Model 8960 series

Digital Vibrating Wire Interfaces

Instruction Manual

Document Revision: Init | Release date: 11/10/22

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1. INTRODUCTION

GEOKON's 8960 Series Digital Vibrating Wire Interfaces incorporate state-of-the-art signal conditioning and digital addressing to enable Modbus RTU clients to read GEOKON vibrating wire sensors.

The 8960-01C interfaces allow reading both the vibrating wire and the thermistor built into the sensor.

Interfaces are queried using industry standard Modbus Remote Terminal Unit (RTU) protocol over a simple half-duplex RS-485 connection. The sensor is excited and measured by the interface, and the digitized measurement is then read.

1.1 8960 MODEL LIST

8960-01C-CBL	Single-Channel Digital VW Interface in enclosure
8960-04C-CBL	Four-Channel Digital VW Interface in enclosure
8960-08C-CBL	Eight-Channel Digital VW Interface in enclosure
8960-01C-CAB-SL	Digital VW Interface for single sensor (non-bussed), 3 m cable length, bare leads
8960-01C-CAB-VL	Digital VW Interface for single sensor (non-bussed), customer specified cable length, bare leads
8960-01C-12P-SL	Digital VW Interface for single sensor (non-bussed), 3 m cable length, sensmetrics 12-pin connector
8960-01C-12P-VL	Digital VW Interface for single sensor (non-bussed), customer specified cable length, sensmetrics 12-pin connector

TABLE 1: *Model List*

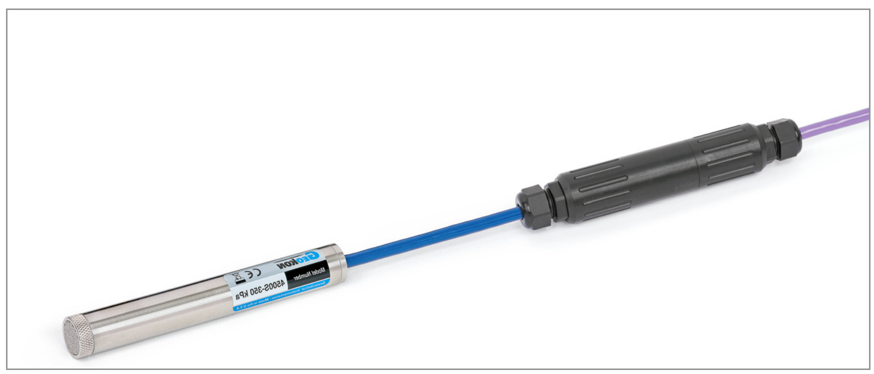

FIGURE 1: *8960-01C-CAB Addressable VW Interface*

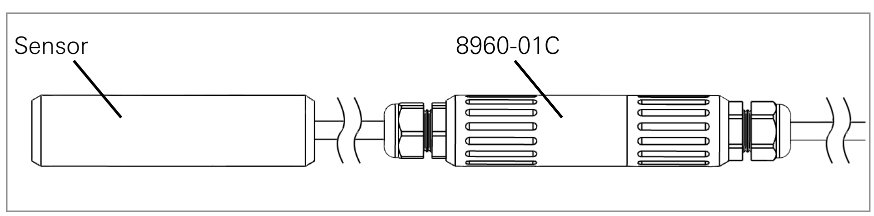

FIGURE 2: *Sensor connected to 8960-01C interface*

2. INSTALLATION

2.1 INSTALLATION PROCEDURE 8960-01C-CAB

For your convenience, the 8960-01C Addressable Vibrating Wire (VW) Interface is assembled with the readout cable already attached.

2.1.1 HARDWARE REQUIREMENTS

Communications: RS-485, half-duplex

Data Rate: 115,200 baud

Power: 5V to 15V DC, 57mA (peak)

To connect your sensor to the 8960-01C, attach your sensor's cable using the following steps:

1. From one end of the sensor cable, trim off 2" to 3" of the jacket, exposing the five individual wires.
2. Trim all of the insulation off the shield wire, if applicable.
3. Cut the four remaining wires 6 mm (0.24") shorter than the shield wire.
4. Trim 6 mm (0.24") of insulation off each of these four wires. This short length reduces the possibility of a short circuit.

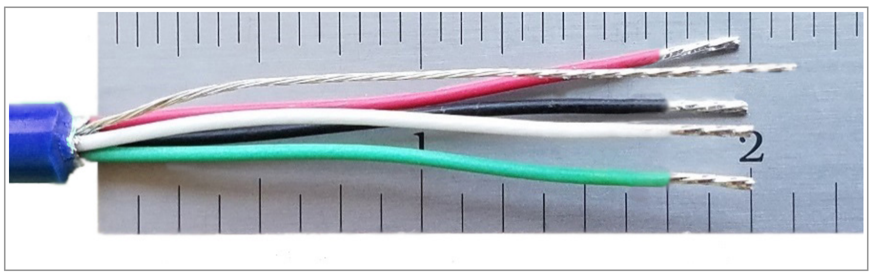

FIGURE 3: *Wires trimmed to two inches*

5. The ends of the wires should be as neat as possible (e.g., twisted, tinned, or ferruled), to ease insertion into the connectors of the interface.
6. Loosen the cable nut on the open end of the 8960-01C. See below.

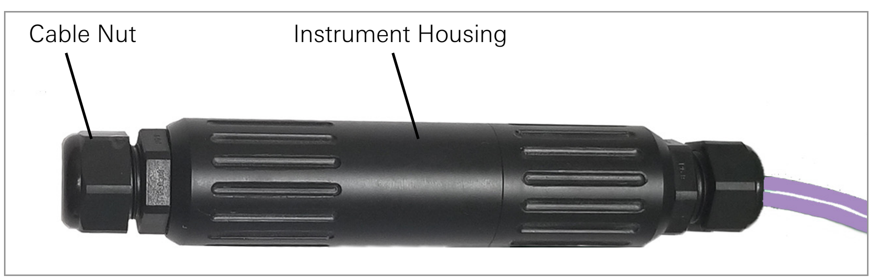

FIGURE 4: *Cable Nut*

7. Unscrew the instrument housing into two halves.
8. Remove and save the white plastic dowel. If you plan to eventually disconnect and store the 8960-01C interface, you should replace the dowel to ensure the housing remains water-tight.

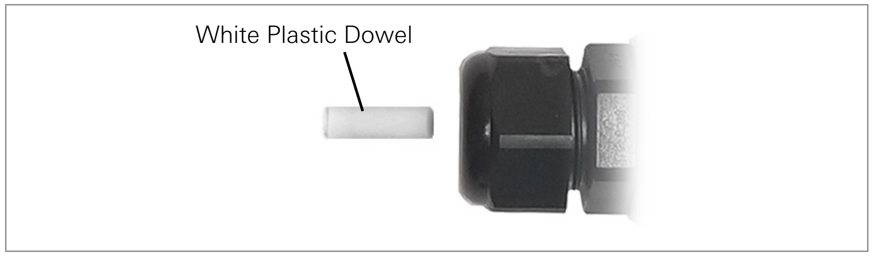

FIGURE 5: Plastic Dowel

9. Slide the sensor cable through the cable nut and the cable gland.
10. For ease of wiring, the male half of the connector can be removed from the female half, which is mounted to the circuit board. To separate the two halves, pull with steady pressure on the male half until it comes free. Refer to the figure below.

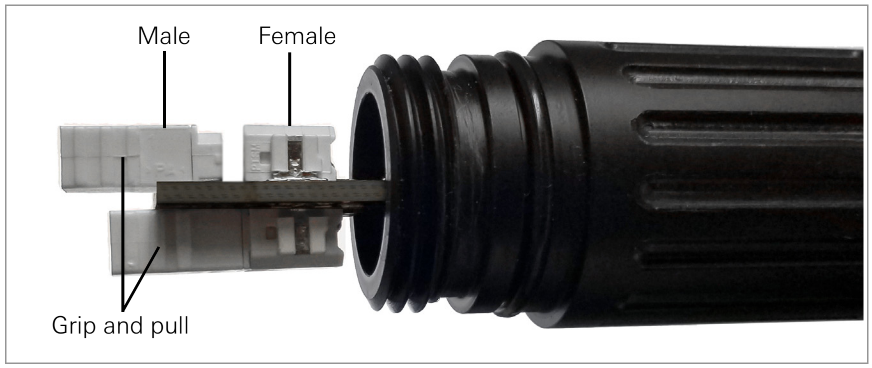

FIGURE 6: Detaching PCB Connectors

11. Insert the shield wire into the **center** hole of the male three-wire connector. If the shield wire isn’t stiff enough to penetrate the center hole, double the thickness of the wire by bending the last 6 mm (0.24") of the shield wire over onto itself and try again. Refer to the figure below.

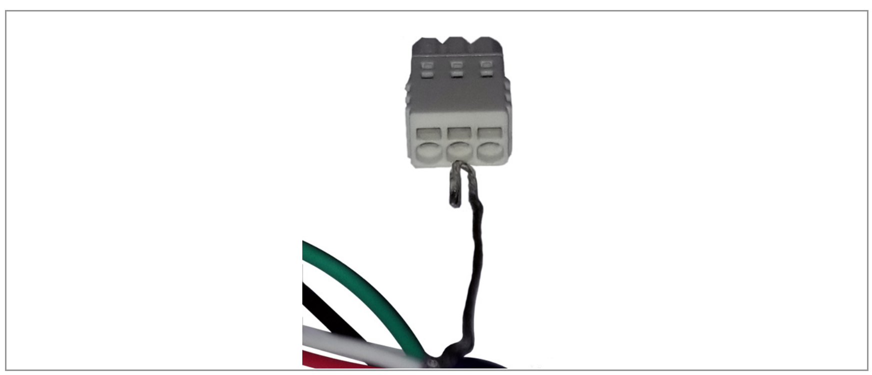

FIGURE 7: Doubled Shield Wire

CAUTION! The shield wire must be inserted into the **center** hole of the three-hole connector; inserting the shield wire into any other position will cause a short and may damage the sensor and/or the interface.

12. Insert the two thermistor wires (white and green conductors are standard for GEOKON sensors) into the holes on either side of the shield wire (**hole choice does not matter**).

13. Insert the remaining wires (red and black conductors are standard for GEOKON sensors) into the two-wire connector (**hole choice does not matter**).
14. If the male halves of the connectors were removed from female halves, reinsert them to their counterparts on the circuit board. Refer to the figure below.

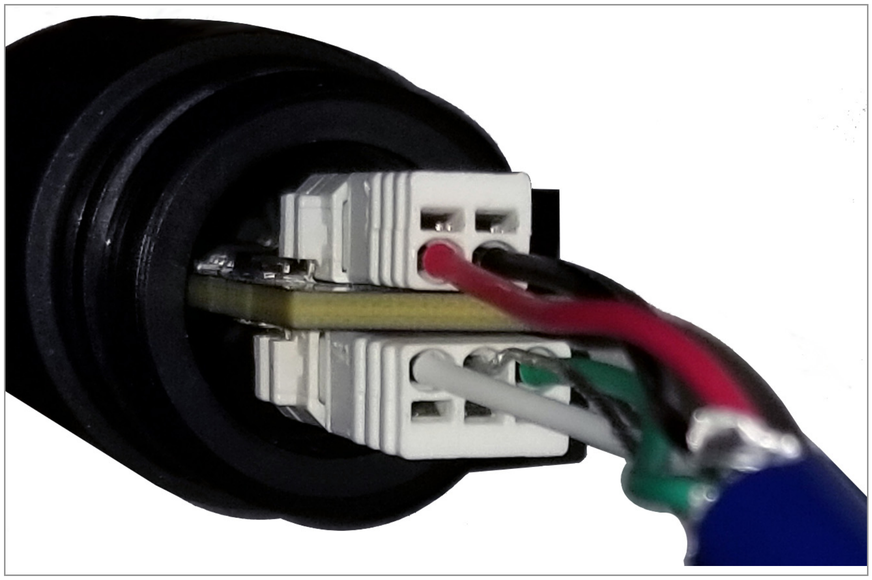

FIGURE 8: *Connector Assembly*

15. Gently pull on each conductor of the cable to make sure the connections are secure.
16. Screw together the two halves of the housing.
17. Tighten the cable gland nut until it firmly grips the outer jacket of the cable. Doing this ensures that water does not enter the housing. (**Do not over tighten the nut; doing so may damage the plastic threads.)**
18. Connect the wires at the open end of the readout cable to the unit intended for reading the instrument.

The wiring functions are displayed below:

8960-01C Conductor Color	Description
White	Communication RS-485+
Green	Communication RS-485-
Red	12-volt power to the string
Black	Ground
Shield	Analog ground

TABLE 2: *8960-01C Wiring Functions*

2.1.2 RELEASING CONDUCTORS FROM THE INTERFACE CONNECTORS

To release a conductor wire from the connector after it has been inserted, use the supplied screwdriver to push and hold in the small tab located just above the tinned end of the wire, as shown in the figure below. Then pull on the wire below the screwdriver.

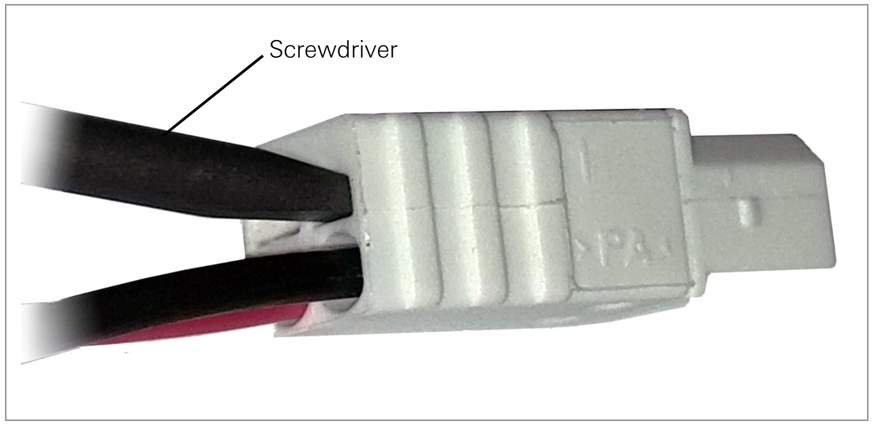

FIGURE 9: Releasing a Conductor

2.2 INSTALLATION PROCEDURE (8960-01C, 04C AND 08C-CBL)

2.2.1 CONNECT THE SENSORS TO THE LOGGERS

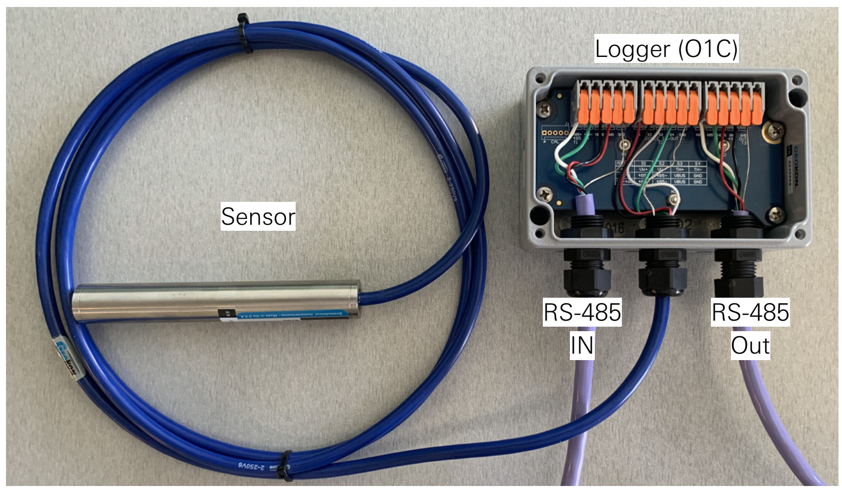

FIGURE 10: Sensor to Logger Connection

2.2.2 MAKING CABLE GLAND CONNECTIONS

To connect a device using a cable gland connection:

1. Loosen the nut on the cable fitting and remove the white plastic dowel.
2. Slide the sensor cable through the cable gland nut and fitting.
3. Wire each conductor into the terminal block by pulling up on an orange tab (It takes some force to open the tab), inserting the bare end of the conductor into the terminal blocks, and then pressing the tab down. Refer to the tables below for wiring information. *To prevent a short circuit, do not allow bare leads to touch each other during or after wiring*.

Single/Multiple-Channel VW Loggers		
Position	**Color**	**Description**
VW+	RED	Vibrating Wire+
VW-	BLACK	Vibrating Wire-
TH+	WHITE	Thermistor+
TH-	GREEN	Thermistor-
SHD	BARE	Analog Ground (shield)

Digital Loggers		
Position	**Color**	**Description**
485+	WHITE	RS-485 Data+
485-	GREEN	RS-485 Data-
12 V	RED	12 V Bus
GND	BLACK	Bus Ground
SHD	BARE	Analog Ground (shield)

TABLE 3: *Logger wiring information*

4. Pull gently on each conductor to make sure it is secure.
5. Tighten the cable gland nut until it firmly grips the outer jacket of the cable. The cable gland nut must be properly tightened to prevent water entry. *Do not over-tighten, because this might strip the plastic threads*.
6. Pull gently on the gauge cable to make sure it is held in place by the cable gland.
7. Repeat these steps for each sensor cable and RS-485 cable connection.

NOTE: The max distance between a logger and the last interface is 1200 m.

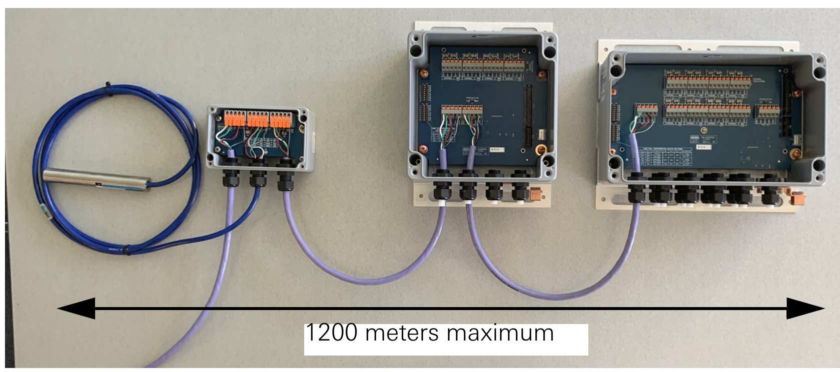

FIGURE 11: *Maximum Distance*

2.2.3 RS-485 CONNECTIONS

NOTE: For the single channel logger (8960-01C-CBL), remove the terminator when an RS-485 OUT cable is used.

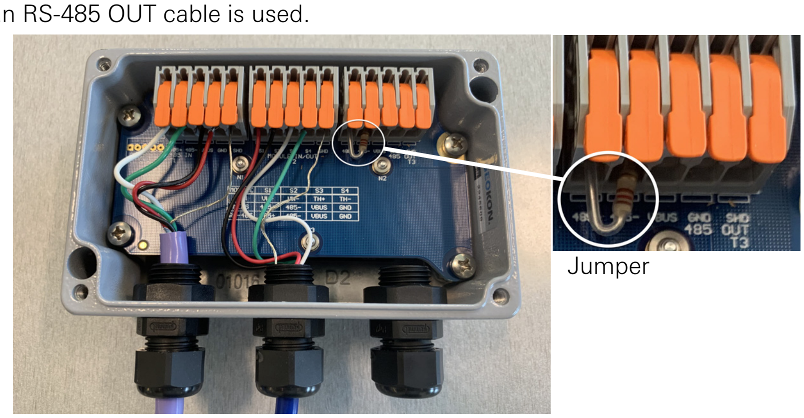

FIGURE 12: *Jumper Location for* 8960-01C-CBL

8. Use the tables on the previous page and the table inside the interface (see below) to make the RS-485 connections.

MODULE	S1	S2	S3	S4
AVW	VW+	VW-	TH+	TH-
MEMS	485+	485-	VBUS	GND
RS-485	485+	485-	VBUS	GND

FIGURE 13: *Internal Wiring Table*

9. Set the termination switch for the last device on the bus to ON.

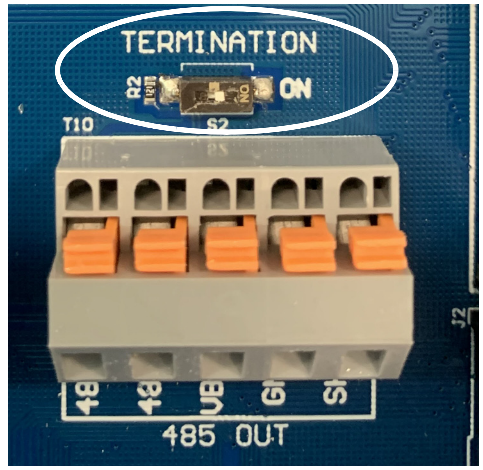

FIGURE 14: *Termination Switch*

10. Indicators can be used to verify which channels are read, and when. Turning off the indicators when they are not needed saves some battery power.

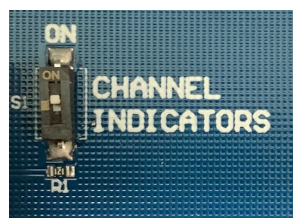

FIGURE 15: *Channel Indicator*

2.2.4 ADDRESSING THE LOGGERS

2.2.4.1 DIP SWITCHES

Factory Default: Switch #1 is ON = Starting Address value is **1**

Example 1: Set starting address to **7**
The resulting value is 1 + 2 + 4 = 7

Switch Number	On/Off	Value
1	ON	**1**
2	ON	**2**
3	ON	**4**
4		**8**
5		**16**
6		**32**
7		**34**
8		**128**

TABLE 4: *DIP Switch Example 1*

Example 2: Set starting address to **38**
The resulting value is 2 + 4 + 32 = **38**

Switch Number	On/Off	Value
1		**1**
2	ON	**2**
3	ON	**4**
4		**8**
5		**16**
6	ON	**32**
7		**34**
8		**128**

TABLE 5: *DIP Switch Example 2*

NOTE: 250 is the maximum Modbus address value.

An 8-CH module will assign 8 sequential address values beginning with the value of the Starting Address set by DIP switches.

If the starting address value is set to 11, then 11 -18 will be assigned.

Example:

The starting address of the 8940-04C-CBL logger will by default begin with address value 1 and establish addresses 1-4.

Adding an additional 4 channels to the 8940-04C-CBL Logger with an 8960-04C-CBL interface, the starting address of the interface must be set to 5 establishing channels 5-8.

If you were to add an 8960-08C-CBL next, it's starting address must be 9 and will establish addresses 9-16.

NOTE: The interfaces and addresses defined by each of their address switches DO NOT need to be sequential or in order when physically connected.

- The addresses must be unique
- Gaps in addresses are OK

2.2.5 RECORD LOGGER AND SENSOR SERIAL NUMBERS

- Record the serial numbers of both the loggers and of the attached sensors.
- Also record the channel to which each sensor has been connected.

The serial numbers are needed to correlate channels to sensors when commissioning the logger.

2.2.6 SEAL THE LOGGERS

1. Place the supplied desiccant packs inside the enclosure.
2. Make sure the cover gasket and the mating ridge on the enclosure are clean and that the gasket is properly seated inside the groove on the cover. Place the cover on the unit.
3. Tighten the cover screws slowly. If using an electric screwdriver, **Do not** fully tighten the screws. Perform the final tightening by hand. Work in a diagonal pattern.

NOTE: Make sure any unused sensor and RS485 openings are plugged and tightened.

3. MODBUS RTU PROTOCOL

3.1 INTRODUCTION TO MODBUS

GEOKON's Model 8960-01C uses the industry standard Modbus Remote Terminal Unit (RTU) protocol to communicate with dataloggers. As the name suggests, Modbus was designed to work on what is known as a **bus network**, meaning that every device receives every message which passes across the network. Model 8960-01C strings use the RS-485 electrical interface because of its prevalence, simplicity, and success as a robust industrial physical layer.

More information about Modbus can be found at the following website: http://www.modbus.org/specs.php

3.2 MODBUS RTU OVERVIEW

The Modbus RTU protocol uses packets (messages made up of multiple sections) to communicate and transfer data between devices on the network. The general format of these packets is as follows:

1. Modbus Address (1 byte) – The address of the specific device on the bus.
2. Function Code (1 byte) – The action to be carried out by the server device.
3. Data (multi-byte) – The payload of the function code being sent.
4. Cyclic Redundancy Check or CRC (2 bytes) – A 16-bit data integrity check calculated over the other byes in the packet.

3.3 MODBUS TABLES

Modbus tables (maps) define the memory locations within each 8960-01C interface and what information they contain. For example, the most recent sensor reading is stored in a table. This reading is presented in different formats in different sections of the table. The register location and size of these variables is detailed in the table below.

Variable	Type	Modbus Register	Decimal	Description
Frequency	float32	0x0100	256	Measured frequency in Hz
Resistance	float32	0x0102	258	Measured thermistor-resistance
Trigger	uint16	0x0118	280	Writing to this register initiates a sample

TABLE 5: *RAM Storage*

3.4 READING SENSORS WITH THE 8960-01C INTERFACES

While Modbus RTU supports roughly 20 different function codes, the simple functionality of a bused VW sensor eliminates the need for all but two of them. Specifically, the **Preset Single Register** (0x06) and the **Read Holding Registers** (0x03). The **Preset Single Register** function code is used to issue a 'trigger' command to the interface. This initiates a pluck and read sequence. The **Read Holding Registers** function code is used to read the values stored in 16-bit registers in the 8960-01C. In this case, the measurement result occupies two 16-bit registers. The readings can be retrieved as frequency (Hz). An example of this trigger and subsequent query is shown in Tables 6 and 7 below.

TX->01 06 0118 00 01 C9 F1	Trigger address #1
RX<-01 06 0118 00 01 C9 F1	Sensor acknowledges the single write
TX->01 03 0100 00 02 C5 F7	Get contents of 2 registers @ 0x0100 (gauge frequency)
RX<-01 03 71 58 45 4B 12 7B	Registers = 0x454B7158, 3255.08 Hz
TX->01 03 01 02 00 02 64 37	Get contents of 2 registers @ 0x0102 (thermistor resistance)
RX<-01 03 5D 3A 45 51 3A FE	Registers = 0x45515D3A, 3349.83 Ω

	Device Address	Function Code	Data Address	Data to Write	*CRC
HEX_{16}	01	06	0118	0001	C9F1
DEC_{10}	1	6	280	1	51697

TABLE 6: *Example Trigger Command - Sensor #1*

The following table shows the IEEE-754 floating point response as two parts, each one composed of two bytes. Because of how this information is stored in the memory, the two parts are received in reverse order. The complete floating point number in HEX is 0x454B7158 (3255.08).

	Device Address	Function Code	Byte Count	Lower 16 bits	Upper 16 bits	*CRC
HEX_{16}	01	03	04	7158	454B	127B
DEC_{10}	1	3	4	3255.08		4731

TABLE 7: *Example Response - Sensor #1, Floating Point Frequency Reading*

14:20:01.750 [TX] - 01 03 01 00 00 02 C5 F7

14:20:01.860 [RX] - 01 03 71 D1 45 4B C3 91

FIGURE 15: *PC terminal program screen capture*

Note: The Modbus CRC is sent the least-significant byte (LSB) first. When calculating the CRC for the write of address 0118 in Table 5, the Modbus CRC algorithm will return 0xF1C9 (61897D). Our examples show the decimal value after the LSB and most-significant byte (MSB) are swapped.

3.5 EXCITATION SWEEPS

The Model 8960-01C interface is designed to excite and measure all GEOKON VW transducers. It will automatically detect any resonant frequency between 400 and 5,000 Hz. There are no settings for sensor type.

The maximum time between sending a trigger and data availability is **370** milliseconds.

4. MODBUS AND CAMPBELL SCIENTIFIC DATALOGGERS

4.1 DESCRIPTION

CRBasic is the programming language used with all Campbell Scientific CRBasic data loggers. Campbell Scientific's LoggerNet software is typically used when programming in CRBasic.

Campbell Scientific's CR6 datalogger can directly communicate with the Model 8960-01C interface, using the RS-485 protocol. However, the CR1000 and CR800 dataloggers don’t support the RS-485 protocol. To accommodate this, GEOKON provides the Model 8020-38 RS-485 to TTL/USB converter.

4.2 MODEL 8020-38 RS-485 TO TTL/USB CONVERTER

GEOKON makes the Model 8020-38 Addressable Bus Converter for connecting addressable strings to personal computers, readouts, dataloggers, and programmable logic controllers. The converter acts as a bridge using the TTL or USB protocols between readers and the GEOKON RS-485-enabled sensor strings.

For more information, please refer to the Model 8020-38 instruction manual.

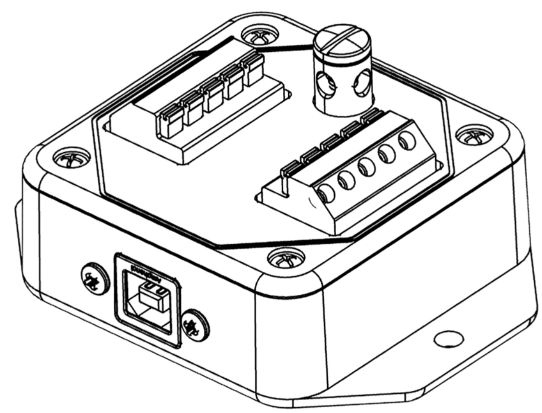

FIGURE 16: *Model 8020-38 RS-485 to TTL/USB Converter*

Note: The datalogger you use must have the appropriate port available.

- If your datalogger does not have built-in RS-485 communications, connect the wiring using the diagram in Figure 17.

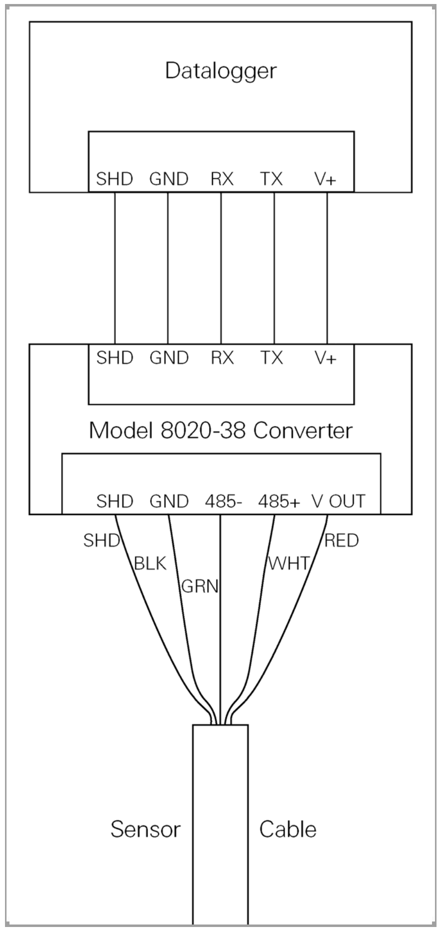

FIGURE 17: *Wiring of Datalogger without built-in RS-485 Conversion*

- If your datalogger has built-in RS-485 communications, connect the wiring using the diagram in Figure 18.

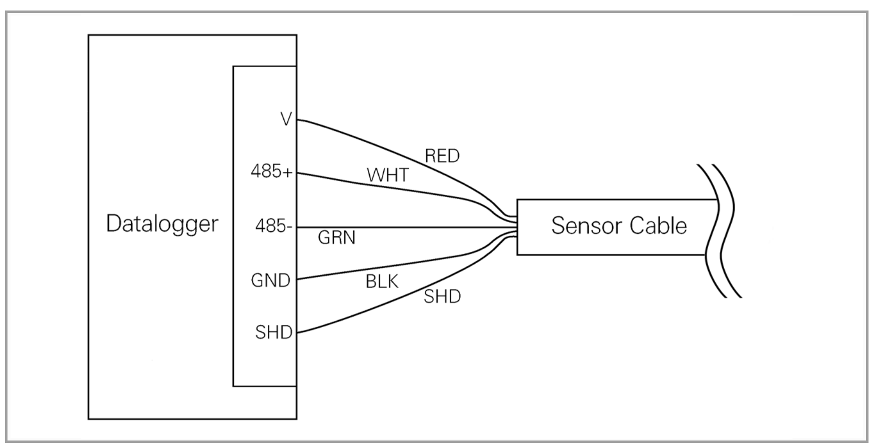

FIGURE 18: *Wiring of Datalogger with built-in RS-485 Conversion*

4.3 SAMPLE PROGRAM

The following program uses a Model 8960-01C interface to directly connect to any single GEOKON vibrating wire sensor. The 8960-01C interface uses MODBUS RTU commands and returns a frequency (Hz) reading for the vibrating wire. It returns a resistance reading (Ohms) for the thermistor.

Note: The 8960-01C MODBUS RTU table register numbers begin with **0**. Campbell Scientific Dataloggers recognize MODBUS RTU table register numbers as beginning with **1**. All CRBasic register numbers are +1. Example: ModbusMaster won't send 0x118 unless "&H119" is entered in the command line.

```
'Define address of the 8960-01C
 Const Address = 1          'Address of Interface, used in variable declaration

'Constants used in Steinhart-Hart equation to calculate sensor temperature
'for 3k thermistor
 Const A = 1.4051E-3
 Const B = 2.369E-4
 Const C = 1.019E-7

 Public ErrorCode           'Error Code sent back from ModBus command
 Public Hz(Address)         'Frequency (Hz) from incoming data
 Public Digits(Address)     'Calculated Digits
 Public Res(Address)        'Resistance (Ohms) from incoming data
 Public Celsius(Address)    'Calculated temperature (Celsius)
```

'Define Data Tables

```
 DataTable (Test, 1,-1)
  Sample (Address,Digits(),IEEE4)
  Sample (Address,Celsius(),IEEE4)
 EndTable
```

'Main Program

```
BeginProg
 'Open COMport with RS-485 communications at 115200 baud rate
    SerialOpen (ComC1,115200,16,0,50,3)   'CR6 program
    SerialOpen (Com1,115200,16,0,50)      'CR1000 program
 'Read the interface/sensor every 30 seconds
    Scan (30,Sec,0,0)
 'Reset temporary storage for both Resistance and Hz so not to retain
 'previous reading
    Res(Address) = 0
    Hz(Address) = 0
  'Flush Serial between readings
    SerialFlush (ComC1)
  'Write to register 0x118 to trigger interface
  'NOTE: ModbusMaster won't send 0x118 unless "&H119" is entered
    ModbusMaster (ErrorCode,ComC1,115200,Address,6,1,&H119,1,1,10,0)
  'Delay after triggering the measurement
    Delay (1,1,Sec)
  'Use Modbus command to retrieve Hertz from string
    ModbusMaster (ErrorCode,ComC1,115200,Count,3,Hz(Address),&H101,1,1,10,0)
  'Calculate Digits from Hertz
    Digits(Address) = (Hz(Address)^2)/1000
  'Use Modbus command to retrieve thermistor resistance
    ModbusMaster (ErrorCode,ComC1,115200,Address,3,Res(Address),&H103,1,1,10,0)
  'Calculate thermistor temperature from Ohms to Celsius using Steinhart-Hart
  'equation
    Celsius(Address) = 1/(A+B*LN(Res(Address))+C*LN(Res(Address))^3)-273.15
   Next
 'Call table to store data
  CallTable Test
 NextScan
EndProg
```

APPENDIX A. SPECIFICATIONS

Power	
Power Supply:	12 VDC
Current Per Sensor:	1.2 mA (idle)
Maximum Current:	35 mA (180Ω VW Coil), 57 mA (50Ω VW Coil)
Operating Temperature:	-40 °C to 80 °C
Communication	
Interface:	RS-485, Half-duplex (two-wire differential)
Protocol:	Modbus RTU
Baud Rate:	115,200 bits/second
Measurements	
Frequency Range:	400 Hz to 6,500 Hz
Frequency Trueness:	0.082 Hz
Frequency Precision:	0.146 Hz (99% Confidence Interval)
Frequency Resolution:	> 0.002 Hz
Frequency Measurement Duration:	< 370 ms
Thermistor Range:	-20° C to +80 °C
Thermistor Accuracy:	±1% (25 °C thermistor point match)
Temperature Resolution:	10-bit, non-linear, 0.6 °C (worst case at -40 °C)
Mechanical	
Cable:	4 conductor, 2 twisted pairs, 6.35 mm (±0.25mm) diameter
Housing:	100 x 25 mm (L x D)

TABLE 8: *Specifications*

APPENDIX A. THERMISTOR TEMPERATURE DERIVATION

A.1 THERMISTOR RESISTANCE FOR 3KΩ

Thermistor Types:

- YSI 44005, Dale #1C3001-B3, Alpha #13A3001-B3
- Honeywell 192-302LET-A01

Resistance to Temperature Equation:

$$T = \frac{1}{A+B(LnR)+C(LnR^3)} - 273.15$$

EQUATION 1: *Thermistor Resistance for 3kΩ*

Where:
T = Temperature in °C
LnR = Natural Log of Thermistor Resistance
A = 1.4051×10^{-3}
B = 2.369×10^{-4}
C = 1.019×10^{-7}
Note: Coefficients calculated over the -50 to +150 °C span.

Ohms	Temp	Ohms	Temp	Ohms	Temp	Ohms	Temp	Ohms	Temp
201.1K	-50	15.72K	-9	2221	32	474.7	73	137.2	114
187.3K	-49	14.90K	-8	2130	33	459.0	74	133.6	115
174.5K	-48	14.12K	-7	2042	34	444.0	75	130.0	116
162.7K	-47	13.39K	-6	1959	35	429.5	76	126.5	117
151.7K	-46	12.70K	-5	1880	36	415.6	77	123.2	118
141.6K	-45	12.05K	-4	1805	37	402.2	78	119.9	119
132.2K	-44	11.44K	-3	1733	38	389.3	79	116.8	120
123.5K	-43	10.86K	-2	1664	39	376.9	80	113.8	121
115.4K	-42	10.31K	-1	1598	40	364.9	81	110.8	122
107.9K	-41	9796	0	1535	41	353.4	82	107.9	123
101.0K	-40	9310	1	1475	42	342.2	83	105.2	124
94.48K	-39	8851	2	1418	43	331.5	84	102.5	125
88.46K	-38	8417	3	1363	44	321.2	85	99.9	126
82.87K	-37	8006	4	1310	45	311.3	86	97.3	127
77.66K	-36	7618	5	1260	46	301.7	87	94.9	128
72.81K	-35	7252	6	1212	47	292.4	88	92.5	129
68.30K	-34	6905	7	1167	48	283.5	89	90.2	130
64.09K	-33	6576	8	1123	49	274.9	90	87.9	131
60.17K	-32	6265	9	1081	50	266.6	91	85.7	132
56.51K	-31	5971	10	1040	51	258.6	92	83.6	133
53.10K	-30	5692	11	1002	52	250.9	93	81.6	134
49.91K	-29	5427	12	965.0	53	243.4	94	79.6	135
46.94K	-28	5177	13	929.6	54	236.2	95	77.6	136
44.16K	-27	4939	14	895.8	55	229.3	96	75.8	137
41.56K	-26	4714	15	863.3	56	222.6	97	73.9	138
39.13K	-25	4500	16	832.2	57	216.1	98	72.2	139
36.86K	-24	4297	17	802.3	58	209.8	99	70.4	140
34.73K	-23	4105	18	773.7	59	203.8	100	68.8	141
32.74K	-22	3922	19	746.3	60	197.9	101	67.1	142
30.87K	-21	3748	20	719.9	61	192.2	102	65.5	143
29.13K	-20	3583	21	694.7	62	186.8	103	64.0	144
27.49K	-19	3426	22	670.4	63	181.5	104	62.5	145
25.95K	-18	3277	23	647.1	64	176.4	105	61.1	146
24.51K	-17	3135	24	624.7	65	171.4	106	59.6	147
23.16K	-16	**3000**	**25**	603.3	66	166.7	107	58.3	148
21.89K	-15	2872	26	582.6	67	162.0	108	56.8	149
20.70K	-14	2750	27	562.8	68	157.6	109	55.6	150
19.58K	-13	2633	28	543.7	69	153.2	110		
18.52K	-12	2523	29	525.4	70	149.0	111		
17.53K	-11	2417	30	507.8	71	145.0	112		
16.60K	-10	2317	31	490.9	72	141.1	113		

TABLE 9: *Thermistor Resistance for 3kΩ*

A.2 THERMISTOR RESISTANCE FOR 8.2KΩ

Figure 5Figure 6Thermistor Type: Figure 5Figure 6Thermometrics BR55KA822J

Resistance to Temperature Equation:

$$T = \frac{1}{A+B(LnR)+C(LnR^3)} - 273.15$$

EQUATION 2: *Thermistor Resistance for 8.2kΩ*

Where:
T = Temperature in °C
LnR = Natural Log of Thermistor Resistance
A = 1.02569×10^{-3}
B = 2.369×10^{-4}
C = 1.019×10^{-7}
Note: Coefficients calculated over the -50 to +150 °C span.

Ohms	Temp	LnR	LnR^3	Calc. Temp	Diff	F.S. Error	Ohms	Temp	LnR	LnR^3	Calc. Temp	Diff	F.S. Error
113898	-30	11.643	1578.342	-30.17	0.17	0.06	407.62	120	6.010	217.118	120.00	0.00	0.00
86182	-25	11.364	1467.637	-25.14	0.14	0.05	360.8	125	5.888	204.162	125.00	0.00	0.00
65805	-20	11.094	1365.581	-20.12	0.12	0.04	320.21	130	5.769	191.998	130.00	0.00	0.00
50684.2	-15	10.833	1271.425	-15.10	0.10	0.03	284.95	135	5.652	180.584	135.00	0.00	0.00
39360	-10	10.581	1184.457	-10.08	0.08	0.03	254.2	140	5.538	169.859	140.01	-0.01	0.00
30807.4	-5	10.336	1104.068	-5.07	0.07	0.02	227.3	145	5.426	159.773	145.02	-0.02	-0.01
24288.4	0	10.098	1029.614	-0.05	0.05	0.02	203.77	150	5.317	150.314	150.03	-0.03	-0.01
19294.6	5	9.868	960.798	4.96	0.04	0.01	183.11	155	5.210	141.428	155.04	-0.04	-0.01
15424.2	10	9.644	896.871	9.98	0.02	0.01	164.9	160	5.105	133.068	160.06	-0.06	-0.02
12423	15	9.427	837.843	14.98	0.02	0.01	148.83	165	5.003	125.210	165.08	-0.08	-0.03
10061.4	20	9.216	782.875	19.99	0.01	0.00	134.64	170	4.903	117.837	170.09	-0.09	-0.03
8200K	25	9.012	731.893	25.00	0.00	0.00	122.1	175	4.805	110.927	175.08	-0.08	-0.03
6721.54	30	8.813	684.514	30.01	-0.01	0.00	110.95	180	4.709	104.426	180.07	-0.07	-0.02
5540.74	35	8.620	640.478	35.01	-0.01	0.00	100.94	185	4.615	98.261	185.10	-0.10	-0.04
4592	40	8.432	599.519	40.02	-0.02	-0.01	92.086	190	4.523	92.512	190.09	-0.09	-0.03
3825.3	45	8.249	561.392	45.02	-0.02	-0.01	84.214	195	4.433	87.136	195.05	-0.05	-0.02
3202.92	50	8.072	525.913	50.01	-0.01	-0.01	77.088	200	4.345	82.026	200.05	-0.05	-0.02
2693.7	55	7.899	492.790	55.02	-0.02	-0.01	70.717	205	4.259	77.237	205.02	-0.02	-0.01
2276.32	60	7.730	461.946	60.02	-0.02	-0.01	64.985	210	4.174	72.729	210.00	0.00	0.00
1931.92	65	7.566	433.157	65.02	-0.02	-0.01	59.819	215	4.091	68.484	214.97	0.03	0.01
1646.56	70	7.406	406.283	70.02	-0.02	-0.01	55.161	220	4.010	64.494	219.93	0.07	0.02
1409.58	75	7.251	381.243	75.01	-0.01	0.00	50.955	225	3.931	60.742	224.88	0.12	0.04
1211.14	80	7.099	357.808	80.00	0.00	0.00	47.142	230	3.853	57.207	229.82	0.18	0.06
1044.68	85	6.951	335.915	85.00	0.00	0.00	43.673	235	3.777	53.870	234.77	0.23	0.08
903.64	90	6.806	315.325	90.02	-0.02	-0.01	40.533	240	3.702	50.740	239.69	0.31	0.11
785.15	95	6.666	296.191	95.01	-0.01	0.00	37.671	245	3.629	47.788	244.62	0.38	0.13
684.37	100	6.528	278.253	100.00	0.00	0.00	35.055	250	3.557	45.001	249.54	0.46	0.16
598.44	105	6.394	261.447	105.00	0.00	0.00	32.677	255	3.487	42.387	254.44	0.56	0.19
524.96	110	6.263	245.705	110.00	0.00	0.00	30.496	260	3.418	39.917	259.34	0.66	0.23
461.91	115	6.135	230.952	115.00	0.00	0.00							

TABLE 10: *Thermistor Resistance for 8.2kΩ*

A.3 THERMISTOR RESISTANCE FOR 10KΩ

Thermistor Type: US Sensor 103JL1A

Figure 5Figure 6Resistance to Temperature Equation:

$$T = \frac{1}{A+B(LnR)+C(LnR)^3+D(LnR)^5} - 273.15$$

EQUATION 3: *Thermistor Resistance for 10KΩ*

Where:
T = Temperature in °C
LnR = Natural Log of Thermistor Resistance
A = 1.127670×10^{-3}
B = 2.344442×10^{-4}
C = 8.476921×10^{-8}
D = 1.175122×10^{-11}

Note: Coefficients optimized for a curve "J" Thermistor over the temperature range of 0 °C to +250 °C.

Ohms	Temp	Ohms	Temp	Ohms	Temp	Ohms	Temp	Ohms	Temp	Ohms	Temp	Ohms	Temp	Ohms	Temp
32,650	0	7,402	32	2,157	64	763.5	96	316.6	128	148.4	160	76.5	192	42.8	224
31,029	1	7,098	33	2,083	65	741.2	97	308.7	129	145.1	161	75.0	193	42.1	225
29,498	2	6,808	34	2,011	66	719.6	98	301.0	130	142.0	162	73.6	194	41.4	226
28,052	3	6,531	35	1,942	67	698.7	99	293.5	131	138.9	163	72.2	195	40.7	227
26,685	4	6,267	36	1,876	68	678.6	100	286.3	132	135.9	164	70.8	196	40.0	228
25,392	5	6,015	37	1,813	69	659.1	101	279.2	133	133.0	165	69.5	197	39.3	229
24,170	6	5,775	38	1,752	70	640.3	102	272.4	134	130.1	166	68.2	198	38.7	230
23,013	7	5,545	39	1,693	71	622.2	103	265.8	135	127.3	167	66.9	199	38.0	231
21,918	8	5,326	40	1,637	72	604.6	104	259.3	136	124.6	168	65.7	200	37.4	232
20,882	9	5,117	41	1,582	73	587.6	105	253.1	137	122.0	169	64.4	201	36.8	233
19,901	10	4,917	42	1,530	74	571.2	106	247.0	138	119.4	170	63.3	202	36.2	234
18,971	11	4,725	43	1,480	75	555.3	107	241.1	139	116.9	171	62.1	203	35.6	235
18,090	12	4,543	44	1,432	76	539.9	108	235.3	140	114.5	172	61.0	204	35.1	236
17,255	13	4,368	45	1,385	77	525.0	109	229.7	141	112.1	173	59.9	205	34.5	237
16,463	14	4,201	46	1,340	78	510.6	110	224.3	142	109.8	174	58.8	206	33.9	238
15,712	15	4,041	47	1,297	79	496.7	111	219.0	143	107.5	175	57.7	207	33.4	239
14,999	16	3,888	48	1,255	80	483.2	112	213.9	144	105.3	176	56.7	208	32.9	240
14,323	17	3,742	49	1,215	81	470.1	113	208.9	145	103.2	177	55.7	209	32.3	241
13,681	18	3,602	50	1,177	82	457.5	114	204.1	146	101.1	178	54.7	210	31.8	242
13,072	19	3,468	51	1,140	83	445.3	115	199.4	147	99.0	179	53.7	211	31.3	243
12,493	20	3,340	52	1,104	84	433.4	116	194.8	148	97.0	180	52.7	212	30.8	244
11,942	21	3,217	53	1,070	85	421.9	117	190.3	149	95.1	181	51.8	213	30.4	245
11,419	22	3,099	54	1,037	86	410.8	118	186.1	150	93.2	182	50.9	214	29.9	246
10,922	23	2,986	55	1,005	87	400.0	119	181.9	151	91.3	183	50.0	215	29.4	247
10,450	24	2,878	56	973.8	88	389.6	120	177.7	152	89.5	184	49.1	216	29.0	248
10,000	**25**	2,774	57	944.1	89	379.4	121	173.7	153	87.7	185	48.3	217	28.5	249
9,572	26	2,675	58	915.5	90	369.6	122	169.8	154	86.0	186	47.4	218	28.1	250
9,165	27	2,579	59	887.8	91	360.1	123	166.0	155	84.3	187	46.6	219		
8,777	28	2,488	60	861.2	92	350.9	124	162.3	156	82.7	188	45.8	220		
8,408	29	2,400	61	835.4	93	341.9	125	158.6	157	81.1	189	45.0	221		
8,057	30	2,316	62	810.6	94	333.2	126	155.1	158	79.5	190	44.3	222		
7,722	31	2,235	63	786.6	95	324.8	127	151.7	159	78.0	191	43.5	223		

TABLE 11: *Thermistor Resistance for 10KΩ*

GEOKON
48 Spencer Street
Lebanon, New Hampshire
03766, USA

Phone: +1 (603) 448-1562
Email: info@geokon.com
Website: www.geokon.com