



# Digital Pressure and Temperature Sensor



## Introduction

Stevens Smart PT is an advanced digital pressure and temperature sensor ideal for water level measurements as well as many other pressure and fluid level monitoring applications.

The SDI-12 communications interface provides universal compatibility with industry standard data loggers. In addition, Modbus RTU (over RS485) support expands communications to other types of data loggers and programmable logic controllers (PLCs).

In addition to simple instantaneous pressure, level, and temperature measurements, Smart PT includes the ability to automatically record peak crest levels, calculate average level as well as standard deviation all without complex datalogger configurations. Other advanced features include adjustable fluid density, automatic water temperature density compensation, and adjustable local gravity compensation.

An M14-1 threaded sensor head allows for easy mounting to pipes. An included threaded cap offers a loophole which can be used to mount weights or pull the sensor through pipes or other small areas. The Smart PT is built to last for years in the field with fully sealed and potted components, a robust ceramic membrane, stainless-steel housing, and an industrial quality cable.

Order Number	Range (bar)	Water Depth (m)	Water Depth (ft)	Overpressure (m)
<b>Vented</b>				
51168-201	0.2	2	6.6	50
51168-202	0.4	4	13	60
51168-203	1	10	33	100
51168-204	2	20	66	150
51168-205	4	40	130	250
51168-206	10	100	330	400
51168-207	20	200	660	400
<b>Non-Vented</b>				
51168-303	1.4	4	13	90
51168-304	2	10	33	140
51168-305	4	30	100	240
51168-306	10	90	300	390
51168-307	20	190	630	390
<b>Recommended Yearly Calibration</b>				
32142				

Parameter	Accuracy	Unit
Pressure accuracy	0.1%	Full scale
Long term stability	Max 0.15% per year	Full scale
Temperature accuracy	±0.25	°C
SDI-12 average current consumption	1.5	mA
Modbus average current consumption	1.5	mA

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

## Warranty

The Smart PT has internal surge protection components 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.



## Wiring

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

Note: Only one communication interface should be connected: SDI-12 or Modbus.

## 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 desiccant 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 every 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

### Addressing

The first character of any command or response on SDI-12 is the sensor address. A lowercase ‘a’ is used to represent the address. Each SDI-12 sensor must have its own unique address. The default address is “0”. Use SDI-12 “Transparent Mode” to issue commands.

### Basic SDI-12 Commands

Command	Response	Description
a!	a	<b>Acknowledge active</b>  a – sensor address
aI!	a14cccccccmmmmmmvvxxx...xx  Example: Vented: 014STEVENSW_SVP01_VT_1234567890 Non-vented: 014STEVENSW_SVP01_NV_1234567890	<b>Send identification</b>  a – sensor address 14 – SDI-12 protocol version ccc... – manufacturer identification mmm... – sensor identification vvv – sensor version xxx... – serial number
aAb!	b	<b>Change address</b>  b – new address
?!	a	<b>Address query</b>  a – sensor address
aM!	atttn  Example: a0002	<b>Request a single pressure and temperature reading</b>



Command	Response	Description
		<p>t – seconds until the measurement is ready (always zero)</p> <p>n – number of data fields in the measurement (always two for this command)</p>
aD0!	<p>a&lt;value1&gt;&lt;value2&gt;</p> <p>Example: a+1.0+25.6</p>	<p><b>Send a single pressure and temperature reading</b></p> <p>a – sensor address</p> <p>value1 – depth or pressure</p> <p>value2 – temperature</p>
aM1!	<p>atttn</p> <p>Example: a0004</p>	<p><b>Request min and max (crest and trough) since the last M1 command</b></p> <p>Smart PT takes a sample every second and stores min and max in nonvolatile memory. Min and max are reset when the M1 command is received.</p>
aD0!	<p>a&lt;min&gt;&lt;max&gt;&lt;tmin&gt;&lt;tmax&gt;</p> <p>Example: a+1.0+1.4+48+67</p>	<p><b>Send min and max since the last M1 command</b></p> <p>a – sensor address</p> <p>min – lowest pressure encountered since last M1 reading</p> <p>max – highest pressure encountered since last M1 reading</p> <p>tmin – seconds elapsed since the minimum reported in &lt;min&gt;</p> <p>tmax – seconds elapsed since the maximum reported in &lt;max&gt;</p> <p>See the section, “Using Excel to extract timestamped crest values from a data set” for more information on using tmin and tmax</p>
aM2!	<p>atttn</p> <p>Example: a0003</p>	<p><b>Request average and standard deviation of pressure since the last M2 command</b></p> <p>Smart PT takes a sample every second and maintains a cumulative average and standard deviation. Average and standard</p>



Command	Response	Description
		deviation are reset when the M2 command is received.
aD0!	a<avg><stddev><nsamples>  Example: a+1.2+0.01+129	<b>Send average and standard deviation since the last M2 command</b>  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

### Variation in the last digits of pressure readings

Smart PT reports pressure results to a precision of 0.0001 bars or better. This ensures that each pressure range of the Smart PT will return results with the same number of significant figures. Because this level of precision is higher than either the accuracy or the inter-reading stability of the Smart PT, it's normal to see variation in the last few digits of the pressure 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. Vented sensors can be set to either pressure or depth units. Non-vented or absolute Smart PTs can only report in units of pressure as depth measurements require atmospheric pressure compensation.

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.

Command	Response	Description																		
aXR_PUNITS!	aPUNITS='UUU'  Example: aPUNITS='M'	<b>Query pressure units</b>  UUU... – pressure units																		
aXW_PUNITS_UUU!	aPUNITS='UUU'  Example: aXW_PUNITS_M! aPUNITS='M'	<b>Configure pressure units</b>  UUU... – pressure units <table><tr><td>* meters</td><td>M</td></tr><tr><td>* centimeters</td><td>CM</td></tr><tr><td>* millimeters</td><td>MM</td></tr><tr><td>* feet</td><td>FT</td></tr><tr><td>* inches</td><td>IN</td></tr><tr><td>bars</td><td>BAR</td></tr><tr><td>millibars</td><td>MBAR</td></tr><tr><td>kilopascals</td><td>KPA</td></tr><tr><td>pounds per square inch</td><td>PSI</td></tr></table> * Only allowed for vented	* meters	M	* centimeters	CM	* millimeters	MM	* feet	FT	* inches	IN	bars	BAR	millibars	MBAR	kilopascals	KPA	pounds per square inch	PSI
* meters	M																			
* centimeters	CM																			
* millimeters	MM																			
* feet	FT																			
* inches	IN																			
bars	BAR																			
millibars	MBAR																			
kilopascals	KPA																			
pounds per square inch	PSI																			
aXR_TUNITS!	aTUNITS='UU'  Example: aXR_TUNITS! aTUNITS='DC'	<b>Query temperature units</b>  UU... – temperature units																		



Command	Response	Description						
aXW_TUNITS_UU!	aTUNITS='UU'  Example aXW_TUNITS_DC! aTUNITS='DC'	<b>Configure temperature units</b> <table><tr><td>degrees Celsius</td><td>DC</td></tr><tr><td>degrees Fahrenheit</td><td>DF</td></tr><tr><td>Kelvin</td><td>DK</td></tr></table>	degrees Celsius	DC	degrees Fahrenheit	DF	Kelvin	DK
degrees Celsius	DC							
degrees Fahrenheit	DF							
Kelvin	DK							

## Configuring gravity compensation

Gravity on the surface of the earth can vary by 0.7%, from a minimum of 9.7639 m/s<sup>2</sup> in Peru, to a peak of 9.8337 m/s<sup>2</sup> 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'	<b>Query gravity</b>  a – sensor address vvv... – gravitational acceleration
	Example: aXR_GRAVITY! aGRAVITY='9.80665'	
aXW_GRAVITY_vvv!	aGRAVITY='vvv'	<b>Configure gravity</b>  a – sensor address vvv... – gravitational acceleration Default: 9.80665 m/s <sup>2</sup>
	Example: aXW_GRAVITY_9.80665! aGRAVITY='9.80665'	

## Configuring density compensation

The density of water can vary 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'  Example: aXR_DENSITY! aDENSITY='1'	<b>Query density</b>  a – sensor address vvv... – density
aXW_DENSITY_vvv!	aDENSITY='vvv'  Example: aXW_DENSITY_1.1! aDENSITY='1.1'	<b>Configure density</b>  a – sensor address vvv... – density Default: 1 g/mL

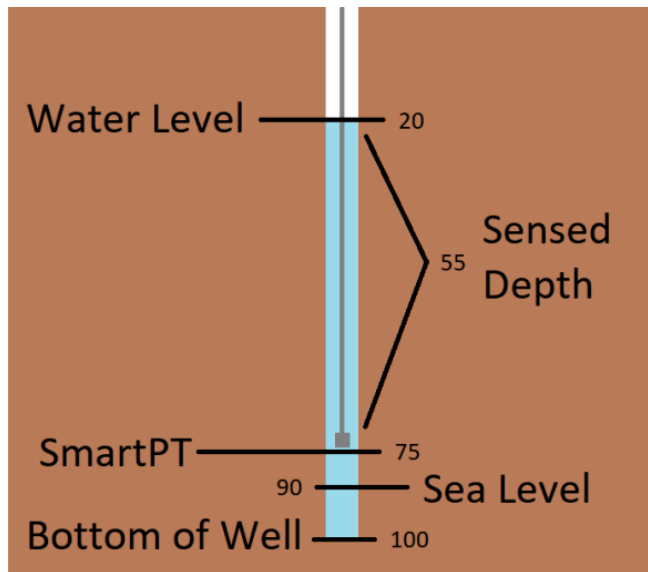
### Configuring the Smart PT for top-of-casing or reference-relative measurements

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

Command	Response	Description
aXR_TOC_vvv!	aTOC='vvv'	<b>Query top of casing</b>  a – sensor address vvv... – top of casing
aXW_TOC_vvv!	aTOC='vvv'  Example: aXW_TOC_1! aTOC='1'	<b>Configure top of casing</b>  If non-zero, the reported depth will be the TOC value minus the sensed depth Default: 0
aXR_OFFSET_vvv!	aOFFSET='vvv'	<b>Query offset</b>  a – sensor address vvv... – offset
aXW_OFFSET_vvv!	aOFFSET='vvv'  Example: aXW_OFFSET_1! aOFFSET='1'	<b>Configure offset</b>  This value will be added to the depth after all other corrections have been applied. 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_75!`

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!`



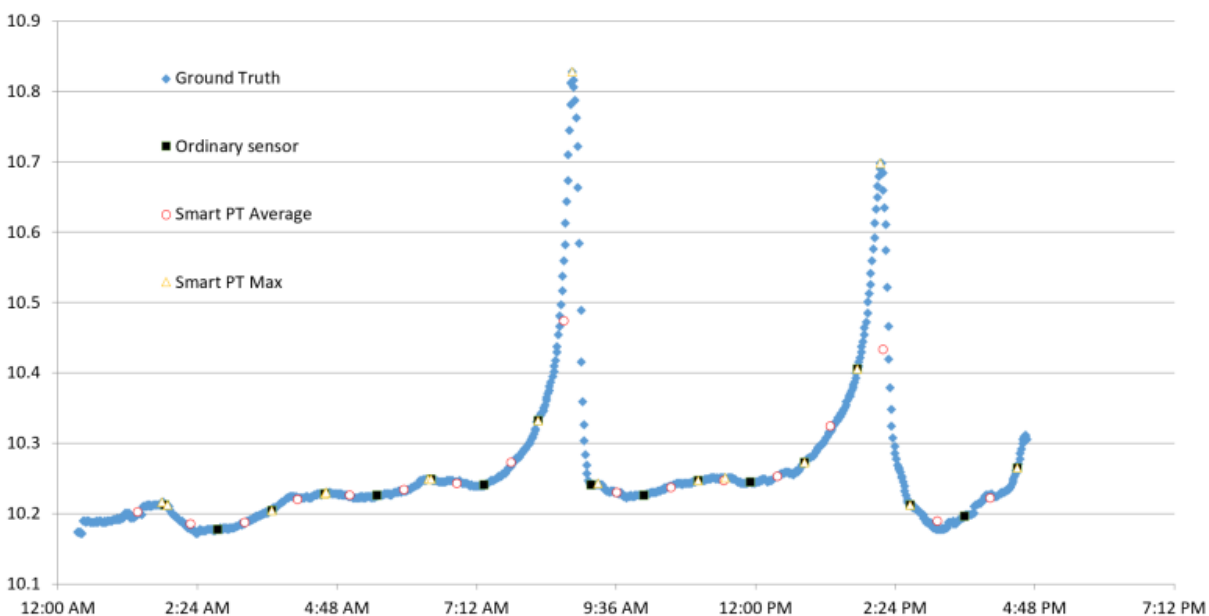
## Restoring the Smart PT to the default configuration

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

Command	Response	Description
aXD_*	arestore factory configuration...	<b>Restore the sensor to a factory default state</b>  Stored data will be lost. Sensor retains factory calibration.

## 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.

### Example configurations for average and daily maximum

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



## Modbus RTU

### Addressing

Each Modbus sensor must have its own unique address. The default address is “1”

### Power Saving

After one second without Modbus activity, the Smart PT enters a power-saving standby state. To wake the Smart PT, send any Modbus command. The Smart PT will not respond to the wake command, but it will be awake and ready to receive further commands. After one second without any activity, the Smart PT will return to the standby state.

### Baud rate and com settings

Communications settings are fixed at 19200 baud, 8 data bits, no stop bit, no parity.

### Request readings

To read data from the Smart PT use function code 03, “read holding registers”. Data is stored as 32 bit floating point, starting at register 40001.

It’s possible and recommended to read contiguous registers in a single operation.

Modbus Register Address	Description	Equivalent SDI-12 "M" Command	Equivalent SDI-12 Data Field
40001	Most recent pressure or depth reading, updated once/second	0	0
40003	Most recent temperature reading, updated once/second	0	1
40017	Minimum pressure or depth since last request for this value	1	0
40019	Seconds elapsed since last minimum pressure or depth	1	1
40021	Seconds elapsed since last maximum pressure or depth	1	2
40023	Maximum temperature since last request for this value	1	3
40033	Average pressure or depth since last request for this value	2	0



40035	Standard deviation of pressure or depth since last request for this value	2	1
40037	Number of samples used to calculate Average and Standard Deviation	2	2

### Variation in the last digits of pressure readings

Smart PT reports pressure results to a precision of 0.0001 bars or better. This ensures that each pressure range of the Smart PT will return results with the same number of significant figures. Because this level of precision is higher than either the accuracy or the inter-reading stability of the Smart PT, it's normal to see variation in the last few digits of the pressure reading.

### Set and Get configuration

The Smart PT has many configuration objects. Objects are stored either as 32-bit floating point value, or as null terminated strings. Each configuration object is allocated 16 Modbus registers, allowing for strings of up to 31 characters.

To get a configuration object from the Smart PT use function code 03, "read holding registers"

To write a configuration object to the Smart PT use function code 16, "write multiple holding registers"

It's not possible to read or write multiple configuration objects with a single Modbus command.

Configuration Object	Description	Modbus Register Address	Type	Writable
BUILD	Date of firmware build	41001	NULL-Terminated String	N
SERIAL	Serial number	41009	NULL-Terminated String	N
ADDRESS	SDI-12 address	41017	NULL-Terminated String	N
MODADDR	Modbus address	41025	Floating Point	Y
CYCLES	# of power cycles	41033	Floating Point	N
RATE	Auto sampling interval in seconds	41041	Floating Point	Y
485STAY	RS-485 stay awake	41049	Floating Point	Y
GRAVITY	Gravitational acceleration, used in depth calculation	41057	Floating Point	Y
DENSITY	Fluid density, used in depth calculation	41065	Floating Point	Y
PUNITS	Pressure or depth units	41073	NULL-Terminated String	Y
TUNITS	Temperature units	41081	NULL-Terminated String	Y



Configuration Object	Description	Modbus Register Address	Type	Writable
GRANUL	Pressure granularity, used to calculate # of significant digits for pressure and depth readings	41089	Floating Point	N
OFFSET	Offset, used in depth calculation	41097	Floating Point	Y
TOC	Top of casing, used in depth calculation	41105	Floating Point	Y
CALSLP	Calibration data	41121	Floating Point	N
CALYCPT	Calibration data	41129	Floating Point	N
MIN	Backup for crest function	41177	Floating Point	Y
MAX	Backup for crest function	41185	Floating Point	Y
MINTIME	Backup for crest function	41193	Floating Point	Y
MAXTIME	Backup for crest function	41201	Floating Point	Y
LIFEMIN	Lifetime minimum temperature, used for warranty purposes	41209	Floating Point	N
LIFEMAX	Lifetime minimum temperature, used for warranty purposes	41217	Floating Point	N
VENT	VT' or 'NV', used to disable depth readings for non-vented sensors	41225	NULL-Terminated String	N
CALDATE	Date of last calibration	41249	NULL-Terminated String	N

A few of the string-type objects – TUNITS and PUNITS - are writable. There is no standard for transmitting strings in Modbus. This translation table allows writing a float to those objects.

Value to Send	String Translation
10	BAR
11	MBAR
12	KPA
13	HPA
14	PA
15	PSI



Value to Send	String Translation
16	TORR
20	M
21	CM
22	MM
23	FT
24	IN
30	DC
31	DF
32	DK

### Metadata Commands

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;

### Calculation of depth

Depth is computed as follows

$$\text{Reported Depth (m)} = \text{Sensed Depth (m)} * (9.80665 / \text{Gravity}) * (1000 / \text{Density})$$

Density automatically has temperature correction applied. If the density value is set by the user, the user defined value will override the temperature corrected value.

Smart PT temperature corrected density equation:

$$\text{Density} = (999.83952 + 16.945176 * t - .0079870401 * t^2 - 0.000046170461 * t^3 + 0.00000010556302 * t^4 - 0.00000000008054253 * t^5) / (1 + .016897850 * t)$$

If top of casing is zero (the default value),

$$\text{Reported Depth} = \text{Sensed Depth} + \text{Offset}$$

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

$$\text{Reported Depth} = \text{Top of Casing} - \text{Sensed Depth} + \text{Offset}$$

