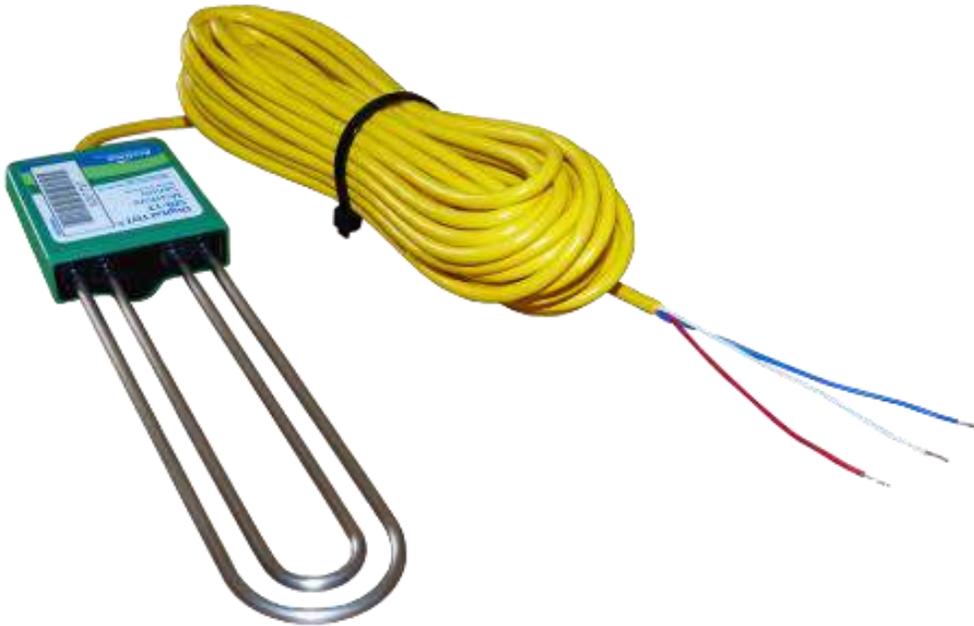# User Manual SDI-12 Soil Moisture

Digital TDT® Sensor with SDI-12 Interface Version 1.4
Part Number: **ACC-SEN-SDI**

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Introduction

NOTE: The Acclima Series SDI-12 Soil Moisture Sensor uses the industry standard SDI-12 interface for communicating with a Data Recorder or other SDI-12 equipped controller device. The SDI-12 communications standard is digital serial data communications hardware and protocol standard based on 1200 baud, ASCII character communications over the three-wire BUS. The SDI-12 Series is compliant with Version 1.4 of the SDI-12 standard. Version 1.4 is the latest standard at the time of this printing November, 2017.

Firmware and Manual Disclaimer

This manual was prepared for the current sensor firmware release at the time of the manual publication. The manual has been thoroughly edited and is believed to be reliable. Acclima assumes no liability for inaccuracies. Errata may be published on our website or when deemed necessary by Acclima. Acclima reserves the right to change any specification(s) without notice.

You can learn more about Acclima's products at www.acclima.com or email questions to sales@acclima.com.

Product Introduction

The Series SDI-12 moisture sensor is a Digital Time Domain Transmissometer that measures the permittivity of soils by determining the propagation time of an electromagnetic wave transmitted along a waveguide through the soil. The absolute moisture content of the soil is calculated from the permittivity using the Topp equation. The sensor can be commanded to produce both the bulk permittivity and the moisture content of the soil.

The accuracy and stability of the SDI-12 moisture sensor is obtained through a patented hardware and firmware system that digitizes the return waveform and them uses proprietary digital signal analysis algorithms to extract the real propagation time and distortion parameters of the returned wave. High accuracy is achieved over a wide range of soil temperatures and electrical conductivity. In the SDI-12 series the resolution of the digitized waveform is 5 picoseconds – permitting a small transducer to report very high resolution data. From the extracted distortion parameters the transducer calculates and reports the electrical conductivity of the soil. The permittivity and soil moisture measurements are compensated for temperature. The transducer also reports soil temperature.

Installation and Connection

The three wires from the sensor are the SDI-12 connections to the data recorder. The white wire is the common return or ground terminal on the data recorder SDI-12 connector block. The red wire is the power line and must attach to the power supply line on the data recorder SDI-12 connector block or to the positive side of an external power source. The blue wire is the bidirectional (half-duplex) data line that attaches to the serial data line on the data recorder SDI-12 connector block. If a power supply is used that is external to the data recorder then the negative side of the power supply must be attached to the ground terminal on the data recorder SDI-12 connector block.

Diagram for RS232 (Serial Port)

SDI-12 Data Recorder providing 12 volts* to SDI-12 port

V+   D   G (COMM)

RED

BLUE

WHITE

*12 volts as required by the SDI-12 spec. The sensor can be powered by less in low power setups/situations.
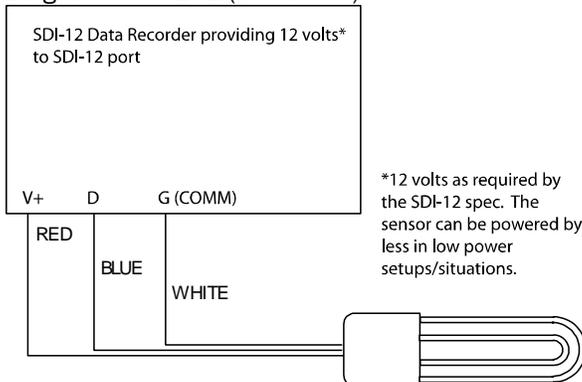
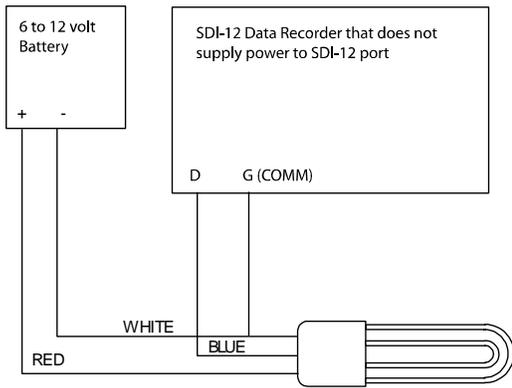Diagram for a data logger providing power to the SDI-12 port

Diagram for the data recorder using an external battery

Operation

The SDI-12 protocol allows multiple devices to be attached to one SDI-12 port. In order for the data recorder and devices to facilitate unambiguous communications each device on the SDI-12 port is given a unique address. The default address of the transducer (as shipped from the factory) is 0 (zero). If this is the only device on the SDI-12 port on the recorder then you may leave the address as 0. If other devices are connected then you will need to ensure that they each have unique addresses. Setting the address will be discussed later.

SDI-12 commands are a concatenation of three fields. The first is the device address. This is a single character – typically in the range of "0" to "9" but can also use the characters "a" to "z" and "A" to "Z". The second is the command which may consist of several characters. The command characters are always upper case. The last is the command terminator which is always an exclamation point "!".

Command Summary

The SDI-12 sensor implements commands that comply with versions 1.0, 1.1, 1.2, 1.3 and 1.4 of the SDI-12 specifications. All commands require for full compliance of the version 1.3 specifications are implemented in the SDI-12 sensor. However, the 'additional measurements' commands in the SDI-12 specification are meaningless to the Acclima SDI-12 sensors, since the permittivity, moisture, conductivity, and temperature measurements are all required and all made with every single measurement. Hence the response for all of these additional measurements commands is **"a<CR><LF>"** as required by the SDI-12 specification. The sensor ignores unimplemented commands outside those require by the SDI-12 specification. There is no response to them.

Additional 'Extended Commands' that are not innumerate here, are incorporated by Acclima for digitized waveform dumps and factory calibration settings and readings.

Command Reference

The table below documents all commands supported by the SDI-12 sensor in alphabetical order:

Command	Function	Sensor Response
?!	Address Query	a Note: only one device can be connected to the SDI-12 port when this command is used.
a!	Acknowledge Active	a
aAb!	Change Address	b
aC! aCC!	Start Concurrent Measurement Start Concurrent Measurement-Request CRC	a00104 Measurement takes 1 second. 4 values are returned
aC1! . aC9!	Start Additional Concurrent Measurement	a00000 No data to be provided

5

Command	Function	Sensor Response
aCC1! . acc9!	Start Additional Concurrent Measurement – Request CRC	a00000 No data to be provided
aD0!	Get First 4 Data Items in response to a Measurement command: VWC, Soil Temp., Soil Permittivity, Soil EC Get the response from a Verify command	Asppp.ppsTT.skk.kksee.e ppp.pp is the water content (%) TT.TT is the soil temp (C) kk.kk is the soil relative permittivity ee.e is the soil EC (dS/m) n+a n is the verifying results
aI!	Send Identification	aSSVVVVVVPPPPPPcccxx...xx a13Acclima0030316.2xx...xx ss= SDI-12 version 1.3 (2 ch) v= Vendor ID Acclima (8 ch) p= Product ID (6 ch) c= Product Version (3 ch) xx...xx= Serial Number (13 ch)
aM! aMC!	Start Non-Concurrent Measurement Start Non-Concurrent Measurement – Request CRC	a0014 Measurement takes 1 second and returns 4 values. a Sensor returns a Service Request after measurement is made. The data can be retrieved using a aD0! command
aM! . aM9! aMC1! . aMC9!	Additional Measurements Additional Measurements – Request CRC	a0000 The SDI-12 sensor does not require the use of this command. If the command is received the sensor reports "no data" to be returned.
aR0! . aR9!	Continuous Measurement	a The SDI-12 sensor does not use this command and responds with no data.
aV!	Start Verification	a0031 One data item will be returned after 3 seconds The data item will be the verification code requested by this command. a The sensor returns a service request after the measurement is made. The data can be retrieved using a aD0! Command.

Setting the Address

If more than one device is wired to the SDI-12 port you will need to assure that they all are set up with unique addresses. If you are not sure you can connect them one at a time and use the "Address Query" command "?" to read the addresses. Only one device can be connected to the SDI-12 port when using this command. The device will respond with its address.

To change the address of a device use the "Change Address" command. The syntax is "aAn!", where "a" is the present address "A" is the Set Sensor Address command and "n" is the new address. The device will return the new address. For example, if 0A4! Is transmitted, the sensor address will be re-programmed to 4 and the sensor will return "4".

To verify that the SDI-12 sensor is responding to its address use the "Send Identification" command "aI!". The SDI-12 sensor will respond with "a13Acclima..." In the response the "a" is the device address, "13" represents Version 1.3 the SDI-12 standard and the "Acclima" is the vendor ID.

Making Measurements with the SDI-12 Sensor
There are two commands that cause the SDI-12 sensor to take measurements and store them for subsequent retrieval. The first is the **"Non-Concurrent Measurement Command" "M"**. The second is the **"Concurrent Measurement Command" "C"**. The sensor responds to both of the commands with **"atttn"** where "a" is the sensor address, **"ttt"** is the number of seconds before the data will be ready, and "n" is the number of data items that will have been prepared. For the Acclima SDI-12 sensor the number of data items is 9.

Non-Concurrent Measurement
When using the non-concurrent command, the recorder waits for the sensor to complete its measurement and then retrieves the result. The sensor sends a "Service Report" code to the recorder after preparing the data so that the recorder will retrieve the data at the appearance of the Service Request or after the indicated time has expired, whichever occurs first. The Service Request code is simply the address of the sensor "a", followed by carriage return and line feed characters.

Concurrent Measurement
When using the concurrent measurement command the sensor does not return a service request when the data is ready for retrieval. The recorder is allowed to perform other communications to other devices while the sensor is making the measurement and preparing the data. Then when the recorder is available and the indicated measurement time has elapsed the recorder retrieves the data.

Data Retrieval
To retrieve the requested measurement data the recorder sends a **"D0"** command to the sensor. The D0 command returns the basic 4 measurement items: Volumetric Water Content, Soil Temperature, Soil Relative Permittivity, and Soil Electrical Conductivity. The syntax for the command is: **"aD0"**, where "a" is the sensor address. Below is a table showing the data available from the SDI-12 sensor and the commands used to retrieve them.

Data Item Request	Command	Response Example	Units
Volumetric Water Content	aD0!	+25.03	%
Soil Temperature	aD0!	+/-32.16	C
Bulk Relative Permittivity	aD0!	+32.13	--
Soil Electric Conductivity	aD0!	+1.6	dS/m

The format of the returned data is:

a+25.03+32.16+32.13+1.6<CR><LF>
Note that the returned data is always preceded by the device address **a.** Each data value is preceded by a sign. No units are returned but are assumed known by the user. The units are as shown in the table above. Each return data string is terminated by carriage return and line feed characters.

Examples of Using the Sensor
Example 1: Reading sensors using non-concurrent commands:
This first example shows how a data recorder would obtain 4 data items from a sensor that has address 5: (1) Volumetric Water Content, (2) Soil Temperature, (3) Soil Permittivity or Dielectric Constant and (4) Soil Electric Conductivity. In this example the data recorder will operate in the non-concurrent mode – that is, it will not spend any time with other sensors until this sensor has completed its measurements and has reported them.

The first command from the data recorder is:

5M!

This command is called the "Start Measurement" command. The "5" in this command is the address of the sensor you wish to respond to the command. It will cause the SDI-12 sensor to begin the process of taking a set of measurements. The sensor will immediately respond to this command as follows:

50014<CR><LF>

This response starts with the address of the sensor (5), then continues with the number of seconds that are required to take the readings, **001** (1 second), then finished with the number of data items that will be returned with each measurement request (4). Every response from the sensor is terminated with a carriage return and line feed characters. After the sensor has finished its measurements it transmits a **service request** to the recorder.

5<CR><LF>

The **service request** is just the address of the sensor. The recorder then sends a command to get the first set of data items:

5D0!

The items requested are: volumetric water content, soil temperature, soil permittivity, and soil electrical conductivity. Upon receiving this command the sensor responds with:

5+25.03+32.16+32.13+1.6<CR><LF>

The first 5 is the sensor address. The remaining string contains the requested data items – each preceded by a "+" or "-" sign.

Example 2: Reading sensor using concurrent commands:
This second example shows how a data recorder would obtain the same 4 data items from a sensor using concurrent commands. In this example the data recorder will operate in the concurrent mode – that is, it will be free to service other sensors while the sensor with address 5 is making its measurements. Concurrent measurement commands use C instead of M in the command. Thus the command to start concurrent measurement is:

5C!

The sensor immediately responds with:

500104

With concurrent commands the sensor does not provide a **service request** after the measurements have been made. The recorder relies on the timing information provided by the sensor and will not request data until the time interval has expired – in this case 1 second.

The recorder then requests the four data items exactly in the same manner as with non-concurrent readings.

Data Communication Error Checking
So far, all **Start Measurement** commands that we have discussed have requested data wherein no error checking is done to verify the correct reception of the data by the recorder. The SDI-12 specification provides for error checking by using an additional command character "C" with the Start Measurement command. Thus when the commands

aMC! Or **aCC!**

are transmitted to the sensor, the sensor appends a CRC code to the end of the returned data. This code is generated from the data in such a manner that if the data changes in the transmission the change can be detected in the recorder. If the recorder experiences such corruption in the data it will repeat the data request automatically.

3.3.6 Verify Command
The SDI-12 specification requires a special command for the purpose of verifying that the sensor is working properly. Acclima's implementation of that command is as follows:

1. The recorder sends out the verify command:
aV!

2. Upon receiving the verify command the sensor will respond with:

atttn

where "a" is the sensor address, "ttt" is the time required to make verification readings, and "n" is the number of data items that will be returned. For this command ttt = 003 and n=1.

3. The sensor takes 3 full sets of readings. The corrected propagation times from the three readings are saved and compared. If any of these propagation times are out range or if they differ by an unacceptable amount an error is acknowledged. The sensor then sends out a **service request**.

a

4. The recorder issue a **read data** command **D0**:

aD0!

Troubleshooting

Problem	Possible Resolution
No Data Return by the SDI-12 sensor	Check the sensor connections to the data recorder. The white wire connects to the SDI-12 port Ground terminal. The blue wire connects to the SDI-12 port Data terminal The red wire connects to the SDI-12 port V+ terminal or to the positive terminal of an external battery. If an external battery is used the negative terminal of the battery connects to the ground terminal of the SDI-12 port.
Unreadable data	Insure that there are no address conflicts. Disconnect all other devices connected to the recorder. Insure that the sensor address is used in the commands you are using.
Sensor not communicating	Check connections Check Voltage Check address Review syntax
Unreadable data/parity errors	Insure that there are no address conflicts. Disconnect all other devices and try to read again. Insure that the cable length to the sensor does not exceed 200 feet.

Specifications

Physical Characteristics:
Dimensions (without cable)	20 cm x 5.33 cm x 1.5 cm
Weight (with 3 meter cable)	220g
Composition	Type 304 stainless steel, crystalline-epoxy, PVC (insulation)
Cable	3 conductor, 22 Ga PVC sheath, 10 meters

Environmental Characteristics:
Operating Temp Range	1˚ C to 50˚ C for VWC (no ice), -20˚ C to 50˚ C for the other data
Storage Temp Range	-20˚ C to 75˚ C

Operating Characteristics:
Volumetric Water Content	0 to 100%
Resolution	0.06% VWC
Absolute VWC Accuracy	+/- 2% typical
VWC Soil EC Stability	+/- 1% of full scale 0 to 5 dS/m BEC
Temp Reporting Accuracy	+/-2˚C from +1˚C to +50˚C (ACC-SEN-SDI)
EC Reporting Accuracy	+/- 0.2 dS/m 0 to 5 dS/m BEC

Architectural Characteristics:
Technology	Waveform Digitizing Time Domain Transmissometer
Effective Acquisition Bandwidth	200 Giga-sample/sec.
Propagation Time Resolution	5 ps
Waveform Propagation Resolution	1.5 mm in air, 0.16 mm in water
Waveguide Length	30 cm
Permittivity to VWC Calculation	Modified Dielectric Mixing Model
Propagation Waveform Bandwidth	>2 GHz

Communications Characteristics:
Communication Protocol	SDI-12 Revision 1.4
Maximum Cable Length	60 meters

Power Characteristics:
Operating Voltage Range	6 – 15 VDC
Listening/Sleep Mode Current	60 uA at 50˚ C

Communications Current	6 mA typical, 8 mA max
Read Moisture Comm Time	425 ms total for each read cycle
Moisture Sense Current	84 mA at 12 VDC input
	98 mA at 8 VDC input
	110 mA at 6 VDC input
Moisture Sense Time	450 ms each sensing operation

Notes:

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