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SDI-12 communication Protocol

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Abstract This document contains additional information for SDI-12 communication with KELLER Level Probes supporting SDI-12 communication.

1 Introduction

Details of SDI-12 commands for Keller level probes.

2 Communication SDI-12

SDI-12 protocol based on Version 1.3

2.1 SDI-12 frame format

1200 Baud 1 Start bit, 7 Data bits, 1 Parity bit (even), 1 Stop bit,

All characters are printable ASCII characters except the response of an SDI-12 sensor. It ends with <CR><LF> and sometimes the CRC code includes a non-printable ASCII character. ‚!' marks always the end of a request. It cannot be used within a command.

The default address of an SDI-12 sensor is always '0', but it is possible to set the sensor to an address form '1' to '9', from 'A' to 'Z' or from 'a' to 'z'.

The option of continuous measurements is only supported with a specific extended command. As said in the SDI-12 standard, a<CR><LF> is returned to an R-command or with CRC switched on, it is a: a<CRC><CR><LF>, as long as continuous mode is not switched on and configured over the extended command aXR!

Error handling and recognition:
The readable pressure range is limited to at least +/- 10% of the specified range. If the pressure is below or above these readable limits, +9999999 for Overflow and –9999999 for Underflow is displayed.

If the pressure element is damaged, the pressure value shows +9999999 as well.

With temperature and conductivity value it is the same, an Overflow is displayed as +9999999 and an Underflow as -9999999, as well as a nan in case of damaged or not readable sensor value +9999999.

This concerns only the D-command and the R-command, if the continuous measurement mode is switched on with the corresponding extended command.

2.2 Standard commands

The standard commands are supported and used as described in the document:
SDI-12 a Serial-Digital Interface Standard for Microprocessor-Based Sensors Version 1.3 / January 12, 2009

Send Identification

Description	Command	Response
Send Identification	aI!	allccccccccmmmmmmvvvxxxxxxxxxxxxx<CR><LF>
Example	aI!	a13KellerAG PR36X 0020000000000001<CR><LF>

Where:

ll:	SDI-12 version number:	'13'
cccccccc:	8 character vendor identification:	'KellerAG'
mmmmmm:	6 character sensor model number (Hardware Type):	'PAA36X', 'PR36X', 'PA36X'
vvv:	3 character specifying the sensor version:	'005'
xx..xxx:	13 character for serial number with leading zero	

Change Address

Description	Command	Response
Change Address	aAb!	b<CR><LF>

'a' is the old address and 'b' is the new one.

The address can be changed from '0' to '9', from 'A' to 'Z' or from 'a' to 'z'. The default address is always '0'. When a '?' is used as address, the Transmitter gives an answer whatever address it has. To use this command only one sensor at the bus is allowable. Otherwise it gives a collision on the bus, when all available sensors answer at the same time.

Start measurement

Description	Command	Response
Start measurement	aM!	a0012<CR><LF> after 1 second 2 measurements available (<pressure><temperature>)
Start measurement with CRC	aMC!	a0012<CR><LF> after 1 second 2 measurements available (<pressure><temperature>)
Start measurement	aM1 - 2!	a0002<CR><LF> after 0 second 2 measurements available 1 (<pressure_min><pressure_max>) 2(<temperature_min><temperature_max>)
Start measurement with CRC	aMC1 - 2!	a0002<CR><LF> after 0 second 2 measurements available 1 (<pressure_min><pressure_max>) 2(<temperature_min><temperature_max>)
Start measurement	aM3 - 4!	a0033<CR><LF> after 3 seconds 3 measurements available 3(<pressure><temperature><conductivityTC>) 4(<pressure><temperature><conductivityRaw>)
Start measurement with CRC	aMC3 - 4!	a0033<CR><LF> after 3 seconds 3 measurements available 3(<pressure><temperature><conductivityTC>) 4(<pressure><temperature><conductivityRaw>)
Start measurement	aM5 - 9!	a0000<CR><LF> not used: zero measurements returned
Start measurement with CRC	aMC5 - 9!	a0000<CR><LF> not used: zero measurements returned

The sensor can only measure pressure and temperature and conductivity as an option. That's why, only two / three values are returned to an 'M'-command. So, only the 'D0'-command is needed to get the measurement. The sensor sends a service request approximately 0.5 seconds after the 'M'-command and 2.75 seconds after the 'M3'- and 'M4'-command. After this service request the measured data can be collected with the 'D0'-command.

Additional it is possible, to read out the pressure range over the 'M1'-command as well as the temperature range over the 'M2'-command. In both cases, two values are returned, the minimum first, the maximum second. Independent of the selected pressure and temperature unit, the values are always read out in bar and degree Celsius. These information values are available direct after the command and therefore do not generate a service request.

Start concurrent measurement

Description	Command	Response
Start concurrent measurement	aC!	a00102<CR><LF> after 1 second 2 measurements available (<pressure><temperature>)
Start concurrent measurement with CRC	aCC!	a00102<CR><LF> after 1 second 2 measurements available (<pressure><temperature>)
Start concurrent measurement	aC1 - 2!	a00002<CR><LF> after 0 second 2 measurements available 1 (<pressure_min><pressure_max>) 2(<temperature_min><temperature_max>)
Start concurrent measurement with CRC	aCC1 - 2!	a00002<CR><LF> after 0 second 2 measurements available 1 (<pressure_min><pressure_max>) 2(<temperature_min><temperature_max>)
Start concurrent measurement	aC3 - 4!	a00303<CR><LF> after 3 seconds 3 measurements available 3(<pressure><temperature><conductivityTC>) 4(<pressure><temperature><conductivityRaw>)
Start concurrent measurement with CRC	aCC3 - 4!	a00303<CR><LF> after 3 seconds 3 measurements available 3(<pressure><temperature><conductivityTC>) 4(<pressure><temperature><conductivityRaw>)
Start concurrent measurement	aC5 - 9!	a00000<CR><LF> not used: zero measurements returned
Start concurrent measurement with CRC	aCC5 - 9!	a00000<CR><LF> not used: zero measurements returned

The difference between the ‘M’-command and the ‘C’-command is only, that with the ‘C’-command no service request is generated and the SDI-12 master has to wait at least one / three seconds after the ‘C’-command to collect the data.

Additional it is possible, to read out the pressure range over the ‘C1’-command as well as the temperature range over the ‘C2’-command. In both cases, two values are returned, the minimum first, the maximum second. Independent of the selected pressure and temperature unit, the values are always read out in bar and degree Celsius.

Continuous measurement

Continuous measurement is not supported, as long as it is not switched on over the extended command aXR! (Detailed descriptions of these extended commands see below: section 2.3.6). The response to an 'R'-command is always a<CR><LF> or a<CRC><CR><LF> if CRC is requested. See below:

Description	Command	Response
Continuous measurements	aR0 - 9!	a<CR><LF>
Continuous measurements with CRC	aRC0 - 9!	a<CRC><CR><LF>

With continuous measurement mode switched on, the pressure and temperature values, as well as optional the conductivity are returned as with the aD0!-command, but additional to the mean pressure value of all pressure values in the ring buffer, the minimum and maximum pressure values of the ring buffer are returned as well(detailed description see below: send Data):

Description	Command	Response
Continuous measurements	aR0!	a<pressure_mean><pressure_min><pressure_max><temperature><CR><LF>
Continuous measurements with CRC	aRC0!	a<pressure_mean><pressure_min><pressure_max><temperature><CRC><CR><LF>
Continuous measurements	aR3 - 4!	3:a<pressure_mean><pressure_min><pressure_max><temperature><conductivityTC><CR><LF> 4:a<pressure_mean><pressure_min><pressure_max><temperature><conductivityRaw><CR><LF>
Continuous measurements with CRC	aRC3 - 4!	3:a<pressure_mean><pressure_min><pressure_max><temperature><conductivityTC><CRC><CR><LF> 4:a<pressure_mean><pressure_min><pressure_max><temperature><conductivityRaw><CRC><CR><LF>
Continuous measurements	aR1 - 2! aR5 - 9!	a<CR><LF>
Continuous measurements with CRC	aRC1 - 2! aRC5 - 9!	a<CRC><CR><LF>

The pressure and the temperature are always displayed in the unit set with the 'XP' and 'XT' command. Internally all values are calculated in bar and °C. Conductivity, if available is always displayed in mille Siemens (mS).

The values are displayed as follows: <value>: pd.d (p = polarity sign (+ or -); d = numeric digit before decimal place; . = decimal point (optional); d = numeric digit after decimal place) the maximum number of characters in a data value is 9 (polarity sign + 7 digits + decimal point).

Start verification

Description	Command	Response
Start verification	aV!	a0012<CR><LF> after 1 second 2 values available

The answer to a 'V'-command is the ADC value of pressure and the ADC value of temperature. The answer is collected in the same way as with the 'M'-command. So, the values need to be collected with the 'D0'-command.

Send data

Description	Command	Response
Send data	aD0!	a<pressure><temperature><CR><LF> a<pressure><temperature><conductivity><CR><LF> if no CRC requested a<pressure><temperature><CRC><CR><LF> if CRC requested a<pressure><temperature><conductivity><CRC><CR><LF> if CRC requested

The pressure and the temperature are always displayed in the unit set in the 'XP' and 'XT' command. Internally all values are calculated in bar and °C. Conductivity if available is always displayed in mille Siemens (mS).

The values are displayed as follows: <value>: pd.d (p = polarity sign(+ or -); d = numeric digit before decimal place; . = decimal point (optional); d = numeric digit after decimal place) the maximum number of characters in a data value is 9 (polarity sign + 7 digits + decimal point).

2.3 Extended command set

All commands starting with the address followed by an 'X' are extended commands specific to products of Keller AG für Druck-messtechnik. These commands are used for calibration and further product specific uses.

Description	Command	Response
read / write offset value for pressure	aXZZ! / aXZZ<value>!	a<value><CR><LF>
read / write gain factor for pressure	aXZF! / aXZF<value>!	a<value><CR><LF>
read / write pressure unit	aXP! / aXP0x!	a0x<CR><LF>
read / write gravitational acceleration [m/s2] (default: +9.80665m/s2)	aXG! / aXG<value>!	a<value><CR><LF>
read / write offset value for temperature T	aXZZT! / aXZZT<value>!	a<value><CR><LF>
read / write offset value for temperature TOB	aXZZTOB! / aXZZTOB<value>!	a<value><CR><LF>
read / write temperature unit	aXT! / aXT0x!	a0x<CR><LF>
read / write gain conductivity range x (1..4)	aXZC<x>! / aXZC<x><value>!	a<value><CR><LF>
read / write conductivity temperature coefficient (default 0.0225 -> water)	aXZC6! / aXZC6<value>!	a<value><CR><LF>
read / write conductivity range	aXZCA! / aXZCA<value>!	a<value><CR><LF>
read / write conductivity temperature compensation method	aXZCB! / aXZCB<value>!	a<value><CR><LF>
read conductivity firmware and hardware version	aXZCC!	a<value><CR><LF>
read / write UserID	aXI! / aXI<cccccccccccccccc>!	a<cccccccccccccccc><CR><LF>
State continuous measurement	aXR!	aXRS<tt>B<ss>RUN<CR><LF> aXRM<tt>B<ss>STOP<CR><LF>
Configuration continuous measurement	aXRS<tt>B<ss>! aXRM<tt>B<ss>!	aXRS<tt>B<ss>STOP<CR><LF> aXRM<tt>B<ss>STOP<CR><LF>
Start continuous measurement	aXRON!	aXRS<tt>B<ss>RUN<CR><LF> aXRM<tt>B<ss>RUN<CR><LF>
Stop continuous measurement	aXROFF!	aXRS<tt>B<ss>STOP<CR><LF> aXRM<tt>B<ss>STOP<CR><LF>
switch to RS485 (Kellerbus) [1)]	aXC02Fe13!	aXCE<CR><LF> error aXCD<CR><LF> done

<value>: pd.d (p = polarity sign(+ or -); d = numeric digit before decimal place; . = decimal point (optional); d = numeric digit after decimal place) the maximum number of characters in a data value is 9 (polarity sign + 7 digits + decimal point). The minimal number of characters is 3 (the decimal point should always be used!)

[1)] Be careful using this command because SDI-12 communication will no longer be available! See further comment below.

2.3.1 Pressure

The pressure value is scaled in the following way: value = value * gain + offset

Offset value for pressure

The offset value for the pressure is saved in the EEPROM and can be read and changed with the command:

Description	Command	Response
read offset value for pressure	aXZZ!	a<value><CR><LF>
write offset value for pressure	aXZZ<value>!	a<value><CR><LF>

The offset is always displayed in the actually selected unit. Transmitter internal it is laid down in bar, but it is read and changed at actual unit! The offset can also be changed or viewed by Keller- or Modbus (always and only in bar). Offset is not allowed to reach over +/-2 bar. Default value = 0.000. If an offset greater is programmed, an error occurs and the old offset value is still valid.

Gain value for pressure

The gain value for the pressure is saved in the EEPROM and can be read and changed with the command:

Description	Command	Response
read gain value for pressure	aXZF!	a<value><CR><LF>
write gain value for pressure	aXZF<value>!	a<value><CR><LF>

The gain is always free of unit, it does not matter what unit is chosen. The gain can also be changed or viewed by Keller- or Modbus. The gain is only allowed in a range from 0.80 to 1.20. The default Gain is 1.000. If a gain out of range is programmed, an error occurs and the old gain value is still valid.

Gravitational acceleration

The gravitational acceleration value g for the pressure is saved in the EEPROM and can be read and changed with the command:

Description	Command	Response
read gravitational acceleration [m/s^2]	aXG!	a<value><CR><LF>
write gravitational acceleration [m/s^2]	aXG<value>!	a<value><CR><LF>

The default value of g is set to 9.80665. (9.80665 is the conventional standard value)

Pressure unit

There are six different pressure units available to choose. They can be selected via a table which is laid down in the internal EEPROM: (g default: 9.80665)

Number	Unit Pressure	Factor	
00	factory	(1)	
01	bar	1	
02	mbar	1000	
03	mH2O, mWC	100 / g	(10.1972)
04	psi	142.2334 / g	(14.5038)
05	ftWC, ftH2O	328.084 / g	(33.4553)
06	inWC, inH2O	3937.008 / g	(401.463)

2.3.2 Temperature

The value is scaled in the following way: value = value * gain + offset

Depending on the sensor version, there are possibly two different temperature sensors available

Offset value for Temperature
The offset value for the temperature is saved in the EEPROM and can be read and changed with the command:

Description	Command	Response
read offset value for temperature T (high accuracy)	aXZZT!	a<value><CR><LF>
write offset value for temperature T (high accuracy)	aXZZT<value>!	a<value><CR><LF>
read offset value for temperature TOB	aXZZTOB!	a<value><CR><LF>
write offset value for temperature TOB	aXZZTOB<value>!	a<value><CR><LF>

The offset is always given with the actually selected unit. Transmitter internal it is laid down in °C, but it is read and changed at actual unit! The offset can also be changed or viewed by Keller- or Modbus (always and only in °C). Offset is not allowed to reach over +/-2 °C. Default value = 0.000. If an offset greater is programmed, an error occurs and the old offset value is still valid.

Temperature value
There are three different temperature units available to choose. They can be selected via a table which is laid down in the internal EEPROM:

Number	Unit Pressure	Factor	Offset
00	factory	(1)	0
01	°C	1	0
02	°F	1.8001	32°
03	K	1	273.15°

Description	Command	Response
read temperature unit	aXT!	a0x<CR><LF>
write temperature unit	aXT0x!	a0x<CR><LF>

The temperature is internal always in °C, it is only multiplied with the “unit”-factor and added with its offset before it is given out over SDI12 communication.

If the temperature channel T is active (can only be activated over Kellerbus) and there is no conductivity sensor available, the returned Temperature is always T. TOB1 is only returned if no T-channel is available. If there is a conductivity sensor available, the high accuracy temperature T is returned with each conductivity value, but if only the pressure is requested, then temperature TOB is returned. This is due to short measuring times for TOB and long ones for T, if a conductivity sensor is available.

2.3.3 Conductivity

Gain conductivity range

The gain value for the conductivity is saved in the EEPROM and can be read and changed with the command:

Description	Command	Response
read gain conductivity range x (1…4)	aXZC<x>!	a<value><CR><LF>
write gain conductivity range x (1…4)	aXZC<x><value>!	a<value><CR><LF>

The gain can also be changed or viewed by Keller- or Modbus. The default gain is 1.000.

Conductivity temperature coefficient

Description	Command	Response
read conductivity temperature coefficient (default 0.0220 -> water)	aXZC6!	a<value><CR><LF>
write conductivity temperature coefficient (default 0.022 -> water)	aXZC6<value>!	a<value><CR><LF>

The gradient of the conductivity sensor is used for temperature compensation of conductivity value. With the gradient norm conductivity at 25°C is calculated: 2.20%/°C is the default gradient for water. (Value displayed as conductivityTC)

Conductivity range

Description	Command	Response
read conductivity range	aXZCA!	a< number><CR><LF>
select conductivity range	aXZCA< number>!	a< number><CR><LF>

Depending on the conductivity of the fluid, it is possible to choose a conductivity range to reach a good accuracy.

Number	Conductivity range
1	0 .. 0.2 mS
2	0 .. 2.0 mS
3	0 .. 20 mS
4	0 .. 200 mS

Conductivity temperature compensation method after DIN/ EN27888

Description	Command	Response
read conductivity temperature compensation method	aXZCB!	a< number><CR><LF>
select conductivity temperature compensation method	aXZCB< number>!	a< number><CR><LF>

Number	compensation mode
1	Linear temperature compensation @ 25°C
2	Linear temperature compensation @20°C
3	Non-linear temperature compensation (Table) @ 25°C

(Value displayed as conductivityTC)

2.3.4 Conductivity firmware and hardware version string

It is possible to read out the hardware and firmware version of the conductivity sensor. The version consists of eight ASCII characters. The first four characters show the hardware version as a hexadecimal value and the second four show the firmware version in the same way.

Description	Command	Response
conductivity hardware and firmware version read	aXZCC!	a<hhhhffff><CR><LF>

2.3.5 User identification

It is possible for the user to generate its own user Id and to save it in the internal EEPROM of the transmitter. The user Id consists of a maximum of sixteen ASCII characters.

Description	Command	Response
UserID read	aXI!	a<cccccccccccccccc><CR><LF>
UserID write	aXI<cccccccccccccccc>!	a<cccccccccccccccc><CR><LF>

2.3.6 Continuous mode

To measure continuous it is necessary to set an interval time. So, always after elapse of the interval time, the sensor wakes up from low power mode, takes a measurement and goes to low power mode again. These measurements are buffered in a ring buffer (pressure only) and it is possible to read out the average value of this buffer over an aR0! or aRC0! command. The depth of the buffer can be set over the configuration command between 1 and 8. Calculation of the average pressure:

$$Pressure_{Average\_new} = \frac{\sum_{i=1}^{Buffersize} Pressure_i}{Buffersize}$$

Interval time and buffer depth

The interval time can be set to a value from 4 to 60 seconds with steps of one second or to a value from 1 to 60 minutes with steps of one minute. The depth of the pressure buffer can be set between 1 and 8.

Time unit	Time value	note
S (seconds)	04	minimum 4 second
S (seconds)	60	maximum 60 seconds
M (minutes)	01	minimum 1 minute
M (minutes)	60	maximum 60 minutes

Buffer	Minimum size	Maximum size
B	01	08

Command description

Description	Command	Response
State continuous measurement	aXR!	aXRS<tt>B<ss>RUN<CR><LF> aXRM<tt>B<ss>STOP<CR><LF>
Configuration continuous measurement	aXRS<tt>B<ss>! time interval in seconds aXRM<tt>B<ss>! time interval in minutes	aXRS<tt>B<ss>STOP<CR><LF> aXRM<tt>B<ss>STOP<CR><LF>
Start continuous measurement	aXRON!	aXRS<tt>B<ss>RUN<CR><LF> aXRM<tt>B<ss>RUN<CR><LF>
Stop continuous measurement	aXROFF!	aXRS<tt>B<ss>STOP<CR><LF> aXRM<tt>B<ss>STOP<CR><LF>
Example	aXRON!	aXRS12B08RUN<CR><LF>

Explication of the example:

S<tt> time interval is 12 seconds M<tt> time interval is <tt> minutes

B<ss> depth of ring buffer is 8

RUN continuous measurement mode is on STOP continuous measurement mode is switched off

The continuous measurement is switched on. Every 12 seconds, the transmitter wakes up and writes a pressure value to the ring buffer. Also, the temperature value is updated before the transmitter goes to low power mode again. The ring buffer has a depth of 8 pressure values. If an aR0!-command is used, the average value of the last 8 pressure values taken over the last 96 seconds is given out.

2.3.7 Switch to RS485 (Kellerbus)

It is possible to switch from SDI-12 mode to the Kellerbus-mode (RS485 communication, Kellerbus or MODBUS RTU):

Description	Command	Response
Switch to RS485 (Kellerbus) aXC!	aXC02Fe13!	aXCD<CR><LF> (successful) aXCE<CR><LF> (not successful)

After this command **it is not possible** to communicate over SDI-12 bus with the transmitter any more.

Be sure to have all hardware equipment for Kellerbus (RS485) available and the according software before switching SDI-12 off. There is always only one communication interface active and the hardware of the other interface is switched of meanwhile and can only be activated over a software command.

3 Appendix

3.1 Changes

- **Document version 1.0**: Release version
- **Document version 1.1**: Added description of extended possibility for continuous measurement
- **Document version 1.2**: Added description of the handling of T-channel
- **Document version 1.3**: Added description of the handling of conductivity and gravitational acceleration
- **Document version 1.4**: Added description of the conductivity temperature compensation method and set longer time for data request.
- **Document version 1.5**: Correction of time values because of changes in conductivity electronics.

3.2 Software versions

The software version can be read out using the Identification command.

Version	Date of production	Major changes
001	2012 ..	Base version
002	2013	Added the function for continuous measurement
005	2013	T integrated in measurement system
009	2014	Implementation of conductivity sensor and changeable gravity acceleration
010	2015	Implementation of conductivity sensor temperature compensation method and longer time for data request of conductivity (set to 4sec).
011	2015	Adaption to revised conductivity sensor module. time for data request of conductivity set to 3sec again.

3.3 Support

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