Endress+Hauser
People for Process Automation

Customer Manual

USR30

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/			-
/			USR30
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Template: DWP Version 1

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1 Introduction

This document contains the specification of the radar sensor USR30. The sensor can measure the distance to the medium and can be used to monitor the level of liquids and solids.

1.1 General functionality

The sensor uses an UART interface for communication. Measurements must be triggered through a special command and cannot be done in continuous mode. After a measurement is finished the ready state is signalized meaning that the measurement data can be read through the interface.

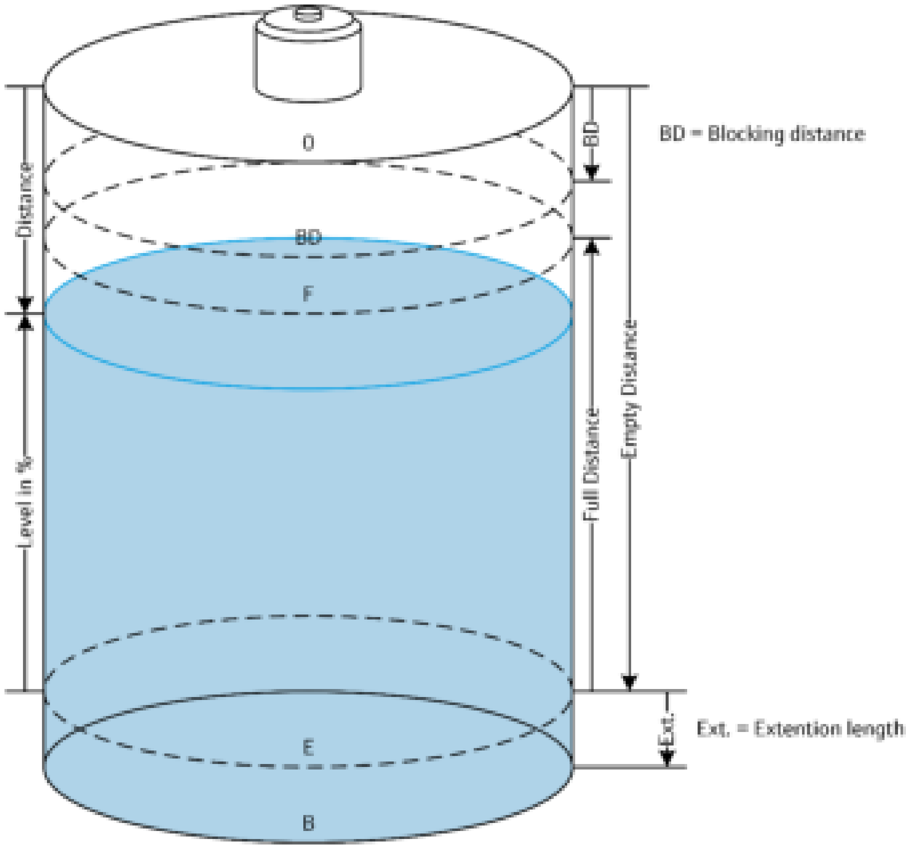


Figure 1: Tank parameters

To ensure quick and easy commissioning the parametrization is done with only five parameters:

- Medium Type (Liquid / Solid)
- Empty distance
- Full distance
- Blocking distance
- Sensitivity (Low / Medium / High)

After a measurement is triggered, the sensor generates an electromagnetic wave which propagates through the tank. Using the time-of-flight method the distance to the medium is calculated. According to the tank's parameters a level percentage is determined and the internal algorithm evaluates the measurement quality.

If a measurement fails, the error is indicated through the *ErrorState* parameter.

1.2 Typical applications

- Plastic or metal tanks used in production processes (i.e. IBC tank)
- Solid building materials
- Animal food in agricultural industry

Note: The device functions with a wide variety of materials and is not limited to the applications listed here.

2 Specification

2.1 General specification

- **Measuring range:** 0 … 35 m (0 ... 114.8 ft) ± 2 mm (0.08 in)
- **Operating Temperature:** -40 … +85 °C (-40 … +185 °F)
- **Medium:** liquids and solids
- **DK value of medium:** >1.9 (0 … 30 m)
- **Radar signal frequency:** 80 GHz
- **Beam angle:** 8 °

2.2 Electrical specification

2.2.1 Power supply

Parameter	Symbol	Min	Typ	Max	Unit
Positive HF supply voltage	V_{DD_RADAR}	3.5		5.5	V
Positive interface supply voltage	V_{DD_IF}	1.7		3.6	V
Negative supply voltage	GND	0	0	0	V

2.2.2 DC/AC characteristics for digital inputs and outputs

Parameter	Symbol	Min	Max	Unit
High level input voltage	V_{IH}	$0.7 * V_{DD\_IF}$		V
Low level input voltage	V_{IL}		$0.3 * V_{DD\_IF}$	V
High level output voltage	V_{OH}	$V_{DD\_IF} – 0.4$		V
Low level output voltage	V_{OL}		0.4	V

2.3 Mechanical specification

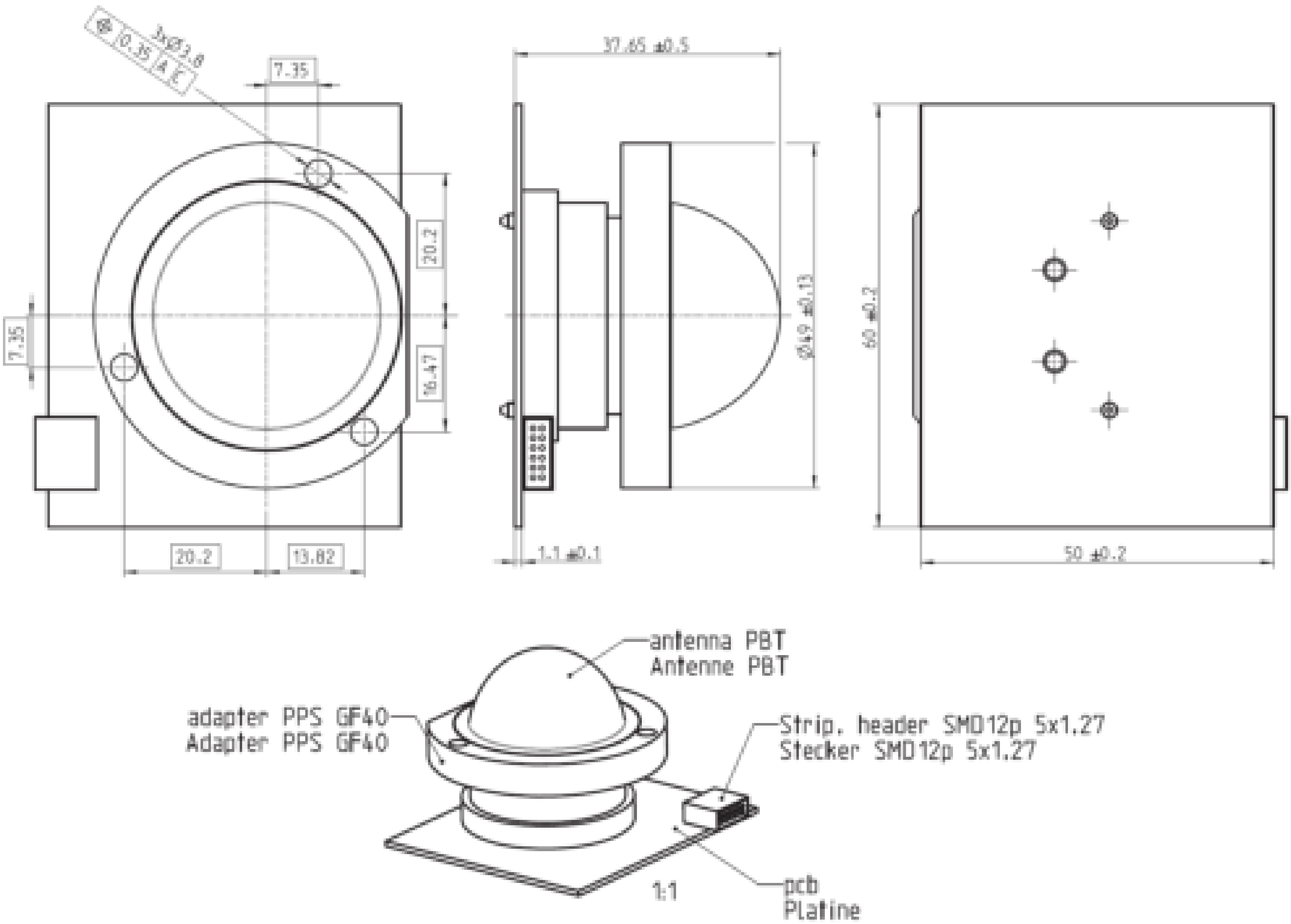


Figure 2: Mechanical drawings of USR30

3 Electrical connection

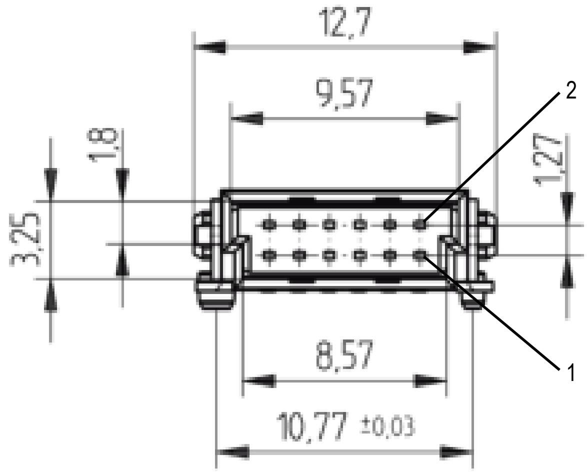


Figure 3: Pin out

Parameter	Connector	Cable (example)
Manufacturer	ERNI	ERNI
Type	SMC Connector	SMC Cable
Part. No.	154763	173799

Alternative:

Parameter	Connector	Cable (example)
Manufacturer	HARTING	HARTING
Type	har-flex	har-flex
Part. No.	15150122601000	33152430500102

Pin	Type	Name	Description
1	Input	GND	Ground
2	Input	V_{DD_RADAR}	Power Supply for HF Part
3	Input	GND	Ground
4	Input	V_{DD_RADAR}	Power Supply for HF Part
5	Input	GND	Ground
6	Input	V_{DD_IF}	Digital Power Supply
7	Input	RX	UART RX (data to USR30)
8	Output	TX	UART TX (data from USR30)
9	Input	RESET	Reset signal. If ‘HIGH’ the USR30 is in reset.
10	Output	SIG1	Ready state indication. If ‘HIGH’ the USR30 is ready to start a new measurement.
11	Input	GND	Ground
12	Input	GND	Ground

4 Sequence/Timing

The USR30 is designed to be permanently powered or only powered up for each measurement.

The recommended startup sequence is as followed (Step 1 and 2 can be ignored if the power supply's voltage is already stabilized):

1. Switch on V_{DD_RADAR} and V_{DD_IF} with RESET being HIGH.
2. Set RESET to LOW when supply voltages are stable.
3. The USR30 boots up and sets SIG1 to HIGH when finished (< 250 ms).
4. Optional: change configuration of USR30 using UART commands.
5. Trigger measurement using UART command. The USR30 sets SIG1 to 'LOW' during measurement and calculation process (< 100ms).
6. After SIG1 is set to 'HIGH' state by the USR30, the measurement data can be read out using UART commands. Alternatively, the trigger measurement address can be read and if the value returned to 'OFF' the data can be requested.
7. To turn off the device just turn off the power supply.

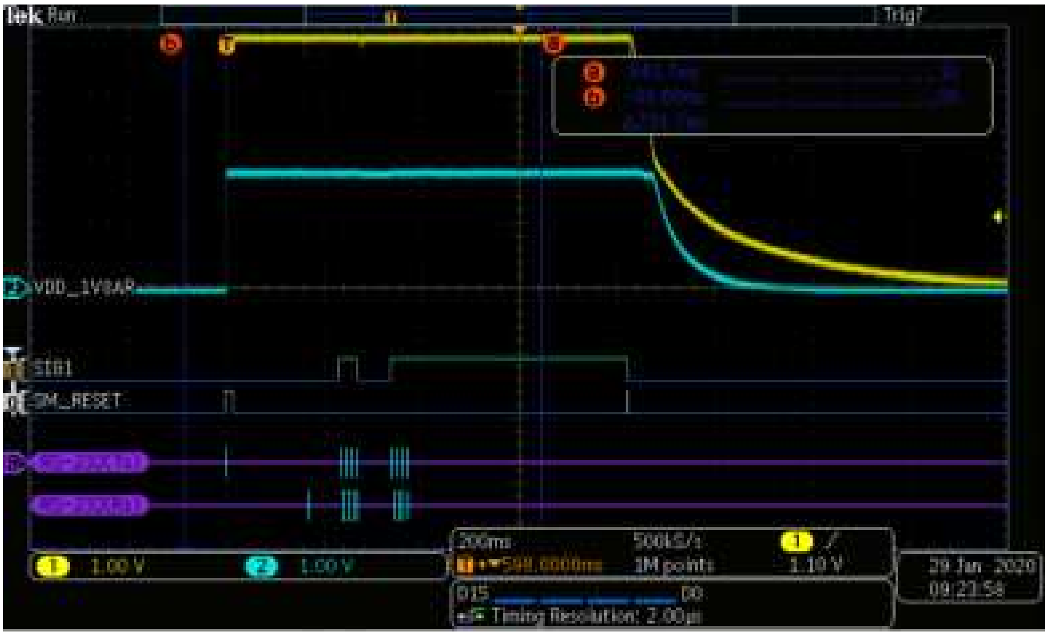


Figure 4: Signals of a startup and a single measurement

5 Communication

The communication to the USR30 is performed using UART with following properties:

- **Voltage:** V_{DD_IF}
- **Baudrate:** 230.4 kBd
- **Type:** 8-N-1
- **Polarity:** Inverted (idle low)
- **Order:** LSB first

Note: This configuration cannot be adjusted.

5.1 Protocol

The USR30 protocol support two command types:

- **Write Parameter:** CID = 0x34
- **Read Parameter:** CID = 0x35

5.1.1 Request

STX	LEN	ADL	TID	CID	PID						CRC H	CRC L
0x02	LEN	ADL	TID	0x35 Read	Block ID LSB	Block ID MSB	Instance	Rel. ParamID LSB	Rel. ParamID MSB	Array ID	CRC H	CRC L
	CRC											

Figure 5: USR30 read request

STX	LEN	ADL	TID	CID	PID						DATA				CRC H	CRC L
0x02	LEN	ADL	TID	0x34 Write	Block ID LSB	Block ID MSB	Instance	Rel. ParamID LSB	Rel. ParamID MSB	Array ID	Byte 0	Byte 1	...	Byte N	CRC H	CRC L
	CRC															

Figure 6: USR30 write request

- STX is the start byte and is always 0x02
- LEN and ADL define the length of the frame. The length of the frame starts from CID and ends before the CRC. LEN is the low byte of the frame length, ADL the high byte.
- TID is the transfer ID to identify the response of a request.
- CID is the command ID. The only commands supported are 0x35 (Read) and 0x34 (Write).
- The parameter to read/write is selected in the PID bytes. For USR30 the Instance is always 0.
- The CRC is calculated over all data except STX and is defined as followed:
    - **Order:** 16
    - **Polynomial:** 0x1021 (x16 + x12 + x5 + 1)
    - **Reflection input:** No
    - **Reflection Output:** No
    - **Initial Value:** 0xFFFF

5.1.2 Response

The response to a read request is described in Figure 7 and to a write request in Figure 8. It is like the request frame, but instead of the PID the response has a status byte STA that is always 0 for USR30.

STX	LEN	ADL	TID	CID	STA	DATA				CRC H	CRC L
0x02	LEN	ADL	TID	ACK	STA	Byte 0	Byte 1	...	Byte N	CRC H	CRC L
				NACK	STA	ERR 0	ERR 1				
	CRC										

Figure 7: USR30 read response

STX	LEN	ADL	TID	CID	STA	DATA		CRC H	CRC L
0x02	LEN	ADL	TID	ACK	STA			CRC H	CRC L
				NACK	STA	ERR 0	ERR 1		
	CRC								

Figure 8: USR30 write response

- The CID of the response is the CID of the request with an additional bit indicating if the request was successful. On success, Bit 8 (MSB) is set, otherwise Bit 7 is set. Therefore, for a read request (CID=0x35), ACK is 0xB5 and NACK is 0x75.
- STA is always 0 for USR30.
- On unsuccessful request, an error code ERR is given as 2-byte data.

5.2 Parameters

Parameter	BlockID	Rel-ParameterID	ArrayID	Type	Note
Distance	280	0	0	FLOAT32	Measured Distance D in mm
BlockingDistance	280	1	0	FLOAT32	Radar Configuration: BD in mm
MeasurementQuality	280	2	0	UINT16	Quality of Radar Measurement: • 194: Strong • 195: Medium • 196: Weak • 197: NoSignal
ErrorState	280	3	0	UINT32	Error Bitmask • Bit 0: IFSignalInvalid • Bit 1: EchoLostWarning • Bit 2: CommunicationError • Bit 3: DMASamplingError • Bit 4: MemoryContentError
Empty	280	4	0	FLOAT32	Radar Configuration: E in mm
Full	280	5	0	FLOAT32	Radar Configuration: F in mm
TriggerMeasurement	280	6	0	UINT16	Parameter to start measurement • 33006: On • 33004: Off USR30 will set this parameter to 'Off' when measurement is finished.

MediumType	280	7	0	UINT16	Radar Configuration: Type of Media to be measured • Liquid = 32957 • Solid = 33080
HwRevision	280	8	0	STRING	Hardware Revision of USR30. 16 Bytes.
BuildNumber	280	9	0	STRING	Build number of USR30 Software. 6 Bytes.
SerialNumber	280	10	0	STRING	Serial number of USR30. 16 Bytes.
Sensitivity	280	11	0	UINT16	Radar Configuration: Sensitivity of Evaluation • 946: Low • 616: Medium • 947: High
Level	280	12	0	FLOAT32	Measured Level L in %
MmPerIndex	1500	5200	0	FLOAT32	Step size between each EchoCurve sample.
DigitsAt0dB	1500	5208	0	FLOAT32	Uint16 value representing 0dB.
DigitsPerdB	1500	5209	0	FLOAT32	Uint16 value representing a difference in 1dB.
EchoCurve1	1500	12020	0	BYTE ARRAY	Echo Curve data part 1. Length: 2000 Bytes. See chapter 7 for more information.
EchoCurve2	1500	12021	0	BYTE ARRAY	Echo Curve data part 2. Length: 2000 Bytes. See chapter 7 for more information.
EchoCurve3	1500	12022	0	BYTE ARRAY	Echo Curve data part 3. Length: 96 Bytes. See chapter 7 for more information.
Z-Offset	1501	5019	0	FLOAT32	Z-Offset value. Default: 85mm

5.3 Examples of Communication with USR30

STX, LEN, ADL, TID
CID
PID
Status
Data
CRC

5.3.1 Configuration

To configure the Device, use the given order of commands. The configuration is stored permanently in the USR30 and therefore has only to be performed when configuration changes.

5.3.1.1 Write empty distance

Request: 2000 mm

STX, LEN, ADL, TID				CID	PID						Data				CRC	
02	0B	00	46	34	18	01	00	04	00	00	00	00	FA	44	B7	AE

Response:

STX, LEN, ADL, TID				CID	Status	CRC	
02	02	00	46	B4	00	28	4B

5.3.1.2 Write full distance

Request: 1823 mm

02	0B	00	47	34	18	01	00	05	00	00	00	E0	E3	44	15	60

Response:

02	02	00	47	B4	00	1F	7B

5.3.1.3 Write blocking distance

Request: 100 mm

02	0B	00	48	34	18	01	00	01	00	00	00	00	C8	42	DD	AE

Response:

02	02	00	48	B4	00	33	4A

5.3.1.4 Write sensitivity

Request: 616 (Medium)

02	09	00	49	34	18	01	00	0B	00	00	68	02	76	EC

Response:

02	02	00	49	B4	00	04	7A

5.3.1.5 Write medium type

Request: 32957 (Liquid)

02	09	00	4A	34	18	01	00	07	00	00	BD	80	17	10

Response:

02	02	00	4A	B4	00	5D	2A

5.3.2 Information data

5.3.2.1 Read hardware revision

Request:

02	07	00	4B	35	18	01	00	08	00	00	E9	A0

Response: „HWREVISION   "

02	12	00	4B	B5	00	48	57	52	45	56	49	53	49	4F	4E	20	20	20	20	20	20	3A	AB

5.3.2.2 Read build number

Request:

02	07	00	4D	35	18	01	00	09	00	00	5E	5B

Response: 8022

02	08	00	4D	B5	00	38	30	32	32	00	00	C0	EC

5.3.2.3 Read serial number

Request:

02	07	00	4C	35	18	01	00	0A	00	00	40	D8

Response: „SERIALNUMBER   “

02	12	00	4C	B5	00	53	45	52	49	41	4C	4E	55	4D	42	45	52	20	20	20	20	03	55

5.3.3 Trigger measurement

5.3.3.1 Write trigger measurement

Request: 33006 (Start measurement)

02	09	00	4E	34	18	01	00	06	00	00	EE	80	4B	98

Response:

02	02	00	4E	B4	00	81	EA

5.3.4 Measured values

5.3.4.1 Read distance

Request:

02	07	00	4F	35	18	01	00	00	00	00	4F	6C

Response: 0x4322F209 = 162.954 mm

02	06	00	4F	B5	00	09	F2	22	43	CB	34

5.3.4.2 Read measurement quality

Request:

02	07	00	50	35	18	01	00	02	00	00	C5	7A

Response: 0x00C4 = 196 = Weak

02	04	00	50	B5	00	C4	00	B0	13

5.3.4.3 Read error state

Note: It is recommended to check the error state with every measurement.

Request:

02	07	00	5A	35	18	01	00	03	00	00	63	36

Response: 0x00000000 = No Error

02	06	00	5A	B5	00	00	00	00	00	E3	8E

5.3.4.4 Read level

Request:

02	07	00	51	35	18	01	00	0C	00	00	87	72

Response: 0x42C98B40 = 100.77%

02	06	00	59	B5	00	40	8B	C9	42	5A	71

6 Offset Calibration

It is recommended to do an offset calibration of the sensor after installation in a housing. From factory the sensors are calibrated to the flat plane of the recommended horn construction. If a different construction is used the sensor must be recalibrated to the new reference plane. The measured reference length shall be ≥1m.

The following command sequence has to be executed for a calibration:

1. Write default Z-Offset value: 85 = 0x42AA0000

02	0B	00	00	34	DD	05	00	9B	13	00	00	00	AA	42	05	17

2. Read reference length (e.g. Laser reference[1])
3. Trigger Measurement
4. Read Error Flags
   a. Verify, that no Error Flags are set
5. Read Distance
6. Calculate Z-CORRECTED = DISTANCE – REFERENCE + Z-DISTANCE
7. Write Z-CORRECTED to Z-Offset parameter

[1]The accuracy of the reference can directly affect the accuracy of the sensor.

7 Echo Curve

The echo curve is stored in an array of 2048 unsigned 16-bit integers. Due to its length, it is split in 3 separate parts each of which has to be read out individually. Further the echo curve has to be scaled to correctly map the peaks with the corresponding distance.

7.1 Reading

Use the following three commands to read all three curves.

EchoCurve1 request:

02	07	00	01	35	DC	05	00	F4	2E	00	0C	41

Response:

02	D2	07	01	B5	00	BYTE0	…	BYTE1999	CRCH	CRCL

Data block of response has a length of 2000 bytes.

EchoCurve2 request:

02	07	00	02	35	DC	05	00	F5	2E	00	F3	04

Response:

02	D2	07	02	B5	00	BYTE0	…	BYTE1999	CRCH	CRCL

Data block of response has a length of 2000 bytes.

EchoCurve3 request:

02	07	00	03	35	DC	05	00	F6	2E	00	ED	87

Response:

02	62	00	03	B5	00	BYTE0	…	BYTE95	CRCH	CRCL

Data block of response has a length of 96 bytes.

The received data from all three requests should be saved in a byte array of the length 4096. The data of each request shall be appended after the last byte of the previous request so that the array can be represented as follows (the numbers below indicate the byte array index):

EchoCurve1	EchoCurve2	EchoCurve3
0		4095

As the data is stored in 16-bit unsigned integers the byte array shall be reinterpreted to that. The byte order returned from the requests is little endian which will result in a 16-bit unsigned integer array of the length 2048.

7.2 Scaling

For the correct representation of the echo curve the received array must be scaled and mapped to the distance.

7.2.1 X-Axis

To correctly represent the echo curve over the distance a second array can be generated to hold the corresponding distance values for each sample. Use the following command to request the scaling factor.

MmPerIndex request:

02	07	00	04	35	DC	05	00	50	14	00	CF	FD

Response:

02	06	00	04	B5	00	F2	B3	15	41	4A	78

$$\Delta d = 4115B3F2_{FP} \frac{\mathrm{mm}}{sample} = 9.35643196106_{10} \frac{\mathrm{mm}}{sample}$$

Note: Depending on the sensor's tank configuration this value may be different from this example.

Additionally, the Z-Offset parameter has to be read out.

Z-Offset request:

02	07	00	05	35	DD	05	00	9B	13	00	82	1F

Response:

02	06	00	05	B5	00	C0	25	EF	42	35	68

$$z = 42EF25C0_{16} = 119.573730469_{10}\ \mathrm{mm}$$

Use the following formula to calculate the position of each sample:

$$d(i) = \Delta di - z$$

7.2.2 Y-Axis

To correctly represent the amplitudes of the echo curve, two additional parameters have to be read out.

DigitsAt0dB request:

02	07	00	04	35	DC	05	00	58	14	00	66	5C

Response:

02	06	00	04	B5	00	00	C0	5A	45	E4	73

$$a = 455AC000_{FP} = 3500_{10}$$

DigitsPerdB request:

02	07	00	04	35	DC	05	00	59	14	00	51	6C

Response:

02	06	00	04	B5	00	00	00	F0	41	70	B5

$$b = 41F00000_{FP} \frac{1}{dB} = 30_{10} \frac{1}{dB}$$

Use the following formula to calculate the amplitude of each sample:

$$A(i) = \frac{A_{raw}(i) - a}{b \frac{1}{dB}}$$

Note: The amplitude in dB does not represent actual physical values from the process.

8 Installation

The following things have to be considered when installing the USR30:

- The sensor has to be installed horizontally and parallel to the tank's ceiling. Otherwise, undesired reflections can cause interference with the signal.
- The radar antenna must not be covered by metal objects.
- Do not mount any objects which may cause interference, such as tank internal fittings, grids or agitators, below or in the direct vicinity of the radar.

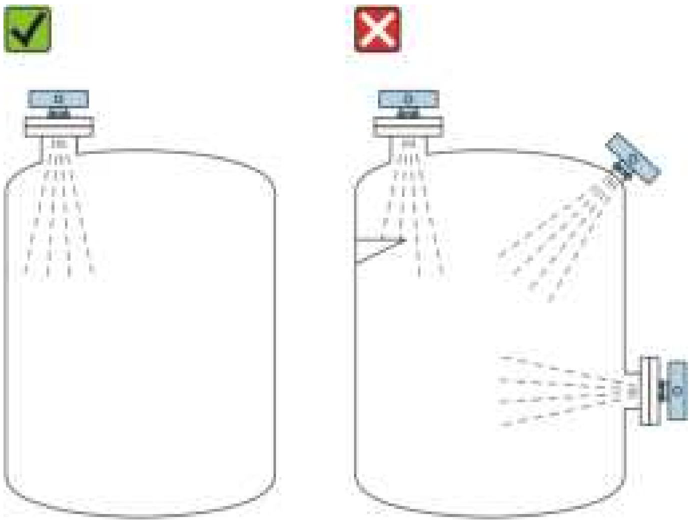


Figure 9: Recommended installation

When installing the sensor on nozzles it must be ensured that the nozzle does not interfere with the sensor's beam angle.

9 Getting Started

This chapter will describe all steps necessary to use the USR30-USB with the Demo Software for Windows.

9.1 Requirements

For the device to work properly you will need to make sure the following tools are installed:

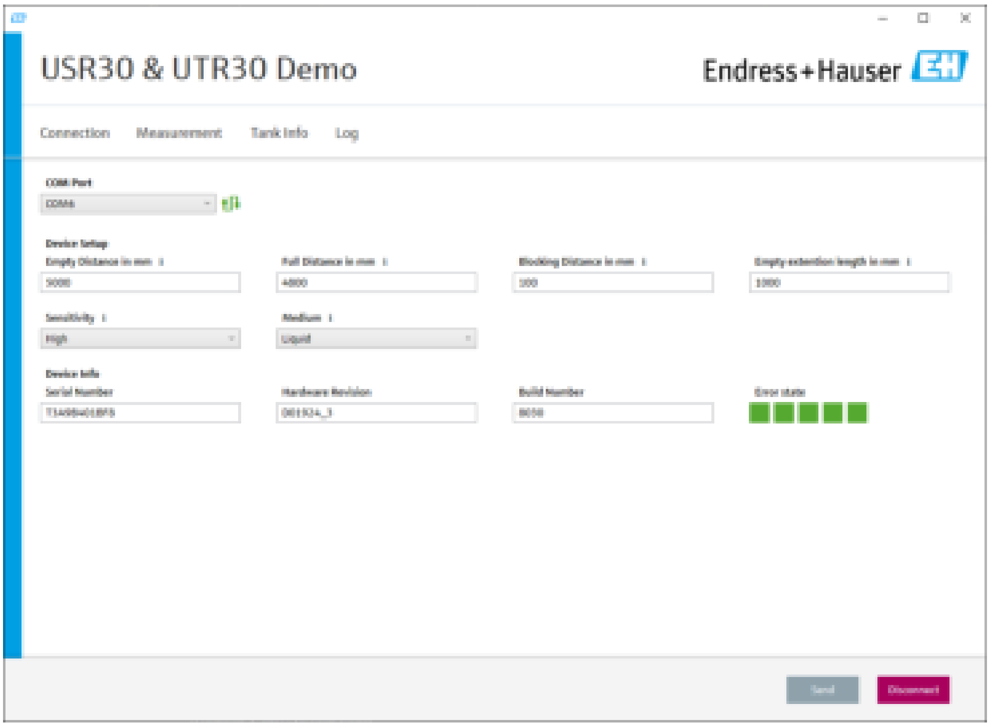
- .NET Framework 4.8 Runtime, Download

9.2 Using the demo software

1. Connect the USR30-USB sensor to your PC by using a USB Type-C cable
2. Open Windows Device-Manager to check which COM port is used. The device will appear as “USB Serial Port”.
3. Start “EH_USR30_UTR30_Demo.exe” from the provided folder.

9.2.1 User interface

1. Select the corresponding COM-Port and press “Connect
2. The user interface gets unlocked upon successful connection and the device returns all parameters that were saved in its memory and takes the first measurement.



3. Pressing the “Tank Info” button reveals a visualization of all parameters. Parameters on the right side of the tank are from the configuration and the parameters on the left side are the actual measurements and calculations. Note: “Empty Extention Length” is not user configurable!

4. The measurement page contains a visualization of the echo curve as well as all measured and calculated parameters. The application also shows the quality of the measurement which is decided by the sensor's algorithms. The displayed plot has markers for all tank parameters.

5. To send a new tank configuration enter your tank parameters and press the "Send" button on the "Connection" page. This function will automatically trigger a measurement after the settings have been sent.
6. To Trigger a measurement, press the "Trigger" button on the "Measurement" page.
7. It is possible to scroll through the history of all measurements of a session by using the buttons in the lower left corner. The history can also be exported into a .csv file.
8. To start a cyclic measurement an interval and a count has to be set. The shortest interval can be set to 1s.

10 Miscellaneous

10.1 List of figures

10.2 History

Version	Date	Author	Review	Release	Changes
01	13.06.2022	A. Lopatin	/	/	Creation of the document
02	17.11.2022	A. Lopatin	/	/	Increased max limit of interface supply to 3.6V Confidential changed to internal Fixed issues with some commands Updated software description V_{DD_1V8} renamed to V_{DD_IF} Programmatic synchronization described Added info to check error states
03	13.01.2023	A. Lopatin	/	/	Added Z Offset parameter Added chapter “Offset Calibration” Added alternative connector for US market Added pin markings to connector drawing
04	25.05.2023	A. Lopatin	/	/	Added chapter for reading envelope curve Added example command for Z-Offset
05	03.07.2023	A. Lopatin	/	/	Changed envelope curve naming to echo curve.

End of Document