

## SOIL MOISTURE PROBE MANUAL

The TBSMP03 is a sensor for monitoring soil moisture levels and soil temperature values in precision farming and environmental monitoring applications. It provides the data required for cost efficient irrigation, crop yield optimisation and protection of natural resources.

The TBSMP03 has been designed to work in any type of soil. It has a low current consumption and an SDI-12 interface. It is ideally suited for battery or solar powered remote applications. The TBSMP03 has short measurement time and fast response to any fluctuation in the soil moisture level. It is easy to install and easy to calibrate. The TBSMP03 is a rugged, hermetically sealed design, equipped with a IP67 connector and customizable cable length.

Its advanced soil specific calibration capability gives volumetric readings with high absolute accuracy. The TBSMP03 is a direct, compatible replacement for the TBSMP02.



### Features

- Accurate volumetric soil moisture and temperature measurement
- Fast response
- Not influenced by salinity levels
- Suitable for any soil type
- Temperature compensated
- SDI-12 Interface
- Low Power Consumption
- Simple installation
- Advanced soil specific calibration
- Small size
- Rugged design
- Hermetically sealed, casted
- Customizable cable length
- Operating Temperature Range: -20°C - +65°C

### Target Applications

- Crop yield optimisation
- Precision irrigation
- Soil hydrology monitoring
- Erosion monitoring
- Protection of natural resources

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## 1 Introduction

Controlled irrigation of crops is an essential part of successful farming. Supplying plants with the correct amount of water results in maximum crop yield and/or maximum crop quality. Natural resources are protected and the overall cost is optimized.

Under irrigation restricts plant growth, over irrigation deprives the roots of oxygen and negatively effects plant health and growth as well. In between the two points there is a zone of maximum crop quality and a zone of maximum crop growth. Consequently, it is important to know the soil moisture level in order to keep the root zone of the plants in the favoured moisture zone.

### 1.1 Soil Moisture Level Measurement

There are two alternative units to express soil moisture levels:

- Soil moisture tension (matrix potential) – Adhesive intermolecular forces between water and soil particles require the plant to apply a certain amount of tension to draw water from the soil (normally expressed in kPa)
- Soil moisture content – The amount of water stored in a given volume of soil (normally expressed in %)

The TBSMP03 measures volumetric soil moisture content, based on the relationship between dielectric constant of the soil and its moisture content. The TBSMP03 responds instantly to any change in the soil moisture content level.

### 1.2 Product Features

TBSMP03 is based on an innovative sensor circuitry, a low power controller and robust SDI-12 interface hardware:

- Measurement of volumetric soil moisture content and soil temperature
- 5V, 1200 baud SDI-12 data interface with transient protection
- 6 - 17V, 21 mA sensor supply voltage
- Rugged design, electronics completely casted
- Dimensions: 32mm tube diameter, 175mm length
- Weight: 200g
- IP67 connector, cable length upon order
- Operating temperature range: -20 - +65°C

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## 1.3 Calibration

**Volumetric water content**,  $\theta$ , is defined mathematically as:  $\theta = \frac{V_w}{V_T}$

where  $V_w$  is the volume of water and  $V_T = V_{soil} + V_{void} = V_{soil} + V_{water} + V_{air}$  is the total volume (that is soil volume + water volume + air space).

To simplify, below saturation, we can consider the total volume as constant and equivalent to the value of dry soil. Adding water to dry soil, in most cases, will not change the total volume. Water will fill the voids in between the soil particles. Once all voids are completely filled with water, the soil is saturated.

As an example, 10 dm<sup>3</sup> of coarse, dry sand can be mixed with up to 4 litres of water without increasing the total volume. Consequently, the maximum volumetric water content is 0.4 or 40%.

The TBSMP03 can be operated with different methods of calibration. The utilized calibration mode can be selected using an Extended SDI-12 command

### 1.3.1 Air / Water Calibration

As the maximum water storage capacity largely depends on the soil type, the TBSMP03 comes factory calibrated 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 deliver measurement results higher than 0% when placed in dry soil. As an example:

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

Nevertheless, for many purposes, when soil moisture monitoring is rather about observing trends than measurement of absolute values, an air/water calibration is sufficient.

The calibration is long term stable, however it can be repeated 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.

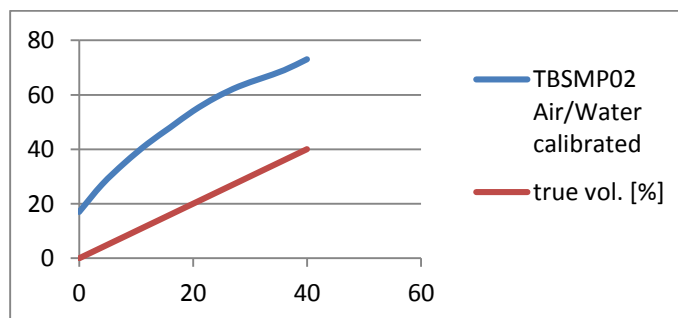


Figure 1 – Sand: air water calibrated measurement response compared to true volumetric value

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Figure 1 shows the measurement response of an Air/Water - calibrated probe versus the real volumetric values. An Air/Water – calibrated TBSMP03 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.

**Summary:** An Air/Water calibration is a simple calibration method, suitable if the probe is used to monitor trends rather than absolute volumetric values. If absolute volumetric values are required, the TBSMP03 offers additional calibration methods, described in the next chapters. By default, the TBSMP03 comes factory calibrated for air/water, sand and potting soil. The calibration method and soil type can be selected by issuing the corresponding Extended SDI-12 Commands.

## 1.3.2 Soil specific Min/Max - calibration

Before carrying out a Min/Max calibration, ensure that the probe is in air/water calibrated measurement mode.

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. At Tekbox we usually take 10dm<sup>3</sup> to have sufficient soil to cover the probe. Record the measurement response of the probe in dry soil.

As a next step add defined quantities of water, and thoroughly mix it with the dry soil until it reaches saturation. Saturation is reached, once the water ponds. Record the volume of water it took to get the soil saturated. Bed the probe inside the saturated soil and record the measurement response.

### Example calibration procedure, using sand:

#### STEP 1

Probe set to address 0. Set probe into air/water calibrated measurement mode: **0XGS0!**

Place probe into dry sand and 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

4dm<sup>3</sup> of water are required to saturate 10dm<sup>3</sup> of sand -> real volumetric value of saturated sand = **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]** 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

**[dry]** represents the measurement response in dry soil. It is a four digit number with decimal point anywhere.

**[sat]** represents the measurement response in saturated soil. It is a four digit number with decimal point anywhere.

**[max]** represents the true volumetric volume of 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!**

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Upon selecting soil type 1 using the extended SDI-12 command for soil type selection: **0XGS1!**, the probe will apply the Min/Max calibration and 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%.

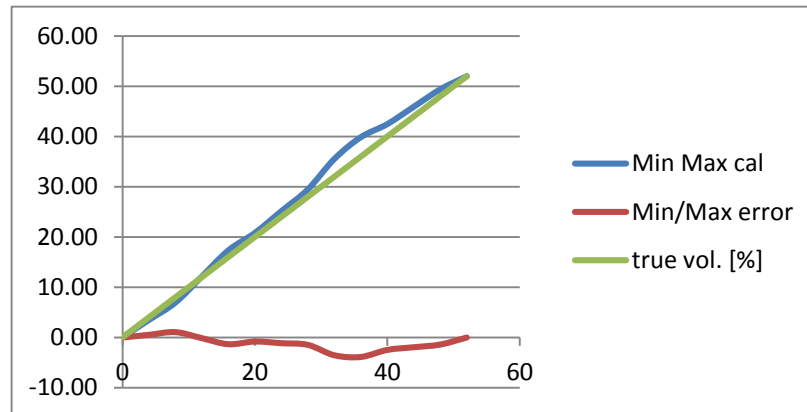


Figure 2 – Sand: min max calibrated measurement response compared to true volumetric value [%]

**Summary:** The Min/Max calibration is a soil specific calibration method, which takes the measurement response in dry and saturated soil and scales it to the true volumetric value of saturated soil. It is a two point calibration which does not take into account any non-linearities. The measurement response of a Min/Max calibrated probe is affected with an absolute error with respect to the real volumetric value. 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.

### 1.3.3 Soil specific Polynomial - calibration

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

[Example calibration procedure, using organic potting soil:](#)

#### STEP 1

Probe set to address 0. Set probe into air/water calibrated measurement mode: **0XGS0!**

Prepare about 10dm<sup>3</sup> of dried potting soil. In case of this example we started with 8,4dm<sup>3</sup> 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 -> measurement response of the probe 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 **0,35dm<sup>3</sup>** of water -> corresponding volumetric value = **4%**

Place probe into the soil and issue Start Measurement Command: **0M!**

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Issue Read Data Command: **OD0!**

Record response: 0+30.20 -> measurement response of the probe in potting soil with 4% volumetric value is **30.2%**

Hint: take the measurement a few times, each time removing and reinserting the probe into the soil at a slightly different place. In case that 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. Insert the probe and record the measurement response.

Continue this process, until the soil reaches saturation.

In case of potting soil, we derived the table below:

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

Table 1 – Measurement response for potting soil

Figure 3 below shows the deviation of the measurement result to the true volumetric value before polynomial calibration.

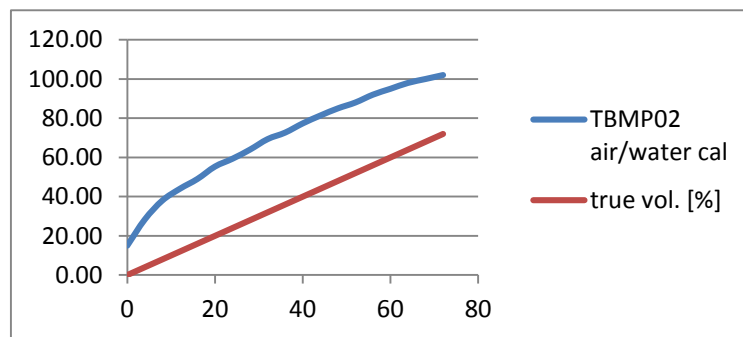


Figure 3 – Potting Soil: air water calibrated measurement response compared to true volumetric value



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## STEP n:

Next we take table 1 and multiply the values of the measurement response column with a 3<sup>rd</sup> order polynomial

$ax^3+bx^2+cx+d$  where x are the measurement response values 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

Table 2 – polynomial calibration applied to the measurement results of table 1

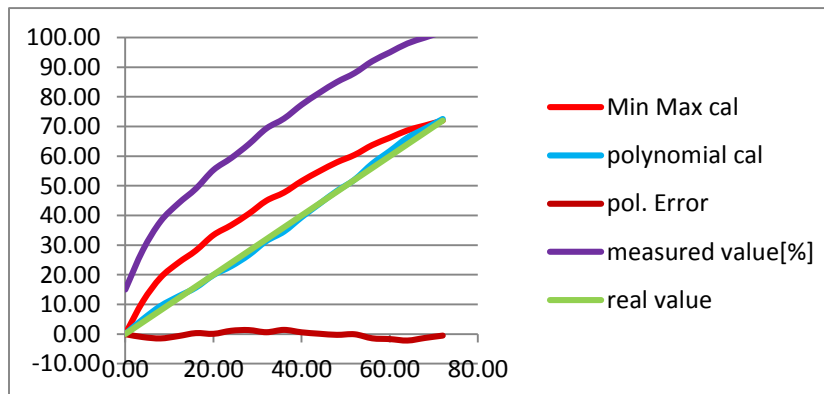


Figure 4 – potting soil: min max calibrated measurement and polynomial calibrated measurement response compared to true volumetric value

Table 2 and figure 4 show that the polynomial calibrated results show good matching with the real volumetric soil value. The maximum error is 2.2%. Figure 4 also shows the deviation with respect to a min/max calibration which in this case is less accurate due to the non linear behavior 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]** at the beginning of the command represents the sensor address

**[t]** represents a number in the range 1...9, which assigns a soil type. Consequently 9 soil specific sets of

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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!**

Upon selecting soil type 2 using the extended SDI-12 command for soil type selection: **0XGS2!**, the probe will apply polynomial calibration and deliver measurement results with good accuracy.

**Summary:** The polynomial calibration is a soil specific multi point calibration which compensates the non-linearity in soils with high organic content. Out of the three calibration methods offered by the TBSMP03, it delivers best accuracy with respect to true volumetric soil moisture value.

## 1.4 Factory calibration

The TBSMP03 is factory calibrated to:

### Air / Water

Air / water calibration is carried individually for each probe. Consequently the probes can be installed instantly.

### Soil Specific Calibration

For 3 soil types, both Min/Max as well as polynomial calibration coefficients are stored to each probe. The parameters are based on measurements taken with a sample lot of probes and subsequent averaging. Thus it is not an individual calibration, but due to good repeatability behavior of the TBSMP03, the measurement results are within a range of typically  $\pm 2\%$ . 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

Table 3 – factory calibration parameters

Typically, Soil Type 3 is a good compromise in many type of soils. The calibration parameters for soil type 1 to 3 can be overwritten by users carrying out their own calibration. They can be restored any time using the values of table 3.

Polynomial coefficients can be calculated using a tool which can be downloaded from the Tekbox website.

Refer to the TBSMP03 calibration manual for more details.

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## 1.5 Placement

When bedding the sensor in the soil, it is essential to establish a close bond between soil and sensor surface, avoiding any air gaps.

Drill or dig a hole into the soil, down to the required depth. Sieve the removed soil to remove any stones or debris. Place the sensor at the bottom of the hole and cover it with sieved soil. Pour sufficient water into the hole and wait until it seeps away. Add more soil and water it again. Repeat this procedure until the hole is completely covered.

It is recommended to place the probe in a tilted position rather than in a horizontal or vertical position.

## 1.6 Removal

Don't pull at the cable to remove the soil moisture probe, as it may damage the product and void warranty. Carefully remove the soil with a small shovel until you can access the body of the sensor. Do not damage the cable jacket or the sensor coating.

## 1.7 Installation

The TBSMP03 is compatible with any data logger or remote telemetry unit with SDI-12 interface. Refer to the data logger or RTU manual and to chapter 2 of this datasheet.

## 1.8 SDI-12

SDI-12 is a standard for interfacing data recorders with microprocessor-based sensors. SDI-12 stands for serial/digital interface at 1200 baud. It can connect multiple sensors with a single data recorder on one cable. It supports up to 60 meter cable between a sensor and a data logger.

The SDI-12 standard is prepared by

**SDI-12 Support Group  
(Technical Committee)  
165 East 500 South  
River Heights, Utah  
435-752-4200  
435-752-1691 (FAX)  
<http://www.sdi-12.org>**

The latest standard is version V1.3 which dates from July 18<sup>th</sup>, 2005. The standard is available on the website of the SDI-12 Support Group.

More information on SDI-12 is presented in chapter 3.

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## 2 Application Examples

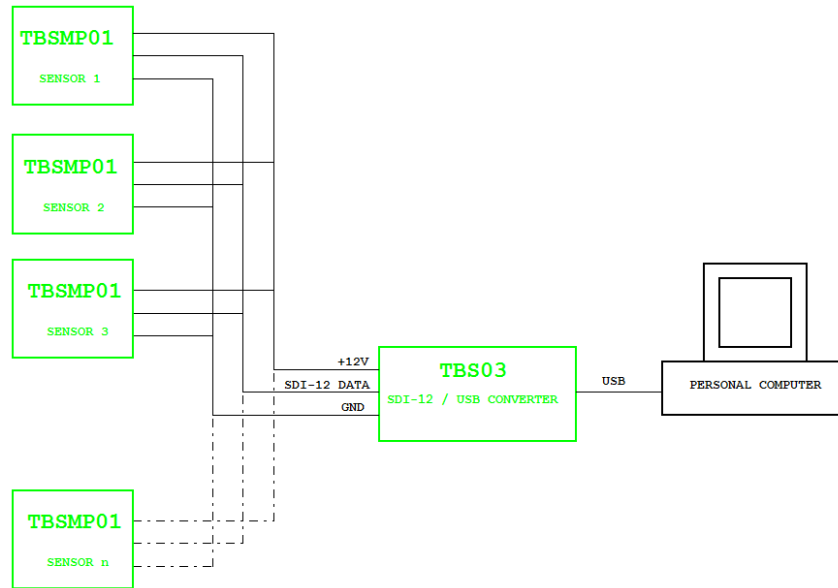


Figure 5 – TBSMP03 sensors connected to TBS03 SDI-12 to USB converter, setup for controlling / testing sensors and for PC based data recording

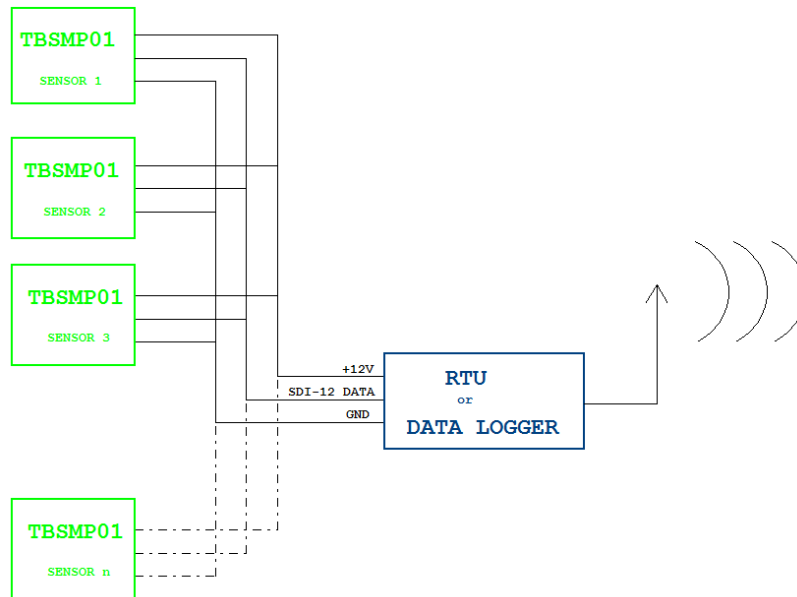


Figure 6 – TBSMP03 sensors connected to Remote Telemetry Unit or Data Recorder

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## 3 Functional Description

### 3.1 Overview

The SDI-12 standard defines a set of commands to configure sensors and to initiate measurements. Upon receiving specific commands, the sensor may carry out internal tasks, respond with information on conversion time or send measurement data.

SDI-12 commands are typically ASCII strings which are generated by the data recorder/controller firmware. TBSMP03 can be connected to a TBS03 SDI-12 to USB converter and controlled by a PC application or hyper terminal. TBS03 converts the command strings to the logic levels and baud rate specified by the SDI-12 standard. Furthermore, TBS03 handles breaks, marks and all other details of the SDI-12 protocol.

Upon receiving data or status information originated by TBSMP03, the TBS03 extracts the corresponding ASCII strings and sends them to the USB Virtual COM Port of the PC.

In remote applications, TBSMP03 can be connected to a data logger, a data terminal or a Radio Telemetry Unit with a SDI-12 interface.

### 3.2 SDI-12 Basics

The SDI-12 is a serial data communication standard for interfacing multiple sensors with a data recorder. SDI-12 uses a shared bus with 3 wires: power (+12V), data, ground Data rate: 1200 baud. Each sensor at the bus gets a unique address which is in the range ASCII [0-9, a-z, A-Z]. The default address of every sensor is ASCII[0]. When setting up a SDI-12 sensor network, every sensor needs to be configured with a unique address. This can be done using the Change Address Command. A sensor can typically measure one or more parameters. Sensor manufacturers usually specify '*Extended Commands*' to configure or calibrate sensors. These commands are specified by the manufacturer, but they follow the command structure specified by SDI-12.

A typical recorder/sensor measurement sequence proceeds as follows:

- 1) The data recorder wakes all sensors on the SDI-12 bus with a break.
- 2) The recorder transmits a command to a specific, addressed sensor, instructing it to make a measurement.
- 3) The addressed sensor responds within 15.0 milliseconds, returning the maximum time until the measurement data will be ready and the number of data values it will return.
- 4) If the measurement is immediately available, the recorder transmits a command to the sensor instructing it to return the measurement result(s). If the measurement is not ready, the data recorder waits for the sensor to send a request to the recorder, which indicates that the data is ready. The recorder then transmits a command to get the data.
- 5) The sensor responds, returning one or more measurement results.

#### **SDI-12 Command Structure:**

Each SDI-12 command is an ASCII string with up to 5 characters, starting with the sensor address and terminated by a "!" character.

#### Example:

#### **Send Identification Command 0!**

0 is the sensor address (sensor zero). Upon receiving this command, the sensor will send an ASCII string containing sensor address, SDI-12 compatibility number, company name, sensor model number, sensor version number and sensor serial number.

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The standard process to carry out a measurement is to send a measurement request upon which the sensor responds with the time that is required to carry out the measurement and the number of data items being returned. After waiting the time that the sensor requires to carry out the measurement, the data recorder sends a “*Read Command*” to get the measurement results.

Example:

Start Measurement Command **0M1!**

Sensor 0 might respond **00012** which means the measurement will take 1 second and deliver 2 values.

After min. 30 seconds, the data recorder can send the “*Read Data Command*” **0D0!** to which Sensor 0 might reply **0+67.75+17.23**. +67.53+17.23 is the two measurement results which may be 67.75% soil moisture level and 17.23°C soil temperature.

The response string of a sensor is always in ASCII format and may contain up to 40 or up to 80 characters, depending on the type of command. Out of 40 or 80 characters, the values part of the response string may contain up to 35 or 75 characters.

### 3.3 Sensor Identification

The soil moisture probe sensor interface will respond with a string of the following format when sending the “*Send Identification*” command **al!**:

allccccccmmmmmmvvvxxxxxxxxxxxxx<CR><LF>

Example: 013TEKBOXSMP00001003123456<CR><LF>

Where:	0	SDI-12 Sensor address
	13	SDI-12 version number, version 1.3
	TEKBOX	Company name
	SMP0000	Model Name
	1.00	Firmware version 1.00
	123456	Serial number of Soil Moisture Probe

### 3.4 Sensor Address

Each soil moisture probe is delivered with a default address of “0”

The soil moisture probe accepts SDI-12 addresses in the range “0” to “9”, “A” to “Z” and “a” to “z”. Setting the soil moisture probe address can be done using the “*Change Address Command*” **aAb!**.

Note:

- If the new address is invalid, the current address will be kept.
- The soil moisture probe sensor will remain unresponsive for approximately 1 second while the new address is saved in the EEPROM memory.
- The soil moisture probe sensor interface supports “?” as an address only for “*Acknowledge Active*” Command **a!**.

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## 3.5 Measurement

The soil moisture probe sensor interface accepts the “Start Measurement” Command **aM!**, “Additional Measurement” Commands **aMn!** and “Start Concurrent Measurement” Command **aC!**, “Additional Concurrent Measurement” Commands **aCn!** for obtaining calibrated values from the probe.

The soil moisture probe sensor interface will not support the “Continuous Measurement” Command **aRn!** and “Continuous Measurement and Request CRC” Command **aRCn!**. The soil moisture probe sensor will respond with its address followed by <CR><LF> in response to this command.

The response to “Start Measurement” **aM!**, “Additional Measurement” Commands **aMn!** and “Start Concurrent Measurement” Command **aC!**, the “Additional Concurrent Measurement” Command **aCn!** reports how many sensor values - Soil Moisture Level and/or Temperature - will be sent. In order to receive the desired sensor values, the recorder needs to issue the corresponding “Send Data” Command(s) **aDn!**.

Note: The soil moisture probe sensor interface uses a format of “sign” followed by n digits.

## 3.6 Commands – Quick Reference

### Measurement commands:

aM! aMC! aC! aCC! measure Soil Moisture level [%]

aM1! aMC1! aC1! aCC1! measure Soil Moisture level [%] and Soil Temperature [°C]

aM2! aMC2! aC2! aCC2! measure Soil Temperature [°C]

### Extended SDI-12 commands:

aXCA!:	Air calibration
aXCW!:	Water calibration
aXCTsnn.nn!:	Temperature calibration
aXSAnn!:	Set number of samples to be taken for averaging of the soil moisture value (2 digits)
aXSPnn!:	Set number of samples to be taken for gliding averaging of the soil moisture value (2 digits)
aXSTnn.nn!:	Set scaling factor
aXSMt,dry,sat,max!:	set parameters for Min/Max calibration (4 digits per coefficient; the decimal point may be at any position)
aXSSt,a,b,c,d!:	set coefficients for polynomial calibration max. 7 digits for a, b; max. 5 digits for c, d; the decimal point may be at any position
aXSCn!:	Set calibration method n = 0 : min – max n = 1 : Polynomial
aXSD!:	Restore default settings 1. Sensor address: 0 2. Soil scaling coefficient: 1 3. Temperature unit: Celsius 4. Temperature offset: 0 5. Soil type: 0; air/water calibration 6. Polynomial coefficients: a = 0; b = 0; c = 1; d = 0 7. Calibration method: Min-max
aXGSt!:	Select soil type for measurement

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- aXGA!: Query number of samples set for averaging of the soil moisture value
- aXGP!: Query number of samples set for gliding averaging of the soil moisture value
- aXGT!: Query soil type
- aXGCT!: Query temperature calibration offset

## 3.7 Measurement Examples

### aM!, aC! : Measure Soil Moisture level [%]

Command	Response	Comment
aM!	a0011<CR><LF>	
aD0!	a+9.25<CR><LF>	
aC!	a00101<CR><LF>	
aD0!	a+9.25<CR><LF>	

The value +9.25 is the soil moisture level in [%]. The soil moisture level is represented by two digits after the decimal point. The maximum soil moisture level is +100 and does not have any digits after the decimal point.

### aM1!, aC1! Measure Soil Moisture Level [%] and Soil Temperature [°C]

Command	Response	Comment
aM1!	a0012<CR><LF>	
aD0!	a+nn.nn + mm.mm<CR><LF>	

Value nn.nn: Soil Moisture Level      Value mm.mm: Soil Temperature value

### aM2!, aC2! : Measure Soil Temperature [°C]

Command	Response	Comment
aM2!	a0011<CR><LF>	
aD0!	a+nn.nn <CR><LF>	



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## 3.8 Supported SDI-12 Commands

Following commands are supported by the soil moisture probe:

Command	Description	Response
<b>a!</b>	Acknowledge Active	<b>a&lt;CR&gt;&lt;LF&gt;</b>
<b>a!</b>	Send Identification	<b>allccccccmmmmmmvvvxxxxxxxxxxxxx&lt;CR&gt;&lt;LF&gt;</b> Identification information
<b>aAb!</b>	Change Address	<b>b&lt;CR&gt;&lt;LF&gt;</b> Changing the probe sensor address
<b>?!</b>	Address Query	<b>a&lt;CR&gt;&lt;LF&gt;</b>
<b>aM!</b>	Start Measurement	<b>atttn&lt;CR&gt;&lt;LF&gt;</b> Delay (ttt) in seconds and number of values (n) up to 9
<b>aMn!</b>	Additional Measurement	<b>atttn&lt;CR&gt;&lt;LF&gt;</b> Delay (ttt) in seconds and number of values (n) up to 9 A response of <b>a0000&lt;CR&gt;&lt;LF&gt;</b> is provided indicating the additional measurement are not supported in sensor
<b>aMC!</b>	Start Measurement and Request CRC	<b>a0000&lt;CR&gt;&lt;LF&gt;</b> Supported
<b>aMCn!</b>	Additional Measurement and Request CRC	<b>a0000&lt;CR&gt;&lt;LF&gt;</b> Supported
<b>aC!</b>	Start Concurrent Measurement	<b>atttnn&lt;CR&gt;&lt;LF&gt;</b> Delay (ttt) in seconds and number of values (nn) up to 20
<b>aCn!</b>	Additional Concurrent Measurement	<b>a0000&lt;CR&gt;&lt;LF&gt;</b> Not supported
<b>aCC!</b>	Start Concurrent Measurement and Request CRC	<b>a0000&lt;CR&gt;&lt;LF&gt;</b> Not supported
<b>aCCn!</b>	Additional Concurrent Measurement and Request CRC	<b>a0000&lt;CR&gt;&lt;LF&gt;</b> Not supported
<b>aV!</b>	Start Verification	<b>a0000&lt;CR&gt;&lt;LF&gt;</b> Not supported
<b>aRn!</b>	Continuous Measurement	<b>a&lt;CR&gt;&lt;LF&gt;</b> Not supported
<b>aRCn!</b>	Continuous Measurement and Request CRC	<b>a&lt;CRC&gt;&lt;CR&gt;&lt;LF&gt;</b> Not supported

Table 4 – Standard SDI-12 commands

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## 3.9 Supported Extended Commands

Command	Description	Response
<b>aXSTnn.mm!</b>	<p>Set the soil type coefficient ; nn.mm : 00.00 to 99.99.</p> <p>The soil type coefficient (nn.mm) is represented as: 01.99 to 99.99; depending on the soil type, the moisture levels are divided by this coefficient. Default value is 01.00; "n.m" is always in 4 digits format.</p> <p>[a] is the sensor address</p> <p>Application: by default, the soil type coefficient is set to "1". Changing the soil type coefficient can be used, if any scaling of the soil moisture level value is required. It is however recommended to make a soil specific calibration instead.</p>	<b>aX_OK&lt;CR&gt;&lt;LF&gt;</b>
<b>aXCA!</b>	<p>Soil Moisture Air Calibration</p> <p>[a] is the sensor address</p> <p>Application: by default, the sensor is already calibrated to air. Placing the sensor in air and then sending the <b>aXCA!</b> command triggers a re-calibration</p>	<b>aX_OK&lt;CR&gt;&lt;LF&gt;</b>
<b>aXCW!</b>	<p>Soil Moisture Water Calibration</p> <p>[a] is the sensor address</p> <p>Application: by default, the sensor is already calibrated to water. Placing the sensor in water and then sending the <b>aXCW!</b> command triggers a re-calibration</p>	<b>aX_OK&lt;CR&gt;&lt;LF&gt;</b>
<b>aXCTsnn.nn!</b>	<p>Soil Temperature Calibration</p> <p>[a] is the sensor address</p> <p>s:sign</p> <p>nn.nn : 00.00 -&gt;±99.99</p> <p>example : 0XCT+01.00! , add 1 degree Celsius to measured value</p> <p>Application : temperature calibration; factory calibrated by default</p>	<b>aX_OK&lt;CR&gt;&lt;LF&gt;</b>
<b>aXSAnn!</b>	<p>Set number of samples for averaging</p> <p>Max value nn = 10</p> <p>[a] is the sensor address</p> <p>Application: averaging; default value is "1"</p>	<b>aX_OK&lt;CR&gt;&lt;LF&gt;</b>
<b>aXSPnn!</b>	<p>Set number of samples for gliding average</p> <p>Max value nn = 10</p> <p>[a] is the sensor address</p> <p>Application: gliding averaging; default value is "0"</p>	<b>aX_OK&lt;CR&gt;&lt;LF&gt;</b>
<b>aXSD!</b>	<p>Restore all parameters to default values</p> <ol style="list-style-type: none"> <li>1. Sensor address: 0</li> <li>2. Soil scaling coefficient: 1</li> <li>3. Temperature unit: Celsius</li> <li>4. Temperature offset: 0</li> <li>5. Soil type: 0; air/water calibration</li> </ol>	<b>aX_OK&lt;CR&gt;&lt;LF&gt;</b>

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	<p>6. Polynomial coefficients: a = 0; b = 0; c = 1; d = 0</p> <p>7. Calibration method: Min-max</p> <p>To restore default parameters for soil type 1, 2, 3, refer to Table 3</p>													
<b>aXSMt,dry,sat,max!</b>	<p>Set parameters for Min/Max calibration</p> <p>[a] is the sensor address</p> <p>[t],1...9 is the number assigned to the soil type</p> <p>[dry] is the value of dry soil measured in air/water calibrated mode</p> <p>[sat] is the value of saturated soil measured in air/water calibrated mode</p> <p>[max] is the real volumetric value of saturated soil (volume of water required to reach saturation/volume of dry soil)</p> <p>4 digits per coefficient; the decimal point may be at any position</p>	<b>aX_OK &lt;CR&gt;&lt;LF&gt;</b>												
<b>aXSSt,a,b,c,d!</b>	<p>Set coefficients for polynomial calibration: <math>ax^3+bx^2+cx+d</math></p> <p>[a] is the sensor address</p> <p>[t],1...9 is the number assigned to the soil type</p> <p>[a, b, c, d] are the polynomial coefficients</p> <p>max. 7 digits for a, b; max. 5 digits for c, d; the decimal point may be at any position</p>	<b>aX_OK &lt;CR&gt;&lt;LF&gt;</b>												
<b>aXGSt!</b>	<p>Select soil type for measurement</p> <p>[a] is the sensor address</p> <p>[t],1...9 is the number assigned to the soil type (see associated numbers below)</p> <p>The TBSMP03 will store all calibration parameters of each soil type in the EEPROM; before measurement, initialize the soil type (once).</p> <table border="1"> <thead> <tr> <th>Soil Type</th> <th>Associated number</th> </tr> </thead> <tbody> <tr> <td>Default</td> <td>0 - not soil specific; uses air/water calibration only</td> </tr> <tr> <td>Sand</td> <td>1</td> </tr> <tr> <td>Potting soil</td> <td>2</td> </tr> <tr> <td>50% mineral / 50%organic</td> <td>3</td> </tr> <tr> <td>User defined</td> <td>4.....9</td> </tr> </tbody> </table>	Soil Type	Associated number	Default	0 - not soil specific; uses air/water calibration only	Sand	1	Potting soil	2	50% mineral / 50%organic	3	User defined	4.....9	<b>aNow Soil Type:t &lt;CR&gt;&lt;LF&gt;</b>
Soil Type	Associated number													
Default	0 - not soil specific; uses air/water calibration only													
Sand	1													
Potting soil	2													
50% mineral / 50%organic	3													
User defined	4.....9													
<b>aXSCn!</b>	<p>Set calibration method</p> <p>[a] is the sensor address</p> <p>[n] = 0: Min/Max calibration</p> <p>[n] = 1: polynomial calibration</p> <p>The TBSMP03 will store the calibration method setting in the EEPROM; before measurement, initialize the calibration method (once).</p>	<b>an&lt;CR&gt;&lt;LF&gt;</b>												
<b>aXGA!</b>	Query number of samples for set for averaging	<b>an&lt;CR&gt;&lt;LF&gt;</b>												
<b>aXGP!</b>	Query number of samples for set for gliding average	<b>an&lt;CR&gt;&lt;LF&gt;</b>												
<b>aXGT!</b>	Query soil type	<b>an.m&lt;CR&gt;&lt;LF&gt;</b>												
<b>aXGCT!</b>	Query temperature calibration offset	<b>Asn.m&lt;CR&gt;&lt;LF&gt;</b>												

Table 5 – Extended SDI-12 Commands

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## 4 Application Example

This chapter is a practical guide on how to set up a TBSMP03 soil moisture probe, interface it to a PC with a TBS03 SDI-12 to USB converter and carry out measurements.

### 4.1 Setting up TBSMP03 together with TBS03

#### 4.1.1 Requirements

##### User Interface

Any hyper terminal (e.g.: Windows Hyper Terminal, Terminal V1.9B, RealTerm) or specific application software (e.g. LabVIEW VI)

##### Hardware Interface

PC or laptop with USB interface and mini USB-B cable (USB cable supplied with TBS03)

#### 4.1.2 Driver

Silicon Labs CP210x driver must be installed on PC (on CD supplied with TBS03 or download from Silicon Labs)

**Do not connect TBS03 to the PC, when starting the CP2102 driver installation process!**

- 1) Start the driver installation executable
- 2) Follow the installation instructions step by step until the driver installation process is finished
- 3) The system may need to restart
- 4) Upon restart after successful driver installation (**and not before**), connect the TBS03 to the USB interface of the PC
- 5) Wait until you get the notification, that the new hardware has been installed and is ready to use.

Some terminal programs need manual COM port set up.

Open the hardware manager to check the COM port number assigned to the Silicon Labs

Every TBS03 device is serialized with an individual number. This enables the use of several devices on a single PC or Laptop.



## 4.2 Hardware

- Connect the USB / SDI-12 Converter to PC via USB port.
- Connect the TBS03 SDI-12 data interface to the TBSMP03 SDI-12 data Interface.
- Place the TBSMP03 in a pot of soil.

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Figure 7 – Setup

## 4.2.1 Setting up the

## HyperTerminal application

- Open the hardware manager to check the COM port number assigned to the Silicon Labs USB bridge.
- Start the Windows HyperTerminal application.
- Connect to the COM Port assigned to the SDI-12 USB converter.
- Set the COM speed to 19200, 8 Bits, No Parity, 1 Stop Bit, No Handshake.
- In Settings, click “ASCII Setup” and activate “Send line ends with line feed” and “Echo typed characters locally”.

## 4.3 Operation

### 4.3.1 SDI-12 / USB converter transfer mode

Every mode of TBS03 needs to be initialized with an ASCII string. Upon reception, the TBS03 will switch into the initialized mode and remain in this mode until the device receives an initialization string for another mode or the device gets disconnected. At the start up time, “Transfer Mode” is the default mode.

Transfer Mode initialisation:

In Windows hyper terminal, enter **run sdi recorder** and press the enter key (or <CR><LF>)

The TBS03 will respond with **ACK<CR><LF>**



Figure 8 –TBS03 Transfer mode initialization using Windows Hyper Terminal

The TBS03 is now in transfer mode and ready to transfer commands to the sensor and respond data to the PC. The following screenshots show how to communicate with the TBSMP03 soil moisture sensor.

TBS03: Entering **0!<CR><LF>** will respond with the sensor ID:

TBSMP03 response: 013TEKBOXVN\_LCSMP1.0000005<CR><LF>

Upon sending the ID command **0!<CR><LF>**, the sensor responds with SDI-12 compatibility level, Manufacturer name, Model name, Firmware release number and serial number

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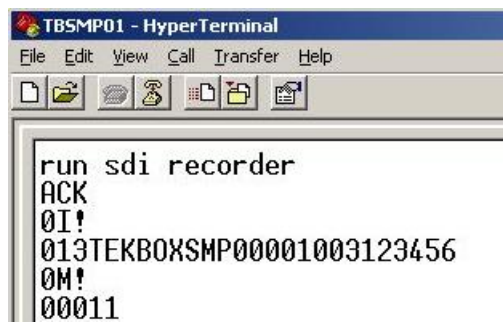
```
TBSMP01 - HyperTerminal
File Edit View Call Transfer Help
run sdi recorder
ACK
0I!
013TEKBOXSMP00001003123456
```

Figure 9 – TBSMP03, sensor response to ID command **0I!**

TBS03: Entering **0M!** <CR><LF> will respond with:

TSMP01 response: 00011 <CR><LF>

which means that the sensor will be able to deliver 1 value after an acquisition time of 1 second



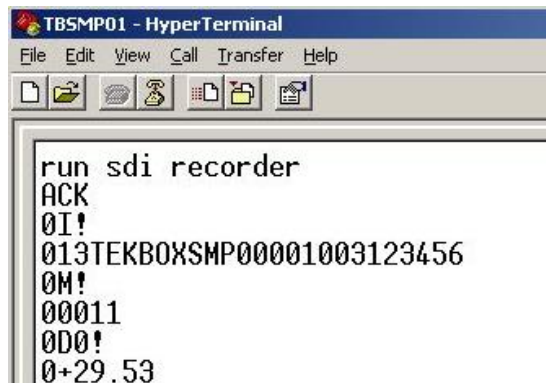
```
TBSMP01 - HyperTerminal
File Edit View Call Transfer Help
run sdi recorder
ACK
0I!
013TEKBOXSMP00001003123456
0M!
00011
```

Figure 10 – TBSMP03 response to Start Measurement command **0M!**

TBS03: Entering **0D0!** <CR><LF> will respond with:

Sensor response: 0+29.53 <CR><LF>

where 29.53 is the measured soil moisture level of 29,53%



```
TBSMP01 - HyperTerminal
File Edit View Call Transfer Help
run sdi recorder
ACK
0I!
013TEKBOXSMP00001003123456
0M!
00011
0D0!
0+29.53
```

Figure 11 – TBSMP03 response to Send Data command **0D!**

TBS03: Entering **0M1!** <CR><LF> will respond with:

TSMP01 response: 00012 <CR><LF>

which means that the sensor will be able to deliver 2 values after an acquisition time of 1 second

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```
OM1!  
00012
```

Figure 12 – TBSMP03 response to Send Data command **OM5!**

TBS03:                    Entering **OD0!** <CR><LF> will respond with:  
Sensor response:        **0+29.53+36.36** <CR><LF>  
where 29.53 is the measured soil moisture level of 29,53% and 36.36 is the soil temperature of 36.36°C

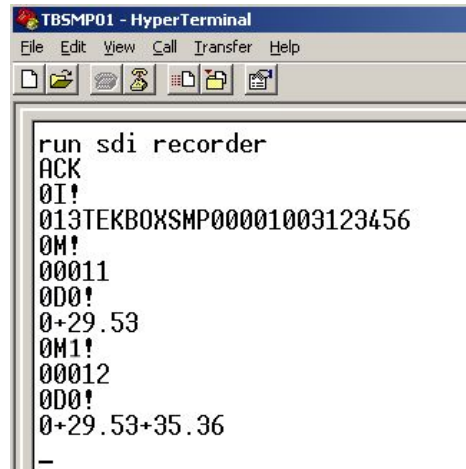


Figure 13 – TBSMP03 response to Send Data command **OD!**

Other SDI commands will work similarly.

### 4.3.2 Auto-measurement mode

Auto-measurement mode is only available on TBS03 with option OTBS03-1 or option OTBS03-2  
Like SDI Transfer commands, this application sends measurement commands which are set up by the user, to the SDI-12 / USB interface. Then, it automatically collects measured data by sending aDn! commands and transfers the data via USB Interface. After that, the next measurement command is started with a user defined time interval inbetween consecutive measurements. The maximum timer value is 4294967295ms. The maximum number of different SDI-12 measurement commands in an auto measurement string is 9. Auto-measurement mode is stopped by sending **stop** <CR><LF>

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Syntax: run *auto* <measurement command 1> <timer value 1> ... <measurement command n> <timer value n>

Example of controlling a TBSMP03 in auto measurement mode:

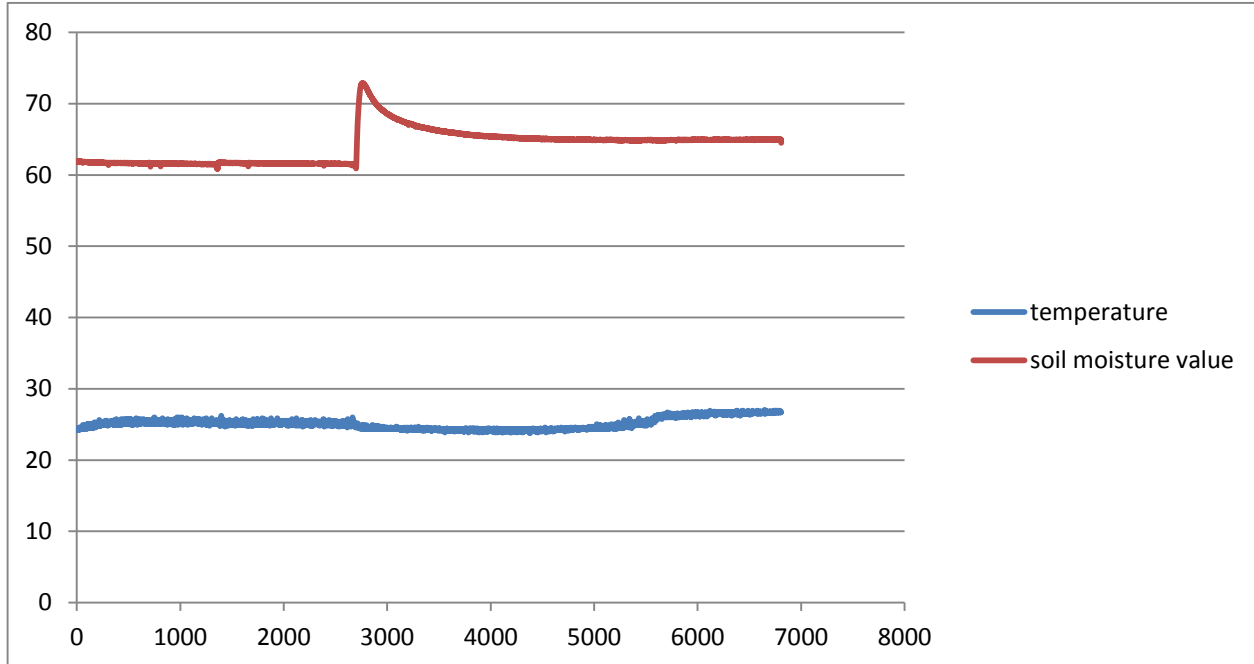
TBS03: Entering **run auto OM1! 800**<CR><LF> will respond with periodically measured soil moisture and temperature values. The time interval between two consecutive measurements is 800ms:

```
run auto OM5! 800
ACK
OM1!: 0+61.86+24.34
OM1!: 0+61.86+24.34
OM1!: 0+61.86+24.34
OM1!: 0+61.86+24.34
OM1!: 0+61.86+24.34
OM1!: 0+61.86+24.34
OM1!: 0+61.86+24.34
OM1!: 0+61.86+24.34
OM1!: 0+61.86+24.34
....
....
....
OM1!: 0+65.02+24.34
OM1!: 0+65.02+24.34
OM1!: 0+65.02+24.34
OM1!: 0+65.02+26.22
stop
ACK
```

The results converted into an EXCEL graph:



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Measurement over 24hrs; at T=2700, poured 0,66 litre water into a pot with 9l moistured sand

Figure 14 – TBS03 auto-measurement mode, periodical measurement of soil moisture level and soil temperature

## 5 Tools for TBS03

The TBS03 can be controlled using hyper terminals or customized PC application software. National Instruments, for example, offers a LabView SDI-12 API which could be used for designing customized applications for TBS03.

When using Hyper Terminal programs, take care that the representation of <CR><LF> may be different for different programs.

Windows Hyper Terminal requires activation of “Send line ends with line feed” in ASCII setup and thereafter pressing the ENTER-key results in <CR><LF>

Many Hyper Terminal programs require \n at the end of each SDI-12 string – e.g. *0M!\n* or *run sdi recorder\n*

Terminal v1.9b – 20080315β – by Br@y ++ requires adding \$0D\$0A for <CR><LF>. This tool offers user defined macros for frequently used commands - a convenient feature when working with TBS03.

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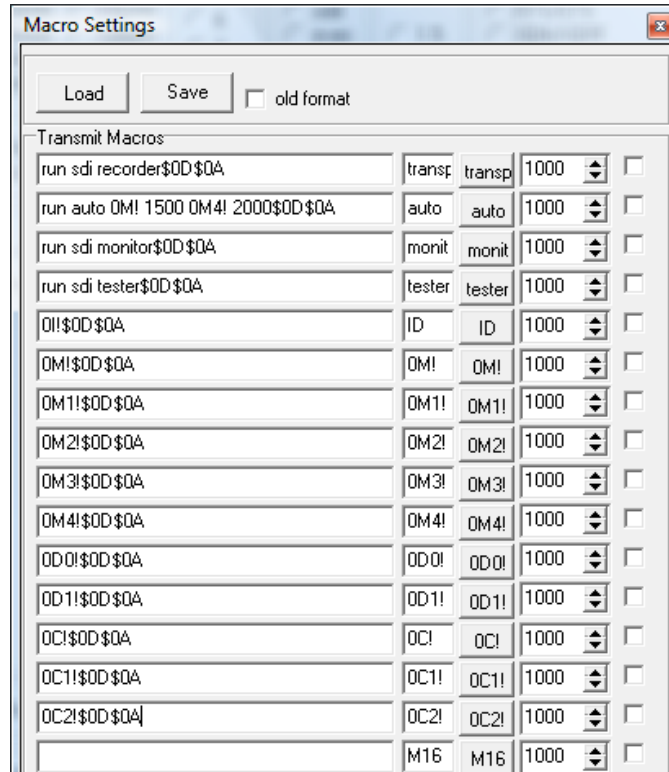


Figure 15 – Terminal v1.9b, defining Macros for mode initialization and SDI-12 commands

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When manually entering commands in Terminal v1.9b, tick the CR=CR+LF and +CR box.

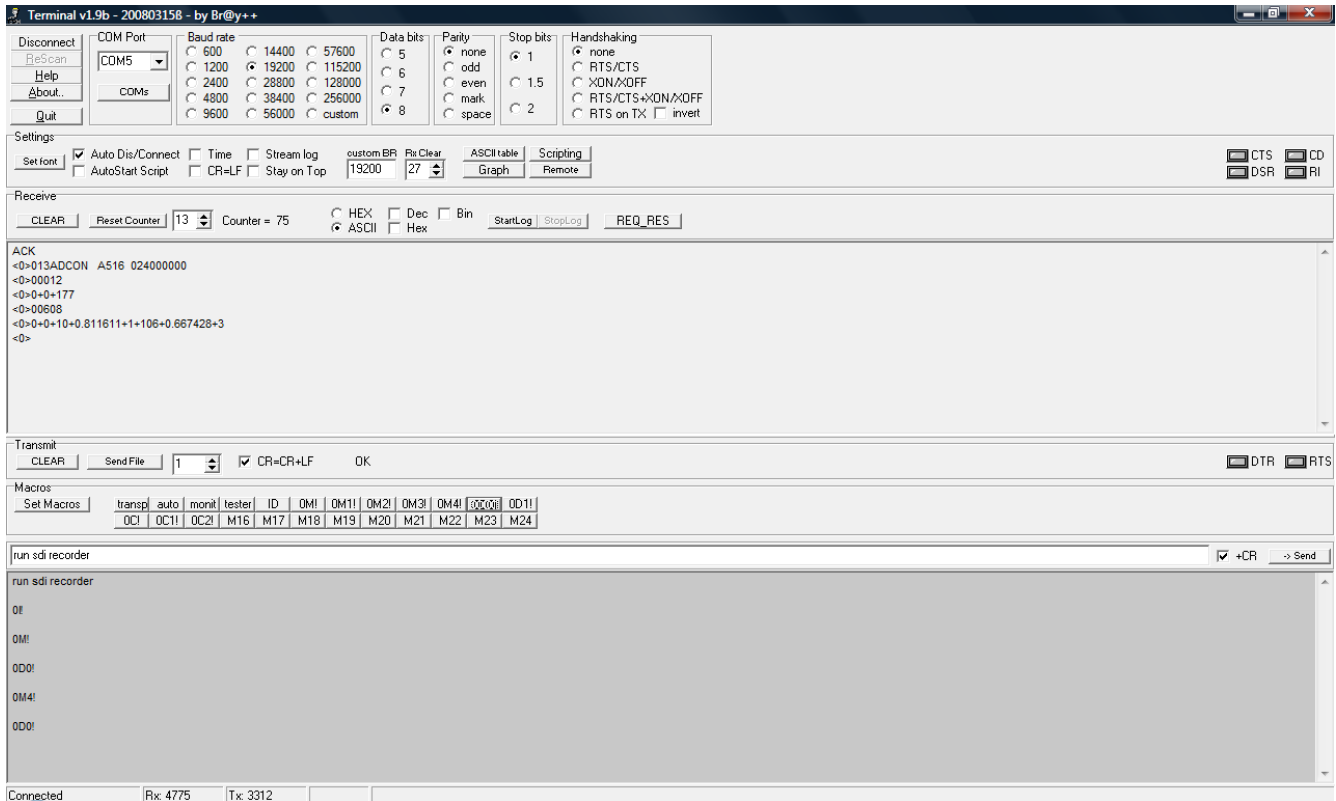


Figure 16 – Example set up of Terminal v1.9b

The above mentioned Hyper Terminal Programes are just examples to highlight that using such tools requires to take care of their way to handle <CR><LF>.

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## 6 Technical Specifications

Symbol	Parameter	Conditions	Min	Typ	Max	Unit
Is	Supply current	Active mode	28	30	32	mA
Is	Supply current	Sleep mode	35	50	55	μA
Vs	Supply voltage		6	12	17	V
tm	Measurement Time	Time in active mode upon receiving a measurement command			150	ms
SMP_LR	Soil Moisture Level measurement range		0		100	%
SMP_R	Soil Moisture Level measurement resolution			0.1		%
SMP_T	Soil Moisture Level temperature drift	From 10°C to 65°C		0.1		% / °C
TR	Temperature measurement range		-20		+65	°C
TA	Temperature calibration accuracy	@ 0°C		±0.5		°C
TL	Temperature measurement linearity	from -20°C to +65°C		±1	±2	°C

Table 6 – Technical Specifications

## 7 Cable Connection

Cable color	Signal Assignment
Green	SDI-12 Power
White	SDI-12 Data
Brown	GND
Black	Shield (GND)

Table 7 – Cable Connection

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## 8 Environmental Specifications

Symbol	Parameter	Conditions	Min	Max	Unit
T <sub>A</sub>	Operating Ambient Temperature Range		-20	+65	°C
T <sub>STG</sub>	Storage Temperature Range		-40	+85	°C
	Moisture level		-	100	%

Table 8 - Environmental Specifications

## 9 Ordering Information

Part Number	Description
TBSMP03	Soil Moisture Probe, SDI-12 Interface, default cable length 5m; any other cable length upon order

Table 9 – Ordering Information

## 10 History

Version	Date	Author	Changes
V1.0	05.04.2018	Mayerhofer	Creation of the document

Table 10 – History