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Instruction Manual
Model 6150D
MEMS Digital Addressable
In-Place Inclinometer
[No Wheels]

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1. INTRODUCTION

The Geokon Model 6150D MEMS Digital Addressable In-Place Inclinator 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 two inch schedule 40 or schedule 80 PVC pipe. Inclinator casing is not required.



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

1.1 Tilt Sensor Construction

Each sensor comprises an addressable, Micro-Electro-Mechanical Systems, (MEMS), tilt sensors mounted inside a sealed stainless steel housing. (A second MEMS sensor at 90° can be included for Biaxial system), The Housing has a prong on the lower end to engage a lower spacer tube and a universal coupling on its upper end to connect to an upper spacing tube which then allows unimpeded relative movement between adjacent spacing tubes, The whole string is designed to rest on the bottom of the PVC pipe and rest against the sides of the two inch PVC pipe. Alternatively, the string may be suspended in the pipe. Each housing contains a device for reading temperatures. The tilt sensors are attached to each other by means of two wire bus cable which runs out of the top of one sensor to the bottom of the sensor above and ultimately from the top sensor to the readout location.

The standard system employs sensors spaced at either 0.5, 1, 2 and 3 meters. Other length spacers are available on request.

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.

Prior to installation, the tilt 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 the bus cable to the readout system and hold each sensor in an approximately vertical 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 temperature devices should be close to ambient.

2.2 Model 6150D Assembly and Installation

2.2.1 Connect the first length of spacer tubing to the bottom cap.

For the standard systems the tilt sensor spacing can be either 0.5, 1, 2 or 3 meters. [If other length spacers are used the lengths of tubing making up the IPI string are tagged and their locations shown in a table supplied separately.] Use the 10-32 screws and nuts, and a thread locking cement to make this joint

2.2.2 The next step is to attach the bottom sensor.

The uniaxial or biaxial sensor is delivered with the orientation set such that the A+ direction is marked on the sensor and is aligned in the direction of anticipated movement.

Tilts in the positive direction yield increasing readings in digits.

The tilt sensor is attached to the first tube section using a single long 10-32 cap screw. (Use Loctite 222 on all threads).

[With 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 3.

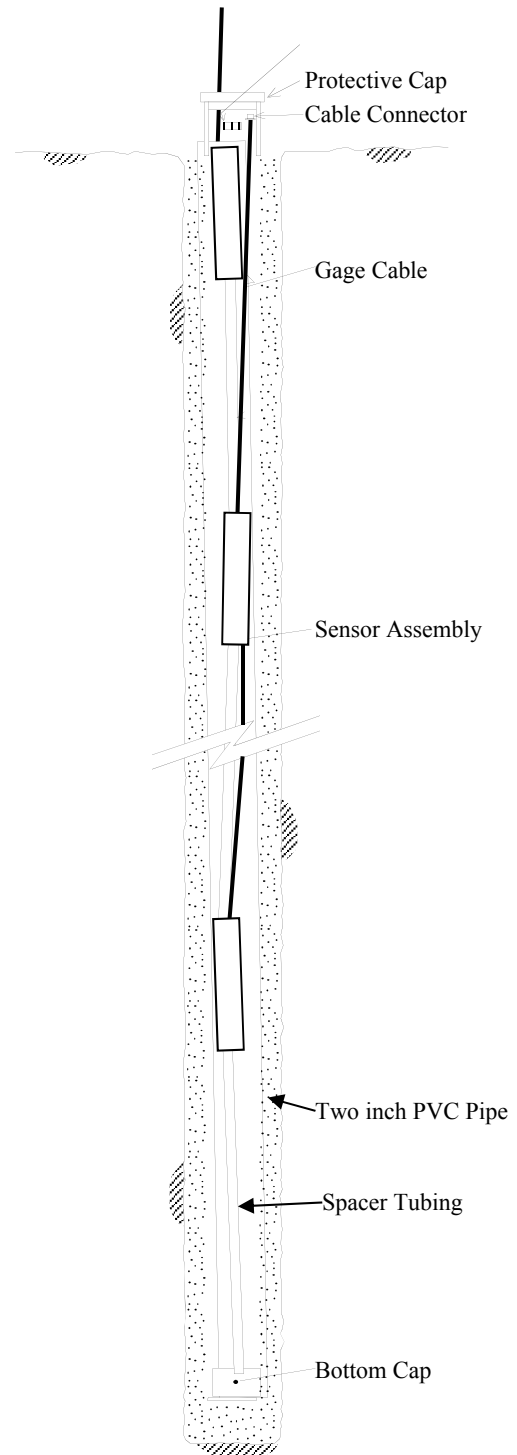


Figure 2 - Model 6150D Installation

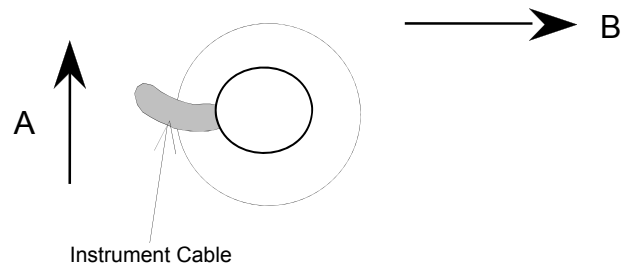


Figure 3 - Biaxial Sensor Orientation View looking down at the top of the sensor

2.2.3 Assembling the IPI string

This next connecting rod can now be connected to the universal coupling on top of the sensor assembly and lowered into the borehole.

While holding the connecting tube at the top of the PVC pipe, the next sensor is attached again making sure that the A+ direction is maintained. At this point the orientation of the entire string of sensors can be checked.

Continue to add gage tubing and sensors until the last sensor has been installed.

To adjust the orientation lift the entire string off the bottom of the hole and while jogging the string up and down turn it until the A + marker points in the correct direction.

At this point, the top suspension must be attached to the upper sensor (or the gage tube). Or alternatively the IPI string can be allowed to rest on the bottom of the pipe.

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 zero conditions.

3. TAKING READINGS

3.1 The 8020-70/6150D FSK Modem Digital Addressable System

The 8020-70 digital addressable system incorporates a 8020-70 FSK Modem that allows multiple 6150D digital MEMS tilt sensor to be connected onto a single two wire bus (string).

Communications with each 6150D tilt sensor is achieved by modulating the system power with the commands and resulting responses. Up to 32 6150D tilt sensors 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 6150D tilt sensors per 8020-70.



Figure 4 - 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 6150D devices, along with various readings and diagnostics. For more details 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 outputs a voltage 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 a voltage proportional to the sine of the angle of inclination from the vertical. For the +/- 15 degree sensor the FS output is approximately +/- 4 volts.

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

$$\theta = \text{Sin}^{-1}(\text{RG}) \quad \text{or} \quad \text{Sin}\theta = \text{RG}$$

Equation 1 - Inclination versus voltage.

G is the Gage Factor, ($\text{sin}\theta/\text{volt}$), 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 $\text{sin}\theta = \theta$ radians.

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

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

Equation 2 - Tilt degrees versus voltage change

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

4.2 Temperature Correction

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

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

Equation 3 - Tilt versus voltage corrected for Temperature

Where;

$$R_{\text{corr}} = R_1 - 0.0003 (T_1 - T_0)$$

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 top of the segment is equal to $L\sin\theta$, where L is the length of the segment, between sensors, and θ is the inclination of the segment to the vertical. The length L_1, L_2, L_3 , etc., is a standard 0.5meters or 1.0 meters [If other tubing lengths are used the spacing can be calculated by adding **410mm**, (both uniaxial and biaxial systems) to the individual lengths of tubing. This will give the correct distance between sensors

The profile of the borehole is constructed by using the cumulative sum of these lateral offsets starting with the bottom segment, L_1 . For instance, referring to Figure 5, 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,

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

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 $\Delta R_1 = (R_1 - R_0)$ i.e. the present reading on Tiltmeter 1 minus the initial reading on Tiltmeter 1; and $\Delta R_2 = (R_2 - R_0)$ 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.

NOTE: 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.

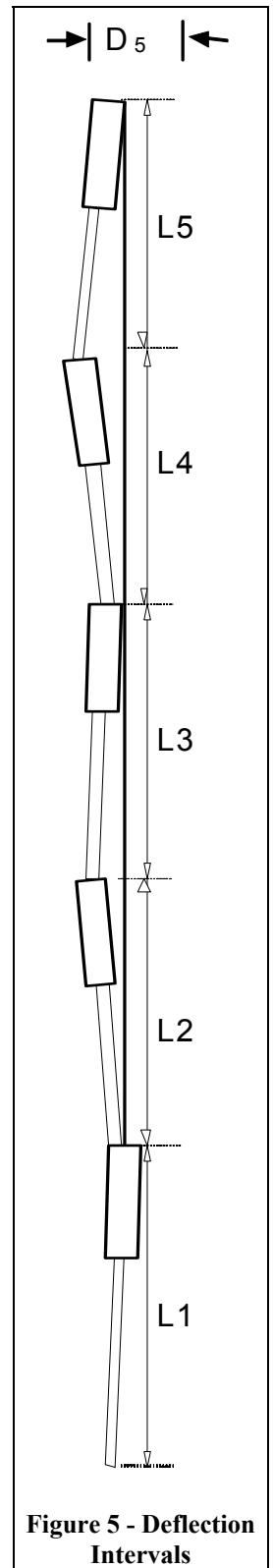


Figure 5 - Deflection Intervals


		48 Spencer St. Lebanon, N.H. 03766 USA				
MEMS Tilt Sensor Calibration						
Model Number: <u>MEMS Tilt Sensor</u>			Calibration Date: <u>July 12, 2012</u>			
Serial Number: <u>1221794</u>			Calibration Instruction: <u>CI-Tiltmeter MEMS</u>			
Temperature: <u>24 °C</u>			Technician: _____			
Inclination (degrees)	Inclination (sinθ)	* Reading 1st Cycle (Volts)	* Reading 2nd Cycle (Volts)	* Average Reading (Volts)	Error in Calculated θ (%FS)	Error in Calculated sinθ (%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 ($G_{\sin\theta}$): <u>0.0630</u> (sinθ / Volt) Deflection = ($G_{\sin\theta}$)L(R₁-R₀) mm (inches)						
6160, 6161 and 6165 Tilt Gage Factor (G_{tilt}): <u>3.642</u> (degrees/ Volt) over +/- 15° range Calculated Tilt = G_{tilt}(R₁ - R₀) 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. This report shall not be reproduced except in full without written permission of Geokon Inc.						

Figure 6 - Sample Model 6150 MEMS Calibration Sheet

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 the MEMS tilt sensors used in the Model 6150D 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 Fails 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 the 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 a connector or tilt sensor.

APPENDIX A. SPECIFICATIONS

A.1 MEMS Tilt Sensor

Model:	6150D
Range	$\pm 15^\circ$
Resolution:	± 2 arc seconds, (± 0.01 mm/m)
Accuracy ¹	± 3 arc seconds
Linearity: ²	$\pm 0.07\%$ FS
Cross axis sensitivity	4%
Thermal Zero Shift:	0.0003 volt/ $^\circ$ C rise
Operating Temperature	-20 to $+80^\circ$ C -4 to 176° F
Power Requirements ³ :	9 Volts
Sensor Output:	± 4 Volts @ FS
Frequency Response:	-3db @ 8-28 Hz
Shock Resistance	2,000g
Sensor Housing Dia:	32 mm, (1.250").
Length:	410mm,(16.14").
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

³ Provided by the 8020-70 Modem.

A.2 Temperature Device

Range: -40 to $+85^\circ$ C

Accuracy: $\pm 1.0^\circ$ 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 - Communication Parameters

B.4 Command Line Interface

Communications with each 6150D 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 6150D 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 6150D

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 6150D 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 6150D

Then;

6150D #2 processes the command as stated above.

6150D #2 transmits the response in Packet Format to 8020-70.

8020-70 processes and formats the response from 6150D.

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 6150D 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 6150D Sensors

Then;

All 6150D sensors process the command.

All 6150D sensors transmit individual time multiplexed responses in Packet Format to 8020-70.

8020-70 processes and formats the responses from the 6150D 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 6150D 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.

Number of Sensors In String	INDIVIDUAL ADDRESSING		BROADCAST ADDRESSING	
	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 6150D firmware version 3.0.0.0, signal timings between the 8020-70 and the 6150D sensors changed considerably. Because of this, there is a backwards compatibility issue between version 3.x.x.x 6150D sensors and version 2.x.x.x 8020-70s.

Working Combinations:

8020-70 version 2.x.x.x 6150D version 2.x.x.x

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

8020-70 version 3.x.x.x 6150D version 3.x.x.x

Problem Combination:

8020-70 version 2.x.x.x 6150D 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)

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.

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 96 sensors. (36*96=3456)*

Public SerialListenString As String * 3456 *'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(16) *'Storage for A axis Output of each MEMs.*

Public B_axis(16) *'Storage for B axis Output of each MEMs.*

Public Temp(16) *'Storage for Temperature Output of each MEMs.*

Public ErrorCode(16) *'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(16) As String * 36 *'Array of strings used for the SplitStr command ,then contains information from individual sensors. Up to 16 sensors on a string.*

DataTable (Table1,True,-1)

 Sample (16,A_axis(1),IEEE4) *'A axis result in Volts*

 Sample (16,B_axis(1),IEEE4) *'B axis result in Volts*

 Sample (16,Temp(1),IEEE4) *'Temperature result in Celsius*

 Sample (16,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. 3457 buffer (max

'incoming data + 1). Serial Open format 16 for TTL, use 0 when using RS232 communications.

SerialOpen (Com1,9600,16,0,3457)

'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 16 for the broadcast command

```
SerialOut (Com1,CHR(13),"wait",1,10)
SerialOut (Com1,"1/1/37/16"+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 15 seconds (Broadcast can read higher quantities of sensors much quicker)

```
SerialIn (SerialListenString,Com1,1500,CHR(04),3456)
```

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

```
SplitStr (GageStrings(),SerialListenString,CHR(13)+CHR(10),16,4)
```

'Loop through each string retrieved.

```
For I = 1 To 16
```

'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)

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.

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. 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(16) *'Storage for A axis Output of each MEMs.*

Public B_axis(16) *'Storage for B axis Output of each MEMs.*

Public Temp(16) *'Storage for Temperature Output of each MEMs.*

Public ErrorCode(16) *'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(16) As String * 36 *'Array of strings used for the SplitStr command ,then contains information from individual sensors. Up to 16 sensors on a string.*

DataTable (Table1,True,-1)

Sample (16,A_axis(1),IEEE4) *'A axis result in Volts*

Sample (16,B_axis(1),IEEE4) *'B axis result in Volts*

Sample (16,Temp(1),IEEE4) *'Temperature result in Celsius*

Sample (16,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 16
```

'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 3.25

'seconds, move onto the next sensor if waiting exceeds 4 seconds.

```
SerialIn (GageStrings(I),Com1,400,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 16

'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:60 μ A (nom) RS-232:110 μ A (nom)	TTL:50 μ A to70 μ A RS-232:100 μ A 120 μ A
Operating Current (User Communications):	6mA (nom) TTL/RS-232	5mA to 7mA
Operating Current (Sensor Communications): Max Peak Operating Current – (Broadcast 32 sensors CMD 1)	20mA (nom) TTL/RS-232 200mA	18mA to 22mA
Operating Temperature:	-20C to +70C	
COMMUNICATIONS (SENSOR):		
BFSK FREQUENCY BINARY 1 (MARK):	117KHz (nom)	\pm 5KHz
BFSK FREQUENCY BINARY 0 (SPACE):	133KHz (nom)	\pm 5KHz
MODULATING LEVEL:	1Vpp	\pm 0.5Vpp
DC LEVEL:	+9.5VDC (nom)	\pm 0.5VDC
CODING:	NRZ	
DATA RATE:	2400bps	

E.2 6150C

POWER:		
Power Supply Voltage:	+9VDC (nom)	+6VDC to 12VDC
Operating Current:	6.25mA	\pm 1mA
Operating Temperature:	-20C to +70C	
COMMUNICATIONS (SENSOR):		
BFSK FREQUENCY BINARY 1 (MARK):	117KHz (nom)	\pm 5KHz
BFSK FREQUENCY BINARY 0 (SPACE):	133KHz (nom)	\pm 5KHz
MODULATING LEVEL:	1Vpp	\pm 0.5Vpp
DC LEVEL:	+9.5 VDC (nom)	\pm 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:	60° 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