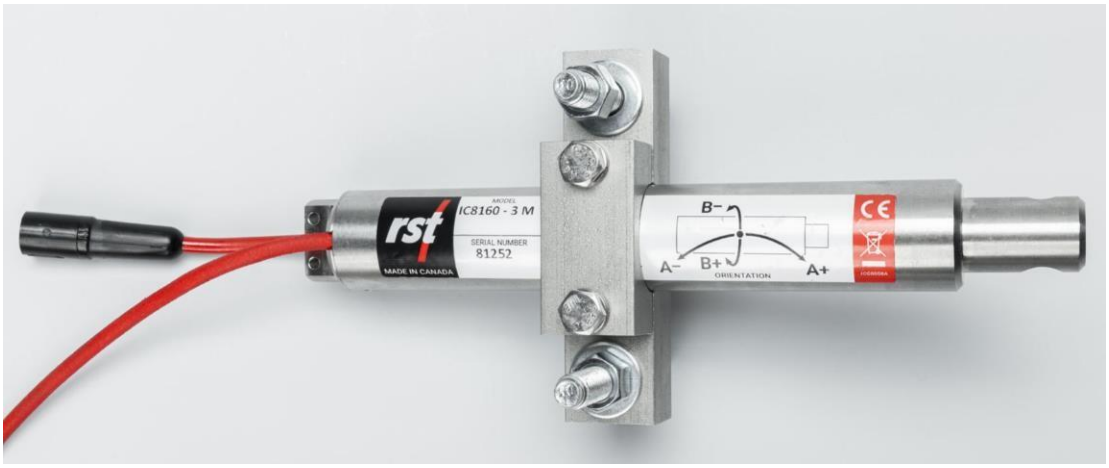

Submersible Tiltmeter (MEMS) Installation and User Manual

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REVISION HISTORY

Rev.	Revision History	Date	Prepared By	Approved By
A	Initial release	December 14, 2022	TW	
B	Added Appendix C: Tiltmeter Command Set for RS-485	June 3, 2024	SM	DH

1 OVERVIEW

RST's Tiltmeter and Submersible Tiltmeter (MEMS) measure tilt in two axial planes. They are designed to be permanently installed to provide long term observation with maximum resolution and sensitivity for manual monitoring or remote data acquisition. Unlike electrolytic sensors which have high coefficients of thermal sensitivity and require precise leveling on structures, MEMS sensors have excellent zero and full-scale stability and do not require precision sensor zeroing.

The Tiltmeter's electronics are installed inside an IP68 stainless steel housing. For watertight performance at depths up to 200 meters, the cables have over-molded connectors. The interconnecting cable is designed to withstand being buried without additional covers.

A typical Tiltmeter system includes the following:

- Tiltmeter(s)
- Mounting bracket mounted vertically, horizontally, or at an angle for each Tiltmeter
- Extension cable(s), as needed (can be ordered separately)
- Data logger or readout instrument (can be ordered separately)

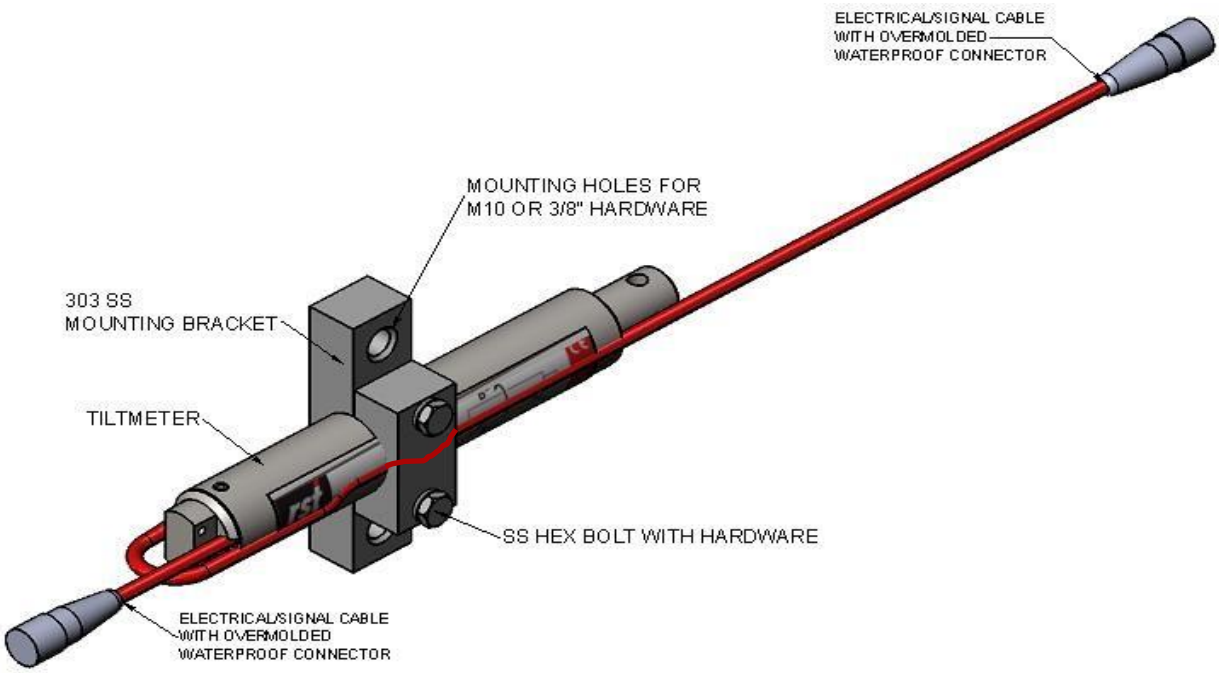

Figure 1: Components arrangement for Digital Bus Tiltmeter

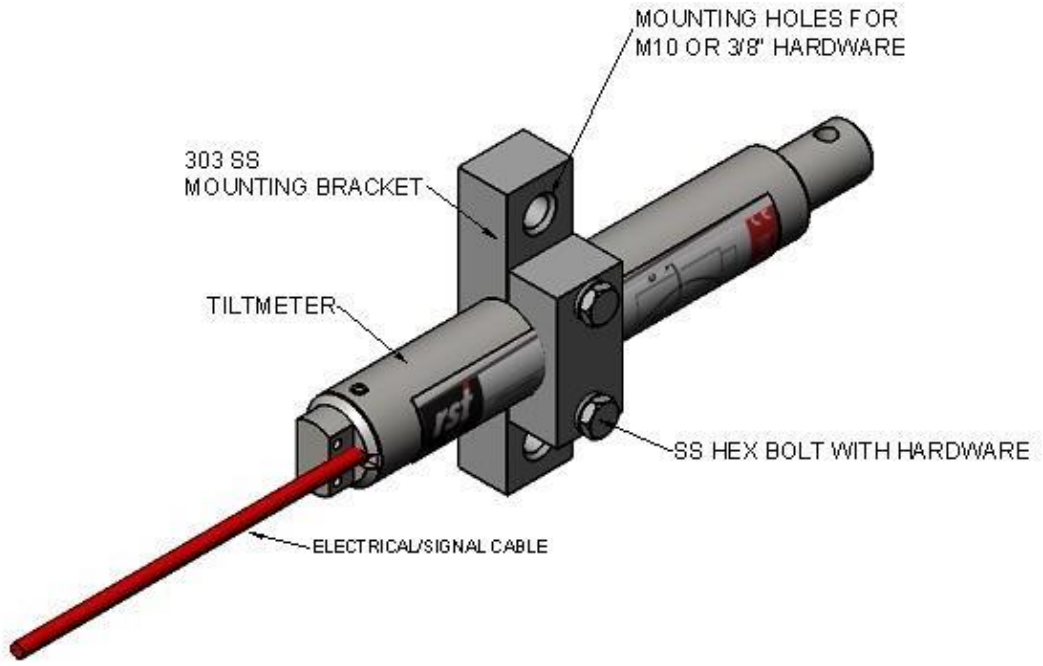

Figure 2: Components arrangement for Digital Non-Bussed System

1.1 INTENDED AUDIENCE

This guide is for the personnel responsible for installing or using RST's Tiltmeter or Submersible Tiltmeter (MEMS). This manual provides steps for installing either type of tiltmeter, and how to take readings and interpret them.

1.2 ICONS AND CONVENTIONS USED IN THIS GUIDE

This guide uses the following icons to call attention to important information.

	WARNING: This icon appears when an operating procedure or practice, if not correctly followed, could result in personal injury or loss of life.
	CAUTION: This icon appears when an operating procedure or practice, if not strictly observed, could result in damage to or destruction of equipment.
	NOTE: This icon appears to highlight specific non-safety related information.

1.3 SIGN CONVENTIONS

Figure 3 and Figure 4 show the sign convention for tilt along the A axis and B axis, depending on how the Tiltmeter and bracket are mounted.

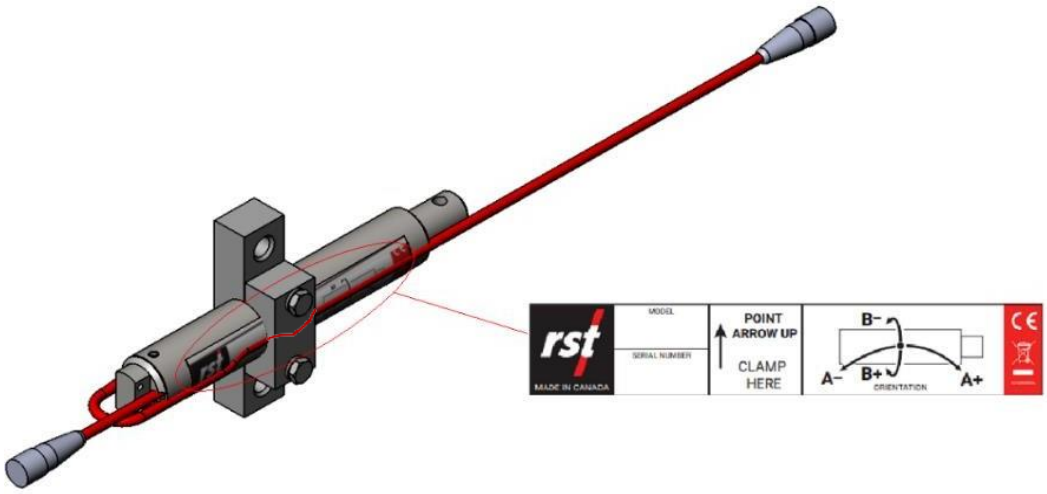

Figure 3: Wall mount Tiltmeter sensor sign convention for A axis and B axis

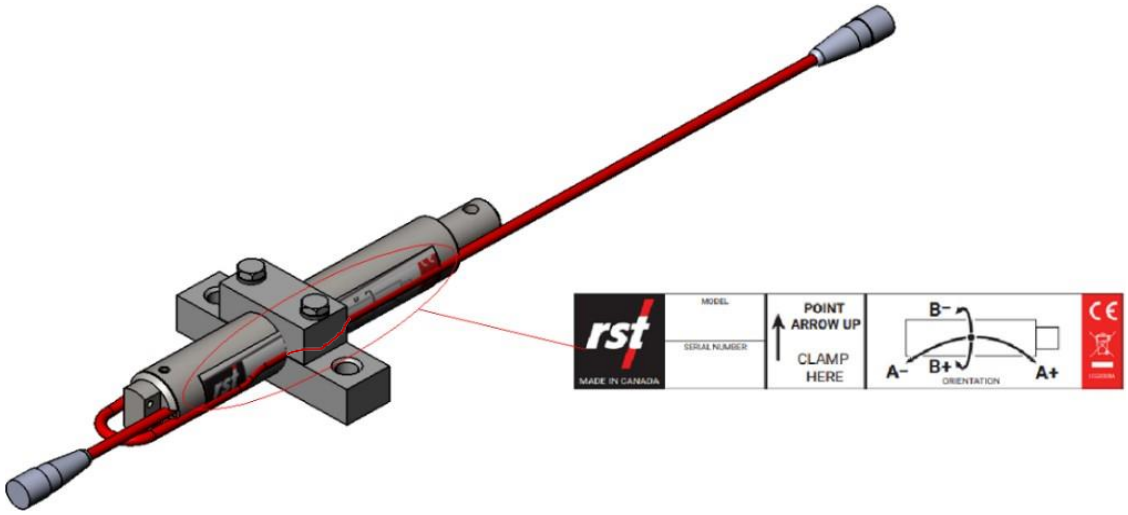

Figure 4: Floor mount Tiltmeter sensor sign convention for A axis and B axis

2 INSTALLATION

2.1 REQUIRED TOOLS AND COMPONENTS

Before installing a Tiltmeter or Submersible Tiltmeter, make sure to have the following components and tools:

- RST Tiltmeter or Submersible Tiltmeter (MEMS)
- Mounting bracket for each tiltmeter
- 6 mm wrench
- Level (optional)
- Anchor kit (recommended M10 or 3/8” anchor kit)
- DT2485 and/or FlexDAQ Data Logger

2.2 INSTALLATION GUIDELINES FOR TILTMETER / SUBMERSIBLE TILTMETER

To install a Tiltmeter or Submersible Tiltmeter, complete the following steps:

1. Place Determine the location where the Tiltmeter will be installed.

2. Securely attach the mounting bracket to a rigid structure or surface that is free of vibration and relatively flat. Refer to figure 5 for the bracket hole dimensions. 3/8” UNC or M10 concrete anchors are recommended for concrete surface and 3/8” UNC or M10 bolts for steel surfaces.

CAUTION: Avoid areas that may expose the tiltmeter to rapid or extreme changes in temperature, such as areas with direct sunlight, or near heating or cooling equipment. If the tiltmeter will be exposed to direct sunlight, RST recommends using a sunshade or cover.

3. Install the anchors according to the Tiltmeter’s bracket mounting hole pattern.

NOTE: Ensure the anchors are installed in line with the anticipated axis of tilt as much as possible and the bracket is anchored flat against the mounting surface.

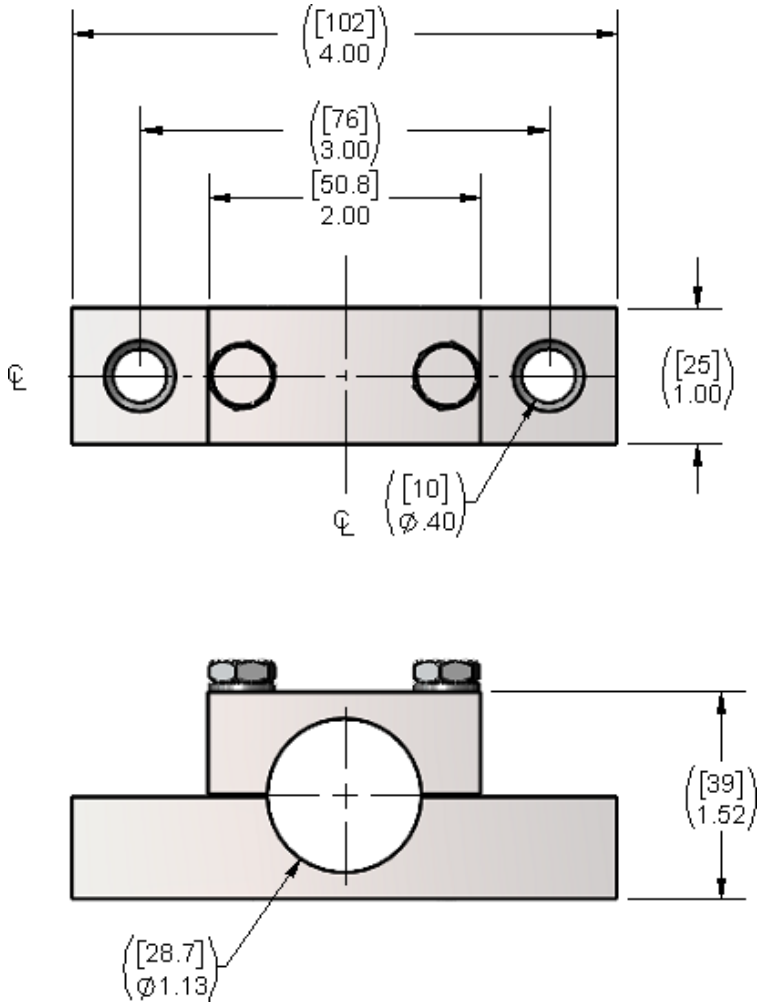

Figure 5: Tiltmeter Bracket Dimensions

4. Insert the Tiltmeter into the bracket.

5. Rotate the Tiltmeter inside the bracket until the arrow on the label is pointing upward against gravity.

   See Figure 1, Figure 3 and Figure 4 for reference.

→| **OPTIONAL**: Connect the Tiltmeter to an Affinity Data Logger, DT2485 logger, FlexDAQ Data Logger, or a compatible readout unit to get live tilt reading and ensure the unit is as vertical as possible.

6. Tighten the bracket with the provided ¼” hex bolts and lock washers to hold the Tiltmeter in place. The recommended torque on ¼” UNC hex bolts is 6 ft-lb [8.13 Nm]. Ensure that the orientation of the Tiltmeter does not change while tightening the bracket.

If installing multiple Tiltmeters, repeat steps 1 to 6, and connect the male connector of one Tiltmeter to the female connector of the next Tiltmeter in the string.

CAUTION: Do NOT twist the connectors when connecting or disconnecting the tiltmeters.

3 OPERATION

Both Tiltmeter and Submersible Tiltmeter (MEMS) are fully compatible with RST Instruments' Affinity Data Logger, DT2485 Logger, and/or FlexDAQ Data Logger.

For information on interrogating the Tiltmeter using RS-485 protocols, refer to Appendix C: Tiltmeter Command Set for RS-485.

NOTE: For information on operating a specific data logger, refer to the logger's instruction manual.

3.1 CALCULATION

Tiltmeters and Submersible Tiltmeters (MEMS) have a ±30° sensor mounted inside its stainless-steel housing. The sensor outputs **sin θ** and temperature, which are read by a data logger or a handheld device. See Section 3.2 for information on electrical connections.

Any tilt in the A axis or B axis changes the angle output of the sensor. The sign convention is discussed in Section 1.3:

Sign Conventions. Sensors output **sin θ** for each axis, which can be used to calculate the tilt angle of the structure.

The change of angle can be calculated using the following equation:

$$\Delta \sin(\theta) = \sin(\theta_C) - \sin(\theta_1)$$

Equation 1 changes in the degree of tilt angle, where:

Δ sin (θ) = change in degree of rotation

sin (θ_C) = current angle of rotation

sin (θ_1) = initial angle of rotation

NOTE: Only read Tiltmeter outputs during periods of low vibration or when there are no heavy pile-driving or construction activity present.

3.2 TAKING READINGS

If possible, connect the Tiltmeter to a data logger and test to confirm full functionality before installation. Once installed, the sensors must be connected to a data logger, and a baseline reading should be taken. This value will be subtracted from subsequent readings to determine the change in orientation of each sensor. Instructions for taking readings are described in the following sub-sections.

3.2.1 Taking Initial or Baseline Reading

The Tiltmeter's initial or baseline reading (**sin θ_1**) is the reference point from which subsequent measurements are made.

To take a Tiltmeter's initial or baseline reading, complete the following steps:

1. Record the serial number of each Tiltmeter.

NOTE: All current RST Tilt products have serial numbers in the 6-digit range, with the address being 5 or 6 digits. For example, 95431 or 100023.

2. Connect the end of each Tiltmeter to the Affinity Logger, DT Logger or FlexDAQ data logger according to the wiring code in Table 1: Digital Output for Tiltmeter.

3. Turn the data logger's power on and note the readings. See Appendix A to interpret the readings.

4. Repeat steps 1 to 3 for all Tiltmeters in the Tiltmeter string.

Wire Color	Tiltmeter (MEMS)
Red	V +
Black	GND
Green	RS485 A-
White	RS485 B+

Table 1: Digital Output for Tiltmeter

3.2.2 Taking Current Readings

To take a Tiltmeter's current reading or degree of tilt (**sin θ_C**) complete the following steps:

1. Record the serial number of each Tiltmeter.

NOTE: All current RST Tilt products have serial numbers in the 6-digit range, with the address being 5 or 6 digits. For example, 95431 or 100023.

2. Turn the data logger's power on and note the readings. See Appendix A to interpret the readings.

3. Repeat steps 1 to 3 for all Tiltmeters in the Tiltmeter string.

4 MAINTENANCE

4.1 CLEAN THE CONNECTORS

Dirt on the connectors may cause contamination or damage and cause an entire string of sensors to fail and become inoperable.

To keep the connectors clean and prevent contamination, make sure to do the following:

- Keep connector caps on until they are ready to be connected to the Tiltmeter or each time a Tiltmeter is disconnected from a Tiltmeter string.
- Store the connector caps in a clean, dry location when not in use.
- To clean a connector, clean with isopropyl alcohol and set aside to dry.

Figure 6: Connectors with Caps

5 PRODUCT SPECIFICATIONS

Item	Specification
Sensor	
Range	± 30°
Resolution	0.0002° (0.004 mm/m)[1]
Precision	± 0.0013° (0.02 mm/m)[1]
	± 0.0005° (0.01 mm/m)[2]
Sensor	MEMS Accelerometer
24hr Stability	± 0.03 mm/m[1]
	± 0.01 mm/m[2]
Temperature Dependent Uncertainty	± 0.016 mm/m/°C (± 0.001°/°C), for ± 5° from vertical
	± 0.033 mm/m/°C (± 0.002°/°C), for ± 15° from vertical
Temperature Accuracy	± 0.5°C (0°C to 60°C) ± 1.0°C (-40°C to 60°C)
Temperature Resolution	± 0.06°C
Operating Temperature	-40 to 60°C (-40 to 140°F)
Electrical	
Supply Voltage	5 to 15 V DC
Signal Output	RS485 Digital Bus (MODBUS RTU Protocol)
Mechanical	
Ingress Protection	IP68 (2 MPa)
Sensor Dimension	ø28.6 mm x 211 mm (ø1.125” x 8.31”)

[1]: 99% Confidence Interval

[2]: 68% Confidence Interval

6 SERVICE, REPAIR AND CONTACT INFORMATION

This product does not contain any user-serviceable parts. Contact RST for product services or repairs.

- For sales information: sales@rstinstruments.com
- For technical support: support@rstinstruments.com
- Website: www.rstinstruments.com
- Toll free: 1-800-665-5599

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Address: 11545 Kingston Street, Maple Ridge, BC, Canada V2X 0Z5

Telephone: 604-540-1100

Fax: 604-540-1005

Business hours: 7:30 a.m. to 5:00 p.m. (PST) Monday to Friday, except holidays

RST UK Office

Address: Unit 4 Charles Industrial Estate Stowupland Road, Stowmarket Suffolk, UK, IP14 5AH

Telephone: +44 1449 706680

Business hours: 9:00 a.m. to 6:30 p.m. (GMT) Monday to Friday except holidays

APPENDIX A: INTERPRETING THE DATA

The RST Tiltmeter or Submersible Tiltmeter (MEMS) is identified with a serial number with a corresponding calibration certificate. See the Appendix B for a sample calibration certificate.

The sensing principle of the micro electro-mechanical systems (MEMS) Tiltmeter is that of an accelerometer with the sensitive axis oriented horizontally. The measured phenomenon is the component of gravity transverse to the sensitive axis, with the formula: **a = g sin (α)**.

Commonly, tilt data is interpreted as linear motion – that is, rotation about a presumed radius gives an equivalent motion. In many cases, where the ultimate variable of interest is a lateral displacement at some presumed radius due to rotation, the accelerometer result can be rescaled as:

$$x = r \sin(\alpha)$$

$$= \frac{ra}{g}$$

In the case of a uniaxial MEMS tilt beam, r is the beam length. For Tiltmeter on rigid bodies, the radius must be chosen with some care.

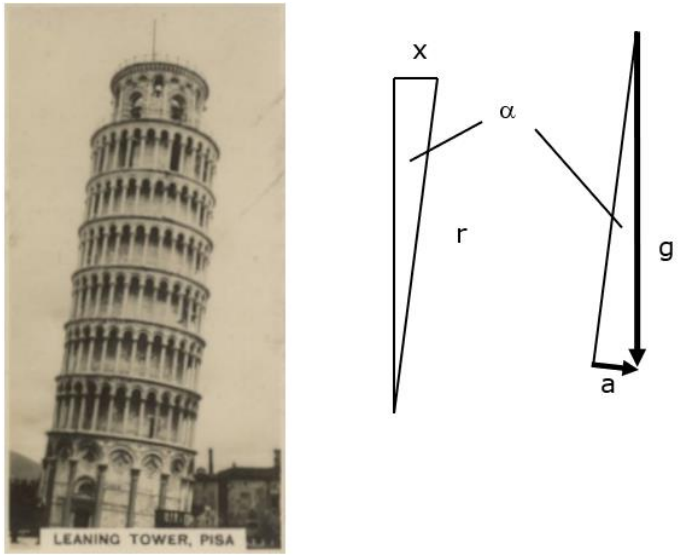

Figure 7: Tiltmeter Data Interpretation

In cases where the actual angle is needed, the arcsine function or a polynomial equivalent may be used: **α = arcsine(a/g).**

NOTE: The Tiltmeter or Submersible Tiltmeter (MEMS) is not designed to measure tilt on “dynamic” structures as the lateral dynamic accelerations may exceed the tilt

accelerations.

APPENDIX B: SAMPLE CALIBRATION CERTIFICATE FOR TILTMETER (MEMS)

Monitor with Confidence

Calibration Record

RST Instruments Ltd., 11545 Kingston St., Maple Ridge, British Columbia, Canada V2X 0Z5
Tel: 604 540 1100 • Fax: 604 540 1005 • Toll Free: 1 800 665 5599 (North America only)
e-mail: info@rstinstruments.com • Website: www.rstinstruments.com

MEMS Vertical Tilt Meter - Digital Bus Output

Serial Number: BI0000092564
Calibration Date: Sept. 9, 2022
Inclinometer Frame: RST07
Referenced to National Standards Annually

Wiring

Colour	Function	Pin
Red	Voltage +	1
Black	Ground	2
Green	RS485 A+	3
White	RS485 B-	4
Bare	Shield	5

A-Axis

Applied Degrees	Applied Sin	Displayed Sin	Error Sin
-30	-0.50000	-0.50000	0.00000
-25	-0.42262	-0.42263	0.00001
-20	-0.34202	-0.34203	0.00001
-15	-0.25882	-0.25882	0.00000
-10	-0.17365	-0.17364	0.00001
-5	-0.08716	-0.08716	0.00001
0	0.00000	0.00000	0.00000
5	0.08716	0.08715	0.00000
10	0.17365	0.17364	0.00001
15	0.25882	0.25881	0.00001
20	0.34202	0.34201	0.00001
25	0.42262	0.42260	-0.00002
30	0.50000	0.49998	-0.00002

B-Axis

Applied Degrees	Applied Sin	Displayed Sin	Error Sin
-30	-0.50000	-0.50000	0.00000
-25	-0.42262	-0.42262	0.00000
-20	-0.34202	-0.34203	0.00001
-15	-0.25882	-0.25883	0.00001
-10	-0.17365	-0.17365	0.00001
-5	-0.08716	-0.08718	-0.00002
0	0.00000	0.00000	0.00000
5	0.08716	0.08715	0.00001
10	0.17365	0.17364	0.00001
15	0.25882	0.25880	-0.00002
20	0.34202	0.34201	-0.00001
25	0.42262	0.42262	0.00000
30	0.50000	0.50000	0.00000

Calibrated By: sm **Date:** 09/09/2022
Checked By: Jane Doe **Date:** 22/09/2022

This instrument has been calibrated using standards traceable to the NIST in compliance with ANSI Z540-1

APPENDIX C: TILTMETER COMMAND SET FOR RS-485

COMMUNICATION INTERFACE

Electrical Specifications = RS-485
Data Transmission = 9600 baud/8 data/no party/1 stop

COMMAND FORMAT

All commands have the following format: @@#####_ComandString<CR>

@@ = Address detect mode character string
= Address in decimal format, 0-9
_ = Character to terminate address, char not in 0-9
ComandString = Command to be processed
<CR> = Carriage return, hex 0x0D. Command termination character.

NOTE: In case only one device is connected, the special address **65535** can be used to access the device.

COMMANDS

There are two commands required to retrieve a set of readings from the Digital Tilt Bus.
TR = Take a set of readings
SR = Send the last set of readings
Reading set = reading from tilt sensor A, tilt sensor B and temperature.

TR

The TR command causes the Digital Tilt Bus to take a set of sensors reading and store the set in memory. Only the most current reading set is stored. The stored reading set is maintained until power is removed from the Digital Tilt Bus or a new reading set is taken.

TR = Take a single reading set then enter low power mode.
TR 1 = Put sensors in continuous reading mode. Sensors do not power down.
TR 0 = Take a single reading then enter low power mode. Terminate continuous mode.

Sample Command: @@100023 TR 1<**CR**>
Return String: TR 1<**CR**>

SR

The SR command causes the Digital Tilt Bus to send the latest reading set. The reading set will not be updated unless continuous reading mode has been entered. If the TR has not been processed, the entries in the returned reading set defaults to 0. The entries are comma separated.

Sample Command:	@@12345 SR<**CR**>
Return String:	SR,ReadingA,ReadingB,Temperature <CR>
ReadingA Format:	#.######

ReadingA Format:	#.######
Temp Format:	#.##
Default Reading	SR,0.00000,0.00000,0.00

Error Response:
If an invalid address is entered, there will be no response. If an invalid command is entered, the echoed command followed by a '?' will be sent.

TYPICAL READING SEQUENCE

- Power on
- Wait 600ms
- Send TR command: Wait for CR after echo.
- Bi-Axial: Wait 2100 ms.
- Send SR command: Wait for CR after echo and data.
- Update rate in continuous mode
- Bi-Axial = 1650 ms