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## Instruction Manual

# **Model 6155**

## **MEMS Horizontal In-Place Inclinometer**

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#### 1. INTRODUCTION

The Geokon Model 6155 MEMS Horizontal In-Place Inclinometer system is designed for long-term monitoring of differential settlements beneath structures such as dams, landfills, embankments, storage tanks and the like. The basic principle is the utilization of tilt sensors to make accurate measurement of inclination, over segments, in boreholes drilled into the structure being studied. The continuous nature of the instrument allows for very precise measurement of changes in the borehole profile to be measured. The instrument is installed in standard grooved inclinometer casing.

See Figure 1.

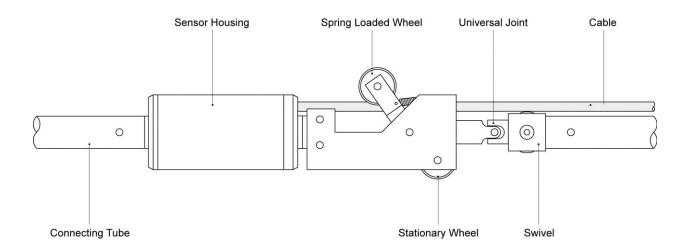


Figure 1 - Model 6155 MEMS Tilt Sensor Assembly

## 1.1. Tilt Sensor Construction

The sensor comprises a micro-electrical-mechanical-sensor, (MEMS), mounted inside a sealed housing. The Housing has a mounting bracket on its nearest end for connecting the sensor to a wheel assembly, which guides the sensors along the vertical pair of grooves in standard inclinometer casing. A lug on the nearest end of the wheel assembly connects to a universal coupling, (which allows unimpeded relative movement between the spacing rods), and a swivel joint, (which accommodates any spiraling of the casing, and prevents the wheel assemblies from running out of the casing grooves). Stainless steel tubing is used to connect and space apart the transducer and wheel assemblies, and the whole string is installed from one end of the casing. Each housing contains a thermistor for reading temperatures.

#### 2. INSTALLATION

#### 2.1. Preliminary Tests

Prior to installation, the sensors need to be checked for proper operation. Each tilt sensor is supplied with a calibration sheet, which shows the relationship between output voltage and inclination. The tilt sensor electrical leads are connected to a Datalogger or RB-500 readout box (see section 3) and the current reading compared to the calibration readings. Carefully hold the sensor in an approximately horizontal position and observe the reading. The sensor must be held in a steady position. The readings should be close to the factory vertical reading. The temperature indicated by the thermistor should be close to ambient.

Checks of electrical continuity can also be made using an ohmmeter. Resistance between any conductor and the shield or the case should exceed 2 megohm.

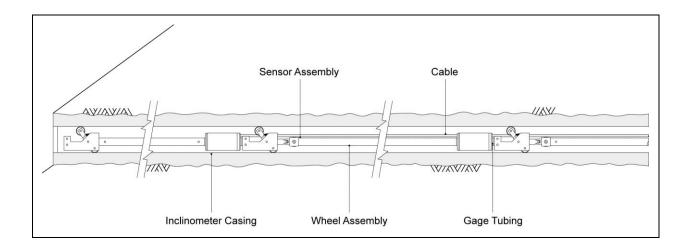


Figure 2 - Model 6155 MEMS Installation

## 2.2. Model 6155 MEMS Assembly and Installation

The 6155 MEMS Assembly is intended for use in inclinometer casing that has been installed so that one pair of grooves is vertical.

1. The first sensor assembly is made up as follows:

Take the end wheel assembly – the one that has no universal joint – and connect it to the first rod – one that has the correct length – using a 10-32 cap screw and nut. Use thread-locking compound on the threads. Note: Tubing joints are purposely made to close tolerances. If the screws will not pass through the joint, it must be reamed with the drill provided (.193").

Now select a tilt sensor and bolt it to the other end of the rod using a 10-32 cap screw and nut, (use thread-locking compound on the threads), so that when the fixed wheel is on the bottom the plus sign on the tilt sensor is on the top.

Now attach the sensor to the next wheel assembly, (complete with universal coupling and swivel joint), using two 10-32 screws and nuts, and a thread locking cement to make this joint.

- 2. Connect the safety cable, if used, to the end wheel assembly and push the first sensors assembly into the casing while keeping the safety cable and sensor cable from becoming entangled. Make sure that the fixed wheel of the wheel assembly is in the bottom groove of the casing.
- 3. The second sensor assembly is made up as follows:

Select the next rod and connect it to the next sensor using a 10-32 cap screw and nut. Use thread-locking compound on the threads. Connect the sensor to the next wheel assembly, (complete with universal coupling and swivel joint), using two 10-32 screws and nuts, and a thread locking cement to make this joint.

Now connect the rod of the second wheel assembly to the swivel joint of the first sensor assembly and push the second sensor assembly into the borehole making sure once again that the plus sign on the sensor is uppermost and the fixed wheel of the wheel assembly is in the bottom casing-groove.

- 4. Proceed as above with the remaining sensors making sure to correctly identify the positions of the various sensors and to keep the various cables from becoming entangled. The cables from the lower sensors should be taped or tie-wrapped to the assembly at intervals to prevent interference as the system is built up and lowered down the borehole.
- 5. After the sensor string is pushed into position and the final wheel assembly has been installed inside the mouth of the casing, it can be locked in place using wooden wedges. The safety cable can be tied off around the end of the casing and the signal cables can be run to the readout location and terminated at a switch box or otherwise fixed. Readings can be taken immediately after installation, but it is recommended that the system be allowed to stabilize for a few hours before recording zero conditions.

## 2.3 Connection to Switch – Boxes or Datalogger – Standard System

For manual readout using a RB-500 readout box, cables from the individual sensors are connected to a switch-box using the wiring code shown in Appendix A. If a datalogger is used the cables are connected directly to the Multiplexer using the same wiring code.

#### 3. TAKING READINGS

#### 3.1 Dataloggers

In most cases the 6155 MEMS In-Place Inclinometer will be monitored continuously and automatically using a Datalogger. Connections to the Geokon Model 8021 Micro-1000 Datalogger, which uses a Campbell Scientific CR1000 MCU are shown in Appendix C Page 11.

#### 3.2 RB-500 Readout Box

The RB-500 readout box is designed to take readings for manually transcribing into a field book; it has no storage capabilities. This method is useful for reading systems that do not require continuous monitoring. The RB-500 readout box is also useful during initial installations and for setting up Datalogger systems.

Note that the RB-500 Readout Box uses a 2:1 voltage divider to halve the full scale output of the MEMS sensor, which is  $\pm$ 4 volts. This is done so that the  $\pm$ 4 volt DVM in the RB-500 readout box can display the full output range of the MEMS sensor.

## 3.3 Measuring Temperature

Although the temperature dependence of the MEMS tilt meter is practically zero, and does not require compensation, it sometimes happens that temperature effects can cause real changes of tilt, therefore each MEMS tilt sensor is equipped with a thermistor for reading temperature. This enables temperature-induced changes in tilt to be distinguished from tilts due to other sources. The thermistor gives a varying resistance output as the temperature changes. Check the instrument wiring codes for the thermistor connections.

1. The RB-500 cannot read temperatures - a separate digital ohmmeter is required. Connect an ohmmeter to the two thermistor leads coming from the tilt sensor. (Since the resistance changes with temperature are so large, the effect of cable resistance is usually insignificant.)

#### 4. DATA REDUCTION

## **4.1. Settlement Calculation**

The output of the MEMS Sensor is proportional to the sine of the angle of inclination from the horizontal. For the  $\pm$ 15 degree sensor the FS output is approximately  $\pm$ 4 volts. The relationship between the readings, **R**, in volts displayed on channels A and B on the RB100X readout box, and the angle of inclination,  $\theta$ , is given by the equation:

$$\theta = \sin^{-1}(RG)$$
 or  $\sin \theta = RG$ 

Equation 1 Inclination versus volts.

Where  $\mathbf{R}$  is the current reading in volts and  $\mathbf{G}$  is the Gage Factor shown on the calibration sheet. Note that the small zero reading at zero inclination can be ignored since it is only the change of inclination that is of interest. If the orientation of the sensors has been performed as described, with the plus sign on the sensor uppermost, then positive outputs will correspond to a settlement of the furthest end of the rod segment relative to the near end.

## **4.2. Temperature Correction**

The Model 6155 MEMS Tiltmeter has zero temperature sensitivity. The tilt corrected for temperature is, as before:

$$Sin\theta_{temp \ corrected} = RG$$
 degrees

Equation 2 Inclination versus volts corrected for Temperature.

Temperature corrections are not required. An important point to note is that sudden changes in temperature will cause both the structure and the Tiltmeter to undergo transitory physical changes, which will show up in the readings. The gage 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.

## **4.3. Settlement Calculation**

The vertical offset,  $\mathbf{D}$ , of the far end of any segment relative to the near end of the segment is equal to  $\mathbf{L}\mathbf{sin}\boldsymbol{\theta}$ , where  $\mathbf{L}$  is the length of the segment, between wheel bearings, and  $\boldsymbol{\theta}$  is the inclination of the segment to the horizontal. The vertical profile of the casing is constructed by using the cumulative sum of these vertical offsets starting with the nearest segment,  $\mathbf{L}_1$ . For instance, referring to figure 3.

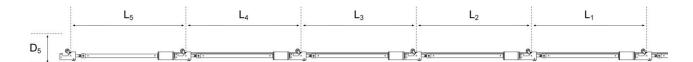


Figure 3 - Settlement Intervals

The total vertical offset of the far end of the casing relative to the near end of the casing is

$$D_5 = L_1 \sin\theta_1 + L_2 \sin\theta_2 + L_3 \sin\theta_3 + L_4 \sin\theta_4 + L_5 \sin\theta_5$$

Equation 3 - Vertical Offset Calculation

Therefore, ignoring temperature corrections,

$$D_5 = G_1L_1R_1 + G_2L_2R_2 + G_3L_3R_3 + G_4L_4R_4 + G_5L_5R_5$$

And the settlement,  $\Delta \mathbf{D}$ , i.e. the change in vertical offset is

$$\Delta D_n = \sum_{1}^{n} G_n L_n \Delta R_n$$

Equation 4 - Settlement Calculation

Where  $\Delta \mathbf{R}_1 = (\mathbf{R}_1 - \mathbf{R}_0)$  i.e. the present reading on Sensor 1 minus the initial reading on Sensor 1; and  $\Delta \mathbf{R}_2 = (\mathbf{R}_1 - \mathbf{R}_0)$  i.e. the present reading on Sensor 2 minus the initial reading on Sensor 2; and similarly for all the other Sensors.

## **4.4. Environmental Factors**

Since the purpose of the 6155 MEMS installation is to monitor site conditions, factors that may affect these conditions should be observed and recorded. Seemingly minor effects may have a 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.



## MEMS Tilt Sensor Calibration

Model Number: MEMS Tilt Sensor Calibration Date: March 12, 2015

Serial Number: Sensor A 1500141 Calibration Instruction: CI-Tiltmeter MEMS

Temperature: 22.5 °C Technician:

|             |                | * Reading | * Reading | * Average | Error in ( | Calculated   |  |
|-------------|----------------|-----------|-----------|-----------|------------|--------------|--|
| Inclination | Inclination    | 1st Cycle | 2nd Cycle | Reading   | θ          | $\sin\theta$ |  |
| (degrees)   | $(\sin\theta)$ | (Volts)   | (Volts)   | (Volts)   | (%FS)      | (%FS)        |  |
| 15.00       | 0.2588         | 4.051     | 4.051     | 4.0507    | -0.15      | 0.01         |  |
| 14.00       | 0.2419         | 3.781     | 3.781     | 3.7808    | -0.09      | -0.01        |  |
| 12.00       | 0.2079         | 3.241     | 3.241     | 3.2410    | 0.02       | -0.01        |  |
| 10.00       | 0.1736         | 2.696     | 2.696     | 2.6963    | 0.08       | -0.02        |  |
| 8.00        | 0.1392         | 2.148     | 2.149     | 2.1485    | 0.10       | -0.03        |  |
| 6.00        | 0.1045         | 1.599     | 1.600     | 1.5995    | 0.11       | -0.02        |  |
| 4.00        | 0.0698         | 1.047     | 1.047     | 1.0472    | 0.07       | -0.03        |  |
| 2.00        | 0.0349         | 0.494     | 0.494     | 0.4939    | 0.02       | -0.03        |  |
| 0.00        | 0.0000         | -0.058    | -0.058    | -0.0577   | 0.00       | 0.00         |  |
| -2.00       | -0.0349        | -0.612    | -0.612    | -0.6120   | -0.06      | -0.01        |  |
| -4.00       | -0.0698        | -1.165    | -1.165    | -1.1646   | -0.10      | 0.00         |  |
| -6.00       | -0.1045        | -1.716    | -1.716    | -1.7160   | -0.12      | 0.01         |  |
| -8.00       | -0.1392        | -2.266    | -2.266    | -2.2661   | -0.13      | 0.00         |  |
| -10.00      | -0.1736        | -2.813    | -2.813    | -2.8132   | -0.10      | 0.00         |  |
| -12.00      | -0.2079        | -3.358    | -3.357    | -3.3575   | -0.04      | -0.01        |  |
| -14.00      | -0.2419        | -3.899    | -3.899    | -3.8987   | 0.06       | -0.02        |  |
| -15.00      | -0.2588        | -4.167    | -4.167    | -4.1672   | 0.14       | -0.03        |  |
|             |                |           |           |           |            |              |  |

6150, 6155 and 6170 In-Place Inclinometer Gage Factor (D): \_\_\_0.0630\_\_ (sin0/ Volt)

Deflection =  $DL(R_1-R_0)$  mm (inches)

6160 and 6165 Tiltmeter Gage Factor (G): 3.640 (degrees/ Volt) over + / - 15° range Calculated Tilt =  $G(R_1 - R_0)$  degrees

Temperature Correction Factor -0.0003 (T1-T0) Volts / °C

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 4. Sample Model 6155 MEMS Calibration Sheet

#### 5. TROUBLESHOOTING

Maintenance and troubleshooting of the vibrating wire tilt sensors used in the Model 6155 MEMS Horizontal Inclinometer are confined to periodic checks of cable connections. The sensors are sealed and there are no user-serviceable parts.

Consult the following list of problems and possible solutions should difficulties arise. Consult the factory for additional troubleshooting help.

## Symptom: Tilt Sensor Readings are Unstable

- ✓ Is there a source of electrical noise nearby? Most probable sources of electrical noise are motors, generators and antennas. Make sure the shield drain wire is connected to ground whether using a portable readout or datalogger.
- ✓ Does the readout work with another tilt sensor? If not, the readout may have a low battery or be malfunctioning.

## Symptom: Tilt Sensor Fails to Read

- ✓ Is the cable cut or crushed? This can be checked with an ohmmeter. The nominal resistance of the thermistor is 3000 ohms at 25 degrees C. If the approximate temperature is known, the resistance of the thermistor leads can be estimated and used as a cable check. Remember to add cable resistance when checking (22 AWG stranded copper leads are approximately  $14.7\Omega/1000'$  or  $48.5\Omega/km$ , multiply by 2 for both directions). If the resistance reads infinite, or very high (megohms), a cut wire must be suspected. If the resistance reads very low (<20 $\Omega$ ) a short in the cable is likely.
- ✓ Does the readout or datalogger work with another tilt sensor? If not, the readout or datalogger may be malfunctioning.

## Symptom: Thermistor resistance is too high.

✓ Is there an open circuit? Check all connections, terminals and plugs.

## Symptom: Thermistor resistance is too low.

- ✓ Is there a short? Check all connections, terminals and plugs.
- ] Water may have penetrated the interior of the tilt sensor. There is no remedial action.

## <u>APPENDIX A - SPECIFICATIONS</u>

## A.1. MEMS Tilt Sensor

| Model:                   | 6155  |
|--------------------------|---|
| Range                    | ±15°  |
| Resolution: <sup>1</sup> | +/-4 arc seconds, (+/- 0.02mm/m)                      |
| Accuracy <sup>2</sup>    | +/- 10 arc seconds, (+/- 0.05mm/m)                    |
| Linearity: <sup>3</sup>  | +/- 0.07%FS   |
| Cross axis sensitivity   | 4%  |
| Sensor Output            | +/- 4 Volts (nominal) @ +/- 15 degrees                |
| Thermal Zero Shift:      | 0.0003 volt/°C rise                                   |
| Operating Temperature    | -20 to +70° C   |
|                          | -4 to 158° F  |
| Power Requirements:      | 6155-1 (Uniaxial): +12V (nom) @ 30mA                  |
|                          | 6155-2 (Biaxial): +12V (nom) @ 45mA                   |
| Sensor Output:           | +/-4 Volts @ FS                                       |
| Frequency Response:      | -3db @ 8-28 Hz  |
| Shock Resistance         | 20,000g   |
| Thermistor Resistance:   | 3000Ω at 25°C   |
| Sensor Housing Dia:      | 32 mm, (1.250").                                      |
| Length and Diameter:     | 219mm x 32mm (6155A-1/2), 362mm x 32mm (others).      |
| Weight:                  | 0.4 kg. (0.9 lbs.).                                   |
| Materials:               | 304 Stainless Steel                                   |
| Electrical Cable:        | 3 twisted pair (6 conductor) 24 AWG                   |
|                          | Foil shield, Polyurethane jacket, nominal OD = 6.3 mm |
|                          | Or  |
|                          | 6 twisted pair (12 conductor) 24 AWG                  |
|                          | Foil shield, Polyurethane jacket, nominal OD = 7.9 mm |

Table A-1 Model 6155 MEMS Tilt Sensor Specifications

## Notes:

- For best results requires a 4 ½ digit digital voltmeter.
   Averaging will yield resolution on the order of 2 arc seconds
   Based upon the use of a second order polynomial
- <sup>3</sup> The output of the MEMS sensor is proportional to the sine of the angle of tilt

## A.2. Thermistor (see Appendix B also)

Range:  $-80 \text{ to } +150^{\circ} \text{ C}$ Accuracy: ±0.5° C

## <u>APPENDIX B - THERMISTOR TEMPERATURE DERIVATION</u>

## Thermistor Type: YSI 44005, Dale #1C3001-B3, Alpha #13A3001-B3

## **Resistance to Temperature Equation:**

$$T = \frac{1}{A + B(LnR) + C(LnR)^3} - 273.2$$

Equation B-1 Convert Thermistor Resistance to Temperature

Where;  $T = Temperature in {}^{\circ}C.$ 

LnR = Natural Log of Thermistor Resistance

 $A = 1.4051 \times 10^{-3}$  (coefficients calculated over the -50 to  $+150^{\circ}$  C. span)

 $B = 2.369 \times 10^{-4}$  $C = 1.019 \times 10^{-7}$ 

| Ohms             | Temp       | Ohms   | Temp | Ohms  | Temp | Ohms  | Temp | Ohms  | Temp |
|------------------|------------|--------|------|-------|------|-------|------|-------|------|
| 201.1K           | -50        | 16.60K | -10  | 2417  | +30  | 525.4 | +70  | 153.2 | +110 |
| 187.3K           | -49        | 15.72K | -9   | 2317  | 31   | 507.8 | 71   | 149.0 | 111  |
| 174.5K           | -48        | 14.90K | -8   | 2221  | 32   | 490.9 | 72   | 145.0 | 112  |
| 162.7K           | -47        | 14.12K | -7   | 2130  | 33   | 474.7 | 73   | 141.1 | 113  |
| 151.7K           | -46        | 13.39K | -6   | 2042  | 34   | 459.0 | 74   | 137.2 | 114  |
| 141.6K           | -45        | 12.70K | -5   | 1959  | 35   | 444.0 | 75   | 133.6 | 115  |
| 132.2K           | -44        | 12.05K | -4   | 1880  | 36   | 429.5 | 76   | 130.0 | 116  |
| 123.5K           | -43        | 11.44K | -3   | 1805  | 37   | 415.6 | 77   | 126.5 | 117  |
| 115.4K           | -42        | 10.86K | -2   | 1733  | 38   | 402.2 | 78   | 123.2 | 118  |
| 107.9K           | -41        | 10.31K | -1   | 1664  | 39   | 389.3 | 79   | 119.9 | 119  |
| 101.0K           | -40        | 9796   | 0    | 1598  | 40   | 376.9 | 80   | 116.8 | 120  |
| 94.48K           | -39        | 9310   | +1   | 1535  | 41   | 364.9 | 81   | 113.8 | 121  |
| 88.46K           | -38        | 8851   | 2    | 1475  | 42   | 353.4 | 82   | 110.8 | 122  |
| 82.87K           | -37        | 8417   | 3    | 1418  | 43   | 342.2 | 83   | 107.9 | 123  |
| 77.66K           | -36        | 8006   | 4    | 1363  | 44   | 331.5 | 84   | 105.2 | 124  |
| 72.81K           | -35        | 7618   | 5    | 1310  | 45   | 321.2 | 85   | 102.5 | 125  |
| 68.30K           | -34        | 7252   | 6    | 1260  | 46   | 311.3 | 86   | 99.9  | 126  |
| 64.09K           | -33        | 6905   | 7    | 1212  | 47   | 301.7 | 87   | 97.3  | 127  |
| 60.17K           | -32        | 6576   | 8    | 1167  | 48   | 292.4 | 88   | 94.9  | 128  |
| 56.51K           | -31        | 6265   | 9    | 1123  | 49   | 283.5 | 89   | 92.5  | 129  |
| 53.10K           | -30        | 5971   | 10   | 1081  | 50   | 274.9 | 90   | 90.2  | 130  |
| 49.91K           | -29        | 5692   | 11   | 1040  | 51   | 266.6 | 91   | 87.9  | 131  |
| 46.94K           | -28        | 5427   | 12   | 1002  | 52   | 258.6 | 92   | 85.7  | 132  |
| 44.16K           | -27        | 5177   | 13   | 965.0 | 53   | 250.9 | 93   | 83.6  | 133  |
| 41.56K           | -26        | 4939   | 14   | 929.6 | 54   | 243.4 | 94   | 81.6  | 134  |
| 39.13K           | -25        | 4714   | 15   | 895.8 | 55   | 236.2 | 95   | 79.6  | 135  |
| 36.86K           | -24        | 4500   | 16   | 863.3 | 56   | 229.3 | 96   | 77.6  | 136  |
| 34.73K           | -23        | 4297   | 17   | 832.2 | 57   | 222.6 | 97   | 75.8  | 137  |
| 32.74K           | -22        | 4105   | 18   | 802.3 | 58   | 216.1 | 98   | 73.9  | 138  |
| 30.87K           | -21        | 3922   | 19   | 773.7 | 59   | 209.8 | 99   | 72.2  | 139  |
| 29.13K           | -20        | 3748   | 20   | 746.3 | 60   | 203.8 | 100  | 70.4  | 140  |
| 27.49K           | -19        | 3583   | 21   | 719.9 | 61   | 197.9 | 101  | 68.8  | 141  |
| 25.95K           | -18        | 3426   | 22   | 694.7 | 62   | 192.2 | 102  | 67.1  | 142  |
| 24.51K           | -17        | 3277   | 23   | 670.4 | 63   | 186.8 | 102  | 65.5  | 143  |
| 23.16K           | -16        | 3135   | 24   | 647.1 | 64   | 181.5 | 103  | 64.0  | 143  |
| 23.10K<br>21.89K | -15        | 3000   | 25   | 624.7 | 65   | 176.4 | 105  | 62.5  | 145  |
| 20.70K           | -13<br>-14 | 2872   | 26   | 603.3 | 66   | 170.4 | 105  | 61.1  | 145  |
| 19.58K           | -14        | 2750   | 27   | 582.6 | 67   | 166.7 | 107  | 59.6  | 140  |
| 19.56K<br>18.52K | -13<br>-12 | 2633   | 28   | 562.8 | 68   | 162.0 | 107  | 58.3  | 147  |
| 18.52K<br>17.53K | -12<br>-11 | 2523   | 29   | 543.7 | 69   | 157.6 | 108  | 56.8  | 146  |
| 17.33K           | -11        | 2323   | 29   | 343.7 | 09   | 137.0 | 109  | 55.6  | 150  |

Table B-1 Thermistor Resistance versus Temperature

## APPENDIX C WIRING CODE

| 03-250V0<br>cable | Connector Pin<br>Designation | Uniaxial MEMS with<br>Thermistor | Connector Pin<br>Designation | Biaxial MEMS without Thermistor |
|-------------------|------------------------------|----------------------------------|------------------------------|---------------------------------|
| Red               | A                            | 12VDC                            | A                            | 12VDC                           |
| Red's Black       | В                            | Ground                           | В                            | Ground                          |
| White             | С                            | A Out Diff +                     | С                            | A Out Diff +                    |
| White's Black     | D                            | A Out Diff -                     | D                            | A Out Diff -                    |
| Bare              | Е                            | Shield                           | E                            | Shield                          |
| Green             | J                            | Thermistor                       | F                            | B Out Diff +                    |
| Green's Black     | K                            | Thermistor                       | G                            | B Out Diff -                    |

Table C-1 Cable 03-250V0 Wiring

| 06-312V0<br>Cable | Connector Pin<br>Designation | Biaxial MEMS with Thermistor |
|-------------------|------------------------------|------------------------------|
| Red               | A                            | 12VDC                        |
| Red's Black       | В                            | Ground                       |
| White             | С                            | A Out Diff +                 |
| White's Black     | D                            | A Out Diff -                 |
| Bare              | Е                            | Shield                       |
| Green             | F                            | B Out Diff +                 |
| Green's Black     | G                            | B Out Diff -                 |
| Blue              | J                            | Thermistor                   |
| Blue's Black      | K                            | Thermistor                   |

Table C-2 Cable 06-312V0 Wiring

#### APPENDIX D 6155 Standard Addressable Systems

## **Description:**

The standard 6155 addressable system incorporates a Distributed Multiplexer Circuit Board that allows multiple MEMS type Inclinometers, uniaxial or biaxial, to be connected as "drops" off of a single bus.

The Inclinometer "string" is addressed via ENABLE and CLOCK signals in the same manner as the Geokon Model 8032-16 Channel Multiplexer.

The addressable Inclinometer string is "enabled" by raising the appropriate Datalogger Control Port to 5V. After the string has been enabled, a delay of 125 mS is required before executing the 1<sup>st</sup> of the two clock pulses required to activate the 1<sup>st</sup> channel. Once the channel is selected, a delay of 100 mS is required for the sensor to warm-up. The sensor's A-axis is read 100 times and then the average of these readings is stored. The sensors B-axis is then read. Finally, the sensor's thermistor is read through a bridge completion circuit and the temperature is calculated using a polynomial formula. Examples of CRBASIC programming can be found in Appendix F.

#### Wiring:

| Connector Pin<br>Designation | Addressable MEMS System<br>(Logic Level Style) |
|------------------------------|--|
| A                            | A-axis Output Differential +                   |
| В                            | A-axis Output Differential -                   |
| С                            | B-axis Output Differential +                   |
| D                            | B-axis Output Differential -                   |
| E                            | 12VDC  |
| F                            | Ground   |
| G                            | Reset  |
| Н                            | Ground   |
| J                            | Clock  |
| K                            | Ground   |
| L                            | Thermistor*                                    |
| M                            | Thermistor*                                    |
| Р                            | Shield   |
|                              | Designation  A B C D E F G H J K L             |

Table D-1 Addressable MEMS (Logic Level Style) Wiring

\* 1K and 5K precision resistors are used to complete the thermistor bridge circuit:

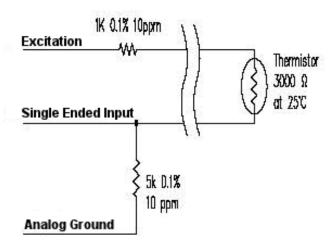


Figure D-1 Thermistor Bridge Circuit

## Specifications for Addressable System (Logic Level Style) Circuit Board:

Board Dimensions: 4.5"(L) x 1.155"(W) x 0.4"(H)

Power Requirements: +12V (+/-3V)

110mA (max) when active 700uA (max) standby

Operating Temperature:  $-20 \text{ to } +70^{\circ} \text{ C}$ 

Contact Resistance:  $100 \text{ m}\Omega \text{ (typ)}$ 

Contact Breakdown Voltage: 1500 Vrms

Relay open/close time: 4mS (max)

#### APPENDIX F CRBASIC PROGRAMMING

## **Programming the MEMS Inclinometer with CRBASIC**

## **Description:**

CRBASIC is the programming Language used with Campbell Scientific CRBASIC Dataloggers. Campbell's Loggernet Software is typically used when programming in CRBASIC. The MEMS sensor should be read with the VoltDiff instruction and the output averaged 100x. No Thermistor in this example.

## Sample Program:

## 'Declare Public Variables for Reading MEMS Sensor

```
Public MEMS_1
Public MEMS_2
Public MEMS_3
Public MEMS_Output 'Output of the MEMS Sensor
```

## 'Store MEMS Output every 2 minutes

```
DataTable (MEMS_EXAMPLE,1,-1)
Sample (1,MEMS_Output,IEEE4)
EndTable
```

#### **BeginProg**

#### '2 min scan interval

Scan (2,min,0,0)

## 'Read MEMS Sensor on Differential Channel 1 and average 100x Readings

```
\label{eq:decomposition} Delay(0,100,mSec)\\ MEMS\_3 = 0\\ For MEMS\_1 = 1 \ To \ 100\\ VoltDiff (MEMS\_2,1,mV5000,1,False,0,250,0.001,0)\\ MEMS\_3 = MEMS\_3 + MEMS\_2\\ Next\\ MEMS\_Output = MEMS\_3 / 100\\ CallTable MEMS\_EXAMPLE\\ NextScan\\ EndProg
```

## **Programming the Addressable MEMS Inclinometer with CRBASIC**

## **Description:**

CRBASIC is the programming Language used with Campbell Scientific CRBASIC Dataloggers. Campbell's Loggernet Software is typically used when programming in CRBASIC. The MEMS sensor should be read with the VoltDiff instruction and the output averaged 100x.

## Sample Program:

'The following sample program reads 20 addressable Bi-Axial MEMS Gages and Thermistors. The A-Axis is read on Differential Channel 1, the B-Axis is read on Differential Channel 2 and the Thermistors are read with Single Ended Channel 5 and the bridge excited with EX1. The string is enabled with Control Port 1 and clocked with control port 8.

## 'Declare Public Variables for Reading MEMS Sensor and Thermistor

```
Public MEMS_1
Public MEMS_2
Public MEMS_3
Public THERM_1
Public THERM_2
Public THERM_3
Public Channel 'Counter
Public Reading_A 'Output of the A Axis
Public Reading_B 'Output of the B Axis
Public Reading_THERM 'Output of Thermistor
```

## 'Store MEMS Output every 5 minutes

```
DataTable (MEMS_EXAMPLE,1,-1)
Sample (1,Reading_A,IEEE4)
Sample (1,Reading_B,IEEE4)
Sample (1,Reading_THERM,IEEE4)
EndTable
```

#### **BeginProg**

#### '5 min scan interval

Scan (5,min,0,0)

'enable String using C1 PortSet(1,1)

'Delay

Delay(0,125,MSEC)

## 'counter for number of sensors

For Channel = 1 To 20

#### '1st clock using C8

PortSet(8,1)

Delay(0,10,MSEC)

PortSet(8,0)

Delay(0,10,MSEC)

## 'Delay

Delay(0,100,mSec)

#### 'Read the A-axis

## 'Reset the temporary storage location

 $MEMS_3 = 0$ 

#### 'counter

For MEMS\_1 = 1 To 100

#### 'differential voltage measurement on DIFF1

VoltDiff (MEMS\_2,1,mV5000,1,False,0,1000,0.001,0)

## 'Sum the readings

 $MEMS_3 = MEMS_3 + MEMS_2$ 

#### 'Increment To 100

Next

## 'Calculate the Average reading value

Reading\_A =  $MEMS_3 / 100$ 

#### 'Read the B-axis

## 'Reset the temporary storage location

 $MEMS\_3 = 0$ 

#### 'counter

For MEMS\_1 = 1 To 100

## 'differential voltage measurement on DIFF2

VoltDiff (MEMS\_2,1,mV5000,2,False,0,1000,0.001,0)

## 'Sum the readings

 $MEMS_3 = MEMS_3 + MEMS_2$ 

#### 'Increment To 100

Next

## 'Calculate the Average reading value

Reading\_B =  $MEMS_3 / 100$ 

## 'Delay

Delay(0,100,msec)

#### 'Read the thermistor

## 'half bridge measurement - SE5 AND EX1

BrHalf(THERM\_1,1,mV2500,5,VX1,1,2500,0,1000,250,2.5,0.0)

## 'Calculate the temperature

 $THERM_2 = THERM_1 / 5000$ 

THERM\_3 =  $(2.5 - (THERM_2*1000) - THERM_1)/THERM_2$ 

 $Reading\_THERM = 1/(.0014051 + (.0002369*LOG(THERM\_3)) + (.0000001019*(LOG(THERM\_3)^3))) - 273.2$ 

## '2nd clock using C8

PortSet(8,1) Delay(0,10,MSEC) PortSet(8,0) Delay(0,10,MSEC)

#### 'Next sensor

Next

## 'Disable String

PortSet(1,0)

CallTable MEMS\_EXAMPLE

NextScan

**EndProg**