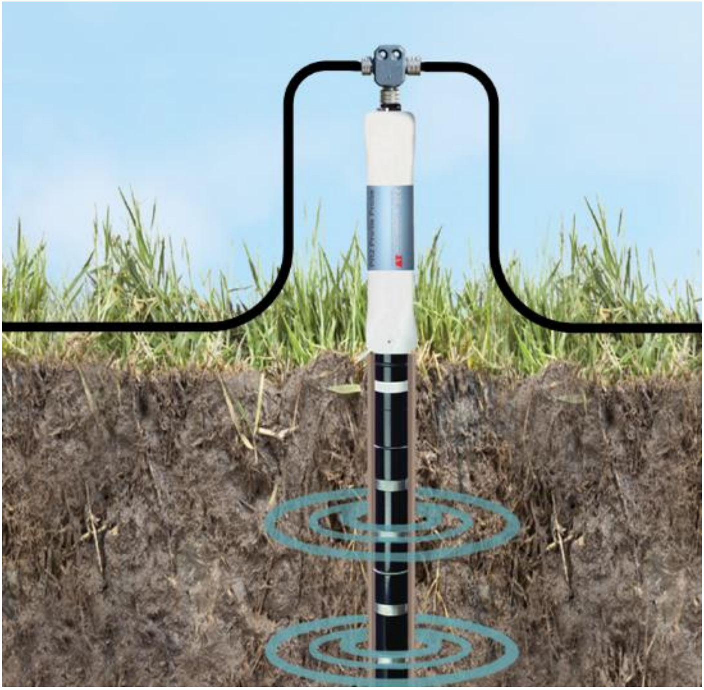
User Manual for the

SDI-12 Profile Probe

Type ***SDI PR2/4 and SDI PR2/6***



PR2 SDI-12-UM-4.1

Delta-T Devices Ltd

Notices

Copyright

Patent

The *Profile Probe* is protected by the following patents:
US7944220, CN101080631(B), EP1836483, AU2005315407

CE conformity

The *Profile Probe* “PR2” and its various versions have been assessed for compatibility with directive 2014/30/EU.
See Software and Manuals DVD for certificate.
To ensure compliance:
1. Probe should be used only with Delta-T approved accessories
2. Probe should only be operated when fully inserted into installed access tubes (see installation instructions).
Install probes a minimum of 1m apart to minimise interference between readings (if measuring concurrently).

FCC Compliance

This equipment has been tested and found to comply with the limits for a Class A digital device, pursuant to part 15 of the FCC rules. These limits are designed to provide reasonable protection against harmful interference when the equipment is operated in a commercial environment. This equipment generates, uses, and can radiate radio frequency energy and, if not installed and used in accordance with the instruction manual, may cause harmful interference to radio communications. Operation if this equipment is in a residential area is likely to cause harmful interference in which case the user will be required to correct the interference at his own expense.

Design changes

Delta-T Devices Ltd reserves the right to change the designs and specifications of its products at any time without prior notice.

User Manual Version: 4.1 May 2016

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Contents

Introduction 5

Description 5

Advantages of the PR2 SDI-12 5

PR2 SDI-12 Commands 6

PR2 SDI-12 Connection to Data Loggers 6

Parts list 8

Care and safety instructions 9

Routine maintenance 9

PR2 Cleaning and Chemical Avoidance Instructions 10

Tutorial Video 10

How the *Profile Probe* works 11

Operation 12

Preparation for reading 12

Install access tubes 12

Equipment 12

Insert the *Profile Probe* 13

Network Cabling Options 14

SDI-12 Cabling System 14

Wire SDI-12 network cable to GP2 logger controller 15

Power supply 16

Use of Continuous Power 16

Input voltage and power consumption 17

Other data loggers 17

Maximum Cable Length 17

Give Each PR2 SDI-12 a Unique Address 20

1: Open DeltaLink Transparent Mode 20

2: Find out PR2 SDI-12's current address 21

3: Tell PR2 SDI-12 to identify itself 21

4: Change the address 22

Create GP2 Program 23

Summary 23

Requirements 23
Measurement 23
Recording Interval 24
1: Add a PR2 SDI-12 Measurement 25
2: Set SDI-12 Parameters for a PR2 Profile Probe 26
Concurrent and Sequential Groups explained 28
3: Set Recording Intervals 30
Maximum Recording Rate 31

Calibration 32
Conversion to soil moisture 34
Reading accuracy 37

Troubleshooting 39
Problems 39

Technical reference 42
Specifications 42
Performance 43
Definitions 45
References 47

SDI 12 Commands 48
Key and Glossary 48
Interpreting Measurement Commands 49
Measurement Commands 50
Send Data Commands 50
PR2 SDI-12 Extended Commands for configuring additional measurements 51
PR2 SDI-12 Extended Command for reading back additional measurement settings 52

Technical Support 53

Appendix A: Soil-specific calibration 55
Laboratory calibration non-clay soils **56**
Laboratory calibration for clay soils 58
Field calibration of soil 61

Index 64

Introduction

Description

The PR2 *Profile Probe* measures soil moisture content at different depths within the soil profile. It consists of a sealed polycarbonate rod, ~25mm diameter, with electronic sensors (seen as pairs of stainless steel rings) arranged at fixed intervals along its length.

When taking a reading, the probe is inserted into an access tube. These are specially constructed thin-walled tubes, which maximise the penetration of the electromagnetic field into the surrounding soil.

Short and long versions of the PR2 are available, with 4 or 6 sensors along the length. These have either analogue outputs (types PR2/4 and PR2/6) or a serial SDI-12 output (types PR2/4-SDI-12 and PR2/6-SDI-12).

The default output from PR2 SDI-12s is the measured permittivity. These outputs are converted into soil moisture using the supplied general soil calibrations, or calibrations measured and applied for specific soils. The GP2 Logger Controller can easily do this.

Advantages of the PR2 SDI-12

- Can be used ***both*** for portable readings from many access tubes ***and*** for installation in one access tube for long-term monitoring.
- Fully sealed and robust.
- High accuracy: ±4%.
- Easy installation with minimal soil disturbance.
- Large sampling volume ~ 1.0 litres at each profile depth.
- SDI-12 serial data output
- Works reliably even in saline soils.
- Large numbers of PR2 SDI-12 Profile Probes can be connected to one data logger via one network cable
- Soil coefficients can be stored in the PR2

PR2 SDI-12 Commands

Whilst the default measured output is permittivity, commands are available to instruct the SDI-12 PR2 to directly report a reading as volumetric soil moisture, for an organic or mineral soil type. This is useful if you have a third party logger that cannot do the conversion.

It is normal, with sensors such as the PR2, to represent different soil types by using two linear coefficients (a_0 and a_1).
In addition to those SDI-12 commands that make use of the standard mineral and organic soil type coefficients, it is possible in the field to configure the PR2 for other custom soil types. This can be used to improve the accuracy of readings in a particular soil, once it has been carefully characterised.
In the Appendix we give an example of characterising a soil with an ML3 soil moisture probe. The derived coefficients, a_0 and a_1, can then be installed into a PR2 SDI-12 or into the GP2, whatever is more convenient.

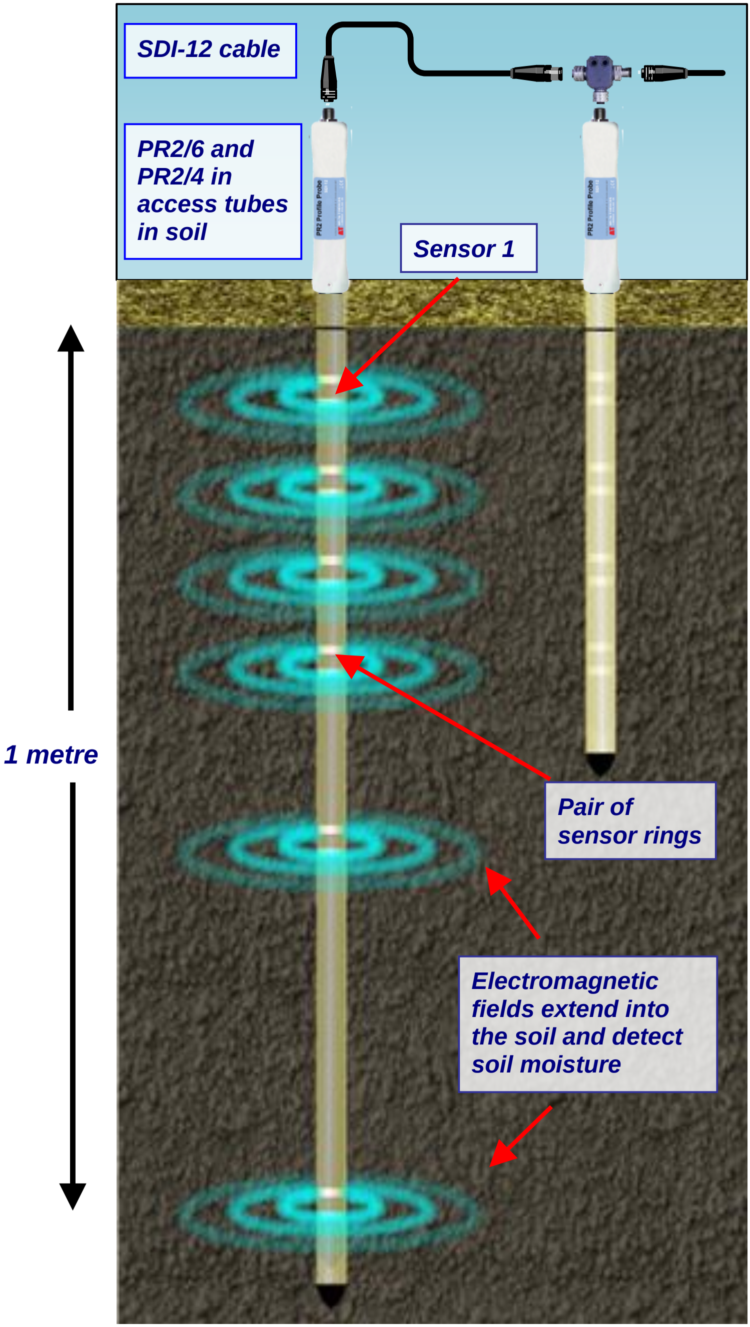
PR2 SDI-12 Connection to Data Loggers

The PR2 SDI-12 Profile Probe serial output is via a 5-way M12 connector. It connects to an SDI-12-enabled logger, such as the GP2, via an SDI-12 network cable which can be connected to a large number of different SDI-12 sensors.

Up to 50 PR2/6 or 62[1] PR2/4 SDI-12 Profile Probes sensors can be connected to a GP2 logger.

The 12 analogue channels in a GP2 logger can also but used (i.e. for two analogue PR2/6s or three analogue PR2/4s) but the total number of measurements in a program is limited to 300.

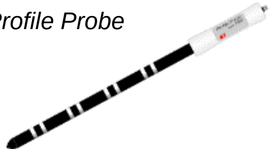
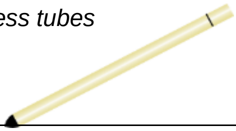
[1] A GP2 logger can take up to 300 (total - analogue plus serial) measurements simultaneously. This imposes a limit of 50 PR2/6s. Another limit, which affects PR2/4s, is the number of SDI-12 addresses - 62 uses up all the normal printable characters (0-9, a-z and A –Z) which are valid SDI-12 addresses. A third limit is the maximum logging rate - which is limited by the capability of the SDI-12 standard itself to approximately 3 seconds per PR2.



SDI-12 cable
PR2/6 and PR2/4 in access tubes in soil
Sensor 1
1 metre
Pair of sensor rings
Electromagnetic fields extend into the soil and detect soil moisture

Parts list

Your consignment may have the following parts:

Part	Sales Code	Description
Profile Probe 	**PR2/4-SDI-12** or **PR2/6-SDI-12**	4 or 6 sensor SDI-12 Profile Probe supplied in protective tube, with spare o-rings and centring springs
Access tube spacer	**SPA1**	Corrects PR2 depths when access tubes are mounted flush with soil surface
Spares kit	**PR2-SP**	
Cleaning kit	**AT-CR1-**	Cleans access tubes
Bag	**PR-CB2**	Carrying bag for PR2
Access tubes 	***ATS1*** *or* ***ATL1***	*Short or long fibreglass tubes suitable for PR2/4 or PR2/6, including cap, bung and collar.*
Auguring equipment	-	See Auguring Manual
Insertion equipment	-	See Auguring Manual
Extraction equipment	-	See Auguring Manual
	**GP2**	General purpose logger controller
	**SDI-12/5W-HH2**	1.5 m cable PR2 SDI-12 to HH2
	GP2-NPC	SDI-12 Network Power Cable – to supply power via a GP2-NTP and/or EXT/5W-xx cabling
	GP2-NTP	3-way network T- Piece for connection to PR2 SDI-12 and EXT/5W-xx cables
	**EXT/5W-01** **EXT/5W-05** **EXT/5W-10** **EXT/5W-25**	1 m, 5 m, 10 m and 25 m extension cables with 5-way M12 connectors for connecting PR2 SDI-12 Profile Probes to a logger via an SDI-12 sensor network

Care and safety instructions

- **Keep your PR2 SDI-12 in its protection tube** and fit the connector cap when the probe is not in use. The *Profile Probe* should be stored in a dry environment (definitely non-condensing), and protected from sharp blows.
- **Earth yourself on the metal connector** before touching the detector rings to avoid any possibility of damage by electrostatic discharge.
- **Don't lay the PR2 in a puddle** because water may creep under the rings – if you suspect this has happened warm gently (<50°C) for 24 hours.
- **Lay as much of the cable as possible along the surface of the soil** when taking a reading in order to minimise any electrical interference with other equipment.
- Twist when inserting the PR2 to ensure the O-ring in the handle seals properly against the wall of the access tube.

Routine maintenance

- **Periodically examine the o-rings and centring springs**. They should be kept clean, and if they show any signs of damage, replace them. Pay attention particularly to the lowest centring spring when inserting the PR2 into an access tube – a gentle twisting action helps.
- **The *Profile Probe* should be periodically recalibrated**. You should run a simple annual check on the calibration (see the **Troubleshooting** section) and contact your local Delta-T representative if there is a problem. Otherwise the PR2 should be returned for routine re-calibration every 2 years.

PR2 Cleaning and Chemical Avoidance Instructions

The PR2 shaft is made of polycarbonate plastic which is an exceptionally strong material, and it can withstand bending forces far in excess of anything likely to be encountered in practice. However, polycarbonate can develop stress cracking when exposed to certain chemicals. Such stress cracking greatly weakens the polycarbonate and may lead to brittle fracture of the shaft, even at very low stresses.

It is important to follow these guidelines. Failure to observe these precautions can damage the probe and may invalidate the warranty.

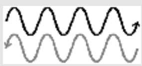
- Clean the probe if necessary by wiping with damp plain paper towels.
- Use only clean water to damp the paper. **Do not use chemicals or cleaning agents** of any sort.
- Never use any chemical solvents or cleaners on the probe, or near to it. Avoid strong chemical vapours, especially during probe storage.
- Do not immerse the probe directly in water. If this happens, allow the probe to dry in warm air for at least 24 hours.
- Ensure the protection tube is dry before inserting the PR2.
- Make sure the probe is thoroughly dry before storing it in the protection tube.

Tutorial Video

See the video about installing access tubes…
https://www.youtube.com/watch?v=KvZC2-xYDL8

How the *Profile Probe* works

Before you rush out and hammer your access tubes into the soil, it will help to understand a little about how the *Profile Probe* works:

	When power is applied to the *Profile Probe* and it receives an SDI-12 command to take a reading...
∿	...it creates a 100MHz signal (similar to FM radio).
	The signal is applied to pairs of stainless steel rings....
	... which transmit an electromagnetic field extending about 100mm into the soil. The field passes easily through the access tube walls, but less easily through any air gaps.
	The water content of the soil surrounding the rings...
ε	...dominates its **permittivity**. (A measure of a material's response to polarisation in an electromagnetic field. Water has a permittivity $\approx$ 81, compared to soil $\approx$ 4 and air $\approx$ 1)
	The permittivity of the soil has a strong influence on the applied field…
V_{out}	…resulting in a stable voltage output that is converted via an SDI-12 measurement into …
Soil Moisture 22 %	... a simple, sensitive measure of **soil moisture content**.

Operation

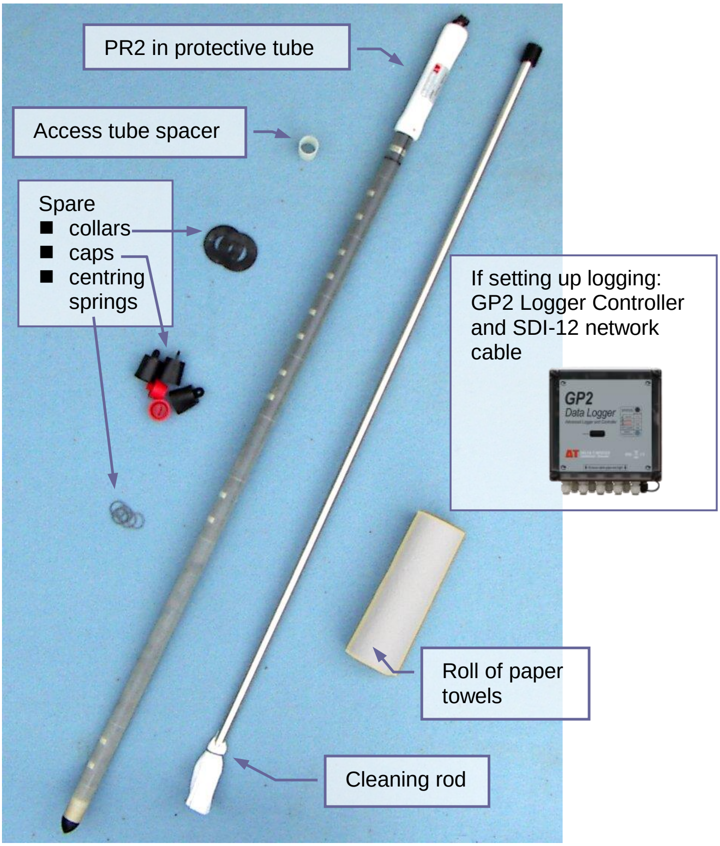
Preparation for reading

Install access tubes

The *Profile Probe* must be used within an access tube. The process of auguring holes and installing access tubes is described in the Auguring Manual.

Equipment

You may require the following equipment for a site visit:

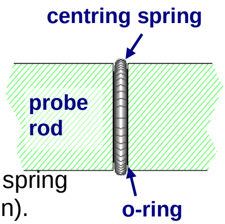


Insert the *Profile Probe*

Remove the tube cap and check for damp

If the access tube has been left empty for several weeks, check for condensation by threading a paper towel into the slot in the cleaning rod and pushing this to the bottom of the tube. If there is any water present, you will need to dry the tube thoroughly.

Check the centring springs



Remove the PR2 from its protective tube.

The *Profile Probe* is fitted with centring springs so that the probe is correctly centred within an access tube. They ***must*** be fitted and working properly for the probe to take accurate readings. Each centring spring (coiled spring) sits on top of an o-ring (see illustration).

Fit spacer (if required)

If your access tube has been installed flush with the soil surface, you will need to fit the access tube spacer (SPA1). Slide the spacer over the tip of the probe and push all the way up past the top o-ring. Note the access tube is not water-tight if the spacer is used.

Insert the Profile Probe

Take care as the first centring spring is pushed into the tube not to pinch the spring unevenly against the side of the tube. A slight twisting motion as the spring goes in will help protect it.

Align the probe

The probe should be aligned consistently each time it is inserted, using the alignment marks on the access tube and the label on probe handle.

If you want to maximise the sampling at each location, we suggest that you take the average of three readings at each location, with the tube rotated through 120° each time – the three small screw heads can be used for this purpose.

Ensure that the *Profile Probe* is pushed all the way down over the top o-ring.

The PR2 is then fully sealed in its access tube and ready either for immediate reading or for attaching to a logger for extended monitoring.

Network Cabling Options

See also the SDI-12 for GP2 User Manual.

SDI-12 Cabling System

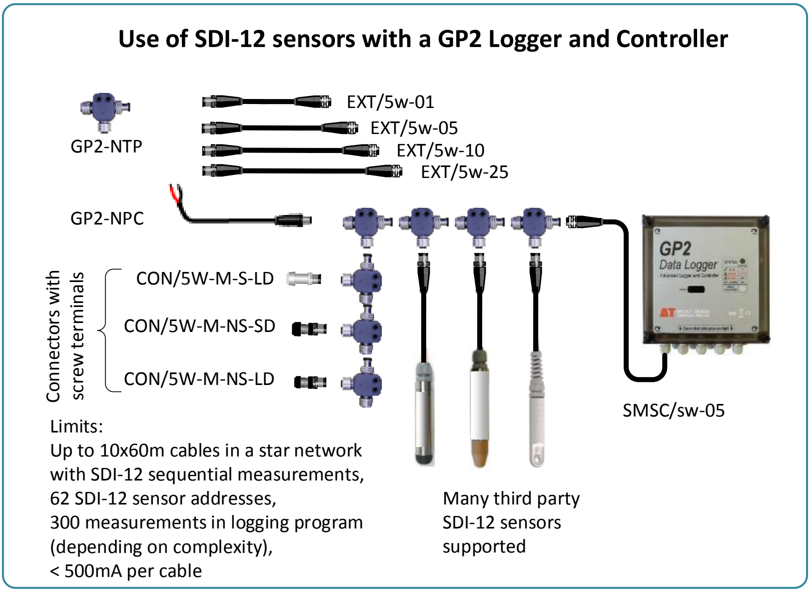


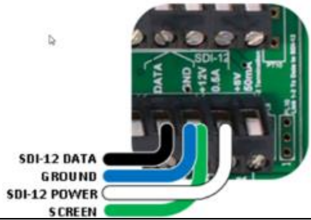
Figure 1 Wiring system used to connect SDI-12 sensors to the GP2 Logger controller, using EXT/5W-xx cables with integral 5-way M12 connectors.

The M12 connector system in Fig 1 has the advantage that it is easy to unplug a sensor and remove it from the SDI-12 network. This can be **very useful** when trying to identify a faulty sensor.

Plugs with screw connectors are available for adding to the M12 connector system. See the **SDI-12 for GP2 User Manual.**

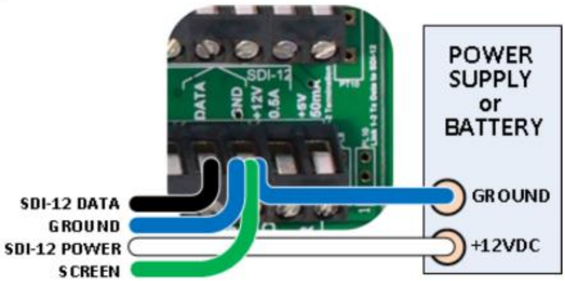
Wire SDI-12 network cable to GP2 logger controller

SDI-12 to GP2 logger wiring connections - using logger power

Wire colour		GP2 terminal		M12 plug pins	
Black		SDI-12 DATA	SDI-12 Data	4	
Blue		GND	Sensor ground / power return	3	
White		12V	Sensor power	2	

Wiring connection diagram for connecting all sensors on the SDI-12 network, including the PR2 SDI-12 Profile Probe (via type SMSC/sw-05 5-way M12 to bare ended cable) to the SDI-12 channel in GP2 logger, using the logger’s internal +12V Power channel.
Set DeltaLINK program’s **Measurement**, **Power channel** to **+12V.**
Power is only put on the SDI-12 cable when required by a sensor,

SDI-12 to GP2 logger wiring connections - using external power



Wiring connection diagram for connecting SDI-12 sensors (via type SMSC/sw-05 5-way M12 to bare ended cable) to the SDI-12 channel in GP2 logger, using an external permanent power supply or battery connection (which should be appropriately fused).
Here the SDI-12 power is permanently on.
If you only want the external power switched on when needed then feed the 12V (white) cable through one of the GP2 relays and select the relay, e.g. RLY1, for the DeltaLINK program’s **Measurement**, **Power channel**

See also SDI-12 for GP2 User Manual

Power supply

PR2 SDI-12 Profile Probes require 7.2 to 16 VDC power and consumes 720mW. Power can be applied continuously, or via a warm-up relay for greater economy of power consumption.

You can power Profile Probes directly using the GP2 internal batteries. The GP2 provides a regulated 12 VDC output at 500 mA, which meets the SDI-12 specification, and which can be switched on and off under software control.

If several probes are to be used, or if the data logger has to supply significant power to other sensors or accessories, we recommend powering the data logger and sensors from an external power supply, which can be switched via a GP2 relay.

The maximum number of PR2 SDI-12s that can be simultaneously powered up is limited by the SDI-12 network cable (type **EXT/5W-xx**) which can only take up to 500mA. Each PR2 SDI-12 takes less than 60 mA at 12 VDC regardless of whether these are PR2/4 or PR2/6s. So only 8 PR2 SDI-12s can be measured concurrently together if using this cabling. But there are ways of measuring more sensors.

1) The SDI-12 **Concurrent Group** parameter can be used to organise PR2 SDI-12s into groups of 8. So, assuming you are taking hourly readings, then on the hour the GP2 first reads Group 1 and then Group 2, and so on.
   When not taking a reading each PR2 SDI-12 only takes ~2 mA from the SDI-12 network. Only those in the Group instructed to take a reading will consume their full 60 mA.
2) Readings may be taken sequentially, one after the other, using the SDI-12 sequential measurement method

A further limitation is that up to 300 measurements may be defined in a given GP2 logger controller program. So a maximum of 300/6 = 50 PR2 SDI-12/6 Profile Probes can be used all together, with no more than 8 in each Concurrent Group.

The corresponding limit for PR2/4 SDI-12 sensors (300/4) is 75, but you start to run out of sensible SDI-12 addresses after 62 (i.e. 0-9, a-z, or A-Z), so it is best to use this limit instead.

Use of Continuous Power

Some SDI-12 sensors from other manufacturers need continuous power. Fortunately the PR2 SDI-12 Profile Probes power down to ~0.4 mA when not taking a reading, so that you can still put 50 of PR2/6s or 62 PR2/4s on the Delta-T M12 5-

way SDI12 cable network, and still have power for other sensors (provided you either sequential readings, or offset readings or use concurrent groups).

Note: *For best economy the Profile Probe should be powered up using a 1 second warm-up time.*

Input voltage and power consumption

The PR2 requires between 7.2 and 16 VDC. It consumes little power- approximately 720 mW when taking a reading, independent of the supply voltage.
With a 12 VDC supply the sensor warmup and reading will consume 60 mA and take 1 second. Reporting back the result will typically take another 2 seconds but only consume 2mA (for a sequential reading). The sensor will then fall asleep, consuming ~0.4 mA until the next reading.

Other data loggers

The default setting for PR2 SDI-12s is to output the measured soil permittivity. You can convert the data to soil moisture units after logging, or program your data logger to convert the output automatically before saving the data, using the information supplied in the **Conversion to Soil Moisture** section.

Alternatively, by using one of the available SDI-12 commands, a PR2 SDI-12 can be instructed to output data in soil moisture units, for either a mineral or organic soil.
See **SDI 12 Commands** on page 48.

When used with the GP2 Logger controller we think the most flexible option is to output the readings as permittivity and have to logger convert it to soil moisture for the corresponding soil type.

Maximum Cable Length

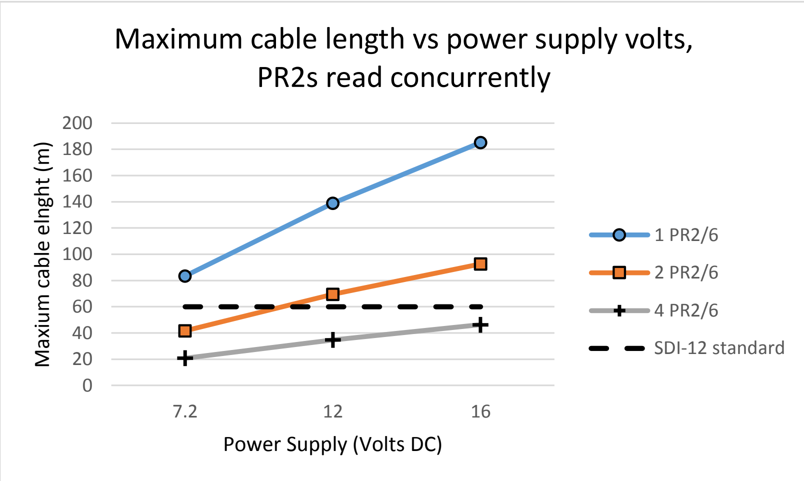
Compared to our GP1 and GP2 logger-to-logger networks, which are quite fast, the SDI-12 network is quite slow. This means that the principal factor limiting the cable length is not the overall cable capacity, independent of geometry, as it is for the loggers, but is instead determined by the cable resistance.

The SDI-12 standard indicates that you can have a star network of up to 10 cables where each cable is up to 60 m long (taking sequential readings).
Delta-T have tested this configuration with PR2s and a GP2 logger and can confirm this combination works.

If you only have one cable the SDI-12 published standard still limits you to the same 60 m, because it's the resistance of the cable which is the limiting factor.

Below is our estimate of the maximum cable length you can have as a function of the supply voltage and the number of PR2s attached at the end of the cable and powered simultaneously, using the SDI-12 Concurrent measurement method.

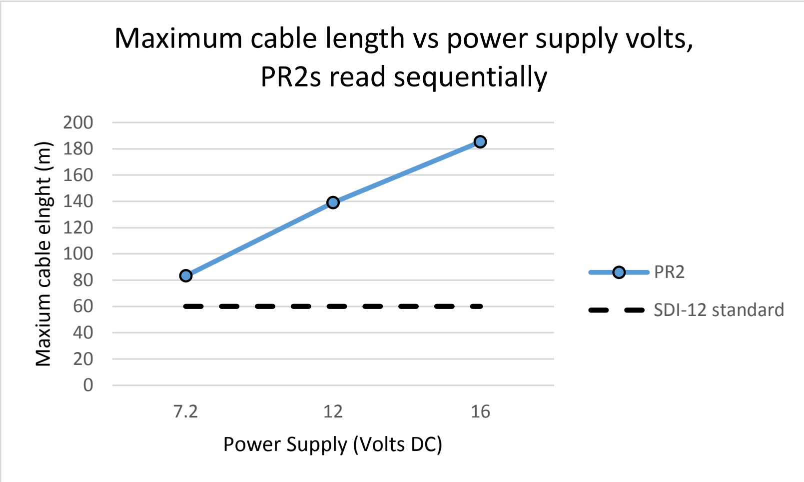
If in doubt, to maximise cable length use the SDI-12 sequential measurement method. It will be slower, but relative to the speed of most soil water movement (except, say, sandy soils) then sequential measurement should always be fast enough.



This graphs shows an estimate[2] of the maximum cable lengths based on the following assumptions:_
> Max SDI-12 signal drop permitted down the cable is 0.5V
> Delta-T EXT/5W-xx cables (0.06 Ω/m)
> All the PR2s are being powered at the same time i.e. via a concurrent measurement, and all at the end of the cable.

[2] We have not tested this - so treat is as indicative of the sort of performance you might hope to achieve, and be sure to test your won configuration if you want to exceed the SDI-12 standards committee's 60m limit.

For the maximum cable length and largest number of sensors use sequential measurements.



This graph shows an estimate of the maximum cable length for each PR2 if measured sequentially.

Note: at the time of writing this, we have only tested 10 PR2s at 60m on a star network connected to a GP2 and measured sequentially.
If you want to use PR2s at more than 60m and on multiple cables (i.e. in a star network and with sequential readings) then we recommend you test it first to make sure the configuration works.

Give Each PR2 SDI-12 a Unique Address

If two sensors have the same address an SDI-12 network will not work. So give each PR2 SDI-12 a unique address before connecting it into a network of SDI-12 sensors.
Delta-T DeltaLINK Logger software provides a means for doing this, called the SDI-12 Transparent Mode.

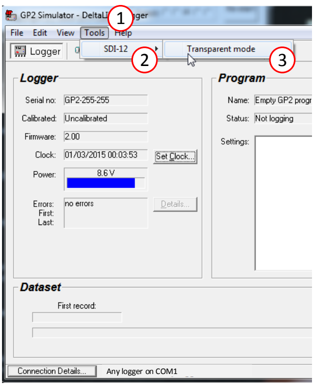
A new sensor will normally have the address set to 0 (number zero).
This can be one of the following 62 addresses:-
0 to 9, a to z or A to Z.
(Other printable characters such a punctuation marks are permitted but think carefully before using such characters).

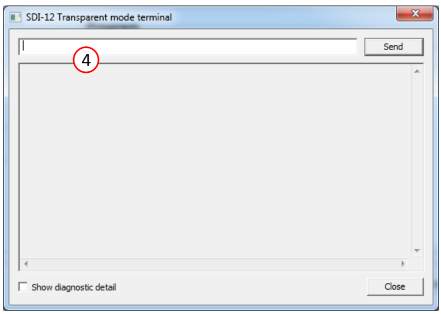
1: Open DeltaLink Transparent Mode

You need a GP2 connected to a PC running DeltaLINK v 3.2 or later.

With no other sensors on the network connect the sensor to the GP2 SDI-12 terminal.

In DeltaLINK select **Tools**, **SDI-12**, **Transparent mode** to open theSDI-12 Transparent Mode Terminal as shown below.





Once the SDI-12 Transparent Mode Terminal is open, the GP2 behaves like a transparent serial link between SDI-12 sensors and the PC.

Ensure only one sensor is on the SDI-12 network.

Type in an appropriate command from the SDI-12 command set on page 48.

2: Find out PR2 SDI-12's current address

Send a command to tell the sensor to reply with its address.

You type	?!
Reply	a<CR><LF>

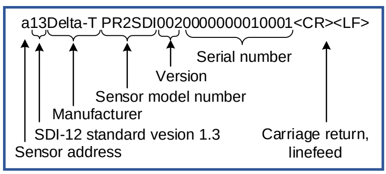
We would normally expect this to be zero, but it might not be. You may already have another sensor with this address.
Note: <CR> <LF> stands for Carriage Return, Line Feed – the same as the keyboard Enter command for moving the cursor back to the beginning of the next line on the screen.

3: Tell PR2 SDI-12 to identify itself

Send a command to tell the sensor at this address to identify itself.

You type	aI!
Reply	a13Delta-T PR2SDI00200000000010001<CR><LF>

The logger tells the PR2 at address "a" to identify itself. The PR2 replies with a long string of characters as shown.



Note this will be different for each sensor, each type of sensor and each manufacturer.

4: Change the address

Send a command to change its address

You type	aAb!
Reply	b<CR><LF>

The PR2 is now at address b. It could be anything from a to z, A to Z or 0 to 9.

Avoid address 0 as it tends to be the default used in new sensors and putting more than one sensor on the network with the same address will crash the network.

Create GP2 Program

Summary

Requirements

A GP2 connected to a PC running DeltaLINK 3.3 or later.
See also the **SDI-12 for GP2 User Manual**.

A PR2 SDI-12 sensor connected to the GP2 SDI-12 input.
See also page 14.

Measurement

Select a PR2/4 or PR2/6 SDI-12 measurement to create a measurement at each sensor depth on the PR2 probe, with the following default settings:

Input

Set the SDI-12 address and value position for each measurement.

- **Address**: defaults to ‘0’. Change it before putting a sensor on the network. All 4 or 6 sensor in a single PR2 have the same SDI-12 address but different Value Positions.
- **Reading Mode**: as Concurrent, this can be change to sequential if required.

Needs to be same for whole probe.

- **CRC:** Yes, this is forced to always request CRC. It is a serial data error check called Cyclic Redundancy Check
- **Value Position**: defaults to 1, 2, 3 and 4, in each measurement row created, corresponding to the sensors at 100, 200, 300 and 400 mm in a PR2/4.
  The PR2/6 is similar, with a row for each depth

Calculation

- **Result Units: %,** this uses the program default setting, and can be changed to theta (m3.m-3).
- **Soil type: Mineral** soil is the default setting. This can be changed to **Organic,** or use custom a0 and a1 values.

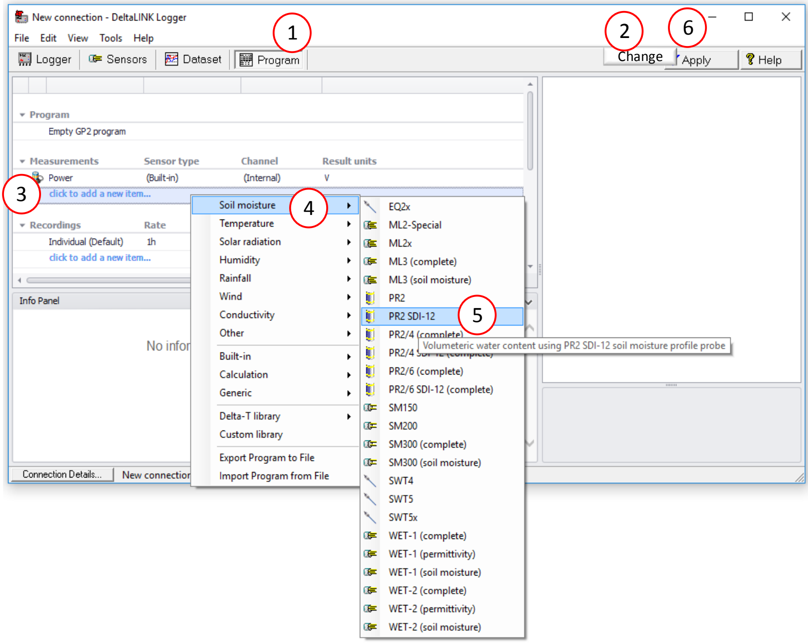
Recording Interval

Accept the default value of 1 hour or change it to your required logging interval.

The fastest recording rate possible with an SDI-12 PR2 connected to a GP2 logger is about reading every 5 seconds

See also **3: Set Recording Intervals** on page 30.

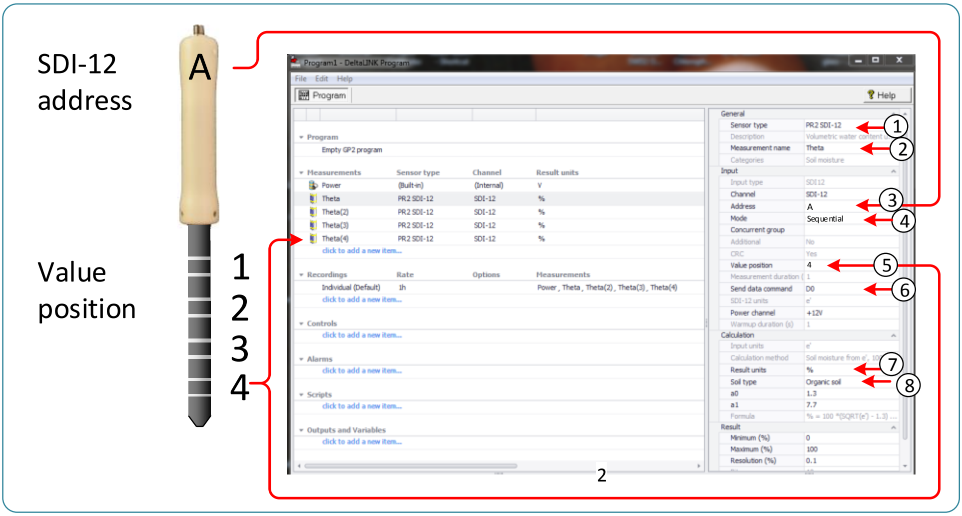
1: Add a PR2 SDI-12 Measurement



1. With **DeltaLINK** 3.3 or later running on your PC and connected to a GP2 select **Program**.
2. Select **Change**.
3. Under Measurements click on “**click to add a new item**”.
4. Select **Soil Moisture**.
5. Select **PR2 SDI-12**.
6. Select **Apply**.

This will create a measurement for a PR2 at SDI-12 at address zero.
To change this and other default settings see the next section.

2: Set SDI-12 Parameters for a PR2 Profile Probe



This explains the Measurement and Parameter settings supplied in the PR2 SDI-12 sensor types in the DeltaLINK sensor library.

For a quick start: accept the default settings and go to **3: Set recording Interval.**

1. **Sensor type**: This is the name of the default PR2 Sensor type as loaded from in the GP2 sensor library.

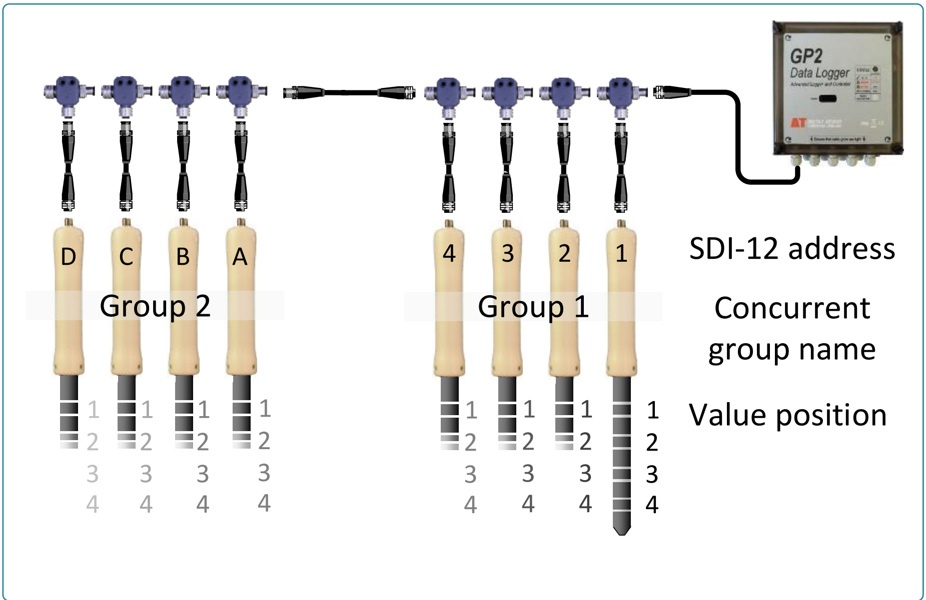
2. Change the **Measurement name** to indicate the soil depth, e.g Theta (100mm).
   If you have more than one Profile probe, give each measurement a unique name here too – e.g. “PR2 A at 100mm”.
   This information will be displayed at the top of each column of measurement in the results

3. **Address**: Enter the SDI-12 **Address** of the PR2 so the GP2 will know which sensor to contact.
   Using DeltaLINK SDI-12, Transparent mode assign it a unique address **before** putting it on the SDI-12 network with other sensors, or else the network will crash.
   See also **Give Each PR2 SDI-12 a Unique Address** on page20.

4. **Mode**: The default PR2 SDI-12 sensor type uses what the SDI-12 standard calls the **Sequential** data measurement and reporting method. Use Concurrent to optimise the throughput of SDI-12 measurements, and **Sequential** to minimise loading on the SDI-12 power supply.

5. **Additional**: The "Additional" field is not enabled in this example, which, in the case of the PR2 SDI-12, means it will send permittivity readings to the logger. The GP2 logger then calculates the volumetric water content for the soil type, Mineral or Organic, and in units of % or m3.m-3 (See **Results units** and **Soil type** below).
(The additional features are of use to less capable loggers from other manufacturers, which can't do maths as well as the GP2)
6. **Value Position**: the position where this sensor's data is to be found in the serial data string when readings are sent to the logger. The data at position 1 in the data string is from the top PR2 sensor at 100 mm nominal depth in the soil.
7. **Send data Command**: The Dn command is sent by the logger to retrieve the results when the sensor is ready (n can be 0 to 8). In reply the sensor may send up to 76 characters to the logger. The number of characters required for each reading can vary: depending, for instance , on whether readings are concurrent or sequential. So additional commands, D1–D8, are available if necessary. Your logger is able to decide which D command to send, so this is not something the user needs to worry about.
8. **Result units:** Choose % or m3.m-3 as the units for the calculated volumetric soil moisture content.
9. **Soil type**: Use Mineral of Organic soils type, or add your own soil type coefficients.

Concurrent and Sequential Groups explained



Concurrent gives extra speed – but do not draw more than 500mA per Concurrent group

Measurements that are defined as concurrent and part of the same group can be taken more quickly than measurements which are specified as sequential.

Sequential measurements are slower because after logger tells a sensor to take a reading, and the sensor has acknowledged this, (reporting how long the reading will take and what the future readings message string will look like), then the logger waits for that sensor's reading before going through the whole procedure again with the next sensor.

In the Concurrent method, the logger gives the whole group of sensors the command to take a reading, one after the other in quick succession and without waiting for the reading. Each sensor says OK and how long it will take. The logger then waits until the readings are ready and then fires of a message to each sensor in quick succession, telling it to send the reading,

Sensors grouped together this way will all be powered up at the same time.

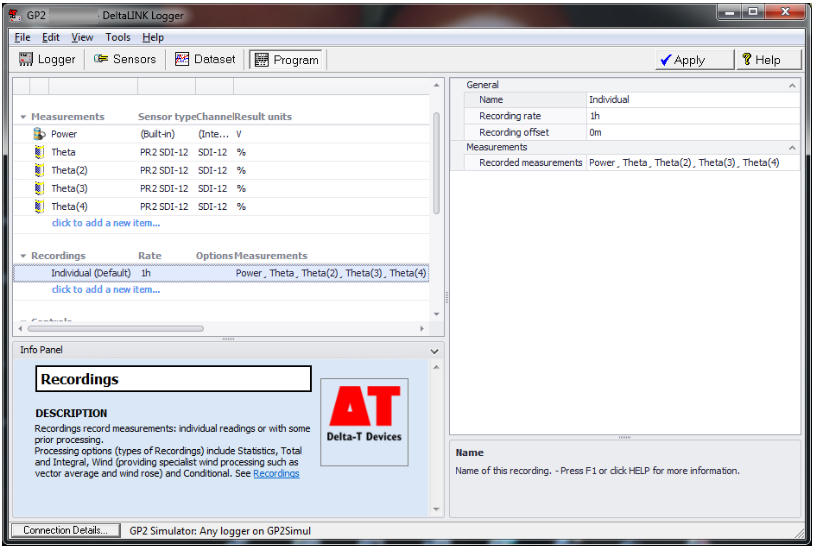
This puts a greater current drain of the SDI-12 cable, so you have to make sure you do not exceed the maximum power limit of the cable. In the case of the Delta-T 5 way M5 cable system the maximum current is 500mA

For example each of the sensor ring pairs on a PR2 SDI12 takes 10mA. So a Pr2/6 SDI 12 takes 60mA. So we would not want to put more than 8 PR2/6 SDI-12 units in any one concurrent group.

Note that if you set the same recording rate for each concurrent group then the first group will complete its measurements first, and then the second group will begin, and so on. So you do not need to set a different offset on the recording rate for each subsequent concurrent group.

3: Set Recording Intervals

On selecting a measurement, DeltaLINK automatically sets a default recording interval for you, of one hour, as shown below.



Screenshot of the DeltaLINK, Program tab with a default Recording interval set to 1 hour for each of the defined Measurements.

Chose a recording interval appropriate for your soil type.
For instance, if it is sandy it may drain quickly, in which case the fastest recording rate possible is about once every five seconds. In a heavy clay soil you may wish to start recording once per hour and wait and see how quickly the soil responds to wetting and drying events.

Maximum Recording Rate

The maximum recording rate depends on many factors - the SDI-12 standard data rate of 1200 baud (120 character per second), the total number of characters that need to be transmitted to and from each sensor with each command, the type of command, the total number of commands needed to take and report each reading and also on the time it takes each sensor to take and report a reading.

In Sequential mode a GP2 may take 12 seconds to log 4 PR2/6s that is, about 3 seconds per PR2.
In Concurrent mode, 4 PR2s in the same concurrent group may take 8 seconds.

Note: The GP2 logger is much faster than the SDI-12 standard baud rate, so the speed of the logger should not normally be a limiting factor.

If a reading cannot complete in the time available then the previous SDI-12 reading for that sensor will be reported. So one way of discovering how fast you can take reading is to vary the relevant environmental parameter increasingly quickly and find out at what recording rate the readings fail to keep up with the rate of change.

Calibration

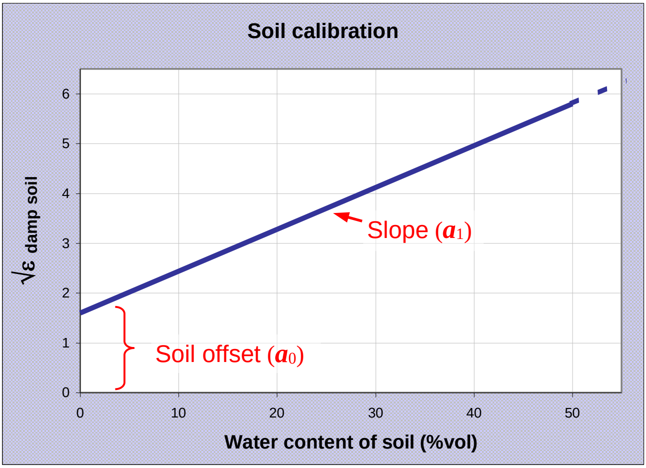
The *Profile Probe* detects soil moisture by responding to the permittivity (ε′) of the damp soil (see illustration on page 7) – or more accurately to the refractive index of the damp soil, which is ~ equivalent to √ε.

As a result, the performance of the Profile Probe is best understood if it is split into these two stages:

Soil calibration: soil moisture (θ) determines √ε

Profile Probe response: √ε determines PR2 output (Volts)
The PR2 SDI-12 can report the output in Volts or in units of soil water content, as described below.

Soil calibration



This method of detection is very sensitive and accurate, but of course soils can be enormously different one from another.

The soil offset and the slope of the line in the graph both depend slightly on soil type, varying with density, clay content, organic matter etc.

This can be usefully summed up in a simple equation describing the relationship between √ε and the soil water content, θ, which contains two parameters ($\boldsymbol{a}_0$ and $\boldsymbol{a}_1$) that reflect the influence of the soil:

$$\sqrt{\varepsilon} = \boldsymbol{a}_0 + \boldsymbol{a}_1 \times \theta \qquad \textbf{[1]}$$

The accuracy of your *Profile Probe* readings can be improved if you choose appropriate values for a_0 and a_1. This is usually very simple…

Generalised calibrations

Most soils can be characterised simply by choosing one of the two generalised calibrations we supply, one for mineral soils (predominantly sand, silt or clay) and one for organic soils (with a very high organic matter content).

	a_0	a_1
Mineral soils	**1.6**	**8.4**
Organic soils	**1.3**	**7.7**

These values have been used to generate the slope and offset conversions and linearisation tables in the **Conversion to soil moisture** section.

Soil-specific calibration

If it is important to work to higher accuracy, you may choose to carry out a soil-specific calibration, but please bear this in mind:

For normal agricultural soils, if you use one of the generalised calibrations, you can expect typical errors of ~ ±0.06 $m^3.m^{-3}$, including installation and sampling errors.

If instead you use a soil-specific calibration, you can expect typical errors of ~ ±0.04 $m^3.m^{-3}$.

*As a guideline, we suggest that you **only** need to do a soil-specific calibration if one of the following applies:*

- *Your soil is heavy clay, highly organic, or in some respect "extreme".*
- *You are working to high levels of accuracy, or you need a controlled error figure rather than a "typical" error figure.*

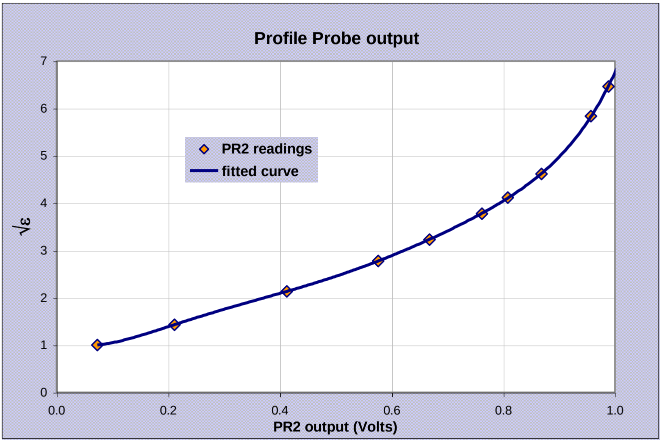
*and the following do **not** apply*

- *Your soil is very stony (insertion errors are likely to outweigh the calibration errors)*
- *your soil cracks when it dries (again measurement errors are likely to be higher than calibration errors)*

The procedure for carrying out a soil-specific calibration is detailed in Appendix A.

Profile Probe response

All Profile Probes have the same dielectric performance:



This relationship can be fitted very precisely up to ~ 0.5 $m^3.m^{-3}$ by the following polynomial:

$$\sqrt{\varepsilon} = 1.125 - 5.53V + 67.17V^2 - 234.42V^3 + 413.56V^4 - 356.68V^5 + 121.53V^6$$

[2]

Up to 0.3 $m^3.m^{-3}$ it can be approximated by the following linear relationship:

$$\sqrt{\varepsilon} = 0.37 + 4.43V$$

[3]

Conversion to soil moisture

Profile Probes can either be used to give instantaneous readings of soil moisture using a hand-held meter, or they can be connected to a data logger to record moisture data over time.

In either case you will probably want to configure the meter or data logger to convert the *Profile Probe* output to soil moisture content. Three data conversion methods can be used:

- ***polynomial*** conversion
- ***linear*** conversion (slope and offset)
- ***linearisation table*** conversion

Polynomial conversion

Combining the *Soil calibration* and *Profile Probe response* steps, the conversion equation becomes:

$$\theta_V = \frac{[1.125 - 5.53V + 67.17V^2 - 234.42V^3 + 413.56V^4 - 356.68V^5 + 121.53V^6] - a_0}{a_1} \text{ m}^3.\text{m}^{-3}$$

where a_0 and a_1 are the calibration coefficients above.

For a generalised mineral soil this becomes:

$$\theta_{min} = -0.057 - 0.66V + 8.00V^2 - 27.91V^3 + 49.23V^4 - 42.46V^5 + 14.47V^6 \text{ m}^3.\text{m}^{-3},$$

And for an organic soil:

$$\theta_{org} = -0.023 - 0.72V + 8.72V^2 - 30.44V^3 + 53.71V^4 - 46.32V^5 + 15.78V^6 \text{ m}^3.\text{m}^{-3}.$$

Slope and offset conversion

Combining the *Soil calibration* and linear *Profile Probe response* equations:

$$\theta_V \approx \frac{[0.37 + 4.43V] - a_0}{a_1} \text{ m}^3.\text{m}^{-3}, \text{ up to } 0.3 \text{ m}^3.\text{m}^{-3}.$$

Using the values of a_0 and a_1 for generalised mineral and organic soils:

From probe V to:	**Slope** *m³.m⁻³ / V*	**Offset** *m³.m⁻³*
$m^3.m^{-3}$, Mineral soil	**0.528**	**-0.146**
$m^3.m^{-3}$, Organic soil	**0.575**	**-0.121**

To convert data readings from volts, multiply by the slope and add the offset. This gives readings in $m^3.m^{-3}$.

Linearisation table conversion

The following table of values is used in the PR2 SDI-12.

soil moisture		*mineral soil*	*organic soil*
$m^3.m^{-3}$	*%vol*	*Volt*	*Volt*
0	*0*	*0.257*	*0.177*
0.05	*5*	*0.379*	*0.280*
0.10	*10*	*0.497*	*0.394*
0.15	*15*	*0.595*	*0.501*
0.20	*20*	*0.677*	*0.590*
0.25	*25*	*0.749*	*0.667*
0.30	*30*	*0.810*	*0.734*
0.35	*35*	*0.860*	*0.793*
0.40	*40*	*0.899*	*0.843*
0.45	*45*	*0.930*	*0.882*
0.50	*50*	*0.956*	*0.914*
0.55	*55*	*0.977*	*0.940*
0.60	*60*	*0.995*	*0.962*
0.65	*65*	*1.011*	*0.981*
0.70	*70*	*1.026*	*0.997*
0.75	*75*	*1.038*	*1.012*
0.80	*80*	*1.050*	*1.025*
0.85	*85*	*1.060*	*1.037*
0.90	*90*	*1.070*	*1.048*
0.95	*95*	*1.079*	*1.057*
1.00	*100*	*1.088*	*1.067*

Reading accuracy

The *Profile Probe* is accurate and reliable.

However this doesn't guarantee that the readings you take with a PR2 are an accurate measure of the soil moisture. There are three particular sources of error that you need to consider when measuring soil moisture with the *Profile Probe*:

- **Installation problems**
- **Soil type and Sampling errors**
- **Salinity**

Installation problems

An ideal installation would avoid creating either air gaps or soil compaction around the access tube – and then the soil would not shrink or swell as it dried out or rewetted. It's possible to get remarkably close to this ideal in some deeply cultivated soils, and close to impossible in some stony soils or hard clay.

We obviously can't quantify your potential installation errors, but experience suggests that a loose, gappy, access tube installation could lead to errors of ± 10% (± 0.1 $m^3.m^{-3}$), so...

- *Take as much care as you can over the installation*
- *Remember to fit a collar to your access tube.*

See also the PR2 video on YouTube

Soil type and sampling errors

Again, it's not really possible to quantify the potential errors associated with soil type, but be aware of the following:

- *Almost all measurement problems are worst in heavy clay soils.*
- *If your soil cracks badly in dry conditions, the readings from your Profile Probe may be more indicative of crack size than soil moisture content!*
- *The linear relationship in equation [1] is less applicable to heavy clay soils at low soil moisture levels (< 0.1 $m^3.m^{-3}$). See ref. [7].*
- *Soil moisture content may vary significantly even within a small volume of soil. When you rotate the Profile Probe within its access tube the reading changes you observe reflect real soil moisture variability.*

Salinity

Changes in soil salinity cause a change in reading, which will appear as a change in soil moisture. Typical effects on *Profile Probe* readings are an apparent change of < 0.005 $m^3.m^{-3}$ soil moisture for a change of 100 $mS.m^{-1}$ soil salinity.

In most situations this sensitivity is of little significance because a change of 100 $mS.m^{-1}$ is very unlikely - but it may need to be considered particularly when irrigating with saline irrigation water.

See **Salinity Performance** in the **Technical Reference** section.

Troubleshooting

Problems

When getting problems from a probe or sensor always try to identify which part of the measurement system is the source of the difficulty. For the *Profile Probe* this may fall into one of the following areas:

The measurement device

What equipment is being used to read the probe output?

- A Delta-T HH2 Moisture Meter
- A Delta-T GP2 logger

Consult the user manuals or the on-line help for these devices, and their related software.

Try alternative types of equipment if you have them available.

Check that the soil calibration being used is appropriate for your soil, and that the correct conversion method is being used – see **Calibration** section.

The cables

Replace the cable, if possible. It might have been damaged.

The probe itself

Try to isolate the problem into one of the following areas

- The Probe or the connecting cable

Then try to narrow down the area further

- Mechanical problems faults, or damage
- Electrical or electronic problems or faults

Calibration check

We recommend that you check the calibration of your PR2 at least once a year by taking an air reading and a water reading in mV. See **How to take a reading in mV**, on page **40**

Air reading

Keep the PR2 in its protection tube and hold it away from any other objects. The reading should be 75 ±20 mV from each

sensor position.
See **How to take a Reading in mV** on page **40**

Water reading

Insert the PR2 fully into an access tube and immerse the tube into a large body of water at 20 to 25°C. The water container should be sufficiently large so that the PR2 is >100mm from any edge. Although this reading is outside the PR2's specified accuracy range, the reading should lie between 1020 and 1100mV.
See **How to take a Reading in mV**, below.

How to take a reading in mV

To take a PR2 reading in millivolts use the **DeltaLINK, SDI-12, Transparent mode** and send the **aC7** command. This will issue a concurrent reading command to read all the sensor positions on the probe at SDI-12 address "a". Wait at least 2 seconds for the reading to complete and then send the **aD0** Send Data command.
Five measurements are returned from a PR2/4 and 7 from a PR2/6. You can ignore the first in both cases – it being an auto zero channel. This is followed by readings from each sensor position in turn, from 1 through to 4 or 6.
See also SDI 12 Commands on page 48

SDI-12

Check the response to SDI-12 commands sent via **DeltaLINK,SDI-12,Transparent mode** to see if the problem is in the program settings or not.
For a list of commands see page 48.

Centring springs

Check that the centring springs are all fitted, clean and undamaged. Immediately replace any that do become damaged.

Installation problems

Auguring and access tube insertion

Most PR2 errors are caused by inserting an access tube into the wrong size of augured hole.

If the hole is too large, gaps around the tube will result in generally low readings and poor response to soil moisture changes – unless the gaps fill with rainwater.

If the augured hole is too small, the effort necessary to hammer the access tube into the soil will often result in gaps forming around the tube at the top and compaction of the soil lower down the tube.

Note the soil around a newly installed access tube may take one or two wetting and drying events to stabilise.

Refer to the Auguring Manual for advice on auguring holes of the correct size.

See the PR2 video on YouTube at https://www.youtube.com/watch?v=KvZC2-xYDL8

…

Technical reference

Specifications

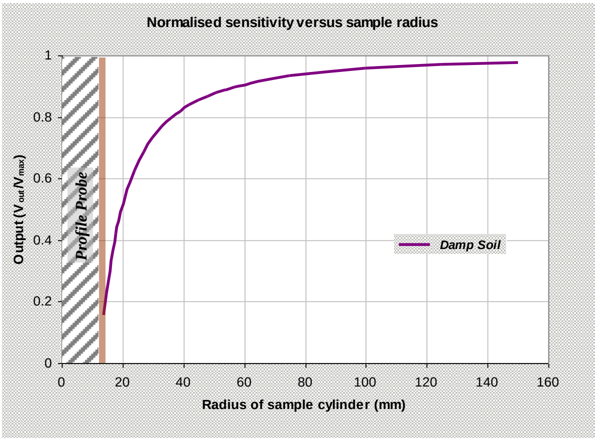
Technical Specifications for PR2/4 and PR2/6		
Measurement	Volumetric soil moisture content, θ_V ($m^3.m^{-3}$ or %vol.) or mV or permittivity.	
Range	Accuracy specified from 0 to 0.4 $m^3.m^{-3}$, Full range is from 0.0 to 1.0 $m^3.m^{-3}$	
Accuracy	± 0.04 $m^3.m^{-3}$, 0 to 40°C	after soil specific calibration
	± 0.06 $m^3.m^{-3}$, 0 to 40°C	with generalised soil calibration in 'normal' soils
Salinity errors	Included in above figures (50 to 400 $mS.m^{-1}$)	
Soil sampling volume	Vertically: ~95% sensitivity within ±50mm of upper ring of each pair. Horizontally: ~95% sensitivity within a cylinder of radius 100mm.	
Environment	0 to 40°C for full accuracy specification, –20 to 60°C full operating range. IP67 rated	
Stabilisation	Full accuracy achieved within 1s from power-up.	
Power requirement	7.2 to 16 VDC 720 mW (awake), < 60mA at 12 VDC (awake), 0.4 mA at 12V (asleep)	
Output	SDI-12	
Cable	5-core screened. Maximum length: 60m	
Construction material	25.4 mm polycarbonate tube with pairs of stainless steel rings	
Size / weight	PR2/4 length: 750 mm PR2/6 length: 1350 mm	Weight: 0.6 kg Weight: 0.95 kg

*using cables supplied by ΔT

Performance

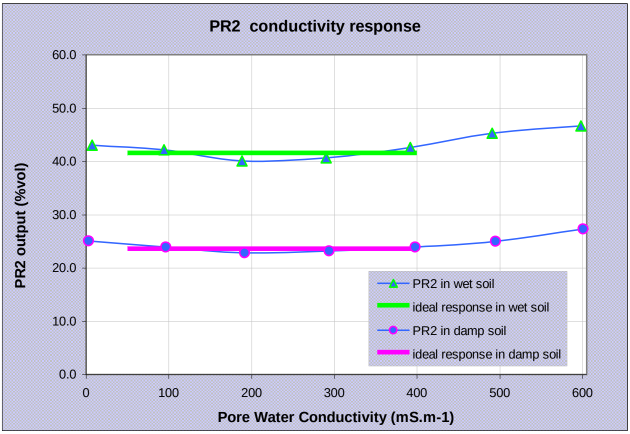
Field sensitivity

The signal is applied to the upper ring of each pair, so the electromagnetic field is stronger around the upper ring. Although this field extends a considerable distance into the soil (~100mm), it is strongest close to the rings, and so the soil close to the rings contributes most to the output.



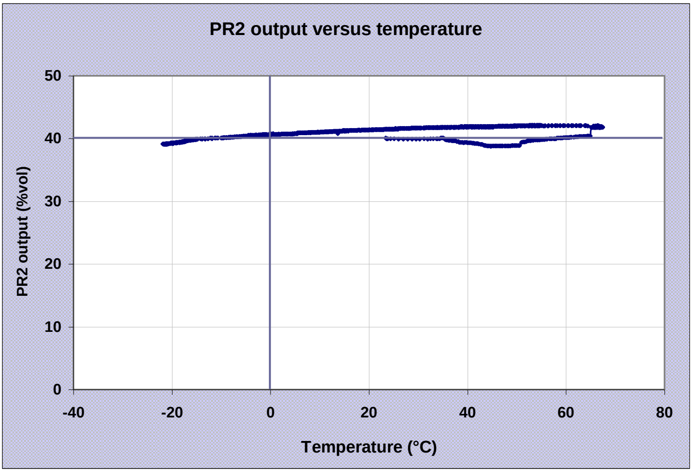
Salinity

The Profile Probe output has been tested as follows:



Temperature

The *Profile Probe* has a very low intrinsic sensitivity to changes in temperature, as in this example:



This relationship is dependent on soil composition (particularly clay content) and the soil moisture level, see ref. [7].

Definitions

Volumetric Soil Moisture Content is defined as

$$\theta_V = \frac{V_W}{V_S}$$

where V_w is the volume of water contained in the sample

and V_s is the total volume of the soil sample.

The preferred units for this ratio are **m³.m⁻³**, though **%vol** is frequently used.

Soil Moisture Content varies from approx. 0.02 $m^3.m^{-3}$ for sandy soils at the permanent wilting point, through approx. 0.4 $m^3.m^{-3}$ for clay soils at their field capacity, up to values as high as 0.85 $m^3.m^{-3}$ in saturated peat soils.

Gravimetric Soil Moisture Content is defined as

$$\theta_G = \frac{M_W}{M_S} \quad g.g^{-1}$$

where M_W is the mass of water in the sample,

*and M_S is the total mass of the **dry** sample.*

To convert from volumetric to gravimetric water content, use the equation

$$\theta_G = \theta_V * \frac{\rho_W}{\rho_S}$$

where ρ_W is the density of water (= 1), and ρ_S is the bulk density of the sample ($= \frac{M_S}{V_S}$).

Organic and Mineral definitions:

The generalised calibrations have been optimised to cover a wide range of soil types, based on the following definitions:

Soil type	**optimised around organic content:**	**use for organic contents:**	**bulk density range:** ($g.cm^{-3}$)	**use for bulk densities:** ($g.cm^{-3}$)
Mineral	~ 1 %C	< 7 %C	1.25 - 1.5	> 1.0
Organic	~ 40 %C	> 7 %C	0.2 - 0.7	< 1.0

Salinity

The preferred SI units for ionic conductivity are **mS.m^{-1}** (where S is Siemens, the unit of electric conductance = ohm^{-1}).

The following conversions apply:

1 mS.m^{-1}	= 0.01 dS.m^{-1}
	= 0.01 mS.cm^{-1}
	= 0.01 mmho.cm^{-1}
	= 10 µS.cm^{-1}

Soil salinity is also partitioned into the following descriptive categories:

non-saline	0 - 200	mS.m^{-1}
slightly saline	200 - 400	mS.m^{-1}
moderately saline	400 - 800	mS.m^{-1}
strongly saline	800 - 1600	mS.m^{-1}
extremely saline	> 1600	mS.m^{-1}

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   Journal of Soil Sci. **45**, 503-508

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   Journal of Soil Sci. **43**, 1-13

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   Temperature effects on soil bulk dielectric permittivity measured by time domain reflectrometry: A physical model.
   Water Resour Res., **35**, 371-383

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   In-field calibration of a dielectric soil moisture meter designed for use in an access tube.
   Soil Use and Management, **20**, 203-206

SDI 12 Commands

Delta-T SDI-12 enabled loggers, such as the GP2, know how to talk to an SDI-12 enabled PR2, so you do not need to understand the whole command set to program the logger.

Understanding at least the first two instructions in the reference table below will help when you are giving the sensor a unique address, before connecting it on a network. It may also help you investigate a faulty SDI-12 sensor.

For a full explanation of these commands and the rest of the SDI-12 standard see the SDI-12 Specification, Version 1.3, January 26 2013 – www.sdi-12.org/specification.php.

Our data loggers also help shield you from some of these details if you are attaching other types of SDI-12 sensors.

The following command and responses are used in connection with an SDI-12 PR2 .
Note: all the responses start with the sensor address and end with a carriage return line feed.

Key and Glossary

a	Denotes the sensor address. It can be any character from 0-9 or a to z or A to Z Address 0 is usually best reserved for new sensors from the manufacturer, so before you put it on a network, change it to something else. Each PR2 should have a unique address.

Command	Response	
?!	a<CR><LF>	**Query Address** Warning: This will only work if only one sensor is on the network. It asks the sensor to **report its address**. The sensor sends back its address followed by <carriage return>, <line feed>.
a!	a<CR><LF>	**Acknowledge Active**. The sensor at address <a> lets you know it is active by sending back its address followed by <carriage return>, <line feed>.
aAb!	b<CR><LF>	Commands the sensor to **change address from a to b**. A new sensor will have address 0. On a network it should be changed to b, which can be any character from 1 to 9, a to z or A to Z.
aI!	a13Delta-T PR2SDI0020000000010001<CR><LF> Sensor address: a SDI-12 standard vesion 1.3: 13 Manufacturer: Delta-T Sensor model number: PR2SDI Version: 002 Serial number: 0000000010001 Carriage return linefeed: <CR><LF>	Device identification. The logger asks sensor at address a to **identify itself**. It replies with a long string which is different for each manufacturer.

Interpreting Measurement Commands

Address *Sequential* *Concurrent*

Command	Response	
aM! / aC! aMC! / aCC!	PR2/6 a0026<CR><LF> PR2/4 a0024<CR><LF>	Soil moisture measurement in permittivity (e')

With Cyclic Redundancy Test *I will be ready in 2 seconds with 4 readings*

Continued…

Measurement Commands

Command	Response	
aM! / aC! aMC! / aCC!	PR2/6 a0026<CR><LF> PR2/4 a0024<CR><LF>	Soil moisture measurement in permittivity (e’)
aM1! / aC1! aMC1! / aCC1!	PR2/6 a0026<CR><LF> PR2/4 a0024<CR><LF>	Soil moisture measurement in Theta (m3.m-3) with Mineral soil type calibration
aM2! / aC2! aMC2! / aCC2!	PR2/6 a0026<CR><LF> PR2/4 a0024<CR><LF>	Soil moisture measurement in Theta (m3.m-3) with Organic soil type calibration
aM3! / aC3! aMC3! / aCC3!	PR2/6 a0026<CR><LF> PR2/4 a0024<CR><LF>	Soil moisture measurement as percentage volumetric (%) with Mineral soil type calibration
aM4! / aC4! aMC4! / aCC4!	PR2/6 a0026<CR><LF> PR2/4 a0024<CR><LF>	Soil moisture measurement as percentage volumetric (%) with Organic soil type calibration
aM5! / aC5! aMC5! / aCC5!		Defaults to same as M4 Can be used for custom settings.
aM6! / aC6! aMC6! / aCC6!		Defaults to same as M5 Can be used for custom settings
aM7! / aC7! aMC7! / aCC7!	PR2/6 a0027<CR><LF> PR2/4 a0025<CR><LF>	Sensor measurement in millivolt (mV). Also includes the auto-zero channel as first value.
aM8! / aC8! aMC8! / aCC8!	PR2/6 a0027<CR><LF> PR2/4 a0025<CR><LF>	Un-calibrated sensor measurement in millivolt (mV). Also include the auto-zero channel as first value.
aM9! / aC9! aMC9! / aCC9!	PR2/6 a0027<CR><LF> PR2/4 a0025<CR><LF>	Sensor measurement in raw ADC conversion (0-4095) Also include the auto-zero channel as first value.

Note: the soil type settings associated with Measurement Commands M2 to M4 are default values, which can be modified for particular sensor positons using the Extended Commands.

Send Data Commands

aD0!...aD9!	a<values><CR><LF> or a<values><CRC><CR><LF>	Send Data **Sequential (M command)** measurement may require multiple Send Data commands due to a character limit of 35. **Concurrent (C command)** measurements can be retrieved in a single request due to an increased character limit of 75

PR2 SDI-12 Extended Commands for configuring additional measurements

Different soil parameters, (a0 and a1) can be used at each sensor position. Commands are also provided to read back settings. Use the Save command **aXW#** to ensure the setting is not lost when power to the PR2 is removed.
For all commands the leading ‘a’ represents the SDI-12 address of the probe.

aXWMnU <value>	Sets additional measurement (**n** where n=1-6) to one of the following **types of unit U** where **<value>** can be 0 = Raw ADC 1 = mV Uncalibrated 2 = mV Calibrated 3 = Permittivity T or 4 = Theta V or 5 = Percent Volumetric **Examples**: 0XWM5UT – Set measurement 5 to Theta reading 0XWM6UV – Set measurement 6 to read % Volumetric 0XWM5U1 – Set measurement 5 to read Calibrated mV.
aXWMnSzX <value>	**Soil calibration a0 value** (X) **<value>** = Decimal numbers, see Note* **z** = sensor position, 1 – 6 or * = all sensor positions **n** = Measurement number 2-6 e.g. **aXWM5S1X1.6** sets measurement 5 sensor position 1 a0 to 1.6 **aXWM5S2X+1.3**, sets measurement 5 sensor position 2 a0 to 1.3
aXWMnSzY <value>	**Soil calibration a1 value** (Y) **<value>** = Decimal numbers, see Note* **z** = sensor position, 1 – 6 or * = all sensor positions **n** = Measurement number 2-6 e.g. **aXWM5S1Y8.6** sets measurement 5 sensor position 1 a1 to 8.6 **aXWM5S2Y+7.4** sets measurement 5 sensor position 2 a1 to 7.4
aXW#	**Save** to flash, commits changes in ram to flash
aXW**$**	**Restores** custom user settings to defaults
aXW**~**	**Abort** changes, invalidates changes in RAM

Note*: Decimal number can include a sign (+ or -) and a decimal point.
It does not require a leading zero before the decimal point.
It will not accept a comma instead of a dot for use as the decimal separator. Up to 3 decimal places may be used e.g. 1.234

For instance, if your soil is mineral apart from sensor position 1 (i.e. at 100mm) then you can send an extended command to the PR2 to tell it to treat position 1 as a mineral soil.
If you then send an M1 or M3 command to initiate a reading, the default reading will be for a mineral soil at all sensor positions apart from sensor position 1 which is now organic.

PR2 SDI-12 Extended Command for reading back additional measurement settings

aXRMxSy	Additional measurement type and soil calibration settings a= sensor's SDI-12 address x = Measurement number 1-9 y = Sensor position 1-6 Example: **Command:** aXRM2S6! (See *note) **Reply:** B M2 U=V,S6,a0=1.2 a1=8.2 Where: B = address M2 = measurement number 2 U = type of units If U=T, units will be Theta (0-1) If U=V, units will be % Volumetric (0-100%) S6 = Sensor position 6 a0 = soil parameter a1 = soil parameter

*Note: The **DeltaLINK, Tools, SDI-12, Transparent Mode** always adds the required terminating "!" to commands. Other terminal programs may not do this for you.

Technical Support

Terms and Conditions of Sale

Our Conditions of Sale (ref: COND: 1/07) set out Delta-T's legal obligations on these matters. The following paragraphs summarise Delta T's position but reference should always be made to the exact terms of our Conditions of Sale, which will prevail over the following explanation.

Delta-T warrants that the goods will be free from defects arising out of the materials used or poor workmanship for a period of twelve months from the date of delivery.

Delta-T shall be under no liability in respect of any defect arising from fair wear and tear, and the warranty does not cover damage through misuse or inexpert servicing, or other circumstances beyond their control.

If the buyer experiences problems with the goods they shall notify Delta-T (or Delta-T's local distributor) as soon as they become aware of such problem.

Delta-T may rectify the problem by replacing faulty parts free of charge, or by repairing the goods free of charge at Delta-T's premises in the UK during the warranty period.

If Delta-T requires that goods under warranty be returned to them from overseas for repair, Delta-T shall not be liable for the cost of carriage or for customs clearance in respect of such goods. However, Delta-T requires that such returns are discussed with them in advance and may at their discretion waive these charges.

Delta-T shall not be liable to supply products free of charge or repair any goods where the products or goods in question have been discontinued or have become obsolete, although Delta-T will endeavour to remedy the buyer's problem.

Delta-T shall not be liable to the buyer for any consequential loss, damage or compensation whatsoever (whether caused by the negligence of the Delta-T, their employees or distributors or otherwise) which arise from the supply of the goods and/or services, or their use or resale by the buyer.

Delta-T shall not be liable to the buyer by reason of any delay or failure to perform their obligations in relation to the goods and/or services if the delay or failure was due to any cause beyond the Delta-T's reasonable control.

Service, Repairs and Spares

Users in countries that have a Delta-T distributor or technical representative should contact them in the first instance.

Spare parts for our own instruments can be supplied and can normally be despatched within a few working days of receiving an order.

Spare parts and accessories for products not manufactured by Delta-T may have to be obtained from our supplier, and a certain amount of additional delay is inevitable.

No goods or equipment should be returned to Delta-T without first obtaining the return authorisation from Delta-T or our distributor.

On receipt of the goods at Delta-T you will be given a reference number. Always refer to this reference number in any subsequent correspondence. The goods will be inspected and you will be informed of the likely cost and delay.

We normally expect to complete repairs within one or two weeks of receiving the equipment. However, if the equipment has to be forwarded to our original supplier for specialist repairs or recalibration, additional delays of a few weeks may be expected. For contact details see below.

Technical Support

Users in countries that have a Delta-T distributor or technical representative should contact them in the first instance.

Technical Support is available on Delta-T products and systems. Your initial enquiry will be acknowledged immediately with a reference number. Make sure to quote the reference number subsequently so that we can easily trace any earlier correspondence.

In your enquiry, always quote instrument serial numbers, software version numbers, and the approximate date and source of purchase where these are relevant..

Contact details:

Tech Support Team
Delta-T Devices Ltd
130 Low Road, Burwell, Cambridge CB25 0EJ, U.K.
email: tech.support@delta-t.co.uk
email: repairs@delta-t.co.uk
web: www.delta-t.co.uk
Tel: +44 (0) 1638 742922
Fax: +44 (0) 1638 743155

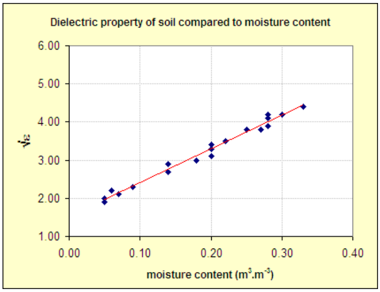
Appendix A: Soil-specific calibration

This note provides details of 3 techniques for generating soil-specific calibrations:

1. *Laboratory calibration for substrates* and non-clay soils*
2. *Laboratory calibration for clay soils*
3. *Field calibration*

* We use the term substrate to refer to any artificial growing medium.

Underlying principle



Soil moisture content (θ) is proportional to the refractive index of the soil (√ε) as measured by the ThetaProbe and *Profile Probe* (see **Calibration** section).

The goal of calibration is to generate two coefficients (a_0, a_1) which can be used in a linear equation to convert probe readings into soil moisture:

$$\sqrt{\varepsilon} = a_0 + a_1 \times \theta$$

Using the ThetaProbe to calibrate the Profile Probe

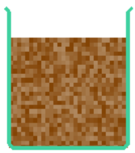
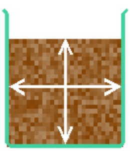
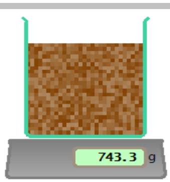
Soil calibrations using the ThetaProbe and *Profile Probe* are very similar - because they measure the same fundamental dielectric property (√ε) at the same frequency (100MHz). However both their calibrations are influenced by their slight sensitivity to conductivity - and they differ in how this sensitivity changes with water content. The ThetaProbe (and methods 1. or 2. below) can be used effectively for creating soil-specific Profile Probe calibrations at low water contents and/or low conductivities. At high conductivity *and* high water content it is far better to generate *Profile Probe* calibrations using the field calibration technique (3.).

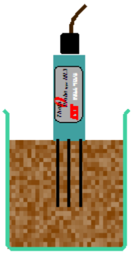
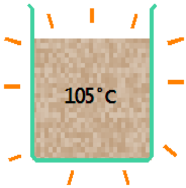
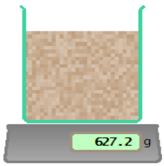
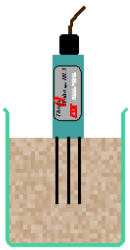
Laboratory calibration non-clay soils

This is the easiest technique, but it's not suitable for soils that shrink or become very hard when dry.

Equipment you will need:

- ThetaProbe and meter
- Soil corer (if doing a calibration for a cohesive soil rather than sand or a substrate)
- Heat-resistant beaker (≥ 500ml)
- Weighing balance (accurate to < 1g)
- Temperature controlled oven (for mineral soils or substrates)

Process	Notes and example
	Collect a damp sample of the soil or substrate. This sample needs to be unchanged from its in-situ density, to be ≥ 500ml, to have the correct dimensions to fit the beaker, and to be generally uniform in water content. For cohesive soils this is most easily done with a soil-corer. Sandy soils can be poured into the beaker, but you should take the subsequent measurements immediately, as the water will quickly begin to drain to the bottom of the beaker. Compressible soils and composts often require measurement of the in-situ density and then need to be carefully reconstituted at that density within the beaker.
	Measure the volume occupied by the sample. ***L_s = 463.5ml***
	Weigh the sample, including the beaker. ***W_w = 743.3g***

	Insert ThetaProbe into the sample and record its output in Volts. **V_w = 0.672*V***
	Dry the sample thoroughly. With mineral soils this is usually achieved by keeping it in the oven at 105°C for several hours or days (the time required depends on the sample size and porosity). For organic soils and composts it's usual to air-dry the sample to avoid burning off any volatile factions.
	Weigh the dry sample in the beaker. **W_0 = 627.2*g***
	Re-insert the ThetaProbe into the dry sample and record this reading. **V_0 = 0.110*V***
Calculate a_0	For the ML2, $\sqrt{\varepsilon} = 1.07 + 6.4V - 6.4V^2 + 4.7V^3$ In the dry soil $V = V_0$ = 0.110 Volts, and substituting this value into the above equation gives $\sqrt{\varepsilon_0} = 1.70$. Since θ_0 = 0, this is the value needed for a_0 **a_0 = 1.70**
Calculate θ_W	The water content of the wet soil, θ_W, can be calculated from the weight of water lost during drying, ($W_W - W_0$) and its volume, L_S:

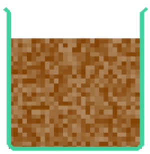
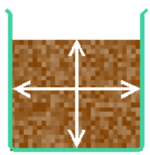
	$\theta_w = (W_w - W_0)/L_s = (743.3 - 627.2)/463.5 = 0.25$ **θ_w = 0.25**
Calculate $\boldsymbol{a_1}$	In the wet soil $V = V_W$ = 0.672 Volts and substituting gives $\sqrt{\varepsilon_w} = 3.91$ Finally $a_1 = \left(\sqrt{\varepsilon_w} - \sqrt{\varepsilon_0}\right)/(\theta_w - \theta_0) = (3.91 - 1.70)/(0.25 - 0) = 8.80$ **a_1 = 8.80**

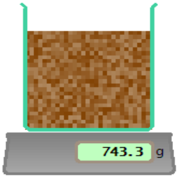
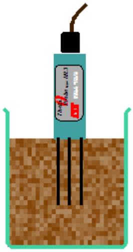
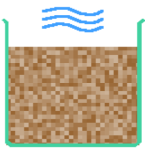
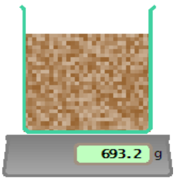
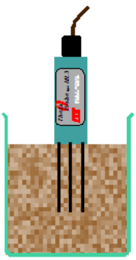
Laboratory calibration for clay soils

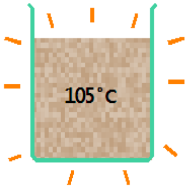
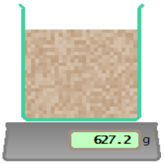
This technique is adapted to avoid the near-impossibility of inserting the ThetaProbe into a completely dry clay soil. It requires taking measurements at 2 significantly different, but still damp, moisture levels.

Equipment you will need:

- ThetaProbe and meter
- Soil corer
- Heat-resistant beaker (≥ 500ml)
- Weighing balance (accurate to < 1g)
- Temperature controlled oven

Process	Notes and example
	Collect a wet sample of the clay soil: 25 to 30% water content would be ideal. This sample needs to be unchanged from its in-situ density, to be ≥ 500ml, to have the correct dimensions to fit the beaker, and to be generally uniform in water content. This is most easily done with soil-corer.
	Measure the volume occupied by the sample. ***L_s = 463.5ml***

	Weigh the wet sample, including the beaker. $W_w = 743.3g$
	Insert ThetaProbe into the wet sample and record its output in Volts. $V_w = 0.672V$
	Dry the sample until still moist, ~15% water content. Gentle warming can be used to accelerate the process, but take care not to over-dry in places, and allow time for the water content to equilibrate throughout the sample before taking a reading.
	Reweigh. $W_m = 693.2g$
	Re-measure with the ThetaProbe. $V_m = 0.416V$

	Dry the sample thoroughly. With mineral soils this is usually achieved by keeping it in the oven at 105°C for several hours or days (the time required depends on the sample size and porosity).
	Weigh the dry sample in the beaker. **W_0 = 627.2g**
Calculations	Substituting in the ML2 equation $\sqrt{\varepsilon} = 1.07 + 6.4V - 6.4V^2 + 4.7V^3$ provides two dielectric values, $\sqrt{\varepsilon_w}$ and $\sqrt{\varepsilon_m}$, at two known water contents, θ_w and θ_m:
For the wet soil	Substituting V_w = 0.672 gives $\sqrt{\varepsilon_w} = 3.91 = a_0 + a_1 \cdot \theta_w$ for $\theta_w = (743.3 - 627.2)/463.5 = 0.25$
For the moist soil	Substituting V_m = 0.416 gives $\sqrt{\varepsilon_m} = 2.96 = a_0 + a_1 \cdot \theta_m$ For $\theta_m = (693.2 - 627.2)/463.5 = 0.14$
Calculate **a_1**	Then $a_1 = \left(\sqrt{\varepsilon_w} - \sqrt{\varepsilon_m}\right)/(\theta_w - \theta_m) = 8.73$ **a_1 = 8.73**
Calculate **a_0**	and $a_0 = \sqrt{\varepsilon_w} - (a_1 \cdot \theta_w) = 1.72$ **a_0 = 1.72**

Field calibration of soil

Field calibration is the surest method of calibration. We strongly recommend it for *Profile Probe* installations featuring high water content (usually high-clay-content) and high conductivity, as it is the only technique likely to give good results. However it is typically far more time consuming and requires access to considerably more equipment than laboratory calibration.

General principle

Install access tubes and take *Profile Probe* measurements (as voltages) over a period of time when the soil moisture content is changing. Over the same period, measure the water content at appropriate depths and spacing around the access tubes either by gravimetric sampling or using a Neutron Probe or using ThetaProbes. These comparison readings can then be used to construct a calibration for the *Profile Probe*.

For best results this approach requires comparison readings over a significant range of soil moisture contents. If the changes in water content over the measurement period are small, the calibration becomes very sensitive to any measurement errors. The extreme case of this occurs when readings are only available at a single soil moisture content. It is still possible to calibrate the *Profile Probe* in these cases - by assuming a default value for the intercept coefficient, $\boldsymbol{a}_0$.

Equipment you will need:

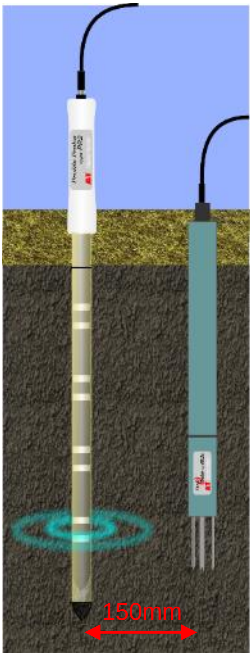
- Installed *Profile Probe* access tubes, and *Profile Probe* with either meter or data logger
- Either **installed ThetaProbes**, ~150mm from the access tubes at the appropriate depth

  Or **Neutron Probe** access tubes installed ~300mm from the Profile Probe tubes

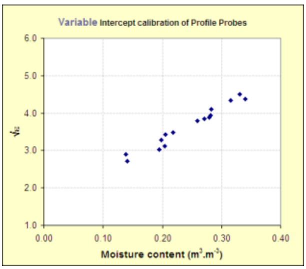
  Or **gravimetric sampling** equipment (see previous methods)

  Or a **portable ThetaProbe** attached to a suitable length extension rod and a suitable auger for sampling at depth

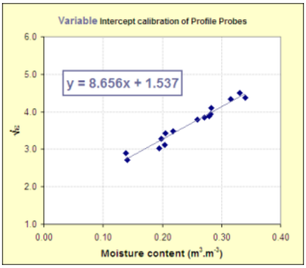
The gravimetric and portable ThetaProbe methods both require essentially destructive measurements, which limit their re-use at the same site, so they may require a number of similar sites. But see below for fixed intercept calibration.

<table>
<tr><th>Process</th><th>Notes and example</th></tr>
<tr><td>
</td><td>Take Profile Probe readings as voltages over a period of time as the soil moisture content changes. Ideally this would include 3 or more distinct soil moisture levels covering a change > 0.1$m^3.m^{-3}$.

At the same time, take several independent soil moisture readings spaced around the Profile Probe access tube. These could be taken either with ThetaProbes or a Neutron Probe or by gravimetric sampling.
The number of samples required depends on the uniformity of the soil and the size of the sampling volume.

If it is difficult to take readings over a range of moisture levels, it is still possible to calibrate the Profile Probe using a single soil moisture comparison using the fixed intercept method below.</td></tr>
<tr><td><table><tr><th>V</th><th>$\rightarrow \sqrt{\varepsilon}$</th></tr><tr><td>0.462</td><td>2.31</td></tr><tr><td>0.577</td><td>2.78</td></tr></table></td><td>Convert the Profile Probe measurements into $\sqrt{\varepsilon}$ using its calibration equation [2].</td></tr>
<tr><td>
</td><td>Graph these $\sqrt{\varepsilon}$ readings against the soil moisture measurements.

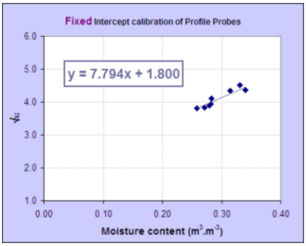
(This illustration and the following procedures are taken from Excel, but the principles can also be applied within other graphing or spreadsheet programs)</td></tr>
</table>



Variable Intercept

Fit a linear trend line to the data, and in the Options tab choose to display the equation. You may need to adjust the number format for the equation to 3 decimal places.

The calibration coefficients can then be read off directly. In the example shown, a_0 = 1.537 and a_1 = 8.656.



Fixed Intercept

Fit a linear trend line as above, but in the Options also choose "Set intercept =".

We suggest you use the following default intercept values:

Organic soil	1.4
Mineral soil	1.6
Heavy clay	1.8

In this example the intercept has been set to a_0 = 1.8, and the calculated value for a_1 = 7.794.

Index

A

Access tube, 5, 8, 9, 11, 12, 13, 35, 37, 42, 47, 61, 62
bung, 8
cap, 8, 9, 13
Accuracy, 37, 42
Air gaps, 11, 37

C

Calibration, 32, 33, 35, 39, 42, 47, 55, 56, 58, 61, 62, 63
soil-specific, 33, 55
Cleaning and Chemical Avoidance Instructions, 10
Conversions, 17, 33, 34
linearisation table, 33, 34
polynomial, 34
slope and offset, 32, 33, 34, 35

D

Data logger, 8, 13, 16, 17, 34, 61
DL2e, 8
Definitions, 45
Dielectric performance, 34, 47, 55, 60

F

Field sensitivity, 43

H

How to take a reading in mV, 40

I

Installation, 5, 12, 33, 37
Interpreting Measurement Commands
SDI-12, 49

M

Moisture content, 5, 11, 34, 37, 42, 47, 55, 61, 62

P

Power supply, 11, 16, 42

R

Range, 42
References, 47

S

Salinity, 37, 38, 42, 43, 46
Sampling
volume, 5, 42, 62
SDI 12 Commands, 48
SDI-12
Address, 20
Extended Command for reading back additional measurement settings, 52
Extended Commands, 51
How to take a reading in mV, 40
Measurement Commands, 50
PR2 SDI-12 Parameterss, 26
Send Data Commands, 50
Soil
clay, 32, 33, 37, 44, 45, 55, 56, 58, 61, 63
composition, 44
dry, 37, 56
mineral, 33, 35, 36, 57, 60
organic, 32, 33, 35, 36, 45, 57
type, 37
Specifications, 42

W

Water reading, 40