BODAS Ultra Sonic System Application Manual

Date: 20.12.2023

CONTENTS

TERMS

DCR	Decoupling ring
DTC	Diagnostic trouble code
DUT	Device under test
ECU	Electronic control unit
EMC	Electromagnetic compatibility
ESA	Electronic sub assembly
ESD	Electrostatic discharge
FOV	Field of view
HS	High-Speed
PCB	Printed Circuit Board
QM	Quality Management
SOI	System of Interest
SW	Software
UDS	Unified Diagnostic Services
USS	Ultrasonic Sensor System
QZ	Quality and reliability testing

1 Product identification

- **Product designation:** BODAS Ultra Sonic System
- **Part number:**

USS Sensor axial	F037000136
USS Sensor radial	F037000137
USS ECU Entry	F037000145
USS ECU Premium	F037000125
USS Starter Kit	F037B00630

- **Number of drawing:**

USS Sensor axial	F037A00528 V02
USS Sensor radial	F037A00529 V02
USS ECU Entry	F037A00671 V01
USS ECU Premium	F037A00599 V08

2 General product description

2.1 Main functions and properties of the product

This technical documentation describes the B-sample ultrasonic sensor system intended as a perception system for off-highway machineries. It is designed to monitor the distance and/or 2D-position of objects in close vicinity to the machinery. This information can be used to assist the operator during maneuvering of the machine at low speeds. The responsibility as well as exceptional cautiousness and obligation for executive care during these maneuvers is fully assigned to the operator. The customer is responsible for providing corresponding clear directions to these points in the corresponding manual. Bosch Rexroth will not take any liability for any harm caused by not appropriate usage of the system.

The system is a nonimpact sensing technique which transmits and receives impulses of variable ultrasonic waves in the frequency range of 43 – 60 kHz. The ultrasonic waves emitted by a sensor are reflected by objects located inside their field of view (FOV) and propagate back to the sensor (see Figure 1). Depending on the time delay between the transmission of the ultrasonic wave and reception of its echo, the object's distance is computed. In addition, when multiple sensors are used as receivers, the system is able to combine the echo data measured by the sensor array to determine the two-dimensional position of the object. The object's size, material and orientation have a significant impact on the reflection of ultrasonic waves. Thus, not all objects located in the sensor FOV can be detected under all circumstances.

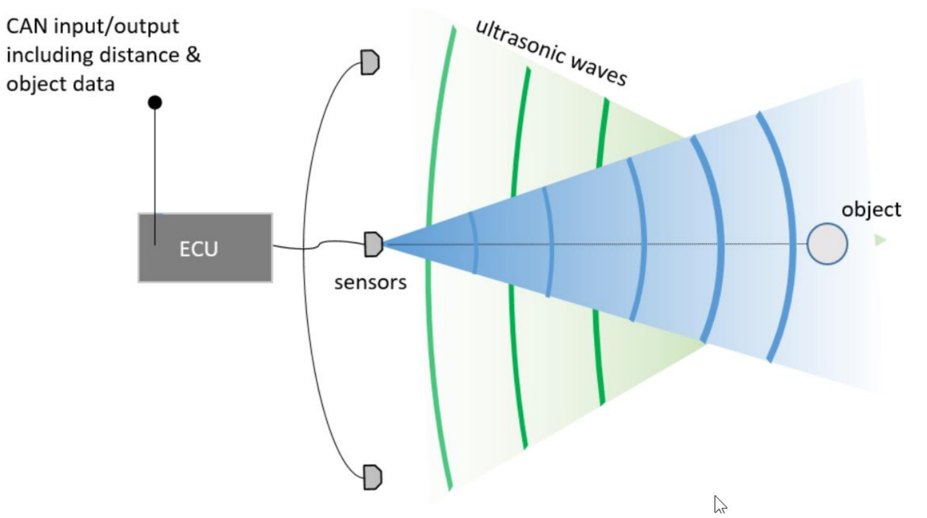


Figure 1 Measurement principle of ultrasonic sensor system with middle sensor in transmission cycle

Depending on the configured variant of the product, it comprises 4, 6, 8, or 12 ultrasonic sensors of type 6.5 and an electronic control unit (ECU). The transmission and reception cycles of the sensors are controlled by the ECU according to a predefined sequence. The received ultrasonic echo information is sent to the ECU where advanced processing and filtering of the data is performed. Provided that a specific sensor arrangement is applied, further algorithms can be enabled to combine the echo data measured by multiple sensors to compute two-dimensional object positions. Depending on several parameters such as the object distance, size and orientation, the object will be represented as a single point or a line in a two-dimensional object map. Ultimately, the distance data measured by individual sensors and the computed object coordinates are provided on a CAN bus to the interface of the customer system.

Parameterization/calibration of the system can be conducted with the diagnostic service, which is secured via authorization.

The product is solely intended for use in off-highway applications, i.e. non-road mobile machines. It is not permitted to use the product for application in automotive vehicles (e.g. passenger cars, trucks, busses).

Main system characteristics

<table>
<tr><th>Parameters</th><th>Sensor</th><th>Electronic control unit (ECU)</th></tr>
<tr><td>Basic measurement function of system</td><td colspan="2">1) Distance measurements between the sensors and objects inside their field of view (direct echo)
2) Object localization: By combining the echo data measured by multiple sensors (direct and cross echo) the two-dimensional object position is computed</td></tr>
<tr><td>Main functions</td><td>Distance sensing based on ultrasound runtime measurements

Transmission and reception of ultrasonic waves

Digital signal processing in the sensor</td><td>Power supply of up to 12 ultrasonic sensors

Processing & filtering of data received by ultrasonic sensors

System control and diagnostics

Exchange of data via CAN interface (measurement data, diagnostics, configuration of use-case specific parameters)</td></tr>
<tr><td>Sensor type</td><td>USS6.5</td><td></td></tr>
<tr><td>Ultrasound propagation medium</td><td>Air</td><td>-</td></tr>
<tr><td>Ultrasonic frequency</td><td>43kHz...60kHz</td><td>-</td></tr>
<tr><td>Measuring range

(standard conditions, standard object) *)</td><td colspan="2">Maximum detection range ~ 550 cm

Minimum detection distance d_{min}: Configuration-dependent (see Table 13 on p. 51) typical: 12/18 cm

Attributed to physical limits, distance measurements are not possible below a configuration-dependent distance (see Table 13 on p. 51). Below d_{min}, multi-reflections between the sensor and the object can lead to false distance values (multiples of real object distance).</td></tr>
</table>

	To a limited extent, object detection without exact distance information below d_{min} is possible for a specific configuration (see 'Presence detection' in section 4.1.6).	
Accuracy and resolution of distance measurement	Accuracy (at well-known ambient temperature): • 1.5-2 cm at d <1 m • 2% for d > 1 m w/o temperature input: ca. +0.17 % additional error per °C ambient temperature deviation from a configurable default value	CAN output distance signal • Resolution – 1 cm • Cycle time ~ 40 ms
Accuracy of object positioning	Lateral and longitudinal measurement error dependent on sensor spacing, object distance and object characteristics (see section 4.1.10)	CAN output x-y coordinate signals • Resolution – 2 cm • Cycle time ~ 40 ms
Measurement rate	Distance measurements (direct echo) are conducted on each sensor every ~120 - 240 ms depending on the selected configuration (see Table 13 on p. 51). As the data of multiple sensors is used for the object localization functionality, a higher measurement rate is expected (typically three times higher, given a proper sensor installation.	
Additional features	Blindness detection due to contamination of membrane, detection of range reduction due to ultrasonic interference source, active damping (see section 4.1.6)	
Operating temperature range	-40°C to + 85°C	
Storage temperature range	See section 0	
IP protection class as per ISO 20653	Dust-, water- and steam-jet-tight / protecting rating IP6KX, IPX6K, IPX8, IPX9K (hot jet spray onto front of installed sensor)	Dust-tight and protected against high-pressure/steam-jet cleaning and temporary immersion in water according to protection rating IP6K9K and IP6K7.
Data interface	Sensor ⇔ ECU: bidirectional single-wire data interface	ECU ⇔ Customer interface: Configurable CAN bus • J1939 or automotive CAN • CAN speed 250 or 500 kBaud • Configurable automotive CAN IDs

Operating voltage	8V to 16V (12V nominal)	9.3V to 31.8V
Operating current	Idle mode: < 17 mA Peak sending current during transmission of ultrasonic waves: < 570 mA	Operating current depends on the selected configuration (e.g. number of sensors). Typical values are: w/o periphery: < 96 mA with 12 sensors: 260 mA peak < 1980 mA
Allowed mechanical load on sensor	Allowed axial pressure on sensor membrane Allowed axial pressure on sensor housing and sensors lid (on lid measured with 23 mm pin) Allowed torque on membrane Allowed lateral force on membrane	167 N/cm² (150N, diameter 15,5mm) 19 N/cm² 30 Ncm 50 N
Allowed mechanical load on ECU	See section 4.2.2 (no validation tests available for B-sample)	
Weight	14 g	381 g

Table 1 Short overview of sensor and ECU properties

*) *Standard conditions: Standard temperature 23 $\pm$ 5 °C in lab-environment, 65 % relative humidity; standard object: tube Ø 75 mm, 1 m in height; distance on main axis*

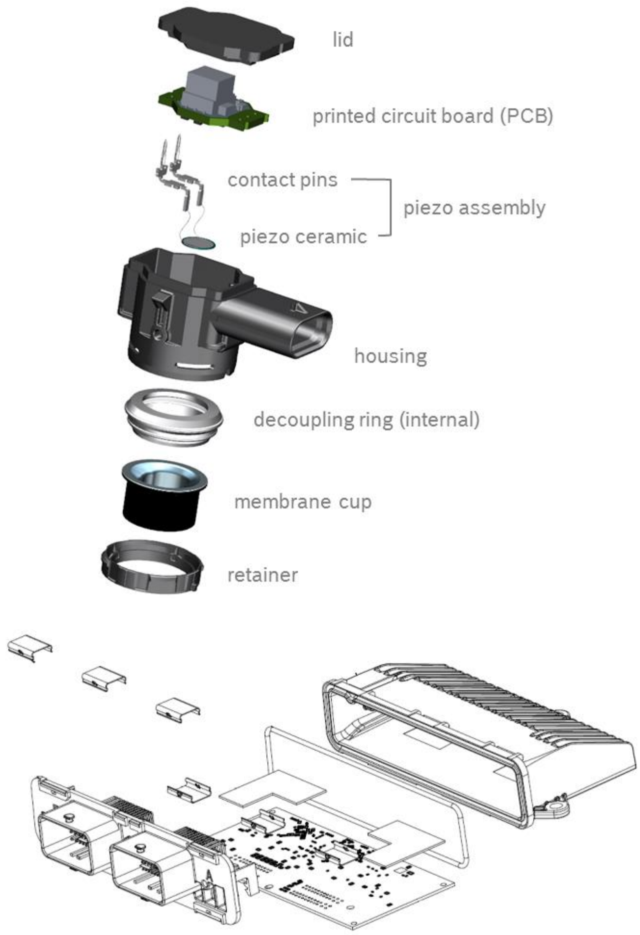


Figure 2 USS Sensor 6.5 with radial connector and ECU exploded view (not binding illustration)

2.2 Intended use

The product is described by Bosch Rexroth for the intended application (cf. Chapter 1) and released on the basis of the legal and normative requirements relevant to the Bosch Rexroth product. Bosch Rexroth complied with the following regulations/standards when developing the product:

- Chemical substances (REACH) Regulation (EC) No 1907/2006
- Restriction of the use of certain hazardous substances (RoHS) Directive 2011/65/EU
- Electromagnetic compatibility Directive 2014/30/EU of the European parliament
- EN12895:2015: Industrial trucks – Electromagnetic compatibility
- EN 61000-6-2:2005: Electromagnetic compatibility (EMC) – Part 6-2: Generic standards – Immunity standard for industrial environments
- EN 61000-6-4:2007 + A1:2011: Electromagnetic compatibility (EMC) – Part 6-4: Generic standards – Emission standard for industrial environments

- EN ISO 13766-1:2018: Earth-moving and building construction machinery – Electromagnetic compatibility (EMC) of machines with internal electrical power supply – Part 1: General EMC requirements under typical electromagnetic environmental conditions
- EN ISO 13766-2:2018: Earth-moving and building construction machinery – Electromagnetic compatibility (EMC) of machines with internal electrical power supply – Part 2: Additional EMCn requirements for functional safety
- EN ISO 14982:2009:*1) Agricultural and forestry machines – Electromagnetic compatibility – Test methods and acceptance criteria
- UN ECE Regulation No. 10 - Rev.6: Electromagnetic compatibility

**1) For the use in agricultural and forestry machines a Transient Voltage Suppressor is needed to react to sudden or momentary overvoltage conditions to fulfill the requirements of ISO 14982 (Testpulse 5 table 1).*

Bosch Rexroth complied with the following regulations when developing the ultrasonic sensors:

- ISO 16750-2 (Second Edition 2012-11-01) Road vehicles - Environmental conditions and testing for electrical and electronic equipment - Part 2: Electrical loads
- ISO 16750-3 (Third edition 2012-12-15) Road vehicles - Environmental conditions and testing for electrical and electronic equipment - Part 3: Mechanical loads
- ISO 16750-4 (Third edition 2010-04-15) Road vehicles - Environmental conditions and testing for electrical and electronic equipment - Part 4: Climatic loads
- ISO 16750-5 (Second edition 2010-04-15) Road vehicles - Environmental conditions and testing for electrical and electronic equipment - Part 5: Chemical loads
- ISO 26262-1 (First edition 2011-11-15) Road vehicles - Functional safety - Part 1: Vocabulary
- ISO 7637-3 (Second edition 2007-07-01) Road vehicles – Electrical interference from wires and coupling
- ISO 17386 (Second edition 2010) Transport information and control systems - Maneuvering Aids for Low Speed Operation (MALSO) - Performance requirements and test procedures
- ISO/TS 16949 (Third edition 2009-06-15) Quality management systems - Particular requirements for the application of ISO 9001:2008 for automotive production and relevant service part organizations
- ISO/TR 14062:2002 (First edition 2002) Environmental management - Integrating environmental aspects into product design and development

2.3 Product safety

2.3.1 Functional Safety

Bosch Rexroth points out that the system/product does not implement any PL-classified requirements (in the sense of ISO 13849). Therefore, it has not been approved by Bosch Rexroth for applications in which Bosch Rexroth delivered system/product has a PL related role.

2.3.2 Data Protection, Cyber Security and Over-the-Air Aspects

The product contains measures to comply with security standards.

2.3.2.1 Bosch Rexroth diagnostic interface

The Bosch Rexroth USS System contains engineering access points in hardware and software to execute diagnostic services for development investigation purposes, including the capability to perform a software re-flash. This is done through CAN interface on the pin as specified in the section 3.2.4.

An abuse of these interfaces allows full control to the system to either permanently change the flash content or alter its operation. The Customer has to ensure that the system is operated in a secure and controlled environment, where the access to the system interface is only allowed to authorized personnel. The customer shall take all necessary measures to avoid any remote access to the system. The customer is responsible for the holistic Security concept for the overall system and the regular determination of the State of the Art of the system.

2.3.2.2 Security of the Bosch Rexroth diagnostic interface

The Bosch Rexroth diagnostic interface is protected with a successive sequence of values to be sent in the right way.

2.3.2.3 Customer diagnostic interface

The delivered software can be configured with a tester over CAN through UDS services as specified in the section 4.1.18.

This is only possible once the ECU is unlocked.

2.3.2.4 Security of the customer diagnostic interface

The extended diagnostic session of the customer diagnostic interface is protected by a symmetric cryptography.

By default, a common customer login value is written in the plant for the release of the extended session. This login is stored in the NVM and used for the calculation of the key. This key sent by the tester is then compared with the ECU internal calculated one to release the access of the extended session.

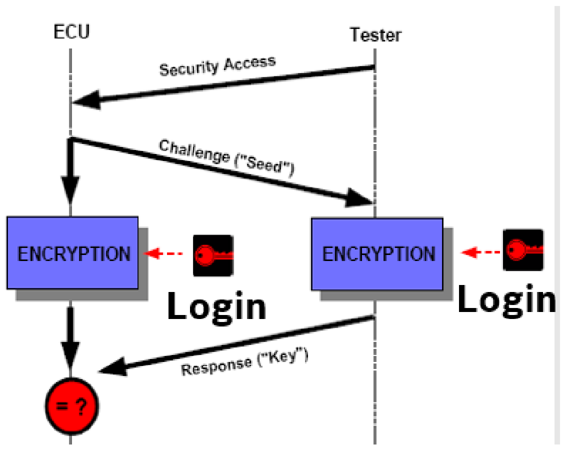


Figure 3 Unlock diagram flow: Tester requests a security access, the ECU answers with a Seed to the tester. A calculated Key from the Seed and the login is sent by the tester to the ECU. To successfully unlock the ECU, this key should be the same as the key calculated by the ECU itself.

In order to be able to change the configuration, the default customer login should be changed (see section 4.1.18).

In order to prevent against unintended change of the configuration by a third party, the customer login should be defined secured enough.

In order to unlock the ECU, the same calculation should be implemented

Details can be found in the security documentation (see section 1).

2.3.3 Safety and Warning Notes

Product safety and proper functionality is only guaranteed if the permissible conditions are respected.

Repairs or modifications of the ECU by the customer or by a third party are not permitted.

Service work has to be performed exclusively by authorized personnel and with original replacement parts.

To ensure proper connection, the latch mechanism of the ECU connector must not be damaged and must be fully engaged.

ECU battery supply must be protected with a suitable fuse (max. 15A).

The delivered system functions are not safety relevant.

2.3.4 Misuse (examples)

The following examples of improper use/application (misuse) are not permissible. This list merely contains examples and does not claim to be exhaustive.

Misuse of sensors

- Using the sensor outside the environmental and load conditions stipulated in the specifications is not permissible.
- Mixing up the sensor ports could cause the sensor to be damaged and is not permissible. There is no reverse polarity protection feature on the sensor.
- An operating voltage of more than 22 V - even if short-time applied - may cause irreversible damage to the sensor.
- Mechanical loads on the membrane cup must be avoided, especially lateral forces on the membrane cup during installation and handling (please refer to section 4.2.2 for permissible values). Applying a torque to the sensor membrane and/or sleeve is not permissible (please refer to section 4.2.2 for permissible values). The sensor membrane is the function-defining element. Make sure that this part of the sensor is joined, accommodated and mounted such that it is free from forces and torque.

- No retainer geometry should be used which is not approved in this document or for which Bosch Rexroth has not issued its consent after prior consultation. Use of not approved retainer can cause relevant safety situations.
- Additional coating/painting of the membrane are not allowed for the application stated in this document.
- Other processes like laminating color films or using protective films onto membranes are not allowed.
- It is not permissible to remove the paint coating by chemical or mechanical means (rework).
- No external decoupling rings are to be used which have not been approved by Bosch Rexroth for the application. Use of not approved decoupling rings can cause relevant safety situations.
- Installing the sensor without an external decoupling ring is not permissible.
- When inserting the sensor module into the sensor retainer, make sure that the decoupling ring is installed correctly and that it is not damaged or dislocated as it is inserted. Rolled or pinched external decoupling rings are not allowed.
- The mating connector for the sensor is the responsibility of the customer. The customer must ensure that no moisture is able to ingress into the sensor connector through the mating connector in any operating conditions.
- Damage to the sensor cable harness is not permissible. Damage to the cable harness could cause the ingress of moisture into the sensor.
- It is not permissible to lock the sensor connector in any way other than that stipulated.
- The sensor is not usually guaranteed to work after a stone impact on the membrane cup. Stone impact can cause the sensor to turn "blind".
- Suitable measures are to be implemented to suppress electrostatic discharge (ESD) when working with the sensors.
- Suitable tools are to be used when removing the sensor from the retainer as this could damage the sensor or the retainer.

Misuses concerning transport, storage are:

- Transport and storage must follow the specifications within this document. Violations against this specifications are not allowed.
- Using the standard RB packaging for sea freight is not allowed

Misuse of ECU

The ECU must not be used after it has been dropped due to the possibility of internal non-visible damage that may impact its proper operation.

Too high electromagnetic disturbance of the ECU by other devices and of other devices by the ECU. In case the connecting harness (explicitly power supply and data connections) of the ECU are led in parallel to harnesses of electro-magnetic sensitive components (e.g. antennas) or high current consumers, then this can lead to functional disturbance of the ECU as well as in other ECUs. Arrangement of the components in the machine/vehicle and the overall electrical function of the machine/vehicle are in responsibility of the customer. The confirmation of the electromagnetic compatibility of the component in the machine/vehicle by the customer is premise for the proper use of the ECU.

Improper mounting methods and positions deviating from those specified in the referenced ECU offer drawing.

Operating the ECU with not fully plugged connectors. To realize electrical connections the connectors of the harness have to be plugged into the ECU.

Plugging of connectors with energized harness. Plugging of ECU only with unplugged battery connection.

Mounting of the ECU near moving components when they can induce not intended loads on the ECU.

Unfixed harness or fixing of the harness not close to the ECU. The harness of the ECU has to be fixed near by the connector, so that not intended movement of the harness cannot lead to loads on the connector and the ECU.

The ECU is repair and maintenance free. Opening of the ECU leads to damaging of the housing and can damage connector, electrical components and solder joints. Opening of the ECU is improper use which leads to loss of warranty.

Mounting the ECU on a highly vibrating structure (e.g. on a protruding fitting panel). This could lead to excessive noise and could damage the ECU or harness.

2.4 Labeling of the product

2.4.1 Sensor labeling

The sensors have a label on their rear side as detailed in the corresponding drawing. The application of label information is by laser marking.

2.4.2 ECU labeling

The ECU has a printed paper label attached to the backside of the housing. The label layout and detailed label information can be found in the corresponding drawing.

2.5 Dimensions and weights

2.5.1 USS6.5 sensor dimensions

Basic sensor dimensions are depicted in Figure 4 and Figure 5. Further details can be taken from the referenced drawings.

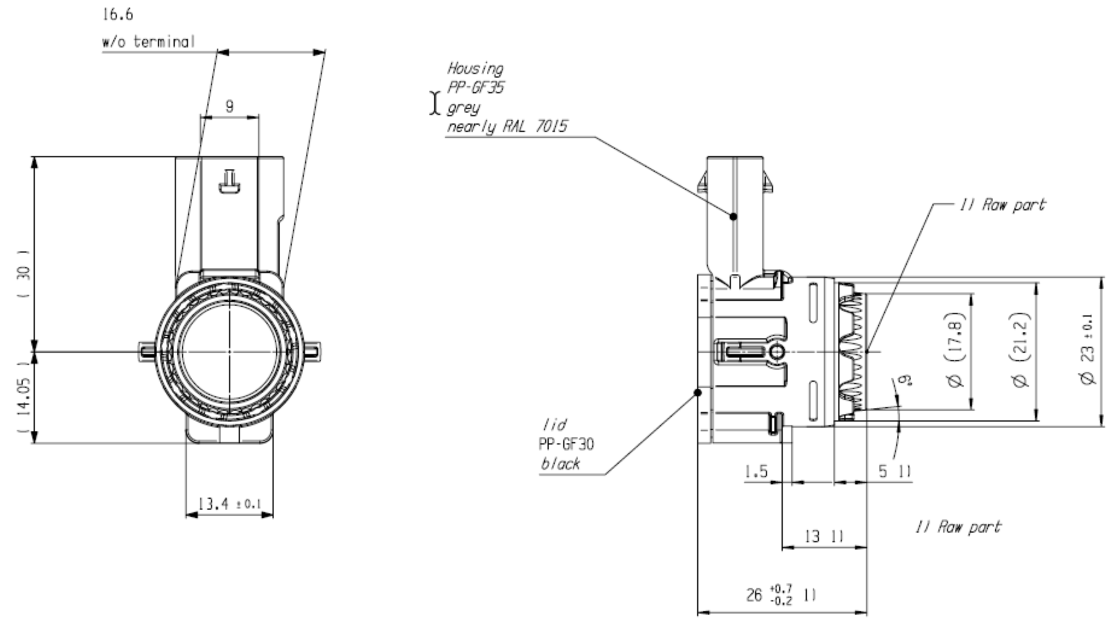


Figure 4 Sensor dimensions with radial connector (taken from drawing)

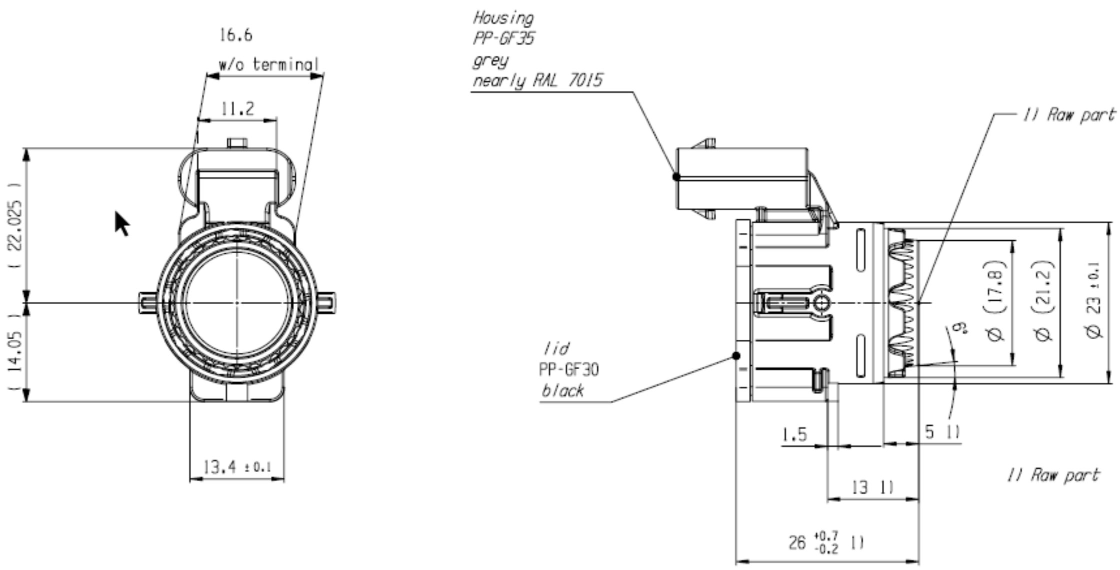


Figure 5 Sensor dimensions with axial connector (taken from drawing)

Bosch Rexroth Mat#	F037.000.136 USS sensor axial configuration

	F037.000.137 USS sensor radial configuration
Dimensions in mm	See Figure 4 and Figure 5
Mass	Approx. 14 g

Table 2 Sensor dimensions and weight characteristics

2.5.2 ECU dimensions and weights

Basic ECU dimensions and weight information are provided in Table 3 and Figure 6. Further details can be taken from the referenced offer drawing.

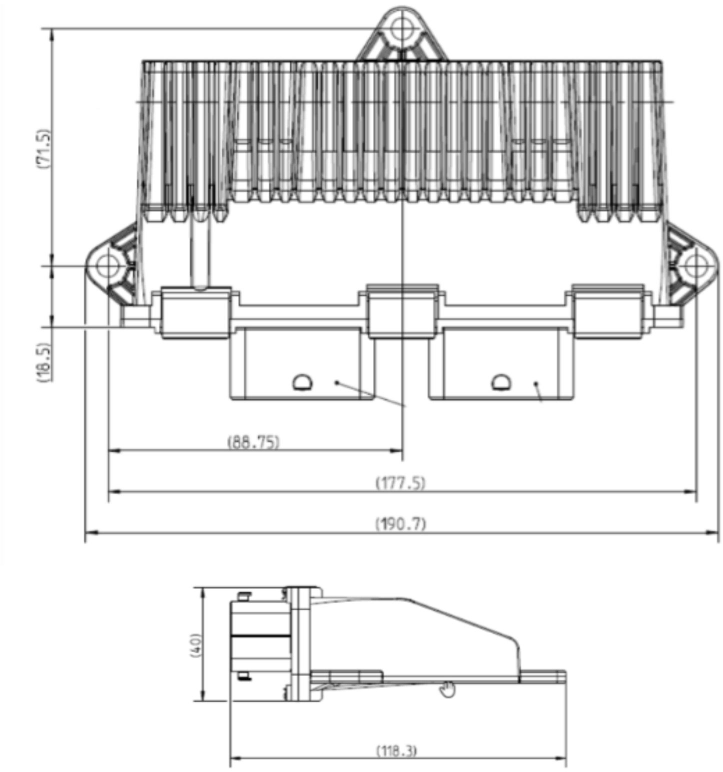


Figure 6 ECU dimensions (taken from offer drawing)

Bosch Rexroth Mat#	F037.000.145 (ENTRY) F037.000.125 (PREMIUM)
Dimensions in mm (w x l x h)	190.7 x 118.3 x 40
Mass	Approx. 381 g

Table 3 ECU dimensions and weight characteristics

2.6 Power consumption / power output

Single USS sensors	Operating voltage:	8-16 V
	Current consumption:	<17 mA (idle mode) < 570 mA (peak current during transmission of ultrasound
ECU (Entry and Premium) (includes sensor power supply)	Operating voltage:	9.3-31.8 V
	The current and power consumption of the USS system depends on the selected configuration (e.g. number of sensors). Typical values are listed below. Typical current and power consumption: • w/o periphery: < 96 mA, 1.1 W @12 V/ 2.2 W @24 W • with 12 sensors: ~260 mA, 3.1 W @12 V/ 6.2 W @24 W • peak < 1980 mA (2 ms duration, 3% duty cycle)	

Table 4 Power consumption

2.7 General remarks on service, repair, and maintenance

The product is maintenance-free.

Repair of the product is not possible.

Service or replacement of the product may only be performed by technically qualified personnel.

Paint repairs of the sensor are not permissible.

Diagnosis of failed parts will be done by Bosch Rexroth.

2.8 Information on disposal and recycling

The product contains electronic components. Local regulation regarding disposal and recycling of electronic components shall apply.

3.0 System description

3.1 System of Interest (SOI)

The product provides a high performance perception system designed to monitor the distance and/or 2D-position of objects in the vicinity of off-highway machineries. It consists of several ultrasonic sensors of type USS6.5 together with an electronic control unit (ECU) (see Figure 7). Depending on the variant configured by the customer, a total of 4, 6, 8 or 12 sensors can be applied. The ultrasonic sensors are used as transceivers to transmit and receive the ultrasonic signals. Moreover, a digital signal processing is performed on the sensor to identify obstacles in the received signal. The resulting data is further processed and evaluated on the ECU to obtain reliable object distance data and estimate the position of the object in a two-

dimensional object map. All ultrasonic sensors are directly connected to the externally powered ECU. The ECU provides a CAN bus interface for data exchange with the customer system (distance & object data, diagnostic information, parametrization).

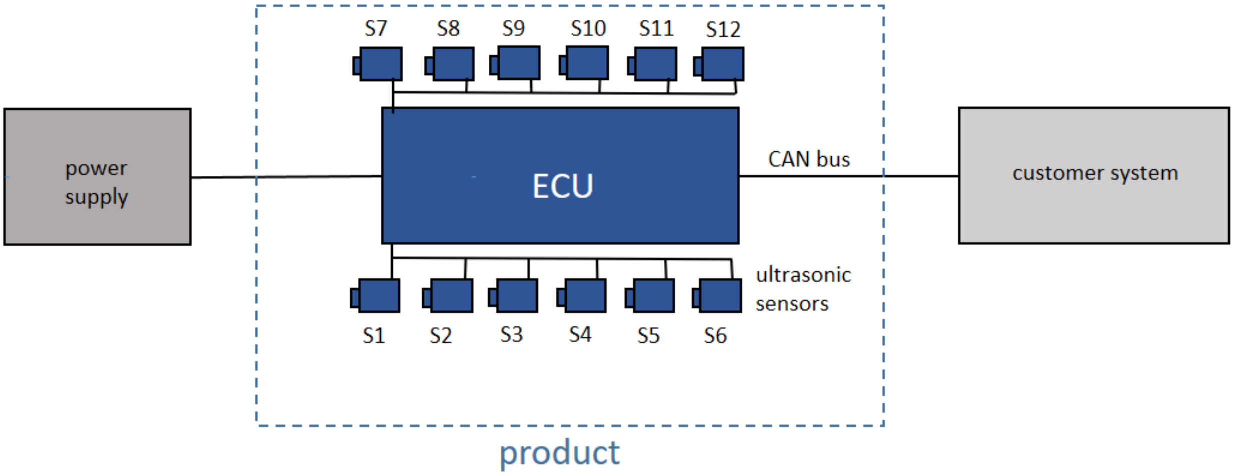


Figure 7 System of interest

3.2 Hardware and software interfaces

Bosch Rexroth is only responsible for the compliance of the system components (ECU and ultrasonic sensors). The wiring harness and its connectors lie within the responsibility of the customer. Bosch Rexroth is not responsible and does not warrant for the connection assembly, especially not for its electrical function, durability and sealing.

3.2.1 ECU ⇔ Customer component interface

To implement the system functions a data exchange via the CAN bus is necessary. This interface contains both the ECU input and output signals that are relevant for the customer-specific application of the product. The CAN interface is described in sections 4.1.14 and 4.1.15 for the automotive CAN and in section 4.1.17 for J1939. Information about the diagnostic interface is given in 4.1.18.

3.2.2 ECU ⇔ Sensor system interface

The sensor interface is a proprietary bidirectional single-wire interface with a digital protocol. The data are validated by means of line coding and via CRC. The interface permits parameterization and activation of the sensor. The sensor responds to the electronic control unit depending on the request with echo and/or diagnostic information.

The idle level on the data line is set by the electronic control unit and is typically 4.5 V and/or 5V. The request from the electronic control unit uses voltage modulated NRZ signals with active low level and a data rate of 20 kBit/s. The sensor responds with current-modulated signals with a stroke of 13 mA at a data rate of max 188 kBit/s. The data rate is set during the application of the system. The electronic control unit can interrupt the sensor at any time with a renewed request.

Features of interface:

- 0-5 V Voltage PHY interface in ECU → Sensor direction
- 0-13 mA Current PHY Layer in Sensor → ECU direction
- 1-wire, bidirectional connection
- Master/Slave comm. with ECU-controlled interrupt
- information is transmitted with digital protocol
- end2end protection with 8/16bit CRC
- Baud rate ECU->Sensor: max 20 kBit/s
- Baud rate Sensor-> ECU: max 188 kBit/s

Wiring harness requirements:

- Maximum length: 10 m
- Minimum wire gauge of Data Line 0.35 mm² (AWG 21-22): 0.51 Ω per single line
- Minimum wire gauge of Supply and GND 0,5 mm² (AWG 20): 0.36 Ω per single line
- The data line must be routed in parallel to the supply and ground line within one dedicated bundle
- Maximum distance of 5 mm (avg. 4 mm) referred to line center
- Distance is allowed to deviate 50 mm before and after a connector
- Maximum 2 additional connectors for harness interconnection are allowed
- The maximum difference in length between the data and ground/supply line must not exceed 2 m

The function of the data interface is ensured up to an electrical shunt > 5 kΩ of the data line against the operating voltage or ground.

The interface is configured as short-circuit proof against ground and operating voltage.

3.2.3 Sensor connector

The Hirschmann connector is available with axial and radial connector orientation (Figure 8). The Hirschmann connectors are combined with a connector coding (Figure 9 left) to differentiate the USS6.5 sensor from other existing types (e.g. USS6.0). In addition, the sensor provides a mechanical coding to the sensor retainer as well as a color coding (Figure 9 right).

axial **radial**

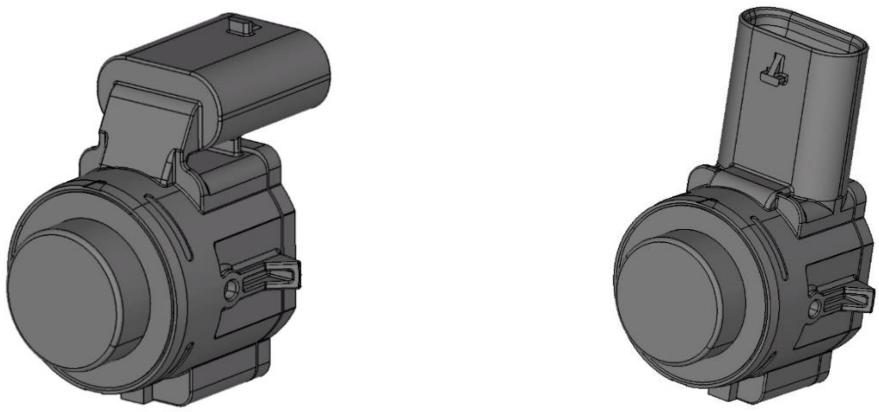


Figure 8 Axial (left) and radial (right) orientation of Hirschmann connector

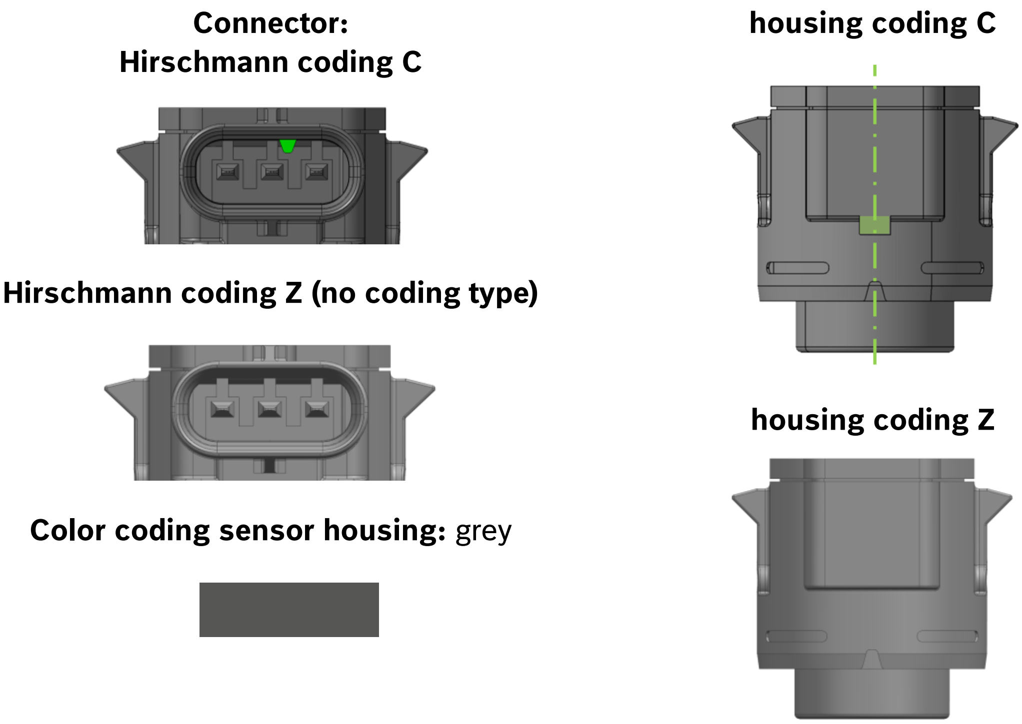


Figure 9 USS6.5 connecter coding, housing & color coding

The pinout of the connector is defined in the related offer drawings. Common definition as follows:

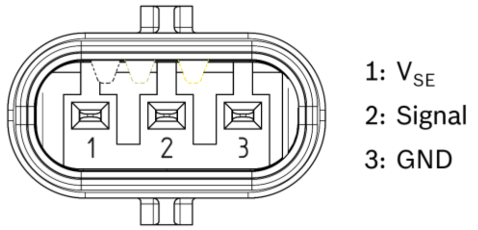


Figure 10 Common pinout definition of sensor connector

Following connector types are suitable:

- Hirschmann 805-121-523 (coding C)
- Hirschmann 805-121-525 (coding Z/no-coding)

3.2.4 ECU connector

The electrical connections are designed with a 2-bay connector with 48 pins each (type: Molex)

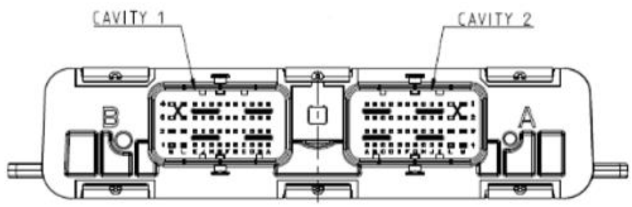


Figure 11 Front view and pin assignment of the connector interface

cavity	pin number	wire outlet	connector
1	48	Right	Molex 0643203311
2	48	Left	Molex 0643201318

Table 5 Connector information of harness side

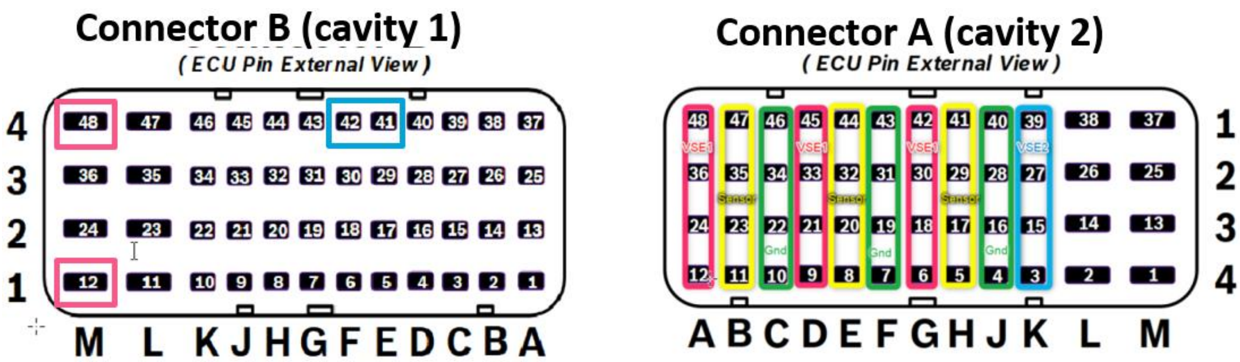


Figure 12 Pin numbering

Connector A (cavity 2		
Pin No.	Pin No.	Description
1	M4	N.C.
2	L4	N.C.
3	K4	N.C.
4	J4	Sensor GND USS12
5	H4	Sensor data USS12
6	G4	Sensor POWER USS12
7	F4	Sensor GND USS8
8	E4	Sensor data USS8
9	D4	Sensor POWER USS8
10	C4	Sensor GND USS4
11	B4	Sensor data USS4
12	A4	Sensor POWER USS4
13	M3	N.C.
14	L3	N.C.
25	K3	N.C.
16	J3	Sensor GND USS11
17	H3	Sensor data USS11
18	G3	Sensor POWER USS11
19	F3	Sensor GND USS7
20	E3	Sensor data USS7
21	D3	Sensor POWER USS7
22	C3	Sensor GND USS3
23	B3	Sensor data USS3
24	A3	Sensor POWER USS3

Connector A (cavity 2)		
Pin No.	Pin No.	Description
25	M2	N.C.
26	L2	N.C.
27	K2	N.C.
28	J2	Sensor GND USS10
29	H2	Sensor data USS10
30	G2	Sensor POWER USS10
31	F2	Sensor GND USS6
32	E2	Sensor data USS6
33	D2	Sensor POWER USS6
34	C2	Sensor GND USS2
35	B2	Sensor data USS2
36	A2	Sensor POWER USS2
37	M1	N.C.
38	L1	N.C.
39	K1	N.C.
40	J1	Sensor GND USS9
41	H1	Sensor data USS9
42	G1	Sensor POWER USS9
43	F1	Sensor GND USS5
44	E1	Sensor data USS5
45	D1	Sensor POWER USS5
46	C1	Sensor GND USS1
47	B1	Sensor data USS1
48	A1	Sensor POWER USS1

Table 6 Pin-out connector A (cavity 2). N.C.: reserved/do not connect

Connector B (cavity 1)		
Pin No.	Pin No.	Description
1	A1	N.C.
2	B1	N.C.
3	C1	N.C.
4	D1	N.C.
5	E1	N.C.
6	F1	N.C.
7	G1	N.C.
8	H1	N.C.
9	J1	N.C.
10	K1	N.C.
11	L1	N.C.
12	M1	ECU GND
13	A2	N.C.
14	B2	N.C.
15	C2	N.C.
16	D2	N.C.
17	E2	N.C.
18	F2	N.C.
19	G2	N.C.
20	H2	N.C.
21	J2	N.C.
22	K2	N.C.
23	L2	N.C.
24	M2	N.C.

Connector B (cavity 1)		
Pin No.	Pin No.	Description
25	A3	N.C.
26	B3	N.C.
27	C3	N.C.
28	D3	N.C.
29	E3	N.C.
30	F3	N.C.
31	G3	N.C.
32	H3	N.C.
33	J3	N.C.
34	K3	N.C.
35	L3	N.C.
36	M3	N.C.
37	A4	N.C.
38	B4	N.C.
39	C4	N.C.
40	D4	N.C.
41	E4	CAN HIGH
42	F4	CAN LOW
43	G4	N.C.
44	H4	N.C.
45	J4	N.C.
46	K4	N.C.
47	L4	N.C.
48	M4	ECU POWER

Table 7 Pin-out connector B (cavity 1). N.C.: reserved/do not connect

4.0 Technical data with measured variables and measuring conditions

4.1 Functions, function states (modes of operation), functional characteristics and boundary conditions

Main functional characteristics and properties are described in section 2.1. A detailed description of the different functions and features as well as the prevailing physical limits is given in sections 4.1.1 – 4.1.12. Functional system inputs and outputs including the CAN matrix are described in sections – 4.1.15. Configurable software parameters, the J1939 interface and the diagnostic feature are detailed in section 4.1.16 – 4.1.18, respectively. Finally, failure handling is explained in section 4.1.19.

4.1.1 System activation/deactivation

The system is activated/deactivated by enabling/disabling the ECU power supply (e.g. ignition on).

All sensors must be properly connected to the ECU to enable the system function.

4.1.2 Basic functionalities of the system

The USS system offers two basic functionalities:

1) Distance measurements between the sensors and objects inside their field of view (direct echo)
2) Object localization via direct and cross echo information: By combining the echo data measured by multiple sensors, the two-dimensional object position (x-y-position) is computed

These functionalities are generally designed to be used separately depending on the requirements of the use case it is intended for. However, simultaneous application of both functionalities is possible as well.

The first functionality of direct echo distance measurements is intended for applications were the distance of the object within the field of view of the sensor offers sufficient information for the object monitoring. An essential feature of this functionality is a very flexible sensor installation. As each sensor conducts independent distance measurements, their position and orientation can generally be selected freely. The only limitation consists in positioning simultaneously transmitting sensors in a way that they do not interfere with each other (see section 6.2.1). However, the sending sequences are designed such that only every fourth sensor fires simultaneously. Thus, these limitations only apply to sensor systems with more than four sensors.

The main feature of the second functionality compared to direct echo distance measurements is that the two-dimensional object coordinates (in the horizontal X-Y-plane) are computed from the echo data received by multiple sensors via trilateration. In comparison to the relatively wide field of view for distance measurements with single sensors, the computation of the object position results in a significantly higher lateral resolution. Furthermore, the combination of the individual sensor data at object level leads to lower false positive rates. The functionality is specifically designed to monitor objects in the surrounding of a vehicle. A suitable installation of the sensors on roughly the same height with restrictions regarding the spacing and installation angles is a prerequisite for a proper object detection. Due to the higher complexity of object localization functionality, a corresponding increase of the calibration time can be expected.

The following sections explain the basic measurement and evaluation principles that are used to enable the above-mentioned functionalities of the system.

4.1.3 Principle of object echo detection and distance measurements

The distance measuring with ultrasound is based on the reflection principle of ultrasonic waves. Individual ultrasonic sensors are used as transceivers to both emit ultrasonic pulses and receive their reflections (echoes). The distance "*d*" covered by the ultrasonic signal equals twice the distance between sensor and obstacle. Using the measured travel time t_1 and the temperature-dependent speed of sound c_s, the distance can be calculated according to

$$d = \frac{c_s(T)}{2} \times t_1$$

The implemented transmission and reception procedure of the ultrasonic sensors as well as the evaluation technique used to detect and verify individual echoes in the signal are described in the following.

Upon a command from the ECU the sensor transmits an ultrasonic pulse and is then ready for reception after a short delay time (ring-down time to decline membrane vibration). While the membrane vibrations decay, echoes cannot be detected. Thus the ring-down time defines the lower limit for the measuring range.

The ultrasonic sensors transmit with different frequency-modulated sending codes in the range of 43-60 kHz. They differ with regard to their starting and end frequencies, and the transmit pulse lengths. The used sending codes vary from measurement cycle to measurement cycle and are chosen by the controlling SW in the ECU. A set of different sending code settings is configurable for the customer (see section 4.1.16).

In the sensors, the received signal is digitized and subjected to several signal processing steps. The implemented matched-filtering approach takes advantage of the frequency-coding of the transmitted pulses (i.e. the sending code), thus maximizing the signal-to-noise-ratio and suppressing disturbances, e.g. by external acoustic sources, other ultrasonic sensor systems, or ultrasonic sensors of the same system which transmit with another sending code in the same measurement cycle. Despite the possibility to discriminate individual ultrasonic signals by their sending codes, not all sensors are transmitting ultrasonic signals simultaneously. This reduces possible interference effects between the sensors and the noise level in the environment due to ultrasound, leading to a higher sensitivity. Section 6.2.16.2.1 describes which sensors are transmitting during the same measurement cycle and should not be placed close to each other to avoid adverse interference effects.

Subsequently, object echoes are detected in the received signal by evaluating the signature (correlation coefficient of transmitted and received signal) as well as the amplitude of the signal. In the latter case, an adaptive threshold is used for the object detection (Figure 13). This threshold is formed using a cell-averaging procedure and thus adapts to the noise level. It is evaluated in real time based on the current measurement (no delays), in order to ensure fast reaction times due to changing environments. With this procedure, no static parameterization using a sensor characteristic curve is required; the sensitivity of the sensor automatically adapts to the noise level. This balances out signal fluctuations, e.g. due to changes in the atmospheric attenuation, reflections from a rough ground surface (clutter) or acoustic interference, thus increasing the detection capability. Moreover, the overall sensitivity can be configured by the customer (resulting in higher/lower values of the adaptive threshold). This can be useful for use case specific tuning of the detection performance (e.g. reducing the detection of unwanted ground echoes, see section 4.1.16).

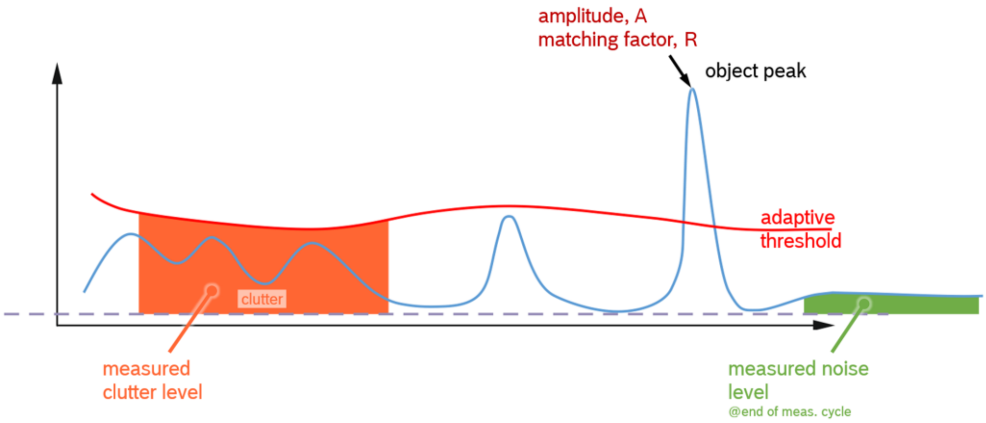


Figure 13 Illustration of received amplitude signal and adaptive threshold

In addition to the travel time of the identified echoes, further signal attributes such as the signal amplitude are measured. All echo information is stored in the sensor, selected according to priority, and transferred across the digital interface to the ECU. In each measurement cycle, multiple object echoes at different distances can be obtained. In addition, the sensor noise level is determined and transferred with each measurement cycle to the ECU. This is done by evaluating the level of the signal in a window of approx. 5.6 ms at the end of each measurement cycle where potential object echoes become very weak and noise is predominant.

4.1.4 Evaluation of distance measurements

One of the main functionalities of the USS system is to provide distance measurements. This information is obtained from the so-called direct echoes, which refer to ultrasound echoes that were transmitted and received by the same sensor. After each measurement cycle, the echo data obtained by the sensors is transferred across the digital interface to the ECU. Here, the echo data is subjected to several advanced filtering and validation steps to provide robust data with low false positive rates. In particular, weak echoes are evaluated over time to ensure reliable detection. The filtering procedure is also designed for a high robustness against disturbances from other ultrasonic interference sources or sensors.

The system offers a few configurable parameters to adjust the level of filtering (see section 4.1.16). A useful filter setting in this context is the distance filter box. These customer-specific filter boxes allow to mask out echoes within a configured distance and amplitude range. The main purpose of this filter is to remove echoes that are reflected by static machine parts and are therefore not relevant.

The main output provided on the system output are the two closest validated direct echoes of each sensor (a detailed output description can be found in section 4.1.14). However, for the first object echo another output signal is additionally computed. Further signal processing is applied in this case to enable a higher signal stability and thus a more convenient data handling by the customer. Here, the echo distance is stabilized by holding the previously validated distance for a certain amount of time in case the distance change between measurement cycles is deemed to be implausible or the object echo is suddenly lost. Such a stability filter is useful when the object detection becomes unstable in certain situations in which case a frequent loss of the signal or jumping to other objects located further away can be observed. Figure 14 exemplifies the effect of this stability filter for a dynamic echo signal that is lost during few measurement cycles. Stabilizing the distance signal also leads to a small additional delay, particularly when the object is detected for the first time and when it moves out of the field of view. The stabilizing filter is designed to provide the smallest delay when an object is constantly approaching the sensor, thus assuring a quick system response.

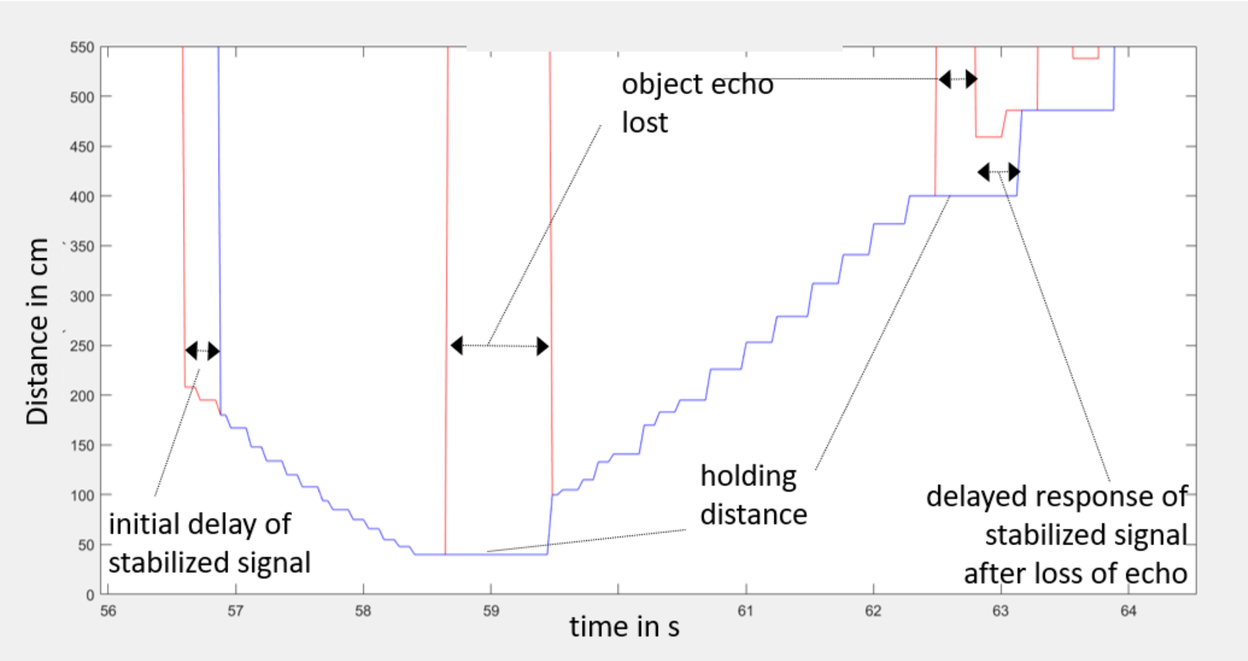


Figure 14 Exemplary distance measurement of a dynamic object with unstable detection (red signal) and the stabilized signal output (blue signal)

4.1.5 Evaluation of two-dimensional object position

In contrast to the basic distance measurements based on direct echoes, another kind of echo is additionally required to determine the object position in a two-dimensional approximation of the environment. Such echoes are called cross echoes and refer to ultrasound echoes that are transmitted by one sensor but received by another neighbouring sensor as opposed to direct echoes where the transmitting sensor is also receiving the echo. The 2D object position is then calculated from both the direct and the cross echo position by using a trilateration approach.

Object creation via direct and cross echoes is performed on the basis of horizontally aligned sensor pairs, i.e. directly neighbouring sensors mounted roughly at the same height. Each sensor pair is able to detect the two closest objects per measurement cycle. With the help of the possible geometrical arrangement of the direct and cross echoes a distinction is made between post-like and wall-like objects. In the two-dimensional representation of the environment, these are referred to as point and line objects. These object types are depicted in Figure 15 and Figure 16. In order to distinguish between line and point objects, three echoes are generally necessary, i.e. one direct echo from each sensor of the sensor pair (DE_1 and DE_2) as well as the cross echo measured between these sensors (CE_{12}). The dependency between the echoes is clearly different for a point or a line object. Echoes that correspond to a point object satisfy the simple equation

$$CE_{12} = \frac{DE_1 + DE_2}{2}$$

whereas another relationship applies for a line object:

$$CE_{12} = \sqrt{\frac{d^2}{4} + DE_1 DE_2}$$

where d is the spacing of the sensor pair. Both equations are evaluated to decide which object type is more probable in the current situation. Line objects are only created if the echo data provides sufficient separability between the two object types. This highly depends on the spacing of the two sensors and their distance to the object.

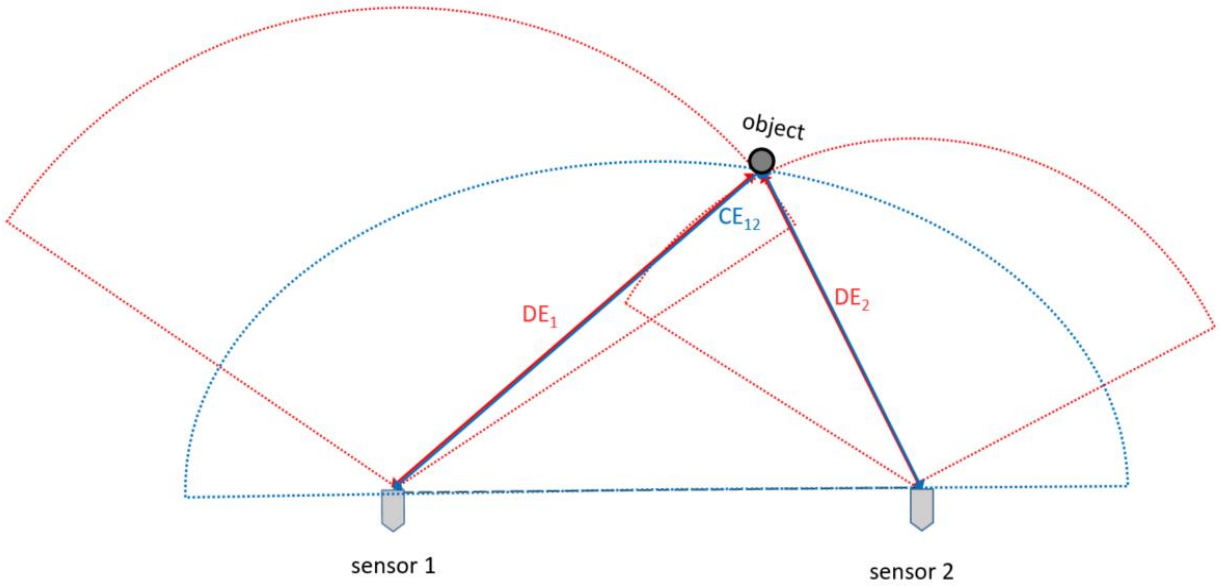


Figure 15 illustration of a post-like object seen by a sensor pair via direct echoes (DE) and cross echoes (CE)

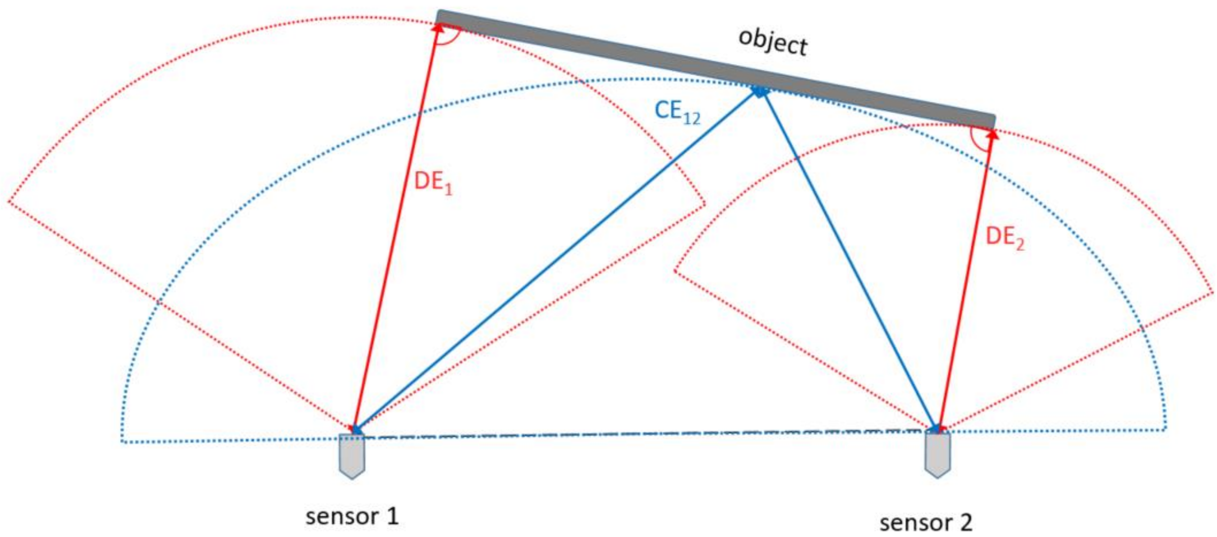


Figure 16 Illustration of a wall-like object seen by a sensor pair via direct echoes (DE) and cross echoes (CE)

As can be seen from Figure 15, the position of a point object can be computed from the intersection point of the two direct echo circles (or one of the direct echo circles and the ellipse enclosing the measured cross echo distance). The position of a line object can be found by computing the tangent to both direct echo circles. The wall is then bounded by the two tangent points as sketched in Figure 16. Except for cases where the end points of the wall are additionally detected, e.g. by neighbouring sensor pairs, the full extension of the wall is generally unknown.

Depending on the position, shape and geometry of the object, certain object scenarios may occur in which the object is only seen by either a direct echo or a cross echo. In the mid to far range, these echoes will not be used for the first object creation as it would lead to a high position uncertainty and is often associated with false positives (e.g. ground reflections). First object creation from single echo information is, however, allowed in the very near range, where such unfavourable object scenes are more likely and the associated positioning error is smaller. In case only the direct echo has been detected in this range, the object is projected at the measured distance in sensor view direction in front of the sensor (Figure 17, top). A single cross echo represents an ellipse around the sensor pair (Figure 17, bottom). In this case the object position is obtained by creating a projection in the middle of the sensors onto this ellipse. The resulting distance to both sensors is equal and the orthogonal projection distance from the middle point of the sensor pair's base line to the projected object position is given by

$$d_{proj} = \sqrt{CE^2 - \frac{d^2}{4}}$$

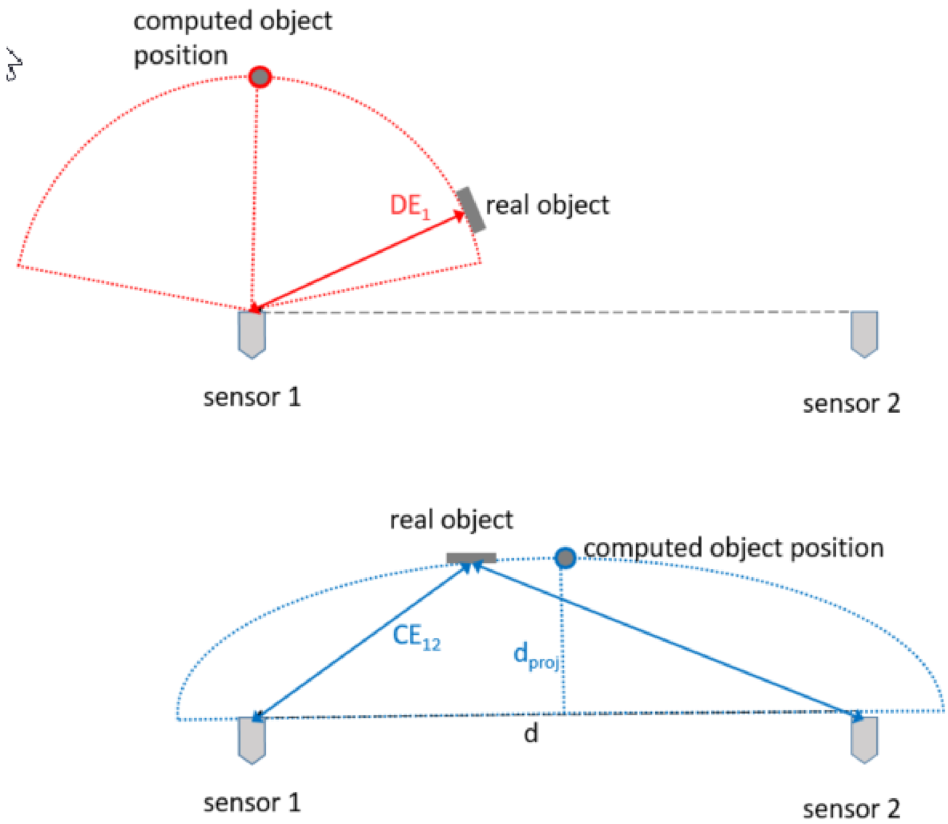


Figure 17 Illustration of object creation when only a direct echo (top) or only a cross echo (bottom) can be detected by the sensor pair

Generated objects that are deemed plausible in further processing procedures are stored in a two-dimensional map and held for a certain time. Advanced algorithms compare currently measured objects to those generated in previous time steps and check whether a match between current and previously existing objects is possible or if a new object is more probable. In case a match is possible, the object position and other object attributes such as its existence probability are updated accordingly. When an object cannot be verified for a certain period of time, its existence probability is decreased until it is ultimately deleted from the object map. Furthermore, a clustering procedure is applied on closely spaced point and line objects stored in the object map. This reduces the complexity of the environment and removes implausible object situations.

The system offers a set of configurable parameters. The configuration of the sensor position and orientation is a prerequisite to enable the object localization. Similar to the basic distance functionality, distance filter boxes can be set for both direct and cross echoes to filter out static machine parts in the field of view of the sensor in order to avoid the creation of unwanted or false objects. Additionally, potential cross talk that is directly travelling from a transmitting sensor to its neighboring receiving sensor without being reflected by an object has to be filtered out by the so-called idle distance filter. There is a set of additional configurable options to adjust the performance of the system to the specific use case. This is described in detail in section 4.1.16.

The main output provided on the customer interface are two x and y coordinates for each object (since two points are needed for a line object). The system can provide maximum 20 objects. A complete description of the object data output can be found in section 4.1.14.

4.1.6 Additional features

Blindness detection
Contamination of the sensor membrane by mud/snow/dirt/ice generally reduces the sensitivity of the sensor and thus its field of view. If the contaminant is in contact with the sensor membrane and the contamination becomes too severe to ensure the basic functionality, i.e. the sensor becomes blind, such defect can be detected by the sensor. This is mainly realized by cyclic measurements and evaluation of the impedance of the sensor membrane. The information about the blindness of the sensor is then indicated in a special info message as well as on the distance signal of the respective sensor (see section 4.1.14.2).

Estimation of maximum detection range
The maximum detection range depends on many parameters (e.g. object dimensions, shape, material, sensor installation, and environment). As a rough estimate, the expected maximum detection range of each sensor for a pole with a diameter of 75 mm is calculated based on the current noise level in the environment. These values are provided on a CAN output message (see CAN signal description in section 4.1.14). Low values (approx. <200 cm) hint at a significant range reduction introduced by a foreign ultrasonic source or electromagnetic interference effects. However, it should be noted that this signal will only reflect the environmental noise in case it is relatively constant in time. Sporadically occurring noise cannot be detected by this approach. Moreover, the estimation of the maximum detection rate based on the noise level can be biased by objects in the field of view of the sensor. Typical values for the estimated detection range without noise-generating external disturbances are 300 to 550 cm.

Active Damping
The active damping is a sensor functionality to reduce the resonance of the membrane by means of active electrical counter-pulses. This is done to prevent longer ring-down times of the sensor membrane to account for aging or temperature effects. This way, the lower limit of the measurable distance range is independent of these effects. The Active Damping feature is exclusively available for one configuration of the ultrasonic sending codes (see default configuration in Table 13 on p. 51).

Presence detection

For the default sending sequence parameter setting (see Table 13 on p. 51), it is generally possible to detect objects between 5 cm and 12 cm without exact information on its distance. This feature, referred to as presence detection, merely provides a hint that an object is present below the physical lower distance limit of 12 cm. This information is provided on the CAN distance signal (section 4.1.14.2). However, due to physical limits the performance of the presence detection is highly dependent on the object (shape, size, orientation and surface), distance and sensor installation. At certain conditions, the object presence can remain undetected or multiples of the real object distance might be measured instead. Below 5 cm, presence detection is generally not possible but may occur due to multi-reflections.

4.1.7 Field of view of a single sensor

The detection range of the sensor is asymmetrical on account of its design. The send/receive range is broader in one direction (horizontal direction for typical installation) and narrower in the other direction perpendicular to that (see section 6.1.2). The ratio between the two opening angle depends on the design and cannot be varied electronically. The resulting field of view of the sensor depends on environmental conditions, mounting conditions, sensor parameterization and object type and shape.

Figure 18 shows two different horizontal fields of view measurements of an USS6.5 sensors obtained for a plastic pole with a diameter of 75 mm on a simulated tarmac ground. The sensor was flush mounted with zero tilt angle and at an installation height of 50 cm (left side of figure) and 150 cm (right side of figure), respectively. It was installed in a way that the wide detection angle was aligned in horizontal direction. The black contours in Figure 18 enclose the field of view with 75% detection rate. The effect of the installation height can clearly be seen on the side of the field of view for X< 2000 mm. Basically, the signal strength of ultrasound decreases with increasing distance to the sensor and increasing azimuthal angle (with respect to the main axis of the sensor). Since the lower installation height results in more ground reflections in the near range, the adaptive threshold in the sensor is raised in this area, further lowering the sensitivity of the sensor. Ultimately, it is becoming increasingly difficult to separate the object echo from the background noise (ground reflections), resulting in a narrower field of view.

Similar phenomena can be expected if the sensor is installed with a tilt angle to the ground. The higher ground reflections can narrow the entire field of view and lead to a reduced detection range. Accordingly, also the properties of the ground can have a strong influence on the detection performance. A gravelly ground will lead to a smaller field of view compared to a flat floor. Furthermore, the parametrization of the sensor by the customer, i.e. the sensitivity setting controlling the level of the adaptive threshold (see section 4.1.16), will also influence the resulting field of view. Another important parameter is the installation condition. When a sensor is not mounted flush but recessed, the surrounding contour may influence the radiation characteristics of the ultrasound, thus affecting the resulting field of view. Further environmental influences on the sensor performance are described in section 4.1.9.

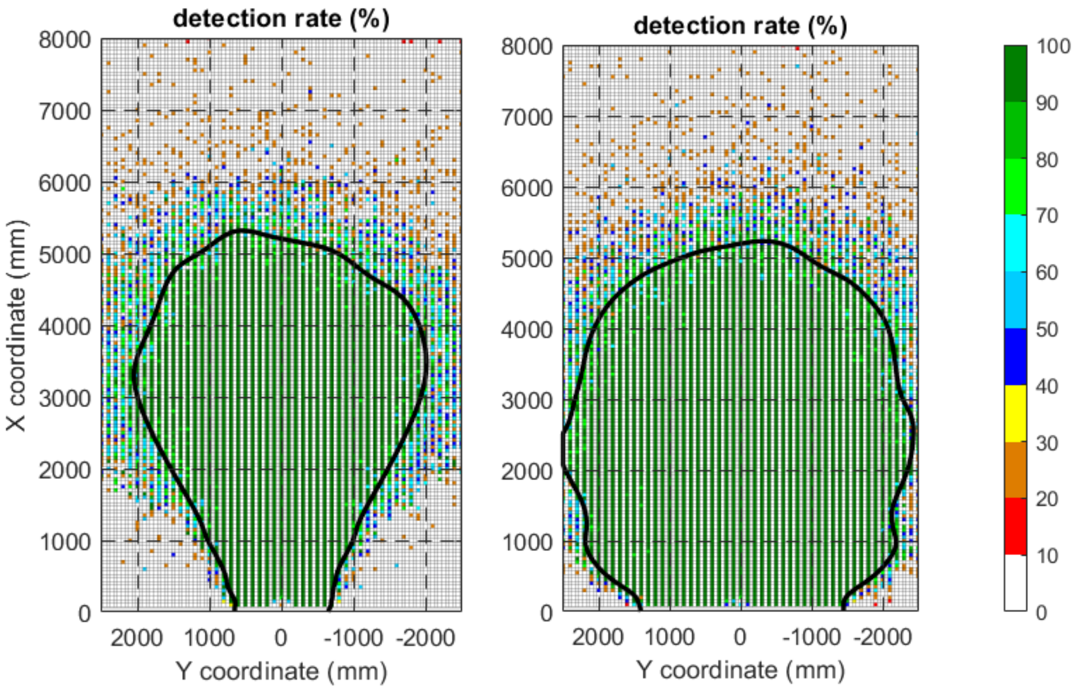


Figure 18 Measured sensor field of view with a plastic pole (75 mm in diameter) for an installation without tilt and a height of 50 cm (left) and 150 cm (right)

4.1.8 Field of view of the sensor system

The field of view of the entire sensor system describes the area in which object generation and 2D localization is possible. It can be classified into the direct and cross echo fields of view. While the first covers the area in which the transmitting sensors receive their own echoes, the cross echo field of view defines the area in which directly neighbouring sensors of the respective transmitter receive the echo. With the exception of the very near range, both direct and cross echoes need to be received to enable the object localization. To avoid blind spots, the sensors must therefore be mounted in such a way that a suitable overlap of the direct and cross echo fields of view is ensured. This is described in more detail in the sensor positioning guideline in section 6.2.5.

In order to obtain a high signal-to-noise-ratio and enable an efficient signal separation with little interference effects between the sensors, not all the sensors are transmitting at the same time. A predefined sequence of measurement cycles is used defining specific transmitters and receivers for each cycle (see example in Figure 19). Consequently, a few measurement cycles are required to update the complete field of view of the sensor system (normally 2-3 cycles).

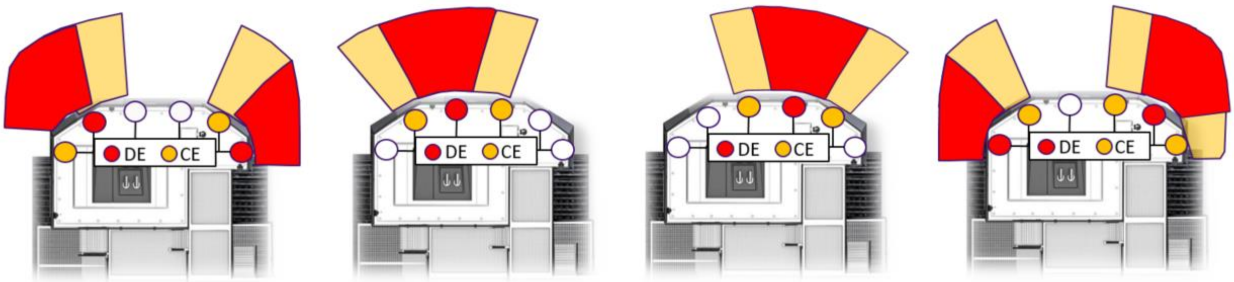


Figure 19 Creation of the complete sensor system field of view at the rear side of an excavator by chronological arrangement of the different direct (DE) and cross echo (CE) fields of view

Similar to the field of view of a single sensor, the system field of view can be influenced by several parameters such as the parametrization of the sensors, mounting conditions (flush or recessed), mounting angle (both horizontal and vertical), the mounting position (x, y, z), and ground conditions.

4.1.9 Influences on sensor performance

Robustness and performance of the ultrasonic measurement system can be reduced due to environmental influences and reflection characteristics of objects caused by physical laws.

Important factors that can lead to a reduction of the detection range or even to a non-detection of existing objects include:

- High airborne sound attenuation, e.g. at high ambient air temperatures with coexistent low relative humidity. Ultrasound is dampened as it dissipates in air depending on temperature and relative humidity (Figure 20), hence affecting the measuring range of the sensor. The sensors are adjusted during trimming to a standard climate. The influence of air pressure on damping can be neglected.
- Heavy rain and/or spume
- Soiling of the sensor membrane with dirt or ice
- Objects with sound-absorbing surface might not be visible to the sensor
- Plain objects that are adversarial angled to the sensors so that reflection will occur only in a narrow angular range.
- Ultrasound from interference sources (see chapter 4.1.10)
- Rough ground conditions (see 4.1.7)
- Sensor installation: Recessed mounting of sensor and/or static parts near the sensor influence the radiation characteristics of the ultrasound, thus affecting the field of view. Furthermore, incorrect positioning of sensors, e.g. by placing transmitting sensors close to each other, may cause additional interference effects between the sensors

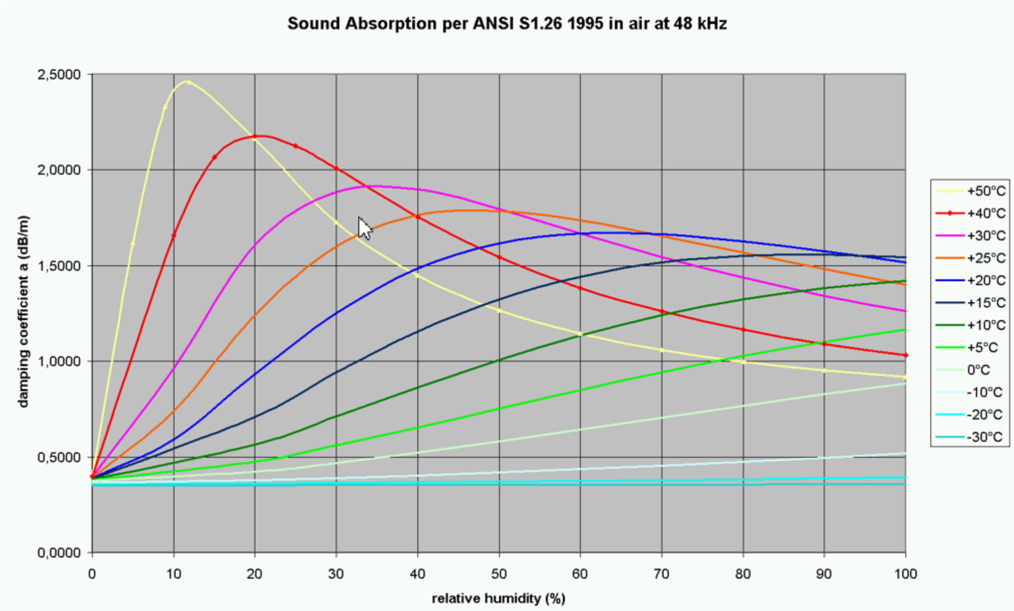


Figure 20 Influence of air temperature and humidity on damping

4.1.10 Interference effects

Ultrasound from interference sources in the environment of the sensor can interfere with the function of the sensor.

If the interference source causes a constant background noise, the sensor function could fail completely when the noise reaches a critical level. Continuous interference sources lead to a rise in the adaptive threshold. The consequence of this is that although the sensor is not damaged, the sensor becomes less sensitive and it might result in objects not being detected or only detected at short distances. As described in section 4.1.6, a high level of constant noise can be indicated by a low estimated detection range which is computed by the SW and transmitted on the CAN output (see section 4.1.14).

If the interference source emits short ultrasound pulses with a very high amplitude and of adequate strength, above all in the range of 40 kHz - 60 kHz, these can appear in the sensor signal as implausible echoes. The sensor detects an obstacle although there is none in reality.

Electromagnetic interference sources with frequency proportions in the 40 kHz - 60 kHz range can have a similar effect.

The ultrasound working frequency, the signal coding and the evaluation algorithms are designed to allow for maximum interference suppression and system resilience. However, 100% interference suppression of all conceivable influences due to external noise and electromagnetic interference sources (other machines with US sensor systems, compressed air, engine noise, electrical ballast units, induction loops, etc.) cannot be warranted in all situations and for reasons related to the laws of physics.

Experience shows that the problem of an environment with interference often occurs when the sensor is electrically tested after it has been installed at the machine. Running machines are a frequent cause of interference noise and electro-smog.

4.1.11 Precision of distance measurement

If an object is detected within the detection range, the precision of the measured distance will depend on a variety of principal factors listed below. In total, the ultrasonic sensor system achieves an accuracy of about 1.5 cm at short range and approx. 2% at long range, provided the exact ambient temperature is known and provided to the system. The ambient temperature, e.g. from an external sensor, can either be provided to a cyclic CAN signal, or by configuration of a default value which is reasonable if relatively low temperature changes are expected. When the current ambient temperature is not provided, an additional error of about +0.17 % per °C ambient temperature deviation from the configured default value can be expected.

Environmental influences: The object distance is calculated from the travel time of the echo signal. Since the speed of sound depends on the ambient temperature, the travel time of the ultrasonic waves is also temperature-dependent. The speed of sound c changes approximately according to

$c = (331.5 + 0.6*T/°C)(m/sec)$

where T is the air temperature in °C

As explained above, this effect can be compensated in the SW if the temperature information is given.

Other environmental influences such as air pressure and air humidity are of lesser importance for the precision of the distance measurement, although they could affect performance.

System and sensor clock – Another influencing factor for the accuracy of the distance measurement is e.g. the accuracy of the clocks used in the system. The clock in the sensor is synchronized with the system clock (typically quartz) in the electronic control unit.

Signal strength – The inertia of the sensor membrane will cause a slight time lag between the sound hitting the membrane and the electric echo signal. If the echo signal is weak, the measured distance will appear slightly larger than it would with a strong signal.

Other influencing variables for the accuracy of distance measurement are e.g. algorithmic inaccuracies resulting from the scan frequency and discretization effects, as well as physical circumstances such as interference effects, filter runtimes, and frequency dependencies that have the effect of slight travel time differences.

4.1.12 Uncertainty of two-dimensional object position

Basically, the uncertainty of the object position can be attributed to the measurement errors of the individual sensor measurements used for the object creation. This is illustrated on the left side of Figure 21. It shows the direct echo circles between a point-like object and a sensor pair together with their inherent measurement error. The intersection area represents all object positions that are possible by pairing the two (inaccurate) echoes. The maximum lateral error is given by the distance between point B and C, whereas the maximum longitudinal error is defined by the distance between point D and E. The lateral error is generally predominant and depends on the spacing of the sensor and the distance of the object. On the right side of

Figure 21, the maximum lateral error for a pole positioned between the two sensors and an underlying distance measurement error of +/- 11 mm is shown. The lateral positioning error increases with larger object distance and smaller sensor spacing. A change of the sensor spacing has a particularly strong effect at an initially low spacing. For instance, by doubling the spacing from 300 mm to 600 mm, the maximum lateral error is reduced approximately by half. Both the object distance and the sensor spacing correlate with the opening angle θ enclosed by the two lines representing the path of the echoes between the object and the sensors. The larger the opening angle is, the smaller the lateral measurement error becomes.

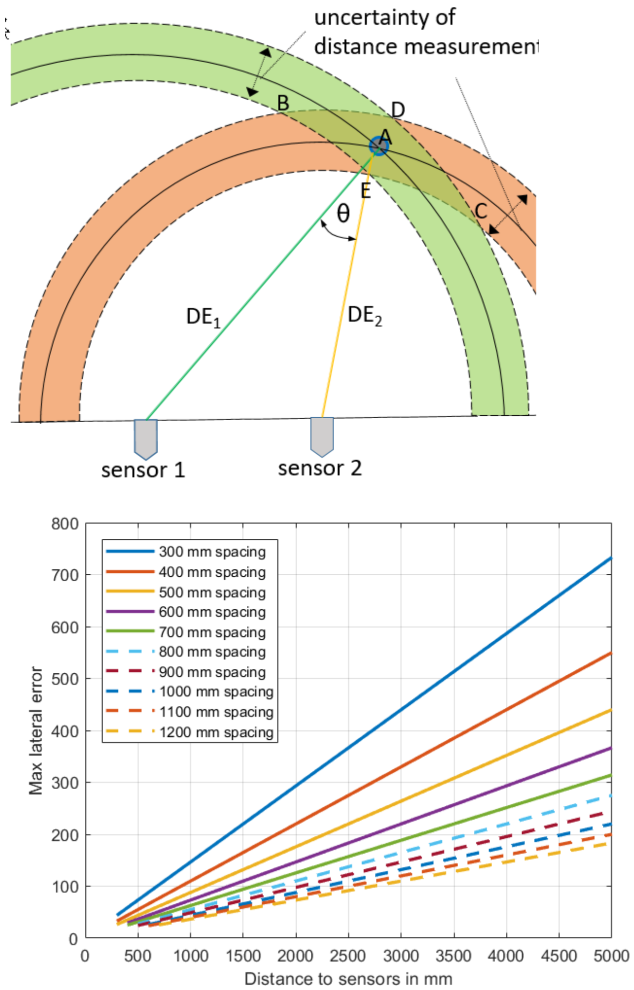


Figure 21 Left: Schematic illustration of positioning uncertainty of a point object at position A. The maximum lateral error is given by the distance between point B and C, while the maximum longitudinal error is defined by the distance between point D and E. Right: Maximum lateral measurement uncertainty of a pole positioned in between a sensor pair for different values of sensor spacing.

In case of wall-like objects, the uncertainty of the distance measurements will lead to inaccuracies regarding the length and angle of the generated object. The object localization principle is based on the two basic object types, point and line objects. However, many objects have a more complex contour with several reflection points, which does not match to such simple object models. Thus, further uncertainties in the object positioning are caused by model deviations of real objects. Even for a pole, its round contour will lead to a small additional error as the echoes which are paired together do not have exactly the same reflection point. In the most adverse case, echoes reflected from two different objects can be paired with each other, leading to the creation of a false object position.

Another essential effect that has to be considered is that only a two-dimensional environment is considered as the height of objects cannot be directly measured by the measurement principle of the system. Thus, objects which are smaller than the installation height of the sensor are generally projected at a farther horizontal distance compared to their real position.

4.1.13 System operating modes

Several operating modes are available to select the required functional system outputs (see Table 8). More information on these system outputs are given in section 4.1.14.

Operating mode	Description	Entry	Premium
Full mode	Both the direct echo data of active sensors and object data are provided on the system output.		x
Direct echo mode	Only the direct echo data of active sensors is provided on the system output.	x	x
Object localization mode	Only the object data is provided on the system output.		x
Calibration mode	Special mode only for calibration purposes. In this mode, the direct and cross echo data is provided in order to perform the calibration of the distance filter boxes (see calibration procedure in section 6.2.6). As some special parameter settings are active, it is not allowed to use this mode for normal operation.	x	x
Calibration Light mode	Special mode only for calibration purposes on prototypes. In comparison to the normal calibration mode described above, different filter settings are used in this mode to enable an easier and faster calibration process on prototype application. For series application, it is recommended to use the normal calibration mode to calibrate the filer box parameters as this will lead to a more robust calibration regarding environmental effects (see calibration procedure in section 6.2.6).	x	x

Table 8 Description of system operating modes

4.1.14 Functional system outputs

4.1.14.1 Description

The main functional outputs for further processing by the customer are described below. Corresponding CAN signals can be taken from the next subsection.

Functional outputs	Description
Direct echo data (Entry/Premium)	**Echo data of two closest objects** The direct echo data, i.e. the direct echo distance and amplitude, of the two closest objects is provided for each active sensor. As described in section 4.1.4, these echo data are validated by several filtering steps to provide robust and reliable output data. The level of filtering, particularly in the case of weak echoes, can be configured by the customer (see section 4.1.16). For most use cases, the first object distance is of highest relevance. Even if a static object, e.g an attached machine part, might be detected on the first echo distance, it can be ignored via a configurable distance filter box that masks out echoes within a configured distance and amplitude range. However, other applications can exist in which known dynamic object that may be irrelevant for that application are detected. For these use cases, it can be useful to switch to the second closest object echo. The provided amplitude value is scaled logarithmically and normalized to a reference object's amplitude characteristics along the sensor main axis. The normalized amplitude of the reference object, which is a plastic pole with a diameter of 75 mm, reaches values of about 21 bins on the main axis and decreases when the object moves away from this axis. The amplitude is an additional echo attribute that is mainly intended for the calibration of the above-mentioned distance filter box. It can be additionally used for use-case specific filtering of echo data by the customer, e.g. when only highly reflective surfaces are intended to be seen. Depending on the object, its properties and location, normalized amplitude values can range from 8 to about 35 bins. **Stabilized echo data** In addition to the above-mentioned echo data, the first object echo distance and amplitude is processed by a special filter providing a higher signal stability in case the sensor loses the object temporarily or an implausible change of the echo distance occurs. This output offers more convenience for the data post-processing on the customer system but also leads to somewhat higher latency times. More information on this filter can be found in section 4.1.4.
Cross echo data (Premium)	The cross echo data is only provided during calibration mode and is only of interest when the object localization functionality shall be used. Similar, to the direct echo data, the two closest cross echo distances and amplitudes are displayed on the system output. The right and left cross echo of a specific sensor refers to a cross echo that was received by this sensor but transmitted by its right and left neighbor, respectively.
Object data (Premium)	The object data that is created from the distance measurements of sensor system (see section 4.1.5) consist of the following: • **Object type**, i.e. point or line object • **X-Y coordinates**: 2 coordinate point are provided per object. For point object, the first and second point are equal. The coordinates are given in a fixed coordinate system that is determined by the configured sensor positions. The possible range is -20 to 20 m in both directions. • **Existence probability** of object – can be used for customer-specific processing and filtering of the data • **Object ID** – The object ID that is assigned to each created object can be used for tracking of the respective object. The ID ranges from 1 to 20. Note that in case of fast moving objects or jumping reflection points, the ID of an object can change.

	A maximum number of 20 objects can be displayed on the system output. The priorization of objects is performed based on the distance to the sensors.
Detection range (Entry/Premium)	The system provides an estimate of the current maximum detection range for a reference object (pole with a diameter of 75 mm). This estimate is based on the current noise level in the environment as described in section 4.1.6.
Sensor blindness (Entry/Premium)	As described in more detail in section 4.1.6, the system is capable of detecting if a sensor has become blind due to severe contamination of the sensor membrane.
Failure indication (Entry/Premium)	Failure handling is described in section 4.1.19.

Table 9 Functional system outputs

4.1.14.2 CAN Matrix

Message name, description and corresponding system variant	Signal name and description		Default CAN-ID	Default J1939-PGN	Average cycle time[a]
USS_DEMsg_Sens_XX: Direct echo data of sensor XX with XX= 01-12 Variant: Entry/Premium	sensXXDe1Distance	1st measured direct echo distance (cm)	XX=01:0x170 XX=02:0x171 XX=03:0x172 XX=04:0x173 XX=05:0x174 XX=06:0x175 XX=07:0x176 XX=08:0x177 XX=09:0x178 XX=10:0x179 XX=11:0x17A XX=12:0x17B	XX=01:0xFF70 XX=02:0xFF71 XX=03:0xFF72 XX=04:0xFF73 XX=05:0xFF74 XX=06:0xFF75 XX=07:0xFF76 XX=08:0xFF77 XX=09:0xFF78 XX=10:0xFF79 XX=11:0xFF7A XX=12:0xFF7B	40 ms
	sensXXDe2Distance	2nd measured direct echo distance (cm)			
	sensXXDe1FilteredDistance	1st measured echo distance with special filter for a stable distance signal (cm)			
	sensXXAmplitude1	amplitude of De1Distance			
	sensXXAmplitude2	amplitude of De2Distance			
	sensXXFilteredAmplitude1	amplitude of De1FilteredDistance			
	MessageCounter_DEMsg_Sens_XX	Alive counter of the message. Rolling counter, increase at each sending from 0 to 3			
	CRC_DEMsg_Sens_XX	Message cyclic redundancy check according SAE1850			
Auromotive CAN: **USS_CEMsg_Sens_XX[b]** J1939: **USS_CE_Left[b] & USS_CE_Right[b]:** Cross echo data of sensor XX with XX= 01-12 Variant: Premium	sensXXCeLeft1Distance	1st measured distance from left cross echo (cm)	: XX=01:0x190 XX=02:0x191 XX=03:0x192 XX=04:0x193 XX=05:0x194 XX=06:0x195 XX=07:0x196 XX=08:0x197 XX=09:0x198 XX=10:0x199 XX=11:0x19A XX=12:0x19B	USS_CE_Left (only left cross echoes): 0xFFA0 USS_CE_Right (only right cross echoes): 0xFFA1	Automotiv eCAN: 100 ms J1939: multiplexe dat 10[c] ms
	sensXXCeLeft2Distance	2st measured distance from left cross echo (cm)			
	sensXXCeLeftAmplitude1	amplitude of CeLeft1Distance			
	sensXXCeLeftAmplitude2	amplitude of CeLeft2Distance			
	sensXXCeRight1Distance	1st measured distance from right cross echo (cm)			
	sensXXCeRight2Distance	2st measured distance from right cross echo (cm)			
	sensXXCeRightAmplitude1	amplitude of CeRight1Distance			
	sensXXCeRightAmplitude2	amplitude of CeRight2Distance			

	Multiplex_ID_CE_Left (J13939)	Multiplexer used on J1939 for signal identification			
	Multiplex_ID_CE_Right (J13939)	Multiplexer used on J1939 for signal identification			
USS_MAP_OBJ_NN : Object data NN=01-10 (in total 20 objects due to multiplexing) Variant: Premium	Multiplex_ID_ **NN**	multiplexer/offset for object identification: 0x00 : **MM=NN+0** 0x01 : **MM=NN+10**	NN=01:0x180 NN=02:0x181 NN=03:0x182 NN=04:0x183 NN=05:0x184 NN=06:0x185 NN=07:0x186 NN=08:0x187 NN=09:0x188 NN=10:0x189	NN=01:0xFF80 NN =02:0xFF81 NN =03:0xFF82 NN =04:0xFF83 NN =05:0xFF84 NN =06:0xFF85 NN =07:0xFF86 NN =08:0xFF87 NN =09:0xFF88 NN =10:0xFF89	Multiplexe dat 20^{d} ms
	MAP_ MM _ObjectType	Object type: 0x0: None 0x1: Point 0x2: Line			
	MAP_ MM _ExistProbability	existence probability of object 0x0: 0% 0x1: 17% 0x2: 23% 0x3: 30% 0x4: 40% 0x5: 60% 0x6: 80% 0x7: 100%			
	MAP_ MM _1st PointX	X coordinate of the first point of the object (cm			
	MAP_ MM _1st PointY	Y coordinate of the first point of the object (cm)			
	MAP_ MM _2ndPointX	X coordinate of the second point of the object (cm) (equal to MAP_NN_1stPointX for point objects)			
	MAP_ MM _2ndPointY	Y coordinate of the second point of the object (cm) (equal to MAP_NN_1stPointY for point objects)			
	MessageCounter_Map_Obj_MM	Alive counter of the message. Rolling counter, increase at each sending from 0 to 3			
	CRC_Map_Obj_MM	message cyclic redundancy check according SAE1850			
USS_InfoSignal:	FailureStatus	Indicating whether a failure is present in which case the measurement functionalities are fully degraded			
	SensorFaulted	Bitfield indication which sensors are faulted. Example: Sensor 1 and 8 is faulted, i.e. SensorFaulted=129 (decimal), 0000 1000 0001 (binary)			
	SensorBlindnessInfo	Bitfield indicating which sensors are blind. Example: Sensor 4 and 10 is blind, i.e. SensorBlindnessInfo =520 (decimal), 0010 0000 1000 (binary)			
	OperatingModeInfo:	Active operation mode: 0: Full Mode 1: Direct Echo Mode 2: Object Localization Mode			

Message with status information Variant: Entry/Premium		3: Calibration Mode 4: Calibration Light Mode	0x17C	0xFF7C	40 ms
	NumberSensorsInfo	Configured number of sensors			
	SendingPatternInfo	Active sending pattern Possible values: 0x00-0x03, See 4.1.16			
	SensitivityInfo	Active sensitivity and filtering setting: Possible values: 0x00-0x04, See 4.1.16			
	OutsideTemperatureInfo	: Currently considered temperature value by the measurement system			
	MessageCounter	Alive counter of the message. Rolling counter, increase at each sending from 0 to 3			
	CRC	Message cyclic redundancy check according SAE1850.			
USS_MaxDetRange: Current sensor detection range Variant: Entry/Premium	sensXX_MaxDetRange XX – sensor ID 01-12	Maximum estimated detection range of all sensor (sensor ID <XX>: 01-12). This estimation is mainly based on the prevailing noise level in the environment	0x17D	0xFF7D	40 ms
	MessageCounter_MaxDetRange	Alive counter of the message. Rolling counter, increase at each sending from 0 to 3			
	CRC_MaxDetRange	Message cyclic redundancy check according SAE1850			

a) By design, CAN frames are sent on trigger every N-10 ms cycles. As a result, the cycle time can vary (typically <±5 ms, max. ±10 ms)
b) Left cross echoes refer to echoes that were transmitted by the left neighbor of a specific sensor, i.e. the sensor with the next smallest ID. Right cross echoes refer to echoes that were transmitted by the right neighbor of a specific sensor, i.e. the sensor with the next highest ID. Note that some do not have right/left neighbors (e.g. sensor 1 does not have a left neighbor, if 6 sensors are configured sensor 6 does not have a right neighbor, etc.).
c) Message is sent roughly every 10ms but signals corresponding to the individual sensors are sent every 110ms due to multiplexing
d) Message is sent roughly every 20ms but signals corresponding to the individual objects (1-20) are sent every 40ms due to multiplexing

Table 10 CAN output signals

Messages related to inactive sensors (deactivated by configuration) will not be transmitted. More details on the CAN message layout can be found in the referenced dbc-file.

It is in the customer’s responsibility to ensure to avoid CAN ID collisions.

4.1.15 Functional system input

4.1.15.1 Description

Functional input	Description
Ambient temperature	For the highest accuracy of the distance measurement, the ambient temperature is required (see section 4.1.11 for temperature effect). For this purpose, either a

	configurable default temperature can be set or the real value measured by an external sensor can be provided over CAN (see section 4.1.18.2). The default setting is a constant ambient temperature of 20°C. Note that the performance of the sensor blindness detection and maximum detection range estimation is best when the actual outside temperature is provided (see section 4.1.6).

Table 11 Description of system operating modes

4.1.15.2 CAN Matrix

Message name and description	Signal name and description		CAN ID	J1939-PGN	Cycle time (ms)
msgVehicleData1: Input Message from customer	OutsideTemperature	Input signal for outside temperature used for accurate distance calculation. This input has to be enabled via the diagnostic service. Acceptable range: -40°C < T < 85°C	0xB500000	0xFFD0	100
	MessageCounter_msgVehicleData1	Alive counter of the message. Rolling counter, increase at each sending from 0 to 3			
	CRC_msgVehicleData1	Message cyclic redundancy check according SAE1850			

Table 12 CAN input signals

If the system has been configured to use the temperature information sent on the message msgVehicleData1 (see section 4.1.18.2), the USS ECU will monitor failures related to this message and react accordingly. If the system repeatedly detects timeouts on this message, a CRC or message counter mismatch, or the temperature value is out of the allowed range, the measurement system will be fully degraded and a DTC will be written to the failure memory.4.1.18.2), the USS ECU will monitor failures related to this message and react accordingly. If the system repeatedly detects timeouts on this message, a CRC or message counter mismatch, or the temperature value is out of the allowed range, the measurement system will be fully degraded and a DTC will be written to the failure memory.

More details on the CAN message layout can be found in the referenced dbc-file.

It is in the customer’s responsibility to ensure to avoid CAN ID collisions.

4.1.16 Configurable system parameters

The USS system offers a variety of possible settings, allowing the customer to adjust the system configuration and its behaviour according to the specific requirements of the application. A basic description of these parameters and the conditions under which certain settings might be useful is given in the following.

General system configuration

- **Sensor configuration** – The system is configurable to operate with 4, 6, 8, or 12 (default) sensors. The number of sensors should be chosen based on the total area where distance sensing and/or object localization is required without introducing interference effects between the sensors (see section 6.2).
- **System operating mode** – Selection of functional system output as described in section 4.1.13.
  - **Ambient temperature** – For the highest accuracy of the distance measurement, the ambient temperature is required (see section 4.1.11 for temperature effect). For this purpose, either a configurable default temperature can be set or the real value measured by an external sensor can be provided over CAN (see sections 4.1.15 and 4.1.18). The default setting is a constant ambient temperature of 20°C.
- **Data interface** – Automotive CAN or J1939 (default)
- **CAN speed** – 250 kBaud (default) or 500 kBaud
- **CAN ID** – The ID of the CAN messages can be changed by an configurable offset (only on automotive CAN)
- **PGN ID –** On J1939, the PGN of each transmitted and received USS frames can be individually configured.

Installation-related parameters (variant depending)

- **Sensor position and orientation (Premium variant only)** – This configuration is only required if the object localization functionality is used. For the sensor position, only the X- and Y coordinate has to be configured for all active sensors. With regard to the orientation of the sensor, only the installation angle in the horizontal (X-Y) plane needs to be configured (see Figure 22).

  The coordinate system of the object map is always defined according to the configured sensor positions. However, it should be noted that the possible range for the object coordinates lies in between -20 and 20 m in both directions. Thus, the sensor positions (and accordingly the origin of the coordinate system should be defined in such way that all possible object position are located within the allowed range. If a coordinate transformation is necessary, e.g .into a specific vehicle coordinate system, this has to be done on the customer system.

  The sensor layout must be set in a clockwise manner so that the sensor with the higher ID is right to the sensor with the lower ID (see Figure 22).

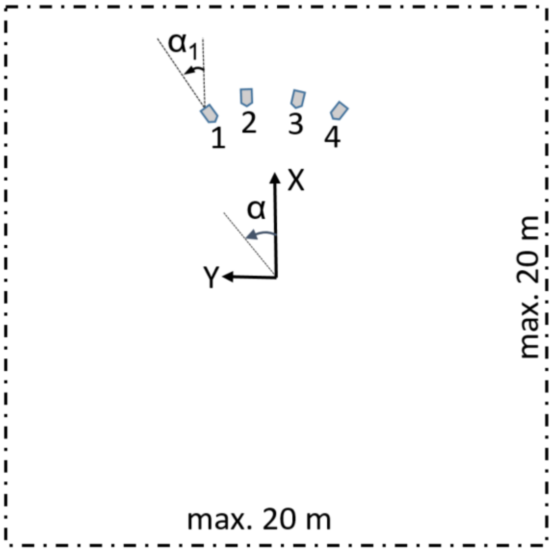


Figure 22 Definition of coordinate system together with exemplary sensor position (1-4).

- **Vehicle contour (Premium variant only)** – A rough approximation of the vehicle contour is used to estimate the distance of the detected objects to the vehicle, which in turn is internally used for object prioritization in case the object buffer has reached its limit (max. 20 objects). In this case, the closest objects are prioritized over more distant objects. In addition, objects which are positioned inside of the vehicle contour are treated as implausible and are accordingly filtered out.

The vehicle contour is a simplified model of the vehicle and assumes symmetry with respect to the x-axis (see Figure 23). It consists of following parameters: the length of the vehicle which is divided into the front and rear length, the half width of the vehicle, and the corner radius for the front and rear side, respectively. The corner radius defines a circular segment at the corner of the vehicle which is tangential to the two perpendicular vehicle sides, thus it sweeps 90°. Note that the vehicle contour parameters are defined with respect to the used coordinate system, which origin is defined according the configured sensor position coordinates.

The vehicle contour should approximate the real vehicle contour as good as possible but must not be larger than the real contour as object that are positioned within the configured contour are filtered out. An example is shown in Figure 23, where the outer green and blue lines enclose the configured vehicle shape. As can be seen at the rear corners of the excavator, the configured contour is slightly smaller than the real vehicle contour. In case of asymmetric vehicles, either a smaller vehicle contour should be configured or, alternatively, the coordinate system (defined by the sensor coordinates) could be shifted to a point where a symmetric vehicle contour model better reflects the real vehicle contour.

When no vehicle contour is configured, the origin of the coordinate system is used for object distance estimation and object prioritization (not recommended).

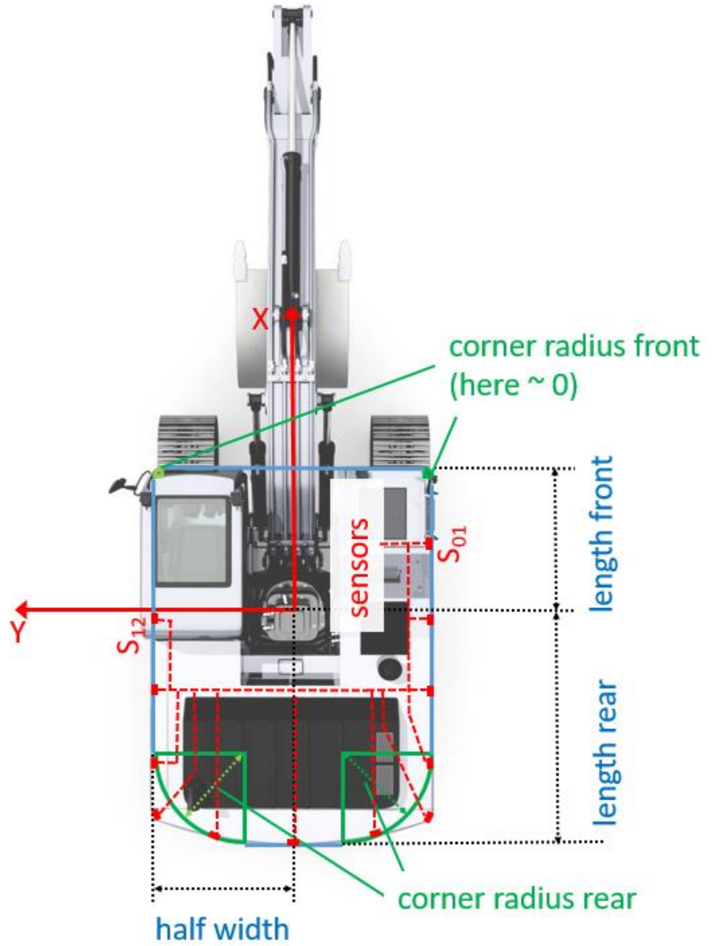


Figure 23 Simplified vehicle contour exemplified for an excavator

- **Direct (Entry/Premium) and cross echo filter box (Premium only)** – Filter boxes can be configured for individual sensor and sensor pairs to ignore echoes (direct and cross echoes) in a certain distance and amplitude range. The main purpose of those filter boxes is to filter out echoes originating from static machine or vehicle parts in the vicinity of the sensor.

  There a two filter boxes available for each sensor to filter out direct echoes and two filter boxes for each sensor pair to mask out cross echoes. The latter is only relevant for applications that use the object localization functionality. The filter box consists of a start distance '$Dist_{start}$', an end distance '$Dist_{end}$', and an upper amplitude limit 'Amp_{lim}' (see Figure 24). Echoes that fall into this distance range and have an amplitude smaller than the specified amplitude limit, will be filtered out. Since echoes that are reflected by near field objects are often on the side of the sensor field of view, their amplitude is usually small. By setting an appropriate limit for the amplitude of the filter box, these near field objects can be ignored without filtering out real objects in the same distance range with typically higher amplitudes (see Figure 24). When the amplitude limit is set to the maximum allowed value, all echoes of the specified distance range are ignored.

  It is generally recommended to apply a certain margins for the filter box distance and amplitude values to account for changing conditions (environmental effects, machine tolerances, installation tolerances, vibrations etc.). Under some circumstances it is possible the multi-reflections between the sensor and the object that should be filtered out occur. In these cases, only filtering out the real object distance might not be sufficient so that a larger filter box or a second filter box is necessary.

Note that the feature of presence detection and active damping (section 4.1.6) is not functional if the filter box is configured in the very near range (approx. less than 35 cm).

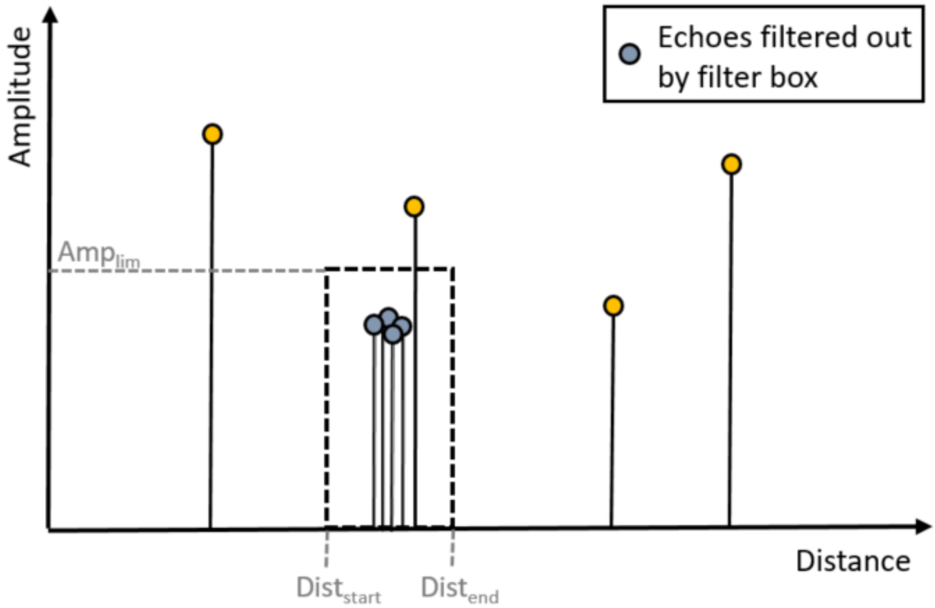


Figure 24 Principle of distance filter box

- **Cross echo idle distance (Premium only)** – Configuration of the idle distances is only relevant for applications which use the object localization functionality. The purpose of these parameters is to filter out cross echoes which are not reflected by objects but are directly travelling from a transmitting sensor to its neighbour that is receiving that ultrasound. The idle distance can be defined as the shortest direct path of the ultrasound travelling between the sensor pair along the contour of the vehicle/machine (see example in Figure 25). Cross echo distances that are equal or smaller than the idle distance are filtered out accordingly. As the cross echo distance of real objects is always larger than the idle distance, no real object echoes are removed by this filter (see Figure 25).

The idle distance needs to be configured for each active sensor pair (e.g. sensor pairs 1 and 2, 2 and 3, 3 and 4 etc.) and can be easily determined by measuring the distance between the sensor pairs along the contour of the vehicle or machine with a measuring tape. The measurement should be taken from the centre of the respective sensor to the centre of its neighbouring sensor. No tolerances need to be taken into account as this is already considered internally by the SW.

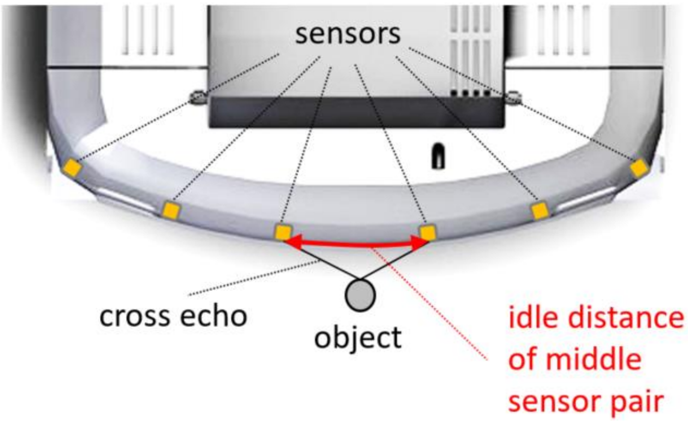


Figure 25 Illustration of the idle distance of the middle sensor pair mounted at the rear of an excavator

Performance-related parameters

- **Sending pattern and sending codes** – As previously mentioned, different ultrasonic sending codes with different performance features exist. In this product, different combinations of sending codes and sending sequences/patterns are configurable, allowing for use-case specific tailoring of the system performance (distance range, dynamic object detection in near and far range, noise suppression). Four different settings with following features are available.

#	Main focus	Range	Description	Measurement rate per sensor	Presence Detection and Active Damping
0 default	Near range performance (d<1.5/2 m)	12 to 550 cm	- Smallest minimum measurable distance - At d< 2 m, best detection of small objects that are in front of large objects - Highest measurement rate in the near range - Lowest measurement rate in far range, thus worse detection of dynamic objects in that range	Near range (d<1.5 m): ~in average every 120 ms Far range (d>2 m) ~every 240 ms	yes
1	Far range	18*) to 550 cm	- due to long send pulse, small object in front of large objects might be suppressed - Best robustness against disturbances from ultrasonic interference sources - Higher measurement rate for far range than default configuration , thus faster detection of dynamic objects in that range - Good cross talk suppression between simultaneously transmitting sensors	~every 165 ms	no

2	Far range	18*) to 550 cm	- small object in front of large objects similar to #1 - High measurement rate and fast dynamic object detection similar to #1 - Slightly better cross talk suppression between simultaneously transmitting sensors than #1 - Slightly larger field of view compared to #1	~every 165 ms	no
3	Far range	19*) to 500 cm	- small object in front of large objects worse than #1 - High measurement rate and fast dynamic object detection similar to #1 and #2 - Best cross talk suppression between simultaneously transmitting sensors - Field of view and detection range smaller than #1 and #2	~every 165 ms	no

Table 13 Configuration of sending pattern and sending codes

**) Since Active Damping is not available for this setting, a constant value of the minimum distance cannot be guaranteed. Aging and temperature can lead to an increase of several centimeters.*

When the object localization functionality is used, a faster update rate can be expected since the detected object is based on the combined data of multiple sensors. The resulting measurement rate depends on the sensor installation at the machine, which has a major effect on the detectability of an object by direct and cross echoes of different sensors. Typically, the rate can become about three times higher than the sensor-specific measurement rate. In certain situations, the object can only be updated by the measurement data of a specific sensor, in which case the sensor-specific update rate is applicable.

- **Sensitivity and filtering settings** – The sensitivity of the sensor and the amount of subsequent filtering is configurable to enable an optimal adaption to the use case specific environment (e.g. ground noise suppression). Following settings are available:

#	Main feature	Description
0 default	Very high sensor sensitivity Low filtering	The sensitivity of the sensor is very high, i.e. the adaptive threshold is low. The amount of echo filtering is low. Setting recommended when the amount of false positives is low or acceptable
1	High sensor sensitivity Low filtering	The sensitivity of the senor is a bit lower by increasing the adaptive threshold. The amount of filtering is low as for #0 This setting can be used to lower the false positive rate (e.g. due to irrelevant ground reflections)
2	Medium sensor sensitivity Low filtering	Lowest sensor sensitivity option, i.e. the adaptive threshold is higher than for setting #0 and #1. The amount of filtering is low as for #0. This setting can be used to lower the false positive rate (e.g. due to irrelevant ground reflections)

3	Medium sensor sensitivity Stronger filtering of filtered distance signal	Lowest sensor sensitivity option (same as #2), i.e. the adaptive threshold is higher than for setting #1 and #2. The amount of filtering is higher for the filtered distance output, i.e. the distance which is processed by the additional stability filter. It generally affects the validation of echoes during first detection. This setting is recommend to achieve a low false positive rate in case setting #1 and #2 is not sufficient. The setting can lead to an additional delay in the first detection time.
4	Medium sensor sensitivity Stronger filtering (all outputs)	Lowest sensor sensitivity option (same as #2), i.e. the adaptive threshold is higher than for setting #1 and #2. The amount of filtering is higher for all functional outputs. Generally, echoes with a weak signature need to be detected before being validated. This setting is recommend to achieve a low false positive rate in case setting #1 and #2 is not sufficient for the respective use case. It provides a high robustness against noise and disturbances from other ultrasonic sources. Note that this setting can lead to an additional delay in the first detection and a lower detection rate.
5	Very high sensor sensitivity Stronger filtering /all outputs)	The sensitivity of the sensor is very high (same as setting #0, i.e. the adaptive threshold is low. The amount of filtering is higher for all functional outputs. It affects all type of echoes (weak/strong) and requires multiple echo detection for validation. This setting is recommend to achieve a low false positive rate but maintain the highest possible sensitivity. It provides a high robustness against noise and disturbances from other ultrasonic sources. Note that this setting leads to an additional delay in the first detection and might cause lower detection rates. It is not recommended for application with a very high demand on short first detection times or distances.

Table 14 Sensitivity and filtering settings

- **Maximum distance for object creation** – A maximum echo distance can be defined beyond which neither direct echoes nor cross echoes are considered for the object creation. The purpose of this parameter is to limit the detection range of the system, which can be useful for particular use cases. The echo clipping distance is configured for the entire system and not for each sensor individually.

  Note that this parameter has no effect on the direct echo distance data provided on the output but only on the object data. Filtering out of direct echo distance zones for each individual sensor can alternatively be conducted via the distance filter box explained above (two filter boxes per sensor configurable).
- **Minimum distance for restricted object creation** – With this parameter a threshold distance for direct and cross echoes can be defined above which object creation become more difficult. The main purpose of this setting is to limit the false positive rate

in the far range which occur in particular use cases due to ground reflections. This feature is designed so that echoes with distances above the configured threshold must be detected very stable over time and the corresponding object has to move a bit for the first object creation. The latter condition is due to the fact that completely static object can often be attributed to ground noise.

Note that the direct echo data on the system output is not affected by this setting.

4.1.17 J1939 Interface description

The USS ECU supports the SAE J1939 CAN protocol. In the following sections, the J1939 interface is described in detail.

4.1.17.1 Source address and address claiming

Source Address for address claim of J1939 shall have below range addresses:

- 0...127 Preferred address range
- 128...247 Arbitrary address range
- 248...253 Preferred address range

If the Source Address is set to a value between 0 to 127 and 248-253, the used USS ECU Address claim procedure is:

a. At Power ON USS ECU sends Address claim message
b. regular network communication can start with claimed address
c. if new ECU with Higher priority name claims Address conflicting to USS OHW Premium ECU address, then next Address is claimed by USS ECU within the range 128 to 247
d. If Address claim successful, then regular network communication will start immediately, new Address claimed is updated into the NVM
e. if Address cannot be claimed then USS ECU will Send a Cannot Claim Address Message to inform all other CAs that it is no longer able to take part in the network communication.

If Source Address is set to a value between 128 to 247, the used USS ECU Address claim procedure is described below:

a. At Power ON USS ECU sends Address claim message
b. wait 250ms after successful address claim on power up before sending any other messages, during this if conflict then arbitrate if necessary
c. After 250ms regular network communication can start with claimed address
d. After 250ms, if new ECU with Higher priority name claims Address conflicting to USS ECU address, then next Address is claimed by USS ECU within the range 128 to 247
e. If Address claim successful, then regular network communication will start immediately, new Address claimed is updated into the NVM
f. if Address cannot be claimed then USS will Send a Cannot Claim Address Message to inform all other CAs that it is no longer able to take part in the network communication.

The default source address of the USS ECU is 0x98 (150 in decimal). The USS ECU is capable of claiming a different source address if the default one is not available. Therefore, it is also possible to use multiple USS ECU in a J1939 network as they will automatically claim unused addresses.

4.1.17.2 USS ECU Name

The USS ECU NAME field is filled with the following data:

NAME	Field value	Value Source
Arbitrary Address Capable	0x1	Fixed in ROM
Industry Group	User configurable	NVM to be set with DID 0x6002 See 4.1.18.2
Vehicle System Instance	User configurable	NVM to be set with DID 0x6003 See 4.1.18.2
Vehicle System	User configurable	NVM to be set with DID 0x6004 See 4.1.18.2
Function	User configurable	NVM to be set with DID 0x6005 See 4.1.18.2
Function Instance	User configurable	NVM to be set with DID 0x6006 See 4.1.18.2
ECU instance	User configurable	NVM to be set with DID 0x6007 See 4.1.18.2
Manufacture code	51(dec) 33(hex)	Fixed in ROM
Identity number	ECU Serial Number in (hex) Set in plant	NVM See 4.1.18.2

4.1.17.3 PGN

4.1.17.3.1 Standard PGN

PGN 65242 (0xFEDA) Software identification

SPN	Signal Name	Length	Type	Field value	Value source
965	Number of Software Identification Fields	1 byte	Hex	0x02	Fixed in ROM
234	Software Identification	Variable	Ascii	See next	Fixed in ROM Same as DID 0xF195 and 0xF188 See 4.1.18.2

PGN 64965 (0xFDC5) ECU Identification Information

SPN	Signal Name	Length	Type	Field value	Value source
2901	ECU part number	10 bytes	Ascii	See next	Same as DID 0xF192 See 4.1.18.2
2902	ECU Serial number	8 bytes	Ascii	See next	Same as DID 0xF18C See 4.1.18.2
2903	ECU Location				
2904	ECU Type		Ascii		Fixed in ROM
4304	ECU Manufacturer Name		Ascii		Fixed in ROM
6714	ECU Hardware ID	20 bytes	Ascii	See next	Same as DID 0xF191 See 4.1.18.2

PGN 65240 (0xFED8) Commanded Address

SPN	Signal Name	Bit Pos	Length (bits)
2837	Identity Number	0	21 bits
2838	Manufacturer Code	21	11 bits
2840	ECU Instance	32	3 bits
2839	Function Instance	35	5 bits
2841	Function	40	8 bits
	Reserved	48	1
2842	Vehicle System	49	7 bits

2843	Vehicle System Instance	56	4 bits
2846	Industry Group	60	3 bits
2844	Arbitrary Address Capable	63	1 bit
2847	New Source Address	64	8 bits

PGN 60928 (0xEE00) Address Claimed

SPN	Signal Name	Bit Pos	Length (bits)
2837	Identity Number	0	21 bits
2838	Manufacturer Code	21	11 bits
2840	ECU Instance	32	3 bits
2839	Function Instance	35	5 bits
2841	Function	40	8 bits
	Reserved	48	1 bits
2842	Vehicle System	49	7 bits
2843	Vehicle System Instance	56	4 bits
2846	Industry Group	60	3 bits
2844	Arbitrary Address Capable	63	1 bits

More details can be found in section 4.1.17.2

PGN 59904 (0xEA00) Request PGN

SPN	Signal Name	Bit Pos	Length
2540	Parameter Group Number (RQST)	0	24 bits

Following PGN can be requested :

PGN 65242 (0xFEDA) Software identification

PGN 65965 (0xFDC5) ECU Identification Information

PGN 65289 (FF09) TLA message

PGN 60928 Address Claimed

DM01 Active DTC

DM02 Previoulsy Active DTC

DM03 Clear Previoulsy Active DTC

PGN 65226 (0xFECA) Active DTC

The USS ECU sends the list of active DTCs. DTCs are considered as active when DTCs are present and confirmed.

PGN 65227 (0xFECB) Previously Active DTC

The USS ECU sends the list of previously active DTCs. DTCs are considered as previously active when DTCs are not present anymore but have been confirmed earlier.

PGN 65228 (0xFECC) Clear Previously Active DTC's

SW 03.00.00 or lower: Requesting DM03 PGN will erase a single previously active diagnostic trouble code only. For clearing [n] previously active diagnostic trouble codes the DM03 PGN needs to be requested [n+1] times. The final call will acknowledge the clearing of all active diagnostic trouble codes with a positive response.

SW 03.00.01 or higher: All diagnostic information pertaining to the previously active trouble codes
are erased when DM03 PGN is requested.
Note (For all SW versions): All previously active diagnostic trouble codes will be erased automatically after 40 power cycles.

4.1.17.3.2 Proprietary PGN

Note that the cycle rates listed for the transmitted frames below is an average value. By design,the frames are sent on trigger every N-10 ms cycles. As a result, the cycle rate can vary (typically <±5 ms, max. ±10 ms).

The PGN stated below for all transmit messages as well as for the receive message ‘msgVehicleData1 refer to the default settings and can be reconfigured to use a different PGNID (see section 4.1.18.2).

PGN 65392 – PGN 65403 (FF70 - FF7B) Direct Echo Sensor 01 - Direct Echo Sensor 12

Signal Name	Bit Pos	Len	Byte order	Fact	Off	Min	Max	Unit	Direction	Cyc Tx	Cyc rate
sensXDe1Distance	0	10	Intel	1	0	0	1023	cm	Transmit	Yes	40ms
sensXDe2Distance	10	10	Intel	1	0	0	1023	cm	Transmit	Yes	40ms
sensXDe1FilteredDistance	20	10	Intel	1	0	0	1023	cm	Transmit	Yes	40ms
sensXAmplitude1	30	6	Intel	1	0	0	63		Transmit	Yes	40ms
sensXAmplitude2	36	6	Intel	1	0	0	63		Transmit	Yes	40ms
sensXFilteredAmplitude1	42	6	Intel	1	0	0	63		Transmit	Yes	40ms
CRC_DeMsg_sensX	48	8	Intel	1	0	0	255		Transmit	Yes	40ms
MessageCounter_DeMsg_sensX	56	2	Intel	1	0	0	3		Transmit	Yes	40ms

For more details refer to section 4.1.14.2.

PGN 65404 (FF7C) USS Info Signal

Signal Name	Bit Pos	Len	Byte order	Fact	Off	Min	Max	Unit	Direction	Cyc Tx	Cyc rate
NumberSensorsInfo	0	4	Intel	1	0	0	15		Transmit	Yes	40ms

SendingPatternInfo	4	2	Intel	1	0	0	3		Transmit	Yes	40ms
OperatingModeInfo	6	3	Intel	1	0	0	7		Transmit	Yes	40ms
OutsideTemperature Info	9	8	Intel	1	-40	-40	215		Transmit	Yes	40ms
SensorBlindnessInfo	17	12	Intel	1	0	0	4095		Transmit	Yes	40ms
SensitivityInfo	29	3	Intel	1	0	0	7		Transmit	Yes	40ms
SensorFaulted	32	12	Intel	1	0	0	4095		Transmit	Yes	40ms
MessageCntr_USSInfoSig	44	2	Intel	1	0	0	3		Transmit	Yes	40ms
FailureStatus	46	1	Intel	1	0	0	1		Transmit	Yes	40ms
CRC_USSInfoSig	56	8	Intel	1	0	0	255		Transmit	Yes	40ms

For more details refer to section 4.1.14.2.

PGN 65405 (FF7D) USS Max Detection Range

Signal Name	**Bit Pos**	**Len**	**Byte order**	**Fact**	**Off**	**Min**	**Max**	**Unit**	**Direction**	**Avg cyc rate**
Sens01_MaxDetRange	0	4	Intel	36.667	0	0	550.005	cm	Transmit	40ms
Sens02_MaxDetRange	4	4	Intel	36.667	0	0	550.005	cm	Transmit	40ms
Sens03_MaxDetRange	8	4	Intel	36.667	0	0	550.005	Cm	Transmit	40ms
Sens04_MaxDetRange	12	4	Intel	36.667	0	0	550.005	cm	Transmit	40ms
Sens05_MaxDetRange	16	4	Intel	36.667	0	0	550.005	cm	Transmit	40ms
Sens06_MaxDetRange	20	4	Intel	36.667	0	0	550.005	cm	Transmit	40ms
Sens07_MaxDetRange	24	4	Intel	36.667	0	0	550.005	cm	Transmit	40ms
Sens08_MaxDetRange	28	4	Intel	36.667	0	0	550.005	cm	Transmit	40ms
Sens09_MaxDetRange	32	4	Intel	36.667	0	0	550.005	cm	Transmit	40ms
Sens10_MaxDetRange	36	4	Intel	36.667	0	0	550.005	cm	Transmit	40ms
Sens11_MaxDetRange	40	4	Intel	36.667	0	0	550.005	cm	Transmit	40ms
Sens12_MaxDetRange	44	4	Intel	36.667	0	0	550.005	cm	Transmit	40ms
MessageCounter_MaxDe tRange	48	2	Intel	1	0	0	3		Transmit	40ms
CRC_MaxDetRange	56	8	Intel	1	0	0	255		Transmit	40ms

For more details refer to section 4.1.14.2.

PGN 65440 - 65451 (FFA0) Cross Echo Message Left (sensors 2-12) – Premium variant

Signal Name*	**Bit Pos**	**Len**	**Byte order**	**Fact**	**Off**	**Min**	**Max**	**Unit**	**Direction**	**Avg cyc rate**
sensXXCeLeft1Distance	0	10	Intel	0	0	0	1023	cm	Transmit	110ms

sensXXCeLeftAmplitude1	10	6	Intel	0	0	0	63		Transmit	110ms
sensXXCeLeft2Distance	16	10	Intel	0	0	0	1023	cm	Transmit	110ms
sensXXCeLeftAmplitude2	26	6	Intel	0	0	0	63		Transmit	110ms
Multiplex_ID_CE_Left	32	4	Intel	0	0	0	15		Transmit	10ms

*) Sensor-specific data (XX=2…12) is multiplexed based on the value of the signal Multiplex_ID_CE_Left.

For more details refer to section 4.1.14.2.

PGN 65408 (FFA1) Cross Echo Message Right (sensor 1-11) – Premium variant

Signal Name*	**Bit Pos**	**Len**	**Byte order**	**Fact**	**Off**	**Min**	**Max**	**Unit**	**Direction**	**Avg cyc rate**
sensXXCeRight1Distance	0	10	Intel	0	0	0	1023	cm	Transmit	110ms
sensXXCeRightAmplitude1	10	6	Intel	0	0	0	63		Transmit	110ms
sensXXCeRight2Distance	16	10	Intel	0	0	0	1023	cm	Transmit	110ms
sensXXCeRightAmplitude2	26	6	Intel	0	0	0	63		Transmit	110ms
Multiplex_ID_CE_Right	32	4	Intel	0	0	0	15		Transmit	10ms

*) Sensor-specific data (XX=1…11) is multiplexed based on the value of the signal Multiplex_ID_CE_Right.

PGN 65408 - 65418 (FF80 - FF89) MAP OBJECTS 01 - MAP OBJECTS 20* – Premium variant only

Signal Name*	**Bit Pos**	**Len**	**Byte order**	**Fact**	**Off**	**Min**	**Max**	**Unit**	**Direction**	**Avg cyc rate**
MAP_0X_1stPointX	0	10	Intel	2	0	-1024	1022	cm	Transmit	40ms
MAP_1X_1stPointX	0	10	Intel	2	0	-1024	1022	cm	Transmit	40ms
MAP_0X_1stPointY	10	10	Intel	2	0	-1024	1022	cm	Transmit	40ms
MAP_1X_1stPointY	10	10	Intel	2	0	-1024	1022	cm	Transmit	40ms
MAP_0X_ExistProbability	20	3	Intel	1	0	0	7		Transmit	40ms
MAP_1X_ExistProbability	20	3	Intel	1	0	0	7		Transmit	40ms
MAP_0X_2ndPointX	23	10	Intel	2	0	-1024	1022	cm	Transmit	40ms
MAP_1X_2ndPointX	23	10	Intel	2	0	-1024	1022	cm	Transmit	40ms
MAP_0X_2ndPointY	33	10	Intel	2	0	-1024	1022	cm	Transmit	40ms
MAP_1X_2ndPointY	33	10	Intel	2	0	-1024	1022	cm	Transmit	40ms
Multiplex_ID_X	43	1	Intel	1	0	0	1		Transmit	20ms
MAP_0X_ObjectType	44	2	Intel	1	0	0	3		Transmit	40ms
MAP_1X_ObjectType	44	2	Intel	1	0	0	3		Transmit	40ms
MessageCounter_Map_Obj_X	54	2	Intel	1	0	0	3		Transmit	40ms
CRC_0X_Map_Obj	56	8	Intel	1	0	0	255		Transmit	40ms
CRC_1X_Map_Obj	56	8	Intel	1	0	0	255		Transmit	40ms

*) There are 10 frames available for the object data, each of which is multiplexed/alternated based on thevalue of the signal Multiplex_ID_X (X=01-10), in total transmitting the data of 20 objects. ‘0X’ and ‘1X’ represent data corresponding to objects 1-10 and 11-20, respectively.

‘0X’ represents signals corresponding to Map Object 01-10, while ‘1X’

For more details refer to section 4.1.14.2.

PGN 65289 (FF09) TLA message

Signal Name	Bit Pos	Length	Format	Value
Byte 1	0	8	Ascii	“U”
Byte 2	8	8	Ascii	“S”
Byte 3	16	8	Ascii	“S”

PGN 65488 (FFD0) msgVehicleData1

Signal Name	Bit Pos	Len	Byte order	Fact	Off	Min	Max	Unit	Direction	Cyc time
Outside Temperature	0	7	Intel	1	-40	-40	87	degC	Receive	100ms
MessageCounter_msgVehicleData1	8	2	Intel	1	0	0	3		Receive	100ms
CRC_msgVehicleData1	56	8	Intel	1	0	0	255		Receive	100ms

For more details refer to section 4.1.15.2.

4.1.18 Diagnostic feature

All monitored failures will be stored in the fault memory of the system. Each of these failures are assigned to a Data Trouble Code (DTC) which can be read either through the ISO 14229-1 Unified Diagnostic Services (UDS) protocol or through SAEJ1939 via the DM1 message.

Furthermore, the UDS includes start and stop of the diagnostic mode, reading and writing of specific data, reading and erasing of error memory, and system parameterization/calibration.

The diagnostics interface for writing data is secured via authorization. Detailed information on the authorization method will be included as an additional application note (see section 1)..

To read or write data, a session change to extended session is necessary. Five seconds after changing to the extended session, a change back to the default session occurs locking the system again. However, if a ‘Tester present’ signal is transmitted within those five seconds, the extended session is prolonged. For safety and security reasons, periodic sending of the ‘Tester present’ signal is needed for longer and/or subsequent configuration tasks.

The CAN ID for the diagnostic communication can be modified. By default, the physical address for request to the ECU is 0x18DA7FFA and the response from the ECU is 0x18DAFA7F. The functional address is 0x18DBFFFA.

4.1.18.1 Service ID overview

SID	Name	Additional info
0x10	**Diagnostic session contro**	
0x11	**ECU Reset**	
0x14	**Clear diagnostics information**	

0x19	**Read DTC information**	Diagnostic Trouble Code (see Detailed information on the DTCs will be included as an additional application note (see section 1)
0x22	**Read data by Identifier**	In Default, Programming, extended Diagnostic and end of line session possible
0x23	**Write data by Identifier**	Only possible in End of line session
0x27	**Security Access**	Required for entering in, Programming, Extended and End of line session possible
0x28	**Communication control**	Not supported
0x2E	**Write Data (secured interface)**	Only in Programming, Extended Diagnostic and End of Line session possible
0x3D	**Write Data by address**	Only possible in Enf of line session
0x3E	**Tester Present**	
0x85	**Control DTC setting**	

4.1.18.2 Data ID overview

DID	Variant	Name	Additional info	Read	Write
0x0101	All	Sensors number	0x04: 4 Ch. Setup (S1-S4) 0x06: 6 Ch. Setup (S1-S6) 0x08: 8 Ch. Setup (S1-S8) 0x0C (default): 12 Ch. Setup (S1-S12)	x	x
0x0102	All	Ambient temperature	1 byte : 0xFF (default): Default temperature (20°C) 0xFE : Temperature from the CAN Signal else Temperature (°C): T = x – 40 Range: -40°C ≤ T ≤ 85°C / 0 ≤ x ≤ 125 Resolution: 1°C	x	x
0x1010	All	Sensor sending pattern and sending codes	See section 4.1.16. Possible values: 0x00-0x03 Default; 0x00	x	x
0x1011	All	Sensitivity and filtering setting	See section 4.1.16. Possible values: 0x00-0x05 Default: 0x00	x	x
0x101A	All	Direct Echo Filter Box: sensor 1 box 1	Diststart: bytes 1+2 for start distance in mm, range 0-6000 mm with 1 mm resolution Distend: bytes 3+4 for end distance in mm, rabge 0-6000 mm with 1 mm resolution Amplim: byte 5 for amplitude threshold, range 0-63 bin with resolution of 1 bin Default: 0 (all byes) See section 4.1.16	x	x
0x101B	All	Direct Echo Filter Box: sensor 1 box 2	See 0x101A	x	x
0x102A	All	Direct Echo Filter Box: sensor 2 box 1	See 0x101A	x	x
0x102B	All	Direct Echo Filter Box: sensor 2 box 2	See 0x101A	x	x
0x103A	All	Direct Echo Filter Box: sensor 3 box 1	See 0x101A	x	x
0x103B	All	Direct Echo Filter Box: sensor 3 box 2	See 0x101A	x	x

0x104A	All	Direct Echo Filter Box: sensor 4 box 1	See 0x101A	x	x
0x104B	All	Direct Echo Filter Box: sensor 4 box 2	See 0x101A	x	x
0x105A	All	Direct Echo Filter Box: sensor 5 box 1	See 0x101A	x	x
0x105B	All	Direct Echo Filter Box: sensor 5 box 2	See 0x101A	x	x
0x106A	All	Direct Echo Filter Box: sensor 6 box 1	See 0x101A	x	x
0x106B	All	Direct Echo Filter Box: sensor 6 box 2	See 0x101A	x	x
0x107A	All	Direct Echo Filter Box: sensor 7 box 1	See 0x101A	x	x
0x107B	All	Direct Echo Filter Box: sensor 7 box 2	See 0x101A	x	x
0x108A	All	Direct Echo Filter Box: sensor 8 box 1	See 0x101A	x	x
0x108B	All	Direct Echo Filter Box: sensor 8 box 2	See 0x101A	x	x
0x109A	All	Direct Echo Filter Box: sensor 9 box 1	See 0x101A	x	x
0x109B	All	Direct Echo Filter Box: sensor 9 box 2	See 0x101A	x	x
0x10AA	All	Direct Echo Filter Box: sensor 10 box 1	See 0x101A	x	x
0x10AB	All	Direct Echo Filter Box: sensor 10 box 2	See 0x101A	x	x
0x10BA	All	Direct Echo Filter Box: sensor 11 box 1	See 0x101A	x	x
0x10BB	All	Direct Echo Filter Box: sensor 11 box 2	See 0x101A	x	x
0x10CA	All	Direct Echo Filter Box: sensor 12 box 1	See 0x101A	x	x
0x10CB	All	Direct Echo Filter Box: sensor 12 box 2	See 0x101A	x	x
0x201A	Prem.	Cross Echo Filter Box: sensor pair 1 & 2 box 1	Diststart: bytes 1+2 for start distance in mm, range 0-6000 mm with 1 mm resolution Distend: bytes 3+4 for end distance in mm, range 0-6000 mm with 1 mm resolution Amplim: byte 5 for amplitude threshold, range 0-63 bin with resolution of 1 bin Default: 0 (all bytes) See section 4.1.16	x	x
0x201B	Prem.	Cross Echo Filter Box: sensor pair 1 & 2 box 2	See 0x201A	x	x
0x202A	Prem.	Cross Echo Filter Box: sensor pair 2 & 3 box 1	See 0x201A	x	x
0x202B	Prem.	Cross Echo Filter Box: sensor pair 2 & 3 box 2	See 0x201A	x	x
0x203A	Prem.	Cross Echo Filter Box: sensor pair 3 & 4 box 1	See 0x201A	x	x
0x203B	Prem.	Cross Echo Filter Box: sensor pair 3 & 4 box 2	See 0x201A	x	x
0x204A	Prem.	Cross Echo Filter Box: sensor pair 4 & 5 box 1	See 0x201A	x	x
0x204B	Prem.	Cross Echo Filter Box: sensor pair 4 & 5 box 2	See 0x201A	x	x
0x205A	Prem.	Cross Echo Filter Box: sensor pair 5 & 6 box 1	See 0x201A	x	x
0x205B	Prem.	Cross Echo Filter Box: sensor pair 5 & 6 box 2	See 0x201A	x	x
0x206A	Prem.	Cross Echo Filter Box: sensor pair 6 & 7 box 1	See 0x201A	x	x
0x206B	Prem.	Cross Echo Filter Box: sensor pair 6 & 7 box 2	See 0x201A	x	x
0x207A	Prem.	Cross Echo Filter Box: sensor pair 7 & 8 box 1	See 0x201A	x	x
0x207B	Prem.	Cross Echo Filter Box: sensor pair 7 & 8 box 2	See 0x201A	x	x
0x208A	Prem.	Cross Echo Filter Box: sensor pair 8 & 9 box 1	See 0x201A	x	x
0x208B	Prem.	Cross Echo Filter Box: sensor pair 8 & 9 box 2	See 0x201A	x	x
0x209A	Prem.	Cross Echo Filter Box: sensor pair 9 & 10 box 1	See 0x201A	x	x

0x209B	Prem.	Cross Echo Filter Box: sensor pair 9 & 10 box 2	See 0x201A	x	x
0x20AA	Prem.	Cross Echo Filter Box: sensor pair 10 & 11 box 1	See 0x201A	x	x
0x20AB	Prem.	Cross Echo Filter Box: sensor pair 10 & 11 box 2	See 0x201A	x	x
0x20BA	Prem.	Cross Echo Filter Box: sensor pair 11 & 12 box 1	See 0x201A	x	x
0x20BB	Prem.	Cross Echo Filter Box: sensor pair 11 & 12 box 2	See 0x201A	x	x
0x3001	Prem.	Cross echo idle distance: sensor pair 1 & 2	Distance between the sensor pair along the machine/vehicle contour 2 bytes, 0-6000 mm, resolution 1 mm Default: 0 (all bytes) See section 4.1.16.	x	x
0x3002	Prem.	Cross echo idle distance: sensor pair 2 & 3	See 0x3001	x	x
0x3003	Prem.	Cross echo idle distance: sensor pair 3 & 4	See 0x3001	x	x
0x3004	Prem.	Cross echo idle distance: sensor pair 4 & 5	See 0x3001	x	x
0x3005	Prem.	Cross echo idle distance: sensor pair 5 & 6	See 0x3001	x	x
0x3006	Prem.	Cross echo idle distance: sensor pair 6 & 7	See 0x3001	x	x
0x3007	Prem.	Cross echo idle distance: sensor pair 7 & 8	See 0x3001	x	x
0x3008	Prem.	Cross echo idle distance: sensor pair 8 & 9	See 0x3001	x	x
0x3009	Prem.	Cross echo idle distance: sensor pair 9 & 10	See 0x3001	x	x
0x300A	Prem.	Cross echo idle distance: sensor pair 10 & 11	See 0x3001	x	x
0x300B	Prem.	Cross echo idle distance: sensor pair 11 & 12	See 0x3001	x	x
0x4001	Prem.	Position sensor 1	x-coordinate : bytes 1+2, -32.000-32.000 mm, resolution 1 mm y-coordinate : bytes 3+4, -32.000-32.000 mm, resolution 1 mm Alpha angle: bytes 5+6, 0-360°, Resolution 1° Default: 0 (all bytes) See section 4.1.16	x	x
0x4002	Prem.	Position sensor 2	See 0x4001	x	x
0x4003	Prem.	Position sensor 3	See 0x4001	x	x
0x4004	Prem.	Position sensor 4	See 0x4001	x	x
0x4005	Prem.	Position sensor 5	See 0x4001	x	x
0x4006	Prem.	Position sensor 6	See 0x4001	x	x
0x4007	Prem.	Position sensor 7	See 0x4001	x	x
0x4008	Prem.	Position sensor 8	See 0x4001	x	x
0x4009	Prem.	Position sensor 9	See 0x4001	x	x
0x400A	Prem.	Position sensor 10	See 0x4001	x	x
0x400B	Prem.	Position sensor 11	See 0x4001	x	x
0x400C	Prem.	Position sensor 12	See 0x4001	x	x
0x5001	Prem.	Minimum distance for restricted object creation	Echo distance threshold for restricted object creation 2 bytes: 300-6000 mm, resolution: 1 mm Default: 6000 mm See section 4.1.16.	x	x

0x5002	Prem.	Maximum distance for object creation	Maximum distance for object creation 2 bytes: 300-6000 mm, resolution: 1 mm Default: 6000 mm See section 4.1.16.	x	x
0x6000	All	Active communication	1 byte : 1: CAN ISO 11898 2: J1939 (default)	x	x
0x6001	All	J1939 Arbitrary Address Capable	1 byte : 00 : No 01 : Yes 01 is always active (arbitrary address capable device)	x	
0x6002	All	J1939 Industry group	1 byte : Values according J1939-DA	x	x
0x6003	All	J1939 Vehicle System Instance	1 byte : Values according J1939-DA	x	x
0x6004	All	J1939 Vehicle system	1 byte : Values according J1939-DA	x	x
0x6005	All	J1939 Function	1 byte : Values according J1939-DA	x	
0x6006	All	J1939 Function instance	1 byte : Values according J1939-DA	x	x
0x6007	All	J1939 ECU Instance	1 byte : Values according J1939-DA	x	x
0x6008	All	J1939 Priority	1 byte : Values according J1939-DA	x	x
0x6009	All	J1939 Name	8 bytes Values according to J1939-81	x	
0x600A	All	J1939 Source address	1 byte Default is 0x98 Range: 0-253 Condition for write: 0x6000 DID != 2 (J1939 not active	x	x
0x7000	Prem.	Vehicle contour	10 bytes : Bytes 1+2 Corner Radius Front in mm Bytes 3+4 Corner Radius Rear in mm Byte 5+6 Length Front in mm Byte 7+8 Length Rear in mm Byte 9+10 Halfwidth in mm For all values a resolution of 1 mm and range of 0-32.000 mm applies Further write conditions: Length Front+Length Rear >= 2*Halfwidth, Corner Radius Front <=Halfwidth Corner Radius Rear <=Halfwidth Default for all values: 0 mm See section 4.1.16	x	x

0x8000	Prem.	PGN configuration for Premium variant	Individual configuration of 27 PGNs, 3 bytes per PGN, 81 bytes in total, PGN range: 0x00FF00-0x00FFFF 01-03: USS_CE_Left 04-06: USS_CE_Right 07-09: USS_msgVehicleData1 10-12: USS_InfoSignal 13-15: USS_MaxDetRange 16-18: USS_MAP_OBJ_01 19-21: USS_MAP_OBJ_02 22-24: USS_MAP_OBJ_03 25-27: USS_MAP_OBJ_04 28-30: USS_MAP_OBJ_05 31-33: USS_MAP_OBJ_06 34-36: USS_MAP_OBJ_07 37-39: USS_MAP_OBJ_08 40-42: USS_MAP_OBJ_09 43-45: USS_MAP_OBJ_10 46-48: USS_DEMsg_Sens_01 49-51: USS_DEMsg_Sens_02 52-54: USS_DEMsg_Sens_03 55-57: USS_DEMsg_Sens_04 58-60: USS_DEMsg_Sens_05 61-63: USS_DEMsg_Sens_06 64-66: USS_DEMsg_Sens_07 67-69: USS_DEMsg_Sens_08 70-72: USS_DEMsg_Sens_09 73-75: USS_DEMsg_Sens_10 76-78: USS_DEMsg_Sens_11 79-81: USS_DEMsg_Sens_12 Default PGNs are listed in sections 4.1.14.2+4.1.15.2	x	x
0x8001	Entry	PGN configuration for Entry variant	Individual configuration of 15 PGNs, 3 bytes per PGN, 45 bytes in total, PGN range: 0x00FF00-0x00FFFF 01-03: USS_msgVehicleData1 04-06: USS_InfoSignal 07-09: USS_MaxDetRange 10-12: USS_DEMsg_Sens_01 13-15: USS_DEMsg_Sens_02 16-18: USS_DEMsg_Sens_03 19-21: USS_DEMsg_Sens_04 22-24: USS_DEMsg_Sens_05 25-27: USS_DEMsg_Sens_06 28-30: USS_DEMsg_Sens_07 31-33: USS_DEMsg_Sens_08 34-36: USS_DEMsg_Sens_09 37-39: USS_DEMsg_Sens_10 40-42: USS_DEMsg_Sens_11 43-45: USS_DEMsg_Sens_12 Default PGNs are listed in sections 4.1.14.2+4.1.15.24.1.14.2+	x	x

0xD3C0	All	Variant handling	Bit field : Bit 0-2 – Type (000=Series, 001=Sample) Bit 3-5 – Variant (000=Entry, 001=Premium) Bit 6-7: Misc (reserved)	x	
0xF010	All	Login configured status	1 Bytes : 00 : Not configured ; 0x01 Configured	x	
0xF011	All	Login	16 bytes		x
0xF181		Customer serial number	20 bytes	x	x
0xF186	All	Active diagnostic session	1 byte : 0x01: Default session 0x82: Programming session 0x03: Extended session 0x60: EOL Bosch session	x	
0xF188	All	Customer part number identifier	64 Ascii bytes	x	x
0xF18A	All	Bosch Engineering Data Identifier	64 Ascii bytes	x	
0xF18B	All	ECU Manufacturing Date	6 bytes Ascii : YYMMDD	x	
0xF18C	All	ECU Serial Number	8 Bytes Ascii : 12345678	x	
0xF191	All	Customer ECU HW number	20 Ascii bytes	x	x
0xF192	All	Bosch Engineering ECU part number	10 Bytes Ascii	x	
0xF193	All	Bosch Engineering Hardware version	32 Bytes Ascii	x	
0xF195	All	Software version	25 Bytes results : - 10 Bytes software number : code ascii of 002892 followed by 0x00 to go until 10 - 15 Bytes software version : code ascii of version number (e.g. 00.01.00) followed by 0x00 to go until 15	x	
0xF19E	All	ODX File Identifier	18 bytes	x	
0xFD12	All	CAN Baudrate next cycle	1 byte : 0 : 500 kBaud 1: 250 kBaud	x	x
0xFD13	All	Current CAN Baudrate	1 byte : 0 : 500 kBaud 1 : 250 kBaud (default)	x	
0xFD14	All	Diagnostic frames CAN ID	12 bytes : Byte 1-4 : Physical address, byte 5-8 : Functional address, byte 9-12 Answer from ECU to tester	x	x
0xFD15	All	CAN ID offset for Tx messages	2 byte : First CAN ID is x+0x170. Affected messages: USS_DEMsg_Sens_XX with XX=01…12 USS_CEMsg_Sens_XX with XX=01…12 USS_MAP_OBJ_NN with NN=1…10 USS_MaxDetRange USS_InfoSignal	x	x

0xFD20	All	Operation Mode (variant-dependent range)	1 byte : 0: Full Mode (Premium variant) 1: Direct Echo Mode (Entry/Premium) 2: MAP Object Mode (Premium variant) 3: Calibration Mode (Entry/Premium) 4: Calibration Light Mode (Entry/Premium) Default values : - Premium variant: 0 - Entry variant : 1	x	x

Table 15 Overview of implemented diagnostic services

4.1.19 Failure management

All monitored failures will be stored on the fault memory of the system.

4.1.19.1 UDS Interface

All faults are mapped with a DTC at its corresponding fault status.

Detailed information on the DTCs will be included as an additional application note (see section 1).

4.1.19.2 J1939 Interface

USS ECU system support UDS based diagnostics and DTCs are coded in two byte. Based on DTC a mapping has been implemented in order to assign the SPN and FMI as follow:

DTC in range between 0x0000 to 0x0FFF , SPN = 0x7E000 + DTC Code
DTC in range between 0x2000 to 0x2FFF , SPN = 0x7F000 + (0x2000 - DTC Code)

DTCCode	DTC Description	FMI	FMI Description
0x_02	HW fault in the sensor, damaged membrane, insufficient ultrasonictransmission power due to mechanical or electrical failure, contamination of membrane (e.g. ice)	FMI=7	Mechanical System Not Responding Or Out Of Adjustment
0x_03	Short circuit of sensor data line to supply line	FMI=3	Voltage Above Normal, Or Shorted To High Source
0x_04	Short circuit of sensor data line to ground line	FMI=4	Voltage Below Normal, Or Shorted To Low Source
0x_05	Electromagnetic external disturbances, creeping short circuits, intermittent interruption/short circuit of the data line Different cablelengths of ground and data line	FMI=2	Data Erratic, Intermittent Or Incorrect
0x_0A	Power supply overvoltage	FMI=3	Voltage Above Normal, Or Shorted To High Source
0x_0B	Open circuit of data/supply/ground line	FMI=5	Current Below Normal Or Open Circuit

0x_0F	Power supply undervoltage	FMI=4	Voltage Below Normal, Or Shorted To Low Source
0x_57	Internal error / Please contact Bosch Engineering	FMI=14	Special Instructions
0x_84	OEM Login not set	FMI=14	Special Instructions
0x_99	CAN Bus Off errror	FMI=19	Received Network Data In Error
Else		FMI=12	Bad Intelligent Device Or Component

4.1.19.3 CAN Interface

Basic failure indication is given on the CAN output signals (see also section 4.1.14.2):

1) Failure status:
   A 1-Bit ‘FailureStatus’ signal on the ‘USS_InfoSignal’ message) informs about the presence of any failure which leads to a degradation of the system functionalities, in which case no valid measurement data can be provided anymore by the system.
2) Sensor-specific failure status:
   Another signal (‘SensorFaulted’ on the ‘USS_InfoSignal’ message) indicates if there is any critical sensor-related failure and on which sensor or sensors it occurs.
3) Failure information on echo distance and amplitude signals:
   In addition, the failure information is also provided on the measured direct and cross echo data using special values.
   a) Sensor-independent system failure: ‘Sna’ (signal not available) will be displayed on all distance signals.
   b) Sensor-dependent failure: the distance signals of the faulted sensors will show ‘SensorFaulted’, while the distance signal of all remaining sensors will display ‘Sna’.
   c) The amplitude signals will display ‘Sna’ for both sensor-dependent and sensor-independent failures.

For detailed information about the failure the DTC has to be read via the UDS interface.

In case of electrical over- or undervoltage situations, the ECU will be disabled until a normal operating voltage is present again. For the electrical details see Table 17.

When the input voltage of the sensor drops below a certain minimum value, the sensor autonomously lowers the sound pressure level on transmission. This prevents the sensor voltage from dropping to any greater extent due to the transmit current (values detailed in Table 16). These characteristics increase the system availability, particularly in the case of short voltage drops, e.g. during a warm start. If the sensor-internal temperature rises above a threshold of approximately 125°C, the sensor autonomously lowers the sound pressure level on transmission. This provides thermal protection for the sensor.

4.2 Mechanical Characteristics

The cable harness is not part of the Bosch Rexroth delivery content. The connector plugs are chosen on the responsibility of the customer.

4.2.1 Protection class

IP protection classes are defined in ISO 20653.

Sensor	The sensor is dustproof, waterproof and steam-jet-tight in accordance with protecting rating IP6KX, IPX6K, IPX8, IPX9K. Steam-jet-tightness is required for the front, onto the membrane cup with the sensor installed. For the plug connection, the same protection class applies as that valid for the connector type.
ECU	Dust-tight and protected against high-pressure/steam-jet cleaning and temporary immersion in water according to protection rating IP6K9K and IP6K7. These ratings are met only when the appropriate connectors are inserted and correctly locked.

4.2.2 Mechanical load for product

Sensor	**Pressure and tuning pressure on sensor membrane/lid:** Allowed axial pressure on sensor membrane: 167 N/cm² Allowed torque on membrane: 30 Ncm Allowed lateral force on the membrane: 50 N Maximum axial pressure on sensor housing and sensor lid: 19 N/cm²(on lid measured with 23 mm pin) The membrane is not protected against stone impact. Stone impact could damage the piezo-ceramic material bonded to the inside of the membrane. **Sensor acceleration:** Mechanical shock: Acceleration up to 500 m/s Free fall: 1 m fall on ground (concrete)
ECU	The ECU resists the mechanical loads described below without damage or functional limitation **Vibration**

	Random vibration profile: 10 to 2000 Hz, 32h each main axle direction (table below) **Acceleration** **M**echanical shock – 10 times shock each main axle direction acceleration up to 500 m/s2 **Tightening torque** For mounting the ECU to a steel bracket using M6 bolts: 6 Nm ± 1.5 Nm

Frequency Hz	PSD $[(m/s^2)^2/Hz]$
10	18
20	36
30	36
180	1
2 000	1
r.m.s. acceleration value = 57,9 m/s^2	

4.2.3 Material

Sensor	See drawing and IMDS data record.
ECU	Housing material: Die-cast Aluminum per “ANSI/AA A413.0” (E-coat over anodized). Color: Black. Connector: Nylon 66 with 30% Glass Fiber (PA66 GF30) Sealing: Silicone (DC7091) Clip: Stainless steel per DIN EN 10151, DIN EN 10270-3

4.3 Electrical Characteristics

Sensor	The sensor has no inverse-polarity protection.

Parameter *)	**Symbol**	**Unit**	**Value (range)**
Nominal voltage	U_{NOM}	V	12
Operating voltage for full sensor function	U_{Sensor}	V	8 to 16
Operating voltage for restricted sensor function (reduced measuring distance)	U_{Sensor}	V	< 8 > 16
Reduced sound pressure level (reduced measuring distance)			
¼ sound pressure level	U_{UV1}	V	<6.4

	U_{OV}	V	> 16
1/8 sound pressure level	U_{UV2}	V	< 4.6
"Power On" reset threshold	$U_{POR\uparrow}$	V	4.1
Absolute maximal voltage **)	U_{Max}	V	22
Peak current during send (duration 170us ... 2ms)	$I_{S\ max}$	mA	< 570
Max. quiescent current at room temperature	$I_{R\ max}$	mA	< 17

Table 16 Electrical characteristics of sensor

*) *The values for the operating voltage and current consumption apply to measurements at the sensor connector.*
**) *Exceeding the voltage – even if only briefly – could irreversibly damage the sensor.*

ECU

Parameter *)	**Symbol**	**Unit**	**Value (range)**
Operating voltage range	U_{ECU}	V	9.3 to 31.8
Nominal current w/o periphery	I_{nom_0}	A	<0.096
Nominal current (typ. 12 sensors)	I_{nom_12}	A	approx. 0.26
Peak current	I_{peak}	A	< 1.98
Sensor supply voltage		V	U_{ECU} -1.2 / max. 14.0V
Sensor Data: HIGH-level/LOW-level		V	5 V/0.7 V

Table 17 Electrical characteristics of ECU

4.4 Climatic Characteristics

The ultrasonic sensor fulfill following environmental requirements:

- Temperature: -40°C – 85°C

The ECU fulfill following environmental requirements:

- Temperature: -40°C – 85°C

Permissible temperature ranges for transport and storage are given in sections 4.8.3 and 4.8.5, respectively.

4.5 Chemical Characteristics

For details regarding chemicals, please get in contact with Bosch Rexroth.

4.6 Acoustic Characteristics

The mean sound pressure, measured on the sensor axis at a distance of 30 cm from the sensor membrane for the reference sending code during adjustment is 103 dB for the USS6.5 sensor.

The ECU does not emit noise on a remarkable level.

4.7 Lifetime

The lifetime is determined primarily by stress. The stated values only apply for the load profile described in this technical documentation. The most influencing parameter is the ambient temperature (see section 4.4).

Service life profile in operation:

Sensor		ECU	
Ambient temperature [°C]	**Distribution [%]**	**ECU temperature) [°C]**	**Distribution [%]**
-40	6	15	10
+23	20	+25	10
+60	65	+35	20
+80	8	+45	20
+85	1	+55	20
		+65	10
		+75	8
		+85	2

With respect to the use and usage conditions described in this TD, the sensor is designed for 8.000 hours of operational lifetime and a service life of 15 years.

With respect to the use and usage conditions described in this TD, the ECU is designed for 10.000 hours of operational lifetime and a service life of 20 years.

The commercial warranty and liability is not affected by this and is governed separately by the delivery conditions.

Throughout lifetime, operation is only permissible for the intended use and under the environmental and load conditions stated in this TD.

4.8 Transport, assembly, start and end of operation, storage

Please pay special attention to the safety and warning notes!

4.8.1 Packaging

The packaging concept is defined by Bosch Rexroth.

Other packages can also be used, as long as sufficient protection of the coating, the membrane and the sensor connector is guaranteed.

The connector must be free of particles (i.e. paint) and humidity. It is not allowed to handle sensors as loose goods, since this might cause damage to the coating, the membrane, or the sensor connector. The storage should preferably perform in the original packaging. If other packaging designs are used the protection of the painted areas and the connector area must be taken into account.

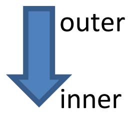
4.8.2 Transport

Sensors must be carried in their original package. Throwing, mechanical shocks or heavy strokes of the packaging must be avoided at all events. It´s most important to avoid any impacts / loads on the membrane surface since the risk of a damaged membrane and thus a defective sensor. Dropping of the sensor must be avoided.

In terms of sea freight, a suitable special packaging is needed for such kind of shipping. Sea freight in RB Standard packaging is not permissible. The risk of corrosion by intrusion of salt water must be avoided. Some hints to be considered about sea freight are given by the following list (recommendation CR/ART4).

- The packaging must be airtight sealed by a plastic bag. Stretch film instead of a plastic bag is not permissible as it is not airtight. The damage of the plastic bag must be avoided during the transport.
- Inside of the plastic bag desiccant bags are needed for absorption of the humidity.
- Example for a package from outside to inside:

  ⇨ Cardboard box
    ⇨ airtight sealed plastic bag with desiccant bag
      ⇨ sensor trays in the air tight sealed plastic bag



- To avoid condensation inside the packaging, the packaging must be done under cold condition and at minor air humidity.

4.8.3 Shipping conditions

Following permissible conditions apply during transport of the product (in original or higher grade packaging):

<u>Sensor</u>

Temperature during transport	**Duration**
Minimum: T_{min} = -50 °C	max. 24 h
Maximum: T_{max} = +95 °C	max. 48h

<u>ECU</u>

The temperature range of the USS ECU during transport shall be -40 Celsius to +85 Celsius.

4.8.4 Assembly and general handling details

Components which drop to the floor during handling shall not be built in machines.

During handling precautionary measures have to be setup to prevent electrostatic charge of the ECU.

Plugging and de-plugging of electrical connections with un-energized harness only.

Detailed instruction regarding the installation, mounting and operation of the product are given in section 6.

Diagnostic services are described in section 4.1.18.

4.8.5 Storage/Shelf-Life

In general the components should be used by the FIFO principle (first in – first out).

Sensor storage conditions:

Basically without any measures on the corrosion protection of the connector interface (plated terminals) the shelf-life of the sensors is 1 year maximum. Apart from that the below listed storage conditions will apply.

The overall shelf-life for sensors (with coating, started from the manufacturing date) in the original Bosch Rexroth packaging is 5 years by the following parameters.

Relative humidity: 85%

Temperature	**Duration**
-50°C ≤ T ≤ -10°C	24h
-10°C ≤ T ≤ +40°C	5y
+40°C ≤ T ≤ +95°C	48h

For post-series supplies, retrofit, etc. a long-term storage is possible for max. 15 years from manufacturing. Parameters are as follows.

Relative humidity: 80%

Temperature	**Duration**
-50°C ≤ T ≤ -10°C	24h
-10°C ≤ T ≤ +40°C	15y
+40°C ≤ T ≤ +95°C	48h

ECU storage conditions:

At an average relative humidity of 25% to 75% the storage temperature range of the USS ECU shall be -40 Celsius to +85 Celsius. The overall shelf-life in the original Bosch Rexroth packaging is 5 years. During storage the ECU must not be exposed to UV-light irradiation.

5.0 Assessment of products returned from the field

No warranty will be granted for any changes to the product/system caused after delivery by the customer which constitute a breach of the intended use (e.g. stone impact, mechanical damage). Products are considered good if they fulfill the specifications / test data for 0-mileage and field listed in this document

6.0 Add-on operating instruction

This chapter provides information on how to install the ultrasonic sensor system at the machine. The setup of the system comprises the following steps

1) *The wiring harness and connectors have to be set-up by the customer. Useful information can be found in section 3.2.*
2) *The sensors, corresponding connectors, wiring harness as well as the sensor retainers must be properly installed at the machine in accordance with the specifications given in this document and the related drawing. Detailed instructions are given in section 6.1.*
3) *The ECU must be properly fixed at the machine in accordance with the specifications given in this document and the related drawing.*
4) *Operating instructions are given in section 6.2.*

Please note known misuse cases as described in section 2.3.4.

6.1 Installation instructions

6.1.1 Sensor installation and handling

The main item of the ultrasonic system is the sensor which, together with the decoupling ring, enables the detection objects. The sensor comprises the following individual components.

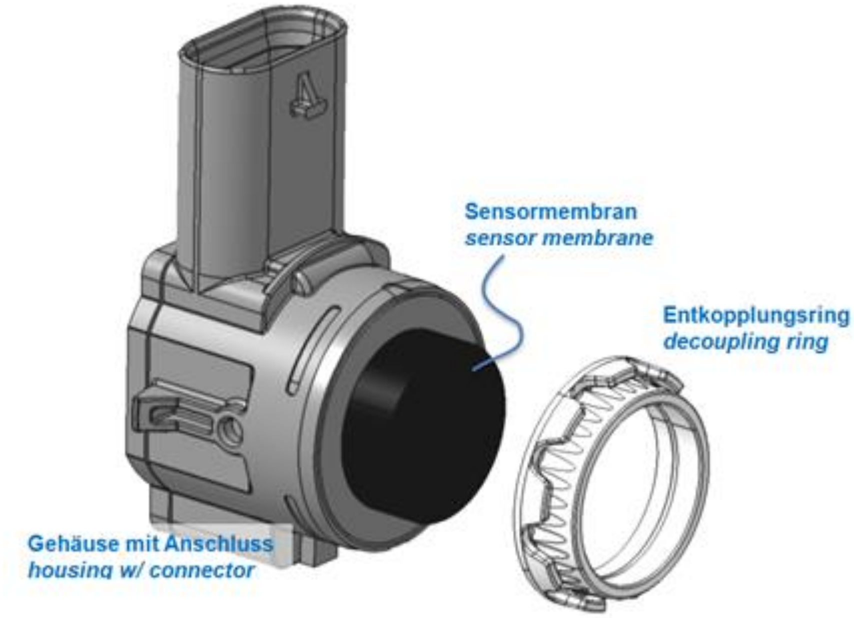


Figure 26 Sensor components

To ensure a proper function, the following prerequisites should be taken into account.

- The sensor and its membrane must be seated free of obstruction in the machine assembly. Required clearances to foam parts, members, etc. must be ensured (see section 6.1.3).
- The sensor must always be installed together with a decoupling ring released by Bosch Rexroth for this application. As the entire sensor membrane represents a vibrating system, direct contact with adjacent components is forbidden.
- The asymmetrical detection zone of the sensor requires correct alignment in the sensor installation location (see section 6.1.2).
- The sensor membrane is the main component on a functional perspective. Especially for the membrane, but for the rest of the sensor as well the installation has to be realized free of torque-and/or lateral forces on the sensor components. This applies to process steps as well, which are performed before the final installation of the sensor.
- The positioning the sensor membrane relative to the adjacent surface at the machine has a significant influence on the detection zone. The finally defined sensor position must be assured in terms of process aspects over lifetime.
- Sensor installations where splash water hits directly sensor are not recommended due to a potential risk of sensor disturbances (pseudo echoes). A protection against a water impact has to be taken into account unless an alternative positioning isn´t possible.
- Cleanliness must be observed in relation to sensor installation. Failure to conform to this can lead to subsequent system failure (connector contamination etc.)
- Electrical discharge to sensors or to the installation location of the sensors must be prevented by the adoption of suitable measures (ESD)

There is a certain risk for installations using electrical conductive materials in terms of electrical disturbances and electrostatic charging as well. That´s why it´s mandatory for those applications to ground conductive components (e.g. carbon parts, etc.) if not otherwise connected to the vehicle body.

6.1.2 Orientation of the sensor

The asymmetrical detection zone of the sensor requires correct alignment in the sensor installation location. The orientation of the sensor with respect to the wide and narrow opening angle is depicted in Figure 27 (also specified in offer drawing). The wide field of view is typically aligned in horizontal direction to avoid potential ground reflections.

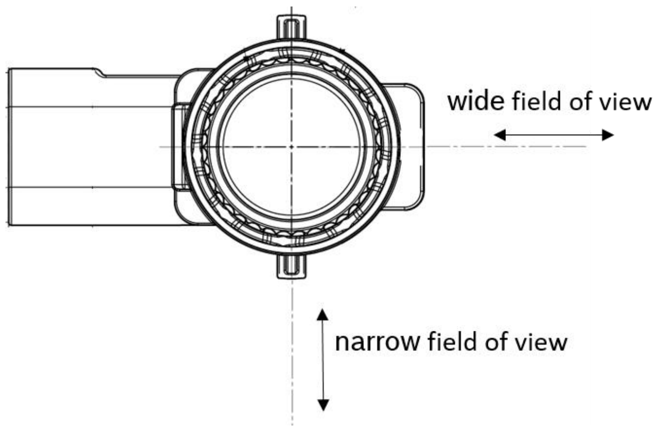


Figure 27 Sensor orientation (exemplary illustration for sensor with radial connector)

6.1.3 Required clearance at machine assembly

Any external load on the sensor, the connector and the housing has to be avoided once the sensor was final assembled. This is valid for the final assembly, the supply chain, and the assembly process. With respect to exposition of external forces clearances around the sensor should be realized in a sufficient way. Fixtures for mounting and transport should also be considered.

The routing of the harness is recommended with a distance of > 30 mm to the sensors.

Any type of antenna (radio, communications etc.) in the immediate vicinity of the sensor causes a reciprocal interaction, which may influence system performance. Strong electrical interference and the respective cables should be avoided in the sensor area. If the prediction of possible interferences can´t be done more or less reliable, physical tests must be taken into account.

An easy way to remove the sensors/harness for repair purposes should be considered.

Connector clearance

Adequate clearance must be ensured in the machine assembly. Wiring harnesses and plug-in couplings must be fixed strain-free at the machine without the possibility of kinking the wiring (observe minimum permissible bending radii for circuits). This is especially important regarding the kinematics during the installation process. In the case of non-observance, there is a danger of resulting damage and/or tension, which may result in malfunction or system failure.

Connector

Insert and lock the harness to the sensor module according to the assembly requirements of the respective connector supplier.

Mounting the harness prior to the assembly of the sensor in the housing is prefered. Otherwise the pluging should be done with low insertion forces (e.g. support on counterside)

Both connector elements must be dry and clean before connecting. The sealing elements should always be tested for their correct seat and may not be damaged.

Harness

Within the definition of the harness, notice has to be kept on the orientation of the harness side connector lock. The favored design allows enough clearance for engagement and disengagement. Otherwise there is a risk of any harm on the sensor assembly by higher lateral loads during the assembly/disassembly of the connector.

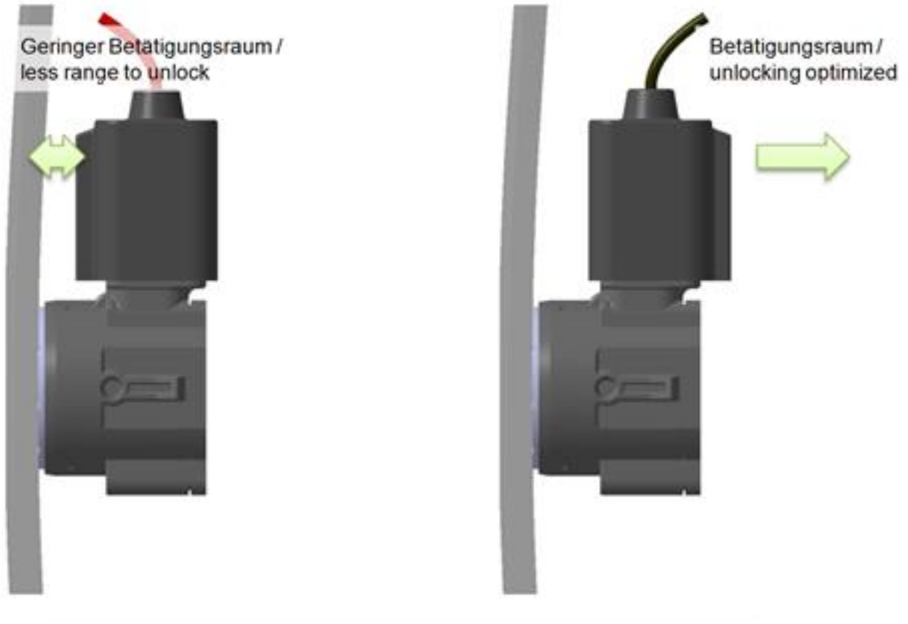


Figure 28 Orientation of connector lock

To avoid a mix-up of the sensors the definition of the harness length should be done in an adequate way to make this impossible.

It is not allowed to wrap the harness around the sensor. The routing of the harness should be straight away from the sensor.

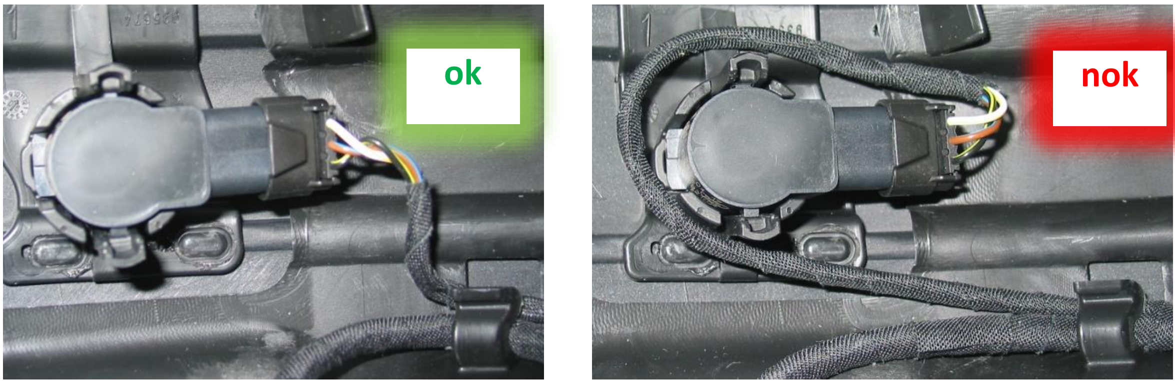


Figure 29 Exemplary harness routing

Wiring harnesses with clocked signals can cause disturbances in the sensor via magnetic coupling if the harness is in close proximity to the sensor. We strongly recommend having as much distance as possible between the sensor and those wirings to avoid negative impacts. The maximal magnetic field intensity by disturbances external to the sensor shall not exceed a value of 10 mA_{RMS}/m (within frequency band 30 – 70 kHz) at the sensor.

Furthermore, clocked signals might cause disturbances to the sensor by electrical field coupling. Typical examples are PWM control signals for lamps, or engine cooling fans, as well as LIN bus wirings. Especially critical for the effect of these disturbances are clock frequencies of 9.4 kHz, 14.4 kHz and multiples of these frequencies.

Named signals shall not be routed closer than 18 cm (7“) to the sensor and/or decoupled from the sensor by adequate shielding measures.

One can achieve suitable shielding by guiding these signals within a wiring harness bundle together with low impedance signals between the clocked line and sensor, as well as by routing the wire harness along metallic (shielding) structures.

Axial connector direction

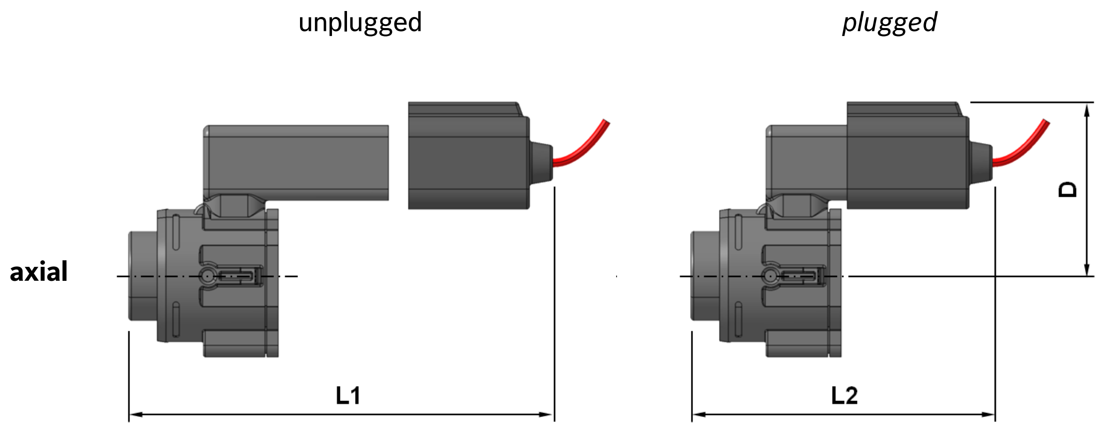


Figure 30 Clearance for axial connector

Connector type	L1 [mm]	L2 [mm]	D [mm]
Hirschman MLK	61	44	28

Radial connector direction

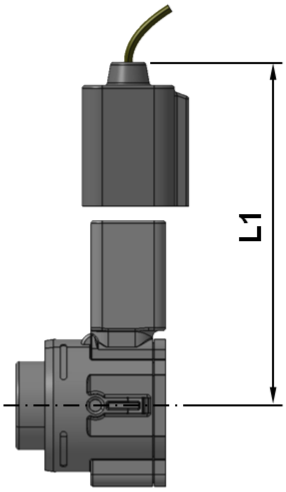
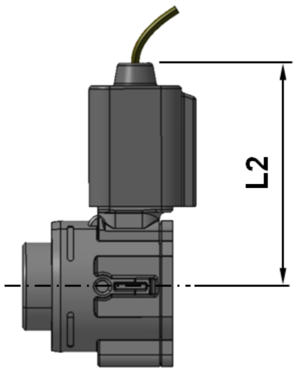
	unplugged	*plugged*
radial		

Figure 31 Clearance for radial connector

Connector type	L1 [mm]	L2 [mm]
Hirschmann LK	60	40

6.1.4 Integration of sensors at the machine

The sensor membrane should be flush with the adjacent surface of the machine. If the membrane sits any deeper (> 1 mm), this influences the sound characteristic of the sensor. Same applies to installations where sensor is fitted by an additional part to the machine. Decisions regarding feasibility as well as the effect on system function must be taken in the individual case.

The sensor retainer, the decoupling ring, the sensor, and the surrounding parts jointly form a matched unit for the ultrasonic system, and thereby also for the electrical function of the sensor.

As an objective the sensor should be mounted without any remarkable clearance into the sensor retainer. This is supported by some guiding ribs (see Figure 34) as well which needs to be matched close to the sensor itself. The decoupling ring ensures sound insulation between sensor retainer and the surrounding surface/machine parts.

When inserting the sensor module into the sensor retainer, ensure that the decoupling ring is properly fitted, is not damaged and does not slip during the insertion.

Furthermore, it must be ensured that, during and after successful installation, no lateral forces are present, especially in the front area of the sensor (sensor membrane with sleeve).

In order to improve the insertion process, a DCR lubricant in form of volatile alcohol (isopropanol) may be used. However, substances containing oil or grease are not suitable and not allowed.

When the sensor is integrated into a part with a curved shape, it is necessary to adapt the contour between the membrane surface and the related outer surface. As a result, there are transition surfs (= funnel) between this surface and the level of the sensor membrane. Generally, this can lead to some acoustical effects (interferences, deflection, etc.) which in turn may affect itself the field of view more or less intensively. Due to those effects it´s strongly recommended to figure out a position where a flush integration can be achieved.

A defined guideline for the funnel design is TBD. With this design approach it´s assumed to have a reduced impact on the field of view, but finally it´s affected by the individual shape of the installation part at the machine.

6.1.5 Interface sensor/sensor retainer/connector

The retainer provides the mechanical attachment and orientation for the sensor at the point of installation. The decoupling ring (DCR) holds the sensor in the retainer in the axial position, provides a sealing function between the external and internal areas of the retainer. The fulfilment of this function is significant for the functioning of the entire system and must therefore be given priority over other constraints (style, etc.).

Depending upon the type of installation (flush integration, bezel design), the DCR can also compensate for tolerances caused by installation. The ability for tolerance compensation without influencing the decoupling function, depends largely on the choice of material. Preferably, silicone with a hardness of 30 Shore A should be used. A higher Shore hardness tends to produce unfavourable insulation characteristics and must be avoided. As the material used for the DCR (silicone) is not compressible, it must be ensured that the displaced material can disperse into cavities provided for that purpose.

To fulfil these requirements Bosch Rexroth is providing predefined DCR´s. These DCR´s have to be used for the applications. The use of DCR´s other than the Bosch Rexroth DCR´s is basically not allowed. Otherwise, different DCR´s need a separate verification and release by Bosch Rexroth.

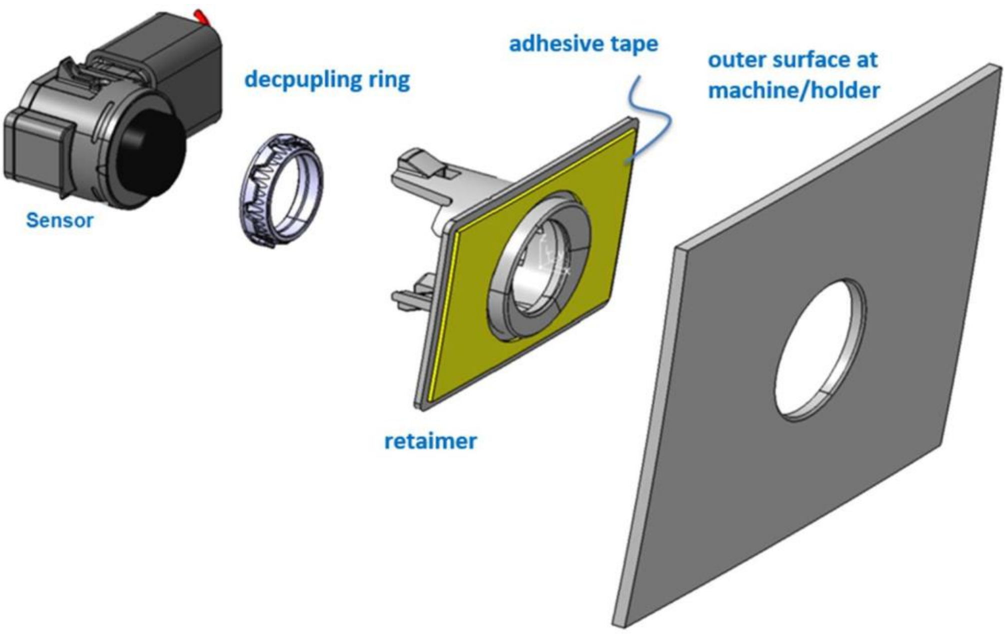
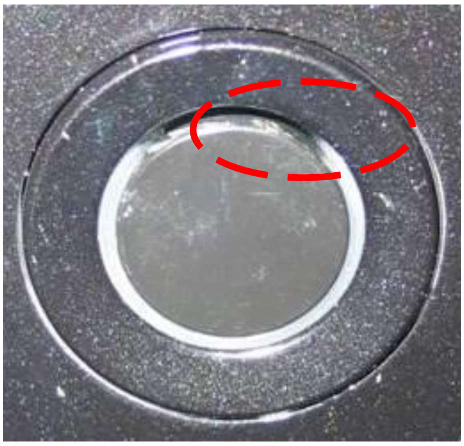


Figure 32 Sensor, decoupling ring, retainer & holder

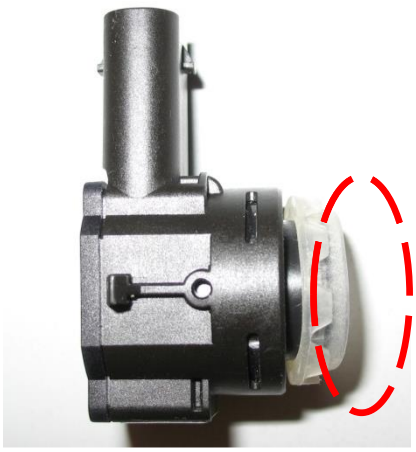
Furthermore, it must be ensured that the DCR is correctly fitted on the sensor membrane before installation. It must also be ensured that the DCR is not detached in the process of installation. Otherwise, a malfunction of the system caused by an insufficient preassembly or a wrong positioned DCR can occur (continuous or intermittent).

To improve fitting characteristics, the DCR is provided with a roughened surface. As a result, the friction between the surfaces can be reduced.

DCR rolled



insufficient pre-assembly



offset DCR position

Figure 33 Exemplary DCR assembly failures

Sensor retainer

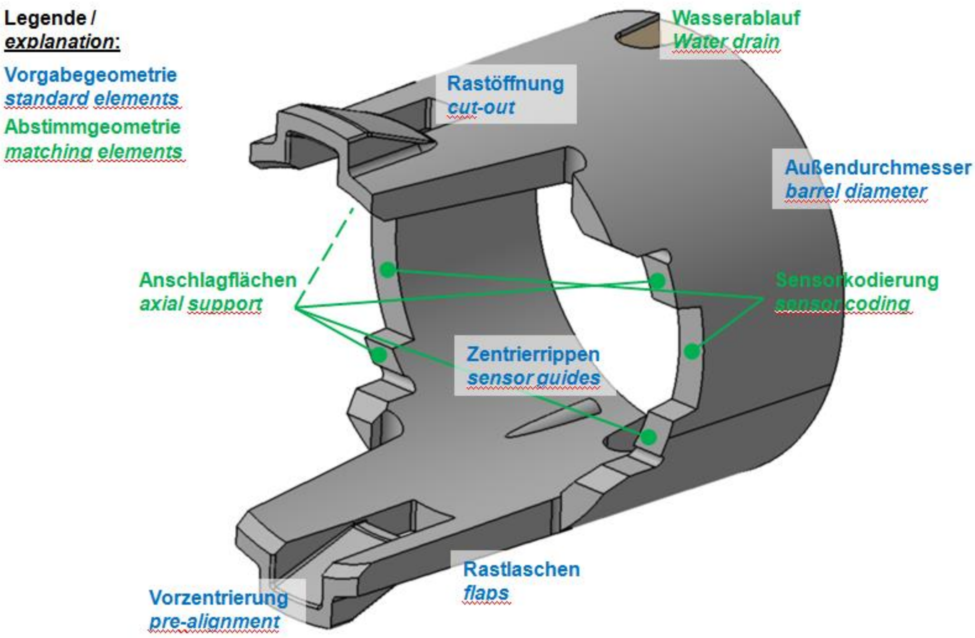


Figure 34 Sketch of sensor retainer

Notes:

- No rejection marks are permitted on the contact surfaces.
- Coding elements (etc.) inside the housing should be designed so that the basic functions of the retainer (guidance, positioning, etc.) are not affected.
- Different locking/clipping designs which leads the sensor to a tilt in a non-axial direction (e.g. plastic hinge) are critical.
- Basically, the locking/clipping must allow the disassembly of the sensor without damaging the sensor and/or the housing.

Coding of sensor housing

For a proper installation, the sensors have a mechanical coding provided on the sensor housing. Additionally, there are different colours for the sensor housing to support a visual separation of the different sensor types (see chapter 3.2.3).

Selected retainer materials

It´s recommended to have elastomeric modified thermoplastics for retainers. The E-modulus should be within a range of 1300 N/mm² and 1900 N/mm². Thermoplastics following this specifiation are providing a sufficient strength to achieve the required retaining and push-out forces over the defined temperature range.

Hard plastic materials or non elastomeric modified thermoplastics such as pure amorphous plastics (e.g. PC, PC-blends) and especially metallic components are not allowed for the use for a retainer due to their poor damping characteristics. When a use of those material can´t be avoided, this must be verified and realeased by Bosch Rexroth.

Sensor fit

A preferred goal is to align the sensor membrane as flush as possible to the adjacent surface at the machine/holder. The position of the membrane is defined by a support between sensor and retainer. It should be taken care that during the assembly the contact surfaces of the support are completely in touch. This allows a correct locking of the notches with the retainer. This is the reason for a barrel shaped body of the retainer. Other designs such as partially opened or half-shelled are not allowed. Also the retainer body must be closed to the sensor to reduce unnecessary spaces as much as possible. Such spaces can allow the acoustic noise to find unwanted paths disturbing the acoustical performance of the system. Possible design related gaps between sensor retainer and the surrounding surface are estimated in this context as critical. Potential gaps like for adhesive retainers (double-sided tape) has to be reduced to a minimum.

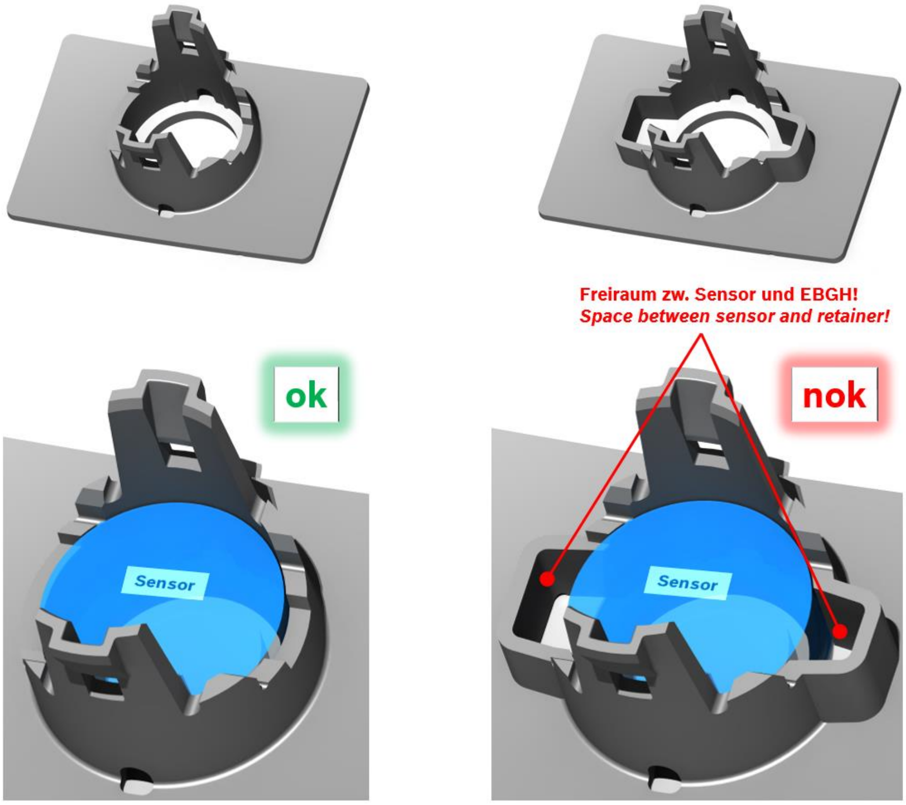


Figure 35 Exemplary retainer spacing

In general circular clearance between sensor and retainer has to be reduced to a minimum.

Another objective is to have a design which easily allows a centric position of the sensor membrane. This has a major relevance for sensor integrations with a gap around the sensor membrane and the environment. A contact between membrane and environment has to be strictly prevented.

Installations where the sensor orientation and location is affected by several parts are requiring a special focus on the centrically alignment of the parts. Otherwise forbidden lateral loads can happen on the sensor membrane.

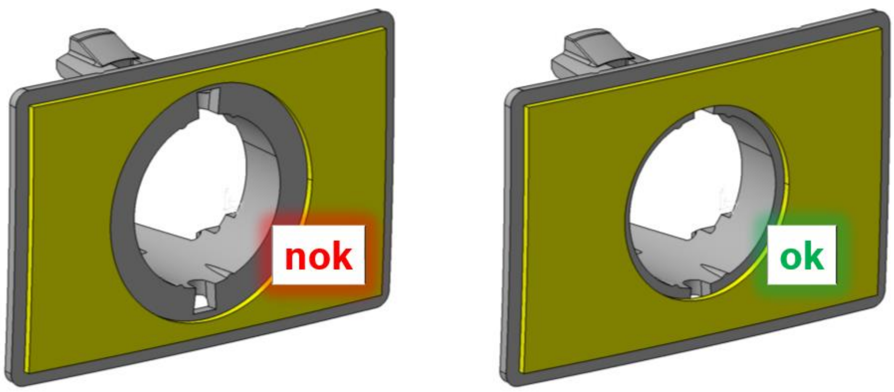


Figure 36 Gap between retainer and mounting part

Design of decoupling ring

The decoupling ring 0.263.016.344 or alternatives based on this design (color types, etc.) has to be used in combination with Gen6 sensors.

See drawing 6.033.M05.65A “offer drawing decoupling ring” and document 1.270.RP1.35M “application USS, appendix 2” for dimensions and additional specifications (compression, etc.) for this decoupling ring. Alternatives of this decoupling ring are represented by appropriate offer drawings, which applies for them.
The use of other decoupling rings must coordinated with Bosch Rexroth.

Different decoupling rings can have an impact on safety topics as well as on Bosch Rexroth processes (pre-assembly, packaging, etc.) and costs which needs to be clarified at early times.

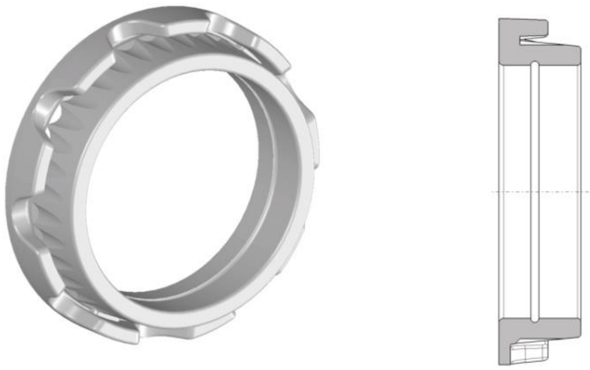


Figure 37 Design of decoupling ring

6.1.6 Integration of sensor retainer at machine surface

Hints for the integration of the sensor retainer at the machine surface can be found in an additional application note (see section 1).

6.2 Sensor positioning

The large variety of possible system configurations and high demands on system performance and functionality require a well-balanced definition of ultrasound sensor installation. This is the main basis of the achievable detection capability within given physical and technological limits of ultrasound. Depending on the specific vehicle shape and design and other customer-specific requirements there are always a lot of different trade-offs to be considered. The following specifications are developed to enable the customer for weighing up those various trade-offs. These specifications are generally intended to be used in an early design stage of a project to determine proper sensor installation parameters for the given application.

6.2.1 Influence of the mounting conditions on the detection performance of the sensor

For best detection performance, the sensor mounting is important. There are three main impacts from the mounting condition: influence on the overall sensitivity, generation of false detections, and creation of interference effects in the sound field.

6.2.1.1 Influence on the overall sensitivity

The Gen6 ultrasonic sensors have a strong directivity, i.e. the emitted sound pressure of the ultrasonic sensor is greatly reduced at higher angles to the main axis. Typical values for the opening angle are ±30° in one direction and ±60° in the other direction (see also section 6.1.2 for the orientation of the sensor). For most applications, the narrow opening angle is aligned in the vertical plane to account for the influence of the ground reflections. Ground reflections (clutter) lead to a rise of the adaptive threshold (see section 4.1.3). As a consequence, an increase of the ground noise level lowers the sensitivity of the sensor (in the distance range of these ground reflections) and reduces the resulting FoV as small echo amplitudes are then masked out by the threshold.

The main influences on the sensitivity are

- Vertical installation angle of the sensor (β angle): When the sensor is tilted towards the ground the sensitivity decreases.
- Sensor installation height: Decreasing the sensor height can also reduce the sensitivity
- Ground surface: The ground noise level will be different on different ground surfaces like a flat floor, asphalt roads or gravel roads. The rougher the ground is, the lower the resulting sensitivity.

To avoid unexpected low sensor sensitivity level which can reduce the sensor field of view, the sensor installation height and β angle specifications stated in section 6.2.2 should be considered.

6.2.1.2 False detections

Detections from ground and low obstacles

Ground reflections not only affect the sensor sensitivity but might also be picked up as distinct echoes. Apart from special use cases where the aim of the system is to measure the distance to the ground, these ground echoes are unwanted false positives. These false positives not only occur on a gravel road (for instance due to large stones) but can be also seen on very smooth ground, where the sensor sensitivity is very high and small imperfections, e.g. cracks, can be detected. Similarly, very low objects (big stones, road bumps etc.) might not be relevant for most applications. Thus, the sensor height and vertical installation angle, β, have to be chosen to minimize the detection of ground and low obstacle echoes (see hints in section 6.2.2).

Detections from attached parts

For best near field performance in the area (<50cm) around the sensor, a mounting condition with reflection points near the sensor shall be avoided. At such short distances, the sensor field of view is almost 180° (see Figure 38). If this is not possible, application specific distance filter boxes must be applied in the system to filter out the echoes from the attached parts. This is done in the control unit based on the detected amplitudes (see section 4.1.16). Therefore, any “true” echo from an object with lower amplitude than the amplitude of the attached parts is lost in the corresponding distance range. Typically, these are echoes from objects located between sensors at higher alpha angles or echoes from low reflecting obstacles. In any case, the detection performance is somewhat degraded. Obviously, the degradation becomes more relevant when the received echo travel time/distance from the attached part becomes large and a larger distance range for the distance filter is required.

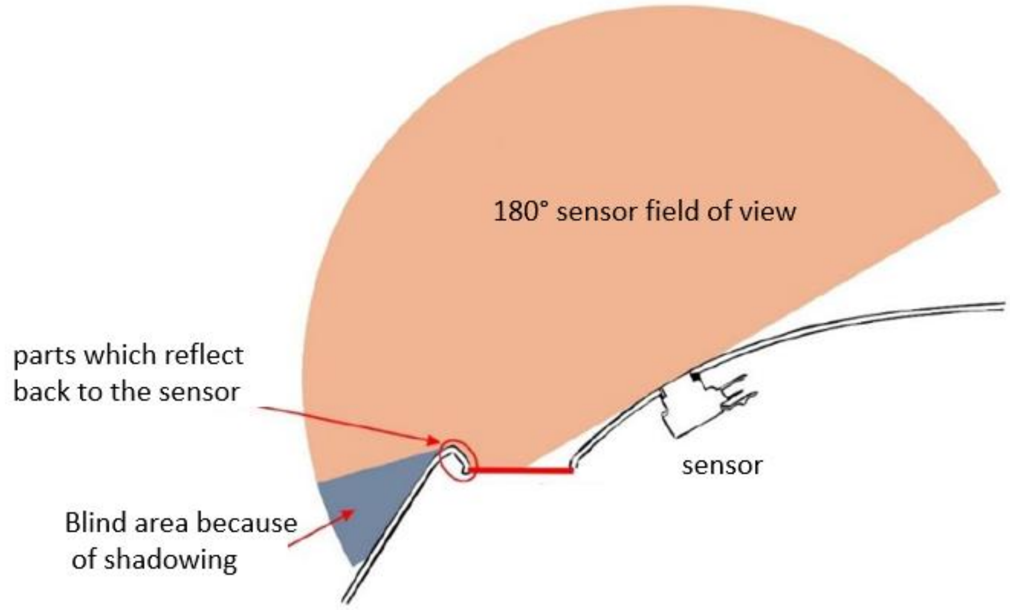


Figure 38 Influences on near field performance

6.2.1.3 Interference effects

Attached parts are not only able to produce echoes but will influence the sound field as well. A prominent effect is shading, i.e., the propagation of the sound wave is blocked by the attached parts. As a consequence, objects in the shadow are not seen (see Figure 38).
Another critical effect is the creation of additional sound sources which will lead to interference effects in the sound field. This can be induced by surfaces where the original sound wave is reflected (e.g. when the sensor membrane is recessed in relation to the surrounding vehicle/machine surface) or due to edges which will act as point like Huygens sources. The result of interference effects is a distortion in the FoV.

Further interference effects may occur between sensors as multiple sensors are transmitting ultrasound in the same measurement cycle. These interference effects must be avoided by a proper sensor positioning as described in section 6.2.2.

6.2.2 Interference effects between sensors

The specifications presented in this section are mainly relevant when the distance functionality (direct echo distance measurements). The possible sensor positions are very flexible in this case compared to an application that requires the object localization functionality (see specifications in sections 6.2.3 – 6.2.5).

To enable a high measurement rate but minimize interference effects between the sensors, the sensor operation is controlled by a defined sequence of measurement cycles in which specific sensors operate at the same time (herein referred to sending pattern). This sequence was designed in such a way to have the same measurement rate per sensor independent of the number of sensors used in the system. Thus, the number of sensors operating at the same time is different for the different sensor configurations as detailed below.

Number of configured Sensors	Measurement sequence with sensor sending at the same time	Sensor that are operating with the same sending code at the same time
12	- S1-S5-S9 - S2-S6-S10 - S3-S7-S11 - S4-S8-S12	- S1-S9 - S2-S10 - S3-S11 - S4-S12
8	- S1-S5 - S2-S6 - S3-S7 - S4-S8	-
6	- S1-S5 - S2-S6 - S3 only S4 only	-
4	Only one sensor in operation per cycle	-

Table 18 Specification of sensors operating at the same time

The specification of the measurement sequence is important for the sensor positioning as simultaneously operating sensors must not interfere with each other. A reasonable separation between those sensors is recommended to avoid adverse interference effects such as:

- Higher noise level on the sensor leading to less sensitivity
- Cross talk between the transmitting sensors. Even though two of maximum three sensors that are active in the same cycle are using different sending codes a perfect suppression and separation between the sending codes is not possible and cannot be guaranteed under all circumstances. In a 12 sensor setup, special attention should be directed toward the positioning of the sensors which are operating with the same sending code in one measurement cycle as no cross talk suppression is possible (see Table 18).

Possible cross talk effects are depicted in Figure 39. In this scenario, sensor A and B are transmitting in the same measurement cycle. Two different types of cross talk can occur, in particular when the two sensors are operating with the same code (which is the case on a 12 sensor system).

- Direct cross talk: The ultrasound emitted by sensor B travels directly to sensor A and is recognized as an object echo (calculated distance half of real sensor spacing). This can be avoided by placing the sensors far apart. Note that in the near range the ultrasound can easily propagate even 90° to the side. If the direct cross talk cannot be avoided, one can consider to apply the configurable direct echo filter box to filter out the cross talk as it remains on a constant distance.

- Remote cross talk: The ultrasound emitted by senor B travels to an objects and is reflected toward senor A where it is recognized as a regular echo. The total travel time of this echo is smaller than the direct echo travelling between sensor A and the object, thus the distance measured by sensor A is generally lower than the real distance between sensor A and the object. This error decreases with increasing object distance or decreasing sensor spacing and disappears when the object is in the middle of the two sensors. Moreover, the sensor can pick up echoes from objects which are outside its normal field of view. Hence, remote cross talk can lead to unexpected detections and erroneous distance values and should be avoided by means of well-thought-out sensor positioning concept. Sensors shall be positioned in such a way that cross talk is geometrically not possible or very unlikely. It should be taken into account that multi-reflections between different objects and the machine can take place and result in unexpected travel paths.

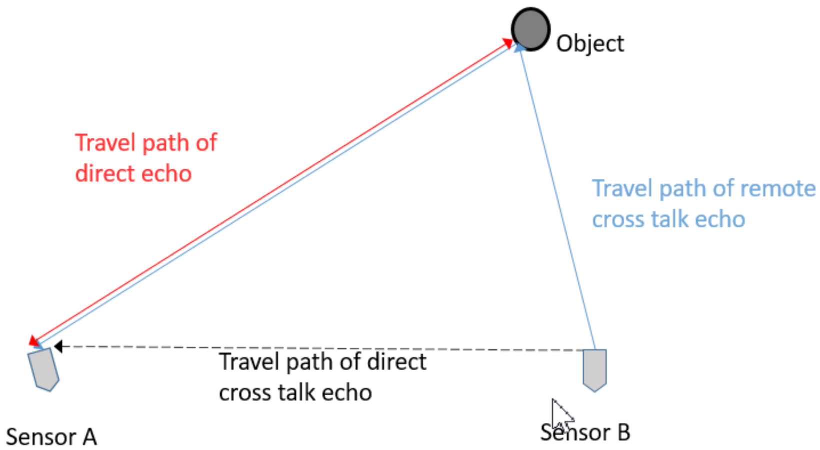


Figure 39 Illustration of cross talk effects

6.2.3 Sensor height and vertical installation angle

The following specifications apply to systems that mainly operate in the horizontal direction. For a system where only the direct echo distance information is required and object detection in vertical direction is of interest (e.g. detection of ground or ceiling), no special installation requirements other than that stated in section 6.2.2.

As explained in section 6.2.1, the vertical mounting conditions have a strong influence on the sensitivity of the sensor and its detection capabilities. To reduce the adverse effect of the ground, the sensors are designed to emit ultrasound with a narrow opening angle in the vertical plane (see section 6.1.2 for mounting orientation).

To enable a high sensitivity, following hints should be considered during the early installation design phase:

- Negative β-angles, i.e. tilting the sensor toward the ground, should be generally avoided. Exceptions might be acceptable for very high sensor height to enable a proper object detection, depending on the relevant object types.
- For a wide range of sensors heights > 45 cm, a β-angle of 0°…+5° is generally recommended

- Higher positive β-angles become necessary at sensor height <45 cm. At the minimum recommended height of 30 cm, the preferred β-angle lies within 9°…15°.
- For very rough ground characteristics, a higher installation height and/or higher positive β-angle can help to optimize the detection performance and false positive rates.
- Higher sensor height and/or higher positive β-angles can help to avoid the detection of low traversable objects

6.2.4 Vertical spacing between sensors

The specifications presented in this section are only relevant when the object localization functionality is used. For the distance functionality (direct echo distance measurements), only the limitations stated in sections 6.2.2 and 6.2.3 apply.

The object localization functionality is based on the assumption of a two-dimensional environment. Here, the object x- and y-position is computed by trilateration of direct and cross echoes of neighbouring sensors. Thus, when sensors are mounted on different heights a systematic error is introduced which can lead to a higher object position uncertainty and a lower object position stability. High position fluctuations, e.g. during the approach of an object, can ultimately result in the loss of the initially detected object and creation of a new object, which may require additional validation time and accordingly reduce the possible reaction time.

In order to find appropriate sensor positions with different sensor heights, the following classification can be used:

- Green area: The best performance with acceptable measurement error can be expected in this area. As the measurement error largely depends on the horizontal sensor spacing, the allowed vertical spacing between two neighbouring sensors becomes higher with increasing horizontal spacing between the two sensors.
- Orange area: Due to the increased measurement error, this area is only acceptable for systems with low demands on system latency and accuracy.
- Red area: The sensor must not be located in the red area. There is a high risk of obtaining unreliable object positions with large latency.

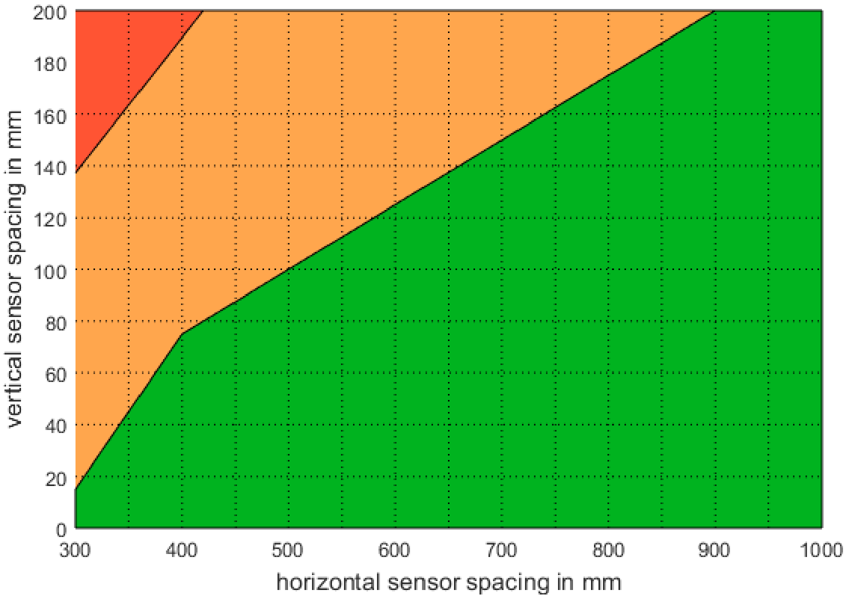


Figure 40 Recommendation of vertical sensor spacing

6.2.5 Horizontal sensor alignment

The specifications presented in this section are only relevant when the object localization functionality is used. For the distance functionality (direct echo distance measurements), only the limitations stated in sections 6.2.2 and 6.2.3 apply.

As explained in section 4.1.5, the object localization principle is based on the combination of the received direct echo (i.e. ultrasound transmitted and received by the same sensor) and cross echo information (i.e. ultrasound transmitted by one sensor and received by its neighboring sensor). The horizontal sensor alignment has to be defined in a way to ensure that the object is detected by at least one direct echo and one cross echo corresponding to at least one pair of neighboring sensors. This should apply for all objects relevant to the specific application within the required field of view of the ultrasonic sensor system.

General remarks

The horizontal sensor installation can be mainly characterized by the horizontal sensor spacing of neighboring sensor pairs and their horizontal orientation relative to each other (Δα). The smaller the α-angle difference is, the smaller the system opening angle (field of view width) becomes. This can be especially relevant for side sensors (first and last sensor and sensors mounted on vehicle corners), where a proper coverage to the side areas might be required. However, high values of Δα can lead to trilateration blind sport in the near and far range, depending on the sensor spacing. The advantage of a high sensor spacing is a decrease of the lateral position error (see section 4.1.12). On the other hand, increasing trilateration blind spots can occur with a high sensor spacing, particular in the near range. Low values of the spacing leads to a decrease of the lateral accuracy but ensure a good detection coverage as an object is often seen by multiple sensor pairs. The same tendency of higher detection coverage applies with decreasing values of Δα.

Recommendations for horizontal alignment

The following specifications can be used to define a first installation concept. They are based on experience from former projects as well as numerical simulations studies conducted for specific conditions (specific sensor mounting height, vertical orientation, ground characteristics, object, flush sensor mounting etc.). Thus, these specifications cannot reflect all possible environmental effects and mounting conditions (see also section 4.1.7). The sensor installation concept always has to be validated on the specific application for the conditions it is intended for to ensure a proper object detection performance.

Figure 41 specifies different areas for the horizontal sensor parameters:

A. Typical operation area with good detection performance. At the transition line to area E, increasing trilateration blind spots in the near range (30…40 cm) between the sensors might occur. However, detection in these trilateration blind spots is still mostly possible in many cases through single echo (direct or cross echo) detections (see section 4.1.5).

B. High detection performance but larger lateral measurement error. When using this configuration for multiple neighboring sensors on a vehicle side, the object will be seen by several sensor pairs. While this is beneficial with respect to the detection performance, the higher lateral error might increase the risk of multiple object creation in certain situations e.g. in the far range or in the very near range at the side of a specific sensor pair.

C. Very high lateral accuracy but increasing risk of blind spots in near range which cannot be compensated by single echo detections.

D. Increasing blind spots in far range which might ultimately reduce the detection range down to 2.5…3 meters.

E. Transition from area A, C, and D to area E leads to an increase of the near range blind spots between the sensors (blind spot at transition line: 30…40 cm. At some point blind spots in the far range will start to evolve as well, consequently reducing the detection range.

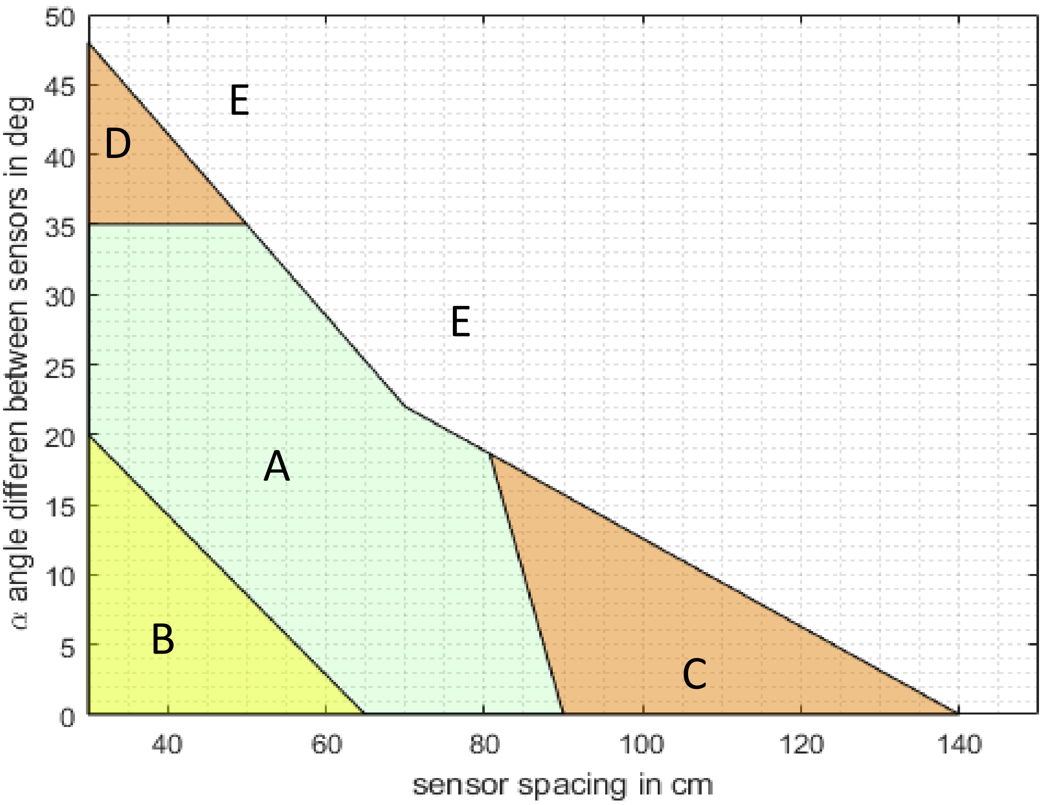


Figure 41 Design recommendations for horizontal sensor installation

A sensor spacing of less than 30 cm shall generally be avoided due to the increasing lateral position error.

If applicable, it is recommended to apply similar horizontal installation parameters from sensor pair to sensor pair (particularly a similar spacing) to obtain a balanced system behavior.

Application and calibration hints

The following list shows and overview of the installation- and performance related parametersavailable for the different system variants and measurement functions.

Parameter group	Systen variant	Relevant functionalities	
		Distance functionality	*Object localization functionality*
Installation-related parameters			
Direct echo filter box	Entry/Premium	x	x
Cross echo filter box	Premium		x
Cross echo idle distance	Premium		x
Sensor position & orientation	Premium		x
Vehicle contour	Premium		x
Performance-related parameters			
Sensitivity & Filtering settings	Entry/Premium	x	x
Sending pattern & sending codes	Entry/Premium	x	x
Maximum distance for object creation	Premium		x
Minimum distance for restricted object creation	Premium		x

Application of a system using only the distance functionality

Following points must be considered during application of a system that uses the distance functionality:

1. Select the sensor positions according to the requirements of the given application, following the instructions given in section 8.2.
2. Preconfigure the ECU according to the requirements of the given application (number of sensors, CAN-communication, baud rate etc., see also section 4.1.16).
3. Install the sensors at the machine/vehicle. Mind the orientation of the sensor (section 8.1.2).
4. Perform the calibration of the direct echo filter boxes as described in section 6.4.3 to avoid disturbing echoes from machine/vehicle part in the surrounding of the sensors.

5. The measurement system should be functional at this point. If required, apply different performance-related parameters as described in section 4.1.16.4

Application of a system using the object localization functionality

Following points must be considered application of a system that uses the object localization functionality:

1. Select the sensor positions according to the requirements of the given application, following the instructions given in section 6.2.
2. Preconfigure the ECU according to the requirements of the given application (number of sensors, CAN communication, baud rate etc., see also section 4.1.16)
3. Install the sensors at the machine/vehicle. Mind the orientation of the sensor (section 6.1.2).
4. Configure the cross echo idle distance for all used sensor pairs. The idle distance values can be determined by measuring the distance between the sensor pairs along the contour of the vehicle or machine with a measuring tape. This distance shall correspond to the shortest distance along which the ultrasound can propagate from sensor to sensor. The measurement should be taken from the center of the respective sensor to the center of its neighboring sensor. No tolerances need to be considered. See section 4.1.16 for more details.
5. Perform the calibration of the direct and cross echo filter boxes as described in section 6.2.1 to avoid disturbing echoes from machine/vehicle part in the surrounding of the sensors.
6. Configure the simplified vehicle contour as described in section 4.1.16.
7. Configure the position and orientation of all active sensors according to the specifications in section 4.1.16
8. If required, apply different performance-related parameters as described in section 4.1.16.

6.2.6 Direct and cross echo filter boxes

Description

The main purpose of this application filter is to remove disturbing echo reflections caused by vehicle/machine parts in the surroundings of the sensor. A box can be defined by means of a start distance $Dist_{start}$, an end distance $Dist_{end}$ and an amplitude limit Amp_{lim}. All echoes within this box will be filtered out (see also Figure 42). Following filter boxes are available:

1. Two direct echo (DE) filter boxes per sensor (relevant for distance functionality and object localization functionality)
   - Sensor 01: DE filter box 1 & DE filter box 2
   - Sensor 02: DE filter box 1 & DE filter box 2
   - ...
   - Sensor 12: DE filter box 1 & DE filter box 2

2. Two cross echo (CE) filter boxes per neighbouring sensor pair (relevant only for object localization functionality)
   - Sensors 01-02: CE filter box 1 & CE filter box 2
   - Sensors 02-03: CE filter box 1 & CE filter box 2
   - ...
   - Sensors 11-12: CE filter box 1 & CE filter box 2

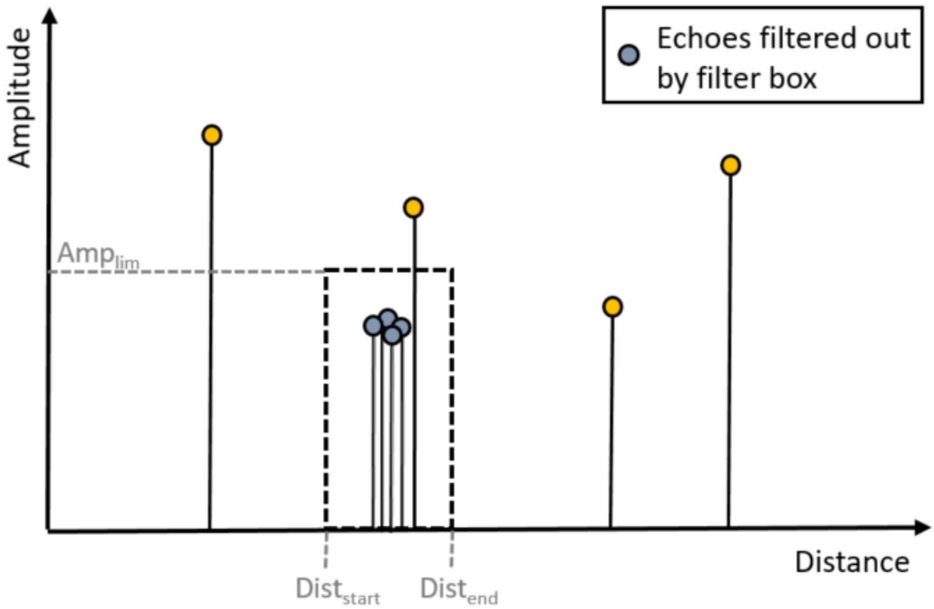


Figure 42 Principle of direct/cross echo filter boxes

Near field object that reflect ultrasound back to the sensor are often on the side of the sensor field of view, usually resulting in low echo amplitudes. Thus, by using an appropriate amplitude limit for the filter box, disturbing near field echoes can be eliminated without compromising the detection of relevant objects in the same distance range with typically higher amplitudes (see Figure 42). Alternatively, when the amplitude limit is set to the maximum allowed value (63), all echoes in the specified distance range are ignored, i.e. the sensor becomes blind in this distance range.

Note that the performance of presence detection and active damping (section 4.1.6) might degrade if the filter box of the specific sensor is configured in the very near range (approx. less than 35 cm), depending on how high the amplitude limit of the filter box is set.

Calibration procedure

The task of the *Direct and Cross Echo Filter Box calibration* is to collect all disturbing echoes from the attached part of the machine/vehicle and define a filter box around them such that all echoes within this box are removed under all relevant system conditions.

Remark: For the first commissioning of the system in an early project phase, the configuration of the filter boxes can be skipped. During first tests it should be checked whether unexpected echoes or objects appear which might be caused by attached parts and need to be filtered out accordingly. For a series application, the filter box calibration procedure should always be performed to ensure robust system behavior under all environmental conditions during the entire lifetime of the system.

Step 1: Pre-configuration of application parameters

1. Cross echo idle distance – these parameters should be set before carrying out the calibration of the cross-echo filter boxes (not relevant if only distance functionality is used). Otherwise, cross echoes at a distance equal to half the sensor spacing of the respective sensor pair might be seen during the calibration. These echoes should be filtered out by the idle distance filter and not be considered for the calibration of the distance filter boxes.
2. Sensitivity: It is recommended to use the default sensitivity setting (very high sensitivity). This will lead to the most robust calibration which is also applicable for all the other sensitivity settings that might be activated later on.
3. Sending pattern and sending codes: Different sending pattern with different ultrasonic sending codes are configurable in this product. As each sending code has different detection characteristics, the calibration of the filter boxes should be conducted with the sending pattern that will be later used for the application of the system. It is generally recommended to start with the default sending pattern (setting ‘0’). The calibration performed with sending pattern settings ‘0’ can be also applied for the sending pattern setting ‘1’ as it contains the same codes (but not the other way around as setting ‘1’ contains part of the codes used for setting ‘0’).

Step 2: Preparation at the machine/vehicle

1. Sensors have to be installed and integrated at the machine/vehicle.
2. Ensure proper connection of all system components (sensor, ECU, power supply, CAN communication).

3. Calibration should be done in a quiet place, preferably indoor without strong air-flow and heat-waves. No other ultrasonic system should be running in the surroundings or the place should be separated and the system protected against the external ultrasound as it might lead to disturbing echoes.

4. Verify that there are no additional interferences sources (acoustic or electromagnetic noise) in the environment by checking the 'Max Detection Range' signal of each sensor. It should lie within a range of 530-550 cm. Note that objects in the field of view (up to 7 m distance) can bias the estimation of the maximum detection range, decreasing it up to 3 m. Thus, an object-free environment around the respective sensor is mandatory for this check.

5. Change the operation mode settings depending on the following scenarios:

    - Usage of the product for series:

      Configure the "Calibration Mode" as the system operating mode. This will have the following effects:
        - Cross echo information will be available on the CAN output, which is needed for the calibration of the cross-echo filter boxes required for the object localization functionality.

        - The level of echo filtering for both direct and cross echoes will become weak compared to the normal operating modes. This ensures a robust calibration of the system which can be later used under various environmental conditions.

    - Usage of the product for a prototype:

      As the level of echo filtering is very low in the above-mentioned calibration mode, the calibration of the filter boxes can become time-consuming. For prototyping, a faster but less robust calibration can be applied.
      The following procedure can be applied for the B-sample of the product (the final release of the product will include an easier method with a special calibration mode for prototyping).
        - Calibration of direct echo filter boxes: Use either the normal "Full mode" or "Direct echo mode" as the operation mode

        - Calibration of cross echo filter boxes: To enable the cross echo information, one has to switch to the 'Calibration mode'. In addition, pre-configuration of the first cross echo filter box for each sensor pair will enable a reasonable level of echo filtering for prototyping purposes. Preconfigure an amplitude limit of 8, a start distance of 400 mm, and end distance of 5500 mm for each cross echo filter box. If no echoes are later visible in the calibration, the preconfigured filter box configuration can be reset/deactivated again as similar filters will be active in a normal operation mode by default.

6. Echoes from real objects must not be taken into account. Ensure that only disturbing echoes that are reflected from adjacent machine parts are visible during the calibration.

    - No objects shall be positioned in the field of view of the investigated sensors in at least a 2-3 m radius.

- Avoid the detection of ground echoes, ideally performing the calibration on a very smooth ground. If this is not possible, fade out the ground reflections around the vehicle or the sensors that are currently under investigation with an absorber-like foam material or using very smooth foil (e.g. pool foil). Note that some foams can also reflects the ultrasonic waves and that bumps in the foil can cause ground reflections as well. During the calibration measurements, it can be useful to localize the origin of observed echoes by systematically covering up the areas in the vicinity of the sensor with sound-adsorbing foam until, finally, the echo cannot be detected anymore. This way it can be ensured that the echo is not coming from the ground.

7. Depending on the temperature input that will be used in the application, do the following:

    - Cyclic temperature input via CAN – If it is planned for the application to provide the current outside temperature via CAN, this should be also done during the calibration process. If it is not possible at this stage, configure the current outside temperature as a constant value.
    - Constant temperature: If a constant temperature input is intended for the application, please configure the intended temperature value before starting the calibration process (even if it deviates from the actual ambient temperature). In case the default temperature of 20°C shall be used, no configuration is needed. In any case, the actual outside temperature should be recorded as it will be used to determine the required distance margins for the filter boxes.

<u>Step 3:</u> Measurement and evaluation process

The measurements and subsequent calibration should be done for each sensor and sensor pair for the definition of the direct echo and cross echo filter box, respectively.

1. Take measurements of the respective sensor (direct echo) or sensor pair (cross echo) for a period of 45 seconds.
2. Analyze the measured echo data
    a. Consider the first two unfiltered echoes provided on the CAN output. Note that four echoes should be taken into account in case of cross echoes as both sensors of a sensor pair are receiving cross echoes in separate measurement cycles.

        - Example 1: Relevant signal for calibration of the direct echo filter box of sensor 1:
            - Sens01De1Distance + sens01Amplitude1
            - Sens01De2Distance + sens01Amplitude2

- Example 2: Relevant signal for calibration of the cross echo filter box of sensor pair 1 and 2:
  - Sens01CeRight1Distance + Sens01CeRightAmplitude1
  - Sens01CeRight2Distance + Sens01CeRightAmplitude2
  - Sens02CeLeft1Distance + Sens02CeLeftAmplitude1
  - Sens02CeLeft2Distance + Sens02CeLeftAmplitude2

b. Collect all measured echoes within the above-mentioned time period and visualize it in an amplitude vs. distance view as illustrated in Figure 43. Usually, a group of echoes with similar distance and amplitude values corresponding to a specific reflection point/area occurs. Amplitude variations are mainly associated with the different characteristics of the used ultrasonic sending codes.

c. Try to verify that the echoes are coming from the machine or attached parts and not from the ground. As already described above, this can be done by systematically covering up the areas in the vicinity of the sensor with sound-adsorbing foam until finally the echo cannot be detected anymore.

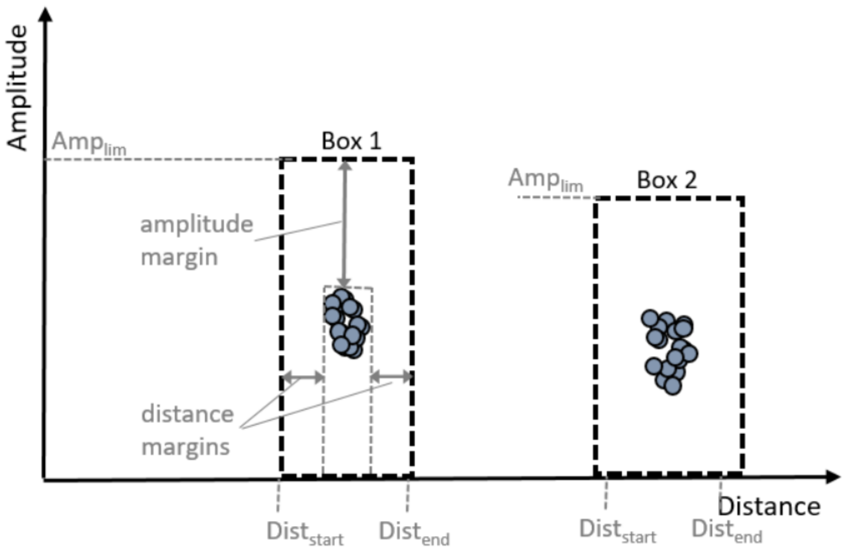


Figure 43 Visualization of measurement data and definition of filter boxes

<u>Step 4:</u> Configuration of the filter box

1. After deciding which echo/echo group should be filtered out, the filter box parameters have to be defined. As the analysed echo data shows the first two echoes, it is also possible that two echo groups corresponding to two different reflection areas are evident. If the echo groups are very close together, it is recommended to define one single box for both echo groups. Otherwise the two available filter boxes can be used to filter out echo group separately.
2. The filter box shall be defined with sufficient margins to the minimum and maximum measured echo distance and amplitude.

a. Amplitude adder: With respect to the maximum measured amplitude of the echo group, an amplitude adder of about 5 [bin] is recommended. This adder accounts for both environmental and aging effects. Note that if the resulting amplitude threshold becomes too large, the detection performance in the specified filter distance range will become worse. For instance. the detection of a pedestrian will become increasingly difficult in case the set amplitude limit is roughly > 17. For such cases, it is recommended to consider a change of the sensor integration design.

b. The margin of the start and end distance ($Dist_{start}$ and $Dist_{end}$) to the minimum and maximum echo distance observed during the calibration measurements ($Dist_{min}$ and $Dist_{max}$), depends on the applied temperature input;

i. If the current temperature is always sent cyclically over CAN, a distance margin of at least 10 mm or 1% of the measured distance is recommended. Ultimately, the necessary margin should be evaluated depending on case-specific tolerances (component tolerances, sensor integration etc.) and the accuracy of the applied temperature input.

ii. When a constant temperature is configured, the dependency of the measured distance on the air temperature has to be considered. In this case, the measured distance changes with about 0.17% per °C deviation from the temperature that was present during the calibration measurements. To account for this effect, the start and end distance of the filter box can be set according to

$$\mathrm{Dist_{start}} = \mathrm{Dist_{min}}\sqrt{\frac{\mathrm{T_{calib}} + 273.15}{\mathrm{T_{max}} + 273.15T}} - \mathrm{Dist_{tol}}$$

$$\mathrm{Dist_{end}} = \mathrm{Dist_{max}}\sqrt{\frac{\mathrm{T_{calib}} + 273.15}{\mathrm{T_{min}} + 273.15T}} + \mathrm{Dist_{tol}}$$

where T_{calib} is the temperature recorded during the calibration measurement, and T_{max} and T_{min} is the maximum and minimum temperature (in degrees Celsius) expected for the specific use case, respectively. $Dist_{tol}$ is an additional tolerance that can account for machine tolerances, sensor integration tolerances etc. Typically, a tolerance of 10 mm or 1% of the measured distance is sufficient.

3. Write the filter box parameters to the ECU

4. Repeat the "Measurement and evaluation" procedure to verify that the echoes are filtered out. As only the closest two echoes were investigated, it is possible that further unwanted reflection points located at a farther distance become evident now. In this case, either the already configured box has to be extended or the second filter box can be used.

5. When no disturbing echoes from attached parts are present anymore, the calibration of the corresponding sensor or sensor pair is complete.

6.3 Operating instructions

After all system components have been installed appropriately, the following instructions should be followed to enable the full system operation.

1. The system is activated/deactivated by enabling/disabling the ECU power supply (e.g. ignition on). Electrical characteristics are given in section 4.3.
2. CAN bus connection is required for exchange of data and configuration of parameters. It is recommended to apply 120 Ohm terminal resistors on each ends of the CAN cable to avoid reflections which could cause interference and potentially damaged signals.
3. ECU login initialization: The login must be changed in the ECU to enable the measurement system and configuration of parameters. Detailed information on how to unlock the ECU (Seed&Key procedure) and the diagnostic layer are given in the referenced documentation (see section 1).
4. System parametrization: There are several use-case specific parameters that can be configured by the customer (see section 4.1.16 and 4.1.18). Please note the application and calibration hints given in section 6.4.
5. All configured sensors shall be connected to the ECU. Plugging and de-plugging of electrical connections with un-energized harness only.
6. The measurement data available on the CAN messages is described in section 4.1.14 and can be interpreted by the customer system in conjunction with the referenced dbc- file (see section 1).
7. In case of failures please read the Diagnostic Trouble Code (DTC). Available DTCs are listed in an accompanying document (see section 1).

7.0 Version history

Edition			
Edition No.:	**Name:**	**Changes:**	**Date:**
01	Matthias Dorsch	Initial edition	16.03.2021
02	Matthias Dorsch	General updates	18.01.2022
03	Matthias Dorsch	Changes due to SW-updates	21.08.2023
04	Matthias Dorsch	Part# update general correction	23.11.2023