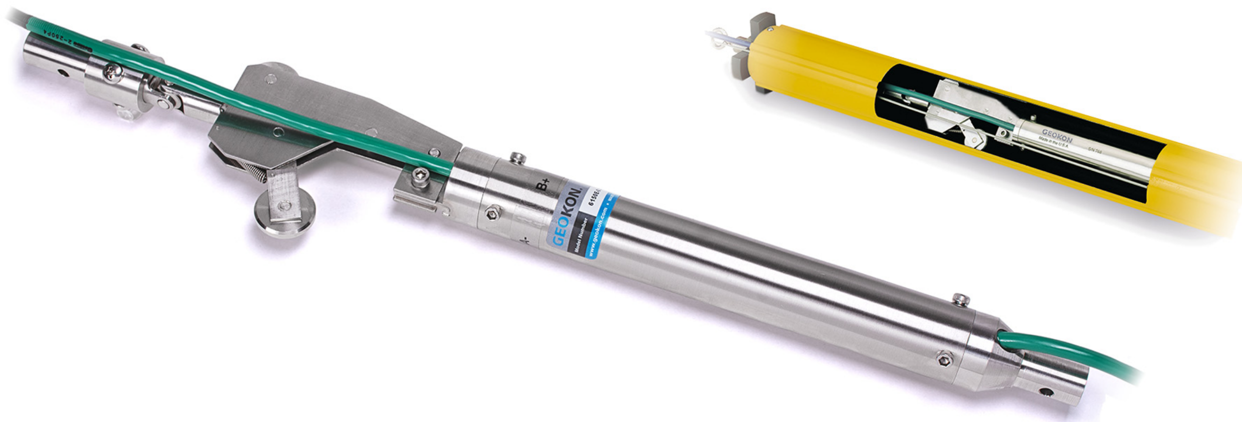
Model 6150F

MEMS Digital Addressable

In-Place Inclinometer

Instruction Manual



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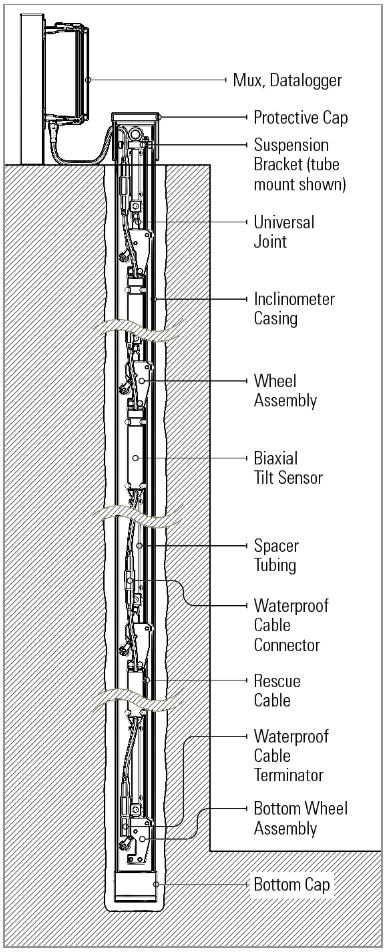

FIGURE 1: *Model 6150F Installed*

The GEOKON Model 6150F MEMS Digital Addressable In-Place Inclinometer system enables long-term monitoring of deformations in structures such as dams, embankments, foundation walls, and similar applications. The basic principle of operation is the use of tilt sensors to make accurate measurement of inclination, over segments of a borehole, which is drilled into the structure being studied. The instrument is designed to be installed in standard grooved inclinometer casing, which is installed in the borehole. Constant monitoring by the instrument allows for very precise measurement of changes in the borehole profile. Each tilt sensor is individually serialized and calibrated. A calibration sheet for each sensor is provided, showing the relationship between sensor output and inclination.

Each tilt sensor is comprised of two addressable Micro-Electro-Mechanical Systems (MEMS) devices inside a sealed stainless steel housing. The devices measure the A and B axes of the borehole. Each sensor also contains a thermistor for reading temperatures.

The tilt sensors are connected to each other using four-wire bus cable. Each sensor has a length of this cable exiting both the top and bottom of the housing. A male connector is attached to the cable exiting the top of the sensor and a female connector is attached to the cable exiting the bottom of the sensor.

The uppermost sensor of the string connects to a customer-specified terminator for attaching to the chosen readout (PC, datalogger, SCADA system, etc.).

The inclinometer system uses stainless steel tubing to mechanically connect the sensors, as well as to fix them at the customer-designated intervals. The tilt sensor housing has a wheel assembly and universal joint on its upper end. This centralizes the sensors in the casing, allows unimpeded relative movement of the spacer tubing, and accommodates any spiraling of the casing. The entire string is normally supported from the top of the casing by a suspension bracket.

2.INSTALLATION

2.1 PRELIMINARY TESTS

Prior to installation, check the sensors for proper operation. Complete the following steps:

1. Place the sensors in the correct order by referring to the labels on the sensors and the provided paperwork.
2. Connect the sensors by plugging the cable exiting the underside of one sensor into the cable exiting the top of the next sensor.

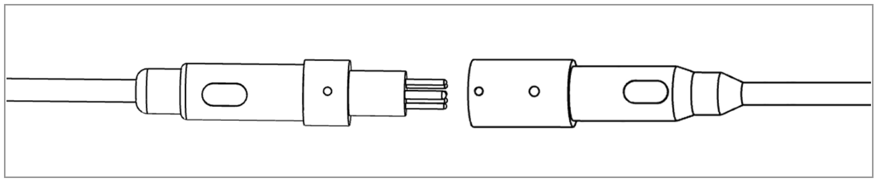

FIGURE 2: *Cable Connection Detail*

Caution! When connecting the sensors, make sure to line up the two nubs on the outside of the female connector with the nub on the outside of the male connector. This will ensure that the pins and holes on the interior of the connectors align correctly. Push the male and female connectors together until they are completely mated.

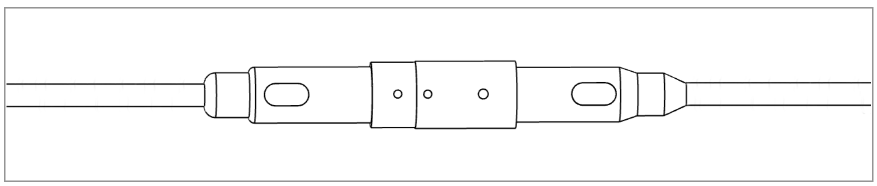

FIGURE 3: *Connected Cables*

3. Once all sensors have been connected, plug the end terminator into the female connector at the bottom sensor. See the figure below.

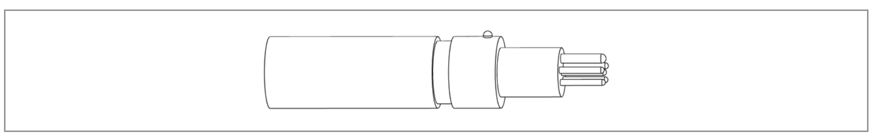

FIGURE 4: *End Terminator Model 6150F-2*

4. Connect the completed string to a readout or datalogger.
5. Hold the first sensor in a vertical position and observe the reading. The tilt sensor must be held steady while taking the reading. The observed reading should be close to the factory vertical reading. Tilts in a positive direction (A+ or B+, as marked on the sensor) should yield increasing readings. Tilts in a negative direction (A- or B-) should yield decreasing readings. The temperature indicated on the readout should be close to ambient. Repeat this process with the remaining sensors.
6. Once the preliminary tests are complete, disconnect the string from the readout.
7. Disconnect all of the sensor cables. (The end terminator may remain on the bottom sensor.)

Should any of these preliminary tests fail, see Section 5 for troubleshooting.

2.2 ASSEMBLY

2.2.1 ASSEMBLING USING WITH SPACER TUBES

Each tilt sensor is supplied with fasteners attached, and with a connecting tube unattached. To complete the assembly of each segment, do the following:

1. Remove the nut/bolt fasteners from the sensor.
2. Connect the spacer tube to the connector at the bottom of the sensor.
3. Fasten the tube to the sensor using the nuts/bolts removed in step 1.
4. Repeat steps 1-3 for each sensor/spacer tube set.

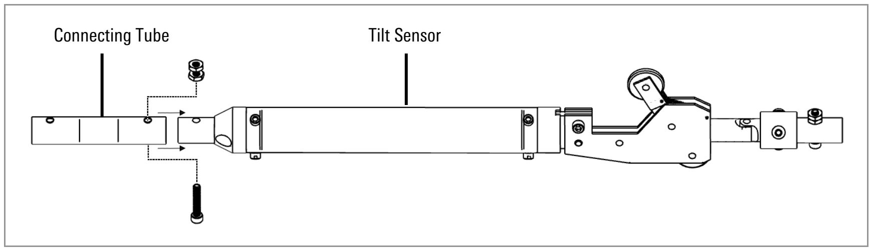

FIGURE 5: *Connect the Segment Assembly*

PLEASE NOTE:

- ☐ The one-inch cap screws used in the assembly procedure are installed in the connecting tubes at the factory and must be removed before attaching the tubing.
- ☐ The string will ship with a few spare cap screws and nuts. The shorter 3/8" cap screws are spares for the screws that attach the wheel assemblies.
- ☐ Where the spacing of the sensors is too long for a continuous length of tubing, connect two tubes together using the 6300-7 Tube Coupling (see the figure below). Use the one-inch cap screws and nuts to secure this connection.

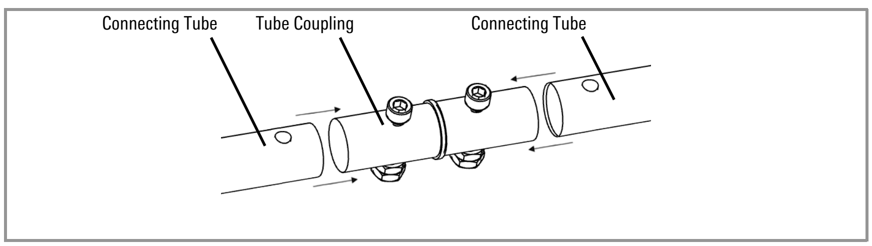

FIGURE 6: *6300-7 Tube Coupling*

- ☐ **Use Loctite 222 thread locking compound on all threaded connections.**

2.2.2 ASSEMBLING USING CABLE

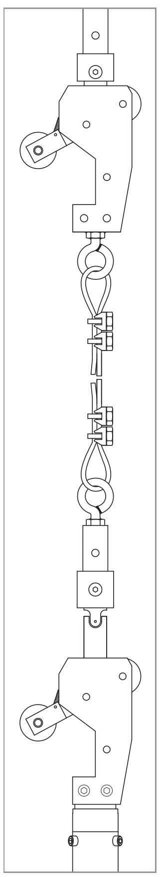

FIGURE 7: *Cable Connecting Segments*

Each tilt sensor is supplied with fasteners attached. To complete the assembly of each segment, do the following:

1. Remove the nut and bolt fasteners from the sensor.
2. Connect a wheel assembly to the top of the sensor.
3. Connect a wheel assembly to the bottom of the sensor.
4. Repeat steps 1-3 for each sensor.
5. Connect the sensors together by attaching a cable to the eyehooks on adjacent sensors.

2.2.3 BOTTOM WHEEL ASSEMBLY

The bottom wheel assembly, Model 6300-5, has no universal joint, only a swivel. Attach this wheel assembly to the bottom segment using the provided hardware.

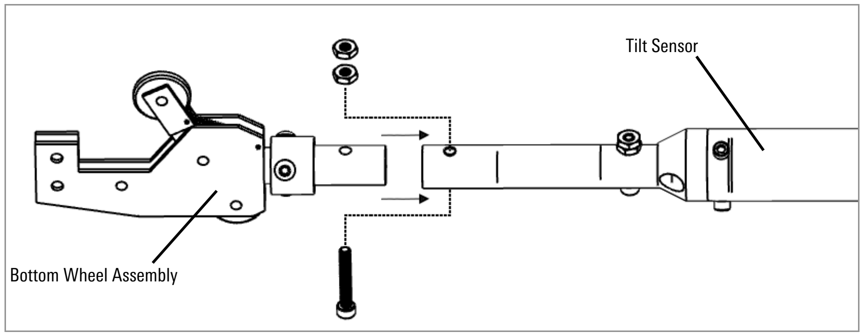

FIGURE 8: *Connect the Bottom Wheel Assembly*

Note: Remember to use Loctite 222 on all threaded connections.

Attaching a safety cable to the bottom wheel assembly is strongly recommended. Not only can it be used to retrieve the assembly if one of the joints breaks loose, but it is also very helpful when lowering the assembly into the casing.

Safety cables purchased from GEOKON will have an eye bolt on one end. Slide the eye bolt onto the 10-32 cap screw used to attach the bottom segment to the bottom wheel assembly. Tighten another nut onto the cap screw; this will trap the safety cable between the two nuts. The completed bottom wheel assembly is shown in the figure below.

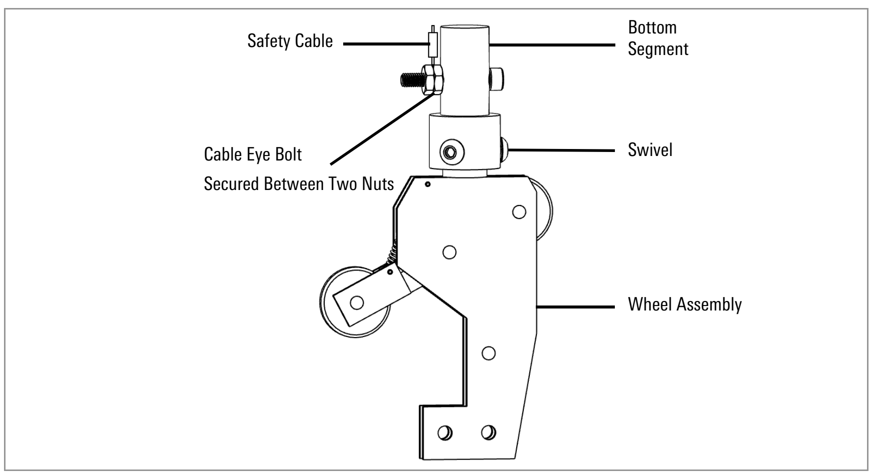

FIGURE 9: *Connect the Safety Cable*

2.2.4 SENSOR ORIENTATION

All wheel assemblies should be oriented in the same direction when installed in the casing. The wheel assemblies are attached at the factory so that the fixed wheel is facing the A+ direction of the sensor (as shown in the figure to the left).

It is customary and recommended to point the A+ (fixed wheel) direction in the same direction as the anticipated movement, i.e., towards the excavation being monitored or downslope for slope stability applications.

A second MEMS device is included in the sensor and is attached with its positive direction 90° clockwise from the first device. This is the B+ direction of the sensor.

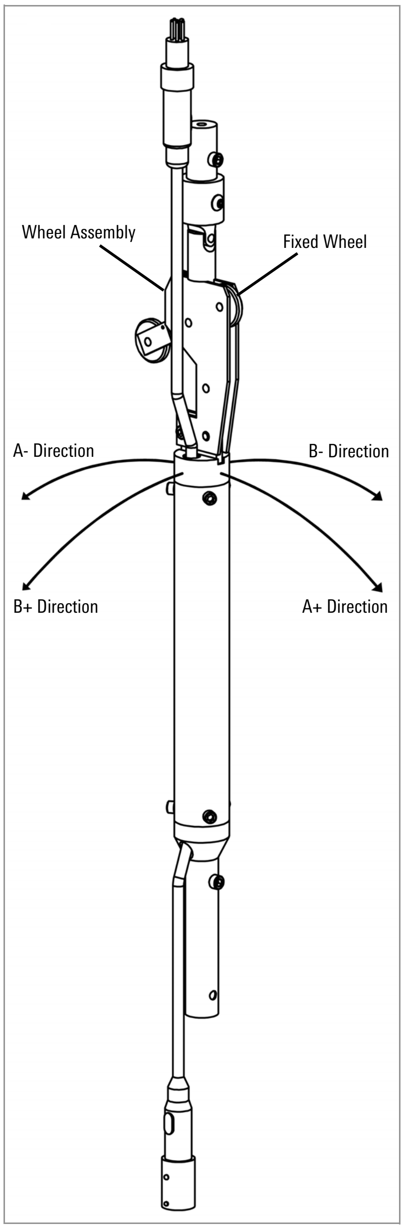

FIGURE 10: *A & B Directions*

2.2.5 SENSOR INSTALLATION

1. Insert the bottom wheel assembly into the casing, making sure to orient the fixed wheel correctly (see Section 2.2.4).
2. Using the safety cable, lower the bottom segment into the casing hole, until the bottom sensor is at the top of the casing.
3. Hold the segment in place at the top of the casing using vice-grips or a similar method.
4. Plug the male connector of the bottom sensor into the female connector of the sensor above it.

   Caution! When connecting the sensors, make sure to align the two nubs on the outside of the female connector with the nub on the outside of the male connector. This will ensure that the pins and holes on the interior of the connectors align correctly. Push the male and female connectors together until they are completely mated.

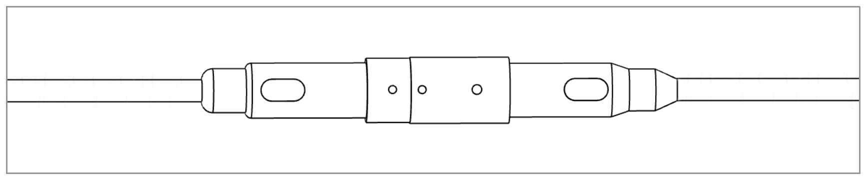

FIGURE 11: *Cable Connection Detail*

5. Tape the signal cable to the tubing, if desired. The connectors may be taped together for additional security.
6. Using the safety cable, lower the bottom segment into the hole, until the next sensor is at the top of the casing. Make sure to orient the A+ direction of the sensor correctly when inserting it into the casing.
7. Continue to add segments to the string. Connect the sensor cables together and lower the string into the casing, until the uppermost sensor is aligned with the top of the casing.

2.2.6 CONNECTING THE SUSPENSION BRACKET

Attach the suspension bracket to the top sensor's wheel assembly via one of two methods: use a cable (sold separately), or use the connector tube provided.

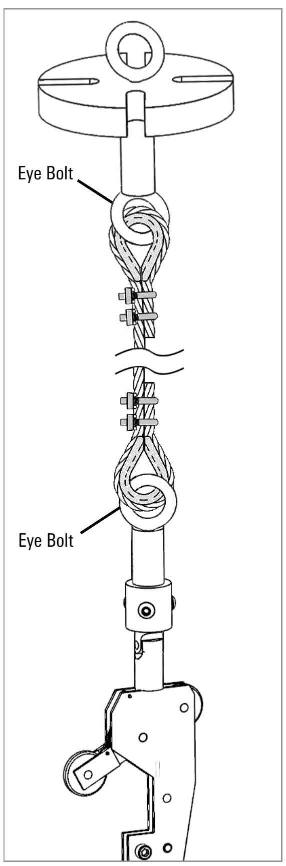

FIGURE 12: *Suspension via Cable*

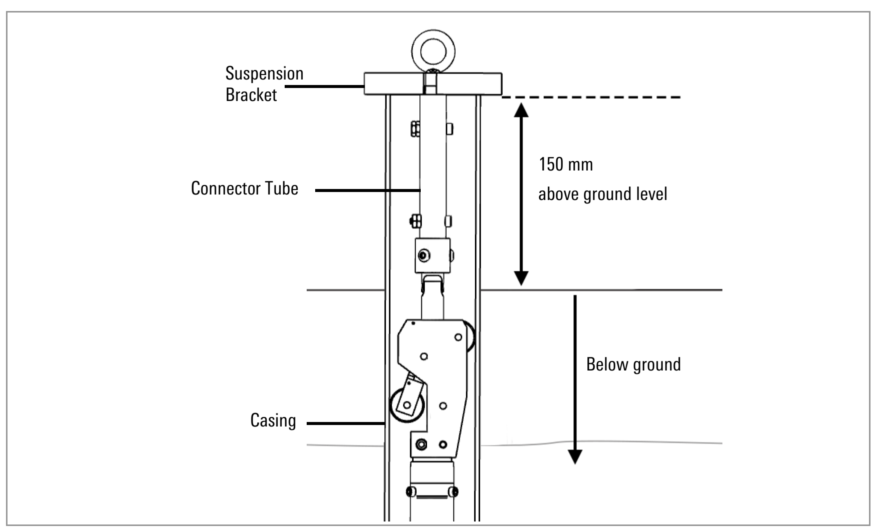

FIGURE 13: *Suspension via Tube*

Lower the final sensor into the casing and position the suspension bracket on top of the casing. It is important that the top rim of the casing be relatively square to prevent any side interference with the wheel assembly of the top sensor.

The safety cable can now be tied off at the top of the casing and the signal cable can be run to the readout location. Readings can be taken immediately after installation, but it is recommended that the system be allowed to stabilize for a few hours before recording the zero readings.

2.3 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 14:** 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 to the left.
- If your datalogger has built-in RS-485 communications, connect the wiring using the diagram in the figure below.

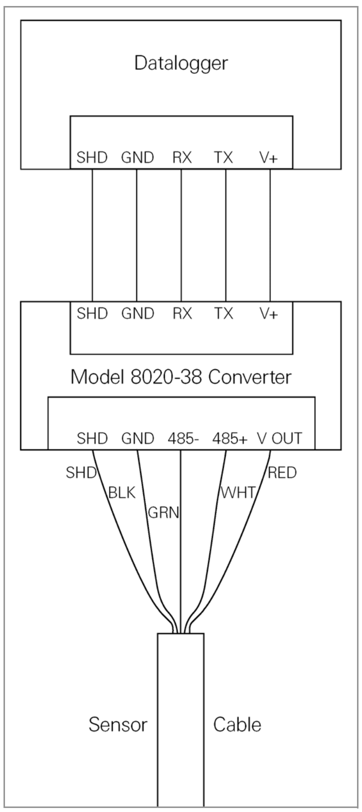

***FIGURE 15:** Wiring of Datalogger without built-in RS-485 Conversion*

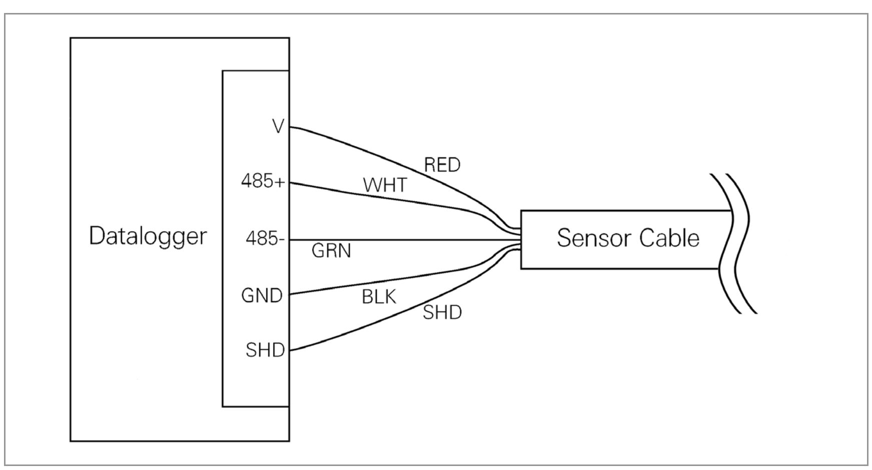

***FIGURE 16:** Wiring of Datalogger with built-in RS-485 Conversion*

2.4 SIX-PIN WATERPROOF CONNECTOR

The pinouts for the six-pin male and female connectors are shown below; the function of each wire is detailed in Table 1 below.

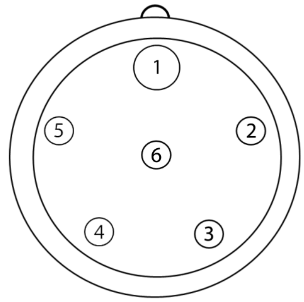

FIGURE 17: *Male Waterproof Connector*

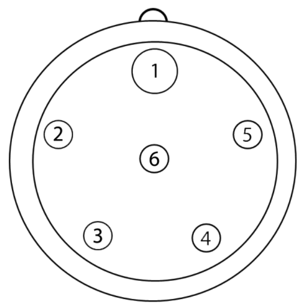

FIGURE 18: *Female Waterproof Connector*

Pin	Wire Color	Function
1	Red	Power
2	Black	Ground
3	White	RS-485+ Data High
4	Green	RS-485- Data Low
5	Bare	Shield Drain
6	N/C	N/C

TABLE 1: *Six-Pin Wiring Chart*

3. MODBUS RTU PROTOCOL

3.1 INTRODUCTION TO MODBUS

Model 6150F inclinometers use the industry standard Modbus Remote Terminal Unit (RTU) protocol to communicate with the chosen readout method. As the name suggests, Modbus was designed to work on what is known as a **bus network**, meaning that every device receives every message that passes across the network. Model 6150F inclinometers 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 (one byte) – The address of the specific device on the bus. (Labeled on the sensors as #1, #2, #3, etc.)
2. Function Code (one byte) – The action to be carried out by the slave device.
3. Data (multi-byte) – The payload of the function code being sent.
4. Cyclic Redundancy Check or CRC (two bytes): A 16-bit data integrity check calculated over the other byes in the packet.

3.3 MODBUS TABLES

The most recent sensor readings are stored in memory registers, read using a Modbus command. Angle and temperature readings are available in processed or precursor formats. Register addresses and formats are described in Table 2 on page 8.

Table 3 on page 8 shows device control addresses. Any nonzero value written to the trigger address initiates a measurement cycle, updating the angle and temperature measurement registers. Any anomalies detected during the most recent measurement cycle produce a non-zero error code. Refer to Appendix C for an explanation of these codes.

The flash password prevents unintended writes to the nonvolatile memory in Table 4 on page 8 and the preprogrammed device information in Table 5 on page 9. Contact GEOKON for instructions.

Register Address	Byte	Word	Parameter	Units	Type	Access
0x100	0	LSW	A-Axis	degrees	float	RO
	1					
0x101	2	MSW				
	3					
0x102	4	LSW	B-Axis	degrees	float	
	5					
0x103	6	MSW				
	7					
0x106	12	LSW	Temperature	°C	float	
	13					
0x107	14	MSW				
	15					
0x108	16	LSW	Uncorrected A-Axis	degrees	float	
	17					
0x109	18	MSW				
	19					
0x10A	20	LSW	Uncorrected B-Axis	degrees	float	
	21					
0x10B	22	MSW				
	23					
0x10E	28	LSW	Thermistor ADC	N/A	uint16	
	29					
0x117	46		Error Code	N/A	uint16	
	47					

TABLE 2: *Register Addresses and Formats*

Register Address	Byte	Word	Parameter	Units	Type	Access
0x118	48		Trigger	N/A	uint16	RW
	49					
0x119	50	LSW	Password	N/A	uint32	
	51					
0x11A	52	MSW				
	53					
0x11B	54		Measure Cycle	N/A	uint16	
	55					

TABLE 3: *Device Control Addresses*

Register Address	Byte	Word	Parameter	Units	Type	Access
0x200	0		Drop Address	N/A	uint16	RO
	1					
0x201	2		Sensor Type	N/A	string	
	3					
0x202	4					
	5					
0x203	6					
	7					
0x204	8					
	9					
0x205	10					
	11					
0x206	12					
	13					
0x207	14					
	15					
0x208	16					
	17					
0x209	18	LSW	Serial Number	N/A	uint32	
	19					
0x20A	20	MSW				
	21					
0x20B	22		Software Version	N/A	uint16	
	23					
0x20C	24		Hardware Version	N/A	uint16	
	25					

TABLE 4: *Non-Volatile Memory*

Register Address	Byte	Word	Parameter	Units	Type	Access
0x20D	26	LSW	A Offset	degrees	float	RO
	27					
0x20E	28	MSW				
	29					
0x20F	30	LSW	B Offset	degrees	float	
	31					
0x210	32	MSW				
	33					
0x213	38	LSW	A Gauge Factor	degrees	float	
	39					
0x214	40	MSW				
	41					
0x215	42	LSW	B Gauge Factor	degrees	float	
	43					
0x216	44	MSW				
	45					

TABLE 5: *Preprogrammed Device Information*

4. DATA REDUCTION

4.1 INCLINATION CALCULATION

The output of the Model 6150F inclinometer sensor is angle of inclination. The standard sensor has a full range of approximately ±15°.

Each sensor is provided with a unique Gauge Factor (G) that is used to calculate the corrected inclination angle (θ) of the sensor:

$$\theta = G(R)$$

EQUATION 1: *Corrected Inclination Angle*

Where:
θ = Corrected inclination angle of the sensor
G = Gauge Factor
R = Reading from sensor

To calculate the change in the inclination angle of the sensor, the following equation is used:

$$\Delta\theta = G(R_1 - R_0)$$

EQUATION 2: *Change in Inclination*

Where:

$\Delta\theta$ = Change in the inclination angle of the sensor
G = Gauge Factor
R_1 = Current reading from sensor
R_0 = Initial or Zero reading from sensor

Positive values are tilts in the direction of the arrows A+ and B+

4.2 DEFLECTION CALCULATION

The lateral displacement (D) of the top of any segment relative to the vertical line running through the bottom of the segment is equal to:

$$D = L\sin\theta$$

EQUATION 3: *Lateral Displacement*

Where:
L = The length of the segment
θ = Inclination angle of the sensor

Equation 3 can also be expressed as: $D = L\sin G(R)$

Where:
G = Gauge factor
R = Reading from the sensor

The profile of the borehole is constructed using the cumulative sum of these lateral displacements starting with the bottom segment (L_1).

For reference, see the figure to the left.

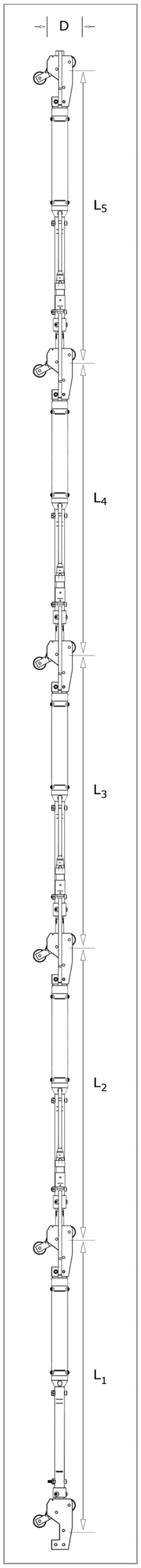

FIGURE 19: *Deflection Intervals*

The total lateral displacement of the top of the upper segment (which is usually at the surface), from the vertical line drawn through the bottom of the lower segment (located at the bottom of the borehole), is:

$$D = L_1\sin\theta_1 + L_2\sin\theta_2 + L_3\sin\theta_3 + L_4\sin\theta_4 + L_5\sin\theta_5$$

EQUATION 4: *Total Lateral Displacement Calculation*

Therefore:

$$D = L_1\sin G(R)_1 + L_2\sin G(R)_2 + L_3\sin G(R)_3 + L_4\sin G(R)_4 + L_5\sin G(R)_5$$

and the change in displacement (ΔD) is:

$$\Delta D_n = \Sigma^n{}_1 L_n G_n \Delta R_n$$

EQUATION 5: *Deflection Calculation*

Where:

ΔR_1 = Sensor's($_1$) current reading ($R_1(_1)$) minus the sensor's ($_1$) initial, or Zero, reading ($R_0(_1)$), or ($R_1(_1)$-$R_0(_1)$).

ΔR_2 = Sensor's($_2$) current reading ($R_1(_2)$) minus sensor's ($_2$) initial, or Zero, reading ($R_0(_2)$), or ($R_1(_2)$-$R_0(_2)$).

Repeat for all the other sensors in the string.

Although the system is designed for use in continuous segments with pivots, the sensors can be installed without interconnecting tubing in standard, round tubing or pipe using special friction anchors. In those systems, the assumption is made that the measured deflection occurs over the segment length, the midpoint of which is at the sensor location, and that L is the distance between adjacent midpoints.

4.3 TEMPERATURE CORRECTION

Although the temperature dependence of the MEMS tilt meter is close to zero, and usually does not require compensation, it sometimes happens that temperature effects can cause real changes of tilt; therefore, each sensor is equipped with a device for reading the sensor temperature. This enables temperature-induced changes in inclination to be distinguished from inclination due to other sources. The device provides a digital output proportional to the temperature.

Normally, temperature corrections are not required. An important point to note is that sudden changes in temperature will cause both the structure and the sensor to undergo transitory physical changes, which will show up in the readings. The sensor temperature should always be recorded, and efforts should be made to obtain readings when the instrument and structure are at thermal equilibrium. The best time for this tends to be in the late evening or early morning hours.

4.4 ENVIRONMENTAL FACTORS

Since the purpose of the inclinometer installation is to monitor site conditions, factors that may affect these conditions should be observed and recorded. Seemingly minor effects may have real influence on the behavior of the structure being monitored and may give an early indication of potential problems. Some of these factors include, but are not limited to, blasting, rainfall, tidal or reservoir levels, excavation and fill levels and sequences, traffic, temperature and barometric changes, changes in personnel, nearby construction activities, seasonal changes, etc.

5. TROUBLESHOOTING

Maintenance and troubleshooting of Model 6150F inclinometers is confined to periodic checks of the cable connections. The sensors are sealed and there are no user serviceable parts.

Should difficulties arise, consult the list of possible solutions shown below. Refer to Appendix C for Modbus error codes. Consult the factory for additional troubleshooting help.

SYMPTOM: TILT SENSOR READINGS ARE UNSTABLE OR FAIL TO READ

- ☐ Is there a source of electrical noise nearby? Most probable sources of electrical noise are motors, generators, and antennas.
- ☐ Check all cable connections, terminals, and plugs.
- ☐ Water may have penetrated the interior of the tilt sensor. There is no remedial action.

APPENDIX A. SPECIFICATIONS

Range	±15° (±54000 arcseconds)
Resolution[1]	±0.0001° (±0.2 arcseconds)
Precision[2]	±0.0018° (±6.5 arcseconds)
Nonlinearity	±0.006° across ±8° range (±20.8 arcseconds) ±0.016° across ±15° range (±59.3 arcseconds)
Temperature Dependent Uncertainty	±0.0054°/°C (±19.3 arcseconds/°C)
Cross axis sensitivity[3]	4%
Frequency Response	-3 dB @ 8-28 Hz
Thermistor Accuracy	±0.65 °C
Thermistor Precision	±0.06 °C
Operating Temperature	-40 to 80 °C (-40 to 176 °F)
Power Supply Voltage	12 VDC ±20%
Operating Current[4]	26 mA ±1 mA
Standby Current	1.2 mA ±0.1 mA
Maximum Supply Current[5]	500 mA
Housing Diameter	32 mm (1.250")
Housing Length	240 mm (9.5")
Weight of 0.5 m Segment[6]	1.3 kg (2.8 lb)
Materials	316 Stainless Steel
Electrical Cable	Four Conductor, Foil shield, Polyurethane jacket, nominal OD = 6.3 mm
Minimum Sensor Spacing	0.5 m

TABLE 6: *Model 6150F Inclinometer Specifications*

Notes:

[1] All but one in a hundred individual readings would fall within our published tolerance. (Most measuring devices are specified with only a 95% confidence interval, meaning one in twenty readings exceed the stated limit, on average.)

[2] Expanded uncertainty for 99.0% confidence interval includes angle random walk and incidental seismic noise during tests. Angle 'random walk' describes the changes between consecutive readings that have no discernible cause.

[3] Per MEMS device datasheet.

[4] Operating and standby current are for each individual sensor drop in a string.

[5] Per entire string.

[6] Weight of sensor without cable.

A.1 PARTS LIST

6150F-0.5-M	MEMS IPI Addressable RS485 Vertical In Place Inclinometer Segment, Biaxial	Segment length = 0.5 m
6150F-1-M	" " " " " " " " "	Segment length = 1 m
6150F-2-M	" " " " " " " " "	Segment length = 2 m
6150F-3-M	" " " " " " " " "	Segment length = 3 m
6150F-5-M	" " " " " " " " "	Segment length = 5 m
6150F-2-E	" " " " " " " " "	Segment length = 2 ft
6150F-5-E	" " " " " " " " "	Segment length = 5 ft
6150F-10-E	" " " " " " " " "	Segment length = 10 ft
6150F-2	Termination assembly connector (one required per string)	
6150F-3V	Readout cable, female connector to bare leads. Specify length of 02-250P4 cable required	
6150F-4V	Readout cable, female connector to 5-pin. Specify length of 02-250P4 cable required	
02-250P4-M	Green polyurethane cable 0.250", 2 twisted pairs	
6150F-6	Suspension bracket	
6300-5	Bottom wheel assembly (one required per string)	
6300-6E/M	Rescue cable for in-place inclinometer, runs to bottom of assembly	
6300-7	Tube Coupling	
07-125SS-M	Aircraft cable, 1/8"	

TABLE 7: *Model 6150F Inclinometer Parts List*

APPENDIX B. SAMPLE CALIBRATION SHEETS

GEOKON® 48 Spencer St. Lebanon, NH 03766 USA

MEMS Tilt Sensor Calibration

Model Number: 6150F-1

Calibration Date: January 17, 2018

This calibration has been verified/validated as of 02/05/2018

Serial Number: 1745224 Sensor A

Temperature: 23.1

Calibration Instruction: CI-Tiltmeter MEMS Sensor

Technician:

Inclination 1 (degrees)	Reading 1 (degrees)	Inclination 2 (degrees)	Reading 2 (degrees)	Reading Average (degrees)	Calculated Inclination (degrees)	Error (%FS)
-15.0015	-17.0786	-15.0011	-17.0767	-17.0777	-15.0107	-0.03
-8.0005	-10.1660	-8.0005	-10.1658	-10.1659	-7.9985	0.01
-3.9997	-6.2206	-3.9997	-6.2183	-6.2194	-3.9948	0.02
-1.9999	-4.2512	-1.9999	-4.2512	-4.2512	-1.9980	0.01
-0.9994	-3.2615	-0.9994	-3.2611	-3.2613	-0.9938	0.02
0.0000	-2.2805	-0.0003	-2.2792	-2.2798	0.0019	0.01
1.0001	-1.2956	1.0004	-1.2957	-1.2957	1.0004	0.00
1.9995	-0.3074	1.9995	-0.3067	-0.3070	2.0034	0.01
4.0004	1.6596	4.0004	1.6594	1.6595	3.9984	-0.01
8.0015	5.6028	8.0018	5.6037	5.6032	7.9994	-0.01
15.0011	12.4962	15.0008	12.4967	12.4964	14.9926	-0.03

6150F Deflection Gage Factor (G): 1.01451 (degrees/degree)

Deflection = L sin (G * (R_1 - R_0)) (mm or inches)

Tilt = G (R_1 - R_0) (degrees)

Wiring Code: See Manual for further information

The above instrument was found to be in tolerance in all operating ranges.
The above named instrument has been calibrated by comparison with standards traceable to the NIST, in compliance with ANSI Z540-1.

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FIGURE 20: *Sample Model 6150F Calibration Sheet, Sensor A*

GEOKON® 48 Spencer St. Lebanon, NH 03766 USA

MEMS Tilt Sensor Calibration

Model Number: 6150F-1

Calibration Date: January 17, 2018

This calibration has been verified/validated as of 02/05/2018

Serial Number: 1745224 Sensor B

Temperature: 23.7

Calibration Instruction: CI-Tiltmeter MEMS Sensor

Technician:

Inclination 1 (degrees)	Reading 1 (degrees)	Inclination 2 (degrees)	Reading 2 (degrees)	Reading Average (degrees)	Calculated Inclination (degrees)	Error (%FS)
-15.0011	-14.4014	-15.0011	-14.4006	-14.4010	-15.0098	-0.03
-8.0001	-7.4959	-8.0005	-7.4963	-7.4961	-7.9986	0.01
-4.0004	-3.5528	-3.9997	-3.5504	-3.5516	-3.9934	0.02
-2.0002	-1.5866	-2.0002	-1.5866	-1.5866	-1.9982	0.01
-0.9994	-0.5982	-1.0001	-0.5994	-0.5988	-0.9952	0.02
-0.0007	0.3814	-0.0003	0.3827	0.3821	0.0008	0.00
1.0001	1.3659	1.0001	1.3659	1.3659	0.9997	0.00
2.0005	2.3530	2.0002	2.3543	2.3537	2.0027	0.01
4.0004	4.3184	4.0001	4.3190	4.3187	3.9980	-0.01
8.0005	8.2601	8.0008	8.2591	8.2596	7.9995	0.00
15.0005	15.1482	15.0008	15.1489	15.1485	14.9945	-0.02

6150F Deflection Gage Factor (G): 1.01539 **(degrees/degree)**

Deflection = L sin (G * (R_1 - R_0)) (mm or inches)

Tilt = G (R_1 - R_0) (degrees)

Wiring Code: See Manual for further information

The above instrument was found to be in tolerance in all operating ranges.
The above named instrument has been calibrated by comparison with standards traceable to the NIST, in compliance with ANSI Z540-1.

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FIGURE 21: *Sample Model 6150F Calibration Sheet, Sensor B*

APPENDIX C. MODBUS ADDRESSABLE SYSTEM

C.1 MODBUS COMMUNICATIONS PARAMETERS

Port Setting	Required Value
Bits per Second	115,200
Data bits	8
Parity	None
Stop bits	1
Flow Control	None

TABLE 8: *Modbus Communications Parameters*

C.2 ERROR CODES

Number	Name	Cause	Remedy
2	Temperature Sensor Range	Measured temperature out of range. Thermistor may be too hot or too cold, or it may be damaged.	Use adjacent sensors to validate or estimate temperature.
4	Temperature Sensor Verify	Secondary temperature sensor differed too much from high accuracy primary sensor.	Use adjacent sensors to validate or estimate temperature.
8	System Reset	Unexpected interruption in prior measurement cycle.	Ensure supply voltage is sufficient.

TABLE 9: *Error Codes*

Note: The sensor stores and transmits errors in binary code to compact the information. Though unlikely, two errors could occur in one measurement cycle. The resulting code will be the sum of the error numbers, e.g., error 4 plus error 8 appears as number 12.

APPENDIX D. CRBASIC PROGRAMMING

D.1 SAMPLE CR1000 PROGRAM

The following sample program reads one 6150F sensor string with three biaxial sensors. The string in this example communicates with the CR1000 through the control ports C1 and C2, which are setup as COM1. A RS-485 to TTL converter is required. GEOKON provides Model 8020-38 for this purpose. For more information, please refer to the Model 8020-38 instruction manual.

```
Public ErrorCode              'Error Code sent back from ModBus Command
Public A_Axis_Degrees(3)      'A Axis Degree Output
Public B_Axis_Degrees(3)      'B Axis Degree Output
Public Celsius(3)             'Temperature Celsius
Public Count                  'Counter to increment through sensors
```

'Define Data Tables

```
DataTable(Test,1,-1)
  Sample (3,A_Axis_Degrees(),IEEE4) 'Store Degree Reading for A Axis
  Sample (3,B_Axis_Degrees(),IEEE4) 'Store Degree Reading for B Axis
  Sample (3,Celsius(),IEEE4)        'Store Thermistor C Reading
EndTable
```

'Main Program

```
BeginProg
 'Open COMport with TTL communications at 115200 baud rate
 SerialOpen (Com1,115200,16,0,50)
  'Read 3 sensors in MEMS String every 10 seconds
  Scan (10,Sec,0,0)
   'Loop through addresses of connected String
   For Count = 1 To 3
    'Reset temporary storage for both Degrees and Temp so not to retain
    'previous reading
    A_Axis_Degrees(Count) = 0
    B_Axis_Degrees(Count) = 0
    Celsius(Count) = 0

    'Flush Serial between readings
    SerialFlush (Com1)

    'Write to register to begin reading MEMS String
    NOTE: ModbusMaster won't send 0x118 unless "&H119" is entered

    ModbusMaster (ErrorCode,Com1,115200,Count,6,1,&H119,1,1,50,0)
    'Delay after write register
    Delay (1,1,Sec)

    'Use Modbus command to retrieve A Axis and B Axis Degree Readings
    ModbusMaster (ErrorCode,Com1,115200,Count,3,A_Axis_Degrees(Count),&H101,1,1,50,0)
    ModbusMaster (ErrorCode,Com1,115200,Count,3,B_Axis_Degrees(Count),&H103,1,1,50,0)

    'Use Modbus command to retrieve Thermistor Celsius from string
    ModbusMaster (ErrorCode,Com1,115200,Count,3,Celsius(Count),&H107,1,1,550,0)

    'Delay before proceeding to next reading
    Delay (1,1,Sec)
   Next
  'Call Table to store Data
  CallTable Test
 NextScan
EndProg
```

D.2 SAMPLE CR6 PROGRAM

The following sample program reads one 6150F sensor string with three addressable sensors. The string in this example communicates with the CR6 through the control ports C1 and C2, which are setup as ComC1.

```
Public ErrorCode              'Error Code sent back from ModBus Command
Public A_Axis_Degrees(3)      'A Axis Degree Output
Public B_Axis_Degrees(3)      'B Axis Degree Output
Public Celsius(3)             'Temperature Celsius
Public Count                  'Counter to increment through sensors
```

'Define Data Tables

```
DataTable(Test,1,-1)
  Sample (3,A_Axis_Degrees(),IEEE4) 'Store Degree Reading for A Axis
  Sample (3,B_Axis_Degrees(),IEEE4) 'Store Degree Reading for B Axis
  Sample (3,Celsius(),IEEE4)        'Store Thermistor C Reading
EndTable
```

'Main Program

```
BeginProg
 'Open COMport with RS-485 communications at 115200 baud rate
 SerialOpen (ComC1,115200,16,0,50,3)
  'Read 3 sensors in MEMS String every 10 seconds
  Scan (10,Sec,0,0)
   'Loop through addresses of connected String
   For Count = 1 To 3
    'Reset temporary storage for both Degrees and Temp so not to retain
    'previous reading
    A_Axis_Degrees(Count) = 0
    B_Axis_Degrees(Count) = 0
    Celsius(Count) = 0

    'Flush Serial between readings
    SerialFlush (ComC1)

    'Write to register 0x118 to trigger string
    'NOTE: ModbusMaster won't send 0x118 unless "&H119" is entered

    ModbusMaster (ErrorCode,ComC1,115200,Count,6,1,&H119,1,1,10,0)
    'Delay after write register
    Delay (1,1,Sec)

    'Use Modbus command to retrieve A Axis and B Axis Degree Readings
    ModbusMaster (ErrorCode,ComC1,115200,Count,3,A_Axis_Degrees(Count),&H101,1,1,10,0)
    ModbusMaster (ErrorCode,ComC1,115200,Count,3,B_Axis_Degrees(Count),&H103,1,1,10,0)

    'Use Modbus command to retrieve Thermistor Celsius from string
    ModbusMaster (ErrorCode,ComC1,115200,Count,3,Celsius(Count),&H107,1,1,10,0)

    'Delay before proceeding to next reading
    Delay (1,1,Sec)
   Next
  'Call Table to store Data
  CallTable Test
 NextScan
EndProg
```

APPENDIX E. DROPS VERSUS LENGTH

The number of allowed drops on a string is inversely proportional to the length of the cable along which they are placed. Longer cable means fewer drops can be supplied reliably by the power source, and shorter cable means more drops can be supported. The string's bus voltage also plays a role in determining the number of drops that can be supported. The bus voltage must always remain between 9 and 15 volts DC. With a supply of less than nine volts, the drops on the string may not behave as expected, and with a supply of more than 15 volts, the drops may become damaged due to excessive voltage.

Use the chart below to estimate the number of drops for a given cable length and supply voltage, assuming the correct voltage is supplied.

Note: The curves on the chart begin at a 200-meter cable length.

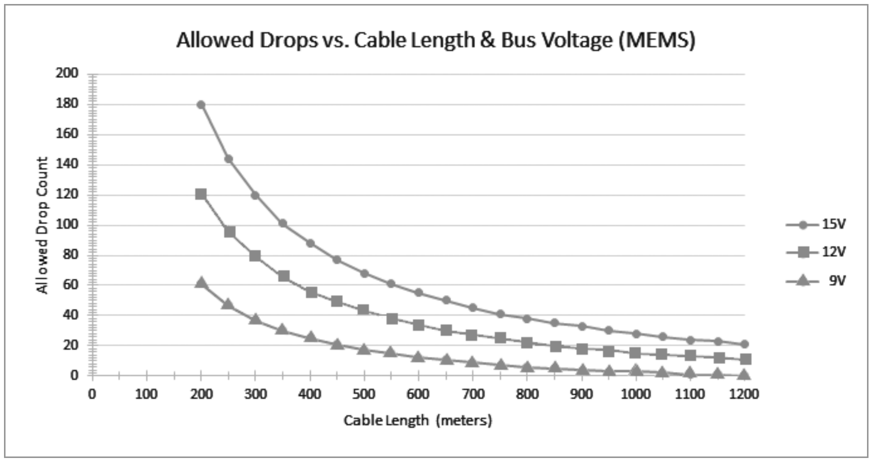

FIGURE 22: *Allowed Drops Graphic Representation*

Note: The number of drops that can be supported on strings shorter than 200 meters must be handled on a case-by-case basis, and may require practical experimentation to obtain a reliable result.

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