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SMART PT

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 types of 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 loop hole 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.

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Portland, Oregon, USA | 1 800 452 5272 | 503 445 8000 | www.stevenswater.com

Order numbers

Vented Version		
Ordering Number PN#	Range in Bar/m/ft	Overpressure Max (meters/ft)
51168-201	0.2/2/6.6	50/150
51168-202	0.4/4/13	60/196
51168-203	1/10/33	100/330
51168-500	Cable, Vented, Specify Length	
93030-001	Desiccant Cartridge	

Non-Vented Version (Absolute Pressure)				
Ordering Number PN#	Total Range in (Bar)	Usable Range in (Bar)*	Usable Water Level Range at Sea Level (meters)	Overpressure Max (Meters/ft)
51168-302	1.4	0.4	4	40/131
51168-303	2	1	10	40/131
51168-305	4	3	30	240/787
32142	Recommended Yearly Calibration			
93539	Cable, 4-conductor, Specify Length			

***non-vented** (note: non-vented pressure is the total pressure which includes atmospheric pressure. Sea level is about 1 Bar. Actual max depth depends on elevation and atmospheric pressure. See page 21 for calculation)

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, Modbus	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 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.

Installing the Smart PT probe

Wiring

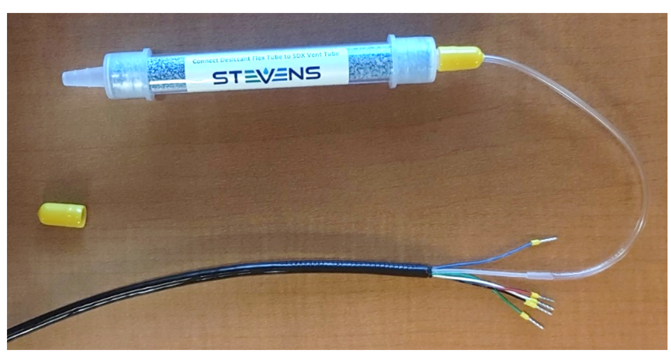
Wire Color	Signal
Black	Ground
Red	+12Vdc
Blue	SDI-12 Data
White	RS485+ / B
Green	RS485- / A

Note: Only one communications interface should be connected: SDI-12 or RS485 Modbus

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 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

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.

Basic SDI-12 Commands

Command	Response	Description
`a!`	`a<CR><LF>`	Acknowledge active a – sensor address

`aI!`	`a14ccccccccmmmmmmvvvxxx...xx<CR><LF>`
	Example:
	Vented:
	`014STEVENSW_SVP01_VT_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>` 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)

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> Example: a0004	Request min and max (crest and trough) since the last M1 command. 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.
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> Example: a0003	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 BAR
		
		*** Only allowed for vented**

`aXR_TUNITS!`	`aTUNITS='UU'<CR><LF>`
	
	Example:
	
	`aXR_TUNITS!`
	`aTUNITS='DC'`
		Query temperature units
		
		UU… – temperature units

`aXW_TUNITS_UU!`	`aTUNITS='UU'<CR><LF>`
	
	`aXW_TUNITS_DC!`
	`aTUNITS='DC'`
		Configure temperature units
		
		degrees centigrade DC
		degrees fahrenheit DF
		kelvin DK
		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… – gravitational acceleration
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 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'<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.

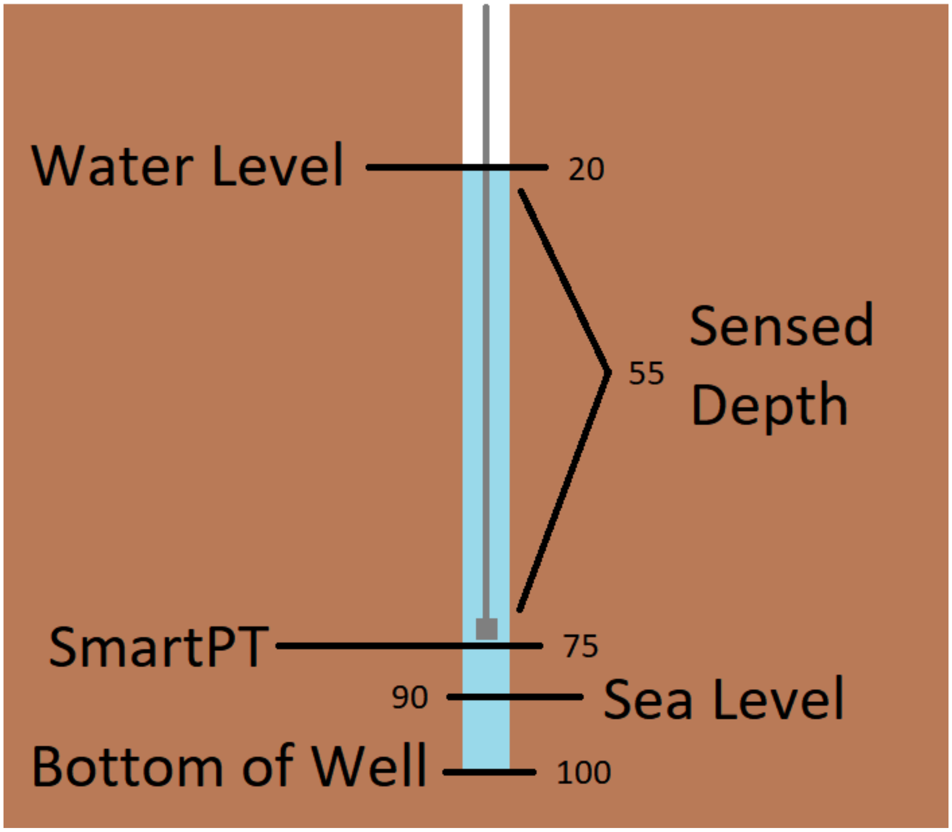
Command	Response	Description
`aXR_TOC_vvv!`	`aTOC='vvv'<CR><LF>`	Query top of casing

`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_OFFSET_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_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!
```

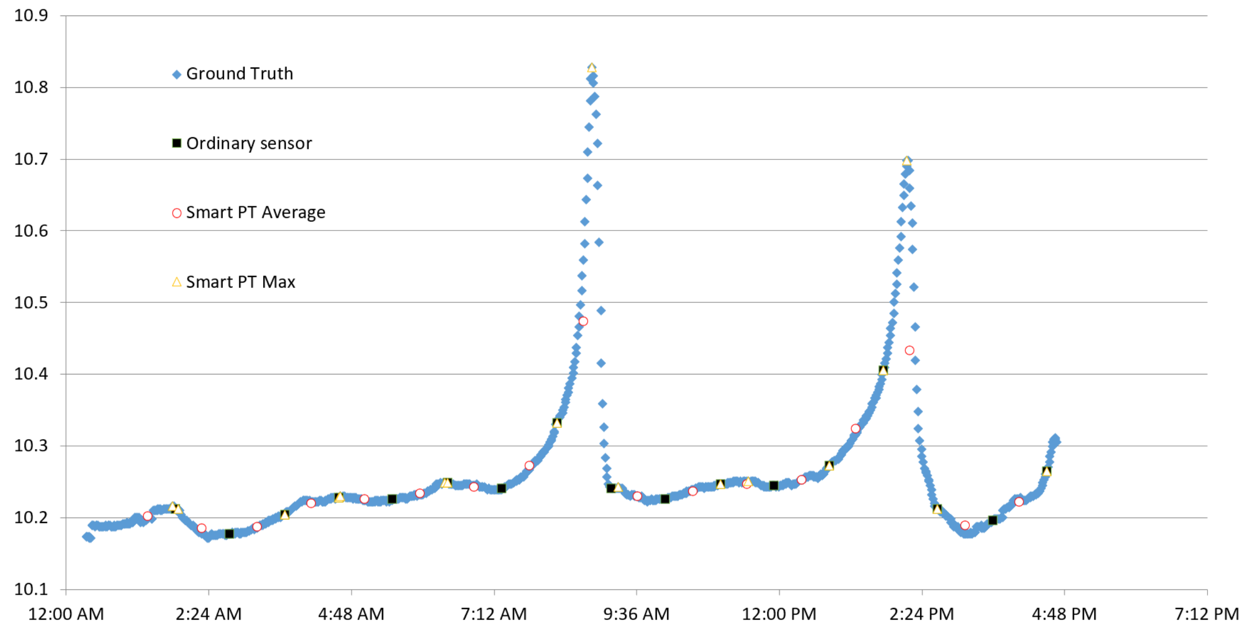
Restoring the Smart PT to the default configuration

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

Command	Response	Description
aXD_*!	arestore factory configuration...	Restore the sensor to a factory default state. 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

Autodetection of Modbus / RS485 or SDI-12

To save power, when Smart PT receives a valid SDI-12 command addressed to itself, it will disable the Modbus / RS485 transceiver until the next power cycle.

Wake sequence

After one second without RS-485 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.

Equivalent SDI-12 "M" Command	Equivalent SDI-12 Data Field	Description	Modbus Register Address
0	0	Most recent pressure or depth reading, updated once/second	40001
0	1	Most recent temperature reading, updated once/second	40003
1	0	Minimum pressure or depth since last request for this value	40017
1	1	Seconds elapsed since last minimum pressure or depth	40019
1	2	Seconds elapsed since last maximum pressure or depth	40021
1	3	Maximum temperature since last request for this value	40023
2	0	Average pressure or depth since last request for this value	40033
2	1	Standard deviation of pressure or depth since last request for this value	40035
2	2	Number of samples used to calculate Average and Standard Deviation	40037
3	0	Immediate pressure reading in bars	40049
3	1	Immediate pressure reading in degrees centigrade	40051

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Set and Get configuration

The Smart PT has a number of 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	Default
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	1
CYCLES	# of power cycles	41033	Floating Point	N	
RATE	Autosampling interval in seconds	41041	Floating Point	Y	1
485STAY	RS-485 stay awake	41049	Floating Point	Y	1500
GRAVITY	Gravitational acceleration, used in depth calculation	41057	Floating Point	Y	9.806650
DENSITY	Fluid density, used in depth calculation	41065	Floating Point	Y	1
PUNITS	Pressure or depth units	41073	NULL-Terminated String	Y	"BAR"
TUNITS	Temperature units	41081	NULL-Terminated String	Y	"DC"
GRANUL	Pressure granularity, used to calculate # of significant digits for pressure and depth readings	41089	Floating Point	N	0.0001
OFFSET	Offset, used in depth calculation	41097	Floating Point	Y	0
TOC	Top of casing, used in depth calculation	41105	Floating Point	Y	0

PREBIAS	Pressure transducer prebias level	41113	Floating Point	Y	2
CALSLP	Calibration data	41121	Floating Point	N	
CALYCPT	Calibration data	41129	Floating Point	N	
RAW A	Calibration data	41137	Floating Point	N	
RAW B	Calibration data	41145	Floating Point	N	
BAR A	Calibration data	41153	Floating Point	N	
BAR B	Calibration data	41161	Floating Point	N	
CALSDEV	Calibration data	41169	Floating Point	N	0.001
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	
RESERVED		41233			
RESERVED		41241			
CALDATE	Date of last calibration	41249	NULL-Terminated String	N	
RESERVED		41257			

A few of the string-type objects – TUNITS and PUNITS - are writable. Because there's no standard for transmitting strings in Modbus, there's a translation table that allows writing a float to those objects.

Master sends this float32 value	**Sensor sets this string value**
10	BAR
11	MBAR
12	KPA
13	HPA
14	PA
15	PSI
16	TORR
20	M
21	CM
22	MM
23	FT
24	IN
30	DC
31	DF
32	DK

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;
```

Appendix B – Calculation of depth

Absolute Sensor Calculation

Water Level Depth of an absolute pressure is computed as follows

$$H = (P_{tot} - P_{baro})/(\rho g)$$

Where:
-H is Hydraulic head or water level over the sensor in meters
-P_{tot} is the total pressure of an absolute sensor in Pascals
-P_{baro} is the barometric Pressure in Pascals
-ρ is the density of water in kg/m^3 , Typically 0.99 or can be calculated from temperature for fresh water
-g is gravity in m/s^2 , Typically 9.8 m/s^2 Or can be calculated

Depth using an absolute sensor will need to be post processed in a logger.

Vented depth is calculated

A Depth correction can be applied.

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

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

```
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);
```

Where density is kg m^{-3} and t is temperature in C°.
If density is set to a value other than 1, that value will override the temperature correction.
Taken from Journal of NIST, Vol. 97, Number 335, 1992

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
```