GEOKON
The World Leader in Vibrating Wire Technology

48 Spencer Street
Lebanon, NH 03766, USA
Tel: 603•448•1562
Fax: 603•448•3216
E-mail: geokon@geokon.com
http://www.geokon.com

Instruction Manual

Model 6150C

MEMS Digital Addressable
In-Place Inclinometer

(Rev. F 9/19/17)

Warranty Statement

Geokon, Inc. warrants its products to be free of defects in materials and workmanship, under normal use and service for a period of 13 months from date of purchase. If the unit should malfunction, it must be returned to the factory for evaluation, freight prepaid. Upon examination by Geokon, if the unit is found to be defective, it will be repaired or replaced at no charge. However, the WARRANTY is VOID if the unit shows evidence of having been tampered with or shows evidence of being damaged as a result of excessive corrosion or current, heat, moisture or vibration, improper specification, misapplication, misuse or other operating conditions outside of Geokon's control. Components which wear or which are damaged by misuse are not warranted. This includes fuses and batteries.

Geokon manufactures scientific instruments whose misuse is potentially dangerous. The instruments are intended to be installed and used only by qualified personnel. There are no warranties except as stated herein. There are no other warranties, expressed or implied, including but not limited to the implied warranties of merchantability and of fitness for a particular purpose. Geokon, Inc. is not responsible for any damages or losses caused to other equipment, whether direct, indirect, incidental, special or consequential which the purchaser may experience as a result of the installation or use of the product. The buyer's sole remedy for any breach of this agreement by Geokon, Inc. or any breach of any warranty by Geokon, Inc. shall not exceed the purchase price paid by the purchaser to Geokon, Inc. for the unit or units, or equipment directly affected by such breach. Under no circumstances will Geokon reimburse the claimant for loss incurred in removing and/or reinstalling equipment.

Every precaution for accuracy has been taken in the preparation of manuals and/or software, however, Geokon, Inc. neither assumes responsibility for any omissions or errors that may appear nor assumes liability for any damages or losses that result from the use of the products in accordance with the information contained in the manual or software.

TABLE of CONTENTS

LIST OF FIGURES, TABLES AND EQUATIONS

1. INTRODUCTION

The Geokon Model 6150C MEMS Digital Addressable In-Place Inclinometer system is designed for long-term monitoring of deformations in structures such as dams, embankments, foundation walls 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.

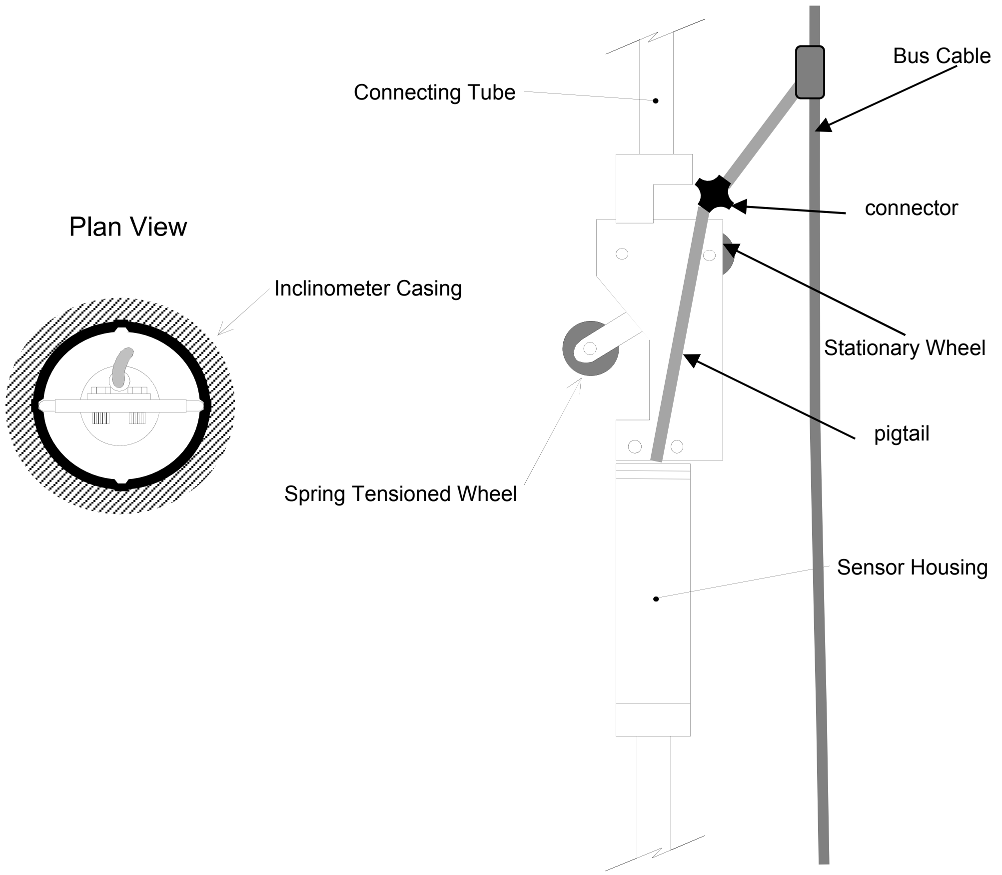


Figure 1 - Model 6150C MEMS Digital Addressable Tilt Sensor Assembly

1.1 Tilt Sensor Construction

Each sensor comprises one or two Microelectromechanical Systems, (MEMS), sensors mounted inside a sealed housing. The Housing has a mounting bracket on its upper end for connecting the sensor to a wheel assembly, which centralizes the sensors and allow the assembly to be oriented into the casing grooves. A lug on the lower end of the sensor 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 normally supported from the top of the casing. (Biaxial systems use two transducers inside the housing, mounted at 90° to each other.) Each housing contains a device for reading temperatures. The sensors are attached to short cable pigtails which are connected to the two wire bus cable running from the bottom sensor to the readout location.

2. INSTALLATION

2.1 Preliminary Tests

The bus cable is manufactured to customer specification such that the sensor spacing is fixed and matches the connecting rod segments provided. The far end of the cable has a cable termination block

Prior to installation, the sensors can be checked for proper operation. Each tilt sensor is numbered and supplied with a calibration sheet, which shows the relationship between output voltage and inclination. Connect each sensor pigtail to the bus cable and the bus cable to the readout system and hold each sensor in an approximately vertical position and observe the reading. The tilt sensor must be held in a steady position. The readings should be close to the factory vertical reading. The temperature indicated by the built –in device should be close to ambient. Disconnect the sensors from the bus cable so installation can begin.

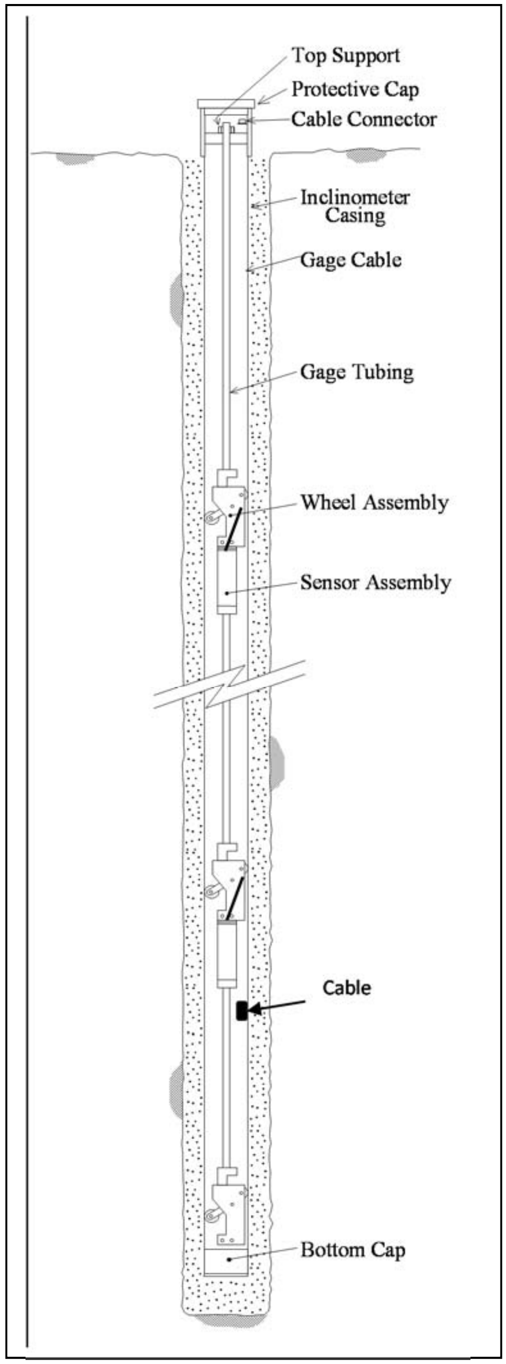


Figure 2 - Model 6150C Installation

2.2 Assembly and Installation

2.2.1 Connections to the bottom wheel assembly

Attach the bottom wheel assembly to the first tube section using a long 10-32 cap screw and nut. (*Use Loctite 222 on all threads.*) The lengths of tubing that make up the IPI string are shown in a table supplied along with the calibration sheets.

(Where the inter-anchor spacing is large, two tubes are joined together by a special union.

Use 10-32 screws, nuts, and a thread locking cement to make this joint.)

Attaching a safety cable to the bottom wheel assembly is strongly recommended. Not only can it be used to retrieve the assembly in the event that one of the joints breaks loose, but it is also very useful in lowering the assembly into the casing. (The alternative to using the safety cable is to hold the tube sections with vice-grips at the top of the casing.)

The safety cable has a loop at its bottom end which fits over the long bolt used to hold the bottom wheel assembly to the first tube section. (The bottom wheel assembly is labeled, and it has no universal joint, just a swivel.) Slide the cable eyebolt onto the screw and attached a second nut, thus trapping the safety cable between the two nuts. See Figure 3.

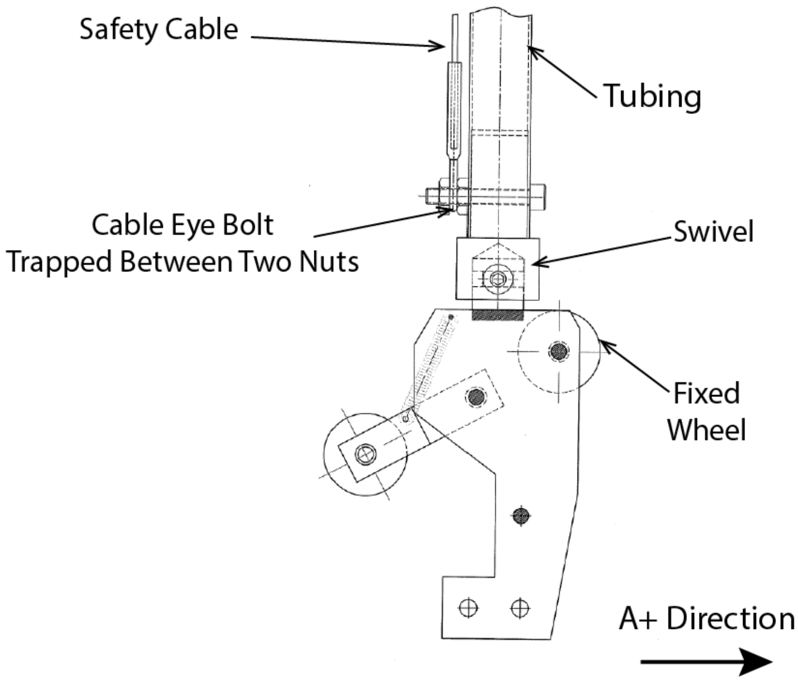


Figure 3 - Bottom Wheel Assembly

2.2.2 Connect the first sensor to the tubing and begin lowering the string

The bottom sensor with wheel assembly attached is connected to the next tube section using a long 10-32 cap screw and nut. (*Remember, use Loctite 222 on all threads.*)

Now connect the pigtail cable to the bus cable and tape the bus cable to the connecting rod as it is lowered into the hole.

The gage and tube assembly is now lowered into the borehole, using the safety cable, with the upper assembly fixed wheel aligned in the A+ direction (See Figure 3).

It is customary (and recommended) to point the A+ direction in the same direction as the anticipated movement, i.e., towards the excavation being monitored or downslope in the case of slope stability applications. Be sure that the lower wheel assembly and swivel are also aligned this way.

Both uniaxial and biaxial sensors are delivered with the orientation set such that the A+ direction marked on the sensor is aligned on the same side as the fixed wheel on the wheel assembly. (See Figure 3 above.) In a biaxial system, a second MEMS sensor is included in the housing and is attached with its positive direction 90° clockwise from the upper sensor (looking downwards in plan). This is the B+ direction. (See Figure 4.) Tilts in the positive direction yield increasing voltage readings.

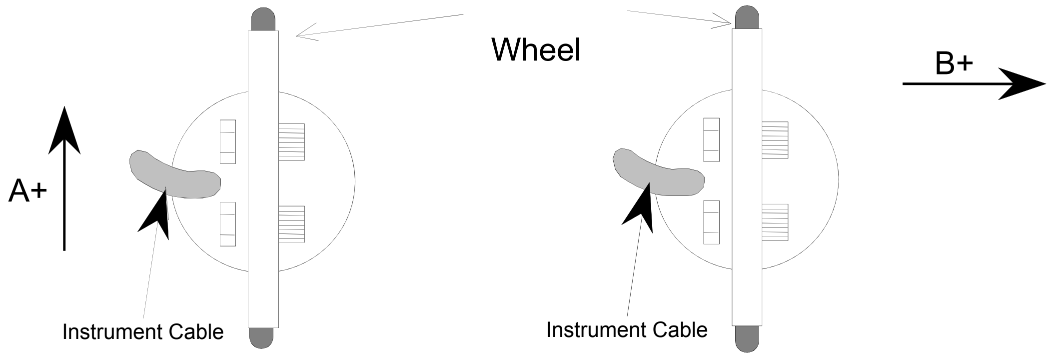


Figure 4 - Biaxial Sensor Orientation

2.2.3 Continue assembling and lowering the string

While holding the assembly at the top of the casing, the next tube segment is attached to the next sensor, the next pigtail connected to the bus cable, and the bus cable taped to the connecting rod as the assembly is lowered in the hole in same orientation as before. The system can become quite heavy and a clamp of some sort (vice-grips) should be used to hold the rods in place while being assembled. The use of a winch to hold the safety cable can be of help. Note that the longer cables are on reels to facilitate handling. Something like two little saw horses (or even folding chairs) with a broom stick across them to act as an axle will allow the cable to spool off as needed, avoid entanglements and provide a holding point for extra cable.

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.

Continue to add gage tubing to the sensors and connect the pigtails to the bus cable, until the last sensor has been installed.

At this point, the top suspension must be attached to the upper wheel assembly (or the gage tube). The assembly is bolted to the wheel assembly (or tube) as before, and then lowered into position on the casing. It is important that the casing be relatively square to prevent any side interference in the upper sensor wheel assembly.

After the sensor string is lowered into position, the safety cable can be tied off around the top 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.

3. TAKING READINGS

3.1 The 8020-70 / 6150C Digital Addressable System

The 8020-70/6150C digital addressable system incorporates an 8020-70 FSK Modem that allows multiple 6150C digital MEMS Inclinometers to be connected onto a single two wire bus (string). Communications with each 6150C Inclinometer is achieved by modulating the system power with the commands and resulting responses. Up to 32 6150C transducers may be incorporated onto a single string with a maximum string length of 2700’ (823 m). (Max string length depends upon the number of sensors – see Table 8 in Section B.9 for more information.) Each 8020-70 modem is capable of providing six individual strings, allowing a total of 192 6150C Inclinometers per 8020-70.

Figure 5 - The 8020-70 FSK Modem

The 8020-70 FSK Modem includes a 9-pin D-Sub connector for communications, and may be configured via internal jumpers as either a RS-232 DCE device or a TTL DCE device (default). A command set is provided that allows for the configuration of the 8020-70 and connected 6150C devices, along with various readings and diagnostics. For more details and the wiring diagram see Appendix B.

3.2 Measuring Temperature

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 MEMS tilt sensor is equipped with a device for reading temperature. This enables temperature-induced changes in tilt to be distinguished from tilts due to other sources. The device provides a digital output proportional to the temperature.

The above remarks apply mainly to structures exposed to sunlight. In these situations it is not uncommon for the structure to expand and contract differentially during the course of the day. For landslide applications where the MEMS sensors are buried in the ground, temperature variations are very small or nonexistent and ground movements are unaffected by temperatures. In these situations it is not necessary to measure temperatures.

4. DATA REDUCTION

4.1 Tilt Calculation

The output of the MEMS Sensor is proportional to the sine of the angle of inclination from the vertical. For the ± 15 degree sensor the FS output is approximately four volts.

The relationship between the readings **R**, and the angle of inclination **θ,** is given by the equation:

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

Equation 1 - Inclination versus voltage.

Where **R** is the reading in Volts and **G** is the Gage Factor (sinθ/volt) shown on the calibration sheet. Note that the small voltage reading at zero inclination can be ignored since it is only the tilting, i.e. change of inclination that is of interest. Note also that for small angles sinθ = θ radians.

So the amount of tilt, in degrees, is given by the equation:

$$\text{Tilt} = \sin^{-1}(R_1 - R_0)G \text{ degrees}$$

Equation 2 - Tilt degrees versus voltage.

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

<u>Note:</u> The 8020-70 FSK Modem provides Tilt readings in both Volts and Digits where there are 2500 digits per Volt.

4.2 Temperature Correction

The Model 6150 MEMS Tiltmeter has very small temperature sensitivity equal to +1 arc second per degree centigrade rise. The tilt corrected for temperature is:

$$\text{Tilt} = \sin^{-1}(R_{1corr} - R_0)G \text{ degrees}$$

Equation 3 - Tilt versus voltage corrected for Temperature.

Where $R_{1corr} = R_1 - 0.0003\,(T_1 - T_0)$

Normally, 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 Deflection Calculation

The lateral offset, **D**, of the top of any segment relative to the vertical line running through the bottom of the segment is equal to **Lsinθ,** where L is the length of the segment, between pivot points, and θ is the inclination of the segment to the vertical.

The length L_1, L_2, L_3, etc., can be calculated by adding **336 mm**, (both uniaxial and biaxial systems) to the individual lengths of tubing. This will give the correct distance between pivot points.

The profile of the borehole is constructed by using the cumulative sum of these lateral offsets starting with the bottom segment, $\mathbf{L_1}$. For instance, referring to Figure 6, the total lateral offset 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:

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

Equation 4 - Offset Calculation

Therefore, ignoring temperature corrections:

$$\mathbf{D_5 = G_1L_1R_1 + G_2L_2R_2 + G_3L_3R_3 + G_4L_4R_4 + G_5L_5R_5}$$

And the deflection, **ΔD,** i.e. the change in offset is

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

Equation 5 - Deflection Calculation

Where $\mathbf{\Delta R_1 = (R_1 - R_0)}$ i.e. the present reading on Tiltmeter 1 minus the initial reading on Tiltmeter 1; and $\mathbf{\Delta R_2 = (R_2 - R_0)}$ i.e. the present reading on Tiltmeter 2 minus the initial reading on Tiltmeter 2; and similarly for all the other Tiltmeters.

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.

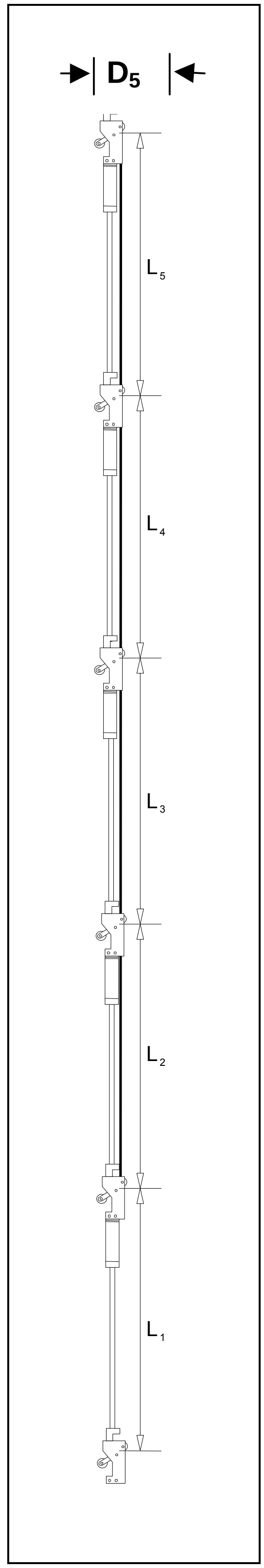


Figure 6 - Deflection Intervals

<u>NOTE</u>: The bottom sensor, though referred to as Tiltmeter 1 for deflection calculation, will be addressed per its position in the string, from the surface downward. In the above example, Tiltmeter 1 would be addressed as #5, and will be displayed as CH5 or Sensor 5 in the data file.

GEOKON 48 Spencer St. Lebanon, N.H. 03766 USA

MEMS Tilt Sensor Calibration

Model Number: MEMS Tilt Sensor

Calibration Date: July 12, 2012

Serial Number: 1221794

Calibration Instruction: CI-Tiltmeter MEMS

Temperature: 24 °C

Technician:

Inclination (degrees)	Inclination ($\sin\theta$)	* Reading 1st Cycle (Volts)	* Reading 2nd Cycle (Volts)	* Average Reading (Volts)	Error in Calculated θ (%FS)	Error in Calculated $\sin\theta$ (%FS)
15.00	0.2588	4.176	4.177	4.1763	-0.07	0.09
14.00	0.2419	3.908	3.908	3.9078	0.00	0.09
12.00	0.2079	3.365	3.365	3.3654	0.08	0.05
10.00	0.1736	2.820	2.820	2.8197	0.13	0.03
8.00	0.1392	2.273	2.273	2.2728	0.15	0.03
6.00	0.1045	1.721	1.722	1.7216	0.13	0.00
4.00	0.0698	1.169	1.169	1.1694	0.09	0.00
2.00	0.0349	0.617	0.617	0.6173	0.06	0.01
0.00	0.0000	0.063	0.063	0.0631	0.00	0.00
-2.00	-0.0349	-0.489	-0.489	-0.4891	-0.04	0.02
-4.00	-0.0698	-1.040	-1.041	-1.0408	-0.07	0.03
-6.00	-0.1045	-1.592	-1.593	-1.5925	-0.10	0.03
-8.00	-0.1392	-2.141	-2.142	-2.1415	-0.09	0.04
-10.00	-0.1736	-2.686	-2.687	-2.6865	-0.04	0.06
-12.00	-0.2079	-3.229	-3.230	-3.2296	0.03	0.06
-14.00	-0.2419	-3.769	-3.769	-3.7691	0.15	0.06
-15.00	-0.2588	-4.038	-4.037	-4.0373	0.23	0.06

6150, 6155 and 6165 Deflection Gage Factor ($G_{\sin\theta}$): 0.0630 ($\sin\theta$ / Volt)

Deflection = $(G_{\sin\theta})L(R_1-R_0)$ mm (inches)

6160, 6161 and 6165 Tilt Gage Factor (G_{tilt}): 3.642 (degrees/ Volt) over + / - 15° range

Calculated Tilt = $G_{tilt}(R_1 - R_0)$ degrees

Temperature Correction Factor -0.0003 (T_1-T_0) Volts / °C

Wiring Code: See manual for further information

The above instrument was found to be in tolerance in all operating ranges.

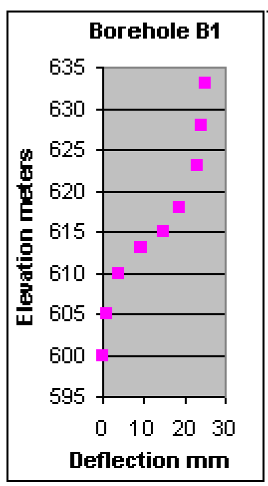
The above named instrument has been calibrated by comparison with standards traceable to the NIST, in compliance with ANSI Z540-1.

Figure 7 - Sample Model 6150 MEMS Calibration Sheet

4.4 Sample Calculation

	MEMS		Borehole#1					
	DEFLECTION							
	CALCULATION							
SENSOR		L	Depth	Elevation	G	R0	T0	
		meters	meters	meters	Sinθ/V	Volts	° C	
Surface								
1		5	5	628	0.06271	0.582	20	
2		5	10	623	0.06303	0.5632	18	
3		5	15	618	0.06221	0.5495	18	
4		3	18	615	0.06295	0.532	17	
5		2	20	613	0.06284	0.5144	17	
6		3	23	610	0.06291	0.4883	17	
7		5	28	605	0.06273	0.4321	17	
8		5	33	600	0.06289	0.3962	17	

		R1	T1	$R1_{corr}$	$R1_{corr}$ -R0	GL(R1-R0)	Acc Defl	
		Volts	° C	Volts	Volts	mm	mm	
Surface								
1		0.5802	10	0.5832	0.0012	0.38	24.23	
2		0.5644	12	0.5662	0.003	0.95	23.85	
3		0.5632	17	0.5635	0.0140	4.35	22.90	
4		0.5514	17	0.5514	0.0194	3.66	18.55	
5		0.5602	17	0.5602	0.0458	5.76	14.89	
6		0.5169	17	0.5169	0.0286	5.40	9.13	
7		0.4404	17	0.4404	0.0083	2.60	3.74	
8		0.3998	17	0.3998	0.0036	1.13	1.13	



4.5 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 the vibrating wire tilt sensors used in the Model 6150C 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 or Fail to Read

- ✓ 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 white wire of the Bus cable at the 8020-70 connector.

- ✓ 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

A.1 MEMS Tilt Sensor

Model:	6150C
Range:	±15°
Resolution:	±2 arc seconds, ± 0.01 mm/m)
Accuracy:[1]	±3 arc seconds
Linearity:[2]	± 0.07% FS
Cross axis sensitivity:	4%
Thermal Zero Shift:	0.0003 volt/°C rise
Operating Temperature:	-20 to +80° C -4 to 176° F
Power Requirements:	9 Volts
Sensor Output:	±4 Volts @ FS
Frequency Response:	-3db @ 8-28 Hz
Shock Resistance	2,000 g
Sensor Housing Dia:	32 mm, (1.250").
Length:	362 mm,(14.25").
Weight:	0.7 kg. (1.5 lbs.).
Materials:	304 Stainless Steel
Electrical Cable:	Two Conductor Foil shield, Polyurethane jacket, nominal OD = 6.3 mm

Table 1 - Model 6150 MEMS Tilt Sensor Specifications

Notes:
[1] Based upon the use of a second order polynomial.
[2] The output of the MEMS sensor is proportional to the sine of the angle of tilt.

A.2 Temperature sensor

Range: -40 to +85° C
Accuracy: ±1.0° C

APPENDIX B. 8020-70 DIGITAL ADDRESSABLE FSK MODEM

B.1 Wiring

01-250P0 Cable Color	Connector Pin Designation	Connector Pin Description
Blue	1+	String 1 Power/Signal
White/Shield*	1-	String 1 Ground
Blue	2+	String 2 Power/Signal
White/Shield*	2-	String 2 Ground
Blue	3+	String 3 Power/Signal
White/Shield*	3-	String 3 Ground
Blue	4+	String 4 Power/Signal
White/Shield*	4-	String 4 Ground
Blue	5+	String 5 Power/Signal
White/Shield*	5-	String 5 Ground
Blue	6+	String 6 Power/Signal
White/Shield*	6-	String 6 Ground
*Cable Shield and White are twisted together and connected to the specified terminal.		

Table 2 - 8020-70 Terminal

8020-70 CS-95/M Adapter	CR1000/CR800 Datalogger
RX+	COM1 RX (C2)
TX+	COM1 TX (C1)
GND	Ground

Table 3 - 8020-70 CS-95/M Adapter with Datalogger Wiring

8020-70 DB9 Pin Designation	CR1000/CR800 Datalogger
Pin 2	COM1 RX (C2)
Pin 3	COM1 TX (C1)
Pin 5	Ground

Table 4 - 8020-70 DB9 with Datalogger Wiring

Note: Other COM ports may be used as well COM2 (C3 & C4), COM3 (C5& C6) and COM4 (C7 &C8), COM3 and COM4 are only available when utilizing a CR1000.

B.2 Communications Setup

The 8020-70 Modem offers a standard 9-pin RS-232 Serial Port for connection to desktop and laptop computers (an optional USB to Serial interface adapter is available). TTL operation is provided through this same 9-pin connector as well.

Connector Pin Designation	Connector Pin Description RS-232	Connector Pin Description TTL
1	DCD	N/C
2	Receive Data	Receive Data (Idle High)
3	Transmit Data	Transmit Data (Idle High)
4	Data Terminal Ready	N/C
5	Signal Ground	Signal Ground
6	Data Set Ready	N/C
7	Request To Send	N/C
8	Clear To Send	N/C
9	Ring	N/C

Table 5 - 8020-70 DB9 RS-232/TTL Connector Wiring

Note:

1. DCD and RING are not used
2. DTR and RTS are internally looped back to CTS
3. RS-232/TTL selection is made by setting internal jumpers on the 8020-70 circuit board. For RS-232 operation, set jumpers across pins one and two of JP3, JP4 and JP5. For TTL operation (default), set jumpers across pins two and three of JP3, JP4 and JP5.
4. Selection of baud rate is made within the 8020-70 TEST menu (<CR>TEST<CR>).

B.3 Communications Parameters

Port:	Serial port that 8020-70 is connected to, i.e. COM1, COM2
Bits per Second:	9.6kbps (default) / 115.2 kbps
Data bits:	8
Parity:	None
Stop bits:	1
Flow Control:	None
Intercharacter delay:	3mS min. / 15S max.

Table 6 - Communications Parameters

B.4 Command Line Interface

Communications with each 6150C Sensor is accomplished by way of ASCII commands (READ-SET-GET) that are sent by the User to the 8020-70 Modem. As each command is received, it is processed and translated into packet format for transmission down the string. Each 6150C Sensor receives the packetized command, and if there is a match with its own Sensor Address, processes the command and transmits its response back up the string. The 8020-70 Modem receives this response and formats it for ASCII transmission to the User.

Communications Syntax:

<CR> <String Address> '/' <Sensor Address> '/' <Command> '/' <Command Parameter*> <CR>

<CR> — Wakeup 8020-70 (ASCII Carriage Return – HEX 0D)
String Address — (Enter an integer from 1 to 6)
Forward Slash
Sensor Address — (Enter an integer from 1 to 32)
Forward Slash
Command — (Enter a command number from the Command Set in the next section.)
Forward Slash — (Needed only if followed by a Command Parameter)
Command Parameter — (Used for the SET commands only)
<CR> — Transmit Command in Packet Format to 6150C

B.5 Command Set

B.5.1 Commands 1-9, Read Type

(No command parameters.)

#	DESCRIPTION	RETURNS
1	FULL SENSOR READING (Degrees)	STRING ADDRESS, SENSOR ADDRESS, CHA(Deg), CHB(Deg), SENSOR TEMPERATURE(C), ERROR CODE
2	CH A READING (Degrees)	STRING ADDRESS, SENSOR ADDRESS, CHA(Deg), SENSOR TEMPERATURE(C), ERROR CODE
3	CH B READING (Degrees)	STRING ADDRESS, SENSOR ADDRESS, CHB(Deg), SENSOR TEMPERATURE(C), ERROR CODE
4	TEMPERATURE READING	STRING ADDRESS, SENSOR ADDRESS, TEMPERATURE(C), ERROR CODE
5	VIN (9V @ PROBE)	STRING ADDRESS, SENSOR ADDRESS, VIN(V), ERROR CODE
6	VREF (+5V @ PROBE)	STRING ADDRESS, SENSOR ADDRESS, VREF(V), ERROR CODE
7	FULL SENSOR READING (Volts)	STRING ADDRESS, SENSOR ADDRESS, CHA(V), CHB(V), SENSOR TEMPERATURE(C), ERROR CODE
8	CH A READING (Volts)	STRING ADDRESS, SENSOR ADDRESS, CHA(V), SENSOR TEMPERATURE(C), ERROR CODE
9	CH B READING (Volts)	STRING ADDRESS, SENSOR ADDRESS, CHB(V), SENSOR TEMPERATURE(C), ERROR CODE

B.5.2 Commands 10-37, Set Type

(Command Parameters for Commands 10-15 & 20-25: Five decimal places maximum. Accepts negative sign.)

#	DESCRIPTION	RETURNS
10	SET A-AXIS ZERO READING (Degrees)	STRING ADDRESS, SENSOR ADDRESS, NEW ZERO READING (Deg), ERROR CODE
11	SET A-AXIS GAGE FACTOR	STRING ADDRESS, SENSOR ADDRESS, NEW GAGE FACTOR, ERROR CODE
12	SET A-AXIS GAGE OFFSET (Volts)	STRING ADDRESS, SENSOR ADDRESS, NEW GAGE OFFSET (V), ERROR CODE
17	SET A-AXIS DEFAULTS (NO COMMAND PARAMETER)	STRING ADDRESS, SENSOR ADDRESS, COMMAND, ERROR CODE (ZERO READING=0deg, GAGE FACTOR=0.0625, GAGE OFFSET=0V)
20	SET B-AXIS ZERO READING (Degrees)	STRING ADDRESS, SENSOR ADDRESS, NEW ZERO READING (Deg), ERROR CODE
21	SET B-AXIS GAGE FACTOR	STRING ADDRESS, SENSOR ADDRESS, NEW GAGE FACTOR, ERROR CODE
22	SET B-AXIS GAGE OFFSET (Volts)	STRING ADDRESS, SENSOR ADDRESS, NEW GAGE OFFSET (V), ERROR CODE
27	SET B-AXIS DEFAULTS (NO COMMAND PARAMETER)	STRING ADDRESS, SENSOR ADDRESS, COMMAND, ERROR CODE (ZERO READING=0deg, GAGE FACTOR=0.0625, GAGE OFFSET=0V)
30	SET SENSOR ADDRESS (COMMAND PARAMETER 1-32)	STRING ADDRESS, NEW SENSOR ADDRESS, ERROR CODE (Valid addresses are 1-32)
31	SET SERIAL NUMBER (COMMAND PARAMETER 16 CHAR MAX)	STRING ADDRESS, SENSOR ADDRESS, NEW SERIAL NUMBER, ERROR CODE
33	SET BOTH-AXIS DEFAULTS (NO COMMAND PARAMETER)	STRING ADDRESS, SENSOR ADDRESS, COMMAND, ERROR CODE (ZERO READING=0deg, GAGE FACTOR=0.0625, GAGE OFFSET=0V)

35	SET CALIBRATION DATE (COMMAND PARAMETER mm/dd/yy)	STRING ADDRESS, SENSOR ADDRESS, NEW CALIBRATION DATE (mm/dd/yy),ERROR CODE
36	RESET COMMUNICATION ERROR COUNTS (NO COMMAND PARAMETER)	STRING ADDRESS, SENSOR ADDRESS, COMMAND, ERROR CODE
37	TOTAL # OF SENSORS PER STRING (COMMAND PARAMETER 1-32)	: STRING ADDRESS, TOTAL # OF SENSORS, ERROR CODE Required for the Broadcast Address (99)

B.5.3 Commands 40-67, Get Type

(No command parameters.)

#	DESCRIPTION	RETURNS
40	GET A-AXIS ZERO READING (Degrees)	STRING ADDRESS, SENSOR ADDRESS, ZERO READING (Deg), ERROR CODE
41	GET A-AXIS GAGE FACTOR	STRING ADDRESS, SENSOR ADDRESS, GAGE FACTOR, ERROR CODE
42	GET A-AXIS GAGE OFFSET (Volts)	STRING ADDRESS, SENSOR ADDRESS, GAGE OFFSET(V), ERROR CODE
50	GET B-AXIS ZERO READING (Degrees)	STRING ADDRESS, SENSOR ADDRESS, ZERO READING (Deg), ERROR CODE
51	GET B-AXIS GAGE FACTOR	STRING ADDRESS, SENSOR ADDRESS, GAGE FACTOR, ERROR CODE
52	GET B-AXIS GAGE OFFSET (Volts)	STRING ADDRESS, SENSOR ADDRESS, GAGE OFFSET(V), ERROR CODE
60	GET SENSOR ADDRESS	STRING ADDRESS, SENSOR ADDRESS, ERROR CODE
61	GET SERIAL NUMBER	STRING ADDRESS, SENSOR ADDRESS, SERIAL NUMBER, ERROR CODE
63	GET 6150C FIRMWARE VERSION	STRING ADDRESS, SENSOR ADDRESS, FIRMWARE VERSION, ERROR CODE
64	GET 8020-70 FIRMWARE VERSION	FIRMWARE VERSION, ERROR CODE
65	GET CALIBRATION DATE	STRING ADDRESS, SENSOR ADDRESS, CALIBRATION DATE (MM/DD/YY), ERROR CODE
66	GET COMMUNICATION ERROR COUNTS	STRING ADDRESS, SENSOR ADDRESS, Rx CHECKSUM ERROR COUNT, TxCHECKSUM ERROR COUNT, RETRIES EXCEEDED COUNT, ERROR CODE
67	GET TOTAL # OF SENSORS PER STRING	STRING ADDRESS, TOTAL # OF SENSORS (as set by Command 37), ERROR CODE

B.6 Error Codes

The last field in the data string returned from the 8020-70 Modem is the communications error code. Normally this should be “E0” representing successful transmission with no errors. Other codes are used to represent possible errors in communications or commands:

E0: COMMAND SUCCESSFUL - NO ERROR
E1: BUFFER ERROR
E2: STRING ADDRESS ERROR
E3: SENSOR ADDRESS ERROR
E4: COMMAND ERROR
E5: FLOATING POINT PARAMETER ERROR
E6: DATE PARAMETER ERROR
E7: SENSOR ADDRESS ERROR
E8: NO RESPONSE FROM SENSOR (DIRECT ADDRESSING) OR CHECKSUM ERROR (BROADCAST ADDRESSING)
E9: HOST TIMEOUT
E10: SENSOR EEPROM ERROR
E11: CONVERSION PARAMETER ERROR
E12: NO RESPONSE FROM SENSOR

READING = 99999.0: SENSOR OVERRANGE OR NO RESPONSE

B.7 Broadcast Addressing

The special sensor address “99” is recognized by all sensors. Use of this address allows responses from all sensors to a single command. As shown in the table below, an entire string may be read in a fraction of the time it would take to read the string using individual addressing. The User must set the number of sensors per string (COMMAND 37) before using broadcast addressing. Note that command #30 SET SENSOR ADDRESS is not allowed with broadcast addressing. Other commands not allowed with broadcast addressing are SET NUMBER OF SENSORS PER STRING (COMMAND 37), GET 8020-70 FIRMWARE REVISION (COMMAND 64) and GET TOTAL # OF SENSORS PER STRING (COMMAND 67).

COMMAND	Individual Addressing (32 Sensors)	Broadcast Addressing (32 Sensors)	Speed Improvement (Broadcast Addressing)
1	5.5 S / Sensor	21 S	8.38x
2	3.3 S / Sensor	12.6 S	8.38x
3	3.3 S / Sensor	12.6 S	8.38x
4	1.12 S / Sensor	5.15 S	6.96x
5	0.48 S / Sensor	3.58 S	4.29x
6	0.48 S / Sensor	3.58 S	4.29x
7	5.12 S / Sensor	20.93 S	7.83x
8	3.12 S / Sensor	13.35 S	7.48x
9	3.12 S / Sensor	13.35 S	7.48x

Table 7 - Speed Comparison – Individual vs. Broadcast Addressing

B.8 Command Examples

B.8.1 Take full reading (A and B axis) on sensor #2 of string #1 and return the reading in Degrees

EXAMPLE COMMAND STRING:
<CR>1/2/1<CR> (FULL PROBE READING - DEGREES)

Where;
<CR> — Wakeup 8020-70
1 — STRING ADDRESS 1
2 — SENSOR ADDRESS 2
1 — FULL PROBE READING (Deg)
<CR> — Transmit Command in Packet Format to 6150C

Then;
6150C #2 processes the command as stated above.
6150C #2 transmits the response in Packet Format to 8020-70.
8020-70 processes and formats the response from 6150C.

Then;
8020-70 will return to the User:
"1,2,+1.1230,-0.4560,+25.3230,E0<CR><LF><EOT>"

Where;
1 = STRING ADDRESS
2 = SENSOR ADDRESS
+1.1230 = CH A READING (Deg)
-0.4560 = CH B READING (Deg)
+25.3230 = SENSOR TEMPERATURE
E0 = No Errors
<CR>*
<LF>*
<EOT>*

*NOTE: The 8020-70 adds a "Carriage Return/Line Feed/End of Transmission" (HEX 0D HEX 0A HEX 04) at the end of each string. When using broadcast addressing, the <EOT> is added at the end of the very last string. (See Section B.8.2.)

B.8.2 Using Broadcast Addressing, Take A axis readings from all 16 6150C Sensors connected to string #3 and return the readings in Volts

EXAMPLE COMMAND STRING:
<CR>3/99/8<CR> (ALL SENSORS A AXIS)

Where:
<CR> — Wakeup 8020-70
3 — STRING ADDRESS 3
99 — SENSOR ADDRESS 99 (BROADCAST)
8 — A AXIS - VOLTS
<CR> — Transmit Command in Packet Format to all 6150C Sensors

Then;
All 6150C sensors process the command.
All 6150C sensors transmit individual time multiplexed responses in Packet Format to 8020-70.
8020-70 processes and formats the responses from the 6150C Sensors.

Then;
8020-70 will return to the User:
"3,1,+0.5543,20.8577,E0<CR><LF>
3,2,+0.5551,19.7668,E0<CR><LF>
3,3,+0.5211,20.1213,E0<CR><LF>
3,4,+0.4352,20.0985,E0<CR><LF>
3,5,+0.3336,19.9982,E0<CR><LF>
3,6,+0.3125,19.8750,E0<CR><LF>
3,7,+0.2876,20.0025,E0<CR><LF>
3,8,+0.2117,20.2674,E0<CR><LF>
3,9,+0.1995,20.1229,E0<CR><LF>
3,10,+0.1126,19.9981,E0<CR><LF>
3,11,+0.0048,20.0625,E0<CR><LF>
3,12,-0.1132,20.2112,E0<CR><LF>
3,13,-0.2656,19.9987,E0<CR><LF>
3,14,-0.3152,20.0062,E0<CR><LF>
3,15,-0.4441,20.1026,E0<CR><LF>
3,16,-0.5241,20.1492,E0<CR><LF><EOT>"

B.8.3 Set the total number of 6150C Sensors on String #2 to 8

EXAMPLE COMMAND STRING: <CR>2/1/37/8<CR>

Where;
<CR> — Wakeup 8020-70
2 — STRING ADDRESS 2
1 — SENSOR ADDRESS (ignored by 8020-70)
37 — SET TOTAL NUMBER OF SENSORS
8 — EIGHT SENSORS
<CR> — PROCESS COMMAND

Then;
8020-70 processes the command.

Then;
8020-70 will return to the User:
"2,8,E0<CR><LF><EOT>" indicating that STRING 2 is setup for eight SENSORS.

B.9 Cable Lengths and Addressing

The table below shows the recommended maximum end to end cable lengths for various quantities of sensors. As can be seen, the use of individually addressed sensors results in greater overall cable lengths per # of sensors than sensors that are broadcast addressed. Broadcast addressing sacrifices cable length for reading speed.

	INDIVIDUAL ADDRESSING		**BROADCAST ADDRESSING**	
Number of Sensors In String	MAX CABLE (ft.)	MAX CABLE (m)	MAX CABLE (ft.)	MAX CABLE (m)
2	2700	823	2500	762
3	2451	747	1890	576
4	2282	696	1526	465
5	2143	653	1279	390
6	2026	618	1101	336
7	1927	587	967	295
8	1842	561	920	280
9	1769	539	899	274
10	1705	520	879	268
11	1649	503	860	262
12	1600	488	842	257
13	1555	474	825	251
14	1516	462	808	246
15	1480	451	792	241
16	1448	441	776	237
17	1419	433	762	232
18	1392	424	747	228
19	1367	417	733	223
20	1344	410	720	219
21	1323	403	707	215
22	1302	397	695	212
23	1283	391	683	208
24	1265	386	672	205
25	1248	380	660	201
26	1230	375	650	198
27	1213	370	639	195
28	1197	365	629	192
29	1181	360	619	189
30	1164	355	610	186
31	1148	350	601	183
32	1131	345	592	180

Table 8 - Maximum Sensors per Cable Length

B.10 Individual and Broadcast Command Response Timings

The table below shows the minimum response times between the transmission of the reading command by the user and the transmission of the reading response by the 8020-70. These timings need to be incorporated into the datalogger control programs used for automated data recording. (Note: ‘n’ is the number of sensors on the string, ‘S’ is seconds)

Command	INDIVIDUAL ADDRESSING (S)	BROADCAST ADDRESSING (S)
1	5.5	5.5 + 0.5(n-1)
2	3.3	3.3 + 0.3(n-1)
3	3.3	3.3 + 0.3(n-1)
4	1.12	1.12 + 0.13(n-1)
5	0.48	0.48 + 0.1(n-1)
6	0.48	0.48 + 0.1(n-1)
7	5.12	5.12 + 0.51(n-1)
8	3.12	3.12 + 0.33(n-1)
9	3.12	3.12 + 0.33(n-1)

Table 9 - 8020-70 Response Timings (Read Commands)

B.11 Firmware Versions and Backwards Compatibility

With the release of 8020-70 and 6150C firmware version 3.0.0.0, signal timings between the 8020-70 and the 6150C sensors changed considerably. Because of this, there is a backwards compatibility issue between version 3.x.x.x 6150C sensors and version 2.x.x.x 8020-70s.

Working Combinations:

8020-70 version 2.x.x.x 6150C version 2.x.x.x
8020-70 version 3.x.x.x 6150C version 2.x.x.x
8020-70 version 3.x.x.x 6150C version 3.x.x.x

Problem Combination:

8020-70 version 2.x.x.x 6150C version 3.x.x.x

All of the above timings apply to current (version 3.x.x.x and greater) firmware releases

APPENDIX C. PROGRAMMING THE DIGITAL ADDRESSABLE MEMS WITH CRBASIC (BROADCASTING)

C.1 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 sensors should be read with the SerialOut and SerialIn instructions.

C.2 Sample Program

The following sample program reads 16 addressable biaxial MEMS Gages and Thermistors. The string in this example communicates with Com1; Control Port 1 and Control Port 2. Broadcast addressing is used to collect and store data.

```
SequentialMode

'String size 36 * number of sensors. Up to 192 sensors. (36*192=6912)
Public SerialListenString As String * 6912  'String that receives data from all sensors.
Public lengthofstring = 0  'Variable that holds string length to compare the length of the received
string.
Public readingsplit(6) As String   'Array of strings to hold chunks of a sensors response.

'Numeric values that will get stored into the data table.
Public A_axis(32)  'Storage for A axis Output of each MEMs.
Public B_axis(32)  'Storage for B axis Output of each MEMs.
Public Temp(32)   'Storage for Temperature Output of each MEMs.
Public ErrorCode(32)  'Storage for the error code of each MEMs, 0 signifies no error detected.

Public I   'A counter to iterate through the string splitting process.

Public GageStrings(32) As String * 36  'Array of strings used for the SplitStr command ,then
contains information from individual sensors. Up to 32 sensors on a string.

DataTable (Table1,True,-1)
  Sample (32,A_axis(1),IEEE4)   'A axis result in Volts
  Sample (32,B_axis(1),IEEE4)   'B axis result in Volts
  Sample (32,Temp(1),IEEE4)     'Temperature result in Celsius
  Sample (32,ErrorCode(1),IEEE4)'Error code to ensure successful reading
EndTable

BeginProg

  'Open port to be used, 9600bps, 8 data bits, 1 stop bit, no parity, no flow control. 6913 buffer (max
  'incoming data + 1). Serial Open format 16 for TTL, use 0 when using RS232 communications.

  SerialOpen (Com1,9600,16,0,6913)
```

```
 'Speak to the sensors and check for a response.

 lengthofstring = 0
 SerialOut (Com1,CHR(13),"wait",1,0)
 SerialIn (SerialListenString,Com1,100,-1,10)
 lengthofstring = Len (SerialListenString)

 'When no response is found communication is already in sync. Step through command stage to
retain pattern.

 If lengthofstring = 0 Then
   SerialOut (Com1,CHR(13),"wait",1,10)
 EndIf

 'Set the number of sensors to 32 for the broadcast command

 SerialOut (Com1,CHR(13),"wait",1,10)
 SerialOut (Com1,"1/1/37/32"+CHR(13),"",0,0)

 Scan (180,Sec,0,0)

   'Wake up sensor with carriage return and wait 0.1 seconds to allow sensor(s) to wake up.

   SerialOut (Com1,CHR(13),"wait",1,10)

     'Flush port since multiple readings will be taken.

     SerialFlush (Com1)

   'Use a broadcast command to receive data from all sensors on the string.

   SerialOut (Com1,"1/99/7"+CHR(13),"",0,0)

   'Listen to Com1 for 22 seconds (Broadcast can read higher quantities of sensors much quicker)

   SerialIn (SerialListenString,Com1,2200,CHR(04),6912)

   'Split data by sensor with Carriage Return and Linefeed (CHR(13) and CHR(10)).

   SplitStr (GageStrings(),SerialListenString,CHR(13)+CHR(10),32,4)

   'Loop through each string retrieved.

   For I = 1 To 32

     'Separate comma delimited response to get the sensor reading and temperature.

     SplitStr (readingsplit(),GageStrings(I),",",6,0)
```

```
    'With this specific command the split response is as follows.
    'readingsplit(1); Holds the string address.
    'readingsplit(2); Holds the sensor address.

    'readingsplit(3); A axis result in Volts.

    A_axis(I) = readingsplit(3)

    'readingsplit(4); B axis result in Volts.

    B_axis(I) = readingsplit(4)

    'readingsplit(5); Temperature reading in degrees Celsius.

    Temp(I) = readingsplit(5)

    'readingsplit(6); Any resulting error code, a zero (0) means no error detected.

    ErrorCode(I) = readingsplit(6)

   Next

   'Store collected data into data table.

   CallTable(Table1)

  NextScan

EndProg
```

APPENDIX D. PROGRAMMING THE DIGITAL ADDRESSABLE MEMS WITH CRBASIC (INDIVIDUALLY)

D.1 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 sensors should be read with the SerialOut and SerialIn instructions.

D.2 Sample Program

The following sample program reads 32 addressable biaxial MEMS Gages and Thermistors. The string in this example communicates with Com1; Control Port 1 and Control Port 2. Each sensor is called individually to collect and store data.

```
SequentialMode

Public lengthofstring = 0  'Variable that holds string length to compare the length of the received string.
Public readingsplit(6) As String   'Array of strings to hold chunks of a sensors response.

'Numeric values that will get stored into the data table.
Public A_axis(32)  'Storage for A axis Output of each MEMs.
Public B_axis(32)  'Storage for B axis Output of each MEMs.
Public Temp(32)   'Storage for Temperature Output of each MEMs.
Public ErrorCode(32)  'Storage for the error code of each MEMs, 0 signifies no error detected.

Public I   'A counter to iterate through the string splitting process.

Public GageStrings(32) As String * 36  'Array of strings used for the SplitStr command ,then contains information from individual sensors. Up to 32 sensors on a string.

DataTable (Table1,True,-1)
  Sample (32,A_axis(1),IEEE4)   'A axis result in Volts
  Sample (32,B_axis(1),IEEE4)   'B axis result in Volts
  Sample (32,Temp(1),IEEE4)     'Temperature result in Celsius
  Sample (32,ErrorCode(1),IEEE4)'Error code to ensure successful reading
EndTable

BeginProg

  'Open port to be used, 9600bps, 8 data bits, 1 stop bit, no parity, no flow control. 37 buffer (max
  'incoming data + 1). Serial Open format 16 for TTL, use 0 when using RS232 communications.

  SerialOpen (Com1,9600,16,0,37)

  'Speak to the sensors and check for a response.

  lengthofstring = 0
```

```
  SerialOut (Com1,CHR(13),"wait",1,0)
  SerialIn (GageStrings(1),Com1,100,-1,10)
  lengthofstring = Len (GageStrings(1))
```

'When no response is found communication is already in sync. Step through command stage to retain pattern.

```
  If lengthofstring = 0 Then
    SerialOut (Com1,CHR(13),"wait",1,10)
  EndIf

  Scan (180,Sec,0,0)
```

'Loop through each sensor

```
    For I = 1 To 32
```

'Wake up sensor with carriage return and wait 0.1 seconds to allow sensor(s) to wake up.

```
      SerialOut (Com1,CHR(13),"wait",1,10)
```

'Flush port since multiple readings will be taken.

```
      SerialFlush (Com1)
```

'Make individual commands to retrieve data for each sensor on the string.

```
      SerialOut (Com1,"1/"+I+"/7"+CHR(13),"",0,0)
```

'Listen for the end of transmission character (CHR(04)) Response of a single sensor takes 5.12 'seconds, move onto the next sensor if waiting exceeds 6 seconds.

```
      SerialIn (GageStrings(I),Com1,600,CHR(04),100)
```

'One second gives the string plenty of time for sensors to go back into waiting mode

```
      Delay (1,1,Sec)

    Next
```

'Loop through each string retrieved.

```
    For I = 1 To 32
```

'Separate comma delimited response to get the sensor reading and temperature.

```
      SplitStr (readingsplit(),GageStrings(I),",",6,0)
```

'With this specific command the split response is as follows.

```
      'readingsplit(1); Holds the string address.
      'readingsplit(2); Holds the sensor address.

      'readingsplit(3); A axis result in Volts.

      A_axis(I) = readingsplit(3)

      'readingsplit(4); B axis result in Volts.

      B_axis(I) = readingsplit(4)

      'readingsplit(5); Temperature reading in degrees Celsius.

      Temp(I) = readingsplit(5)

      'readingsplit(6); Any resulting error code, a zero (0) means no error detected.

      ErrorCode(I) = readingsplit(6)

    Next

    'Store collected data into data table.

    CallTable(Table1)

  NextScan

EndProg
```

APPENDIX E. SPECIFICATIONS

E.1 8020-70

POWER:		
Power Supply Voltage:	+12VDC (nom)	+10.8 to +15VDC
Operating Current (Standby):	TTL:60µA (nom) RS-232:110µA (nom)	TTL:50µA to70µA RS-232:100µA 120µA
Operating Current (User Communications):	6mA (nom) TTL/RS-2	5mA to 7mA
Operating Current (Sensor Communications): Max Peak Operating Current – (Broadcast 32 sensors CMD 1)	20mA (nom) TTL/RS 200mA	18mA to 22mA
Operating Temperature:	-20C to +70C	
COMMUNICATIONS (SENSOR):		
BFSK FREQUENCY BINARY 1 (MARK):	117KHz (nom)	±5KHz
BFSK FREQUENCY BINARY 0 (SPACE):	133KHz (nom)	±5KHz
MODULATING LEVEL:	1Vpp	±0.5Vpp
DC LEVEL:	+9.5VDC (nom)	±0.5VDC
CODING:	NRZ	
DATA RATE:	2400bps	

E.2 6150C

POWER:		
Power Supply Voltage:	+9VDC (nom)	+6VDC to 12VDC
Operating Current:	6.25mA	±1mA
Operating Temperature:	-20C to +70C	
COMMUNICATIONS (SENSOR):		
BFSK FREQUENCY BINARY 1 (MARK):	117KHz (nom)	±5KHz
BFSK FREQUENCY BINARY 0 (SPACE):	133KHz (nom)	±5KHz
MODULATING LEVEL:	1Vpp	±0.5Vpp
DC LEVEL:	+9.5 VDC (nom)	±0.5VDC
CODING:	NRZ	
DATA RATE:	2400bps	

E.3 CABLE

CONDUCTOR:	TWISTED PAIR 22AWG 7/30 STRANDED
INSULATION:	FOAMED POLYPROPYLENE
SHIELD:	ALUMINIZED POLYESTER FOIL WITH 22AWG TINNED COPPER DRAIN WIRE
JACKET:	POLYURETHANE – BLACK
OVERALL CABLE DIAMETER:	0.250” ±.010”
TEMPERATURE RATING:	60º C (max)
CAPACITANCE(MUTUAL):	12.3PF/FT
CAPACITANCE(GROUNDED):	22.8PF/FT
DIELECTTRIC WITHSTANDING:	500VRMS (min)
VOLTAGE RATING:	30V (max)
DC RESISTANCE:	14.7Ω/1000
CHARACTERISTIC IMPEDANCE:	107Ω