

# Implexx Sap Flow Sensor SDI-12 Integrator's Guide

Version 1.3, August 2021

## **WARNING!**

Only ever start a measurement of the Sap Flow Sensor when the needles, or probes, are embedded inside a material such as the foam block or a tree. **NEVER** start a measurement when the needles are in air. This may cause damage to the heater element and void warranty.

## **WARNING!**

The most frequent data collect interval is 10 minutes. An SDI-12 M! command should **NEVER** be sent to the sap flow sensor more frequently than 10-minute intervals.

## **Contact Details:**

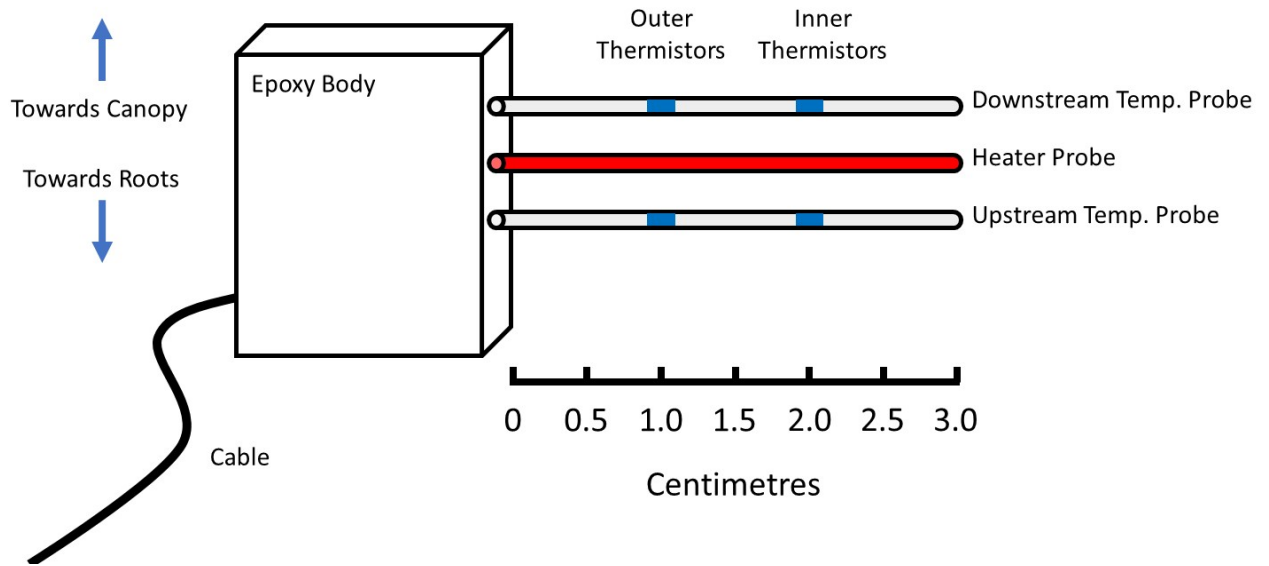
Implexx Sense

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# Implexx Sap Flow Sensor

## Design Overview



## Wiring Diagram

RED -> 12 VDC power supply

BLACK -> Ground

White -> Data

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BROWN -> 12 VDC power supply

GREEN -> Ground

White -> Data



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## General

The sap flow SDI12 interface conforms to the SDI12 version 1.4 specification, which is a superset of and compatible with versions 1.2 and 1.3.

The measurement process commences when an M or C command is received and the measurement is completed in 95 seconds. After retrieving the heat velocity and stem water content results from the measurement with the D0 command, additional measurement results can be obtained with M1 through M5 (or C1 through C5) which return the measurements of temperature and time used to calculate the velocity and water contents. The M5 or C5 command can also be used to report the current temperatures.

## SDI-12 Commands

The following table shows all the SDI-12 v1.4 commands and the generic response from the sensor. The contents of the responses are described below the table.

Notes on the command table:

- every response is terminated by CR LF characters
- a and b denote a device address (0-9, A-Z, a-z)
- ttt is the time (seconds) until the sensor measurement will be ready
- n or nn is the number of measurement values that will be produced
- on completion of a measurement initiated by an M command, the sensor will respond with a service request consisting of its address and CR LF

Command	Response	Comment
a!	a	Acknowledge active
aI!	Allcccccccmmmmmmvvwx...x	Identity string
aAb!	b	Change address to b
?!	a	Address query
aM!	atttn	Start measurement
aMC!	atttn	Start measurement, use CRC on data response
aD0! – aD9!	a<values> a<values><CRC>	Report measurement values, with CRC if requested by M, R or C command
aM1! – aM9! aMC1! – aMC9!	atttn	Additional measurements
aC!	atttnn	Start concurrent measurement
aCC!	atttnn	Start concurrent measurement, use CRC on data response
aV!	a0000	Start verification (not implemented)
aR0! – aR9! aRC0! – aRC9!	a<values> a<values><CRC>	Continuous measurement, returns results immediately
aX<command>!	a<response>	Extended commands, used for setting measurement parameters
aHA!	a000000	High volume ASCII measurement command (not implemented)



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aHB!	a000000	High volume binary measurement command (not implemented)
aIM! aIMC! aIM1! - aIM9! aIMC1! - aIMC9!	atttn	Identify measurements, responds as for measurement commands but does not initiate a measurement
aIV!	a0000	Identify verification (not implemented)
aIC! aICC! aIC1! - aIC9! aICC1! - aICC9!	atttnn	Identify concurrent measurements, responds as for measurement commands but does not initiate a measurement
aIHA! aIHB!	a000000	Identify high volume measurements (not implemented)
aIM_001! etc aIR0_001 etc	a,name,units,description;	Measurement descriptions
aIV_001 etc aIHA_001 etc aIHB_001 etc	a	Verification and high volume descriptions (not implemented)

### Response details

Note that '+' characters will be replaced with '-' when the value being reported is negative.

The examples use address 3. Devices are configured as address 0 on delivery and can be changed to any valid address using the change address (A) command.

### Identification

The identification string consists of a series of fields with pre-defined meanings:

a	ll	cccccccc	mmmmmm	vvv	xxx...xxx
Address	SDI version	Vendor	Sensor model	Version number	Additional information
Varies	14	Implexx	HPV-06	001	Version and serial numbers

The SDI-12 specification implies that the Vendor, Sensor model and Version number fields may be used by a data recorder to infer what commands and responses the sensor uses. To comply with this, the version number will increment when the SDI12 commands or responses change and serves as the firmware major version number. The "Additional information" field has 12 characters:

- '.' followed by 3 digits, the firmware minor version number
- 2 letters, the hardware version
- 6 digits, the unit serial number

Example:

3I!314Implexx HPV-06002.001Ba000127

This is a version 002 sensor, firmware minor version 001, hardware version Ba, serial number 127.

## Standard measurement

In response to an M or C command, a measurement is initiated and sap flow and related data is reported after the measurement is complete. The measurement completes in about 95 seconds. The measurement produces 9 data values that are reported in two groups using data commands D0 and D1:

```
aM!a959 (followed by the measurement cycle)
a
aD0!a+SapFlowTotal+SFDOuter+SFDInner+AlphaOuter+AlphaInner
aD1!a+BetaOuter+BetaInner+tMaxTouter+tMaxTinner
```

The second line is the service request issued by the sensor to indicate that the measurement is complete and data is available. The nine values returned by the D0 command are:

1. SapFlowTotal, the total sap flow of the stem in litres per hour
2. SFDOuter, sap flux density at the outer thermistor
3. SFDInner, sap flux density at the inner thermistor
4. AlphaOuter, the natural log of the ratio of temperatures ( $\ln \frac{\Delta T_d}{\Delta T_u}$ ) at the outer thermistor
5. AlphaInner, the natural log of the ratio of temperatures at the inner thermistor
6. BetaOuter, the natural log of the ratio of maximum temperatures ( $\ln \frac{\Delta T_{d,max}}{\Delta T_{u,max}}$ ) at the outer thermistor
7. BetaInner, the natural log of the ratio of maximum temperatures at the inner thermistor
8. tMaxTouter, time to maximum temperature at the outer thermistor
9. tMaxTinner, time to maximum temperature at the inner thermistor

Example:

```
3M!3959      start measurement; two data values will be ready within 95 seconds
3           service request from sensor
3D0!3+TBC
```

## Additional measurements

The additional measurement commands (M1..6) provide access to measured values used to calculate the heat velocity and water contents (the service request from the sensor between the M and D commands is not shown):

- M1 – outer thermistor temperatures: pre-pulse, maximum and post-pulse temperatures at the downstream and upstream positions, available immediately:  
aM1!a0006  
aD0!a+TpreDsOuter+dTmaxDsOuter+TpostDsOuter+TPreUsOuter+dTmaxUsOuter+TpostUsOuter
- M2 – inner thermistor temperatures: pre-pulse, maximum and post-pulse temperatures at the downstream and upstream positions, available immediately:  
aM2!a0006  
aD0!a+TpreDsInner+dTmaxDsInner+TpostDsInner+TPreUsInner+dTmaxUsInner+TpostUsInner

- M3 – stem water content, heat capacity and pulse energy, available immediately:  
aM3!a0006  
aD0!a+StemWaterContentOuter+StemWaterContentInner+VolHeatCapOuter+VolHeatCapInner+ PulseEnergyPerUnitLength+PulseTime
- M4 – voltage and current during the heating period, and a diagnostics flag, available immediately:  
aM4!a0005  
aD0!+AvgVolts+AvgCurrent+MinVolts+MaxVolts+Diagnostic  
The MaxVolts value is recorded just before the heater is turned on. The diagnostic value is zero when everything is normal; for details of abnormal conditions see Diagnostic values below
- M5 – time to maximum temperature for upstream thermistors:  
aM5!a0002  
aD0!a+tMaxTusOuter+tMaxTusInner
- M6 – current temperatures:  
aM6!a0004  
aD0!a+TdsOuter+TusOuter+TdsInner+TusInner

Remaining Mn commands return no values, eg:

aM8!a0000

Example:

3M1!30006

3D0!3+20.904+1.783+22.3423+20.849+1.467+22.035

The same measurements are also available through the concurrent additional measurement commands (C1..6).

Current temperatures are also available through the R0 command, which returns the data in response to the command and does not require a separate data (D0) command:

aR0!a+TdsOuter+TusOuter+TdsInner+TusInner

Supply voltage is reported using the R1 command:

aR1!a+Vsupply

## Reporting precision and accuracy

Type of value	Units	Decimal places	Accuracy*
Sap flow	litres/hour	3	0.01
Sap flux density	cm <sup>3</sup> /cm <sup>2</sup> /hour	2	0.03
Logs of ratios (alpha and beta)	None	5	0.00003
Time	seconds	3	0.01
Temperature	Degrees C	3	0.015 (-10 to +70) 0.03 (-30 to -10)
Stem water content	Percent	2	0.03
Volumetric heat capacity	kJ/m <sup>3</sup>	0	3
Voltage	Volts	3	0.5%**
Current	Amps	3	1.5%**
Pulse energy per unit length	J/m	3	2%**

\* Calculation accuracy, not including sensor measurement error except for those marked \*\* which includes both measurement and calculation accuracy



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## Measurement descriptions

The measurement description commands are used to obtain information about the values returned in response to a standard measurement or additional measurement command.

Standard measurement (for data returned after M or C command):

- `aIM_001!a,SapFlowTotal,L/hr,Total stem sap flow;`
- `aIM_002!a,SFDOuter,cm3/cm2/hr,Sap flux density for outer thermistors;`
- Etc

Additional measurements (for data returned after M1..9 or C1..9 command):

- `aIM1_001!a,TpreDsOuter,deg C,Temperature before heat pulse of downstream outer;`
- `aIM1_002!a,dTmaxDsOuter,deg C,Max temperature rise of downstream outer;`
- Etc

The same description information is returned for IM, IMC, IC and ICC commands.

Immediate measurements:

- `aIR0_001!a,TdsOuter,deg C,Current temperature of downstream outer;`
- Etc

## Diagnostic values

The diagnostics value, the last value returned for the M4 command, is zero when no problems have been detected. If one or more problems have been detected the value will be the sum of the values for each error condition:

- Heater current low= 1, high = 2. Low is less than 200 mA, high is above 400 mA; nominal heater current at 12V supply is 270 mA
- Downstream outer thermistor low = 10, high = 20, heatpulse induced variation = 40. The lowest accepted temperature is -33 °C and the highest is 71 °C; values outside this range are almost certainly a shorted or open circuit thermistor. The heatpulse induced variation test looks for changes in temperature values of more than 0.1 °C above or below the last value measured before the heat pulse, to detect leakage from the heater to the thermistor circuit in the sensor.
- Downstream inner thermistor low = 100 high = 200 heatpulse variation = 400
- Upstream outer thermistor low = 1000 high = 2000 heatpulse variation = 4000
- Upstream inner thermistor low = 10,000 high = 20,000 heatpulse variation = 40,000
- Supply voltage low = 100,000 high =200,000. Low is less than 9 V, high is above 17 V.



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## Changing Parameters

All stem properties, measurement timing parameters and the thermal parameters for calculating heat capacity and water content can be reported and modified:

- `aXmmm!` Reports current value of parameter mmm
- `aXmmm=value!` Sets parameter mmm to new value

The parameters that can be reported and set, and their default values and allowed ranges, are:

- TDD trunk diameter in cm (default 10.0, float, allowed 0-300)
- BDD bark depth in cm (default 0.5, float, allowed 0-10)
- DDW density of dry wood in  $\text{g}/\text{cm}^3$  (default 0.4, float, allowed 0.2-0.9) – see note below
- TDF thermal diffusivity in  $\text{cm}^2/\text{second}$  (0.0020, float, allowed 0.001-0.004)
- BMD baseline temperature measurement duration in seconds (default 10, integer, allowed 1-60)
- HTD heater duration in seconds (default 3.0, float, allowed 0.001-10)
- PMS post-heat temperature measurement start in seconds (60, integer, allowed 1-120)
- PMD post-heat temperature measurement duration in seconds (20, integer, allowed 1-60)
- TMD maximum temperature measurement duration in seconds (80, integer, allowed 1-200)
- CDW specific heat capacity of dry wood in  $\text{J}/\text{kg}/\text{K}$  (default 1200, integer, allowed 800 to 2000)

(from version 002.002) The thermal diffusivity TDF can be reliably estimated from dry wood density DDW, so TDF is automatically calculated from DDW whenever DDW is set. The automatically calculated value can be overridden by setting TDF after setting DDW.

(from version 002.004) The interface handles both HPV06 and SF3 sensor heads. The XSNV command can be used to set which sensor is attached:

- `aXSNV=0` HPV06 sensor
- `aXSNV=1` SF3 sensor

(from version 003.010) The calculation of heat velocity is normally done by the SapLinx method, choosing either the heat ratio method (HRM) or Tmax methods. The XHRM command can be used to use only the HRM method for calculating heat velocity:

- `aXHRM=1` use HRM method only for heat velocity
- `aXHRM=0` use DMA (dual method approach) for heat velocity

With HRM=1 the BetaOuter, BetaInner, tMaxTouter and tMaxTinner results are all reported as 0 as an indication that the tMax method has not been considered in the calculation of heat velocity.