GroPoint™ GPLP
Lite Multi Segment
Soil Moisture Profiling Probe

Operation Manual

(GPLP shown with optional hand-held reader unit)

GroPoint™

Table of Contents

Overview

This highly accurate **GroPoint ™** Lite Multi-Segment Soil Moisture Profiling Probe (GPLP) provides cost effective soil moisture measurement over several depths using a single probe, eliminating the need for multiple sensors placed at different depths and cumbersome installations. GPLP can be deployed in irrigation sensitive zones, to enable full control of precision irrigation needs, providing an understanding of water movement through the soil. Profiling moisture measurement is ideal in a multitude of agricultural applications including vineyards, row crops, and orchards as well as silviculture and research to better manage irrigation practices, increase plant/crop quality and yield, and reduce fertilizer run-off. The sleek light weight design installs quickly with minimal soil disruption using a pilot rod and slide hammer tool. Designed for vertical installation, the sensor takes measurements over multiple soil layers, with each measurement zone providing the average volumetric soil moisture content over a 15 cm (6 inch) zone. The probe is attached to a 5 meter (16.3') cable. Soil temperature measurements are also available.
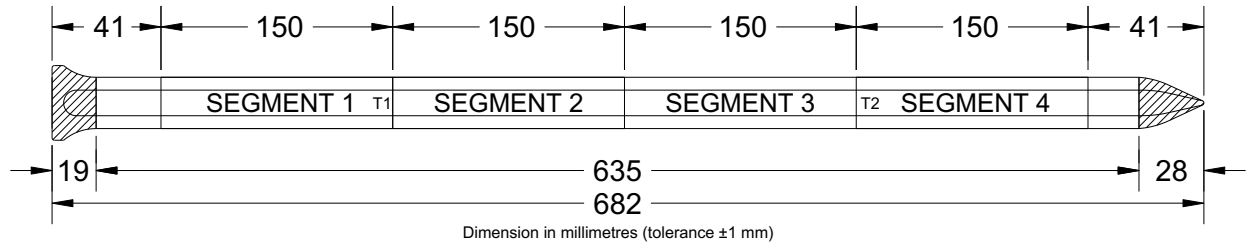
Technology (TDT)

GroPoint ™ sensors and probes use Time Domain Transmissometry (TDT) and patented technology as the basis for it measurement. The patented technology employs a unique antenna design that enables extremely accurate and repeatable measurements while maintaining a highly cost efficient electronics and mechanical design. TDT measures the time taken for an electromagnetic wave to propagate (travel) along a given length of a transmission line in the soil. Moisture in the soil changes the soil's dielectric properties, so that the electro-magnetic wave travels at different rates in wet soil compared to dry soil. This allows for the accurate determination of the soil moisture content.

The **GroPoint ™**TDT profiling probes detect water as much as 5 centimetres (2 inches) from the surface of the probe fins although, like all dielectric based sensors, moisture closest to the surface of the probe has more influence on the readings than moisture further away so that soil closely surrounding the sensor will have a greater influence on the soil moisture reading than the soil.

Probe Geometry

The drawing below shows the probe dimensions of a four segment probe and precise locations of each segment probe and the of the two soil temperature sensors:

41	150	150	150	150	41

| SEGMENT 1 | T1 | SEGMENT 2 | SEGMENT 3 | T2 | SEGMENT 4 |

| 19 | 635 | 28 |

682

Dimension in millimetres (tolerance ±1 mm)

Probe Insertion/Extraction

The correct installation procedure requires the use of the Slide Hammer Insertion tool kit to form a pilot hole using the steel pilot rod and then insert a **GroPoint ™** Lite profiling probe into this preformed hole. The pilot rod has the same cross section as the profiling probe. For accurate readings it is essential to use the pilot rod to pre-form the hole for the profiling probe. The Slide Hammer is used to insert and extract the pilot rod.

Care must be taken when using and carrying the slide hammer as the bottom part of the slide may drop down, potentially causing injury. Steel toed work shoes are recommended to prevent possible injury to toes and feet. Eye and ear protection are recommended at all times when using the slide hammer. Care must also be taken to avoid getting fingers caught in slide mechanism.

## *Assembly/Insertion of Pilot Rod*

First, the pilot rod must be tightly screwed into the slide hammer. During the insertion process, periodically check that the pilot rod remains tightly screwed onto the slide hammer.

Protective Equipment

When in use the slide hammer generates harmful levels of acoustic energy. Hearing protection with a Noise Reduction Rating of 20 decibels is provided with ESI's Slide Hammer Insertion/Extraction Tool Kit and it should always be worn. In addition, the driver user should wear work gloves (user provided), and keep both hands on the slide hammer when driving pilot rods and probes.

At the desired installation site, use repetitive up then down motion on the slide hammer to drive the pilot rod into the ground as far as required. Continue to check that the pilot rod is tightly screwed to the slide hammer during the insertion process, as the threads may loosen during repeated impacts. Failure to check this may place excessive force on the threads and damage them. Care must also be taken to ensure that the pilot rod is inserted as near to vertical as possible.
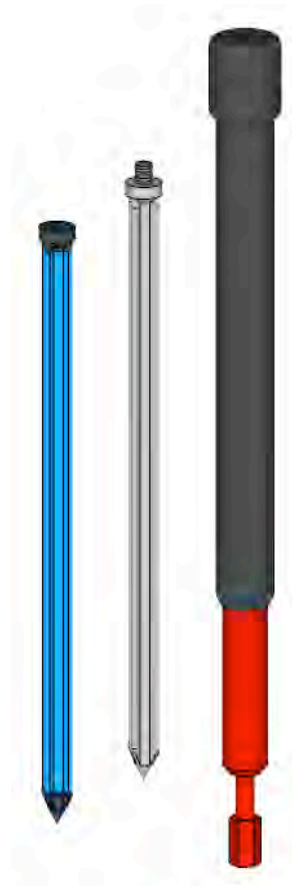
Insert the pilot rod only as far as needed for the length of probe being used. A hole that is too short may cause damage to the probe during insertion. A hole that is too long may allow water to collect in the void below the probe and cause inaccurate readings.

TIP: Refer to probe dimensions for the appropriate depth of installation and use a piece of tape on the pilot rod to mark the appropriate depth of insertion.

Extraction of Pilot Rod

Extraction of the pilot rod is achieved by using a repetitive upward motion on the slide hammer until the pilot rod is fully extracted.

Care must be taken to ensure that the extraction is done, as near to vertical as possible and that the hole is not enlarged during this process. Enlargement of the hole may result in air gaps forming between the probe and soil, potentially resulting in incorrect soil moisture readings.

Probe Insertion

Remove the pilot rod and insert the probe as soon as possible. Any delay in inserting the probe into the pre-formed hole may allow moisture to swell the hole sides, or water to enter the hole.

Place the probe in the hole formed by the pilot rod and press in as far as possible by hand. For short probes (45cm or less), this should be sufficient for proper installation of the probe

Never use a hammer, or other unapproved driving tools to insert pilot rods or probes. Probes may be permanently damaged if driven with unapproved driving tools

Problems Affecting Soil/Probe

For accurate readings the soil must be in direct contact with the probe. When a **GroPoint ™** profiling probe measurement takes place, an electro-magnetic field propagates out from the probe and into the soil. The electromagnetic field strength diminishes with the distance away from the probe in an exponential fashion. The net result of this changing field strength is that the soil right next to the probe has a much greater influence on the moisture reading than the soil further away from the probe. In practical terms, the volume of soil that affects 95% of the moisture reading is within approximately 1 cm of the side of the probe.

The fact that most of the moisture reading is based on measurements taken from soil that is close to the probe requires that the contact between the soil and the probe be very good. This in turn, has a bearing on how, and into what type of soil, the probe is inserted.

The goal of the insertion process is to place the probe into the soil and have no air gaps between the probe and the soil. Air gaps can be caused by a number of processes. A cavity can be created near the probe when the pilot rod pushes rocks out of the way and soil doesn't completely fill the space previously occupied by the rock.

While being tapped into the soil the pilot rod or probe can wobble back and forth, enlarging the pilot hole at the surface and for 15 to 20 cm below the surface. Care must be taken not to insert at an angle relative to the vertical. Field experience has shown that air gap problems are avoided by following the recommended insertion method.

Even if the insertion process initially results in an installation with no air gaps it is still possible for air gaps to form.

Certain types of clay soils will expand as they get moist and contract as they dry out (only some clay soils expand and contract; it depends on the type of clay). If the probe were inserted into this type of soil when it was moist and the then the soil subsequently dried out, air gaps will form as the soil shrinks away from the probe. Even inserting the probe into this type of soil when it is dry is no guarantee of good soil/probe contact.

The expansion/contraction characteristics of the soil can exhibit significant hysteresis. After a few wetting/drying cycles the soil may not fit snugly around the probe giving rise to air gaps. This type of soil is often characterized by the appearance of moderate to severe surface cracks when the soil dries out.

Air gaps caused by the motion of rocks during the formation of the pilot hole as required for the recommended insertion method may be unavoidable. If the soil contains a significant amount of rock, an alternative insertion method may be required to obtain reliable soil/probe contact. See below for a description of alternate insertion methods.

Air gaps caused by the soil expanding and contracting are more difficult to overcome. In an agricultural setting it may be possible to limit the variation of moisture content of the soil by periodic irrigation. Limiting the variation in moisture will limit the amount of expansion and contraction and thus reduce the chances that an air gap will form between the probe and the soil. If it is not possible to limit the variation in moisture level of the soil then a technique of filling the gaps may work. If, after a probe has been inserted into the soil for some time, the soil pulls away from the side of the probe, a slurry can be poured down the resulting crack to fill it. The slurry is made by mixing some of the soil from the immediate vicinity of the probe with water. The amount of water should be enough to make the slurry quite liquid. Some time after the slurry is poured down the crack it will dry out and shrink. This process will need to be repeated a number of times before the crack remains filled.

Probe Extraction

Probe extraction of **GroPoint™** Lite Profiling probes can only be done by digging out the probe. Expose at least 30cm of the probe, grasp firmly with two hands and pull upward. Do not grab

on to the black probe head in any way, it is not secured with enough strength for probe extraction.

Wiring Connections

This version of the **GroPoint™** Lite profiling probe uses the SDI-12 specification for the serial communications wires. Wiring connections are as follows:

Red: DC Input Voltage (6 to 14VDC)
White: SDI-12 Serial I/O
Black: No connection
Green: Ground

Reading Methods

The GPLP Lite multi-segment soil moisture profiling probes use the SDI-12 Protocol for serial communications. The sensors conform to V1.3 of the SDI-12 protocol. Serial communication settings are 1200 baud, 7 data bits, even parity, 1 stop bit. SDI-12 commands must begin with a minimum 12.5 ms break signal, followed by an 8.3 ms mark space, then the command characters. Note: for a complete description of the SDI-12 communications protocol, please refer to http://www.sdi-12.org/specification.php

Probes may be read with any compatible SDI-12 logger, communications interface or reader unit. ESI has available a hand held display unit for taking field readings, and a USB to SDI-12 Interface for probe configuration. Contact RIOT Technology Inc. for more details.

Sensor Start Up Time/Measurement Time

The time from application of power to the SDI-12 power bus until the sensor is ready to receive a command is approximately 75ms. The reported measurement time in response to the **M!** measure command (where "a" is sensor address) is 002 seconds. Actual measurement time is approximately 100ms per segment, so the three segment probe measurement will typically be less than one second from the end of the **aM!** command response (a0021<CR><LF>) until the measurement finished service request (a<CR><LF>). Power current consumption is at an active level (about 15-20 mA) only during measurement time, otherwise current is usually less than 0.5 mA.

Following is a list of the supported commands for the sensor. In the descriptions below, SDI-12 command/response sequences are show in Courier font, with a box surrounding the text. The command from the SDI-12 Logger/Recorder is shown in bold text. The response from the sensor is shown in normal text. As is normal, SDI-12 commands are always terminated with the '!' character. Responses from the sensor always include the sensor's address as the first character, and are always terminated with the <CR><LF> (carriage return-line feed) sequence.

Basic SDI-12 Command list

The **GroPoint™** Lite Three-Segment Profiling Probe responds to the following basic SDI-12 commands. In all cases, a=sensor address. Default sensor address is '0'.

Command:	Meaning:	Response
a!	Acknowledge active	Device address (default address is '0')
aI!	Send Identification	Identification string:
aAb!	Change Address	Change device address to 'b'
?!	Address Query	Device address
aM0!	Start Measurement	Measurement time and count (e.g. "a0023")
aC0!	Start Concurrent Meas.	Measurement time and count (e.g. "a00023")
aD0!	Send Data	Volumetric moisture content(s), in percent.

All other commands received by the sensor will be acknowledged with the device address only.

Acknowledge Active Command: a!

Use this command to ensure that a sensor is responding to a data recorder or other SDI-12 device. The command consists of the sensor's address and the '!' command termination character. When this command is received by the sensor, it responds with its address, followed by the <CR><LF> sequence. For example, for a sensor with address '0' (the default address), the command/response sequence is as follows:

0!0<CR><LF>

Send Identification String Command: aI!

Use this command to query the sensor for its SDI-12 compatibility level, vendor, model number, and firmware version number. The command consists of the sensor's address, the 'I' character, and the '!' command termination character. The response, for a sensor with address '0' (the default address), is as follows:

0I!013ESIENVIRGPLPT 018<CR><LF>

This identifies the supported SDI-12 compatibility level as 1.3, sensor vendor as 'ESIENVIR' (ESI Environmental Sensors Inc.), the model as GPLPT (**GroPoint™** Lite Profiling with soil temperature) and the firmware version as '018' (V1.7 firmware). ***Note: Newer models will report 'RIOTINC' (RIOT Technology Inc.).***

Query Address Commnad: ?!

Use this command to query a sensor for its address. This will allow a user to determine the address of a sensor if it is unknown. Please understand that if more than one sensor is connected to the SDI-12 communication bus, they will all respond to this command, causing a bus contention, and usually a garbled response. For a sensor with address '0' (default address), the command/response sequence is as follows:

?!0<CR><LF>

Change Address Command: aAb!

Use this command to change a sensor with address 'a' to new address 'b'. The factory default address for all sensors is the '0' character. If there will be more than one sensor on the SDI-12 communication bus, they must all have a unique address. ASCII '0' through ASCII '9' are the standard addresses. Should there be a need for more than 10 sensors, you can also use an address in the range ASCII 'A' through ASCII 'Z' and ASCII 'a' through ASCII 'z'. The sensor responds with the new address, and the <CR><LF> sequence. For example, the following command/response sequence changes a sensor with address '0' to address '5':

0A5!5<CR><LF>

Start Measurement Command: aM0! or aM! or aM1!

Use this command to start a sensor measurement. Use **M0!** or **M!** to start the soil moisture measurements. Use **M1!** to start the temperature measurements. The sensor responds with its address, and a string of numbers (e.g. '0024') which represents the expected time in seconds until the measurements will be ready ('002' seconds) and the number of measurements that it will make ('4' measurements). The data recorder is then expected to wait (no other commands may be sent) and monitor the SDI-12 communication bus up to the expected time, or until the sensor responds with its address as a service request. The send data (D0!) command can then be issued to get the measurements. Note that the commands M! and M0! are equivalent. For example, sensors with address 0 and 1 respond as follows:

0M0!00024<CR><LF>	(sensor 0 will be ready in 002 seconds with 4 measurements)
0<CR><LF>	(sensor 0 sends this when the measurement is complete)
1M!10024<CR><LF>	(sensor 1 will be ready in 002 seconds with 4 measurements)
1<CR><LF>	(sensor 1 sends this when the measurement is complete)

The actual measurement may take less than the expected time of 002 seconds. The service request will be sent by the sensors as soon as the measurement is complete and data is ready.

Once the service request is received, use the Send Data command (**aD0!**)to get the measurement results.

Start Concurrent Measurement Command: aC0! or aC!

Use this command to start a concurrent sensor measurement. The sensor responds with its address, and '00204' which represents the expected time in seconds until the measurements will be ready ('002' seconds) and the number of measurements that it will make ('04' measurements). The sensor begins the measurement process, but does **not** send a service request on completion. With a concurrent measurement command the data recorder may send additional commands to other devices while the sensor is busy taking measurements. Only after the expected measurement time has expired may the data recorder use the send data (**aD0!**) command to get the measurement data. (Note: The sensor will also start a measurement in response to just aC!) For example, sensors with address 0 and 1 respond as follows:

0C0!000204<CR><LF>   (sensor 0 will be ready in 002 seconds with 04 measurements)
1C!100204<CR><LF>   (sensor 1 will be ready in 002 seconds with 04 measurements)


Send Data Command: aD0! or aD!

Use this command to instruct the sensor to return the measurement results. The sensor responds with its address, and the moisture values for the four segments in the following order: segment 1 (0-15 cm), segment 2 (15-30 cm), segment 3 (30-45 cm), and finally segment 4 (45-60 cm). Each moisture value has the format '+mm.m' which represents the volumetric moisture content in percent. Note: The sensor will also send data in response to just aD! For example, a sensor with address 0 might respond as follows if the measure command used was M! or M0!:

0D0!0+15.2+22.7+27.5+26.0<CR><LF>

In this case, segment 1 (0-15 cm) has volumetric moisture content of 15.2%, segment 2 (15-30 cm) is 22.7%, segment 3 (30-45 cm) is 27.5%, and segment 4 (45-60cm) is 26.0%.

If not all data is returned in response to the D0! command then additional Send Data commands must be sent to obtain the remainder of the data, for example, D1!, D2! etc. SDI-12 data loggers should automatically manage the requirement to send the required number of Send Data commands in order to obtain the number of measurements the sensor indicated it would return for the M! command.

If the previous Measure command was M1!, then the sensor will return temperature readings in response to the D0! command. The first temperature sensor T1 is located at the boundary of the first and second segment, the second temperature sensor T2 is located at the boundary
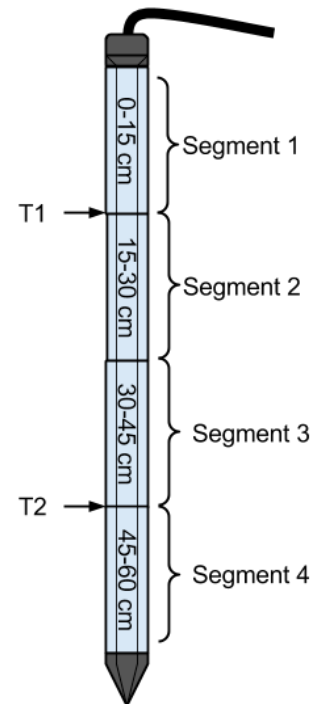
of segments 3 and 4. Temperature units are always in degrees Celsius (°C). For example, a sensor with address 0 may respond as follows:

0D1!0+21.3+18.5<CR><LF>

In this case, temperature reading for temperature sensor T1 is 21.3°C and temperature reading for temperature sensor T2 is 18.5°C

Extended SDI-12 Command list

The extended SDI-12 commands are used to adjust the sensor settings, serial number, calibration equation, etc. Caution must be exercised when using the extended commands, as certain combinations of commands could render the sensor partially or completely inoperable, or corrupt the sensor's base calibration. Many of these commands require internal processing that delays the response from the sensor, so strictly speaking they do not conform to certain timing requirement aspects of the SDI-12 protocol. This may require some timing adjustments in the communicating equipment, for example extending the wait time when waiting for a response from the sensor after a command is sent. Most commands that write a new setting or coefficient value fall into this category. See the specific commands for further information.

aXI!   Read/Write Serial Number

Command	Response	Comment
aXI!	aSN: ssssss<CR><LF>	read the current serial number
aXIssssss!	aSN: ssssss<CR><LF>	write the new serial number ssssss

Notes:
The serial number can be any combination of alphanumeric characters, however it must be exactly six characters in length. The first digit must indicate the number of segments in the probe. If this is not correctly set, then all segments will not be correctly measured. It is not recommended to change the serial number, as it is used by RIOT in record keeping associated with the initial calibration settings of the sensor, and in correctly measuring all segments in a probe.

aXDn!Read/Write Digital Potentiometer Setting

Command	Response	Comment
aXDn!	aD: n, ddd<CR><LF>	read the digipot n setting
aXDnddd!	aD: n, ddd<CR><LF>	write the new setting ddd to digipot n

Notes:
This command is used to adjust digital potentiometers (digipots) that affect the base circuit calibration. This command is reserved for factory calibration only, and should **never** be used to change the settings. Doing so may render the sensor inoperable.

The digipot number n must be 0, 1, 2, or 3 for adjusting segment 1 digipots, must be 5, 6, 7, or 8 for segment 2 digipots, and must be 9, A, B, C for adjusting segment 3 digipots.

The setting value ddd has a valid range of "000" to "255", and must be 0 padded to three characters, e.g. the setting value of 57 must be entered as "057".

aXSc!   Segment Element Power Control

Command	Response	Comment
aXSc!	ac ON<CR><LF> or aOFF<CR><LF> for c=0	write the new power setting

Notes:

This command is used enable or disable power to specific segments of the sensor. Except for the special case GPLP Lite profiling probes, it is generally only useful for factory debugging purposes. For GP-Lite sensors, the only valid entries for c are "0" or "1", where "0" turns the segment power off, "1" turns the segment power on. For GPLP Lite Profiling probes the valid values for c are "0", "1", "2", and "A", where "0" turns all segment power off, "1" turns segment 1 power on, "2" turns segment 2 power on, "3" turns on segment 3 power on, and "A" provides pass through analog power to subordinate boards (if any). See "Profiling Probe" section below for special notes regarding profiling probes with more than two segments.

aXMn!   Read/Write Mode Setting

Command	Response	Comment
aXM!	aMode: n<CR><LF>	read the current mode setting
aXMn!	aMode: n<CR><LF>	write the new mode setting to n

Notes:

This command is used to adjust the operating mode of the sensor. The mode setting is non-volatile, and only needs to be set once. Currently there are only two supported operating modes, "0" and "1":

Mode 0:   Default Operating Mode, no special actions taken.
Mode 1:   Enable application of third order polynomial to the measurement value.

Mode 1 allows the measured moisture value m to be recalculated by application of a third order polynomial equation to the original measured value *m*. The new reported value *n* is given by the expression:

$$n = A * m^3 + B * m^2 + C * m + D$$

The coefficient A, B, C and D are viewed and modified using the aXCn! command. The default settings for these coefficients are 0, 0, 1, and 0 respectively so that n = m.

aXCn! Read/Write Coefficient Setting

Command	Response	Comment
aXCn!	aCoeff(n): cccccccc_{<CR><LF>}	read the coefficient n setting
aXCncccccccc!	aCoeff(n): cccccccc_{<CR><LF>}	write the new coefficient n value

Notes:

This command is used to read or write the calibration coefficients used for calculating the moisture reading, and the coefficients used for temperature compensation of the sensor. All coefficients are non-volatile, and only need to be set once. Valid values for n are "0" to "9", and the letters "A" to "Q". The value "cccccccc" is the coefficient setting, it must be exactly eight characters long. For explicit accuracy, these parameters must be entered as the IEEE-754 hexadecimal representation of the decimal coefficient. For example, the number 0 is represented as "00000000", 1.0000000 is represented as "3F800000", etc. ESI also provides on request a calibration program that makes the necessary conversions from decimal values to IEEE-754 32 bit values. Also, see http://babbage.cs.qc.edu/IEEE-754/Decimal.html for a useful on-line conversion tool that can be used to generate the hexadecimal values given a decimal number.

Coefficients are defined as follows, and are described in further detail below:

> C(0): segment 1 scaling factor
> C(1): coefficient A in 3rd order polynomial, segment 1
> C(2): coefficient B in 3rd order polynomial, segment 1
> C(3): coefficient C in 3rd order polynomial, segment 1
> C(4): coefficient D in 3rd order polynomial, segment 1
> C(5): segment 2 scaling factor
> C(6): coefficient A in 3rd order polynomial, segment 2
> C(7): coefficient B in 3rd order polynomial, segment 2
> C(8): coefficient C in 3rd order polynomial, segment 2
> C(9): coefficient D in 3rd order polynomial, segment 2

Scaling Factor

The sensor electronics measures the moisture sensing circuitry with a 10 bit ADC. This raw ADC value is scaled using an adjustable coefficient. The default value of this coefficient is 100.0/1024 = 0.09765625 = 0x3DC80000. This gives a nominal output range of 0% to 100%, although typically values over 50% are quite non linear. This value should **not** be changed. However, if absolutely necessary, the scaling coefficient can be adjusted with the extended command aXCn. Coefficient 0 is the scaling factor for segment 1, coefficient 5 is the scaling factor for segment 2. Refer to the table of commands on the following page for the appropriate commands for segments 3 and 4. Please note that changing this scaling factor may then require recalibration of the sensor, so it is better to leave this factor unchanged and instead modify the third order polynomial coefficients (see below).

Third Order Polynomial Coefficients

The scaled output can be further modified by application of a third order polynomial function to correct for different soil types, soil compaction levels, non linearity in the sensor output, etc. It is activated by setting the mode parameter to "1" using the SDI-12 extended command **aXM1!**

The polynomial equation is shown below. Coefficients are adjusted with the SDI-12 extended command aXCn. Refer to the following table for correlation between 'n' and the associated coefficient:

$$n = A*m^3 + B*m^2 + C*m + D$$

Default settings for the A to D coefficients are 0, 0, 1, 0 respectively, which is equivalent to the original reading of m. The coefficients are entered and expressed as IEEE-754 32 bit hexadecimal values, e.g. 1.0 = 0x3F800000. The normal scaling factor c(0) of 100.0/1024 = 0.09765625 = 0x3DC80000. See http://babbage.cs.qc.edu/IEEE-754/Decimal.html for a conversion tool that can be used to generate the hexadecimal values given a decimal number. ESI also provides on request a software program called "IEEE-754 Convert" that can be used convert the decimal numbers to the hexadecimal equivalent.

Commands to read or modify the third order polynomial coefficients:

Seg #	Coeff.	#	Read	Write	Default (decimal)	Default (hex)
1	scale	0	aXC0!	aXC0cccccccc!	0.09765625	3DC80000
1	A	1	aXC1!	aXC1cccccccc!	0	00000000
1	B	2	aXC2!	aXC2cccccccc!	0	00000000
1	C	3	aXC3!	aXC3cccccccc!	1	3F800000
1	D	4	aXC4!	aXC4cccccccc!	0	00000000
2	scale	5	aXC5!	aXC5cccccccc!	0.09765625	3DC80000
2	A	6	aXC6!	aXC6cccccccc!	0	00000000
2	B	7	aXC7!	aXC7cccccccc!	0	00000000
2	C	8	aXC8!	aXC8cccccccc!	1	3F800000
2	D	9	aXC9!	aXC9cccccccc!	0	00000000
3*	scale	0	aX1XC0!	aX1XC0cccccccc!	0.09765625	3DC80000
3*	A	1	aX1XC1!	aX1XC1cccccccc!	0	00000000
3*	B	2	aX1XC2!	aX1XC2cccccccc!	0	00000000
3*	C	3	aX1XC3!	aX1XC3cccccccc!	1	3F800000
3*	D	4	aX1XC4!	aX1XC4cccccccc!	0	00000000
4*	scale	5	aX1XC5!	aX1XC5cccccccc!	0.09765625	3DC80000
4*	A	6	aX1XC6!	aX1XC6cccccccc!	0	00000000
4*	B	7	aX1XC7!	aX1XC7cccccccc!	0	00000000
4*	C	8	aX1XC8!	aX1XC8cccccccc!	1	3F800000
4*	D	9	aX1XC9!	aX1XC9cccccccc!	0	00000000

*before sending these commands you must first issue the following command (where a is the sensor address): aXSA!

Special Notes Regarding Profiling Probes

GPLP Lite Profiling probes with more than two segments have special requirements for communicating. Internally, these probes consist of several circuit boards daisy chained together. The first board ordinarily handles all normal communications, particularly handling all

basic SDI-12 commands. When necessary, there is a specific mechanism and requirements for sending commands directly to attached daisy chained boards and some special cautions must also be employed. In particular:

- Power to daisy chained boards is normally off and must be specifically turned on first with the **aXSA!** command. A start up delay of at least 75ms must occur after this command before sending any further commands to the daisy chained board.

Commands to a daisy chained board are embedded in the following special extended command format:

aX*ncommand*!

where n is the position in the daisy chain. "1" is for the first attached board (segments 3 and 4), 2 is for the second attached board (segments 5 and 6) etc. The *command* can be any valid SDI-12 command already listed above. For example, to get the ID string for the first attached board (when the main sensor has address 0) send the command **0X1I!** The response will be something like "0013ESIENVIRGPLPT 016"

- Note that all subordinate/attached boards in a probe have a default address of 0, and this address must **NEVER** be changed! If you send the address change (aX0Ab!) command to an internally daisy chained board, this will render that board and all subsequent boards unresponsive and inoperative.

- The coefficients table above lists the necessary commands for reading/modifying the settings stored coefficients for the additional segments in the four segment profiling probe. The third order polynomial calculation for attached boards must also be specifically enabled using the aXM mode command for the subordinate board. Use the full command **aX1XM1!** to do this.

Specifications

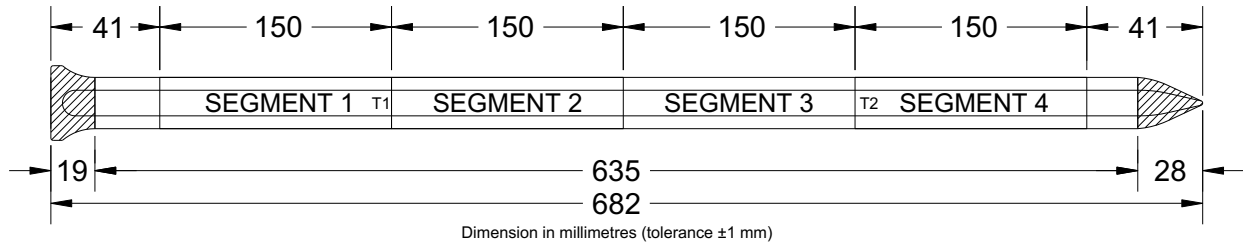Moisture Measurement: 0% to 100% volumetric water content
Temperature Measurement: -20°C to +70°C
Output: SDI-12 V1.3 (all basic commands)

Ratings

Parameter:	Operating:	Absolute Maximum:
DC Input Voltage:	6 to 14 VDC	18.0 VDC
DC Input Current:	15 mA (0.1mA idle)	100 mA
Temperature:	-20°C to +70°C	-40°C to +85°C

Dimensions

Dimension in millimetres (tolerance ±1 mm)

Appendix A: Soil Specific Calibration Process

• *Introduction*

The GPLP probes are initially calibrated in fine sand, as this provides an easy to reproduce reference point. For this reason there may be slight differences between the readings given by the sensor and actual moisture content due to differences in the measured soil's dielectric. These differences are usually small, on the order of a few percent, however for highest accuracy the user may wish to calibrate for the specific soil type used in their own application. The process described here may be used to custom calibrate the **GroPoint™** Lite Profiling probes for specific soil types.

As with any calibration process, it is vital to ensure the highest level of accuracy at all stages of the process. Any errors introduced, for example in the manual determination of volumetric moisture content, or in soil compaction around the probes, will affect the accuracy of the calibration.

Important First Step: Before proceeding with this process you must disable the use of the third order polynomial in the sensor measurement. This is done by issuing the following SDI-12 extended commands (assuming the sensor has the default address = 0):

    0XM0!

You can also use the GPLP Reader program to disable the third order polynomial via the checkbox on the "Coefficients" dialog.

• *Overview*

Sensor readings are taken in a variety of soil moisture levels and are compared with manually determined volumetric moisture contents. The first soil moisture level is the initial moisture of the dry soil, after it has been allowed to air dry to ambient conditions for several weeks. It does need to be completely dry, but it should be less than 5% volumetric moisture content (VMC). The last moisture level should be at or very near saturation. Calculate the volume of water to add based on the measured volume of the soil used. The desired increase for each moisture level should be approximately 4-5%. For each test moisture level, water must be carefully and evenly applied to the soil using a spray bottle. The soil is well mixed, returned to the soil box and allowed to equilibrate for at least an hour (longer if the soil is clay or clay loam). When the soil is ready, remove the top half of the soil, place the probe in the soil container, then replace the soil over the probe. Ensure that the sensor is in good contact on all sides with the soil (no air gaps), and that there is at least 7-8 cm of soil in all directions around the probe. Try to ensure uniform soil compaction when replacing the soil. Take several measurements from the sensor and record the results. Take several samples (at least three) of the soil and determine

the volumetric moisture content (see Appendix A). Log the manually determined moisture content along with the results measured by the sensor.

Repeat the above process, increasing the moisture by approximately 5% for each step, until a saturated soil is achieved. Seven to eight moisture levels should be used.

When all data is collected, chart the results and then apply a polynomial fit to the data points to establish the soil calibration coefficients.

Equipment Required

Soil that is being calibrated, initially dried to less than 5%, sufficient amount to fill the soil box:

Soil container/box – must be of sufficient volume to contain enough soil to extend at least 7-8 cm around the probe in all directions. If necessary, a container may be made from wood, if so, then it should be lined with heavy plastic sheeting to prevent any loss of moisture due to drainage or absorption by the wood. The above example box is a commercially available wooden planter box, approximate <u>inner</u> dimensions 7.25" high by 7.5" wide

by 32" long (18.5 cm x 19 cm x 82 cm). This can contain up to 28 liters of soil.

Plastic sheeting - to cover soil (to minimize loss of moisture due to evaporation), and if necessary to line the soil container.

Spray bottle (used to evenly apply water to the soil)

Hand Trowel (for mixing and preparing soil)

Graduated cylinder (to measure amount of water to add).

Plastic scraper/Wooden tongue depressors (useful to scrape soil off of gloves, probes, etc.)

The following is required for manual determination of soil moisture content (refer to Appendix A for more details): digital scale with minimum resolution to 0.1 g, ceramic microwaveable bowl, microwave oven.

- *Safety Equipment*

Keep clean and protect your lungs!

- Strong rubber gloves (always wear gloves when handling soil)
- Face mask (dry soil is very dusty, avoid inhaling the dust, particularly until the second or third moisture level)
- Lab coat (protect your clothes from becoming soiled)

Procedure

1. Initial Soil Preparation

Soil is left out for two to three weeks in uncovered containers to allow it dry down to the ambient humidity. Alternatively, soil may be oven dried to reduce moisture content down to approximately 2-3%.

Once soil has softened a bit (about 1.5 weeks or more), break down all clumps by rubbing out by hand. Discard any debris, tiny rocks, etc. Soil must be clump free and as uniform as possible in size (less than 2 mm).

Once soil is broken down, measure the soil volume. Volume is measured using a plastic 2L measuring cup or similar. The soil is scooped into the cup and settled by tapping the bottom of the cup on the table. This is done by 1/2 liter increments. Place the measure soil into the soil box until sufficient soil has been obtained. Note that some soils may collapse and pack more tightly once a certain level of moisture is reached, plus some soil is lost via spills, stuck on gloves, etcetera, so it is better to have extra soil rather than to discover later that there is not enough. Record the total volume of soil started with. This will be used to estimate the amount of water to add at each stage.

2. Measure Soil Moisture

- Install the probe into the soil box. First remove about half the soil, then pack the probe horizontally in the soil box. Need at least 7-8 cm of soil all around probe, including tip, sides, top and bottom. Make an even bed of soil in the bottom half of the soil, then place the probe on the bed. Make sure probe is clean and dry each time it is packed into soil. Pack soil firmly over and around probe, including where the cable comes out. Do not want any air bubbles, soil clumps, cracks etc. Ensure uniform soil compaction. Return the removed soil, compacting it evenly in several thin layers as it is returned to the box.

Take sensor readings and record the measurements. Let sit for a few minutes then repeat. Record at least 3 (5 is better) sets of readings. When all readings are recorded, determine the starting volumetric moisture content as described in Appendix A. Note: the soil does not need to be perfectly dry, but should be less than 5% at the start to allow for sufficient steps in the calibration process. If soil is greater than 5%, further drying is required, or adjust the amount of water that will be added to ensure that there will be sufficient moisture level steps.

3. Adding Water to the Soil

The amount of water to add at each stage is determined based on soil volume/mass. Use the type of soil and the total volume of the soil to estimate the total amount of water to reach soil saturation. For example, if working with a sandy loam soil, then soil saturation is reached at approximately 34%-38% volumetric moisture content (exact amount depends on precise soil texture). If the volume of the soil is 25 liters, then total water necessary to saturate the soil is approximately 36%*25 liters = 8.75 liters. The amount of water to add to the soil to allow for 7-8 different moisture levels is thus around 8.75 liters/8 = 1.1 liters, assuming that the soil is mostly dry to start with. This amount does not have to be exact. Actual volumetric moisture content is measured directly, and the amount added can be adjusted during the course of the calibration process. It is better to start with a slightly smaller amount (say 1 liter in this case).

Each increase in moisture level is achieved through application of measured amounts of water to the soil. Measure water using a graduated cylinder or by zeroing a beaker on a scale, then pour in water until desired weight is reached (1ml = 1g). Transfer water to a spray bottle using a funnel. To make mixing easier, transfer the soil from the soil box into a larger mixing container. Be careful not to lose any soil. Expose a layer of soil, then apply water with the spray bottle. The water is sprayed onto the soil, and next layer of dry soil uncovered with the trowel, more sprayed and so on. After all water is added, mix the soil well with trowel to get rid of any dry spots. Then use fingers to break up any soil clumps to ensure that the soil is uniform. It is very important that the water is thoroughly and evenly mixed so that the soil is uniformly moistened.

Note that it is hard to make clay soils 'non-lumpy', but all big clumps should be rubbed out. Also, when soil gets very wet, do not pack too hard or this will squeeze water out.

After the measured amount of water has been incorporated into the soil, return the soil into the soil box and cover with plastic sheeting. Let it sit for an hour before starting to take any measurements. For *loamy clay or clay* soil let sit for at least two hours.

When the soil has sat for the required time, return to step 2 and take the next set of measurements. Repeat steps 2 and 3 for as many moisture levels as is required until the soil is saturated (when measured moisture level no longer increases).

4. Data Analysis

Note: these instructions assume the use of Microsoft Excel. Please refer to Excel's Help for assistance with using a spreadsheet and charting the data. For other applications (e.g. Open Office), please refer to application program's help system.

Enter each moisture level's measurements into spreadsheet in a format similar to that shown below:

	Seg 1	Seg 2	Seg 3	Seg 4
	11.40	12.00	11.20	12.70
	11.40	12.00	11.20	12.70
	11.70	12.30	11.50	12.80
	11.70	12.30	11.50	12.80
	12.00	12.60	11.70	12.80
Average	**11.64**	**12.24**	**11.42**	**12.76**
Standard Deviation	**0.25**	**0.25**	**0.22**	**0.05**

Use formulas to calculate the average and standard deviation.

You should have a similar table for the manually determined volumetric moisture contents (Reference Moisture), with three readings minimum, and the calculated average and standard deviation.

Next, enter all of the averaged data from each moisture level into a separate spreadsheet in a format similar to that shown below:

Seg 1	Seg 2	Seg 3	Seg 4	Reference Moisture
0.34	0.60	0.22	0.32	0.40
3.80	4.46	3.62	4.00	4.10
6.88	7.60	7.00	7.18	7.62
9.66	10.88	9.46	9.42	12.02
11.64	12.24	11.42	12.76	17.74
17.90	19.10	21.10	20.66	22.87
22.20	24.86	25.08	26.92	29.29
32.82	34.28	33.68	34.78	33.20

Use this table of data to plot an **X-Y (Scatter)** chart, sub type is data points with no line. The X data should be from the Seg data column (value measured by the sensor), the Y data should be from the Reference Moisture column (value determined manually). Do a separate chart for each segment.

Select each chart, then select the **Chart|Add Trendline…** menu option. The type of trend line should be "polynomial", select either 2 or 3 for the order of the polynomial*, and for trend line options choose **"Display equation on chart"** and **"Display R-squared value on chart".**

$$y = -0.0214x^2 + 1.7919x - 1.8242$$
$$R^2 = 0.9844$$
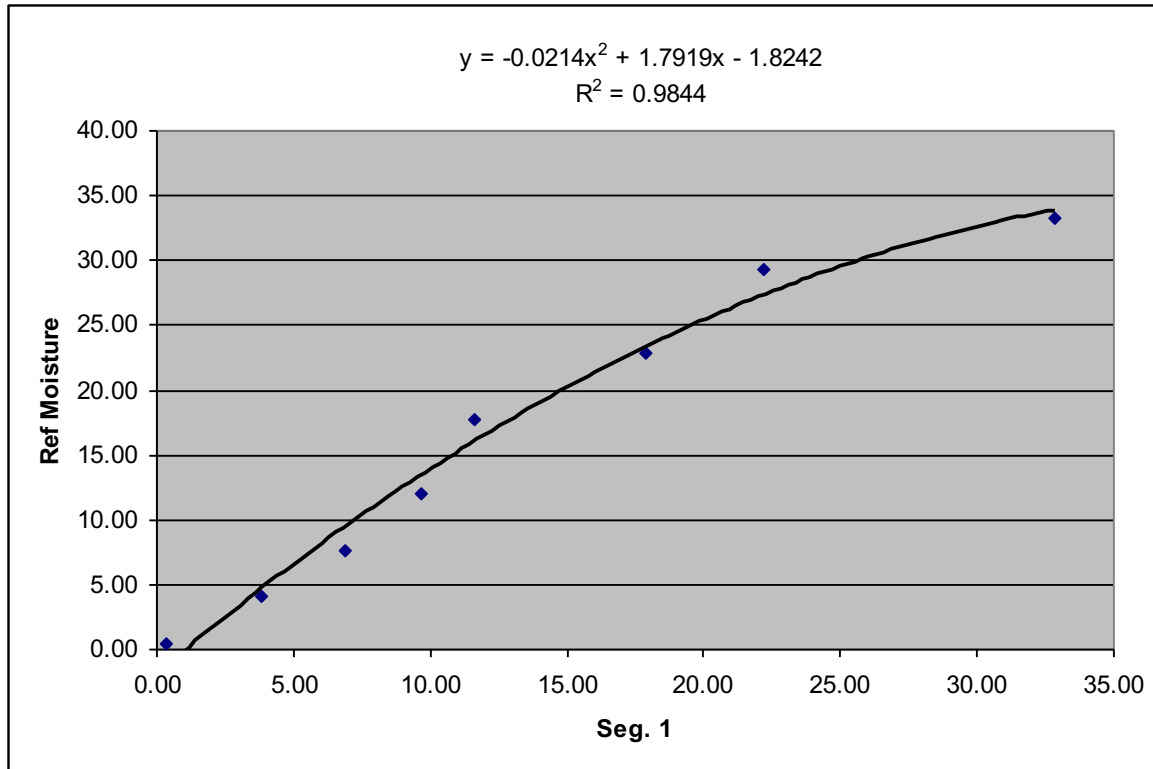
The coefficients displayed in the equation are the coefficients that should be entered into the sensors coefficients table, using the GPLP Reader software. Note that there will be a set of coefficients for *each* segment, take care to ensure that each segment is set to use the correct set of coefficients. The R^2 value is a measure of how well the trend line fits the data (above 0.98 is good, the closer to 1, the better the fit is).

***A note about the polynomial order to use**: Depending on the data collected, it may be better to use a second order polynomial rather than a third order polynomial. Some third order polynomial trend lines result in a downward curve at high moisture levels, which is not representative of how the sensor will actually perform. If this appears to be the case with your data, it is recommended to instead use a second order polynomial (degree 2).

Entering Coefficients into the Probe

Once the soil coefficients have been determined they must be entered into the probe's non volatile memory. This is done using the extended SDI-12 command a**XC**i! where a=sensor address (default address is 0) and i is the coefficient to modify. Please refer to the Operation Manual, Extend Commands section for more details. ESI also has available a USB to SDI-12 Interface and special software that simplifies the task of viewing and changing the probe's coefficient. Contact ESI for more information.

General Observations

Loamy Clay/Clay soils

Loamy Clay/Clay soils can be very time consuming to work with. Although the loamy clay does not stick to the gloves and trowel below about 32% moisture, it can form clumps that are difficult to reduce to smaller size, especially at lower moisture levels. At around 32% it may turn very stiff and required a lot of hand strength to pack the soil around the probes so that there are no air spaces, so be aware of this to ensure accurate readings from the probes. Above around 32% the soil will start getting softer, and easier to work with. Above 36%, consistency may be much softer, but it will become very sticky. Take care not to lose soil at this stage.

See Also

Resources on soils

- A Compendium of On-Line Soil Survey Information - Soil Classification for Soil Survey

B Appendix B - Determining Volumetric Moisture Content

Weight Method – In Laboratory

The following procedure describes a method to determine the volumetric moisture content of a soil sample. A soil sample of a known volume is taken, and its weight is recorded. The soil sample is dried. The loss of weight is due to loss of water, this can be used to calculated the volumetric moisture content.

Equipment Required:

- Soil sampling ring of known volume (see below for requirements)
- Digital scale with minimum resolution of one tenth of a gram, e.g. 0.1 grams
- Trowel
- Plastic scraper/tongue depressors
- Ceramic bowl
- Microwave oven

Soil Sampling Ring Requirements

The soil sampling ring should be a thin-walled metal cylinder. A section of metal pipe may be used, provided the wall thickness is no more than 1.5 mm (a wall that is too thick may cause soil compaction as the cylinder is pressed into the soil, which could introduce errors in the measurement).

Calculate the volume of the sampling ring by measuring the interior diameter and cylinder length. The pictured example has length of 3.80 cm and interior diameter of 3.35 cm, corresponding to a volume of 33.5 cm^3 or 33.5 ml:

Volume of a cylinder = π * radius^2 * length = π * (diameter/2)^2 * length

V = π * (3.35 cm/2)^2 * 3.80 cm

V = 33.494 cm^3 = 33.5 cm^3 or 33.5 ml

Sampling Method

For the most accurate results, soil must have been allowed to sit for at least one hour after water has been applied before any moisture measurements are taken. Also, for larger soil containers, take at least three soil samples and average the results.

The volumetric moisture percentage is calculated according to the following process:

- Let covered soil box sit for an hour or more after adding water.

- Stir soil with trowel or fingers, then tamp soil down to desired compaction level (ideally this would be with the probe still in the soil, just after the probe measurements are taken).
- Use the trowel to dig a small hole:

- Push the sampling ring into undisturbed soil on the side of the hole. Try to ensure no additional soil compaction, that is do not pack the cylinder more tightly or less tightly than the surrounding soil (this will introduce an error in the sample.

- Remove the sampling ring from the soil by scraping the surrounding soil away (use the tongue depressor) until the ring is exposed.

Cut away any excess soil from the open ends of the sampling ring, and also ensure the that the outside of the sampling ring is free of soil.

- Empty the contents of the sampling ring into the ceramic bowl.

- Weigh the soil sample and cup together on the scale to the nearest tenth of a gram (0.1 g). Record the weight.
- Microwave the cup and soil for 2 minutes, then stir. Weigh again. **CAUTION**: the bowl will be hot. Repeat this step until there is no further change in weight. Record the final weight.

Appendix B: Determining Volumetric Moisture C

- The difference in sample weight is due to the moisture that was boiled off from the sample. Use this weight difference divided by the sample cylinder volume (for example 33.5 ml) to calculate the volumetric moisture content.

Example Calculation:

Initial Weight: 368.7 g

Final Weight: 362.8 g

Difference: 368.7 g - 362.8 g = 5.9 g = 5.9 ml

Volumetric Moisture Content = 5.9 ml / 33.5 ml = 0.176 ml/ml = 17.6 %

- Remember, for large soil containers, you should do at least three samples equally spaced along the soil box, then average the results together.
- When finished all measurements, return the soil samples to the soil box and mix in well.