OTTO
SOIL MOISTURE PROBE

Version 1.80
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1 Otto Soil Moisture Probe

This manual is written for the Otto family of Above Ground and Sub Surface soil moisture probes.

The probes are designed to be flexible and easy to use. They are available in lengths from 30cm to 150cm (longer probes are available as custom orders). The probe electronics comprise of a top board and a number of sensor boards. The sensor boards are 10cm in length. Because not all applications require sensors every 10cm, spacer boards can be fitted between the sensors. The spacer bards are available in lengths 10, 20 and 30 40cm.

The above ground version of the probe is fitted with a 5cm diameter probe head with a removable cap. A breather vent is fitted to the cap to prevent moisture build up inside the probe column.

The below ground is sealed and potted – it needs no maintenance and, once built, the configuration cannot be changed.

The sensors on the probes include compensation for temperature induced change in the dielectric properties of the soil: removing the unwanted diurnal variation that otherwise exists on capacitance probe data.

Unlike traditional “variable frequency” capacitance probes, the Otto sensors operate on a fixed frequency. The wide frequency spread (40 to 70 MHz) of simple capacitance sensors causes the shape and behavior of the produced electric field to vary. The fixed frequency design of the Otto avoids this issue, reducing the variability in performance between wet and dry soil and between soil types.

All probe configuration tasks are performed using extended SDI-12 commands, alleviating the need for additional programming software or hardware.

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2 Introduction

An Otto Soil Moisture Probe will be made up with a number of key items:

- ➢ An SDI-12 concentrator board (TBS11) in either above ground or sub-surface version
  - Note that it is possible to supply a 3 or 4 sensor “naked” version without the SDI-12 Concentrator and where each sensor occupies a separate SDI-12 address
- ➢ As few as 3 or as many as 15 soil moisture sensors
- ➢ None or a number of 10, 20 or 30cm spacer boards
- ➢ A set of probe plastics (head, probe tube and bottom seal) in either above ground or sub-surface format
  - The above ground probe head is re-enterable, that is, the cap may be removed to check and maintain the probe or to change its configuration
  - The below ground head version is not re-enterable: after the probe has been built, it cannot be opened again.

2.1 Above Ground Probes

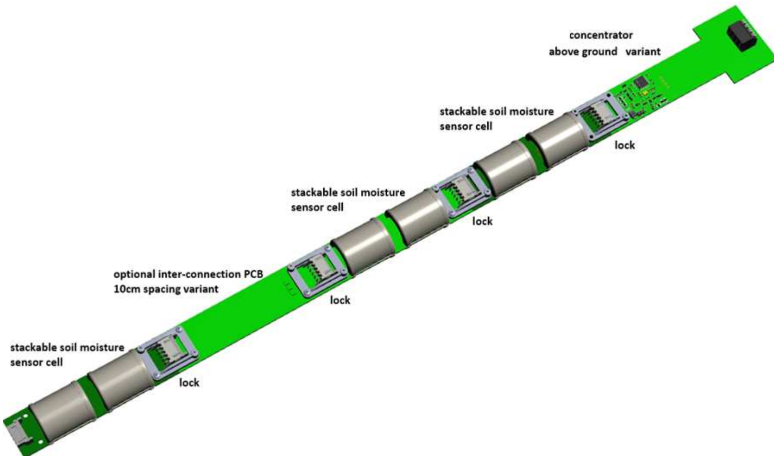
The Probe Plastics for the above ground versions con following parts:

- ➢ A probe head with removable cap
  - The probe cable exits through a cable gland f head
  - The cap can be unscrewed to gain access to components
  - The cap is fitted with a breather vent to preve building up inside the probe tube
  - The probe cable is routed into the head via a (terminates on the PCB using cage clamps
- ➢ A probe tube
  - The probe has an outer diameter of 32mm an of 27 mm
  - The sensors are installed inside the tube and an electric field generated by each sensor passes through the tube into the soil
  - The tube will nominally 5cm longer than the probe length
- ➢ A bottom stopper
  - This is normally glued on to the probe tube during assembly

- However if you are installing on a site where there is a risk of hitting an impeding layer (i.e. limestone rock) you can specify that the stopper is to be supplied loose
- This allows you to drill the installation hole to the maximum length, then to cut off the probe tube to length and glue the bottom stopper on while in the field.

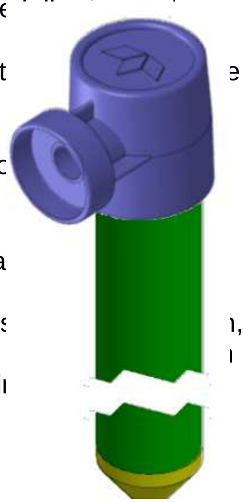
The SDI-12 Concentrator Board connects to a column made up of 10cm long sensor elements, which may be mounted end to end or separated by 10cm, 20cm or 30cm spacer boards. This allows you to choose a sensor density appropriate for the application: where fine analysis of soil moisture levels is critical, 10cm sensor resolution is a must; but if you are looking for changes over a deep profile, you can skip depths by adding spacer boards. A site looking at moisture profiles for environmental purposes for instance, may only require sensors every 50cm.

The sensors and spacer boards are fixed together using a pair of lock plates and 4 small screws.



2.2 Sub-Surface Probes

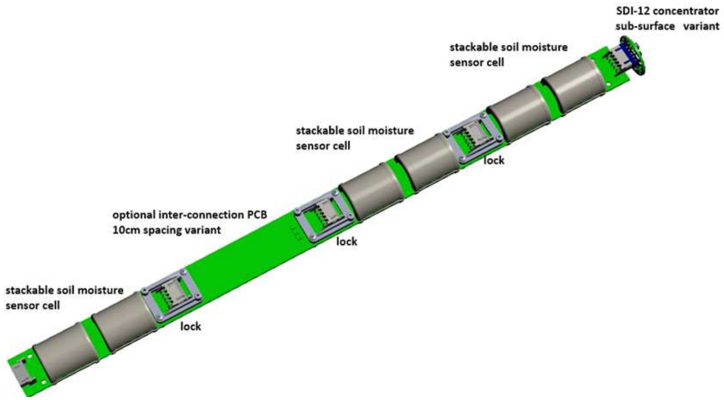
The probe plastics for the sub-surface probe include the



- ➢ A sealed probe head
    - The probe cable exits through a cable gland fitt e head
- ➢ A probe tube
    - The tube will nominally 5cm longer than the prc
    - The tube will be glued to the probe head
- ➢ A bottom stopper
    - This will be glued on to the probe tube during a

Once the probe length, number of sensors and sensor s n, the probe column is assembled, configured and tested. n inserted into the probe tube and the tube filled with resi is then fitted and the probe head glued on.

The sub surface head is fitted with an M12 connector. Probe cables fitted with a matching plug will be supplied to order in the length required by the purchaser.



3 Specifications

Parameter	Value / Range	Comment
Soil Moisture	0 to 120% (0 for Air 100% for Water)	When Air-Water calibration applied
Soil Temperature	-40 to +85 °C	+/- 0.25 °C at 25 °C Max error +/- 1 °C
Measurement Time	1 sec + (n x 1 sec)	N = Number of sensors
Operating Temperature	-20 to +85 °C	+/- 0.25 °C at 25 °C Max error +/- 3 °C
Power Supply	6 to 16 V DC	
Supply Current	Read: typ 8mA Sleep: 80uA	

Note:

- No claim is made for the accuracy of the soil moisture readings because the performance depends on the fit of the chosen calibration to the soil at the installation site
- With Polynomial calibrations, accuracies of +/- 3% are achievable.

4 Ordering

When ordering your probe, you must first work out what version and configuration you require. Once this has been determined you can determine the appropriate part number.

You can use the Order Form shown in Section 16 as a template for your own purchase orders.

	Part Number format
Above Ground	OT-AG-XX-YY-ZZ
Sub Surface	OT-SS-XX-YY-ZZ

XX	= Probe tube length	e.g. 03 = 30cm, 10 = 100cm, 15 = 150cm
YY	= Number of sensors	Min = 3, Max = 15
ZZ	= Cable length in metres	Min = 03m, Max = 40m

When compiling a part number, if a field value comes out to a single digit, always add a leading zero so the value occupies two digits.

First determine the required probe length (in multiples of 10cm) then divide this figure by 10. This figure becomes the tube length XX . The minimum length is 30cm and the maximum length 150cm (03 to 15) e.g. for a 100cm probe, length = 100/10 = 10. Contact TOIP if you should require pricing for probes longer than 150cm.

Now determine the number of sensors you require (this becomes YY):

- The number of sensors can be between 3 and 15 (03 to 15)
- The maximum number of sensors (at 10cm spacing) will equal the length divided by 10 e.g. the maximum number of sensors on a 100cm probe is 10
- You can skip sensors to save cost, which can generate considerable savings on longer probes
  - If possible, use a 10cm spacing for the first three to five sensors as this is where the bulk of the crop water use occurs
  - You can then skip 1, 2 or 3 sensor positions as needed further down the profile and install 10, 20 or 30cm spacer boards.

The next step is to determine the cable length. If no cable length is specified, the probes will ship with 5m of cable. The shortest length is 3m and the longest 40m. The length to be used on the part number is the length in metres divided by 10 e.g. for a probe cable length of 5m, the code is 05.

The part number for a 100cm above ground probe with 10 sensors and 5m cable is thus OT-AG-10-10-05

As it is not practicable to expand the part number to include the individual sensor depths, these should be shown in tabular format as follows:

Position	010	020	030	040	050	060	070	080	090	100
X = Sensor fitted	110	120	130	140	150	160	170	180	190	200

Note: the maximum number of sensors which can be fitted is 15.

The Above Ground probe may also be ordered in a “naked” configuration (i.e. without the SDI-12 Concentrator) however as each sensor in this mode occupies a separate SDI-12 address, it should only be considered when the telemetry / data logging equipment is capable of handling multiple addresses and is only recommended for probes with 3 or 4 sensors.

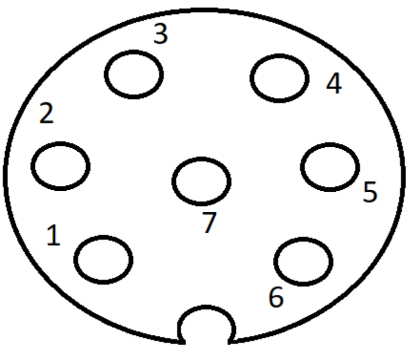
5 Wiring

As the Otto probes use the SDI-12 protocol, there are 3 wires to connect to your telemetry or data logger:

Function	**Power**	**SDI-12 Data**	**Ground**	**Shield**
Label	V	D	G	S
Cable type				
Black Cable	Red	White	Blue	Black
Lapp Unitronic Cable	Brown	Green	Yellow	White
7 Pin Connector	6	5	2	7

The fourth terminal, the Shield (S) is provided for increased noise immunity and may be connected when you are using a shielded cable.

The pinout of the 7 pin connector is shown in the image at right. This view is from the top of the connector (with the backshell removed).



6 Quick SDI-12 Command Summary

The section below shows a quick summary of the standard SDI-12 commands available with the probes.

Command	**Function**
?!	Acknowledge active (any active sensors respond)
aI!	Return sensor information string
aAb!	Change sensor address from a to b
aM!	Measure Soil Moisture – sensors 0 to 8
aC!	**Concurrent Measure Soil Moisture – sensors 0 to 8**
aM1!	Measure Soil Moisture - sensors 9 to 15
aC1!	**Concurrent Measure Soil Moisture - sensors 9 to 15**
aM2!	Measure Soil Temperature – sensors 0 to 8
aC2!	**Concurrent Measure Soil Temperature – sensors 0 to 8**
aM3!	Measure Soil Temperature - sensors 9 to 15
aC3!	**Concurrent Measure Soil Temperature - sensors 9 to 15**
aMC!	Default measure with CRC (also for MC1!, MC2!)
aCC!	Concurrent measure with CRC (also for CC1!, CC2!)

To read the first 9 sensors on a 1m 10 sensor probe on address 0
0C!
To read the last sensor on a 1m 10 sensor probe on address 0
0C1
To read the first 9 temperature sensors
0C2!
To read the last temperature sensor
0C3!

Note:

- Use the C commands in preference to M when supported by the logger/telemetry equipment
- For a list of all of the sensor and concentrator commands, refer to section 14.

7 Driver Setup

This section the settings to be used when creating a driver for the sensors in your telemetry or logger software.

7.1 Creating Individual elements

The settings show a single sensor e.g. 10cm. You must create similar drivers for each individual sensor, incrementing the Index for each as you go i.e. 10cm = 0, 20cm = 1, 30cm = 3 etc.

Soil Moisture:

- Name SM <depth>
- Manufacturer Otto
- Type Soil Moisture
- Engineering Unit %
- Icon SM
- Technology SDI
- Address 0 (default)
- Command C
- Meas Number 0 (sensor 1-9) 1 (sensor 10 – 15)
- Index 0 – 8 (sensor 1&10, 2 & 11….8 & 15)
- Use CRC No
- Measure Time 1 sec
- Sensor Supply Time 1 sec
- Sequential Measurement No
- Sensor Always On No (un-checked)
- Linear input value min 0 max 1
- Linear output value min 0 max 1
- Verifier min 0 max 120
- Display scale min 5 max 50
- Level Above Ground 0

Soil Temperature:

- Name Soil Temp <depth>
- Manufacturer Otto
- Type Temperature
- Engineering UnitTemperature (Celsius)

- Icon TEMP
- Technology SDI
- Address 0 (default)
- Command C
- Meas Number 2 (sensor 0 – 8) 3 (sensor 9 – 15)
- Index 0 to 8
- Use CRC No (un-checked)
- Measure Time Number of sensors + 1 sec
- Sensor Supply Time 2 sec
- Sequential Measurement No (un-checked)
- Sensor Always On No (un-checked)
- Linear input value min 0 max 1
- Linear output value min 0 max 1
- Verifier min -40 max 60
- Display scale min 0 max 30
- Level Above Ground 0

7.2 Creating a Combination Sensor

If your system supports it, you should then create a combination sensor driver which includes all of the individual elements.

The read time for a combination sensor will be 1 second plus 1 second for each sensor e.g. the read time for a 5 sensor probe is 6 seconds.

8 Installation

Installation should only be completed once the probes have been configured and tested.

The probe is installed into an over-sized hole and must be set into a slurry mix. The slurry may be made up of soil removed from the site or using a bentonite-sand mix.

Installation augers are available through TOIP or your local Distributor.

OT-INST-KIT	Installation Kit for Otto Soil Probes

Note:

- the Installation auger kit comprises a 35m auger, T-Handle, 1.0m extension bar and auger cleaning tool
- Additional extension bars may be required for probes longer than 100cm.

8.1 Soil Slurry

In most cases, the slurry may be made up using soil removed from the hole.
Pass the soil through a sieve to remove any rocks and organic material, then mix the sieved soil with water to form a creamy paste.

8.2 Bentonite Slurry

A bentonite slurry can be used is the soil on site is unsuitable – this may occur in very sandy soil or in very heavy clay soil.

If a bentonite slurry is used, the following additional items are required for installation of the sensor

- 1kg of fine sand (e.g. Sibelco 50WS grade)
- 100g Bentonite (civil grade e.g. Sibelco Trugel 100)
- 1L water
- Small bucket with lid
- Funnel
- 2 L plastic bottle with lid

Preparation

- Mix the dry bentonite and sand together in a bucket
- Pour the dry mix through the funnel into the 2 L plastic bottle
- Pour in the water, close the lid and shake until thoroughly mixed
- Continue to shake the mix at regular intervals until it is used.

8.3 Installation

After identifying a site for the sensor, drill a hole down to 5cm greater than the probe length (e.g. 105cm for a 100cm probe)

- When drilling the hole make sure you identify the changes in soil texture as you work your way down
  - As you drill the hole, withdraw the auger every 10 or 15cm
  - Scrape the soil out of the auger flutes onto a tarpaulin, noting the depth of each sample
  - If you want to, you can bag up the samples in zip-lock bags for further analysis off site
- Pre-wet the soil in the hole by pouring in enough water to fill it to close to the surface
  - Wait until the water has drained in to the surrounding soil before proceeding
  - If you do not pre-wet the hole, the soil may draw the water from the slurry too quickly and you will not be able to insert the probe. If this happens, you will have to remove the probe, clear the slurry out with the installation auger and repeat the process (Pre-wetting is usually not required with the bentonite slurry
- Pour a quantity of slurry into the hole
  - Allow 100ml of slurry per 10cm of depth e.g. for a 1m probe, pour in 1 litre of slurry
- Push the sensor down into the hole: as the sensor moves down, it will displace the slurry from the bottom
  - The slurry mix will fill any air gaps around the sensor and provide a consistent contact with the soil
  - Sub surface probe: the centre of the first sensor is 10cm below the top of the probe cap
  - Above ground probe: the centre of the first sensor is 10cm below the bottom surface of the probe cap
- Remove any surplus slurry mix from above ground level
- If the probe does not push down to the required depth on the first attempt (apply a maximum of 15kg of pressure on top of probe), pull

out the probe, clean the hole with the auger, re-wet the hole and repeat the process.

8.4 Cable Considerations

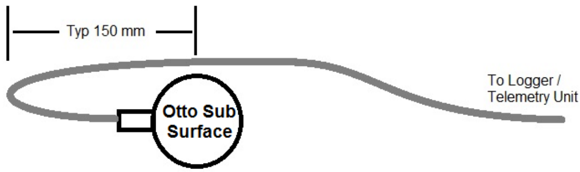
If you are going to bury the probe cable – for example in turf or broadacre crops – you need to be conscious of the risk of damage to the probe if either the cable is snagged by machinery or stretched due to compaction of the ground.

Placing the cable in conduit is a god way to avoid mechanical damage. You can use 13m or 19mm electrical conduit or poly pipe.

The simplest way to avoid damage due to compaction is to leave a goose neck at each end of the cable. If the cable is pulled, the loop can tighten, preventing the cable form being stressed at the junction with the probe body.

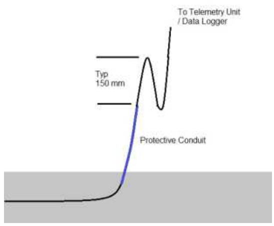
8.4.1 At the Probe end

As you install the probe, orient the probe body so that the cable entry point is pointing in the opposite direction to your trench.



8.4.2 At the logger/telemetry end

Where the cable leaves the ground, you should consider placing it in a protective sheath to prevent damage form vermin or machinery. The sheath can be rigid conduit, flexible conduit or blind poly tube. Leave a goose neck in the cable prior to routing the cable end to the telemetry unit or data logger.



9 Probe Removal

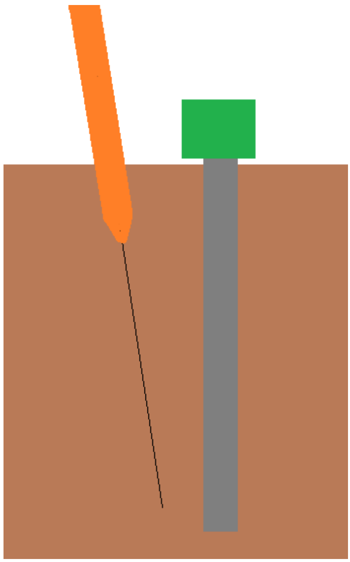
The Otto soil moisture probes may be removed using one of several different techniques according to the type of probe and length.

9.1 Manual (Auger) removal

This technique may be used for shallow probes or where no specific removal tools are available. Under this technique, a hole is drilled down alongside the probe, the soil in the area between the new hole and the probe tube scraped away and the probe pulled out through the void.

Tools Required:

- ➢ Installation auger and sufficient auger extensions to match the probe length
- ➢ “Spoon” made up from length of flat steel
  - The spoon should be shaped from a length of 20mm by 3mm steel bar
  - Beat the end of the bar to flatten it out and shape the last 30mm into a concave form: the curve should have a radius of 15 to 17mm so it can lay against the side of the probe tube
  - Bend the bar slightly 30mm from the end so that the spoon sits at an angle.



Removal procedure:

- ➢ Mark a spot for the new hole about 5cm away from probe cap
  - You will have to move further away from am above ground probe as you do form a below ground probe as the head on the above ground probe is wider
- ➢ Line your auger up just off vertical – with the angle chosen so that the bottom of the new hole will come in close to the bottom of the probe tube

- Carefully drill down with the auger to the same depth as the probe
  - Watch carefully to ensure that your auger does not hit the probe tube
  - If it does, stop drilling immediately and make a new hole 90 degrees around from this hole and further out from the tube
- Once the hole is drilled, use the spoon to carefully break away the soil between the new hole and the probe tube
  - If you have flatted the edge of the spoon so that it follows the same curve as the outside of the probe tube, you should be able to work close up to the tube without damaging it.
- Once you have removed all the soil between the probe and the new hole, you should be able to pull the probe out through the void.

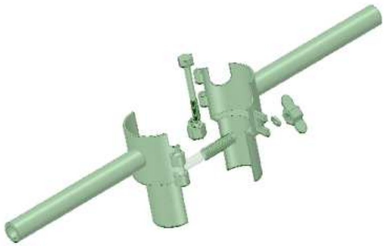
9.2 Using External Probe Removal Clamp

A Removal Tool is available to order through TOIP via your local Distributor.

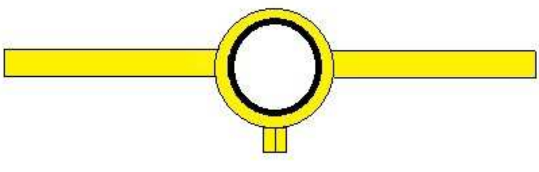
Part Number OT-CLAMP

Removal Process:

- Using a hand trowel or small spade, carefully remove the soil around the head of the probe down to a depth of 10cm below the top of the cap (sub surface) or 10cm below ground level (above ground)
  - With the sub surface probe, be careful not to damage the probe cable



- Loosen the wing nut on the removal tool and spread the jaws apart
- Position the tool so that the open side is facing the cable
- Carefully close the jaws of the tool, making sure that the cable sits neatly in the slot
- Swing the locking bolt around so it sits in the matching slot on the opposite jaw
- Tighten the wing nut firmly by hand to lock the clamp into place
- Grip the two handles of the probe removal tool and rock it clockwise and anticlockwise



- After several attempts you should be able to gain 1 to 2 mm of movement
- You should then be able to lift the probe vertically from the soil

Note:

- Ensure that you lift the probe vertically as any off vertical force may damage the probe and such damage is not covered by the manufacture warranty.

If you cannot lift the probe by hand you may wish to use some mechanical assistance in the form of a high lift jack or star picket puller

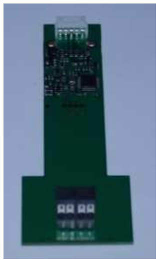
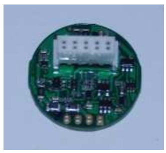
- Obtain a 600mm length of rope or chain
    - If using chain, it should be fitted with eyes on each end which can be slid over the handle of the removal tool
    - If using rope, start with a 2m length and tie it so it is in a loop. Thread the rope around each side of the clamp tool
- Run the centre of the chain / rope up and over to arm on the high lift jack / star picket puller
- Now carefully raise the jack / puller to lift the probe from the soil
    - Ensure that the probe, rope and jack remain vertical at all times

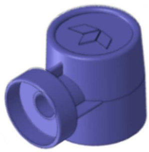
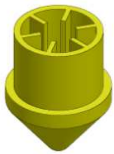
10 Pre-Assembly

Normally customers are supplied with complete above ground and sub-surface probes, but occasionally, in response to custom orders, a customer may be supplied with all of the parts required to build an above ground or naked probe to their requirements. You may find this necessary if you are installing the probes on sites where there is a rock layer at depth and you do not know in advance where it sits in the profile. You can order a longer tube and then cut it to length on site (and adjust the number of sensors used).

Refer to section 16 for the template to use when ordering.

Before proceeding check that you have all of the components needed for your configuration.

OT-PCB-AG	SDI-12 Concentrator Board Above Ground (TBS11-AG)	
OT-PCB-SS	SDI-12 Concentrator Board – Sub Surface (TBS11-SS)	
OT-SC-IF	Sensor Connector Board – for use on Naked probe and in sensor cell testing	

OT-SC	Soil Moisture Sensor Cell (10cm)	
OT-CS-10	SMP Connection Segment – 10cm (gives 20cm sensor spacing)	
OT-CS-20	SMP Connection Segment – 20cm (gives 30cm sensor spacing)	
OT-CS-30	SMP Connection Segment – 30cm (gives 40cm sensor spacing)	
OT-HD-AG	Otto Probe Head for above ground probe	
OT-HD-SS	Otto Probe Head for sub-surface probe	
OT-TUBE-XX	Probe tube to suit probe configuration (length plus aa cm)	
OT-BOT-ST	Otto Probe Bottom Stopper	

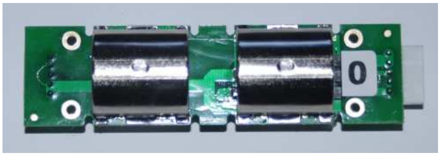
Note:

- Generally the Probe Head, Probe Tube and Bottom Stopper will be supplied pre-assembled
- For each Sensor Cell and Connection segment, you should be supplied with 2 off Retaining Clips and 4 off self- tapping screws.

10.1 Identify Sensors

The first step is to identify the individual sensors as they must be assembled in the correct order.

Each sensor should bear an identification label. As the Otto Soil Moisture Probes can accommodate up to 15 individual sensor cells, the numbers will be in the range 0 to e :



- 0 = first sensor
- 1 = second sensor
- 9 = 10th sensor
- a = 11th sensor
- b = 12th sensor
- c = 13th sensor
- d = 14th sensor
- e = 15th sensor

If you cannot identify the individual sensors, you will have to connect them to a TekBox TBS03 USB to SDI-12 converter and check each one:

- If you have not already done so, plug the TBS03 into a USB port on your computer and install the SDI Commander software. Refer to the User Manual for the TBS03 for details on how to install configure and use the unit and the SDI Commander software
- Once SDI Commander is running, click on the **Connec**t button. You can now enter the commands to configure and test the probe into the Command bar.

To simplify the process of configuring and testing the sensors, SDI Commander allows you to create “button” and “SDI Network” files so that you can issue commands at the press of a button. TOIP has prepared an SDI Network file which can be loaded in to your SDI Commander program. Contact TOIP for a copy of the file and install it as follows:

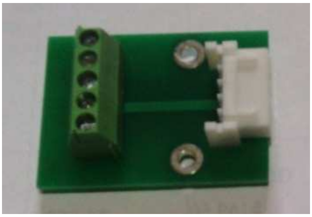
- Obtain a copy of the file “otto_network.sdi” from TOIP
- From the SDI Commander menu ***select File / Open Button File*** and then note the location of the TEMPLATE folder (e.g. C:\Program Files (s86)\SDI Commander\sdi_12 networks
- Close SDI Commander
- Copy the file to the folder identified above
- Re-start SDI Commander

- From the SDI Commander menu select ***File / Open SDI File*** and open the SDI-12 Network file named “otto_network”
- The otto tab has sub tabs for the various functions, each with its own set of buttons: Otto, Sensor, Probe
- You can customize the buttons by selecting ***Buttons / Edit buttons***
- After editing make sure you save the changes (***File / Save***)
- The next time you open the program, you will be prompted to open this file again.

The sensors may be identified using the Sensor Connector Board (OT-SC-IF) or using the SDI Concentrator PCB.

10.1.1 Identification Via the Sensor Connector Board

The Sensor Connector Board allows you to easily gain access to the SDI-12 terminals on the sensor – it contains no electronic components, only a header on which to connect the wires from the TBS3 and a plug in to which the sensor is connected:



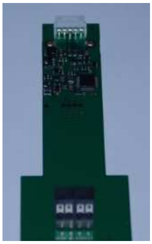
- Connect the TBS03 to your PC and load the SDI Commander software
- Open the Otto_network file and select the “**Sensor**” tab
- Using three short lengths of hook-up wire, connect the Connector Board to the TBS03
- Plug the sensor board into the socket on the Connector Board
- Issue the SDI-12 query command to search for a response from the sensor by typing the command at right or by clicking on the “**Check for sensors**” button **?!**
- Note the address on which the sensor responds e.g. **0**
- If needed, change the address of the sensor using the various buttons on the menu or by typing the SDI-12 A command **<old add>A<new add>**

  e.g. to change a sensor address from 5 to e 5Ae!

10.1.2 Identification via Above Ground SDI Concentrator Board

The SDI Concentrator board supports a “Pass Through” command mode whereby commands issued at the TBS03 can be passed through the SDI Concentrator to a sensor:

- Connect the TBS03 to your PC and load the SDI Commander software
- Load the “otto_network.sdi” file
- Select the **Probe** tab
- Using three short lengths of hook-up wire, connect the SDI Concentrator Board to the TBS03
- Plug the sensor board into the socket on the SDI Concentrator or Connector Board
- Check that the SDI-12 Concentrator Board is present on address 0 **?! OR 0I!**
- If the board responds on a different address, either change it to 0 using the SDI-12 Change Address command (<old add>A<new add>!) or change the address shown in the example below to suit
- In Pass Through command mode, issue the SDI-12 query command to search for a response from the sensor



Command format		***aXS:cmd:addr!***
Where	a	Address of SDI Concentrator
	cmd	Command for sensor
	addr	Address of sensor to receive the command
Response	<add>X_OK	command succeeded
	<add>X_Fail	command failed

- To view the result of the command ***aXGST!***

- To check for a response for sensor number ***y*** when connected to an SDI Concentrator on address ***z*** zXS:I:x!

e.g. SDI Concentrator address 0, check for non-functional sensor 3:

Issue command	0XS:I:3!	
	0X_OK	Command succeeded
Read result	0XGST!	
	0XGST!	
	0,SET_FAIL	No reply from sensor 3

e.g. SDI Concentrator address 0, check for presence of sensor 4

Issue command	0XS:I:4!	
	0X_OK	Command succeeded
Read result	0XGST!	
	0,413GREENSLDTSSPP11.8000558	

- Note the address on which the sensor responds e.g. **0**
- If needed, change the address of the sensor using the SDI-12 A command **aXS:A<new add>:<current add>!**

e.g. SDI Concentrator address 0, to change a sensor address from 4 to e:

Issue command	0XS:Ae:4!	
	0X_OK	Command succeeded
Read result	0XGST!	
	0,e	Address now e
Confirm new add	0XS:I:e!	
	0X_OK	Command succeeded
Read results	0XGST!	
	0,e13GREENSLDTSSPP11.8000558	

11 Configuration

The first step in building a probe is to configure and test the individual sensors. Then the sensors are assembled into a “stack” which will include spacer PCBs in the required positions. Finally, the completed probe is tested. You can use the various tabs under the “Sensor” page in SDI Commander to complete these functions.

11.1 Configuring Individual Sensors

Connect the sensor under test to the Sensor Connection PCB, then connect the Sensor Connection Board to the TBS03. If you are going to configure the sensor using the Pass Through command mode from an SDI Concentrator, adjust the instructions based on the information in section 10.1.2.

It will be easier if you first change the sensor address to 0, that way you will be able to use the same commands to configure and test each one. Then, once finished, set the sensor back to its nominal address.

Check that the TBS03 recognises the SDI Concentrator:

- Check for a response on the SDI-12 bus **?!**
- Note the address on which the Concentrator replies - the default address is 0 **0**
- Issue the command to read the info string from the concentrator <address>I! ***0I!***
- Confirm that the Concentrator’s Information string is displayed
  0I!
  013GREENSLDTSSPP11.8000554

Connect the sensor under test to the Cable Connection PCB, then connect the Cable Connection Board to the TBS03.

11.1.1 Set Calibration Type aXSCn!

The soil calibration method should by default have been set to Polynomial.

n = 1 Polynomial n = 0 Min-Max

To check the calibration type -

To set the calibration type to Polynomial ***aXSC1!***

e.g. Setting sensor on address 0 to polynomial calibration

0XSC1!
0X_OK

11.1.2Check and Set SM Scaling Factor (Optional)

The Scaling Factor may be used to alter the range of the measured values. It is applied before the application of the soil type.

The raw reading from the probe is divided by the scaling factor
i.e. SM = SM raw / Scaling Factor.

For instance if the scaling factor is set to 1 (the default) a probe put through air-water calibration returns 0 in air and 100 in water, but will return 50% in water if the scaling is set to 2. The default value is 1.75.

To check the SM Scaling Factor ***aXGT!***
To set the SM Scaling Factor ***aXSTnn.mm!***

Note that the number is in the format nn.mm and must be entered as two digits before and two digits after the decimal point. There is no sign and no comma separator between the command and the value

0XST01.750!
0X_OK
0XGT!
001.75

11.1.3Set the Soil Type aXGSt!

The soil type is normally set to 3 which is a typical calibration for a 50- 50 mineral/organic soil. But if you have performed a calibration for the soil at the installation site, you can select one of the custom soil types (4 to 9) and write the coefficients for the soil into the sensor.

To check the soil type -

To set the soil type to 3 ***aXGS3!***

0XGS3!
0Now Soil Type:3

11.1.3.1 Using a custom soil type

In place of the supplied soil calibrations, you can create your own custom soil type. The behaviour of the calibration is defined by a polynomial equation of the form:

$$y = (a*x^3) + (b*x^2) + (c*x) + d$$

The coefficients are set with an extended SDI-12 command.
To check the coefficients **_aXGSt_**
To set the coefficients for a soil type **_aXSSt,a,b,c,d!_**

- for custom soil types, t = 7, 8 or 9

After setting the coefficients, set the soil type **_aXSS,t!_**

The table below shows the coefficients for a range of factory supplied calibrations. If you complete your own calibrations you can update the table with their details, write the coefficients to the sensor and then use that soil type.

	Coefficients			
Soil Type	**A**	**B**	**C**	**D**
1 Sand	0	0	0.85	-21
2 Potting Soil	0.00004	0.0004	0.3	-4.7
3 50-50 Mineral Organic	0.00007	-0.01226	1.53233	-27.231
4				
5				
6				
7				
8 Black Clay loam	-0.00002	0.00028	0.5689	-20.02
9 Heavy cracking clay	0.00002	0.0003	0.5689	-20

11.1.4 Check and Set the Soil Temperature Compensation (Optional)

The sensors are programmed with a default soil temperature compensation value of +0.1% per degree C which adjusts for changes in the dielectric properties of the soil as the soil temperature changes. Without temperature compensation, capacitance probe data can display high levels of temperature induced diurnal (daily) variation.

To check the compensation **_aXGTC!_**
To set the temperature compensation coefficient **_aXSTC,snn.nn!_**

- Where s is the sign and nn.nn is the compensation value
- After the set command, the sensor will respond with X_OK if the command succeeded or X_FAIL if it was not.

e.g. to set the compensation for sensor on address 0 to a value of +0.1:

0XSTC,+00.10!
X_OK
0XGTC!
0+0.10

You may wish to leave the Soil Temperature Compensation at the default value until the probes have been installed and logging for a couple of days. You can then look at the level of diurnal variation and make a decision on whether the compensation needs to be adjusted.

11.1.5 Calibrate the Soil Temperature Sensor (Optional) aXCT,snn.mm! aXCTsnn.mm!

The temperature sensors on the PCBs can be adjusted so that all sensors on a probe will give the same reading at the reference temperature. This requires an accurate temperature reference (e.g. the SDI-TRH-HP). There are two ways in which you can set the calibration: firstly by entering the reference temperature, or secondly by entering the offset to apply to the current value.

To set to a reference temperature **aXCT,snn.mm!**

To apply a specified offset **aXCTsnn.mm!**

Allow the sensors and reference sensor to stabilize.
Take a reading from the Reference sensor and note it down e.g. Tr 22.85
Now make a Temperature reading from the sensor e.g. Ts 22.8

In this example, the sensor is reading low by 0.05
You can correct the sensor (assuming it is on address 0) using either of the following commands:

- Write the reference temperature **0XCT,+22.85!**
- Apply the correction as an offset **0XCT-00.05!**

Write the reference temperature to the sensor ***aXCT,snn.mm!***
e.g. for the reference temperature of 22.85 above 0XCT,+22.85!

Note that there is no Get version of this command.

11.1.6Set up Averaging

The sensors (and hence probes) support two levels of averaging: arithmetic averaging where the current readings is the average of a number of samples and a rolling average applied to the last measurements.

11.1.6.1 Arithmetic Averaging aXSAnn! aXGA

As capacitance sensors are by nature noisy, averaging can be applied to smooth out the readings. The sensors will take "n" measurements one after the other. It will then discard the highest and lowest readings and calculate the average of the remaining samples.

n = number of samples
m = number used in average = n – 2

The default setting is n = 5 (i.e. 3 samples used in calculating average, after highest and lowest sample are discarded)

To set the number of samples used in the averaging **aXSAnn!**
Where n is the number of samples (0, 4 to 10)
To read the number of samples using in the averaging **aXGA!**

e.g. to set the averaging for sensor on address 0 to a value of 3:
0XSA03!
X_OK

0XGA!
003

11.1.6.2 Rolling (Gliding) Average aXSPnn! aXGP!

The Rolling or Gliding Average smoothes the data based on taking the average of the last “n” logged readings. The effect of the rolling average is to reduce the maximum rate of change between successive samples.

The default setting is for rolling average to be disabled (i.e. n = 0).

To set the number of samples used in the rolling average **aXSPnn!**
Where n is the number of samples (0 to 10)
To read the number of samples using in the averaging **aXGP!**

e.g. to set the averaging for sensor on address 0 to a value of 3:
0XSP03!
X_OK
0XGA!
003

11.1.7 Confirm sensors are giving sensible results to a manual reading aM1! aC1!

The final step is to take a manual reading and confirm that all sensors are returning similar (and sensible) values. The M1 and C1 commands will return the soil moisture and soil temperature values.

Full probe test tanks can be made up using lengths of 150mm DWV PVC pipe – the length of the pipe should be at least equal to the length of the longest probe you will be testing. For initial testing you can make up 3 short tanks, each 300mm long and fitted with a cap at each end. The top cap should be drilled and fitted with a plug. Fill one tank with distilled water and the second with methylated spirits. The third tank should be left filled with air. For consistency you should always try to maintain the test tanks as room temperature (23 degrees C) as changes in temperature effect the calibration.

Make a manual measurement of soil moisture and soil temperature in each tank using the command ***aC1!***
Fetch the values ***aD0!***

11.1.8 Set the Sensor Address aAb!

After configuring and testing the individual sensors, you will need to program them with the correct address

- The top sensor on your probe will always occupy address 0, the second address 1 etc.
- If necessary, change the number written on the ID sticker on the bottom of the sensor, or replace it with a new label showing the correct address.

To check the address the sensor is responding on ***?!***
To change the address ***<current_add>A<new_add>!***

e.g. to change a sensor from address 0 to 3 0A3!

- Work out which address this sensor should be
  - The topmost sensor should be on address 1, the second on address 2, the next on address 3 etc.
- Use the SDI-12 address change command to set the sensor to the correct address **<old add>A<new add>!**
- e.g. to change a sensor from address 0 to 1 **0A1!**
- Place a label on each sensor showing the address and the nominal sensor depth e.g. Address 1 - 010cm

Lay the sensors on the work bench in the correct order, working from left to right

- The top of the Sensor Cells (and spacer boards) is fitted with a plug and the bottom a socket
- Sit the sensors so that the plug is on the right and the socket on the left.

11.1.9 Resetting to Factory Defaults aXSD!

WARNING: Do not perform a factory reset using pass-through commands on a Sub-Surface probe as all the sensors will be set to address “0” rendering the probe inoperable.

If you feel that the parameters within a sensor may have become corrupted and you want to set them back to the defaults, you can do so with the set default command. This sets the sensors as follows:

Sensor address:	0
Soil scaling coefficient:	1
Temperature unit:	Celsius
Temperature offset:	0
Soil type:	0; air/water calibration
Polynomial coefficients:	a = 0; b = 0; c = 1; d = 0
Calibration method:	Min-max

After resetting the sensor to default, you will need to complete the Air-Water calibration before you can use the sensors.

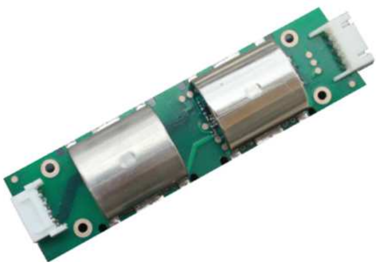
11.2 Building and Configuring a Full Probe

For the following steps you should use the **Probe** tab in the Otto_network under SDI Commander.

11.2.1 Assemble sensor elements

The next task is to assemble the sensor stack. This will be made up of the desired combination of sensor cells and connection segments and an Above Ground PCB (Sub-surface probes will always be supplied pre-built).

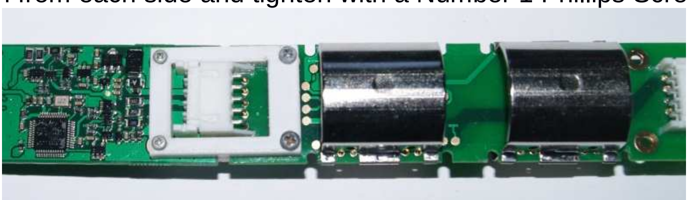
- Identify the locations where Connection Segments will be required and the length of each. Then place the connection segment in the gap between the sensors.



Count out the required number of Connector Clips and screws

- For each junction you will need 2 Connector Clips and 4 screws.

Working from left to right, push the plug on the bottom of the Sensor Cell into the Socket in the top of the next Sensor Cell or Connection Segment. Next place a Connector Clip on either side of the connector. Then fit two screws in from each side and tighten with a Number 1 Phillips Screwdriver.



When all of the Sensor Cells and Connection Segments have been installed, connect the SDI-12 Concentrator board to the first sensor. Then fit two Connector Clips and secure with 4 screws.

Once the sensor stack has been assembled the SDI-12 Concentrator board must be configured. This task utilizes a number of “Extended” SDI-12 commands and can be performed using the Tekbox TBS03 USB to SDI-12 converter. Refer to the Probe tab on the Otto_network.

Check that the TBS03 recognises the SDI Concentrator:

- Check for a response on the SDI-12 bus ***?!***
- Note the address on which the Concentrator replies - the default address is 0 ***0***
- Issue the command to read the info string from the concentrator <address>I! ***0I!***
- Confirm that the Concentrator’s Information string is displayed

  0I!
  013TEKBOXVN_TBS11_1.0_000001

11.2.2 Get – Set Sensor Count aXGSN! aXSSN,nn!

The next step is to configure the SDI Concentrator for the required number of sensors.

Issue the Set Sensor Count command to set the number of sensors ***aXSSC,nn!***
(where n is the number of sensors and can be a value from 0 to 15).

e.g. to set the number of sensors to 6 for an SDI Concentrator on address 0: 0XSSN,6!
0X_OK

You should now confirm that the SDI Concentrator is returning the correct number of sensors ***aXGSN!***

e.g. To read the sensor count from an SDI Concentrator on address 0 :
0XGSN!
0,6

11.2.3 Check Sensors Are Responding aXSCS! & aXGCS

Once you have configured the SDI Concentrator with the number of sensors fitted, you should issue the command to check that all of the programmed sensors have responded.

The aXCS! command sends a command to each sensor in turn to check if it is active. It will take around 5 seconds for the probe to test all of the sensors.

The unit will issue a response showing the status of the command:

a_OK	-	If the command succeeded
a NOK	-	if the command failed

You can then issue the aXGSS! command to display the results of the query:

aOK:x,y,z,a,b,c,d….	The ID of the sensors which responded correctly to the command
FAIL: l,m,n,o	The ID of any sensors which failed to respond

e.g. query for status of probe on address 0

0XSCS!
0X_OK

Get result (all sensors OK)

0XGCS!
0,OK

Get result (sensor failed)

0XGCS!
0OK:4
FAIL:0,1,2,3,5

In the above example, on a probe configured for 6 sensors, only sensor 4 responded and all other sensors failed.

After identifying the faulty sensor(s) remove it from the stack. Connect the sensor to the TBS03 via the Probe Connector Board or as the only cell on the SDI Concentrator. Test the sensor to confirm that it is responding and, if necessary, set to the correct address.

11.2.4 Setting Parameters for Sensors

The SDI Concentrator allows you to send commands to individual sensors to configure them. This is referred to as “Pass through” mode. Note that the Rest to Factory defaults command is NOT available as a pass through command (it would render a sub-surface probe inoperable).

Command format		***aXS:cmd:addr!***	
Where	a	Address of SDI Concentrator	
	cmd	Command for sensor	
	addr	Address of sensor to receive the command	
		0 – 9, a – e	Sensors 1 to 15
		f	All sensors

The sensor elements on the probe column are numbered 0 to 9 and then a to e. Address **f** is reserved as a global address: any command sent to sensor address **f** will be sent to all sensors, enabling configuration commands to be sent to all sensors with one command.

When run at the sensor level, the Extended SDI-12 commands return X_OK if they were successful or X_Fail if they failed. When you run a pass through command (e.g. 0XS:I:3! To get the Info string from sensor 3 on a pronbe) the OK / FAIL relate to the command process on the PCB, not the command sent to the sensor(s). The aXGST command is provided in order to check the status of the pass through command.

To view the result of the command		***aXGST!***
Response	SET_OK	command succeeded
	SET_FAIL	command failed

e.g. to select Soil Type 3 for sensor 4 on a probe on address 0

0XS:XSST,3:4!

e.g. to take a reading from sensor 3 on a probe on address 0

Send the Measure command	0XS:M:3!
	0X_OK
Check the response	0XGST!
	0,30011
Send the Get Data command	0XS:D0:3!

	0X_OK
Get the response	0XGST!
	0,3+11.45

11.2.5 Perform Air and Water Calibration

The completed sensor stack should be run through the air and water calibration process. Ensure that the sensors spend sufficient time in the test tanks for the temperature to stabilize prior to performing the calibration.

11.2.5.1 Air Calibration

Place the completed probe in an Air test tank or hold it in the air, well clear of any other objects. Then send the Air Calibration commands for each sensor via the SDI Concentrator

aXS:XCA:n!	***a = Concentrator address***
	n = sensor number
	(f = all sensors)

e.g. to perform air calibration for a probe on address 0 for sensor 3:

Calibrate sensor	0XS:XCA:4!
	0X_OK
Check result	0XGST!
	0,4X_OK

11.2.5.2 Water Calibration

Place the completed probe in the Water test tank . Then send the Air Calibration commands for each sensor via the SDI Concentrator

aXS:XCW:n!	***a = Concentrator address***
	n= sensor number

e.g. to perform water calibration for a probe on address 0 for sensor 3:

Calibrate sensor	0XS:XCW:3!
	0X_OK
Check result	0XGST!
	0,3X_OK

11.2.6 Set Soil Type *aXS:XGSt:n!*

The Soil Type can be set for each sensor can be set using the remote set command. The default is to use Soil Type 3:

aXS:XGSt:n! ***a = Concentrator address***
n= sensor number
t = soil type

e.g. for a probe on address 0, set the soil type for sensor 3:

Set soil type	0XS:XGS3:3!
	0X_OK
Check response	0XGST!
	0,3Now Soil Type:3

11.2.7 Set Soil Coefficients aXS:XSSt,b,c,d,e:n!

If the sensor has been issued with a Factory reset or if you want to enter or change the soil coefficients, you can set them using the remote set command:

aXS:XSSt,b,c,d,e:n! ***a = Concentrator address***
n= sensor number
t = soil type
b,c,d,e = coefficients

e.g. for a probe on address 0, to set the coefficients for soil type 3 on sensor 3:

Set coefficients	0XS:XSS3,0.00007,-0.1226,1.53233, -27.31:3!
	0X_OK
Check response	0XGST!
	0,3X_OK

11.2.8 Set Scaling Factor *aXS:XSTxx.yy:n!*

The Sensor Scaling Factor can be used to perform a quick reasonableness adjustment on the soil moisture readings. The value from the sensors is divided by the scaling factor and the result returned.

The scaling factor must be entered in the form xx.yy i.e. 2 digits before and after the decimal point. The default value is 1.75

For example, if the default calibration scales the readings for your soil to a range of 10 to 75% volumetric and you know that the saturated value from a soil test result if 45%, you can set the scaling factor to 75/45 = 1.67

aXS:XSTxx.yy:n!	***a = Concentrator address***
	n= sensor number
	xx.yy = scaling factor

e.g. for a probe on address 0, to set the scaling factor for sensor 3 to 1.31:

Set scaling factor	0XS:XST01.75:3!	
	0X_OK	
Check Result	0XGST!	
	0,3X_OK	

e.g. result of trying to set on a non-existent sensor (number 5) to a scaling factor of 1.6, for a probe on address 0:

Set scaling factor	0XS:XST01.60:5!	
	0X_OK	
Read result	0XGST!	
	0,SET_FAIL	No sensor 5

11.2.9 Set Temperature Comp'n aXS:STCsxx.yy:n!

The temperature compensation can be set for all sensors or for an individual sensor using the pass through commands.

aXS:XSTCsxx.yy:n!	***a = Concentrator address***
	s = sign (+ or -)
	n= sensor number (0 to e or "f" for all)
	xx.yy = compensation factor

The sensors are initially programmed with a temperature compensation factor of +00.10. By setting the parameter "n" in the above to a value of "f" the compensation will be written to all sensors. If you set "n" to a value between 0 and e, that sensor alone will be configured.

After issuing the set command, you should use the aXGST! Command to verify that the pass through command succeeded.

e.g. for a probe on address 1, to set the scaling for all sensors to +0.10:

1XS:XSTC,+00.10:f!
1X_OK
1XGST!
1,fX_OK

e.g. for a probe on address 1, to set the scaling for sensor 2 to +0.10:

1XS:XSTC,+00.10:2!
1X_OK
1XGST!
1,2X_OK

To check the value for sensor 0 on probe with address 0:

Read the value via TBS11	0XS:XGTC:0!
Read the result	0XGST!

0XS:XGTC:0! 0
0X_OK
0XGST! 0
0+0.10 0

11.2.10 Calibrate the Soil Temperature Sensor (Optional) aXS:XCT,snn.mm:n! aXS:XCTsnn.mm:n!

The temperature sensors on the PCBs can be adjusted so that all sensors on a probe will give the same reading at the reference temperature. This requires an accurate temperature reference (e.g. the SDI-TRH-HP). There are two ways in which you can set the calibration: firstly by entering the reference temperature, or secondly by entering the offset to apply to the current value.

To set to a reference temperature on sensor 2 to 16.23 degrees for a probe on address 0 **0XS:XCT,+16.23:2!**

To apply a specified offset of +0.05 degrees to sensor 2 on a probe on address 0 **0XS:XCT+0.05:2!**

11.2.11 Set Averaging

11.2.11.1 Set Up Arithmetic Averaging aXS:XSAbb:n!

The averaging can be set for all sensors or for an individual sensor using the pass through commands.

aXS:XSAbb:n!
a = Concentrator address
bb = number of values in average
0 = off
4 to 10 = 2 to 8 samples in Avg
n= sensor number (0 to e or "f" for all)

The value for bb can be in the range 0 to 10, where 0 = no averaging. The minimum practical value for bb is 4, since the highest and lowest reading are discarded. The number of samples used in the actual average calculation is thus bb -2 i.e if bb = 4 then 2 samples will be used in the averaging.

The sensors are initially programmed with 5 values in the average.
By setting the parameter "n" in the above to a value of "f" the value will be written to all sensors. If you set "n" to a value between 0 and e, that sensor alone will be configured. After issuing the set command, you should use the aXGST! Command to verify that the command succeeded.

e.g. for a probe on address 1, to set the averaging for all sensors to 5:

```
1XS:XSA05:f!
1X_OK
1XGST!
1,fX_OK
```

e.g. for a probe on address 1, to set the averaging for sensor 2 to 3:

```
1XS:XSA03:2!
1X_OK
1XGST!
1,2X_OK
```

11.2.11.2 Set Up Rolling Average **aXS:XSPbb:n!**

The averaging can be set for all sensors or for an individual sensor using the pass through commands.

aXS:SPbb:n! ***a = Concentrator address***
bb = number of values in average
0 to 10
n= sensor number (0 to e or "f" for all)

The value for bb can be in the range 0 to 10. However in practice it would be very rare to use values higher than 3 – otherwise the response to changes in soil moisture would become too slow.

By setting the parameter "n" in the above to a value of "f" the value will be written to all sensors. If you set "n" to a value between 0 and e, that sensor alone will be configured. After issuing the set command, you should use the aXGST! Command to verify that the command succeeded.

By default, rolling average is disabled (i.e. bb = 0)
e.g. for a probe on address 1, to set the averaging for all sensors to 3:

1XS:XSP03:f!
1X_OK
1XGST!
1,fX_OK

e.g. for a probe on address 1, to set the averaging for sensor 2 to 3:

1XS:XSP03:2!
1X_OK
1XGST!
1,2X_OK

11.2.12 Confirm Sensors Return Sensible Values

Place the probe in the methylated spirits test tank (or place the probe in its probe tube and wrap the tube in a single layer of damp paper towel) and make a measurement to confirm that all sensors are returning sensible values.

Make a manual measurement of soil moisture in each tank using the command

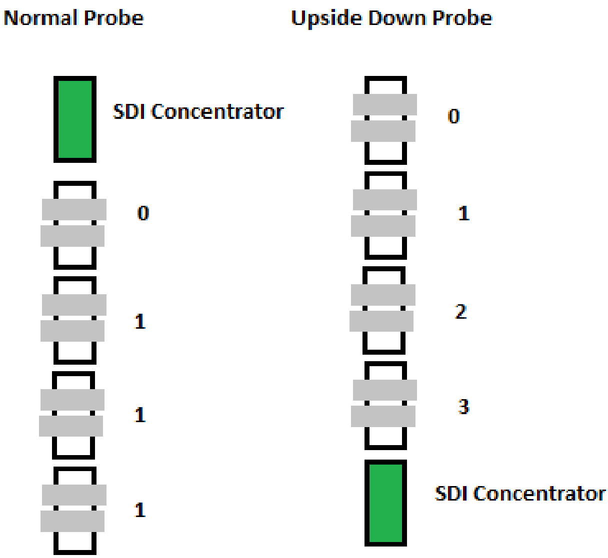
Get values from sensors 1 to 8	***aM!*** or ***aC!***
Get values from sensors 9 to 15	***aC1!*** or ***aC1!***
Fetch the values	***aD0!***

Make a soil temperature reading using the command

Get values from sensors 1 to 8	***aM2!*** or ***aC2!***
Get values from sensors 9 to 15	***aC3!*** or ***aC3!***
Fetch the values	***aD0!***

11.3 Upside Down Sub-Surface Probes

The probe PCB is normally installed on top of the probe and the first sensor just below it. There are some applications where the top sensor must be installed as close to the surface (or to a reference depth) as possible. This means looking at an “upside down” probe, where the PCB is installed at the bottom and the first sensor at the very top. As the Otto Interface PCB does not care which sensor is locate where on the column, this can easily be accommodated: simply fit the sensors together in reverse order i.e. starting with the sensor with the highest address first. Probes may be built in this configuration to specific customer order.



12 Calibration

Volumetric water content, θ, is defined mathematically as:

$$\Theta = W_w / V_t$$

where

V_W is the volume of water and

$V_T = V_{soil} + V_{void} = V_{soil} + V_{water} + V_{air}$

i.e. the total volume (that is soil volume + water volume + air space).

Soils consist of particles of minerals and organic matter with various sized voids which can be filled with either air or water. In oven dried soil, the voids are filled with air. As water is added it displaces the air. Once all voids are completely filled with water, the soil reaches saturation.

Water, air and soil all have vastly different dielectric properties (a measure of how easily the particles are polarised under the influence of an electric field). Air for instance, has a dielectric value of 1 and water 80. The dielectric values of soil will range from around 4 to over 100, with higher values seen in heavy clay soils and in saline soils. Dielectric sensors measure this change in dielectric properties and express it as an equivalent volumetric soil moisture value.

The Otto SMP provides several different calibration methods to convert the raw dielectric readings to a volumetric water content figure. The calibration method and variables used by each, are set using extended SDI-12 commands.

The calibration commands can be entered directly in to each sensor after connecting the sensor to a Sensor Connection Board or, one the sensors are made up into a full probe, using the Pass Through commands available on the SDI Concentrator PCB. The calibration examples all show the commands to use in the former mode.

12.1 Factory Calibration

The sensors for the Otto SMP are normally shipped in air/water calibration mode, but can be set to one of 3 standard soil types and 6 user defined soil types (as per the configuration instructions you should set the sensors to Polynomial Calibration mode).

Air / Water Calibration

- Air / water calibration is carried individually for each probe
- The probe is first suspended in air and the value recorded
- The probe is then placed in a bath of water and the value once again recorded
- The probe is set to return 0 for the air reading and 100 for the water reading
- Note that in soil, the readings will be much higher than the actual volumetric moisture content.

Soil Specific Calibration

- Two variations of soil specific calibrations are provided: Min-Max and Polynomial. The coefficients for each are stored against soil types 1 to 3
- The parameters have been based on measurements averaged over a large quantity of probes
- Thus although not an individual calibration, the high repeatability of the Otto SMP ensures the measurement results are typically within a range of ± 2% in an equivalent soil
- The parameters are as follows:

Soil Type	Min/Max calibration			Polynomial calibration			
	dry	sat	max	a	b	c	d
Soil Type 1 - Sand	26	75	40	0	0	0.85	-21
Soil Type 2 - Potting Soil	15	100	72	0.00004	0.0004	0.3	-4.7
Soil Type 3 - 50% mineral / 50% organic	21	92	65	0.00007	-0.01226	1.53233	-27.231

- Typically, Soil Type 3 is a good compromise in many soils.
- Users can over-rid the parameter for soil types 1 to 3 but can set them back again by using the command to Reset the probe to its default settings.
- Polynomial coefficients can be calculated using a tool which can be downloaded from the Tekbox website.

12.2 Air-Water Calibration

As the maximum water storage capacity largely depends on the soil type, the Otto SMP comes factory configured with a so called “air and water calibration”. This means that a measurement value of 0% corresponds with the sensor placed in air and a value of 100% corresponds with the sensor placed in water. This is a very basic calibration method, not taking into account any soil specific properties.

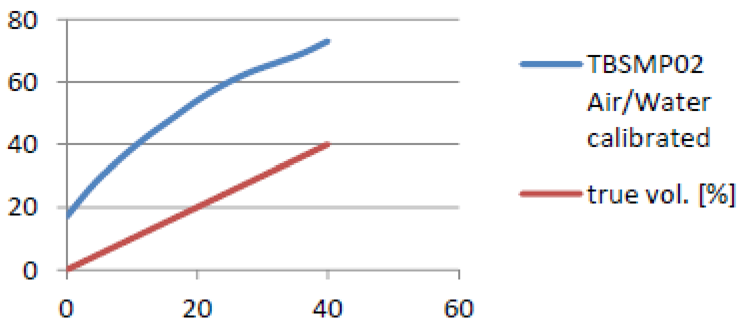
The dielectric constant of dry soil is higher than the dielectric constant of air consequently an air/water calibrated probe will show values above 0% when in dry soil dry soil. As an example:

dry sand:	26%
dry volcanic scoria:	22%
dry potting soil:	15%

Nevertheless, for many purposes, when the focus is on observing trends rather than measurement of absolute values, an air/water calibration is sufficient.

The calibration is long term stable, but can be repeated at any time by placing the sensor in air and sending the extended SDI-12 command **aXCA!** for air calibration and then placing the sensor in water and sending the extended SDI-12 command **aXCW!** for water calibration.

The picture below shows the measurement response of an air/water calibrated probe in sand compared to the true, absolute volumetric value.



An Air-Water – calibrated Otto SMP will respond with 26% in dry sand and with 86% in fully saturated sand. The corresponding, true volumetric values would be 0% and 40% however.

A soil specific variant of the air/water calibration can be carried out by issuing the air calibration command when the probe is placed in dry soil and issuing the water calibration command, when the probe is placed in saturated soil. A measurement response of 0% would then indicate dry soil and 100% would indicate fully saturated soil.

12.3 Soil Specific Min-Max Calibration

The Min-Max calibration process sets the probe to read from 0 to 100 over the range from air dry to saturation, in the soil under test. Prior to completing a Min-Max calibration, the probe must be given an Air-Water calibration.

A basic soil specific calibration can be carried out by taking a defined volume of soil, drying it, bedding the probe inside and using it as a 0% calibration reference. A minimum sample volume of 10 litres is recommended.

First record the measurement response of the probe in dry soil.

As a next step water in known amounts, and thoroughly mix it with the dry soil until it reaches saturation. Saturation is reached, once the water pools on the surface. Record the volume of water it took reach saturation as well as the reading from the probe.

Example calibration procedure, using sand with a probe set to SDI-12 address 0:

STEP 1. Set probe into air/water calibrated measurement mode: **0XGS0!**
Place probe into dry sand

- Issue Start Measurement Command: **0M!**
- Issue Read Data Command: **0D0!**
- Record response: 0+26.12
    - measurement response of the probe in dry sand is 26.12%

STEP 2 Assuming a sample volume of 10 litres, add 4 litres of water to raise the volumetric water content to 40%

- Place probe into saturated sand and issue Start Measurement Command: **0M!**
- Issue Read Data Command: **0D0!**
- Record response: 0+74.70
    - measurement response of the probe in saturated sand is 74.7%

STEP 3 Store soil specific calibration values for MIN/MAX calibration method using following extended SDI-12 command:

aXSMt,dry,sat,max!

where:

[a] sensor address
[t] 1…9 = soil type
[dry] 4 digit number for value in dry (0.000 to 99.99)
[sat] 4 digit number for saturated value (0.000 to 99.99)
[max] the true volumetric value for the saturated soil

Given the measured values of sand, a probe address of 0 and assigning 1 as soil type, the extended SDI-12 command for a Min/Max calibration would look as follows:

0XSM1,26.12,74.70,40.00!

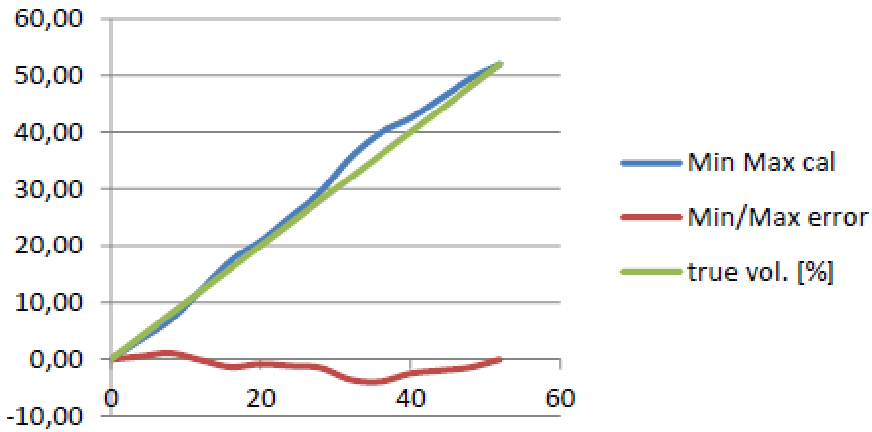
You can then select Soil Type 1 and this Min-Max calibration will be applied to the probe readings

0XGS1!,

- the probe will deliver values from 0% to 40% where 0% indicates dry soil and 40% is the volumetric soil moisture value of saturated sand.

As the relation between dielectric constant and volumetric soil moisture value is not perfectly linear, the measurement response has a certain deviation from the absolute volumetric soil moisture value.

The figure below shows the deviation of a Min/Max calibrated measurement response from the real volumetric value with the probe placed in sand. The brown curve shows the absolute measurement error, which is up to 3.8%.



The maximum error magnitude depends on the soil type. In soil types with mainly mineral content such as sand, the measurement response of the probe is close to linear and a Min/Max calibration results in a good approximation to the real volumetric soil moisture value which is accurate enough for most applications.

In case of soil types with high organic content and requirement for high accuracy, soil specific polynomial calibration is recommended.

12.4 Polynomial Calibration

A polynomial calibration gives the lowest error.

Before carrying out the polynomial calibration, the probe must be set into air/water calibration mode.

Example calibration procedure for a probe on SDI-12 address 0, using organic potting soil:
STEP 1 : For probe set to address 0.

- Set probe into air/water calibrated measurement mode:
  0XGS0!
- Prepare about 10 litres of dried potting soil. In case of this example we started with 8.4 litres of dried potting soil

- Place probe into dry potting soil and issue Start Measurement Command: **0M!**
- Issue Read Data Command: **0D0!**
- Record response: **0+15.07**
  - Measured value in dry potting soil is 15.07%

STEP 2 : Pour a defined quantity of water into the dried potting soil and stir it thoroughly. In this example we started by adding 0.35 litre of water (corresponding volumetric value = 4%)

- Place probe into the soil and issue Start Measurement Command: **0M!**
- Issue Read Data Command: **0D0!**
- Record response: 0+30.20
  - measurement value with 4% volumetric value is 30.2%
  - repeat the measurement a few times. If the measurement results differ more than 3%, the soil is not sufficiently stirred. Continue stirring the soil, until the measurement results become stable.

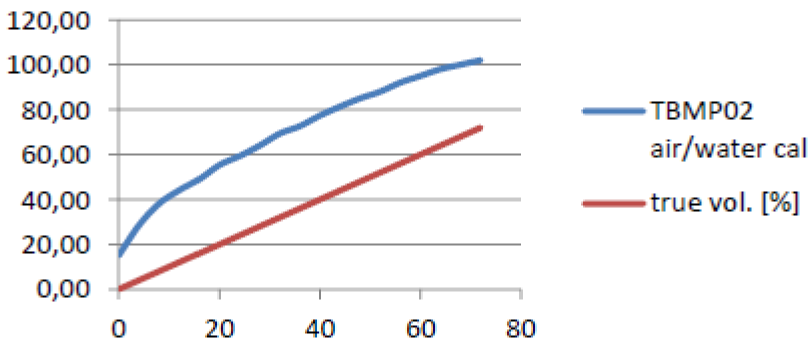
STEP 3 to n-1: add another defined quantity of water to the soil and stir it thoroughly

- Record the measurement response
- Continue this process, until the soil reaches saturation.

The following table has been derives for potting soil:

Water volume [l]	true vol. [%]	Measurement response
0	0	15,00
0,35	4	28,33
0,7	8	38,00
1,05	12	44,00
1,4	16	49,00
1,75	20	55,33
2,1	24	59,33
2,45	28	64,00
2,8	32	69,33
3,15	36	72,67
3,5	40	77,33
3,85	44	81,33
4,2	48	85,00
4,55	52	88,00
4,9	56	92,00
5,25	60	95,00
5,6	64	98,00
5,95	68	100,00
6,3	72	102,00

The graph below shows the deviation of the measurement result to the true volumetric value before polynomial calibration.



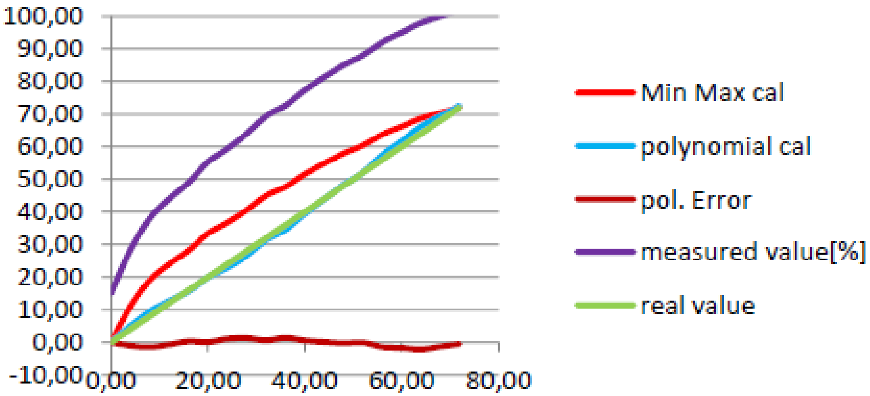
STEP n: Next take table 1 and fit the values of the measurement response column to a 3rd order polynomial

ax^3+bx^2+cx+d

where x is the probe reading and the coefficients a, b, c, d are chosen to correctly convert the measurement response values into true volumetric value. In case of potting soil a = 0.00004, b = 0.0004, c = 0.3, d = -4.7

air / water cal. measured value[%]	Polynomial calibrated result	Min/Max calibrated result	real Vol%	error
15,00	0,02	0,00	-0,02	-0,02
28,33	5,03	11,03	-1,03	-1,03
38,00	9,47	19,03	-1,47	-1,47
44,00	12,68	24,00	-0,68	-0,68
49,00	15,67	28,14	0,33	0,33
55,33	19,90	33,38	0,10	0,10
59,33	22,86	36,69	1,14	1,14
64,00	26,62	40,55	1,38	1,38
69,33	31,35	44,97	0,65	0,65
72,67	34,56	47,72	1,44	1,44
77,33	39,39	51,59	0,61	0,61
81,33	43,87	54,90	0,13	0,13
85,00	48,26	57,93	-0,25	-0,25
88,00	52,06	60,41	-0,06	-0,06
92,00	57,43	63,72	-1,43	-1,43
95,00	61,71	66,21	-1,71	-1,71
98,00	66,19	68,69	-2,19	-2,19
100,00	69,30	70,34	-1,30	-1,30
102,00	72,51	72,00	-0,51	-0,51

a	0,00004
b	0,0004
c	0,3
d	-4.7



The graph above shows that the polynomial calibrated results show good matching with the real volumetric soil value. The maximum error is 2.2%. The graph also shows the error from the Min-Max calibration, which in this case is less accurate due to the non linear behaviour of potting soil.

Finally the polynomial coefficients need to be stored to the EEPROM of the probe using the extended SDI-12 command:

aXSSt,a,b,c,d!

where:

[a] the first “a” represents the sensor address
[t] represents a number in the range 1…9, which assigns a soil type. Consequently 9 soil specific sets of calibration values can be saved to the EEPROM of the probe
[a] represents coefficient a
[b] represents coefficient b
[c] represents coefficient c
[d] represents coefficient d maximum 8 digits per coefficient, the decimal point may be at any place

Given the measured values of potting soil, a probe address of 0, the required polynomial coefficients and assigning 2 as soil type, the extended SDI-12 command for the polynomial calibration looks as follows:

0XSS2,0.00004,0.0004,0.3,-4.7!

Use the Soil Type Selection extended SDI-12 command to activate this soil type:

0XGS2!

- the probe will apply polynomial calibration and deliver measurement results with good accuracy.

Out of the three calibration methods offered by the Otto SMP, the polynomial method delivers best accuracy with respect to true volumetric soil moisture value.

13 Maintenance

13.1 Above Ground Probe

The Above Ground probe requires regular preventative maintenance to help maximize the life of the components. The most common cause of failure of re-enterable soil moisture probes is moisture ingress and maintenance activities are designed to minimize the opportunities for that to occur.

6 Monthly:

- Pre-inspection
  - Review the data from the sensor and check that there are no spikes or dropouts
- On site
  - Inspect the sensor cable to make sure it has not been damaged by machinery or chewed by animals (sheathing the cable in blind poly or conduit will help protect it from damage)
  - Check that the connections from the cable to the data logger / telemetry unit are secure and free from water ingress
  - Remove the cap from the probe head
  - Inspect the breather vent to ensure it has not been blocked by dust or debris
  - Check that the seal is intact and clean
  - Withdraw the probe column and check that there is no sign of condensation on the printed circuit boards or sensor rings
  - Shine a torch down the tube and make sure that the tube is dry: if there is any moisture in the tube do not re-install the probe until you have (1) dried out the tube and (2) identified and rectified the cause of the moisture ingress

13.2 Sub-Surface probe

As the sub surface prove is fully sealed it requires no ongoing maintenance.

However you should still maintain a watch on the sensor data to check for any signs of mechanical damage to the sensor or cable.

6 Monthly:

- Review the data from the sensor and check that there are no spikes or dropouts
- Inspect the sensor cable to make sure it has not been damaged by machinery or chewed by animals (sheathing the cable in blind poly or conduit will help protect it from damage)
- Check that the connections from the cable to the data logger / telemetry unit are secure and free from water ingress.

14 SDI-12 Command List

14.1 Sensors

14.1.1 Standard Commands

The section below shows a quick summary of the standard SDI-12 commands available with the sensors.

Command	Function
?!	Acknowledge active (any active sensors respond)
aI!	Return sensor information string
aAb!	Change sensor address from a to b
aM!	Default Measure Soil Moisture
aC!	Default Concurrent Measure Soil Moisture
aM1!	Measure Soil Moisture & Soil Temperature
aC1!	Concurrent Measure Soil Moisture & Soil Temperature
aM2!	Measure Soil Temperature
aC2!	Concurrent Measure Soil Temperature
aMC!	Default measure with CRC (also for MC1!, MC2!)
aCC!	Concurrent measure with CRC (also for CC1!, CC2!)

14.1.2 Extended Commands

The section below presents a quick summary of the extended SDI-12 commands available with the sensors.

Command	Function
aXCA!	Perform Air Calibration
aXCW!	Perform Water Calibration
aXCTsnn.nn	Set temperature calibration offset s = +/- nn.nn = offset in degrees C
aXGA!	Query number of samples set for averaging of the soil moisture value

aXGCT!	Query temperature calibration offset
aXGP!	Query number of samples set for moving averaging of the soil moisture
aXGT!	Query soil type setting
aXGTC!	Query soil temp compensation factor (compensation for temperature induced changes in soil moisture)
aXSD!	Reset sensor to default settings Add = 0, Soil scaling coeff = 1, Temp unit = C, Temp cal offset = 0, Soil type = 0 (air-water), Polynomial coeff = 0 = a=b=c=d, Cal method = 0 (min-max)
aXSAnn!	Set number of samples for averaging (Default = 3)
aXSCn!	Select calibration method 0 = min-max 1 = polynomial
aX..!	Query scaling factor
aXSMt,dry,sat,max!	Set coefficients for Min-Max calibration
aXSSt,a,b,c,d!	Set coefficients for polynomial calibration
aXGSt!	Set soil type (Default =0)
aXSPnn!	Set number of samples for moving average value (Default =0)
aXSTnn.mm!	Set scaling factor (Default 1.75)
aXSTCsnn.mm	Set Soil Temp Compensation factor (Default +00.10 %/^{o}C)

14.2 SDI Concentrator PCB

This section shows the standard and extended SDI-12 commands available at the SDI-12 Concentrator PCB.

14.2.1 Standard Commands

The section below shows a quick summary of the standard SDI-12 commands.

Command	Function
?!	Acknowledge active (any active sensors respond)
aI!	Return sensor information string
aAb!	Change sensor address from a to b
aM!	Default Measure Soil Moisture - Sensors 0 to 8
aC!	Default Concurrent Measure Soil Moisture - Sensors 0 to 8
aM1!	Measure Soil Moisture - Sensors 9 to 15
aC1!	Concurrent Measure Soil Moisture - Sensors 9 to 15
aM2!	Measure Soil Temperature - Sensors 0 to 8
aC2!	Concurrent Measure Soil Temperature - Sensors 0 to 8
aM3!	Measure Soil Temperature - Sensors 9 to 15
aC3!	Concurrent Measure Soil Temperature - Sensors 9 to 15
aC4!	Concurrent Measure Raw Soil Moisture - Sensors 0 to 8
aC5!	Concurrent Measure Raw Soil Moisture Temperature - Sensors 9 to 15
aCCx!	All of the Concurrent commands are also available in the format which includes a CRC (error checking) and may be used on loggers/telemetry which support the mode e.g. Concurrent Measure 2 for probe on address 0: 0CC2!

14.2.2 Extended Commands

The section below presents a quick summary of the extended SDI-12 commands available with the sensors.

Command	Function
aXGSN!	Query the number of sensors connected to the PCB
aXSSN,nn!	Set the number of sensors connected to the PCB (nn = 0 to 15)
aXSCS!	Scan sensors and check if all are connected
aXGCS!	Display status of aXSCS! Command OK = all sensors responded NOK = one or more sensors failed
aXS:cmd:addr	Send extended command direct to sensor cmd = extended command addr = sensor number (0 to 15)
aXGST!	Get result from direct extended command SET_OK = command succeeded SET_FAIL = command failed

15 Warranty

The Otto soil moisture probe family is covered by a one (1) year warranty.

Warranty is available on a return to base basis only. End users must pay for return shipment of faulty products either TOIP Pty Ltd or their local distributor. If the unit is assessed by TOIP Pty Ltd and found to be a warranty failure, it will be replaced free of charge TOIP Pty Ltd will pay the return shipment to the owner.

The warranty does not cover mechanical damage, damage inflicted during installation or removal or damage caused by animals.

Prior to using the product, please ensure that you read, understand and accept the Warranty Statement. If you do not accept the conditions of the Warranty Statement, please return the probe for a refund.

16 Order Form

To avoid errors, use the following form when creating orders for probe: you can copy and paste this information into your own order template.

Model	**Above Ground (AG)**	**Sub-Surface (SS)**	**Naked (No PCB)**
Quantity		**-**	
Length (cm)		**(03 = 30cm … 15 = 150cm)**	
Number of Sensors		**(03 to 15)**	
Cable Length (m)		**(03 to 40)**	

Position	**010**	**020**	**030**	**040**	**050**	**060**	**070**	**080**
S = Sensor **X = Spacer**								
Position	**090**	**100**	**110**	**120**	**130**	**140**	**150**	**-**
S = Sensor **X = Spacer**								-

17 Regulatory Compliance Declaration

The Otto family of Soil Moisture Probes has been tested for Electromagnetic Compatibility (EMC) and Radio Frequency Interference (RFI).

Test Authority	
Date of Testing	
Test Standard	EN61326-1: 2006 (IEC61326-1: 2005 Ed 1) Electrical requirements for measurement, control and laboratory use – EMC requirements. Part 1 : General Requirements
Manufacturer	Tekbox Digital Solutions 50/11 Truong Son Tan Binh District HO CH MINH CITY VIETNAM
Model Number	OT-AG-XX-YY-ZZ OT-SS-XX-YY-ZZ
Type of Equipment	Otto dielectric soil moisture probe

This is to certify that the Otto family of dielectric soil moisture probes, manufactured by Tekbox Digital Solutions, meets or exceeds the standards for CE compliance as per the Council Directives noted above.