Acclima TDR Sensor User Manual

For Sensor Models: TDR305H TDR310H TDR315H

Acclima TDR Sensor User Manual

For Sensor Models: TDR305H   TDR310H   TDR315H

Product Description:

Acclima's TDR Sensors are Integrated Time Domain Reflectometers that contain an ultra-fast step function generator, an ultra-fast waveform digitizer and a precision time base. The step function generator and waveform digitizer are connected directly to a waveguide of length 5 cm, 10 cm or 15 cm without an intervening coaxial cable. The key to their operation is a patented waveform digitizing hardware and firmware set that has an effective digitizing rate of 200 billion samples per second. The step function generator launches a voltage step on the waveguide with a 20%/80% rise time of 150 trillionths of a second. The digitizer acquires a digital image of the incident wave and its returning reflections with 5 trillionths of a second resolution. The image is then analyzed to determine the round-trip propagation time between the incident wave and the first reflected wave. Using the propagation equation that governs the speed of light through a medium the permittivity of the medium is then calculated as:

$$\varepsilon = \frac{t^2}{4l^2}$$

where t is the round trip propagation time, l is the length of the waveguide and ε is the relative permittivity of the medium though which the wave has passed. The fact that propagation time is independent of soil electrical conductivity leads to the fact that the calculated permittivity is also independent of soil electrical conductivity. This is the main advantage of digitized waveform time domain sensors over all non-time domain electronic sensors. Volumetric Water Content can be derived from permittivity using the Topp equation or a suitable dielectric mixing model. Electrical Conductivity in soils is affected by compaction and hence non-TDR sensors tend to be very sensitive to both installation compaction and follow-on soil settling. TDR sensors report the true volumetric water content independent of soil electrical conductivity, compaction and settling.

An 80 MHz floating point processor inside the sensor is used to process the waveform image. The total time required to send a measurement command to the sensor, acquire the digitized waveform image, process the image and calculate the soil permittivity, water content and conductivity is 0.25 seconds.

The sensors require a power supply from 3.5 volts to 15 volts. The current draw during a reading ranges from 88 mA at 3.5 volts to 32 mA at 15 volts. The idle current is less than 10 uA. Because of the very fast operation time the total energy consumed from a battery is only 0.1 Joule per reading. A typical good-quality 18650 Li-Ion battery stores about 40,000 Joules.

TDR Sensor Models:

Acclima offers three TDR sensor models: The TDR315H, the TDR310H and the TDR305H. These all incorporate the same technology in waveform generation and capture. They are all designed for operation in any soil texture. They differ in waveguide dimensions and optimum application.
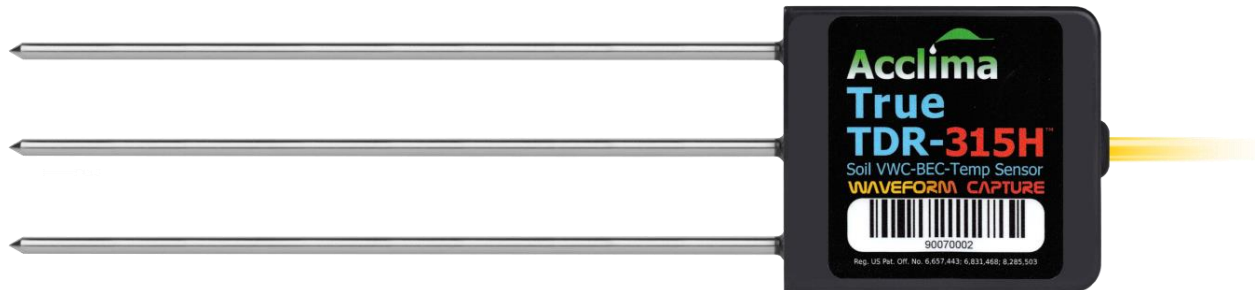
TDR315H Description and Installation:

The TDR315H uses a 15 cm waveguide with a rod spacing of 1.9 cm. Because of its larger waveguide it has the largest measuring volume of the three sensors – than being on the order of 100 ml. It can be installed in any orientation but is usually installed by forcing the waveguide rods into the sidewall of a trench that has been dug to the desired depth of installation. This method results in a horizontal installation in undisturbed soil. A special rod guide supplied by Acclima is used to keep the rods parallel while forcing them into the trench sidewall. It can also be installed in the center of a trench and then be backfilled. With this method the backfill needs to be compacted to avoid air pockets near the waveguide and to prevent the creation of a preferential path for surface water to percolate down to the sensor. When the installation is complete the entire soil volume removed to create the trench must be placed back into the trench with sufficient compaction that the backfilled trench surface is even with the surrounding soil surface.

TDR315H Optimum Application:

The TDR315H provides excellent readings in all types of soils and has the advantage of a larger sampling volume than the TDR310H and TDR301H. Because of the higher impedance waveguide and the longer waveguide length the waveform is more susceptible to attenuation by soil ions than is the case with the TDR310H and TDR305H. Hence the TDR315H is not recommended for use where the salt content of the soil is exceedingly high. For saturated paste extraction electrical conductivity readings in excess of 10 dS/m the repeatability of the readings may degrade and even fail.

TDR310H Description and Installation:

The TDR310H uses a 10 cm waveguide with a rod spacing of 1.14 cm. The round form factor was designed to match the diameter of a 1" schedule 40 PVC pipe. The top shoulder of the sensor can be

glued into the end of a pipe to act as an installation handle. The cable feeds up through the pipe and emerges through a notch at the upper end. The pipe can then be capped off at the upper end to prevent water ingress. The pipe/sensor assembly can them be inserted into a hole that was drilled using a 34 mm flat-bottomed auger. A mallet can be used to pound the top of the pipe and force the sensor waveguide into the undisturbed soil at the bottom of the hole. With the flat-bottomed hole the sideways bias on the waveguide rods is minimal thus allowing the rods to enter the soil in a parallel alignment. This method of installation is generally easier than the trench method used with the TDR315H.

TDR310H Optimum Application:

All types of soils are suitable environments for TDR310H measurements. Its sampling volume is only about ¼ of the TDR315H but that is the tradeoff for easier installation. In addition the TDR310H has a lower impedance waveguide with a shorter length. This makes it particularly suited to soils with high salt content – up to 15 dS/m saturated paste extraction.

TDR305H Description, Installation and Optimum Application:

The TDR305H was developed from the TDR310H as a measurement solution for soils with exceedingly high salt levels. It provides credible measurements in soils with saturated paste extraction EC levels up to 20 dS/m. Because of its low sampling volume the TDR310H or TDR315H would be better choices for applications where salt is not a problem.

Sensor Setup and Connection:

Acclima's TDR sensors use the industry standard SDI-12 communications protocol and are compatible with any Data Recorder, Reader or Wireless Device that incorporates a compliant SDI-12 Port. The sensor cable includes 3 wires. The red wire is the power line. The blue wire is the bi-directional data line and the white wire is the common for both the data and power.

When sensors are installed to a data recorder or other reading device there are two steps that must be taken to insure successful communications. The first is the hardware connection. The second is the sensor addressing. The SDI-12 protocol uses address to distinguish between multiple sensors. These must be set uniquely for each sensor wired to a common SDI-12 recorder or reader. Valid addresses are the numerals 0 through 9, the lower case characters a through z and the upper case characters A through Z for total of 62 possible addresses. The sensors are shipped from the factory with the default address '0'.

Setting Sensor Addresses:

The most convenient method of setting sensor addresses is to use an Acclima SDI-12 Reader. With a few button pushes a sensor can be re-addressed. At the same time the reader can be used to take both readings and waveform images from the sensor to assure that the sensor is installed tightly in the soil and reporting properly. GPS coordinates can also be provided from the reader to document the location of the sensor. After each sensor has been individually addressed the full set of sensors can be connected to the data recorder for operation.   For more information contact Acclima here.
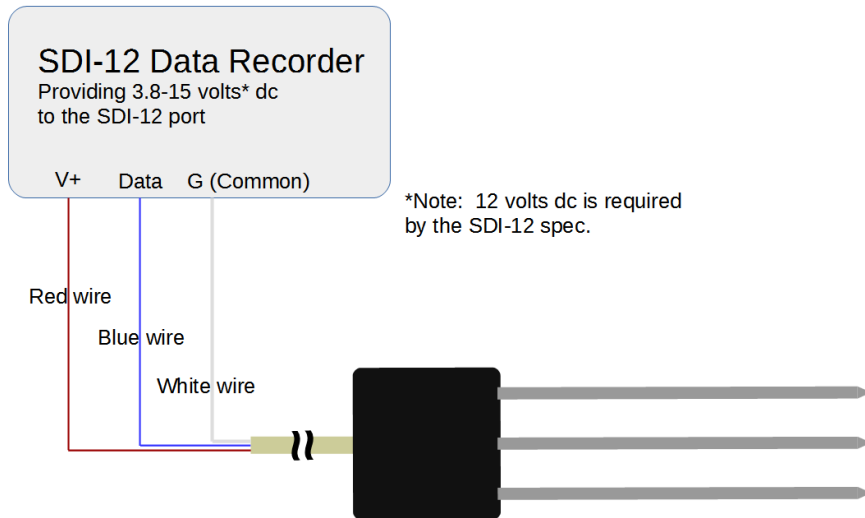

If an Acclima SDI-12 reader is not available then the address setting can be done through the data recorder or other SDI-12 device that the sensor is connected to. This may require the use of a laptop and special software provided by the data recorder manufacturer.
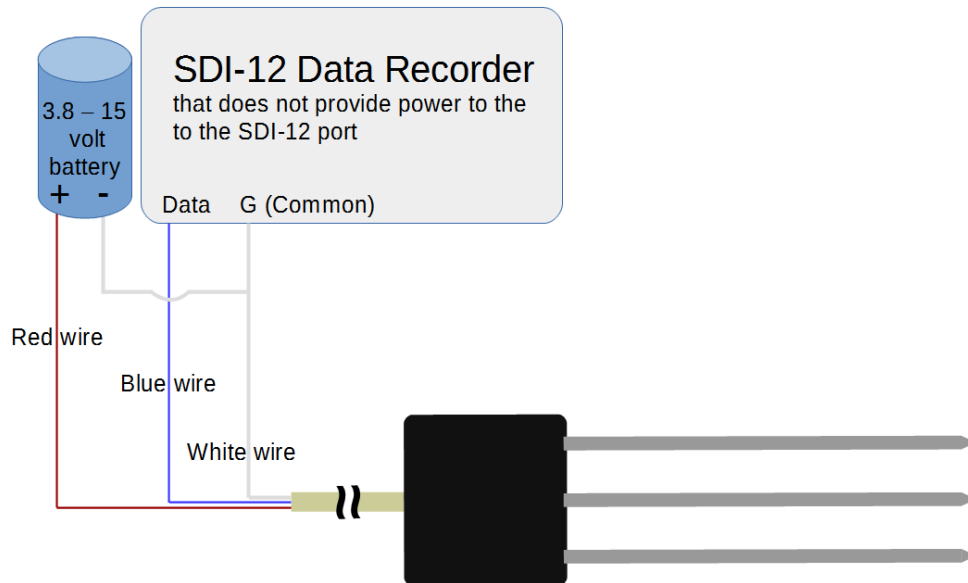
Connecting the Sensors to the Data Recorder:

The wiring diagram for the sensor connection to the data recorder is shown below. All sensors are connected in parallel to the terminals on the data recorder or to a cable connected to the data recorder.

If a cable is used to connect multiple sensors to the data recorder and if concurrent readings are to be taken the voltage drop in long cables may become an issue. For example: 5 sensors operating simultaneously could draw up to 400 mA of current and cause a voltage drop of 3 volts in a 250 foot cable comprised of 22 gauge wire. Such a drop could cause the sensors to misread or misreport. To avoid this do not use concurrent commands or insure that long cables are of sufficient wire gauge to handle the current spike without voltage drops in excess of 1 volt.

SDI-12 Data Recorder
Providing 3.8-15 volts* dc
to the SDI-12 port

V+   Data   G (Common)

*Note: 12 volts dc is required
by the SDI-12 spec.

Red wire

Blue wire

White wire

If the data recorder does not supply power to the SDI-12 port then use the diagram below for connecting the sensors.

SDI-12 Data Recorder
that does not provide power to the
to the SDI-12 port

3.8 – 15
volt
battery
+   -

Data   G (Common)

Red wire

Blue wire

White wire

SDI-12 Command Summary:

Acclima SDI-12 sensors implement commands that comply with versions 1.0, 1.1, 1.2, 1.3 and 1.4 of the SDI-12 specifications. All commands required for full compliance of the version 1.4 specifications are implemented in the TDR sensors. 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 required by the SDI-12 specification. There is no response to them.

Additional 'Extended Commands' that are not enumerated 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<CR><LF>
a!	Acknowledge Active	**a** a<CR><LF>
aAb!	Change Address	**b** b<CR><LF>
aC! aCC!	Start Concurrent Measurement Start Concurrent Measurement-Request CRC	**a00105**<CR><LF> Measurement takes 1 seconds. 5 values are returned
aC1! . aC9!	Start Additional Concurrent Measurement	**a00000**<CR><LF> No data to be provided

Command	Function	Sensor Response
aCC1! . aCC9!	Start Additional Concurrent Measurement – Request CRC	a00000<CR><LF> 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	a + VW.V + TT.T + PP.P + EEEE + CCCC<CR><LF> where: a = device address VW.V = volumetric water content % TT.T = soil temperature degrees C PP.P = soil permittivity EEEE = soil bulk EC in µS/cm CCCC = soil pore water EC in µS/cm

Data buffer Populated by:	Command Description	Response to "aD0!"
none/abort	No data generating command has been issued, or a command was aborted. Data buffer is empty.	a<CR><LF>
aM!	Fill data buffer with standard measurement	a+VVV.V+TT.T+PP.P+EEEE +CCCC<CR><LF> where: VVV.V = Volumetric water (%) TT.T = Temperature (°C) PP.P = Permittivity (no units) EEEE = Bulk electrical conductivity (µS/cm) CCCC = SOIL Pore Water EC (µS/cm)
aC!	Fill data buffer with standard measurement concurrently with other sensors	Same as aM!
aMC!	Fill data buffer with standard measurement and CRC check in the data response	a+VVV.V+TT.T+PP.P+EEEE+CCCC<CR><LF> where: VVV.V = Volumetric water (%) TT.T = Temperature (°C) PP.P = Permittivity (no units) EEEE = Bulk electrical conductivity (µS/cm) CCCC = Soil Pore Water EC (µS/cm)
aCC!	Fill data buffer with standard measurement concurrently with other sensors and with a CRC check in the data response	Same data as aMC!
aM1!	Fill data buffer with standard measurements	Same as aM!

Command	Function	Sensor Response	
	aC1!	Fill data buffer with standard measurements concurrently with other sensors	Same as above
	aMC1!	Fill data buffer with standard measurement and CRC check in the data response	Same as aMC!, except Bulk electrical conductivity (EEEE) is normalized to 25 °C
	aCC1!	Fill data buffer with standard measurement concurrently with other sensors and with a CRC check in the data response	Same as above
	aV!	Verify Sensor operation. This command produces the same result as the aM! Command	Same data as aM!
aD1! . aD9!		No data for these commands	
aI!	Send Identification	aSSVVVVVVPPPPPPcccxx...xx a13Acclima TDR315 1.3xx...xx <CR><LF> 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	a0015<CR><LF> Measurement takes 1 second and returns 5 values. a<CR><LF> Sensor returns a Service Request after measurement is made. The data can be retrieved using a aD0! command	

Command	Function	Sensor Response
aM! . aM9! aMC1! . aMC9!	Additional Measurements Additional Measurements – Request CRC	a0000<CR><LF> 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.
aV!	Start Verification	a0031<CR><LF> One data item (the verification result code) will be returned in 3 seconds. a<CR><LF> The sensor returns a service request after the measurement is made. The data can be retrieved using the aD0! Command.

To verify that the SDI-12 TDR sensor is responding to its address use the **"Send Identification"** command **"aI!"**. The SDI-12 sensor will respond with "a14Acclima TDR315 1.4xx…xx" In the response the "a" is the device address, "14" represents Version 1.4 the SDI-12 standard and the "Acclima" is the vendor ID, TDR315 represents the sensor model in this example, the next three characters report the firmware version of the TDR sensor, which is then followed by the serial number.

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 TDR SDI-12 sensors the number of data items is 5.

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!	+25.0	%
Soil Temperature	aD0!	+/-32.1	C
Bulk Relative Permittivity	aD0!	+32.1	--
Soil Electric Conductivity	aD0!	+1600	µS/cm
Soil Pore Water EC	aD0!	+1700	µS/cm

The format of the returned data is:

a+25.03+32.16+32.13+1600+1700<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 TDR 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 Bulk Electric Conductivity, and (5) Soil Pore Water EC. 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:

50015<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 (5). 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+1600+1700<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:

500105 <CR><LF>

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.

The recorder then requests the five 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.

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:

a0016<CR><LF>

indicating that after 1 second the sensor will respond with 6 data items.

3. The sensor begins a self-diagnostic sequence in which the waveform is examined, the power line voltage is measured and the temperature is measured.   The sensor then sends out a **service request**.

a <CR><LF>

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

aD0!

5. The sensor responds with:

Address+TestErrorCode+SDIVoltsOff+SDI12VoltsOn+Temp+LTAmplitude+MeasureErrCode

The Test Error Code Reports:

       Bit 0   Incident wave begins above specified level

       Bit 1   Incident wave does not rise to specified level

       Bit 2   SDI12 voltage is out of spec when sensor is idle

       Bit 3   SDI12 voltage is out of spec when sensor is operating

       Bit 4   Temperature reading is not reasonable

       Bit 5   Soil Conductivity too high for sensor operation

The measure error code indicates that a point was reached in the waveform analysis where an unresolvable mathematical condition was reached. This would be due to shorted rods or to some internal sensor failure.

Retrieving the TDR Sensor Waveform:

The Acclima TDR sensors were developed as Time Domain soil permittivity and moisture content measuring devices but have application in many other research disciplines. TDR waveforms contain much more data than soil moisture content. Soil electrical conductivity can be determined from them. Also other properties of the soil such as porosity and particle size have an influence on the characteristics of the waveform – hence it is appropriate for some researchers to use TDR waveforms in characterizing these additional properties. The spectral content of the Acclima TDR waveforms is well preserved since there is no low pass filter (coaxial cable) between the waveguide and the digitizer. These factors provide an opportunity for additional time domain and frequency domain analyses of the waveform that can yield

additional characteristics of the medium. Special commands are provided for downloading waveforms to be used for these purposes.

The most convenient approach for capturing a waveform is to use the Acclima SDI-12 Reader. A simple button push will cause the sensor to gather the waveform, compress it to save time in communicating it and then send it over the SDI12 cable at an elevated baud rate. The entire process takes about 6 seconds – most of which is communications time. The waveform can then be retrieved from the reader memory using its USB port. The waveform points are stored in .csv format.

Retrieving a waveform without the Acclima SDI12 Reader can be done using the command

aXAtttt!

Where 'a' is the device address, 'XA' is the extended command code, tttt is a hexadecimal time ordinate in 5ps units and '!' is the command terminator. This command returns a hexadecimal string which represents the waveform amplitude at the 'tttt' time ordinate.

For Example:

If the amplitude of the waveform at 1100ps is desired it is necessary to convert the time ordinate to 5ps units or 220. This number is then converted to hexadecimal 220 decimal = 0DC hex. If the device address is '1' then the following command is sent to the TDR-315: 1XA0DC!

The sensor returns the string: 18E6 <CR><LF> The first character (1) of the string is the device address. The other characters are the waveform amplitude at 1100ps.

You can write your own code to acquire successive points and thus get an entire waveform using this command. Because of the relatively slow baud rate used by the SDI12 protocol it may take several minutes to download a waveform consisting of thousands of points. The Acclima SDI12 Reader speeds this process up to about 6 seconds for a 4000 point waveform. It does so by compressing the data and then increasing the communications baud rate.

Specifications:

315H Physical Characteristics:

Dimensions (without cable)	20 cm x 5.33 cm x 1.9 cm
Weight (with 10 meter cable)	440g
Composition	Type 304 stainless steel, epoxy, ABS sensor head box

305H, 310H Physical Characteristics:

Dimensions (without cable)	15 cm (305H), 20 cm (310H) x 3.5 cm x 3.5 cm (round)
	465g (305H), 480g (310H)
	Type 304 stainless steel, epoxy, ABS sensor head box

Cable **(All sensor models)**	3 conductor, 22 Ga., Water proof and UV resistant PVC jacket, 10 meters

Environmental Characteristics:

Operating Temp Range	-20 C to 50 C
Storage Temp Range	-20 C to 75 C

Operating Characteristics:

Volumetric Water Content	0 to 100%
Resolution	0.1% VWC
Absolute VWC Accuracy	+/- 2% typical
VWC Soil EC Stability	+/- 2% of full scale 0 to 5 dS/m BEC
Temp Reporting Accuracy	+/-0.25 C 0 to 50 C
EC Reporting Accuracy	+/- 25 µS/cm 0 to 1,000 µS/cm BEC +/- 2.5% 1,000 µS/cm to 6,000 µS/cm BEC

Architectural Characteristics:

Waveguide Length 305H/310H/315H	5 cm (305H), 10 cm (310H), 15 cm (315H)
Communication Protocol	SDI-12 Revision 1.4

Power Characteristics:

Operating Voltage Range	3.5 – 15 volts dc
Listening/Sleep Mode Current	<10 µA
Communications Mode Current	6 mA @ 6v, 3.5 mA @ 12v

Current and Energy Consumption during Read:	current	power	energy
15v	32 mA	0.48 W	0.12 J
12v	36 mA	0.43 W	0.11 J
6v	62 mA	0.37 W	0.09 J
3.5v	88 mA	0.31 W	0.08 J