IX-SF60-G2

Implexx Sap Flow Sensor 60mm Model Gen2

SDI-12 Integrator's Guide

Version 2.0, August 2024

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 C! command should **NEVER** be sent to the sap flow sensor more frequently than 10-minute intervals.

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IX-SF60-G2 Design Overview

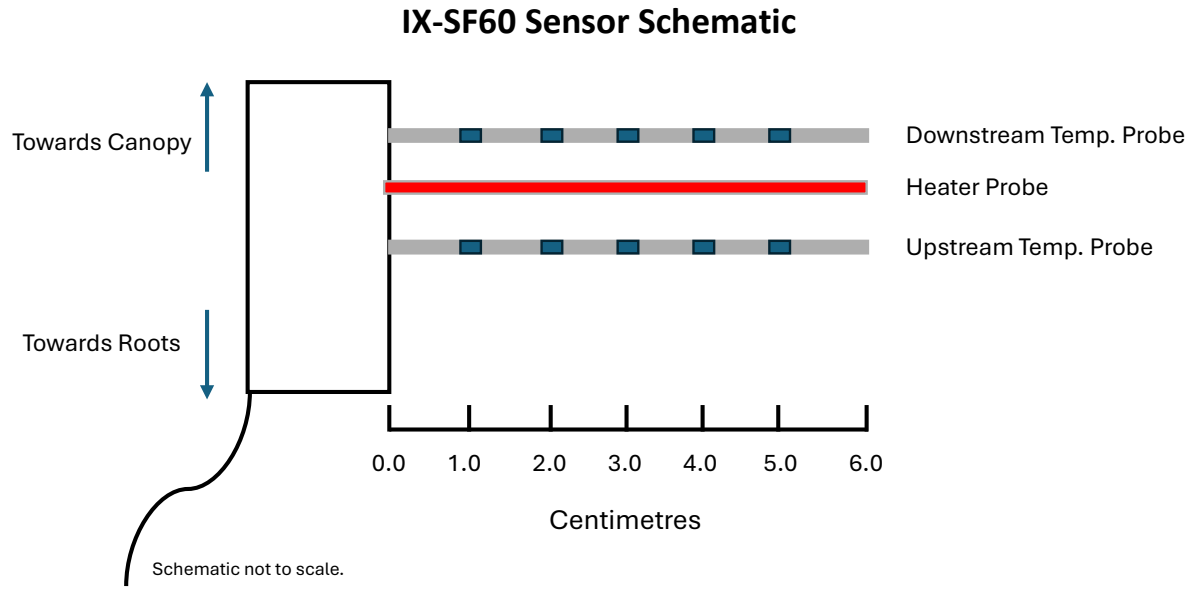

Figure 1. A schematic of the Implexx Sap Flow Sensor Gen2 IX-SF60-G2 model.

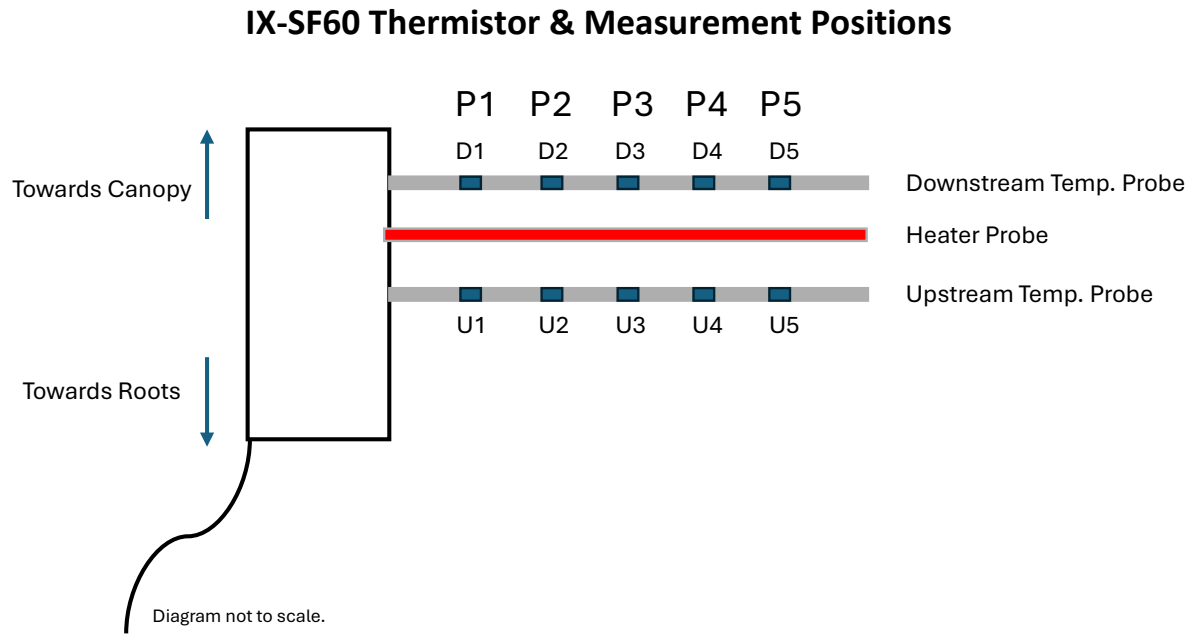

Figure 2. A schematic of the Implexx Sap Flow Sensor Gen2 (IX-SF60-G2 model) indicating the downstream (D1, D2, D3, D4, D5) and upstream (U1, U2, U3, U4, U5) measurement points at positions 1, 2, 3, 4 and 5 (P1, P2, P3, P4, P5).

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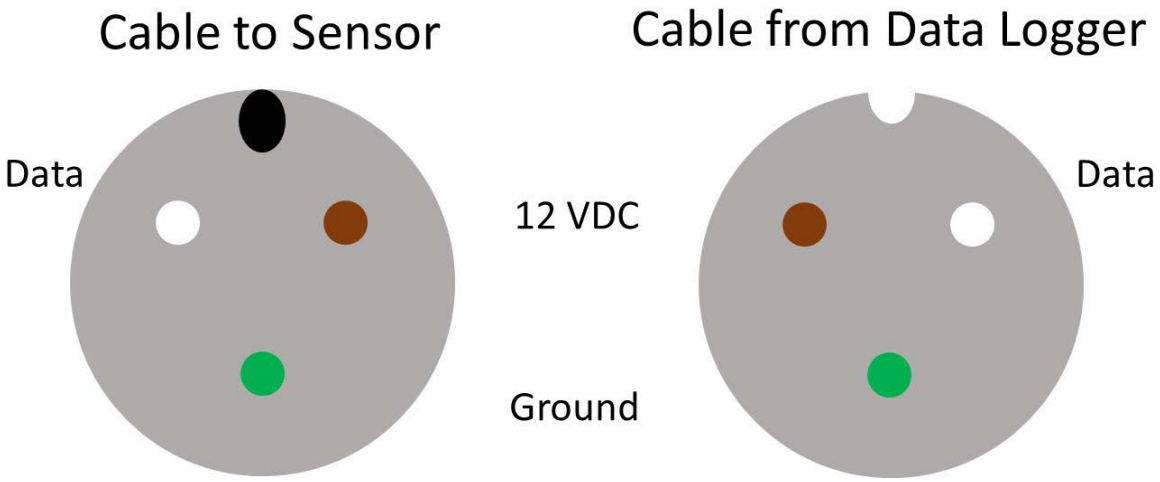
Wiring Diagram

BROWN -> 12 VDC power supply

GREEN -> Ground

White -> Data

Cable Connector Wiring



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General

The Implexx Sap Flow Sensor Gen2's 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 a C command is received and the measurement is completed in 124 seconds.

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
- when a C command is used, the data logger must wait for the time specified in the response to the command before requesting data from the sensor; no service request is sent

Command	Response	Comment
a!	a	Acknowledge active
aI!	Allcccccccmmmmmmvvvx...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

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 (HB 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 (HB not implemented)

Response details

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

The examples use address a. 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	SF60G2	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:

```
0I! 014Implexx SF60G2006.006Qe000109
```

This is a version 006 sensor, firmware minor version 006, hardware version Qe, serial number 109.

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 124 seconds. The measurement produces 6 data values that are reported using data command D0:

```
aC!a012406 (followed by the measurement cycle of 124 seconds)
aD0!a+SapFlowTotal+SFDPosition1+SFDPosition2+SFDPosition3+SFDPositio
n4+SFDPosition5
```

The six values returned by the D0 command are:

1. SapFlowTotal, the total sap flow in litres per hour
2. SFDPosition1, sap flux density at the first thermistor position (see diagram on page 2)
3. SFDPosition2, sap flux density at the second thermistor position
4. SFDPosition3, sap flux density at the third thermistor position
5. SFDPosition4, sap flux density at the fourth thermistor position
6. SFDPosition5, sap flux density at the fifth thermistor position

Example:

```
aC!a12406    start measurement; six data values will be ready after 124 seconds
aD0!0+TBC    0+0.100+0.53+1.64+2.55+3.38+4.06
```

Additional measurements

The additional measurement commands (C1..9) provide access to measured values used to calculate the heat velocity and water contents, and the data from each is available immediately:

- C1 – alpha and beta raw data:
  ```
  aC1!a000010
  aD0!a+alphaPosition1+alphaPosition2+alphaPosition3+alphaPositi
  on4+alphaPosition5
  aD1!a+betaPosition1+betaPosition2+betaPosition3+betaPosition4+
  betaPosition5
  ```

- C2 – time to maximum temperature rise (time to tmax) in the downstream (D) and upstream (U) thermistor positions:
  ```
  aC2!a000010
  aD0!a+tMaxTPositionD1+tMaxTPositionD2+tMaxTPositionD3+tMaxTPos
  itionD4+tMaxTPositionD5
  aD1!a+tMaxTPositionU1+tMaxTPositionU2+tMaxTPositionU3+tMaxTPos
  itionU4+tMaxTPositionU5
  ```

- C3 – stem water content (SWC) in the downstream (D), heat capacity (pc) and pulse energy:
  ```
  aC3!a000012
  ```

```
aD0!a+SWCPositionD1+SWCPositionD2+SWCPositionD3+SWCPositionD4+
SWCPositionD5
aD1!a+pcPositionD1+pcPositionD2+pcPositionD3+pcPositionD4+pcPo
sitionD5
aD2!a+PulseTime+PulseEnergyPerUnitLength
```

- C4 – dTmax: maximum temperature rise after the heat pulse in the downstream (D) and upstream (U) thermistor positions:

```
aC4!a000010
aD0!+a+dTmaxPositionD1+dTmaxPositionD2+dTmaxPositionD3+dTmaxPo
sitionD4+dTmaxPositionD5
aD1!+a+dTmaxPositionU1+dTmaxPositionU2+dTmaxPositionU3+dTmaxPo
sitionU4+dTmaxPositionU5
```

- C5 – Total sap flow and sap flux density estimated via slow rates of flow method (heat ratio):

```
aC5!a000006
aD0!a+SapFlowTotal+SFDPosition1+SFDPosition2+SFDPosition3+SFDP
osition4+SFDPosition5
```

- C6 – Total sap flow and sap flux density estimated via Tmax method:

```
aC5!a000006
aD0!a+SapFlowTotal+SFDPosition1+SFDPosition2+SFDPosition3+SFDP
osition4+SFDPosition5
```

- C7 – temperatures at the beginning of the measurement in the downstream (D) and upstream (U) thermistor positions:

```
aC7!a000010
aD0!a+TempPositionD1+TempPositionD2+TempPositionD3+TempPositio
nD4+TempPositionD5
aD1!a+TempPositionU1+TempPositionU2+TempPositionU3+TempPositio
nU4+TempPositionU5
```

- C9 – instantaneous temperatures in the downstream (D) and upstream (U) thermistor positions:

```
aC9!a000010
aD0!a+TempPositionD1+TempPositionD2+TempPositionD3+TempPositio
nD4+TempPositionD5
aD1!a+TempPositionU1+TempPositionU2+TempPositionU3+TempPositio
nU4+TempPositionU5
```

Reporting precision and accuracy

Type of value	Units	Decimal places	Accuracy*
Sap flow	Litres/hour	3	0.01
Sap flux density	$cm^3/cm^2/hour$	2	0.03
Logs of ratios (alpha and beta)	None	5	0.00003
Time	Seconds	3	0.01
Temperature	Degrees Celsius	3	0.015 (-10 to +70) 0.03 (-30 to -10)
Stem water content	Percent	2	0.03
Volumetric heat capacity	kJ/m^3	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

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 sap flow;`
- `aIM_002!a, SFDOuter,cm3/cm2/hr,sap flux density at 1 cm;`
- Etc

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

- `aIM1_001!a,Alpha1cm, ,LN of deltaTds/deltaTus at 1 cm;`
- `aIM1_002!a,Alpha2cm, ,LN of deltaTds/deltaTus at 2 cm;`
- Etc

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

Immediate measurements:

- `aIR0_001!a,Vsuppy,volts,Supply voltage;`
- `Etc`

Temperature record

The high volume ascii command, HA, can be used to retrieve the raw temperature values recorded by the sensor during the measurement. Up to 350 measurement records are available at intervals of about 0.56 seconds. After the HA command, D commands are used to retrieve the data. The data commands must be sent in sequence (D0, D1 … D9, D10, … D99, D100, D101 etc) but a data command can be repeated if corruption in the data transmission is detected using the CRC. Note that because of the large volume of data, the retrieval of the full temperature record takes 2-3 minutes.

Each record contains a time stamp in seconds followed by the ten temperature values, starting with downstream sensor 1 and 2 and finishing with upstream sensors 4 and 5. The number of values available is larger than 999, the maximum number that can be indicated in the HA command response, so the data logger should ignore the number of values specified in the HA command and continue requesting data until an empty response to the D command is received.

An example of the data reported by the HA command is shown here:

```
0HA!0000999
0D0!0+0.000+18.931+18.968+18.906+19.097+19.158+19.033+18.786+18.823+18.827+18.862HQz
0D1!0+0.562+18.931+18.968+18.907+19.098+19.160+19.034+18.787+18.824+18.828+18.862HA`
0D2!0+1.124+18.932+18.969+18.908+19.099+19.161+19.035+18.788+18.825+18.829+18.863@JS
…
D147 0+82.584+19.378+19.583+19.551+19.776+19.814+19.622+19.413+19.476+19.519+19.534Iae
D148 0+83.146+19.377+19.582+19.551+19.775+19.814+19.621+19.412+19.475+19.518+19.533Eda
…
D213 0+119.663+19.323+19.539+19.505+19.729+19.790+19.590+19.358+19.415+19.445+19.468HOn
D214 0+120.225+19.322+19.538+19.504+19.728+19.790+19.590+19.357+19.415+19.444+19.468Kiu
D215 0AP@
```

The last line shows that there is no more data to report.

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:

- BDD bark depth in cm (default 0.5, float, allowed 0-10)
- BMD baseline temperature measurement duration in seconds (default 10, integer, allowed 1-60)
- CDW specific heat capacity of dry wood in J/kg/K (default 1200, integer, allowed 800 to 2000)
- DDW density of dry wood in g/cm^3 (default 0.4, float, allowed 0.1-1.3) – see note below
- HTD heater duration in seconds (default 3.0, float, allowed 0.001-10)
- PMD post-heat temperature measurement duration in seconds (20, integer, allowed 1-60)
- PMS post-heat temperature measurement start in seconds (60, integer, allowed 1-120)
- PRS probe spacing in cm (0.85, float, allowed 0.2 to 3.0)
- TDD trunk diameter in cm (default 10.0, float, allowed 0-300)
- TDF thermal diffusivity in cm^2/second (0.0020, float, allowed 0.001-0.004)
- TMD maximum temperature measurement duration in seconds (80, integer, allowed 1-200)

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.

Some additional measurement results are also available via X commands:

- DTD average temperature rise measured in the post-heat measurement period for the downstream sensors
- DTU average temperature rise measured in the post-heat measurement period for the upstream sensors
- VHD heat velocity from the dual method approach, equal to the heat velocity from either the heat ratio method or the Tmax method
- VHH heat velocity from the heat ratio method
- VHT heat velocity from the Tmax method