

5 Sap Flow Meter Description

The SFM1 Sap Flow Meter consists of: a set of three (3) measurement needles and an integrated, standalone data logger with Windows Graphical User Interface (GUI) software for instrument configuration and data downloading. A solar panel can be directly connected to the non-polarised charging ports to trickle charge the internal battery for continuous field operation. The SFM1 has an integrated Radio transceiver for wireless two-way communications using a [MCC1 Radio modem](#) connected to a computer.



Photo 1 SFM1 Sap Flow Meter

5.1 SFM1 Needle Set

The SFM1 measurement needles are made from a surgical grade (316) Stainless Steel. The outside diameter is 1.3 mm. Each needle has a strict inside diameter tolerance to ensure equal heat dissipation to all measurement points. Thermistors are positioned with precision at exactly 7.5mm and 22.5 mm from the tip of the measurement needles. The tip is used as a reference point rather than the epoxy hub to eliminate any minor variations that may be caused as a result of the curing process. Every heater is manufactured to precisely 18.0 Ohms resistance.



Photo 2 SFM1 Measurement Needle Set installed in a small diameter woody stem or branch.

5.1.1 Measurement Resolution

The SFM1 Sap Flow Meter sensor uses a 16-bit microprocessor with 24-Bit Analogue to Digital Converter (ADC) that yields a 149 nanovolt resolution. This means temperature measurements are made with a 0.001 °C resolution. The superior resolution of the SFM1 has significantly improved the accuracy of the original analogue HRM design by removing significant levels of electrical interference or noise from the measured data.

This was demonstrated in the study Eller, C.B., Pereira, C.G., Oliveira, R.S., Downey, A.M., Burgess, S.S.O., 2012 **Differences in Sap Flow Data Quality between a Thermocouple based HRM Sensor and a Newly Specialised HRM Sap Flow Meter**, *Technical Note*
<http://www.ictinternational.com/casestudies.html>

5.1.2 Needle Design

All needles sets are made of high-quality electrical components housed in sealed, corrosion-resistant, surgical grade (316) stainless steel needles with high-strength epoxy resin hubs. SFM1 standard needle lengths are 35mm and have two thermistors located 7.5 mm and 22.5 mm from the tip of the needle. This provides a spacing of 15 mm between each measurement point and a 12.5mm distance between the outer measurement point and the epoxy base of the needle. The 15 mm spacing between measurement points is to achieve two discrete readings independent of the thermal sphere of influence of the other. The 12.5 mm spacing from the epoxy base and the outer measurement point allow for varying depths of bark when installing the sensors.

5.1.3 Heater Needle Design

The 35 mm long heater needle consists of a proprietary designed, high resistance wire or filament that dissipates power and yields an exceptionally high and efficient amount of heat. Heaters are designed to be powered by 12 Volts for a period of ~2-8 seconds. As a consequence of the wear and tear associated with repetitive heating and cooling, heater filaments (as is the case with incandescent light bulbs), have a finite and unpredictable life. In this sense, heaters are considered consumables that may require periodic replacement even though the expected lifespan of a heater in constant use in the field is many years. With this in mind, needle-sets (both heaters and temperature needles) are designed for simple replacement by soldering a new probe in its place by a trained technician certified by ICT International.

WARNING 2 – The measurement needles of the SFM1 are made of hollow 1.3 mm stainless steel tubing. They can easily be bent, damaged or broken off if basic care is not taken in handling the instrument. If the needles are damaged please contact ICT international via our web site www.ictinternational.com and submit a ticket explaining the issue and request an RMA # via the Service Desk). Needles must be replaced by a qualified technician certified by ICT International.

5.1.4 Colour coded probes

Each 35 mm long needle is independently attached to the SFM1 Sap Flow Meter by a short, flexible length of cable. Needles are not rigidly fixed to each other to improve the ease of installation. Needle independence allows them to be installed at different distances from the heater so that the Sap Flow Meter can be used to measure sap flow using different Heat Pulse algorithms such as; HRMx, CHPM or T-Max). Finally, independent needles can be easily replaced in the case of damage or failure. Each needle is colour coded to the specific use (Blue for measurement and Red for heater) and specifically labeled for Top – Downstream and Bottom (Upstream) to signify the installation position, as orientation of the needles is important.

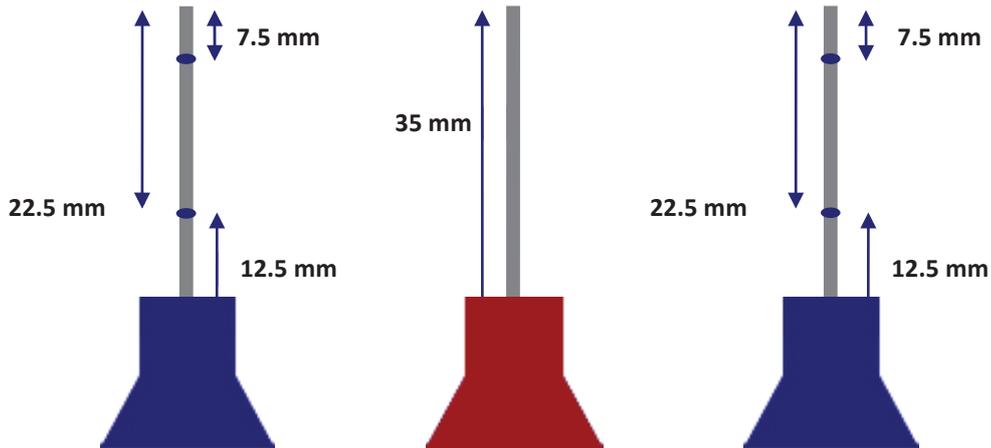


Figure 1 The location of thermistors within the SFM1 needle set



Photo 3: Colour coded and labelled SFM1 needles

NOTE 6: It is important to install the needles in the correct order otherwise the sap flow data will be inverted. This is easily identified from analysis of the data as the data will clearly demonstrate a characteristic diurnal sap flow pattern however, the values will all be negative. This problem is easily fixed by reinserting the needles in the correctly labelled orientation.

5.2 Measurement Reporting Options

The SFM1 Sap Flow Meter can be configured to report the following units:

- (1) Needle Temperatures ($^{\circ}\text{C}$)
- (2) Heat Pulse Velocities (cm hr^{-1})
- (3) Corrected Sap Velocity (cm hr^{-1})
- (4) Corrected Sap Flow ($\text{cm}^3 \text{hr}^{-1}$)

NOTE 7: Additional configuration information must be known and entered into the SFM1 Sap Flow Meter in order to accurately measure corrected sap velocity (V_s) and sap flow directly. See "[Corrections](#)" for details

5.2.1 Needle Temperature

The raw needle temperature mode provides the rawest level of unprocessed data collection. Temperatures for each of the 4 thermistors are logged in engineering units of $^{\circ}\text{C}$ to allow researchers to manually apply any and all corrections to the data and or process the data using either the HRM or HRMx algorithm. Because no processing of the data is done at the time of collection the raw data can be reprocessed at any time without bias or limitation. This provides researchers the opportunity to revisit, reprocess and reinterpret old data sets in the future as their understanding of plant physiological response develops or thinking changes.

5.2.2 Heat Pulse Velocity

Raw Heat Pulse Velocity is a semi-processed form of data in that a default value of thermal diffusivity is applied to the data to calculate the Heat Pulse Velocity. It does not include any corrections for asymmetry or wounding. The data is a relative measure of how the heat supplied to the stem moves through the woody matrix in response to environmental stimuli such as solar radiation and VPD. It cannot be used to quantify absolute sap velocity for the specific plant being measured.

5.2.3 Corrected Sap Velocity

Corrected Sap Velocity is a fully processed value that has had corrections made for; the specific thermal diffusivity of the plant being measured, wounding corrections made for the response of the plant caused by the insertion of the measurement needle; and any possible asymmetry or divergence of the needles from the theoretical geometry required for the application of the Heat Ratio Method algorithm. This parameter, whilst possible to log directly by the SFM1 Sap Flow Meter, is best handled in SFT1 Sap Flow Tool software using either Raw Heat Pulse Velocity or Needle Temperature data. Because many of the correction parameters required to determine sap velocity are only obtainable after the measurements have been made.

5.2.4 Corrected Sap Flow

Corrected Sap Flow is an absolute measure of the volumetric mass flow of water through or within the plant. Due to mechanisms such as hydraulic redistribution, by which plants cope with water or drought stress, the measured sap flow may not be equal to total transpiration through the leaf. It is calculated from the corrected sap velocity by multiplying the sap wood from the annulus surrounding each thermistor and summing them. Again, whilst possible to log directly by the SFM1 Sap Flow Meter, it is best handled in SFT software.

5.3 SFM1 Sap Flow Meter

The SFM1 Sap Flow Meter is a discrete standalone instrument that has been custom designed to specifically measure Sap Velocity and Sap Flow of plants. That is to say each sensor is also a logger with signal processing and integrated power management. It is quite a change in thinking from traditional analogue data loggers. No longer is experimental design limited by cable lengths (due to cable resistance causing degradation of data signals), with each individual sensor requiring cabling to supply raw analogue millivolt signals to a centralised analogue data logger. By eliminating cables and decentralising the data storage, experimental design can be completely flexible and achieve much larger spatial coverage.

The SFM1 Sap Flow Meter is a highly accurate, high precision microvolt meter. It consists of the needle set (sensor); a 16-bit microprocessor with 24-Bit ADC that outputs and logs processed data in calibrated engineering units ($^{\circ}\text{C}$, cm hr^{-1} or Kg hr^{-1}); 4V 1A lithium polymer battery; a dedicated application board to drive the heat pulse protocols specific to perform the Heat Ratio Method sap flow measurement and; a separate generic board for communications both via USB and Wireless RF signal up to 250 m line of sight; 2GB Micro SD Card memory expandable to 32GB; non-polarised power circuit, integrated voltage regulator and inverter circuit; dynamic smart charging circuit that will charge the internal battery more rapidly under full charging conditions up to 200 mA such as a solar panel in full sun, and at a reduced rate to as low as 10 mA under sub-optimal conditions when a solar panel is shaded in diffuse light, all housed in a custom designed water proof enclosure.



Photo 4 SFM1 Sap Flow Meter Installed on a *Pinus radiata* tree

5.3.1 Water Proofing

The custom designed enclosure of the SFM1 has an IP68 rating. It can be submerged under 10 m depth of water (equivalent to 0.1 MPa or 1 atmosphere) without water ingress. This protection is across all electrical circuitry preventing water damage that is common among other field equipment.

Water proofing is achieved through a unique physically separated, but electrically linked dual chamber enclosure design. This ensures that the internal circuitry and battery can be electrically linked and charged from an external power supply without providing any physical pathway for water ingress. For this reason it is important not to open the enclosure because opening the enclosure will void the warranty and water proofing guarantee.

NOTE 8: There is no reason to open the enclosure as ICT have provided water proofed access to all necessary interfaces of the instrument such as USB communication port, Micro SD card and power switch.

Warning 3 – Water proofing cannot be achieved if the communication port cover is left unscrewed. Water entry via this port WILL cause damage and is not covered under warranty.

5.3.2 Power Management

The instrument has its own internal 4.2V (1,000 mA) lithium-polymer battery. It features: a non-polarised power circuit; internal voltage regulation; a voltage inverter to invert from 4V to 12V to drive the Heat Pulse; and optical isolation and lightening protection.

5.3.3 External power

External power can be supplied with a DC voltage supply from either, a 22 W solar panel or mains powered 12V DC plug pack see [Powering - Charging the Instrument](#) for specific details and charging options.

5.3.4 Tools

No custom tools are required for the connection of power supply or instruments. External power is inserted through the non-polarised power-bus ports of the instrument utilising a unique bare wire, push fit connection mechanism see [Individual Power Supply Connections](#) for details.

The needles of the SFM1 are permanently fixed to the instrument with a custom water proofing gland and should only be removed for repair by a qualified technician.

5.3.5 Power Fail Safe Mode

In the event that power is lost due to insufficient solar radiation levels such as, extended monsoonal cloudy conditions, the logger will enter a hibernation mode much like a laptop. As soon as the internal battery is recharged, the instrument will reactivate and recommence logging at the preconfigured intervals without human intervention. Data will not have been recorded for the period that the system was in hibernation, but no data collected prior to hibernation will be lost. It is permanently stored in non-volatile memory on the MicroSD card.

5.3.6 Lightning Protection

Lightning protection is achieved through the design of optical isolation, physical interrupts and barriers into the circuit boards of the instrument. These prevent electrical discharge from lightning running throughout the circuit and destroying the instrument. This is an important protection feature against electrical discharge, but it will not prevent damage and complete destruction from a direct lightning strike on the instrument. Nothing can!

5.3.7 Data Storage & Memory

Data is stored to a 2GB MicroSD card (standard). Larger capacity Micro SD cards (up to 16GB) can be used if required. All SD card memory formats are supported; including SD, SDHC and SDXC. The memory capacity of the standard 2GB MicroSD card is approximately 443 years for the primary *.CSV data file when all parameters are logged at a 10 minute temporal interval (the maximum frequency).

5.3.8 Communication

Communication is via a direct USB cable interface to a computer running a Windows OS. No RS232 serial to USB adapters are required. Alternatively, every instrument includes a 2.4 GHz transceiver for wireless two way communication. This feature is standard in all SFM1 instruments manufactured after April 2012 and does not require activation or upgrading of the instrument. Wireless communications up to a distance of 250 m (line of sight) is achieved when used with an [MCC1](#) radio modem.

5.3.9 Software & Firmware

Software and firmware updates are automatically available via the ICT web site www.ictinternational.com/download.html. Every time you connect to the instrument using the SFM software within internet access the web site is automatically checked for possible updates. If a software update or a firmware update for either the application or generic boards is available, you are given the option to download and install the update. Firmware within the microprocessor of the instrument is updated via the USB Boot Strap Loading function. The process takes less than 10 minutes and ensures your system is updated with the latest functionality and features.

NOTE 9: When updating firmware be sure that both the instrument and your laptop are on charge before attempting and during the update. Any loss of power will cause the corruption and terminal damage to the instruments Microprocessor. The instrument will not allow a firmware update unless the internal battery voltage of the instrument is above 3.8V

5.3.10 Operating Temperature Range

Maximum operating range is between 80 °C to -40 °C. A minimum temperature of -40 °C is possible due to the incorporation of heaters built under the microprocessor chips to warm them to -20 °C which is the minimum international standard operating temperature for silicon chips and microprocessors to operate at.

NOTE 10: Whilst the instrument can operate at these extreme temperatures (80°C to -40°C), it is unlikely that the plant will.