GroPoint™ Lite Multi Segment Soil Moisture & Temperature Profiling Probe

Model 2625-N-T-x and Model 2625-N-x

OPERATION MANUAL

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V1.0

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Overview

The highly accurate **GroPoint™** Lite Multi-Segment Soil Moisture and Temperature 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 3-meter (9.8') 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 its 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 electromagnetic wave travels at different rates in wet soil compared to dry soil. This allows for the accurate determination of the soil moisture content.

GroPoint™ TDT[5] 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 further away.

GroPoint™ Profile Model Variations

The GroPoint™ Profile sensor can be ordered with and without temperature sensors.   The information in this manual covers material for sensors with temperature sensors. If you have ordered sensors without temperature sensors, the commands applicable to the temperature sensor readings <u>will be inactive</u>. Model numbers of sensors are as follows:

Cable Connection: Either flying lead or M12 Connector, **Interface:** SDI-12, modbus or RS485 + SDI-12

Length & Number of Segments	Part No. With Temperature	Part No. Without Temperature
2 Segment (30 cm)	2625-N-T-2	2625-N-2
3 Segment (45 cm)	2625-N-T-3	2625-N-3
4 Segment (60 cm)	2625-N-T-4	2625-N-4
5 Segment (75 cm)	2625-N-T-5	2625-N-5
6 Segment (90 cm)	2625-N-T-6	2625-N-6
8 Segment (120 cm)	2625-N-T-8	2625-N-8

🌡 = temperature sensorplacement
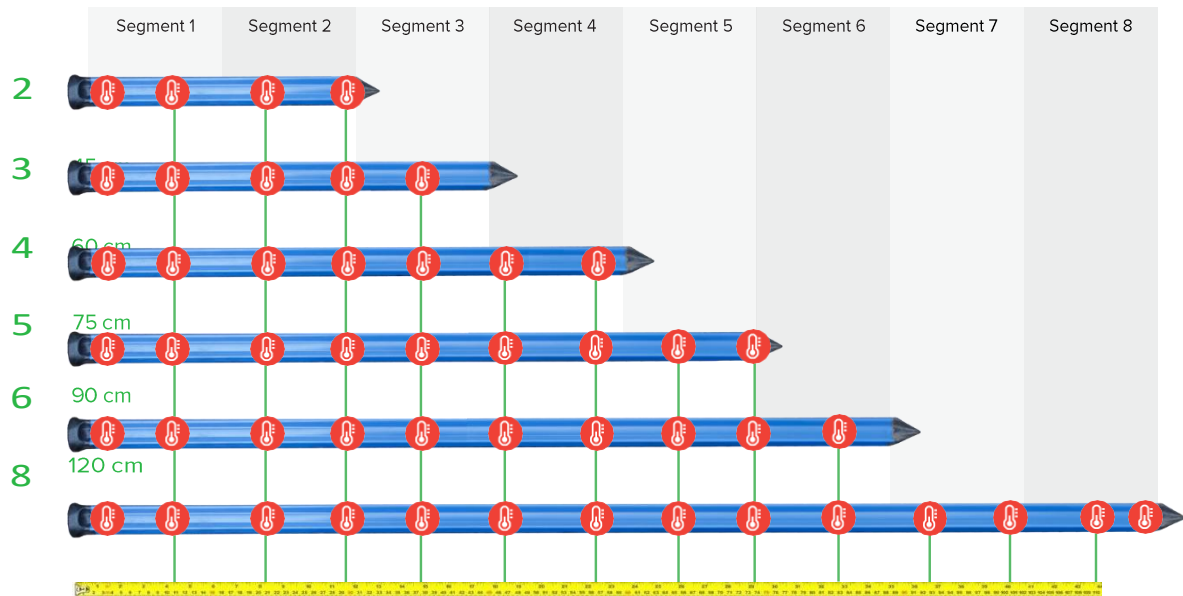
Probe Technology

The drawing below shows the probe dimensions of the 2-8 segment probes, Temperature sensor locations provided in table below:

Sensor	# Temp	Locations (from top)
GPLP-2	4	35, 100, 200, and 300
GPLP-3	6	35, 100, 200, 300, 400, and 450
GPLP-4	7	35, 100, 200, 300, 400, 500, and 600
GPLP-5	9	35, 100, 200, 300, 400, 500, 600, 700, and 750
GPLP-6	11	35, 100, 200, 300, 400, 500, 600, 650, 750, 850, and 900
GPLP-8	14	35, 100, 200, 300, 400, 500, 550, 650, 750, 850, 950, 1000, 1100, and 1200
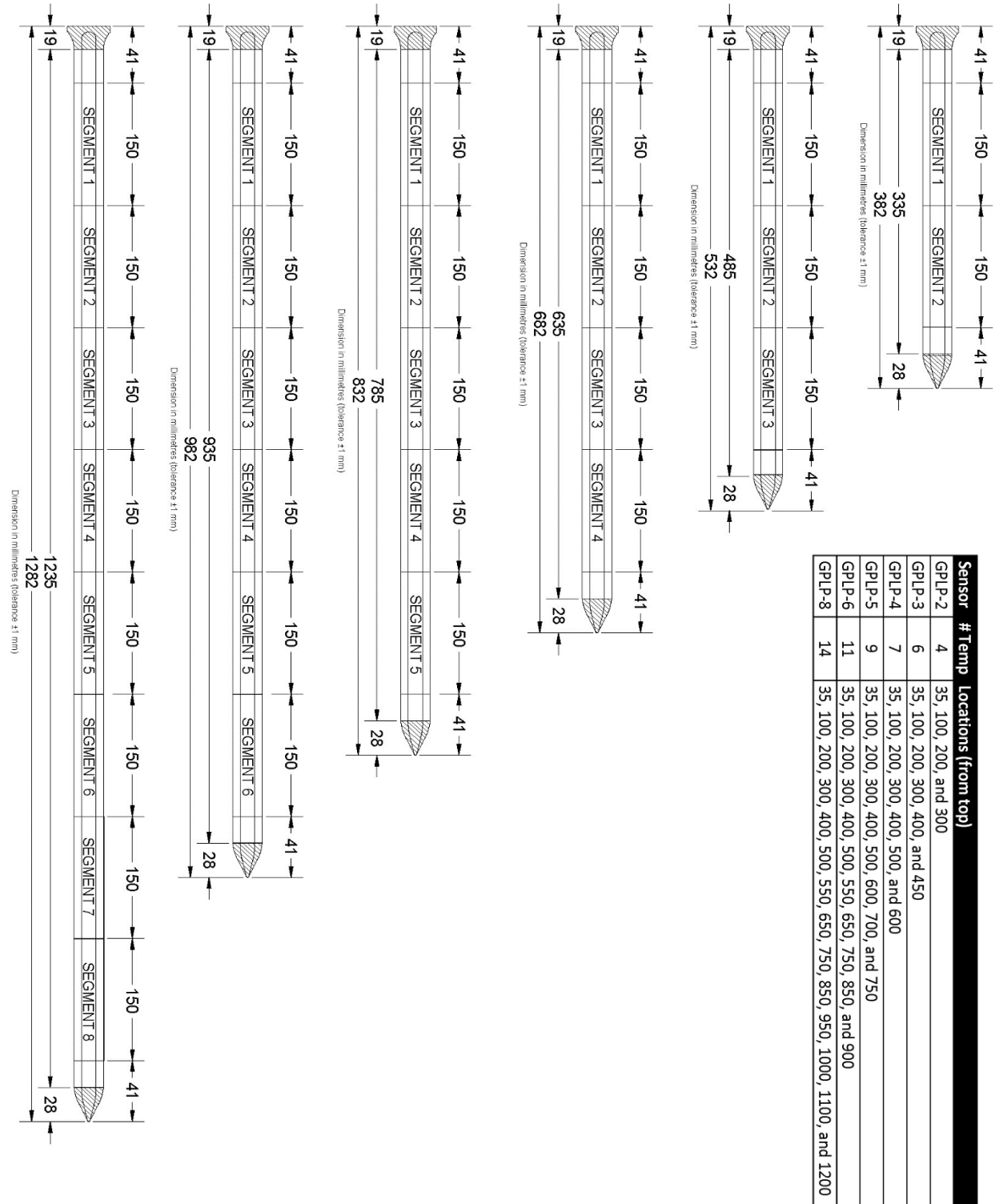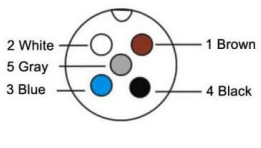
Wiring Connections

Wire Colour	Function
Brown	+ Power (6.5V-18VDC)
White	MODBUS/RS485 D-
Blue	MODBUS/RS485 D+
Black	SDI-12 I/O
Gray	Ground

*Standard cable wire colours. Other cable options available (may have different colours)

Optional M12 5-Pin Male A-Code Connector

Pin #	Colour	Function	Pin Locations
1	Brown	+ Power (6.5V-18VDC)	
2	White	MODBUS/RS485 D-	2 White 5 Gray 3 Blue 1 Brown 4 Black
3	Blue	MODBUS/RS485 D+	
4	Black	SDI-12 I/O	
5	Gray	Ground	

*Available as field installable option, with screw terminal wire termination.

Reading Methods

The GPLP Lite multi-segment soil moisture profiling probes use the SDI-12 Protocol for serial com-munications. 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

GroPoint™ Profile probes may be read with any compatible SDI-12, Modbus or RS485 logger, communications interface, or reader unit. (RIOT offer accessories for reading SDI-12 sensors: the GroPoint™ GP-DU SDI-12 Display Unit (Part# 2628) is a handheld display unit for taking field readings; the GroPoint™ GP-USB Connect - SDI-12 Sensor (Part# 6300) is a USB to Sensor inter-face that connects sensors directly to application software on a USB equipped computer. Gro-Point™ accessories are listed in appendix E of this manual.

Sensor Start Up Time / Measurement Time

Important Things to Note

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 approxi-mately 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.

Basic SDI-12 Command List

How it Works

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 Profiling Probes respond to the following basic SDI-12 commands. In all cases, a = sensor address. Default sensor address is '0'.

Command	Meaning	Response
a?!	Address Query	Device address (default address is '0')
a!	Acknowledge	Device address (default address is '0')
aI!	Send Identification	Identification string
aAb!	Change Address	Change device address to 'b'
aM! aM1!, aM2!	Start Moisture Measurement Start Temp. Measurement	Measure time and count (e.g. "a0023")
aC! aC1!, aC2!	Start Concurrent Measurement	Measure time and count (e.g. "a00023")
aD0!	Send Data	Measurement values

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

Understanding the Basic Commands

Query Address Command: ?!

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 example, for a sensor with address '0' (default address), the command/response sequence is as follows:

```
?!0<CR><LF>
```

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 with matching address, 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.

For example, the response, for a sensor with address '0' (the default address), is as follows:

```
0I!013RIOTTECHGPLPTN027SN300123<CR><LF>
```

This ID string identifies the supported SDI-12 compatibility level as 1.3, sensor vendor as 'RIOT-TECH' (RIOT Technology Corp.), the sensor model as GPLPTN (**GroPoint™** Lite Profiling with soil temperature), the firmware version as '027' (V2.7 firmware), and the sensor's serial number as 300123.

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: aM! or aM1! or aM2!

Use this command to start a sensor measurement. Use **M!** to start the soil moisture measurements. Use **M1!** and **M2! (**6 or 8 segment probes only) to start the temperature measurements. See specification sheet provided with sensor for more details. 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.

For example, sensors with address 0 and 1 respond as follows:

```
0M!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.

Start Concurrent Measurement Command: 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.

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 each segment from top to bottom. Each moisture value has the format '+mm.m' which represents the volumetric moisture content in percent.

For example, a GPLP-4 sensor (4 segments) with address 0 might respond as follows if the measure command used was M!:

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

If the previous Measure command was M1! (or M2! for 6 and 8 segment probes), then the sensor will return temperature readings in response to the D0! command. Refer to [the table] for temperature sensor locations. Temperature units are always in degrees Celsius (°C).

For example, a GPLP-4 sensor with address 0 may respond as follows:

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

aMi! Command Responses for Temperature Sensors:

Sensor	Model	# Temp	Cmd(s)	Response(s)	Sensor Locations (from top)
GPLP-2	GPLPTM	4	M1!	a0024	3.5, 10, 20, 30
GPLP-3	GPLPTN	6	M1!	a0026	3.5, 10, 20, 30, 40, 45
GPLP-4	GPLPTM	7	M1!	a0027	3.5, 10, 20, 30, 40, 50, 60
GPLP-5 (2/3)	GPLPTM	9 (7/2)	M1! M2!	a0027 a0022	3.5, 10, 20, 30, 40, 50, 60 70, 75
GPLP-6 (2/2/2)	GPLPTM	10 (7/3)	M1! M2!	a0027 a0023	3.5, 10, 20, 30, 40, 50, 60 70, 80, 90
GPLP-6 (3/3)	GPLPTN	11 (7/4)	M1! M2!	a0027 a0024	3.5, 10, 20, 30, 40, 50, 55 65, 75, 85, 90
GPLP-8 (2/2/2/2)	GPLPTM	13 (7/6)	M1! M2!	a0027 a0026	3.5, 10, 20, 30, 40, 50, 60 70, 80, 90, 100, 110, 120
GPLP-8 (3/3/2)	GPLPTN	14 (7/7)	M1! M2!	a0027 a0027	3.5, 10, 20, 30, 40, 50, 55 65, 75, 85, 95, 100, 110, 120

All measurement values for a given measurement command are returned on a single aD0! command response.

Extended SDI-12 Command List

Overview
The extended SDI-12 commands are used to adjust the sensor settings and moisture calculation equation. 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.

Special Notes Regarding Profiling Probes of 4 or More Segments
GPLP Lite Profiling probes with more than three segments have special requirements for communicating. Internally, these probes consist of several circuit boards daisy chained together: A four-segment probe has two daisy chained 2-segment boards. A six-segment probe has two daisy chained 3-segment boards. The first board ordinarily handles all normal communications, particularly handling of 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 150 ms must occur after this command before sending any further commands to the daisy chained board.
- All measurement commands automatically turn off power to daisy chained boards to ensure the sensor returns to low power state, so if additional commands are to be sent after a measurement the aXSA! command must be resent to turn power back on.

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

aXn*command*!

where n is the position in the daisy chain. "1" is for the first attached board (segments 3 and 4 in a 4-segment probe), 2 is for the second attached board (usually only with 8-segment probes) etc. The *command* can be any valid SDI- 12 command, including extended commands. Each board in the chain includes its address in the response. 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 "0013RIOTTECHGPLPT 027SN……"

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.

Extended SDI-12 Command List

Command	Meaning	Response
aXSc!	aA ON<CR><LF> for c=A aOFF<CR><LF> for c=0	Enable power to daisy chained board (GPLP-4, 5, 6 or 8)
aXM!	aMode: n<CR><LF>	read the current mode setting
aXMn!	aMode: n<CR><LF>	write the new mode setting to n
aXCn!	aCoeff(n): cccccccc<CR><LF>	read the coefficient n setting
aXCncccccccc!	aCoeff(n): cccccccc<CR><LF>	write the new coefficient n value

Extended Command Descriptions

Sensor Board Power Control: aXSc!

This command is necessary when sending commands to daisy chained boards in probes of 4 or more segments. Replace c with the character '0' or 'A'. Use c = 'A' to turn power on, use c = '0' to turn power off. Note: Power is automatically turned off after any measurement command.

`aXSc!`	`aA ON<CR><LF> or c=A` `aOFF<CR><LF> for c=0`	write the new power setting

Read/Write Operating Mode Setting: aXMn!

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 m' is given by the expression:

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

The coefficient A, B, C and D are viewed and modified using the aXCn! Command (see below). The default settings for these coefficients are 0, 0, 1, and 0 respectively so that m' = m.

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

In probes of 4 or more segments this command must also be issued to the daisy chained board to change its operating mode. For example, for a sensor with address '0' first issue **0XSA!** to enable power to the daisy chained board, then send the command **0X1XMn!** where n is '0' or '1', as desired.

Read/Write Coefficient/Scale Factor Setting: aXCn!

This command is used to read or write the third order calibration coefficients used for calculating the moisture reading. All coefficients are non-volatile, and only need to be set once. Valid values for n are the digits "0" to "9", and the letters "A" to "C". 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.

aXCn!	aCoeff(n): cccccccc<CR><LF>	read the coefficient n setting
aXCncccccccc!	aCoeff(n): cccccccc<CR><LF>	write the new coefficient n value

For example, the number 0 is represented as "00000000", 1.0000000 is represented as "3F800000", etc. RIOT provides on request a calibration program call GP Reader that makes the necessary conversions from decimal values to IEEE-754 32-bit values and simplifies their entry. Also, search "IEEE 754 calculator" for on-line conversion tools 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

Third Order Polynomial Coefficients

The measured moisture values can be 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 aXCi. There is a set of polynomial coefficients for each segment. Refer to the following tables for correlation between 'i' 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 moisture reading of m. The coefficients are entered and expressed as IEEE-754 32-bit hexadecimal values, e.g. 1.0 = 0x3F800000. Refer to the table of commands on the following pages for the appropriate commands for all sensor types.

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 nonlinear. This value should <u>not</u> be changed. Changing the scaling factor will likely require recalibration of the sensor, so it is advised to leave this factor unchanged and instead modify the third order polynomial coefficients (see above).

Coefficient 0 is the scaling factor for segment 1, coefficient 5 is the scaling factor for segment 2, etc.

Command Table: Read / Modify Third Order Polynomial Coefficient
GPLP-3 Coefficient Commands

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	A	aXCA!	aXCAcccccccc!	0.09765625	3DC80000
3	A	B	aXCB!	aXCBcccccccc!	0	00000000
3	B	C	aXCC!	aXCCcccccccc!	0	00000000
3	C	D	aXCD!	aXCDcccccccc!	1	3F800000
3	D	E	aXCE!	aXCEcccccccc!	0	00000000

GPLP-4 Coefficient Commands

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

*Command must be preceded by aXSA! to enable power to second board

GPLP-5 Coefficient Commands

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
5*	scale	A	aX1XCA!	aX1XCAcccccccc!	0.09765625	3DC80000
5*	A	B	aX1XCB!	aX1XCBcccccccc!	0	00000000
5*	B	C	aX1XCC!	aX1XCCcccccccc!	0	00000000
5*	C	D	aX1XCD!	aX1XCDcccccccc!	1	3F800000
5*	D	E	aX1XCE!	aX1XCEcccccccc!	0	00000000

*Command must be preceded by aXSA! to enable power to second board

GPLP-6 Coefficient Commands

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!	aXC6ccccccccc!	0	00000000
2	B	7	aXC7!	aXC7ccccccccc!	0	00000000
2	C	8	aXC8!	aXC8ccccccccc!	1	3F800000
2	D	9	aXC9!	aXC9ccccccccc!	0	00000000
3	scale	A	aXCA!	aXCAccccccccc!	0.09765625	3DC80000
3	A	B	aXCB!	aXCBccccccccc!	0	00000000
3	B	C	aXCC!	aXCCccccccccc!	0	00000000
3	C	D	aXCD!	aXCDccccccccc!	1	3F800000
3	D	E	aXCE!	aXCEccccccccc!	0	00000000
4*	scale	0	aX1XC0!	aX1XC0ccccccccc!	0.09765625	3DC80000
4*	A	1	aX1XC1!	aX1XC1ccccccccc!	0	00000000
4*	B	2	aX1XC2!	aX1XC2ccccccccc!	0	00000000
4*	C	3	aX1XC3!	aX1XC3ccccccccc!	1	3F800000
4*	D	4	aX1XC4!	aX1XC4ccccccccc!	0	00000000
5*	scale	5	aX1XC5!	aX1XC5ccccccccc!	0.09765625	3DC80000
5*	A	6	aX1XC6!	aX1XC6ccccccccc!	0	00000000
5*	B	7	aX1XC7!	aX1XC7ccccccccc!	0	00000000
5*	C	8	aX1XC8!	aX1XC8ccccccccc!	1	3F800000
5*	D	9	aX1XC9!	aX1XC9ccccccccc!	0	00000000
6*	scale	A	aX1XCA!	aX1XCAccccccccc!	0.09765625	3DC80000
6*	A	B	aX1XCB!	aX1XCBccccccccc!	0	00000000
6*	B	C	aX1XCC!	aX1XCCccccccccc!	0	00000000
6*	C	D	aX1XCD!	aX1XCDccccccccc!	1	3F800000
6*	D	E	aX1XCE!	aX1XCEccccccccc!	0	00000000

*Command must be preceded by aXSA! to enable power to second board

Additional Product Information

Specifications

Moisture Measurement	0% to 100% volumetric water content
Temperature	-20°C to +70°C, accuracy ±0.5°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

Appendix A: Probe Installation / Extraction

Summary

The correct installation procedure requires the use of the Slide Hammer Insertion tool kit. Never attempt to drive or hammer a GPLP probe into the ground without a pilot hole; this will damage the probe. The slide hammer Insertion toolkit is used to form a pilot hole using the steel pilot rod 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. Please review this installation video to see a recorded installation example. *Press Ctrl and click simultaneously to see link directly to the online training video.*

Videos — GroPoint Soil Moisture Sensing

⚠ **Caution – Wear Your Protective Equipment** ⚠

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 always recommended when using the slide hammer. Care must also be taken to avoid getting fingers caught in slide mechanism.

⚠ **Caution – Wear Your 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 the 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.

⚠ **Caution – Use the correct tools!** ⚠

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.

Sensor Installation Guidelines

Before installing the sensor, follow these guidelines.

• Install the probe when the soil is dry to minimize the air gaps that can form around the probe as the soil dries out. Also avoid excessively rocky soil whenever possible as cavities may form when rocks are pushed out of the way when creating the pilot hole.

• The sensor probe is typically installed vertically, these instructions and guidelines apply for a vertical installation. Hold the slide hammer and pilot rod perfectly vertical to avoid making the hole larger than the size of the sensor.

• Always maintain control of the slide hammer with a firm grip to avoid wobbling or moving the hammer side-to-side. This is especially important while the first half of the pilot rod is being hammered in place.

• 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 the connection may place excessive force on the threads and damage them. (have 2 adjustable wrenches available, one to hold the pilot rod, a second to tighten the slide hammer shaft onto the pilot rod)

• Drive 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.

• When extracting the pilot rod, make sure it remains vertical to ensure the hole does not become enlarged, which may result in air gaps forming between the probe and soil and potentially incorrect soil moisture readings.

• Once the pilot rod is removed, insert the probe as soon as possible. Any delay may allow moisture to swell the sides of the hole or water to enter the hole.

• If the pilot hole is larger at the top than the bottom due to side-to-side movement of the slide hammer during installation, it may take a few days to a week for the soil to settle back and seal against the probe. You can also create a soil slurry at the surface to fill the hole. See Maintenance for more details on using a slurry.

• To reduce air gaps from forming over time as soil expands and contracts, limit the variation of moisture content of the soil if possible, such as by periodic irrigation.

• Use conduit to protect the cable against damage from animals, lawn mowers, exposure to chemicals, etc.

## Slide Hammer and Pilot Rod Installation Method

1. For assembled pilot rods, skip to step 2. For disassembled pilot rods, select the appropriate number of middle rod segments based on the length of your probe.Assemble the pilot rod by screwing one segment into the other, connecting each rod segment together to form the body of the pilot rod, making sure all edges are aligned. Screw in the pilot rod tip to one end of the pilot rod body and the top cap to the other end.

2. Lay the pilot rod down next to the sensor probe, with both tips aligned. Wrap a piece of tape around the pilot rod at the depth the rod should be driven into the soil (which should line up with the top of the sensor).

3. Screw the pilot rod into the slide hammer as shown. Use two adjustable wrenches to make sure the threads are tight. A loose connection can damage the threads as you are hammering.

4. At the location where you want to install the probe, use a repetitive up-then-down motion on the slide hammer to vertically drive the pilot rod into the soil. Be sure to hold the slide hammer vertically without side-to-side movement. Drive the pilot rod in until it reaches the tape marking made in step 2.
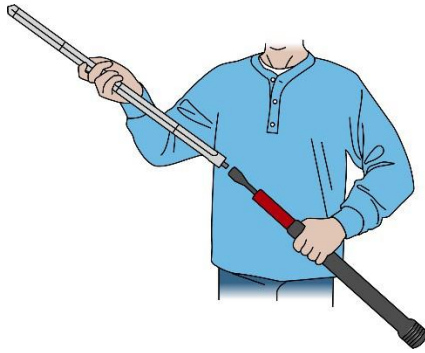
*Left: Illustration of Step 3, **Right:** Illustration of Step 4*

5. Once the pilot rod reaches the desired depth, extract the pilot rod by using the slide hammer in reverse, lifting it rapidly to hammer upwards. Be sure to hold the slide hammer vertically without side-to-side movement to extract the pilot rod straight up.

6. Once the pilot rod is extracted, clear away any loose soil at the top edges of the hole so that it doesn't fall into the hole.

7. Insert the sensor probe into the hole, pressing it in as far as possible by hand. Pour a bit of water around the probe at the top of the hole if the soil is very tightly packed to help it slide more smoothly into the hole. You can use a dead blow hammer to very gently tap the top of the sensor if you are having trouble pushing in the sensor by hand.

8. Once the probe is fully inserted in the hole, pack the soil around the top of the sensor to prevent water from entering the hole. The sensor should be completely covered with soil and only the sensor cable visible.
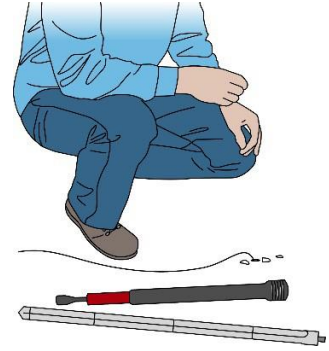
Auger Installation Method

1. Drill a vertical hole with a 3 inch auger.
2. Insert the sensor into the hole, making sure the entire sensor body is in the hole.
3. Make a slurry of the soil from the hole and pour it down slowly so that it settles evenly around the sensor. Stop pouring every few inches and give it time for the water to drain from the soil and the soil to settle. Allow more time for soils that retain water, such as clay soils.
4. Make sure the sensor is completely covered with soil and only the sensor cable visible.

Excavation Installation Method

1. Dig a hole deep enough for the sensor probe and save the soil.
2. Place the sensor probe vertically in the hole.
3. While supporting the sensor at the top and bottom so that it does not move, backfill the hole with the soil that was removed from the hole, using the same soil at each depth as best as possible. Be sure to keep the sensor vertical while backfilling the hole.
4. Pack the soil around and into the sensor so that there is good soil contact on all sensor surfaces. The accuracy depends on not having any air gaps around the sensor.
5. Pack the soil to the same density as it was before excavation. The sensor should be completely covered with soil and only the sensor cable visible.
6. Water the soil thoroughly after installation to help ensure that the soil has filled in around the sensor

Removing the Sensor from the Soil

To remove a sensor probe from the soil:

1. Carefully dig out the soil around the top of the probe with a hand shovel, being sure not to damage the probe or cable. Dig out the hole until at least 30 cm (11.8 inches) of the probe is exposed.
2. Grasp the probe firmly with two hands as you pull it upwards. Do not grab onto the black probe head as it is not secured with enough strength for probe extraction. Do not pull the probe up by the sensor cable.
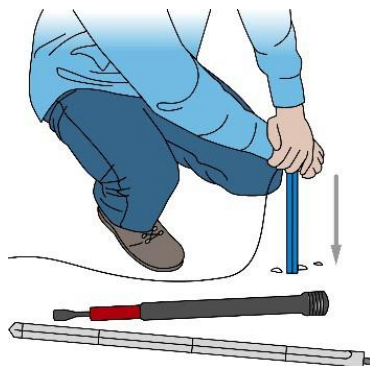
Appendix B: Soil Specific Calibration Process

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 generally 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 the 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%, should have a sufficient amount to fill the soil box:

Basic Equipment

- A soil container / box
- **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 the amount of soil to add
- **Plastic Scraper / Wooden Tongue Depressors:** useful to scrape soil off gloves, probes, etc

Note: Required 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.

Additional Equipment

The following is required for manual determination of soil moisture content:

- **Digital scale:** with a minimum resolution to 0.1 g
- **Ceramic microwavable bowl**
- **Microwave oven**

Safety Equipment

Keep Safe and Protect Your Lungs!

The following safety equipment is required:

- **Strong rubber gloves:** always wear gloves when handling soil
- **Face mask:** dry soil is very dusty; avoid inhaling 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 litre 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

Installing the Probe

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. You 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.

Taking Measurements

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

Amount of Water to Add

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 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: 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.

Waiting Period

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.

Next Steps

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

Required Software

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.

Calculating Measurements

Enter each moisture level's measurements into spreadsheet in a format like 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.

$$y = -0.0214x^2 + 1.7919x - 1.8242$$

$$R^2 = 0.9844$$
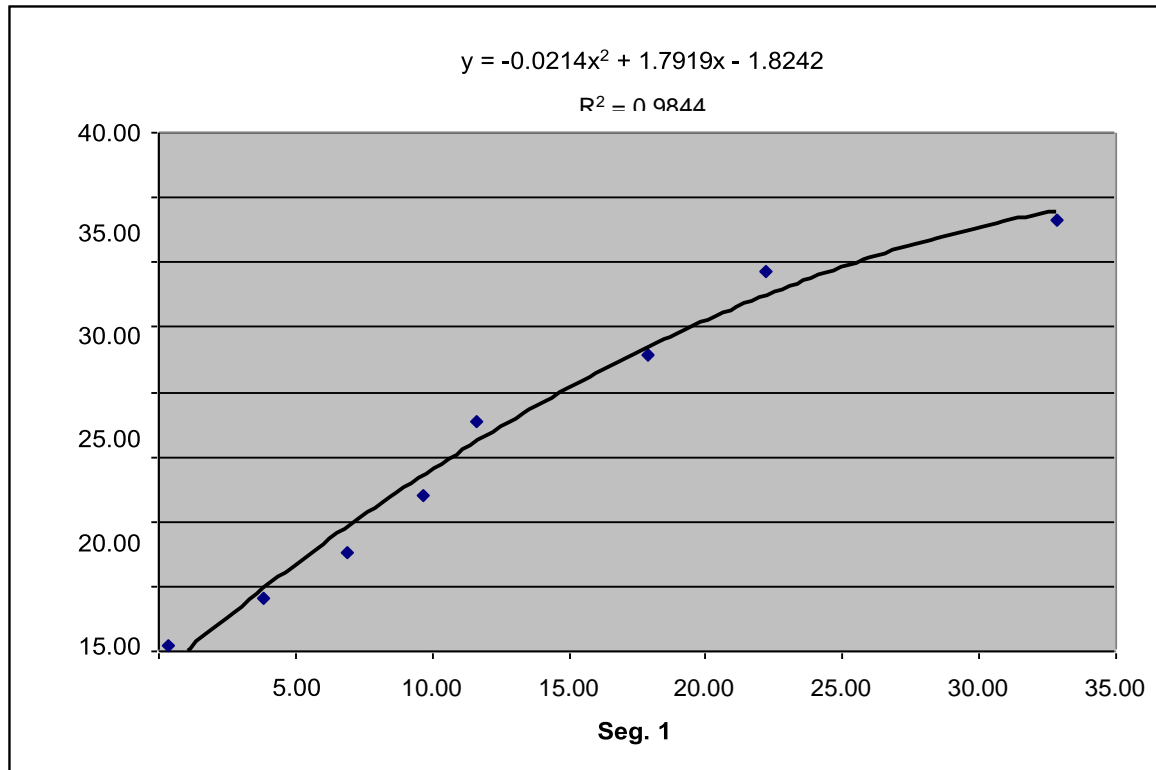
Select each chart, then select the **Chart|Add Trendline...** menu option. The type of trend line should be "polynomial", select either 2 or 3 for the order of the polynomial*, and for trend line options choose **"Display equation on chart"** and **"Display R-squared value on chart"**.

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 R2 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).

Note (what 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 aXCi! where a=sensor address (default address is 0) and i is the coefficient to modify. Please refer to the extended commands section for more details. (A USB to SD-12 interface product (part 6300) is available that simplifies the

task of viewing and changing the probe's coefficient. Contact RioT Technology for more information).

General Observations to Note

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

Appendix C: Determining Volumetric Moisture Content (Weight Method – In Laboratory)

Procedure Overview

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 calculate 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)

Sampling Ring calculation

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 cm3 or 33.5 ml:

Volume of a cylinder = π * radius2 * length = π * (diameter/2)2 * length

V = π * (3.35 cm/2)2 * 3.80 cm

V = 33.494 cm3 = 33.5 cm3 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:

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

2. 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).
3. Use the trowel to dig a small hole:

4. 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).

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

6. 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.
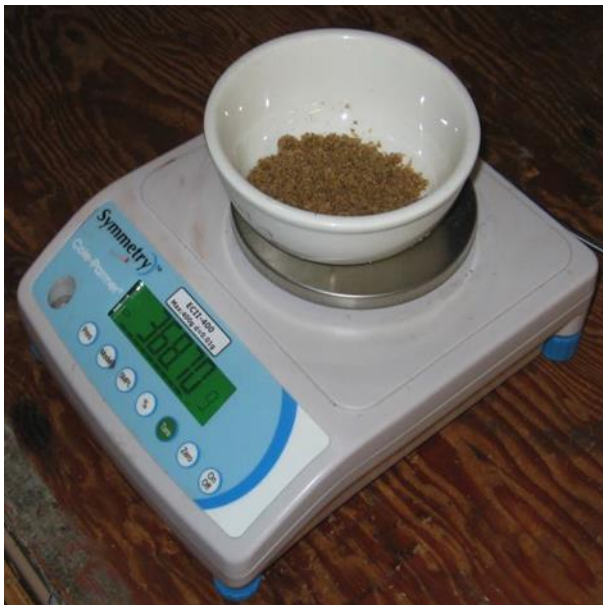

7. Empty the contents of the sampling ring into the ceramic bowl.

8. Weigh the soil sample and cup together on the scale to the nearest tenth of a gram (0.1 g). Record the weight.

9. 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.

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

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 %

Important Notes

- 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.

Appendix D: Modbus Programming Manual

The GroPoint Lite Profiling Probe (GPLP) Modbus version uses standard Modbus RTU protocol (RS-485). The probe can only operate as a slave device. Sensor factory default address is 01. The sensor address can be changed via holding register 40201 (see below). Default communication settings are 19200 Baud, 8 Bits, Even Parity, one Stop Bit. Other communication parameters may be selected by writing to the appropriate holding registers. See GPLP Modbus Register Lists on the following pages for a complete list of the available Modbus registers.

- NOTE: For more information about Modbus RTU protocol, please visit www.modbus.org.

Modbus Command Functions
Supported Function Codes/Commands
The GPLP Modbus probe supports the following subset of Modbus commands:

Function Code	Name	Notes	Broad-cast
03 (0x03)	Read Holding Registers	Maximum of 9 in one read	No
04 (0x04)	Read Input Registers	Moisture Values, Temperature Sensor Values. Maximum of 9 in one read.	No
06 (0x06)	Write Single Register	Single registers only	No
08 (0x08)	Diagnostic	Supported subfunctions [TBD]: 0 - return query data 1 - restart communications 4 – force listen only mode	No
11 (0x0B)	Fetch Comm Event Counter		No
17 (0x11)	Report Slave ID	Returns the ASCII encoded string 'RIOTTECHGPLPTC vvvSNnnnnnn' where vvv is the firmware version (v.v.v) and nnnnnn is the probe serial number.	No

Unsupported Function Codes/Commands
All remaining public command function codes listed below will return an exception response with an exception code value of 01 indicating that the command function is not supported:

01 – Read Coils (0x01)
02 – Read Discrete Inputs (0x02)
05 – Write Single Coils (0x05)
07 – Exception Status (0x07)
12 – Get Comm Event Log (0x0C)
20 – Read File Record (0x14)

21 – Write File Record (0x15)
22 – Write Mask Register (0x16)
23 – Read/Write Multiple Registers (0x17)
24 – Read FIFO Queue (0x18)
43 – Encapsulated Interface Transport (02B)

Exception Responses

Illegal commands and register data addresses, etc. will result in an exception response. The reply has the top bit of the Function Code set and contains a one-byte exception code. For example, a read coil command (not supported on GPLP probes) to slave 0x01 will generate this response:

01 81 01 CRC$_L$ CRC$_H$

which is interpreted as:

01 Slave Address

81 Function Code - Exception on command function 0x01

01 Exception Code (Illegal Function)

CRC$_L$ CRC$_H$ – CRC bytes

Exception codes are:

01 Illegal Function – the command function is not supported.

02 Illegal Data Address – the register address does not exist.

03 Illegal Data Value – attempt to set an illegal data value, for example illegal Modbus sensor address.

05 Acknowledged – command function received; sensor will now be busy processing the command.

06 Slave Busy – response when sensor is busy, e.g. during measurement process.

Response Time-Out

Most command functions will respond immediately (after approximately 4-character times), however the write register functions may take longer, approximately 100 ms. The Master must wait for this time for the response and before sending new commands. See also the Measurement Sequence section below for a description of the measurement processing time during soil moisture and soil temperature measurements.

Data Values

16-bit Data Values

All 16-bit registers are represented in big-endian format, that is the higher byte followed by the lower byte. For example, the 16-bit value 0x1234 would be stored as 0x12 followed by 0x34. When transferred at the byte level this would be sent as: 0x12, 0x34.

Register	16-bit register data	
address n	Bits 15 to 8	Bits 7 to 0
ex. value	0x12	0x34

Moisture and temperature readings from input registers are stored as 16-bit signed integers and will be returned without a decimal place. In order to obtain the true result, the decimal place setting must be applied. The default setting for this is 1 decimal place, so for example a decimal integer value of 123 indicates 12.3 % volumetric moisture content for soil moisture, or 12.3 °C for the soil temperature sensor.

8-bit Data Values

8-bit data values are stored in the lower 8 bits of the 16-bit registers. When reading 8-bit values the upper byte will always be 0. When writing 8-bit values the upper byte should be set to 0 but is ignored in any event. Byte order when reading and writing 8-bit values to and from the 16-bit registers is the same as for 16-bit values, that is the high byte (value of 0) first followed by the low byte.

Register	16-bit register data	
address n	Bits 15 to 8	Bits 7 to 0
ex. value	0	8-bit value

IEEE-754 32-bit Floating Point Values

Floating point values are represented using IEEE-754 format. Each floating-point value requires 32 bits, that is two 16-bit registers; a high 16-bit word and a low 16-bit word. The 32-bit value is stored in little-endian byte swap format, that is with the low word first, followed by the high word. For example, the floating-point value 0.09765625 is represented by the 32-bit value 0x3DC80000. [needs correcting] This is stored as would be stored as 0x1234 followed by 0x5678. When transferred at the byte level this would be sent as: 0x12, 0x34, 0x56, 0x78

Register	32-bit register data	
address n	Bits 32 to 24	Bits 23 to 16
address n+1	Bits 15 to 8	Bits 7 to 0

GPLP Modbus Register Lists

Input Registers (Read with Function Code 04)

The input registers are read-only registers containing soil moisture or temperature measurement values. Moisture and temperature readings are stored as 16-bit signed integers and will be returned without a decimal place. In order to obtain the true result, the decimal place setting must be applied. The default setting for this is 1 decimal place, so for example a decimal value of 123 indicates 12.3 % volumetric moisture content for volumetric soil moisture measurements, or 12.3 °C for the soil temperature sensor measurements.

The GPLP probe supports the following input registers:

Register	Description	Available in Sensor Models:
30001	Segment 1 Moisture reading	GPLP-2, GPLP-3, GPLP-4, GPLP-5, GPLP-6, GPLP-8
30002	Segment 2 Moisture reading	GPLP-2, GPLP-3, GPLP-4, GPLP-5, GPLP-6, GPLP-8
30003	Segment 3 Moisture reading	GPLP-4, GPLP-5, GPLP-6, GPLP-8
30004	Segment 4 Moisture reading	GPLP-4, GPLP-5, GPLP-6, GPLP-8
30005	Segment 5 Moisture reading	GPLP-5, GPLP-6, GPLP-8
30006	Segment 6 Moisture reading	GPLP-6, GPLP-8
30007	Segment 7 Moisture reading	GPLP-8

30008	Segment 8 Moisture reading	GPLP-8
30009 to 30100	undefined (reserved for future use)	
30101	Temperature Sensor #1	GPLP-2, GPLP-3, GPLP-4, GPLP-5, GPLP-6, GPLP-8
30102	Temperature Sensor #2	GPLP-2, GPLP-3, GPLP-4, GPLP-5, GPLP-6, GPLP-8
30103	Temperature Sensor #3	GPLP-2, GPLP-3, GPLP-4, GPLP-5, GPLP-6, GPLP-8
30104	Temperature Sensor #4	GPLP-2, GPLP-3, GPLP-4, GPLP-5, GPLP-6, GPLP-8
30105	Temperature Sensor #5	GPLP-3, GPLP-4, GPLP-5, GPLP-6, GPLP-8
30106	Temperature Sensor #6	GPLP-3, GPLP-4, GPLP-5, GPLP-6, GPLP-8
30107	Temperature Sensor #7	GPLP-4, GPLP-5, GPLP-6, GPLP-8
30108	Temperature Sensor #8	GPLP-5, GPLP-6, GPLP-8
30109	Temperature Sensor #9	GPLP-5, GPLP-6, GPLP-8
30110	Temperature Sensor #10	GPLP-6, GPLP-8
30111	Temperature Sensor #11	GPLP-6, GPLP-8
30112	Temperature Sensor #12	GPLP-8
30113	Temperature Sensor #13	GPLP-8
30114 to 30200	undefined (reserved for future use)	

All other registers values are undefined. Attempting to read from undefined registers will cause an exception response with an exception code value of 02 indicating illegal data address.

Measurement Sequence

Reading multiple input registers is supported, but only one type (moisture or temperature) can be read at a time. Reading multiple registers should also only request the number of soil moisture or temperature sensor measurements that are supported by the probe. Attempting to read more values than are supported will return an exception code value of 02 indicating illegal data address.

A new measurement is triggered by a read request to the input registers (either read single or read multiple). The first read command will initiate the start of a measurement (soil moisture or soil temperature) and will respond to the master with an ACKNOWLEDGE (05) exception response. Moisture measurements take approximately 200 ms per segment. Temperature measurements take approximately 200 ms per sensor. The master should wait for this amount of time to expire before attempting to retrieve the measurement values with another read command. This command will return the measured values. It does **not** trigger another measurement until another read input command is received.

Attempts to read the registers before the measurement time has elapsed will be ignored; there will be no response, the sensor will only respond once the measurements are completed.

Holding Registers (Read: Function Code 03, Write: Function Code 06)

These are registers that can be read and written. These registers contain scaling and polynomial coefficients, as well as operational settings (communication settings, sensor address, etc.) Read

response timeout is typically immediate. Write response timeout is delayed by the non-volatile write time of the registers and is approximately 50 ms maximum per register written [to be verified].

When reading and writing to these registers the offset address used is one less than the lower portion of the register address, for example register 40001 is at 16 bit offset 0, register 40002 is at 16-bit offset 1.

The GPLP probes support holding registers 40001-40204. Note: some registers are only appropriate for probes with those segments. For example, GPLP-3 does not support registers associated with segment 4 and up.

Register	Description	Default Value
40001-40002	Segment 1 scale factor (32-bit IEEE float)*	0.09765625*
40003-40004	Segment 1 third order polynomial A (32-bit IEEE float)	0
40005-40006	Segment 1 third order polynomial B (32-bit IEEE float)	0
40007-40008	Segment 1 third order polynomial C (32-bit IEEE float)	1
40009-40010	Segment 1 third order polynomial D (32-bit IEEE float)	0
40011-40012	Segment 2 scale factor (32-bit IEEE float)*	0.09765625*
40013-40014	Segment 2 third order polynomial A (32-bit IEEE float)	0
40015-40016	Segment 2 third order polynomial B (32-bit IEEE float)	0
40017-40018	Segment 2 third order polynomial C (32-bit IEEE float)	1
40019-40020	Segment 2 third order polynomial D (32-bit IEEE float)	0
40021-40022	Segment 3 scale factor (32-bit IEEE float)*	0.09765625*
40023-40024	Segment 3 third order polynomial A (32-bit IEEE float)	0
40025-40026	Segment 3 third order polynomial B (32-bit IEEE float)	0
40027-40028	Segment 3 third order polynomial C (32-bit IEEE float)	1
40029-40030	Segment 3 third order polynomial D (32-bit IEEE float)	0
40031-40032	Segment 4 scale factor (32-bit IEEE float)*	0.09765625*
40033-40034	Segment 4 third order polynomial A (32-bit IEEE float)	0
40035-40036	Segment 4 third order polynomial B (32-bit IEEE float)	0
40037-40038	Segment 4 third order polynomial C (32-bit IEEE float)	1
40039-40040	Segment 4 third order polynomial D (32-bit IEEE float)	0
40041-40042	Segment 5 scale factor (32-bit IEEE float)*	0.09765625*
40043-40044	Segment 5third order polynomial A (32-bit IEEE float)	0
40045-40046	Segment 5 third order polynomial B (32-bit IEEE float)	0
40047-40048	Segment 5 third order polynomial C (32-bit IEEE float)	1
40049-40050	Segment 5third order polynomial D (32-bit IEEE float)	0
40051-40052	Segment 6 scale factor (32-bit IEEE float)*	0.09765625*
40053-40054	Segment 6third order polynomial A (32-bit IEEE float)	0
40055-40056	Segment 6 third order polynomial B (32-bit IEEE float)	0
40057-40058	Segment 6 third order polynomial C (32-bit IEEE float)	1
40059-40060	Segment 6 third order polynomial D (32-bit IEEE float)	0
40066-40062	Segment 7 scale factor (32-bit IEEE float)*	0.09765625*
40063-40064	Segment 7 third order polynomial A (32-bit IEEE float)	0
40065-40066	Segment 7 third order polynomial B (32-bit IEEE float)	0
40067-40068	Segment 7 third order polynomial C (32-bit IEEE float)	1
40069-40070	Segment 7 third order polynomial D (32-bit IEEE float)	0
40071-40072	Segment 8 scale factor (32-bit IEEE float)*	0.09765625*
40073-40074	Segment 8 third order polynomial A (32-bit IEEE float)	0
40075-40076	Segment 8 third order polynomial B (32-bit IEEE float)	0
40077-40078	Segment 8 third order polynomial C (32-bit IEEE float)	1
40079-40080	Segment 8 third order polynomial D (32-bit IEEE float)	0

40081 to 40199	reserved [future expansion for additional segments]	
40201	Sensor Modbus Address	1
40202	Sensor Calculation Mode: 0=raw value; 1=apply polynomial	1
40203	Serial Baud rate (19K200/9600/4800/2400/1200/600/300)	0 = 19200 baud
40204	Parity setting (0=none, 1=odd, 2=even)	2 = even parity

*Factory setting – do not adjust

All other registers values are undefined. Attempting to read from undefined registers will cause an exception response with an exception code value of 02 indicating illegal data address.

Detailed Description of Holding Registers

Third Order Polynomial Coefficients and Scaling Factors (registers 40001 to 40080, offset 0 to 79)

The measured moisture values can be 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 sensor calculation mode parameter to integer value 1 (register 40202, see below).

The polynomial equation is shown below:

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

Coefficients are adjusted by writing new values to holding registers 40001 to 40080. There is a set of polynomial coefficients for each segment. Refer to the holding register table for correlation between register address/offset and the associated coefficient. Default settings for the A to D coefficients are 0, 0, 1, 0 respectively, which is equivalent to the original moisture reading of m. The coefficients are entered and expressed as IEEE-754 32-bit hexadecimal values, e.g. 1.0 = 0x3F800000.

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 nonlinear. This value should **not** be changed. Changing the scaling factor will likely require recalibration of the sensor, so it is advised to leave this factor unchanged and instead modify the third order polynomial coefficients (see above).

Register 40001 is the scaling factor for segment 1, register 40005 is the scaling factor for segment 2, etc.

Sensor Modbus Address (register 40201, decimal offset 200 (hexadecimal 0x00C8))

This register sets the Modbus address of the probe. It has a factory default value of 1. Use the Write Single Register command to change this value to any valid slave address (1-247). The address change will take effect immediately, so any subsequent commands must use the new address. This register cannot be updated using the broadcast address.

Sensor Calculation Mode (register 40202, decimal offset 201 (hexadecimal 0x00C0))

This register set to 1 means to apply the third order polynomial to the measured moisture values. When set to 0 this means return the "raw" moisture values. Default third order coefficients are 0, 0, 1, and 0 so by default the sensor returns the "raw" moisture value.

Serial Baud Rate (register 40203, decimal offset 202 (hexadecimal 0x0CA))

This register sets the serial communication data rate. It has a factory default value of 0, corresponding to a baud rate of 19200. Use the Write Single Register command to change this value to any of the following valid values: 0=19200, 1=9600, 2=4800, 3=2400, 4=1200, 5=600, 6=300. The new baud rate does not take effect until the sensor is power cycled, or if the restart communications diagnostic command (08, with subfunction 01) is received.

Serial Parity Setting (register 40204, decimal offset 0203 (hexadecimal 0x00CB))

This register sets the serial parity setting. It has a factory default value of 2 corresponding to Even parity. Use the Write Single Register command to change this value to any of the following valid values: 0=None, 1=Odd, 2=Even. The new parity setting does not take effect until the sensor is power cycled, or if the restart communications diagnostic command (08, with subfunction 01) is received.
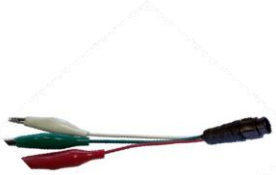
Coil Registers
The GPLP Modbus probe does not utilize coil registers or coil read/write command functions. Using any coil read/write command functions will return an exception response with an exception code of 01 (function code not supported).

Discrete Inputs
The GPLP Modbus probe does not utilize discrete inputs or support the discrete input read command. Using the read discrete input command will return an exception response with exception code of 01 (function code not supported).

Appendix E: Accessories

4-Port Expansion Bar with M12 Cable **PART 2998 & PART 2999**	M12 MALE TO FEMALE CABLE PART 2999	Additional GroPoint Sensor Cable Part CE (Cable Extension)
2-PORT EXPANSION BAR PART 2998-2	Male or Female M12 Connector Part: Male = 3053, Female = 3070	SDI-12 Alligator Clip Adaptor Part 3080 M12
Slide Hammer for GroPoint Profile Part SH	Pilot Rod Part PR-x (30,45,60,90,120cm)	PC (usb) to SDI-12 Sensor Interface with software Part 6300
Handheld Display Unit Instantaneous Readings Part 2628	GP-DLBT Bluetooth SDI-12 Datalogger Part 2992	5.8Ah C-Cell 3.6V High Capacity Battery Part 6300

Click here for full description of GroPoint Accessories

About GroPoint™

GroPoint™ products are manufactured in Canada by RioT Technology Corp. (RioT). RioT acquired the GroPoint™ brand, patents, employees, and sensor and datalogger technologies from E.S.I. Environmental Sensors. RioT is the owner of 4 patents related to antenna design using TDT technology for soil moisture measurement. GroPoint™ is the brand associated with RioT soil moisture and temperature monitoring solutions and technology.

We have the historical expertise for all GroPoint™ products in-house and available to assist former clients of E.S.I. Environmental Sensors ,and new clients interested in leveraging over 25 years of soil monitoring expertise across the science, agricultural, smart agriculture, irrigation, hydrological and industrial sectors. GroPoint™ customer deployments span 20 countries.

Additional product lines designed and manufactured by RioT focus on low power wireless wide area radios (LPWAN) and sensor networks. More information about RioT can be found at www.riotwireless.com.

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