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Instruction Manual
Model 6101D

MEMS
Portable Tiltmeter

(Doc REV C 9/15)

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1. Introduction

The Geokon Model 6101D MEMS Portable Tiltmeter is a precise, portable instrument designed to make rapid determinations of tilting in the monitoring of structures and soil and rock masses.   It has applications in landslide monitoring, movements adjacent to excavations, tilting in buildings, retaining walls, bridge abutments, dams, etc.

Figure 1 - Model 6101D MEMS Portable Tiltmeter

When connected by Bluetooth wireless the Model 6101 Tiltmeter, (see Figure 1), can be read with the Model FPC-1 Handheld Field PC, (see Figure 2. The lack of an interconnecting cable greatly facilitates the readout procedure.

2. Description

The MEMS tiltmeter system usually consists of three main components. They are the tiltmeter, the Handheld Field PC and the tilt plates.

Tilt plates, (examples are shown in figure 3), are designed to be permanently attached to the structure, either by epoxy bonding (ceramic plates) or by bolting, (stainless steel plates), (copper-coated aluminum plates).

The sensing elements in the tiltmeter are two MEMS sensor oriented at 90 degrees and sealed in a waterproof housing. Axis A is aligned with the body of the tiltmeter, and tilting in the direction of the end marked **+** produces a positive change in the readings of the A axis.

At the same time, a reading on the B axis will be taken, and the positive direction of the B axis is at 90 degrees clockwise looking down on the tiltmeter.

The output of the Geokon Model 6101D MEMS tiltmeter is equal to approximately +/- 4 volts at +/- 15°.The sensor is aligned on the tiltplate using alignment bars so that the same position and orientation is guaranteed for every reading.

Readout is accomplished using the Model FPC-1 Handheld Field PC.

Figure 2 - Model FPC-1 Handheld Field PC.

3 Installation and Use of the Tiltplates

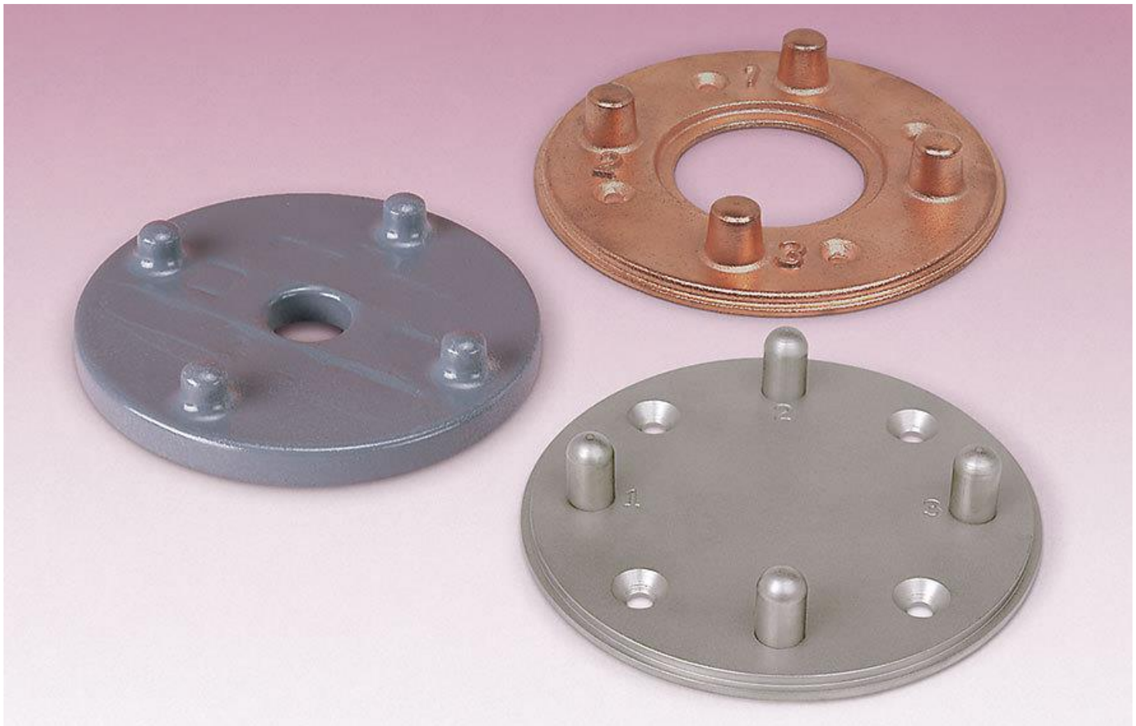


Figure 3 - Tiltplates: 6201-1C (ceramic), 6201-1A (Copper plated Aluminum), 6201-1S (stainless)

Portable tiltmeters must be manually read so the location of the tiltmeter plate must be both protected and accessible. Covers are available for installations in areas where heavy construction is ongoing or where vandalism may be a problem.

The tiltplates should be installed on firm, clean surfaces as close to flat as is possible. Most installations utilize epoxy as the body-bonding medium. A resin such as Devcon VW 11800 can be used. The epoxy should be allowed to fully cure before readings commence.

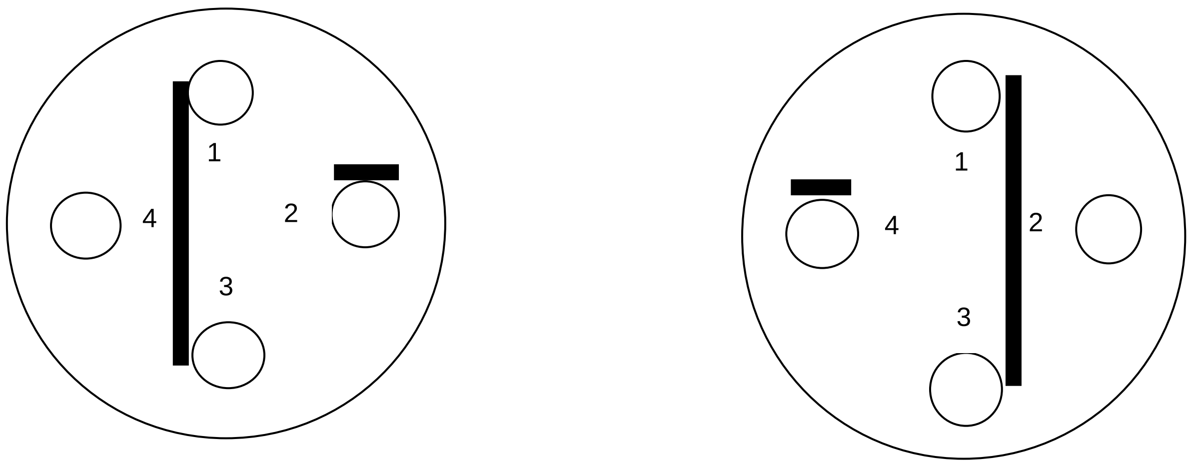
The tilt plate that is being observed should have an I.D. number written on it.

Tiltplates are numbered 1 to 4 in a clockwise direction. It is recommended that Pin 1 be oriented towards the direction of the greatest expected tilting.

Note: If using ceramic tiltmeter plates care should be taken to avoid nicking or cracking the ceramic surface of the tiltplate pegs. The ceramic material is very brittle.

3.1 Vertical installations.

For vertical installations such as building walls, bridge abutments, etc., the tilt plate pegs must be aligned as close to vertical as possible with Peg #1 at the top. See Figure 4



+ Plus End Up **— Minus End Up**

Figure 4 - Measurements in the Vertical Plane

When taking readings in the **vertical plane** first hold the + end of the tiltmeter against the tiltplate so that the long bar lies to the left of pegs 1 and 3 and the short bar lies on top of peg 2, (see Figure 4). Now take the first set of readings, (A axis and B axis)

Turn the tiltmeter end for end and position the long bar to the right of pins 1 and 3 with the short bar resting on top of peg 4. Now take the second set of readings. The second set of reading is the reverse (180°) of the first set of readings. Taking the difference of the two sets of readings and dividing by two yields a number that eliminates any zero offset in the two MEMS sensors.

3.2 Horizontal installations.

For Horizontal installations point the Peg #1 in the same direction as the expected tilt. See Figure 5

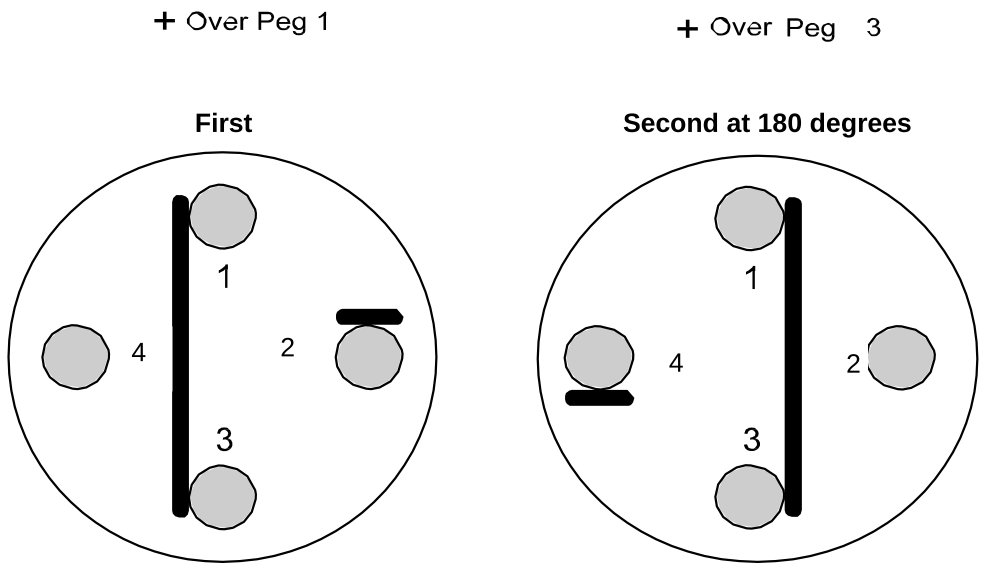


Figure 5 - Measurements in the Horizontal Plane

When taking readings in the **horizontal plane** first hold the **+** end of the tiltmeter over peg 1, so that the long bar on the underside of the tiltmeter lies to the left of pegs 1 and 3 and the short bar lies against peg 2 as shown in figure 4 Now take the first set of readings. Turn the tiltmeter end for end so that the + end of the tiltmeter is over peg 3 and position the long bar to the right of pins 1 and 3 with the short bar resting against peg 4 as shown in figure 4. Now take the second set of readings. The second set of readings is the reverse (180°) of the first

4. Taking Readings

More information regarding the method of reading is given in the GK-604D User's Manual supplied with the portable tiltmeter. They are duplicated here for completeness.

4.1 Dual Channel Digital Tiltmeter (Model 6101D)

The Model 6101D Tiltmeter contains an integral battery and Bluetooth module, allowing the tiltmeter to be read directly with the FPC-1 running the GK-604D IRA. No external Interface Module is needed. The Model 6101D measures tilt in 2 axes: A and B.

It is assumed that a valid Bluetooth pairing exists between the 6101D and the FPC-1 (see section 2.2 of the GK-604 D User's Manual for more information about establishing Bluetooth pairings). The recommended steps for connecting to and taking a reading with the Model 6101D Tiltmeter are as follows:

1. Create an initial "hole" configuration corresponding to the unique location of the tilt plate where tilt is to be measured:

    - Using the Context Menu (see section 3.2.1 of the GK-604D Manual), after highlighting the Project element, select the "Add Hole" menu item to create a new configuration.

    - Since the "hole" corresponds to a physical location, be sure to name it appropriately, such as, "Location1".

    - Additional information may be entered in the "Description" field.

    - For the first location (hole) created, select "UNKNOWN" for "Probe name:".

    - The hole parameters such as "Starting Level", "Interval", "Top Elevation" and "Azimuth Angle" are not applicable for Tiltmeter operation and can be left blank.

    - Tap "Save Settings" to save the new location (hole) configuration. See section 4.1of the GK4-604D manual for more information about hole configuration.

2. Make sure that the "hole" corresponding to the location to be measured is selected in the Project Explorer.

3. Press the "ON/OFF" button on the 6101D Tiltmeter and ensure that the blue indicator is blinking.

4. Tap the "Live Readings" menu item from the "Application" menu to start the reading process. If a valid Bluetooth connection can be established, a dual axis, tiltmeter specific, Live Readings screen will be displayed (see Figure 6).

    Note the drop-down control in Figure 6, located just to the right of the "A" value display. This allows the "A" and "B" values to be displayed in 3 different units, described below:

    Digits — Digit values are read directly from the 6101D Tiltmeter and are internally calculated as follows:
    R1 = internal MEMS module voltage, (volts)
    R0 = Zero Shift A [from internal probe configuration]
    GF = Gage Factor A [from internal probe configuration]
    GO = Gage Offset A [from internal probe configuration – usually zero]
    DIGITS = (((R1 – R0) * GF) + GO) * 2500

    Volts — **PV** = **DIGITS / 2500** [for Geokon probes: ±4V ≈ ±30 degrees]

    Degrees — **DEGREES** = **arcsin(DIGITS / 20000)* 180/Pi**

    From this Menu select "Degrees"

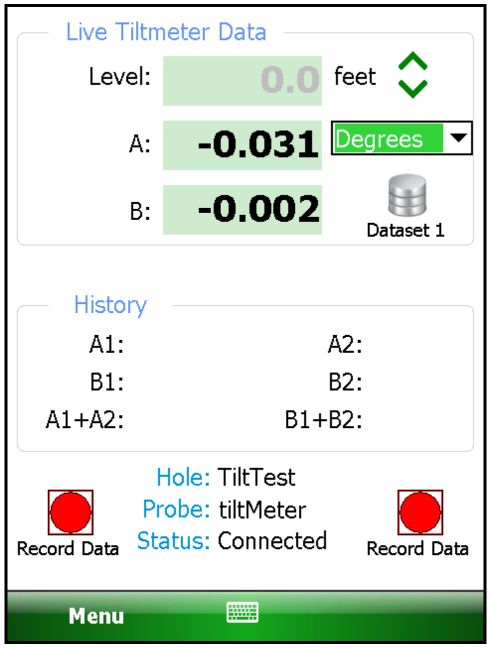


Figure 6 - Live Readings (Tiltmeter)

5. Align the Tiltmeter on the tiltplate in the A+ orientation, then tap “Record Data” to take the “A+” reading For the Model 6101D, the “B+” reading is taken at the same time as “A+”.

6. Tap the “Dataset” icon and observe that the dataset number changes to “2”.

7. Reverse the Tiltmeter orientation to A- and, again, tap "Record Data" to take the "A-" reading. For the Model 6101D, the "B-" reading is taken at the same time as "A-". Tapping "Menu›Exit Live Readings" will display the window in Figure 7.

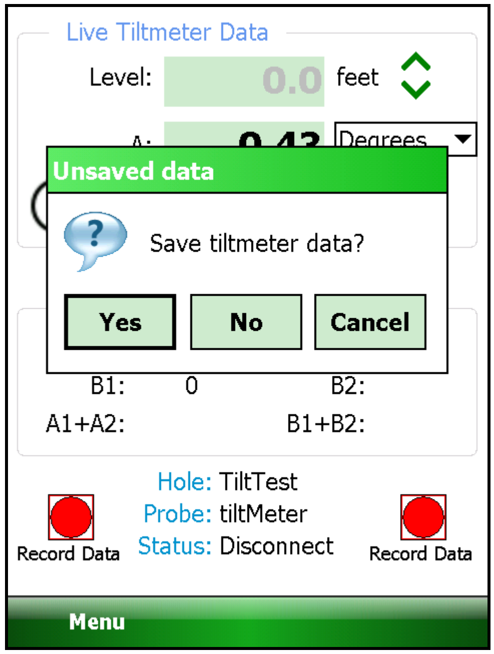


Figure 7 - Saving data query

8. Tap the "Yes" button to start the data saving process. The "Save File" dialog (Figure 8) will be displayed, allowing the user to name the data file to save.

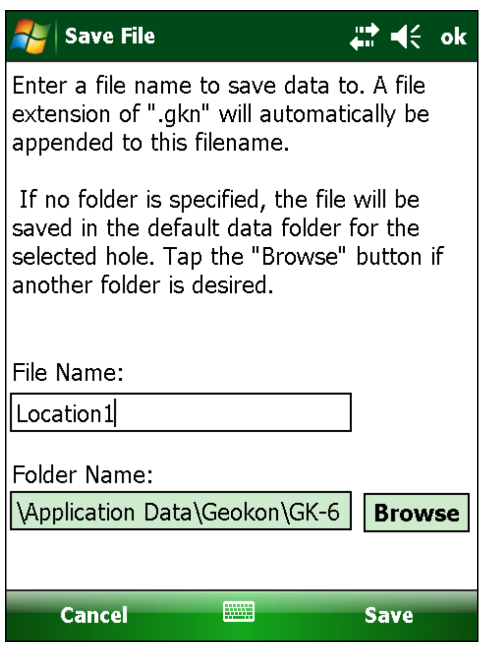


Figure 8 - Save File Dialog

9. After tapping “Save” the GK-604 IRA will determine if the file exists. If this is a new file then the data will be written to it in a format similar to the standard Inclinometer format. If a file of the same name already exists then the dialog shown in Figure 9 will be displayed.

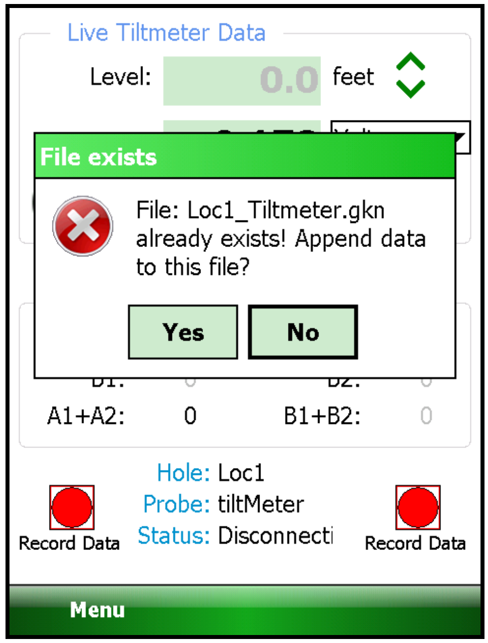


Figure 9 - File Exists Dialog

10. Tapping “Yes” on the “File exists” dialog allows multiple reads for this location to be stored in a single data file. See section G.4 for an example of Dual Axis Tiltmeter data format.

11. Tapping “No” at the “File exists” dialog will again call up the “Save File” dialog (see Figure 8) and another opportunity will be given to select a new file.

4.2. Dual-Axis Tiltmeter Data Format

```
***
GK 604E(v1.3.0.0,02/15);2.0;FORMAT II
PROJECT  :Site 1
LOCATION :Loc1
DATE     :02/19/15
TIME     :14:54:17
PROBE NO.:tiltMeter
UNITS     :DEGREES
FILE NAME:Loc1_Tiltmeter.gkn
   A+,      A-,       B+,    B-,          Date/Time
 -0.031,  +0.028,    +0.002,  -0..002,          2/19/15 14:50:25
 -0.033,  +0.030,    +0.002,  -0..002,          2/17/15 13:54:40
 -0.037,  +0.036,    +0.002,  -0..002,          2/14/15 13.45.20
 -0.038,  +0.035,    +0.002,  -0..002,          2/10/15 11:23:30
```

5. Data Recording and Reduction

5.1 The change in tilt and deflection

Can be calculated by comparing the values of the A+ and A - and the B+ and B - readings on subsequent days, i.e.,

Change of Tilt in the A axis = Δ (A+ - A-)/2

and, **Change of Tilt in the B axis = Δ (B+ - B-)/2**

on subsequent days.

The change of tilt can be converted into a deflection using the conversion factor:

1 arc second = 0.0048mm/meter

or **1 arc second = 0.000058inches/ft**

5.2 Example of readings taken from a horizontal tiltplate

Four readings are taken; two each for Pin 1 and 3 and two each from Pins 2 and 4, following the instructions
of Section 4.

Reading Peg 1 to 3, (A+)	+0.0447 Degrees
Reading Peg 3 to 1, (A-),	–0.0581 Degrees
Reading Peg 2 to 4, (B+),	–0.0469 Degrees
Reading Peg 4 to 2, (B-),	+0.0342 Degrees

Peg 1 and 3. Tilt in the A axis direction is given by the difference,

(A+ - A-) = +0.0447 – (–0.0581) = + 0.1028 Degrees

Peg 2 and 4. Tilt in the B axis direction is given by the difference,

(B+ - B-) = – 0.0469 – (+0.0342) = – 0.0811 Degrees

Note that the tilt is towards Peg 1 (positive) and towards Peg 4. (negative). (A positive figure for both A and B axes means that the tilt is towards Pin 1 and towards Pin 2.)

These two tilts can be combined, to give the maximum resultant tilt and its direction. This is done by first calculating the deflections, in the A axis and the B axis), using the relationships

1 arc second = 0.0048mm/m or 1 arc second = 0.00062 inches/ft

In the above example

Deflection in the A axis direction (DA) = +0.1028 x 3600 x 0.0048 = + 1.78mm/m

Deflection in the B axis direction (DB) = - 0.0811 x 3600 x 0.0048 = - 1.4 mm/m

The maximum deflection, Dmax, is given by the equation

$$Dmax = \sqrt{[(1.78)^2 + (-1.4)^2]} = 2.26 \text{ mm/m}$$

And the angle **θ,** the angle between the direction of Peg 1 and the direction of the maximum tilt, is given by the formula

$$\theta = Tan^{-1}[(DB)/(DA)$$

$$\theta = Tan^{-1}[(1.4)/(1.78)$$

And the direction of the maximum defection is 38 degrees from the direction of Peg 1 in the direction of Peg 4

For further information refer to the GK604D manual

5.3 Calibration

The calibration sheet shown in figure 10 shows the calibration factor, G, which is entered into the tiltmeter at the factory so that the tiltmeter output can be shown directly in degrees.

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

6101D MEMS Portable Tiltmeter Calibration Data

Serial Number: 1530490

Temperature: 22.7 °C

Calibration Date: September 21, 2015

Calibration Instruction: CI-Tiltmeter MEMS

Technician:

Inclination (degrees)	Reading A-Axis (Volts)	Reading B-Axis (Volts)
15	4.108	4.113
10	2.743	2.799
9	2.467	2.524
8	2.191	2.250
7	1.914	1.974
6	1.636	1.697
5	1.358	1.419
4	1.079	1.142
3	0.802	0.865
2	0.522	0.588
1	0.243	0.309
0	-0.036	0.031
-1	-0.315	-0.248
-2	-0.594	-0.526
-3	-0.873	-0.804
-4	-1.152	-1.082
-5	-1.430	-1.361
-6	-1.708	-1.639
-7	-1.987	-1.916
-8	-2.264	-2.193
-9	-2.539	-2.470
-10	-2.816	-2.750
-15	-4.181	-4.113

6101D Tilt A-Axis Gage Factor (G_{tilt}): 3.602 (degrees/ Volt) over + / - 30° range

6101D Tilt B-Axis Gage Factor (G_{tilt}): 3.618 (degrees/ Volt) over + / - 30° 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.
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Figure 10 - A Typical Tiltmeter Calibration Sheet

6. Troubleshooting

The main concerns of tiltmeter surveys are the measurement of change in magnitude and direction of rotational movement. The zero offset of the sensor is not critical because the algebraic difference of the two readings eliminates the effect. A tiltplate tilted at an angle and located on a stable surface can be read periodically to check the calibration of the instrument. The sensor itself should not be opened in the field and if the unit fails to work it should be returned to Geokon for repair.

7. Specifications Model 6101 MEMS Portable Tiltmeter

Range	±15°
Output at +/- 15º tilt[4]	+/- 4 Volts DC (Nominal)
Input Supply Voltage[3]	9 to18 Volts DC
Input Supply Current	25 mA
Resolution[1]	± 4 arc seconds (+/- 0.02mm/m)
Accuracy[2]	± 10 arc seconds. (+/- 0.05mm/m)
Thermal zero shift	0.0003volts/ºC rise
Temperature Range, Operating	-0 to+ 50°C
Temperature Range, Storage	–20 to +80°C
Shock Survival	2000g
Dimensions	Sensor: 172x 102 x 166mm
Weight	6.5Kg(including case)
Connector	Bluetooth ®

Notes:

[1] Depends on readout equipment. For best results requires a 4 ½ digit digital voltmeter. Averaging will yield resolution on the order of 2 arc seconds
[2] Based upon the use of a second order polynomial
[3] Voltages in excess of 18V will damage the circuitry and are to be avoided.

[4] The output is digital.