is important for further logical signal processing. It may well be that the state "Medium detected" is a normal state, e.g. if it is a dry run protection for pumps. Therefore it is recommended to always use the definitions of the sensor, e.g. in the example "active" with medium detected.

1.3 Physical implementation

There are basically four different physical versions of switching outputs:

- **PNP** Switch to positive voltage supply potential (+Vs):
- **NPN** Switch to reference potential (GND, 0 V)
- **Push-pull** Switch between positive voltage supply potential (+Vs) and reference potential (GND, 0 V)
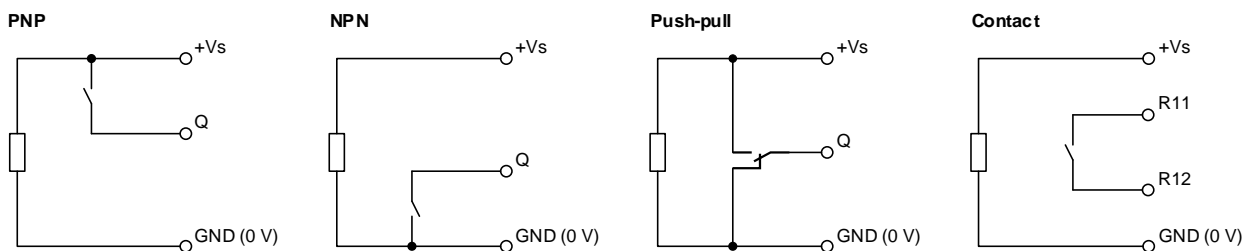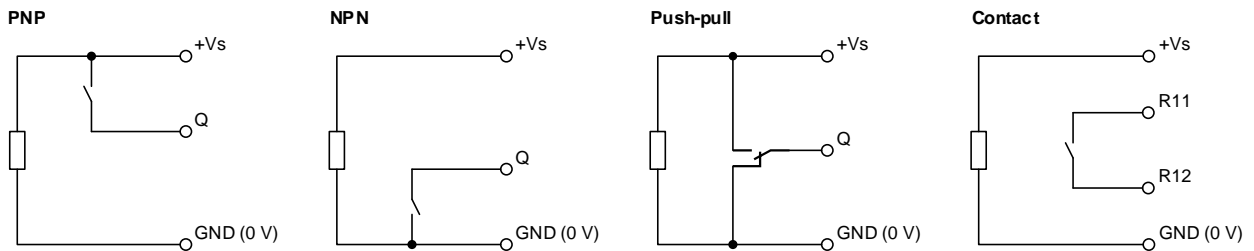- **Contact** Potential-free switching contact

Figure 1: Physical implementation of switching outputs

1.4   Logical signal assignment

With binary switching states one speaks of two different logical signal assignments:

- **Normally Open** (NO)   Switch in normal (inactive) state open
- **Normally Closed** (NC)   Switch closed in normal (inactive) state

Normally Open (NO)

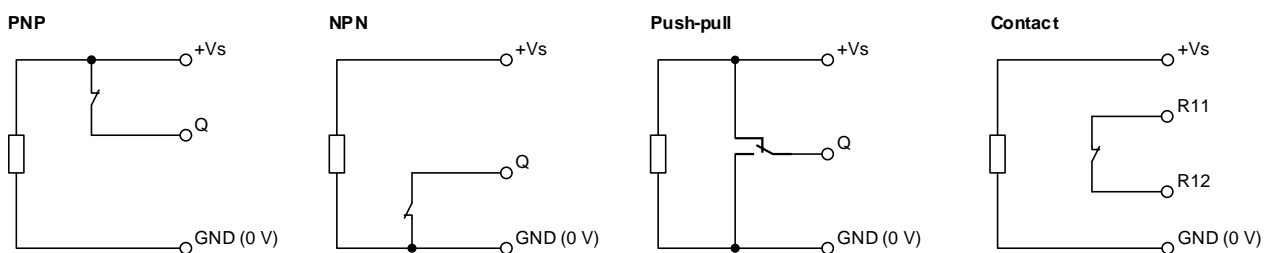

Normally Closed (NC)

Figure 2: Logical signal assignments for the respective physical implementation

The two variants are generated by the sensor by a simple inversion of the two possible logical states "inactive" or "active". The correct configuration depends on the desired "fail-safe" state. Normally Closed" is preferred for an overfill protection, as a defect or broken wire signals the "overfill" state, i.e. the critical state (see section **Fehler! Verweisquelle konnte nicht gefunden werden.**).

1.5   Technological types of switching outputs

There are numerous technologies to realize switching outputs. Besides classical electromechanical relays, integrated circuits are also available. In principle, however, all types can be divided into these categories:

- **Transistor**   Potential-bound bipolar or field effect transistor(s)
- **Relay contact**   Potential-free switching contact of a
  - Electromechanical relays
  - Optoelectronic relay (on semiconductor basis)

Transistors usually switch through the operating voltage potential +Vs or the reference potential GND (0 V) of the sensor. Any potential can be switched with potential-free relay contacts.

2 Functionality and properties of switching outputs

2.1 Transistor outputs

Transistor outputs can be built up with discrete components or can be completely or partially in integrated circuits. Depending on the technology, the switching elements are bipolar or field effect transistors. The designations PNP and NPN are derived from the bipolar transistors, which is why only these are shown in the schematic diagrams below.

2.1.1 PNP switching output

The PNP switching output uses a transistor whose emitter or source terminal is connected to the positive operating voltage potential +Vs. The electronics of the sensor controls this transistor at the base or gate with a control voltage which is pulled in the direction of the reference potential GND (0 V) when the output is to be activated. In this case, the collector or drain terminal of the transistor is conductively connected to the operating voltage potential +Vs. Current then flows from the switching output Q into the load resistor R_L of the input in the control device. For an inactive output, the control voltage at the transistor is practically connected to +Vs, whereupon the transistor blocks and thus no more current can flow out.
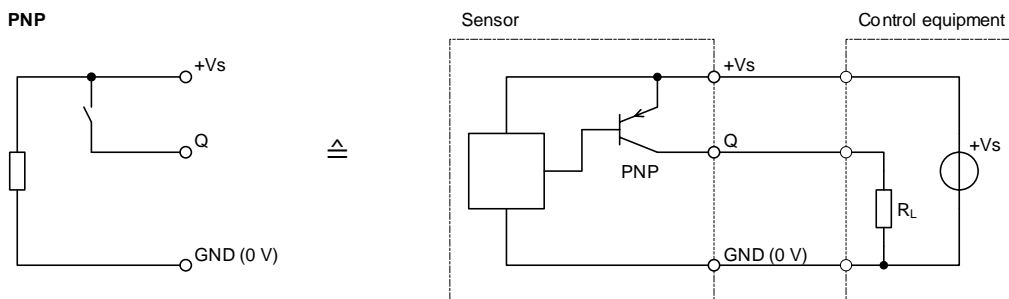
Figure 3: Schematic diagram of a PNP switching output

2.1.2 NPN switching output

With the NPN switching output, the emitter or source terminal of the transistor is connected to the reference potential GND (0 V). The control voltage of the sensor electronics connected to the base or gate of the transistor moves towards the operating voltage potential +Vs for an active output. With such an active output, the collector or drain connection of the transistor is conductively connected to the reference potential GND (0 V). Current then flows into the switching output Q from the load resistor R_L of the input of the control device. When the output is inactive, the control voltage is practically applied to GND (0 V) so that the transistor blocks and no more current flow is possible.
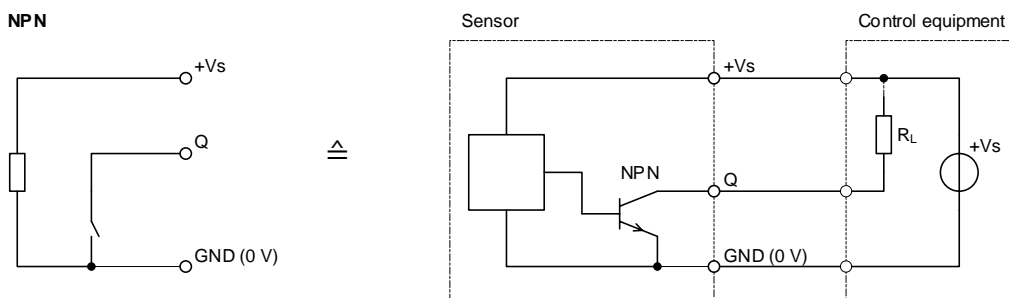
Figure 4: Schematic diagram of a NPN switching output

2.1.3 Push-pull switching output

The push-pull switching output is basically a mixture of PNP and NPN switching output. It is controlled in such a way that only one transistor is conductive at a time, so that the output is either connected to reference potential GND (0 V) or, in the active state, to voltage supply potential +Vs. The connected control device can contain any number of load resistors R_L, the switching potentials are set independently of their size or wiring. The push-pull switching output is generally found in fast interfaces for data transmission, e.g. with IO-Link in communication mode. The connected lines always have a capacitance and act as an RC element with the load resistor R_L. The respective switching edge, which in the case of PNP or NPN switching output is only reloaded by R_L, would be slowed down more and more with higher-resistance R_L and increasing cable length, which reduces the maximum data transmission rate. With push-pull switching outputs, the line capacitances can be reloaded very quickly at both switching edges, since the transistors have very low resistance in the switched state.
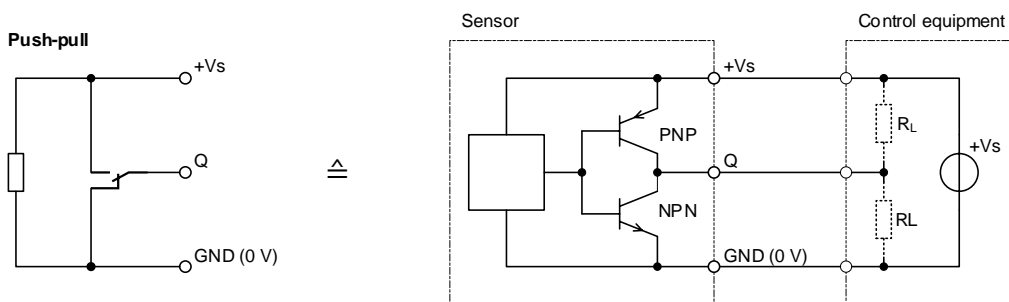

Figure 5: Schematic diagram of a push-pull switching output

2.2 Relay contacts

A relay contact is a potential-free switch. This can be mechanical (electromagnetic relay) or optoelectronic (e.g. Opto-MOS-FET).

2.2.1 Electromagnetic relays

In electromagnetic relays, a current carrying coil moves an armature which actuates the mechanical switching contact via the magnetic field which builds up. In the inactive state (currentless coil) a spring returns the armature and the switch contact opens. The logic can also be inverted, the contact is then opened by energizing the coil. There are also combinations of normally open and normally closed contacts, the so-called changeover contact.
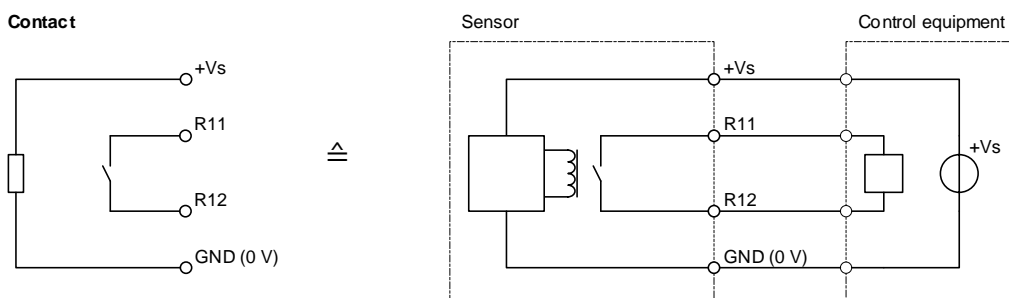

Figure 6: Principle circuit diagram of an electromagnetic relay

Due to their size and the relatively high current requirement to supply the coil, electromagnetic relays are rarely found in sensors. However, they are advantageously used in intrinsically safe isolators (switching repeaters) for hazardous areas.
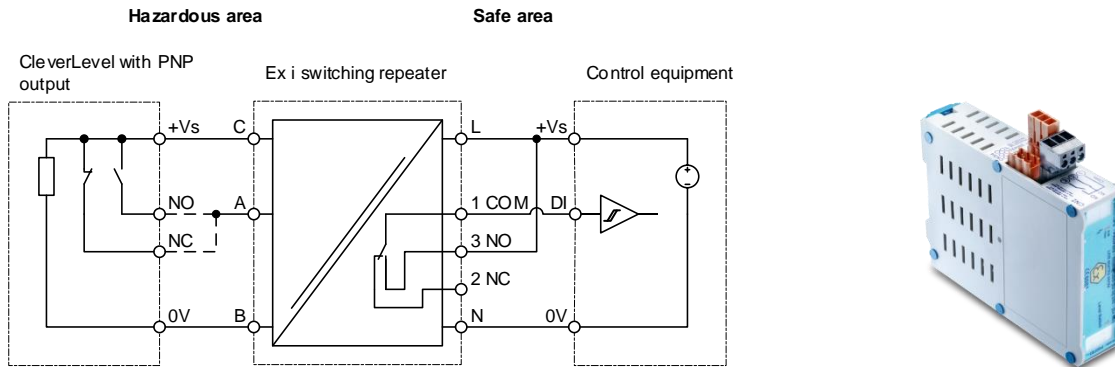

Figure 7: Example of an intrinsically safe Ex i isolator with electromagnetic relay

2.2.2 Optoelectronic relays

Semiconductor circuits offer the advantages of no moving components and are therefore wear-free. Normal optocouplers with simple transistors can only switch the current in one direction. This would not be satisfactory for emulating a contact. Integrated circuits with Opto-MOS-FETs are available which are internally designed to switch the current in both directions. Such a potential-free contact behaves practically like an electromechanical relay, provided that the maximum current load capacity is not exceeded.
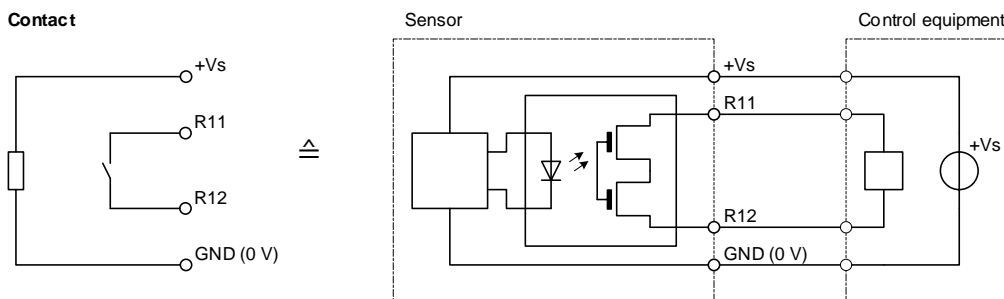

Figure 8: Principle circuit diagram of an optoelectronic relay

The compact design of semiconductor circuits also allows integration into smaller sensors. Figure 9 shows an example of a sensor with display, which additionally visualizes the switching states of the two relay contacts. The terminals Rxx are located on the rear of the electronics insert.

Figure 9: Example of sensor electronics with two optoelectronic relay contacts

2.3 Operation of switching outputs

2.3.1 Current load capacity of switching outputs

Regardless of the technological type of the switching output, e.g. transistors or potential-free relay contacts, the switching capacity with regard to max. switching voltage and max. current load is limited accordingly. For outputs with semiconductor circuits, short-circuit protection is usually implemented. Otherwise, a switching output can be damaged or destroyed by a short circuit or overload.

Example of the specification of a transistor switching output:

Voltage drop	PNP: (+Vs -0,5 V) ± 0,2 V, Rload ≤ 10 kΩ
	NPN: (+0,4 V) ± 0,2 V, Rload ≤ 10 kΩ
Current load capacity	100 mA , max.
Leakage current	< 100 µA
Short-circuit protection	Yes

Example of the specification of a potential-free contact:

On resistance	< 10 Ω
Current load capacity	75 mA , max.
Switching voltage	60 V , max.
Short-circuit protection	Yes

2.3.2 Evaluation of switching signals

Usually the signal swing between "0" and "1" is as large as the operating voltage, e.g. 24 V. Despite the large voltage swing between the two levels, there is a risk of being affected by electromagnetic interference. The load resistor R_L in the evaluation unit of the control unit should not be selected to be too high-impedance, since capacitive interference currents can easily couple in, especially with unshielded cables. The higher the resistance of the load resistor R_L, the greater the interference voltage that arises, since such interference currents act like a current source, i.e. the magnitude of the coupled current is independent of the load by the load resistor R_L. According to Ohm's law, the voltage drop across a resistor is proportional to the product of current and resistance; therefore, with a higher resistance, the voltage drop and thus the interference potential also increases. Leakage currents are a further source of interference. These can already be generated by the sensor (see its specification) or be caused by poor or faulty cable insulation. As a thumb value one can say that up to 1 mA interference current can flow when the switching output is inactive. When the switching output is active, you should therefore draw at least 2 mA current to have a clear reserve for differentiation. Furthermore, a suitable switching threshold with hysteresis must be defined.

Field-proven specification for the evaluation of a PNP switching output with 24 V operating voltage:

Logical state	Voltage (V)	Current (mA)	Load resistance R_L
0	< 5	< 1	< 5 kΩ
1	> 15	> 2 (max. 30)	(< 7,5 kΩ)

- At logic state "0" an interference current of 1 mA can flow, the voltage should not exceed 5 V; a load resistance R_L of max. 5 kΩ is possible.
- In logic state "1" the voltage provided can drop to 15 V, but still at least 2 mA should flow; the maximum load resistance R_L is calculated to 7.5 kΩ.
- Both conditions are fulfilled by a load resistance R_L < 5 kΩ.

The switching threshold is best set in the middle of the voltage limits, i.e. at 10 V; the hysteresis should be at least 1 V.

The results can be transferred accordingly to an NPN switching output.

2.3.3   Fail-safe configuration

To ensure fail-safe operation, the signaling must behave in such a way that a safe operating state is established in the event of a fault.
Example: If an overfill protection system with a level switch fails, the switching signal must indicate the state "Overfill". This switches off the pump or the valve for filling the tank and an alarm can be triggered.

Causes of failure can be:

- Voltage supply failure
- Line break
- Defect of the sensor

If the sensor is defective, it must output a predefined signal. For some sensors, a default can be made in the parameters for this case.

Example based on an overfill protection compared to a dry run protection:

Application	Medium detected	PNP/NPN		Relay contact	
		Normally Open (NO)	Normally Closed (NC)	Normally Open (NO)	Normally Closed (NC)
Overfill protection	No		Active		Closed
	Yes		Inactive		Open
Dry run detection	No	Inactive		Open	
	Yes	Active		Closed	

In case of a failure of the voltage supply or a wire break, a PNP or NPN switching output becomes inactive and a relay contact opens. These states must be selected for signaling the respective critical case. For the example above this means:

- Overfill protection: Normally Closed (NC), switch closed in normal (inactive) state
- Dry run protection: Normally Open (NO), switch in normal (inactive) state open

I.e. in case of overfill protection, the switching output must open when a medium is detected, but in case of dry run protection, the switching output must also open when no medium is detected (red text markings in above table).

2.3.4   Antivalent signaling for function monitoring

For continuous function monitoring, two switching signals can be transmitted in parallel whose logical values are inverted (anti-valence). If the signals are no longer inverted when they are evaluated, an error has occurred.
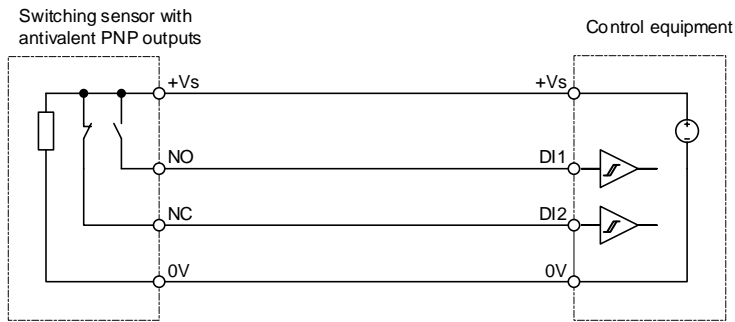
Figure 10: Antivalent signaling for function monitoring using the example of PNP outputs

Truth table for the antivalent signaling:

Sensor status	Inactive	Active	Inactive or active	
Output NO	0	1	0	1
Output NC	1	0	0	1
Status	OK	OK	Error	Error

The antivalent signaling can also be realized with the NPN or push-pull versions.

2.4 Configuration of switching thresholds

Continuously measuring sensors with switching output, e.g. pressure switches, have parameters to configure the switching thresholds or switching windows. The functionality and parameter structure is sensor-specific, therefore the operating instructions should be consulted to make the appropriate settings.
In the following, the possibilities are explained on a generic basis.

2.4.1 Switching threshold

The parameters for a switching threshold are threshold value and hysteresis. The output signal changes to the active state when the threshold value is exceeded. Resetting to the inactive state only occurs when the value falls below the switching threshold minus a so-called hysteresis. This prevents the output signal from oscillating when the excitation moves close to the switching threshold (see Figure 11).
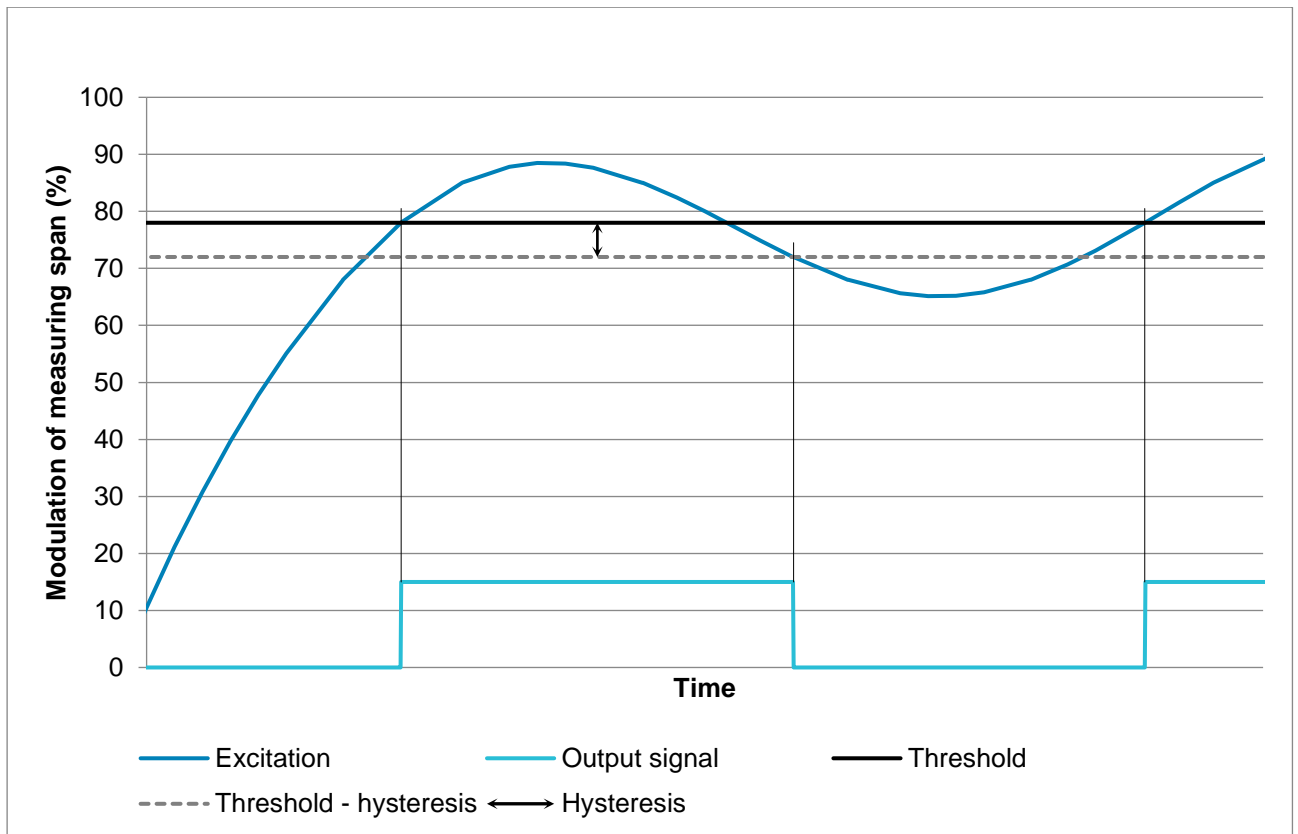
Figure 11: Definition of the switching threshold with hysteresis

The definition of the hysteresis is either implemented with a separate parameter or with an absolute reset threshold value. Such a reset must be performed manually when the threshold value changes. Furthermore, there are definitions of positive and negative or left and right or centered hysteresis. How the threshold values generated in this way are implemented can be found in the respective operating instructions.

2.4.2 Switching window

With the switching window, the output signal is active as long as the excitation is within the two parameters switching window min. and switching window max. (Figure 12).
Also here there is a hysteresis which is either fixed or parameterizable. In addition to an explicit selection option between switching threshold and switching window, there is also an implementation which selects the switching window function if the reset threshold value is greater than the threshold value.
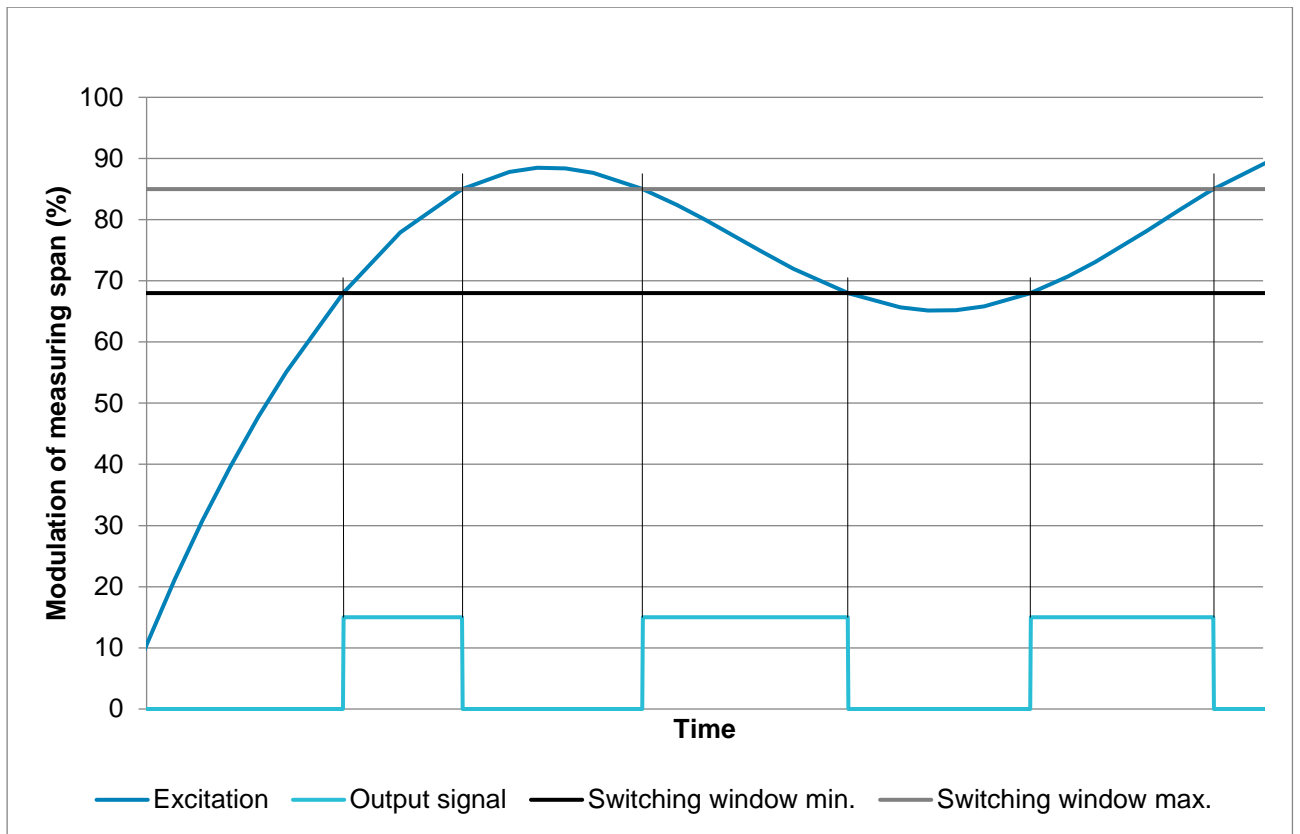
Figure 12: Definition of the switching window

2.5 Extended information transmission with binary signals

2.5.1 IO-Link

IO-Link is based on a switching output. In addition to the standard signaling with a switching output signal, a corresponding IO-Link master can set the sensor to communication mode. The then bidirectional data exchange that is possible is based on a digital protocol with a fixed bit rate. In this communication mode, the output operates in push-pull mode in order not to scramble both signal edges, rising and falling. This results in a low impedance control which allows a fast reloading of the cable capacities.
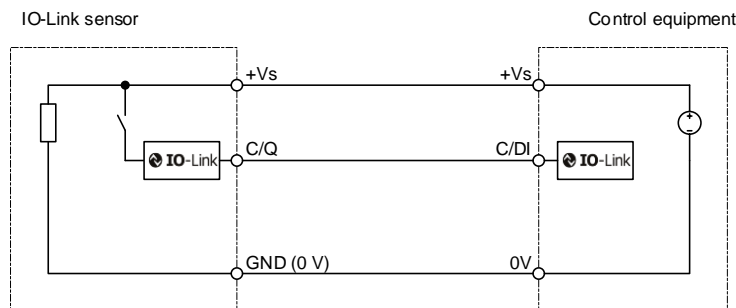
Figure 13: Block diagram of an IO-Link implementation

2.5.2 Pulse width modulation (PWM)

With PWM, a continuous measured value can be transmitted via a binary switching output. The information is contained in a periodic square-wave signal whose ratio of the duty cycle to the total period length represents the measured value between 0 and 100 %.
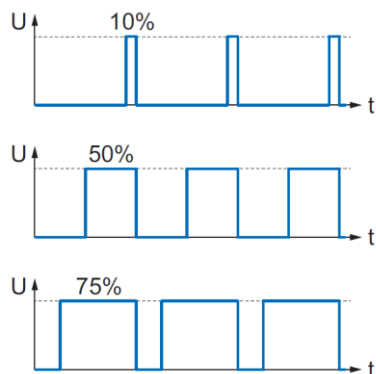

Figure 14: Example for pulse width modulation (PWM)

2.5.3 Pulse output for summation

Flowmeters usually also have a pulse output implemented. When a specified cumulative flow rate is reached, a pulse is emitted via this output, which is summed up by the evaluation unit. This sum then corresponds to the total flow rate (volume) over the period under consideration.
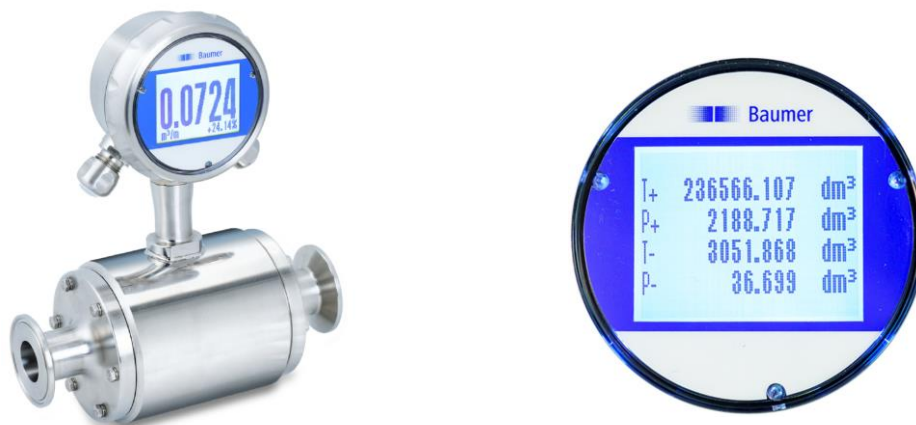
Figure 15: Example of a flow meter with display of the cumulated flow rate

2.5.4 Frequency output for measured value transmission

Continuous measured values can be transmitted via a binary signal with variable frequency. The measured value range 0 ... 100 % is then defined between a lower and upper frequency. Mechanical flowmeters (turbines), for example, output the flow rate this way. Electronic flow meters (e.g. EMF) emulate this signal to enable direct replacement.

3　Appendix

3.1　List of figures

3.2　Documentation history

Version	Date	Reviewed by	Amendment / Supplement / Description
V1.00	27.07.2020	fep	Translation from German document V1.00 DE