INSTRUCTION MANUAL

Smart PT

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Stevens Smart PT
SDI-12 / RS-485 Pressure and Temperature Sensor

Purpose of this document

The purpose of this document is to describe how to order, install, and use the Stevens Smart PT Sensor.

Introduction

The Smart PT Sensor is ideal for water level measurements in lakes, rivers, and wetlands, for well monitoring, and for flow calculation. SDI-12 output provides universal compatibility with any SDI-12-enabled data logger. The Smart PT Sensor features fully-potted components, a robust ceramic membrane, and a stainless-steel housing.

The Smart PT samples pressure and temperature once per second, allowing it to automatically record peak crest levels and providing a replacement for traditional cork-based crest gauges. In addition, the Smart PT can provide averaged measurements and standard deviation.

Every Smart PT Sensor can interface over the industry standard SDI-12 bus for low power applications, or use the standard SDI-12 command set over an RS-485 physical interface for applications that require long cable runs or many sensors. The communications interface is automatically detected.

An M14-1 threaded sensor head allows for easy mounting to pipes. The threaded cap offers a loop hole which can be used to mount weights or pull the sensor through pipes or other small areas.

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Order numbers

Ordering Number	Range in bar	Range in meters	Range in feet	Accuracy in mm	Accuracy in feet	Overpressure in meters
vented						
51168-201	0.2	2	6.6	2	0.01	50
51168-202	0.4	4	13	4	0.01	60
51168-203	1	10	33	10	0.03	100
51168-204	2	20	66	20	0.07	150
51168-205	4	40	130	40	0.13	250
51168-206	10	100	330	100	0.33	400
51168-207	20	200	660	200	0.66	400
non-vented						
51168-303	1.4	4	13	14	0.05	90
51168-304	2	10	33	20	0.07	140
51168-305	4	30	100	40	0.13	240
51168-306	10	90	300	100	0.33	390
51168-307	20	190	630	200	0.66	390

The vented version of the Smart PT is accurate but vulnerable to icing inside the vent tube. The non-vented version is less accurate but more resistant to freezing conditions.

Performance Characteristics

Parameter		Unit
Pressure accuracy	0.1%	Full scale
Long term stability	max 0.15% per year	Full scale
Temperature accuracy	0.25	°C
Average current consumption, SDI-12	0.9	mA
Average current consumption, RS-485	1.5	mA

Environmental Conditions

Parameter	Min	Max	Unit
Supply voltage during operation	6	18	V
Temperature during operation	-20	80	°C

Warranty

The Smart PT has an internal gas discharge tube and surge protection diodes for lightning protection. However, damage due to lightning is not covered under the warranty.

Except for the 0.2 bar vented sensor, the Smart PT is warrantied to withstand freezing conditions without damage if the black cap is removed. The 0.2 bar vented sensor is more sensitive to overpressure and isn't warrantied for freezing conditions.

Installing the Smart PT probe

Wiring

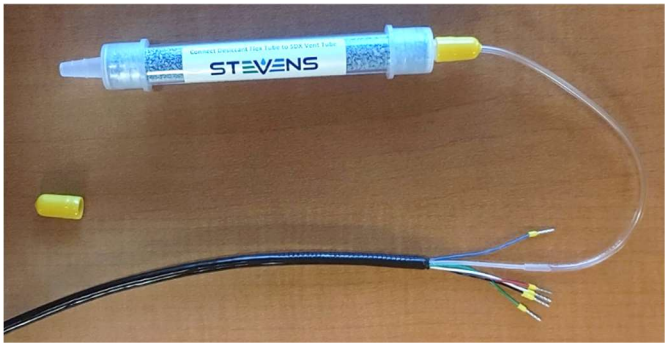
Wire Color	Signal
Black	Ground
Red	+12Vdc
Blue	SDI-12 Data
White	RS485+ / B
Green	RS485- / A

Note: Only one communications interface should be connected: SDI-12 or RS-485.

The Smart PT automatically detects the interface on first command and disables the unused interface until the next power cycle.

Vent Tube

The vented version of the Smart PT has a tube running the length of the cable. This allows the water pressure on the front of the transducer to reference against barometric pressure.



The Smart PT ships with a black cap over end of the vent tube to prevent moisture ingress, and with a separate desiccant capsule. Before installation the dessicant capsule needs to be connected and the yellow cap removed.

Ice

The Smart PT ships with an engineered resin cap designed to protect the ceramic membrane. It's important to remove the cap if the Smart PT is expected to freeze. If the cap isn't removed, expanding ice trapped under the cap will damage the ceramic membrane.

Packaging for calibration and repair

To correct for long term drift, the Smart PT should be calibrated once a year.

Before returning the sensor for calibration or repair, navigate to the 'Support' page at http://www.stevenswater.com/ and fill out the RMA form.

If the sensor was used in contaminated water, the sensor must be cleaned before shipping. Coil and zip tie the sensor cable before shipping.

SDI-12 Commands and Responses

Command quick reference

M: pressure, temperature M1: minimum, maximum M2: average, standard deviation

Basic SDI-12 Commands

Command	Response	Description
a!	a<CR><LF>	Acknowledge active a – sensor address
aI!	a14ccccccccmmmmmmvvvxxx...xx Example: Vented: 014STEVENSW_SVP01_V__1234567890 Non-vented: 014STEVENSW_SVP01_NV_1234567890	Send identification a – sensor address 14 – SDI-12 protocol version ccc… – manufacturer identification mmm… – sensor identification vvv – sensor version xxx… – serial number
aAb	b<CR><LF> Example: b	Change address b – new address
?!	a<CR><LF> Example: a	Address query a – sensor address
aM!	atttn<CR><LF> a<CR><LF> Example: a0002	Request a single pressure and temperature reading t - seconds until the measurement is ready (always zero) n – number of data fields in the measurement (always two for this command) a<CR><LF> - service request indicating that the measurement is ready

Command	Response	Description
aD0!	a<value1><value2><CR><LF> Example: a+1.0+25.6	Send a single pressure and temperature reading a – sensor address value1 – depth or pressure value2 – temperature
aM1!	atttn<CR><LF> a<CR><LF> Example: a0004	Request min and max (crest and trough) since the last M1 command. Smart PT takes a sample every second and stores and min and max in nonvolatile memory. Min and max are reset when the M1 command is received.
aD0!	a<min><max><tmin><tmax><CR><LF> Example: a+1.0+1.4+48+67	Send min and max since the last M1 command a – sensor address min – lowest pressure encountered since last M1 reading max – highest pressure encountered since last M1 reading tmin – seconds elapsed since the minimum reported in <min> tmax – seconds elapsed since the maximum reported in <max> See the section, "Using Excel to extract timestamped crest values from a data set" for more information on using tmin and tmax
aM2!	atttn<CR><LF> a<CR><LF> Example: a0002	Request average and standard deviation of pressure since the last M2 command Smart PT takes a sample every second and maintains a cumulative average and standard deviation. Average and standard deviation are reset when the M2 command is received.

Command	Response	Description
aD0!	a<avg><stddev><nsamples><CR><LF> Example: a+1.2+0.01+129	Send average and standard deviation since the last M2 command a – sensor address avg – average of all pressure samples taken since the last M2 reading stddev – standard deviation of all pressure samples taken since the last M2 reading nsamples – number of samples taken since the last M2 reading

Advanced SDI-12 Commands

Configuring pressure, depth, and temperature units

The Smart PT can be configured to report in various units of pressure and temperature.

To compensate for the density-temperature curve in water, the Smart PT Sensor uses Kell's formulation, as described in the publication *ITS-90 Density of Water Formulation for Volumetric Standards Calibration (Jones 1992)*. This, and the gravity parameter, are applied to all measurements returned in units of depth.

When the Smart PT is configured to report in units of pressure, rather than depth, no temperature compensation will be applied.

The non-vented Smart PT only reports in units of pressure. Because it measures the weight of the water column plus the atmosphere, it wouldn't be useful to report units of depth.

Command	Response	Description
aXr_punits!	apunits='uuu'<CR><LF> Example: aXr_punits! aPUNITS='m'	Query pressure units uuu… – pressure units
aXw_punits_uuu!	apunits='uuu'<CR><LF> Example: aXw_punits_m! aPUNITS='m'	Configure pressure units uuu… – pressure units *** meters** m *** centimeters** cm *** millimeters** mm *** feet** ft *** inches** in **bars** bar **millibars** mbar **kilopascals** kpa **pounds per square inch** psi **default** psi *** Only allowed for vented**
aXr_tunits!	atunits='uuu'<CR><LF> Example: aXr_tunits! aTUNITS='dc'	Query temperature units uuu… – temperature units
aXw_tunits_uuu!	atunits='uuu'<CR><LF> aXw_tunits_dc! aTUNITS='dc'	Configure temperature units **degrees centigrade** dc **degrees fahrenheit** df **kelvin** k **default** dc

Configuring gravity compensation

Gravity on the surface of the earth can vary by 0.7%, from a minimum of 9.7639 m/s^2 in Peru, to a peak of 9.8337 m/s^2 on the surface of the arctic ocean.

The Smart PT can be configured to compensate for local gravitational acceleration.

Wolfram Alpha provides a convenient tool to find your local gravitational acceleration:

https://www.wolframalpha.com/input/?i=gravity+portland+oregon

When the Smart PT is configured to report in units of pressure, rather than depth, no gravity compensation will be applied.

Command	Response	Description
aXr_gravity!	aGRAVITY='vvv'<CR><LF> Example: aXr_gravity! aGRAVITY='9.80665'	Query gravity a – sensor address vvv… – gravity
aXw_gravity_vvv!	aGRAVITY='vvv' Example: aXw_gravity_9.80665! aGRAVITY='9.80665'	Configure gravity a – sensor address vvv… – gravitational acceleration Default: 9.80665 m/s^2

Configuring density compensation

The density of water can very due to salinity, aeration, or suspended sediment.

The Smart PT can be configured to compensate for working fluid density.

Because the built-in temperature density curve is only valid for fresh water, temperature compensation will be disabled when the density parameter is modified.

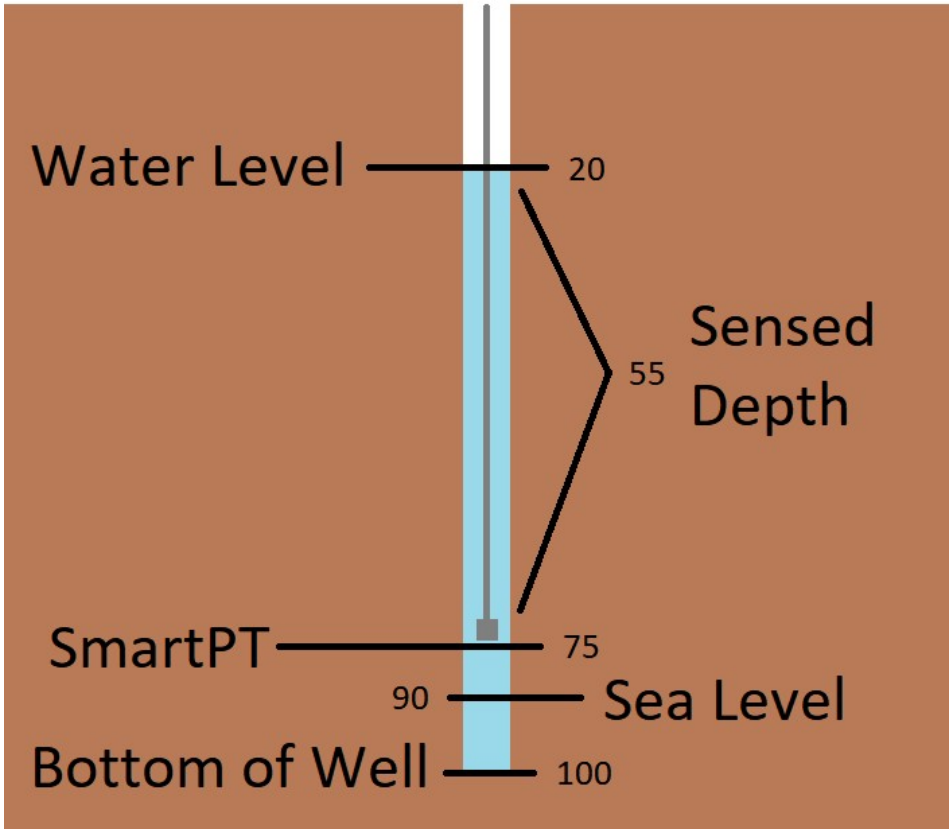
Command	Response	Description
aXr_density!	aDENSITY='vvv'<CR><LF> Example: aXr_density! aDENSITY='1'	Query density a – sensor address vvv… – density
aXw_density_vvv!	aDENSITY='vvv' Example: aXw_density_1.1! aDENSITY='1.1'	Configure density a – sensor address vvv… – density Default: 1 g/mL

Configuring the Smart PT for top-of-casing or reference-relative measurements

The Smart PT can be configured to report depth measurements from actual or surveyed top of casing. Following this command table is an example.

Command	Response	Description
aXr_toc_vvv!	aTOC='vvv'<CR><LF>	Query top of casing
aXw_toc_vvv!	aTOC='vvv' Example: aXw_toc_1! aTOC='1'	If non-zero, depth will be subtracted from the TOC value. See the section, "Calculation of depth with corrections" Default: 0
aXr_offset_vvv!	aOFFSET='vvv'<CR><LF>	Query offset
aXw_offset_vvv!	aOFFSET='vvv' Example: aXw_pffset_1! aOFFSET='1'	This value will be added to depth after all other corrections have been applied. See the section, "Calculation of depth with corrections" Default: 0

In this example, a Smart PT is installed in a 100 foot borewell, 75 feet from the top of casing. The bottom of the well is 10 feet below sea level.



Without any special configuration the Smart PT will report the sensed depth, 55 feet.

To report feet above sea level, set the "offset" parameter to 15. The Smart PT will report the sensed depth plus the offset, for a reported value of 70.

```
aXw_offset_15!
```

To report distance from water to top of casing, set "toc" to 75. The Smart PT will return the "TOC" value minus sensed depth, for a reported value of 20.

```
aXw_toc_20!
```

To report distance from the water surface to bottom of well, set "offset" to 25. The Smart PT will return the sensed depth plus the offset, for a reported value of 80.

```
aXw_offset_25!
```

Restoring the Smart PT to the default configuration

It may be useful to restore the Smart PT to the factory default configuration.

Command	Response	Description
aXd_*!	arestore factory configuration...	Restore the sensor to a factory default state. Stored data will be lost.

Retrieving recorded samples via high volume ASCII

The Smart PT maintains a pair of circular buffers containing the most recent one thousand pressure and temperature readings.

Revision 1.4 of the SDI-12 specification, released in May of 2017, adds the high volume ASCII commands to retrieve bulk data.

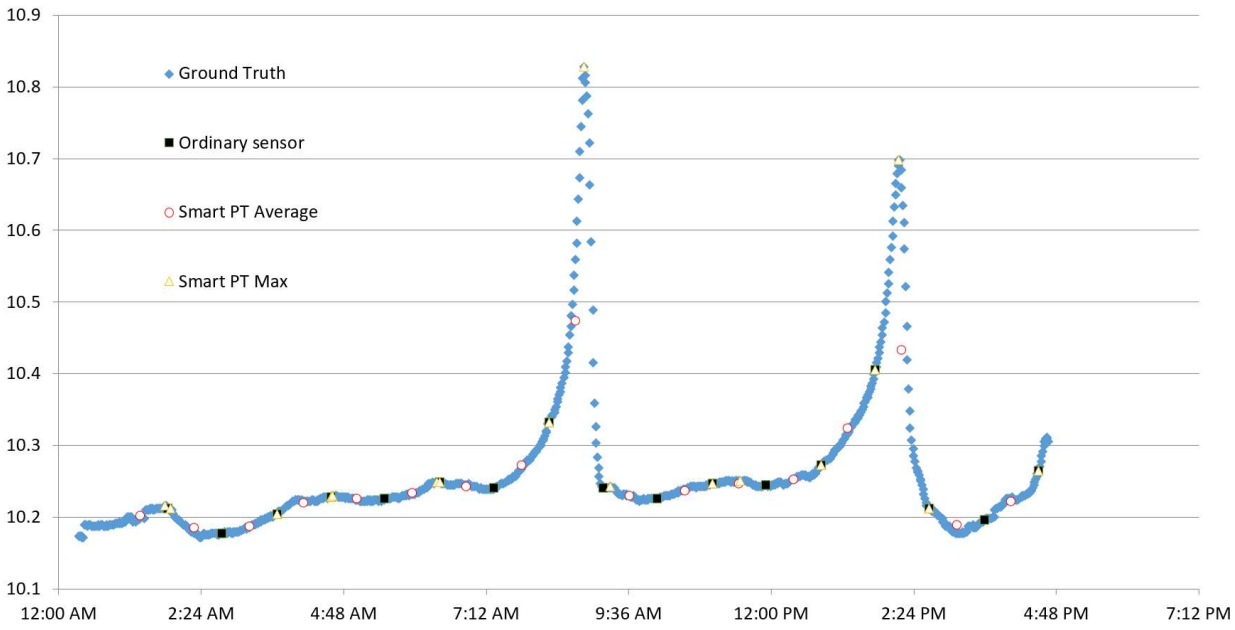
Command	Response	Description
aHA1!	atttnnn<CR><LF> Example: a000999	Request stored pressure data
aD!	a<sample>…<sample><CR><LF> a<sample>…<sample><CR><LF> a<sample>…<sample><CR><LF> a<CR><LF> (no more data)	Send stored pressure data sample – pressure reading
aHA1!	atttnnn<CR><LF> Example: a000999	Request stored temperature data
aD!	a<sample>…<sample><CR><LF> a<sample>…<sample><CR><LF> a<sample>…<sample><CR><LF> a<CR><LF> (no more data)	Send stored temperature data sample – temperature reading

In this example the sensor reports that there are 422 data points in the temperature buffer. When data is returned via the "D" command, the oldest data point will be returned first.

```
aHA1!                                                    a0000422
aD!                                  a+25.7+25.7+25.7+25.7+25.7+25.7+25.7
…
aD!                                  a+25.7+25.7+25.7+25.7+25.7+25.7+25.7
aD!                                                  a+25.7+25.7
aD!                                                              a
```

Using the Smart Sampling features and digital crest gage mode

A conventional pressure sensor only samples data when requested by the logger. As seen in the chart below, if the sampling interval is set too long, there's a risk of missing critical events.



The Smart PT takes a sample once per second and can report relevant statistics on demand, including crest events. As you can see in the chart above, the Smart PT was able to accurately capture crest events that a conventional sensor would have missed.

The Smart PT is also able to report average and standard deviation over the logging interval. This may be useful for integrating data from rough water and quantifying surface roughness. Instead of a sliding window, the Smart PT uses a numerically stable online variance algorithm (Welford 1962) to maintain the mean and standard deviation since the last time those values were queried.

Configuring a data logger to record the ten minute average

To record the ten minute average, configure the data logger to sample the M2 command once every ten minutes.

Configuring a data logger to record the daily maximum

To record the daily maximum, configure the data logger to sample the M1 command once every 24 hours.

Minimum and maximum values are backed up to flash and will persist if the sensor loses power.

Using Excel to extract timestamped crest values from a data set

The Smart PT reports the time at which a min or max event occurred in the 3rd and 4th fields of the M1 response.

These values, tMin and tMax, show how many seconds ago the event occurred.

In the example below, a crest event occurred at 8:24:20 AM. The sensor was polled by a datalogger at 8:30.00 AM, at which time the sensor reported the crest event as happening 340 seconds in the past.

Logger timestamp	Min	Max	tMin	tMax		Time of crest	
						A3-TIME(0,0,E3)	
8:30:00 AM	1004	4996	33	340		8:24:20 AM	
8:40:00 AM	1004	4995	23	324		8:34:36 AM	
8:50:00 AM	1003	4999	47	310		8:44:50 AM	
9:00:00 AM	1001	4991	16	339		8:54:21 AM	

Appendix A - Metadata Commands in SDI-12 version 1.4

Revision 1.4 of the SDI-12 specification, released in May of 2017, adds a set of commands to access metadata – descriptions of the returned data including SHEF codes and units. The Smart PT sensor implements the 1.4 specification.

```
aIM0!                                                    a00002
aIM0_001!                                      0,PW,BAR,pressure;
aIM0_002!                                    0,TW,DC,temperature;
```

As a convenience, we extend the specification with the use of '*' as a wildcard character to return all data fields for a given measurement index.

```
aIM0_*!                          0,PW,BAR,pressure;TW,DC,temperature;
```

Appendix B – Using the Smart PT with RS485

The Smart PT can accept SDI commands over a RS-485 physical interface.

There are a few differences between the SDI-12 and RS-485 interfaces that are intended to make RS-485 easier to use with a non-realtime host, for instance with a Linux single-board-computer:

- RS-485 interface is configured as 9600 8n1: 9600 baud, 8 bits/symbol, no parity bit.
- In place of the extended break that SDI-12 requires for sensor wakeup, RS-485 will wake on any character or series of pulses
- Because the wake sequence isn't unique, RS-485 requires an additional 'start' character before the address is transmitted.

As an example,

. – wake the sensor

<delay 10 ms> - allow the sensor to wake

@ - start of frame

? – wildcard address

R – read command

! - end of frame

There are three parameters that configure how the RS-485 interface functions:

Command	Purpose	Default	Configuration for interactive use
aXr_485echo!	Enable or disable RS-485 echo	0 (disabled)	1 (enabled)
aXr_485stay!	Configure RS-485 stayawake	100 ms	1000 ms
aXr_485strt!	Configure RS-485 start character	"@" (send .@x to wake and address sensor x)	"" (no start character, send address immediately after wake condition)

Appendix C – Calculation of depth with corrections

If density is not set to 1, the Smart PT will use that value directly.

If density is set to 1, the Smart PT will apply a temperature correction like so:

```
density = (999.83952 + 16.945176*t - .0079870401*t*t - 0.000046170461*t*t*t +
0.00000010556302*t*t*t*t - 0.00000000008054253*t*t*t*t*t) / (1 + .016897850*t);
```

Depth is computed as

```
depth = depth * (9.80665 / gravity) * (1000 / density)
```

If top of casing is greater than zero, depth is subtracted from top of casing:

```
depth = top of casing - depth
```

Finally, offset is added to the depth value:

```
depth = depth + offset
```

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