Trillium Seismometer

User Guide

Nanometrics Inc.
Kanata, Ontario
Canada

Trillium Seismometer User Guide

Nanometrics, Inc.
250 Herzberg Road
Kanata, Ontario, Canada K2K 2A1
Tel (613)592-6776
Fax (613)592-5929
Email info@nanometrics.ca

Part number 13912R10
Release date 2004-07-14

Contents

Figures

Tables

Chapter 1 Introduction

Trillium is a three-component, force-balance broadband seismometer suitable for portable and fixed applications. It operates over a wide temperature range without manual recentring, and has very low power consumption. The extended response at higher frequencies makes it ideal for local and regional networks as well as volcano hazard monitoring and aftershock studies.

Trillium uses a symmetrical triaxial arrangement of the sensing elements. The design uses fewer parts and ensures the same frequency response for vertical and horizontal outputs, and is less susceptible to rapid changes in temperature.

Data output can be remotely switched between XYZ and UVW, allowing calibration of the elements independently of the electronics. UVW may be continuously recorded, if desired.

Please read carefully the appropriate sections of this manual before transporting, storing, installing, or operating Trillium. If you need technical support, please submit your request by email or fax. Include a full explanation of the problem and supporting data, to help us direct your request to the most knowledgeable person for reply.

Email: support@nanometrics.ca
FAX: To: Support
(613) 592-5929

Chapter 2 Preparation

This section provides preinstallation guidelines for Trillium. These guidelines are intended to help achieve the best possible performance, but are not necessary for all types of study (e.g. short-period) or site.

2.1 Site Selection

There is no substitute for a geological survey when it comes to site selection, so that the structures over which the sensor is to be installed are known. Low porosity is important as water seepage through the rock can cause tilts which overwhelm the seismic signal at long periods. Clay soils and to a lesser extent sand are especially bad in this sense.

A seismic sensor should be installed on bedrock whenever possible, and as far away as possible from sources of cultural noise such as roads, dwellings and other tall structures.

2.2 Pier Construction

It is recommended that piers be rectangular (rather than round) whenever possible. This means that rigid foam insulation boxes can be easily made to fit.

The pier should be 2" to 4" thick. The surface area should be sized to accommodate the sensors and associated cabling as well as any foam insulation boxes which are to be used.

The surface of the pier should be as smooth and level as possible and clear of debris.

2.2.1 Concrete Selection

The concrete used in a seismic pier should be as homogeneous as possible to avoid inducing tilts due to differing thermal coefficients of expansion. Therefore no aggregate should be used and the concrete should be free of air bubbles. Since strength is not a concern in a seismic pier no steel reinforcing is needed.

The recommended mixture is 50% Portland cement and 50% sieved sand (see Uhrhammer et. al., 1997). After the concrete is poured it should be shaken to allow trapped bubbles to escape. The concrete will have sufficiently hardened to set up the sensor after

24 hours. However the pier may still generate spurious signals as the concrete cures which can take two to four weeks.

2.2.2 Vault Wall Decoupling

When setting up the forms for the concrete be sure to include a gap between the edge of the concrete and the walls of the vault. This decoupling of the pier from the vault wall is important because otherwise wind or other non-seismic forces acting on the walls can be transferred to the pier causing it to tilt or twist, obscuring the desired seismic signal. These signals are mostly long-period and so this is less critical for short-period installations.

2.3 Thermal Insulation

All broadband sensors are sensitive to temperature variations. Even at a very temperature-stable site, they must have some form of thermal insulation. Insulation serves to attenuate the ambient temperature variations, to isolate the sensor from drafts, and to localise and minimise air convection currents. We have repeatedly seen in our testing the critical importance of thermal insulation to long period noise performance with a variety of sensors and sites.

We recommend a five-sided box constructed using rigid polystyrene or polyisocyanuratic foam insulation. Rigid foam is more portable and not as messy as styrofoam peanuts or fibreglass batting. The insulation should be at least 2" thick. Depending on the temperature stability of the site, additional or thicker boxes may be used. Joints should be glued using polystyrene adhesive or polyurethane resin, taking care to leave no gaps for drafts to enter through. Alternatively, rigid foam insulation with foil on one side can be used. There are two advantages to this kind of foam: it has a higher insulation resistance, and the joints can be made using packing tape which is quicker and less messy than glue.

Adhesive 0.5" thick weatherstripping can be used to ensure a good seal between the bottom edge of the box and the pier. Be sure to cut a groove in the bottom of one edge of the box to allow the sensor cable to exit at the appropriate point.

Because thermal insulation boxes are so light it is important to hold it firmly in place with something heavy. A brick works well for this purpose.

Insulation boxes constructed of rigid foam must generally be constructed before visiting the site, but unfortunately they can be unwieldy to transport. In some cases, for example when a vault must be entered through a narrow doorway or for boreholes, other methods of thermal insulation will have to be considered.

2.4 Cable Design

See Appendix B for connector pinouts.

Sensor cables should be designed for good EMI shielding. This is most easily accomplished using double-shielded twisted-pair cable. The twisted pairs provide magnetic shielding, an inner shield grounded at the digitiser provides good electric field shielding, and a continuous outer shield provides good high-frequency RF shielding. The outer shield should be earthed at the digitiser for safety.

The digital ground (DGND) must be used for the return currents of the control signals (CAL_SIG, U_CALEN, V_CALEN, W_CALEN, UVW and ACC). Note that the analog ground (AGND) is connected to chassis ground (CHGND) inside Trillium, so if these signals are already connected at the digitiser, AGND should not be connected through the cable or else a ground loop will be created.

Chapter 3 Installation

Once the vault has been prepared, use the following procedures to install the Trillium. Provided at the end is a checklist for quality control at a typical installation.

3.1 Unpacking

Trillium is shipped in a very sturdy triple-wall coated cardboard box with custom-cut cushioning foam.

Open the box and set aside the user manual, maintenance kit and the top four layers of foam to completely expose the sensor. To minimize the possibility of damaging the sensor, do not remove it from the box until it is ready to be placed directly on the pier.

Be sure to save the foam in case the sensor needs to be shipped again.

3.2 Orientation and Levelling

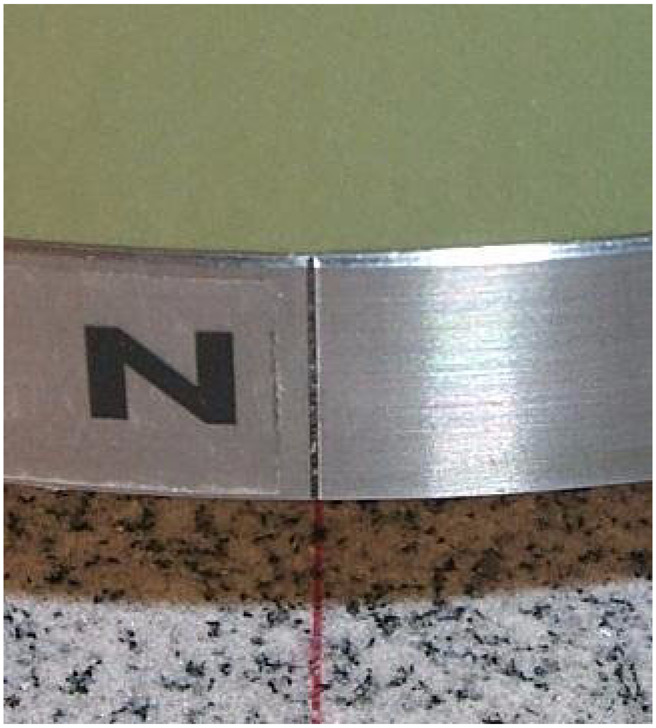
Two methods of alignment are possible with Trillium: vertically scribed marks on the north-south axis and 3/8" diameter holes on the east-west axis.

Levelling is accomplished using the three adjustable-height feet with lock nuts and the levelling bubble on the cover. The bubble accuracy is 0.5° per 2mm. While the sensor will operate properly with the bubble anywhere inside the black ring on the level, the bubble should be perfectly centred to avoid having to recentre the masses.

The simplest way to align Trillium is using the north-south marks. Draw a line on the pier parallel to north-south. Take Trillium out of its box and place it gently down on the pier aligned approximately to north-south. Unlock the feet as required to level the sensor, and then lock them again by threading the lock nut up until it engages firmly with the base. It may be necessary to hold the body of the levelling foot still while locking the nut to avoid disturbing the levelness of the sensor.

Now align the sensor precisely to north-south. It is very important to use the reflection of the line scribed on the pier in the sensor cover as an indication of misalignment and parallax. If the reflection of the pier line in the cover is at all curved, this is an indicator of parallax, i.e. you are not sighting the alignment marks from vertically above. If the pier line, its reflection, and the alignment marks in the base are not perfectly in line, then the sensor is misaligned (see Figure 3-1).

Figure 3-1 Good sensor alignment example



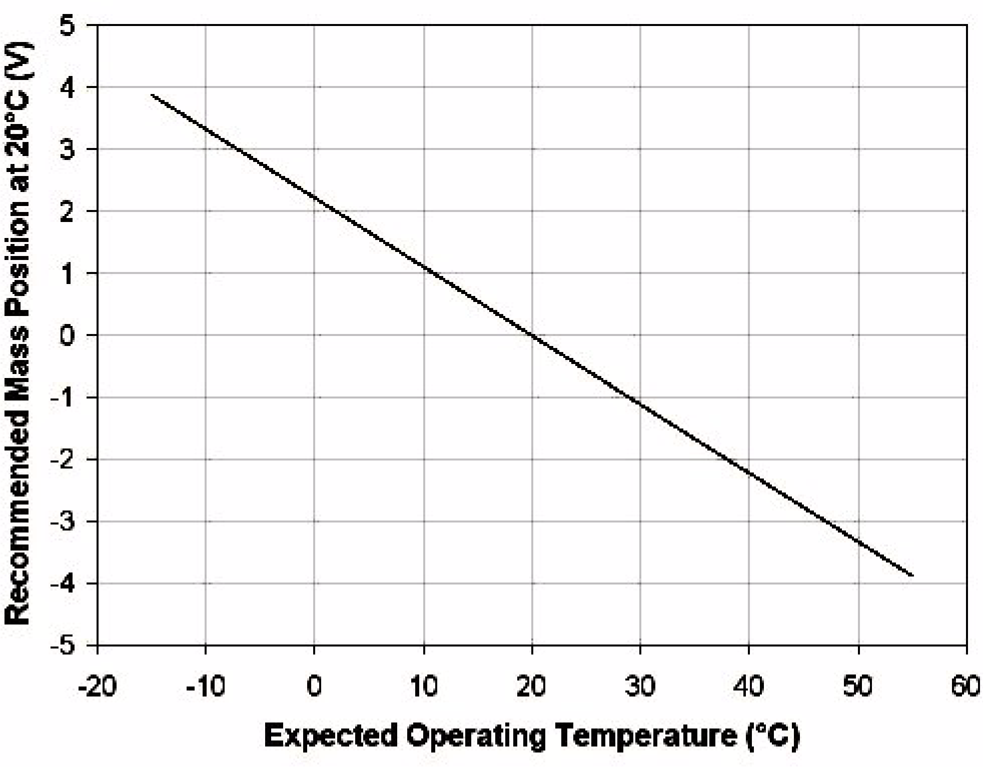
After aligning the sensor to north-south, you may find that the sensor may need to be relevelled and then realigned.

Note that for the most precise alignment possible two 3/8" diameter holes aligned to east-west are provided in the sensor base. However the north-south alignment marks will be precise enough for most installations.

3.3 Mass Centring (Optional)

The Trillium masses are centred at the factory at 20°C. If the sensor is level, it will operate over the range ±35°C (–15°C to 55°C) without recentring. If the sensor is not levelled accurately then the operational temperature range will be reduced. Different operating ranges can be achieved by recentring the masses at different temperatures. For example, to achieve operation from –20°C to 50°C the masses should be centred at 15°C, or set on an offset at 20°C so that it will be centred at 15°C. Use the graph in Figure 3-2 to determine the offset.

Figure 3-2 Mass position by expected operating temperature



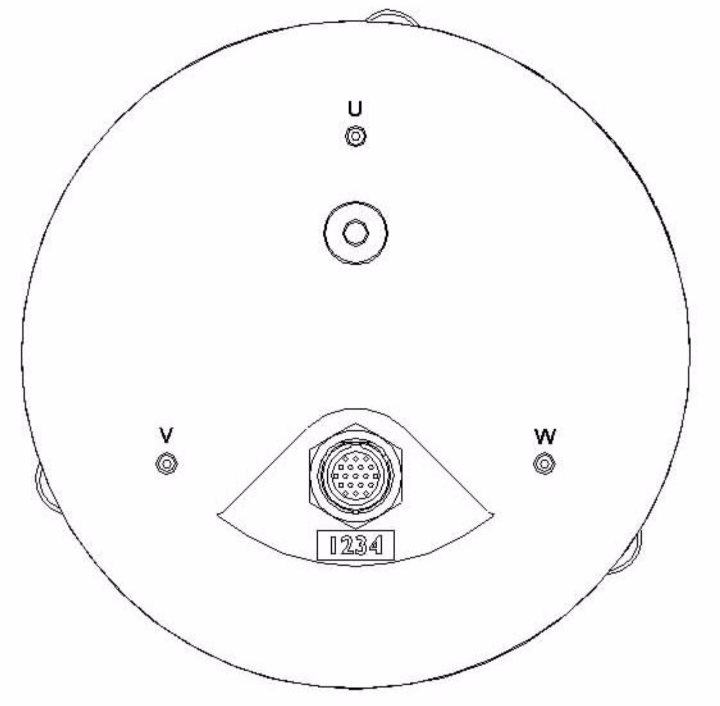
The clip level below the corner frequency will be reduced at the temperature extremes. For example, a mass position of 2V results in a reduction of clip level below the lower corner frequency which is 6dB lower than normal.

For these reasons, after temperature has stabilized in a new installation, it is good practice to physically recentre the boom. This maximizes the dynamic range of the sensor below the lower corner frequency.

This procedure is simple, requiring only a 1.5mm hex screwdriver with a long shaft (provided in the Trillium maintenance kit) and any 2.5mm hex wrench or screwdriver:

1. Wait at least 4 hours for the temperature of the sensor case to come to equilibrium with the temperature of the vault before performing this procedure.
2. Measure the voltage on the mass position outputs of the three sensor channels. This can be easily accomplished when the digitiser is a Trident, by using a laptop running the Nanometrics user interface. If the mass positions are all within the range ±0.4V, then there is no need for recentring; otherwise continue to step 3.
3. Set the sensor in short-period response mode by shorting the ACC control signal to ground. This is also easily done using the Trident user interface.

Figure 3-3 Mass position adjustment access screws



4. For each channel with a mass position greater than ±0.4 V, do the following:
   a) Locate the access seal screw corresponding to the channel of interest using Figure 3-3 as a guide.

Caution Do not remove more than one of the access seal screws at any one time.

   b) Using the 2.5 mm hex wrench, remove the appropriate seal screw. Inspect the O-ring for damage (for example, cuts or pitting), and get a replacement seal screw from the maintenance kit if the original seal screw appears to be damaged.
   c) Place the seal screw where it will remain clean while the mass is being centred.
   d) Insert the 1.5 mm hex screwdriver straight down the hole to where it engages with the screw head.
   e) Adjust the screw by small increments while monitoring the mass position outputs until it is less than ±0.2 V. Note that the adjustment sensitivity is approximately 1 turn = 1 volt.
   f) Using the 2.5 mm hex wrench, replace the seal screw. Be sure to tighten the screw until there is metal-to-metal contact to ensure a good airtight seal.

3.4 Sensor Cable

Install the sensor cable. The cable should be strain-relieved to the pier at some point close to the sensor. This can be accomplished with tie-wraps and tie-wrap anchors, or with a heavy object.

Ensure that the digitiser case is solidly earthed, and that the outer shield of the cable and the sensor case are thereby earthed.

3.5 Checklist

The following checklist can be used as an aid when installing Trillium:

☐ Pier is clear of debris

☐ Sensor is level

☐ Sensor is aligned to north

☐ Sensor feet are locked

☐ Sensor serial number is noted

☐ Cable is connected to the sensor and the digitiser

☐ Cable is strain-relieved to the pier

☐ Cable is not touching the sensor case

☐ Thermal insulation is in place

☐ Thermal insulation is not touching the sensor or cables

☐ Thermal insulation is weighted down

Chapter 4 Operation

This section gives operating parameters and instructions for Trillium.

4.1 External Connector

The Trillium connector is a 19-pin male military circular type hermetic connector. The pinout is given in Appendix B.

4.2 Power

Trillium can be powered from 9V to 36V. Under normal operation the power consumption is approximately 0.6W. On startup the power may briefly rise to 1W.

For very long cables, be sure to account for the resistive voltage drop due to the cable itself. For example 100m of 24AWG wire has a resistance of approximately 8.4Ω. Therefore on startup if the input voltage at the Trillium is 9V then the resistive drop due the peak current of 110mA will be 1.8V so the supply voltage must be at least 10.8V.

4.3 Output Signals

A control signal switches the Trillium output signal to either UVW output or XYZ output. The “natural” sensor output is UVW; in this mode the outputs represent the actual motion of the masses of the three sensor components. The “conventional” sensor output is XYZ; in this mode the outputs represent horizontal and vertical motion.

See Table 4-1 for the polarities of the XYZ outputs and their correspondence to the directions of the compass.

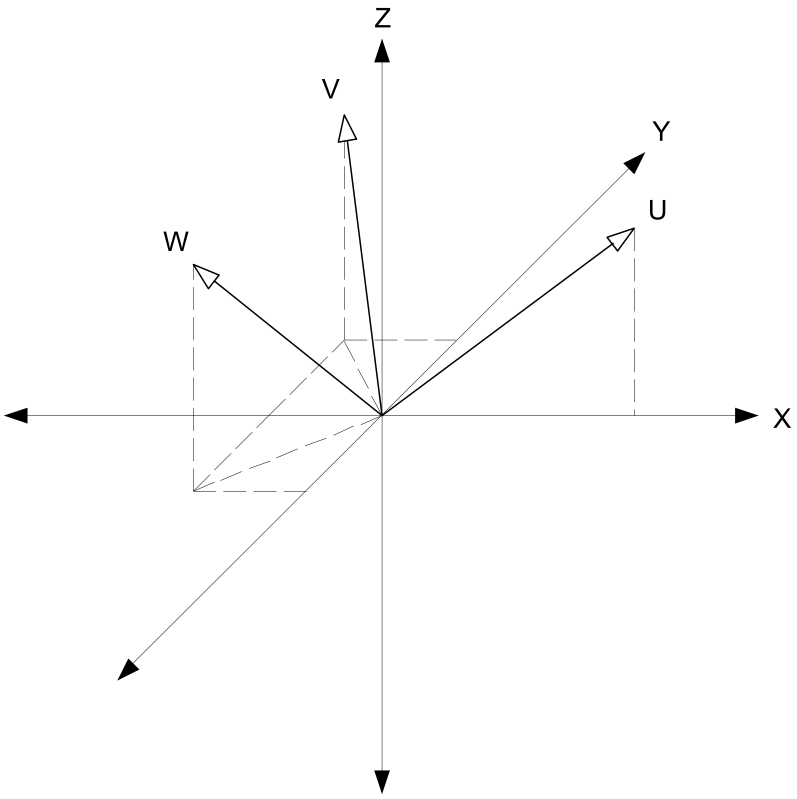
Table 4-1 Axis orientation and polarity of XYZ outputs

Axis	Orientation	Positive voltage represents ...
X	east-west	... case motion to east
Y	north-south	... case motion to north
Z	vertical	... case motion upwards

The UVW outputs are selected by shorting the UVW input to ground. If this input is left floating, then the XYZ outputs are selected.

To understand the difference between the UVW and XYZ outputs, refer to Figure 4-1. The sensor axes have been designed so that they are identical and so that the directions in which they sense motion are orthogonal. Furthermore the U axis was chosen to be aligned with the east-west axis when projected into the horizontal plane.

Figure 4-1 Sensor axis orientations



This arrangement results in the following transformation equations:

$$\begin{bmatrix} u \\ v \\ w \end{bmatrix} = \frac{1}{\sqrt{6}} \cdot \begin{bmatrix} 2 & 0 & \sqrt{2} \\ -1 & \sqrt{3} & \sqrt{2} \\ -1 & -\sqrt{3} & \sqrt{2} \end{bmatrix} \cdot \begin{bmatrix} x \\ y \\ z \end{bmatrix} \qquad \text{(EQ 1)}$$

$$\begin{bmatrix} x \\ y \\ z \end{bmatrix} = \frac{1}{\sqrt{6}} \cdot \begin{bmatrix} 2 & -1 & -1 \\ 0 & \sqrt{3} & -\sqrt{3} \\ \sqrt{2} & \sqrt{2} & \sqrt{2} \end{bmatrix} \cdot \begin{bmatrix} u \\ v \\ w \end{bmatrix} \qquad \text{(EQ 2)}$$

The first equation is implemented mechanically in the orientation of Trillium's individual sensor axes. The second equation is implemented electronically when Trillium is in XYZ mode.

Alternatively, seismic data may be digitised with Trillium in UVW mode and the transformation to horizontal and vertical signals implemented optionally when the data is processed. This allows for studies and calibrations where both UVW and XYZ data are required.

4.4 Frequency Response

The nominal poles (p_n), zeroes (z_n), normalization factor (k), and normalization frequency of the Trillium are shown in Table 4-2. These parameters define the transfer function according to this equation:

$$F(s) = S_{sensor} \cdot k \cdot \frac{\prod_n (s + z_n)}{\prod_n (s + p_n)} \left[\frac{V \cdot s}{m}\right] \qquad \text{(EQ 3)}$$

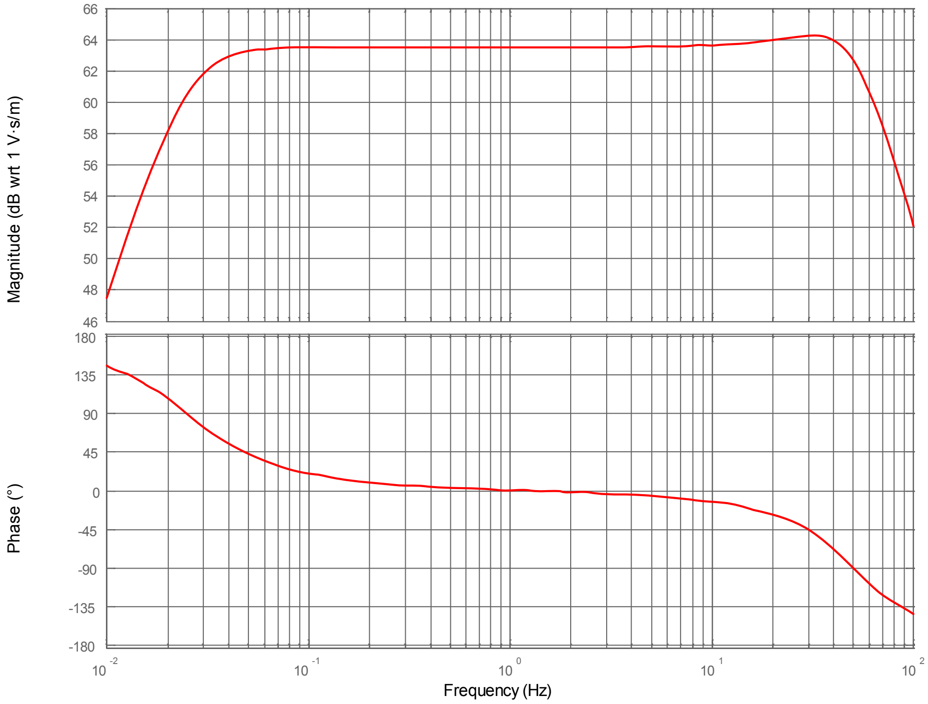
Table 4-2 Poles and zeroes

	Nominal values	Units
Zeroes	0 0 51.5	rad/s
Poles	–272 ±218i 56.5 –0.1111 ±0.1111i	rad/s
Normalization Factor	133310	
Normalization Frequency	1	Hz

The passband sensitivity is 1500 V·s/m.

The transfer function is approximately flat from 40 s to 50 Hz and rolls off at 40 dB/decade below the lower corner frequency, as shown in Figure 4-2.

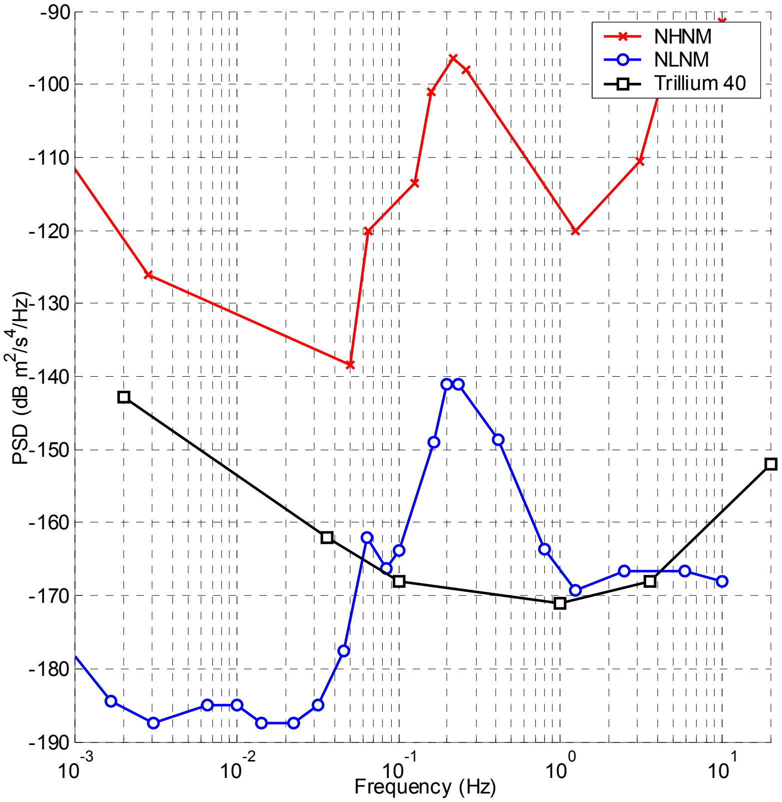
Figure 4-2 Nominal frequency response



4.5 Self-Noise

Typical Trillium self-noise is plotted in Figure 4-3. Curves indicating Peterson’s new high- and low-noise models are included for reference.

Figure 4-3 Self noise



4.6 Calibration

Calibration inputs are provided to allow for relative calibration of the sensor across frequency and over time.

Since Trillium is a symmetric triaxial sensor, calibration must be performed on the individual sensor axes (UVW) rather than the horizontal and vertical outputs (XYZ). Individual axis outputs can be digitized by placing the sensor in UVW mode. This mode is activated by shorting the UVW input to ground.

Each axis has a separate enable signal (U_CALEN, V_CALEN, W_CALEN) which is activated by shorting it to ground. All axes use a common input signal (CAL_SIG) which has a sensitivity of $0.010\,\mathrm{m/s^2/V}$.

4.7 State-Of-Health

Mass position outputs are provided to monitor the effect of tilt and temperature on the spring which sets the rest position of the boom. As with the calibration signals, they represent the state of the individual sensor axes (UVW) rather than the horizontal and vertical outputs (XYZ). The mass positions are zeroed at the factory at room temperature with Trillium perfectly level.

These outputs can be used to infer how much power the integrator is consuming to centre the boom, as well as whether the clip level of the instrument below the lower corner frequency is being reduced significantly. If the mass positions are all within the range ±0.4V, then there is no need for recentring. Otherwise follow the procedure in section 3.3 “Mass Centring (Optional)” on page 8.

4.8 Troubleshooting

4.8.1 Fuse Replacement

The Trillium electronics on earlier models (up to serial number 179) are protected by a replaceable input fuse. Replacement fuses are provided in the maintenance kit that was shipped with the sensor. (Newer models—serial number 180 and higher—have a self-resetting fuse that does not need to be replaced.)

The simplest way to check if the fuse is blown is to apply 12V across the input terminals using a power supply with a built-in current meter. If no current is drawn by the sensor then the fuse needs to be replaced.

Since broadband seismometer mechanics are very sensitive to the presence of contamination such as dust, Trillium is assembled in a cleanroom environment.

- Fuse replacement should be performed in a cleanroom. If one is not available, return the sensor to the factory for maintenance.
- There is a desiccant inside the sensor case which must be replaced after exposure to moisture in the atmosphere. To limit exposure to moisture, fuse replacement must be done quickly, no more than 15 minutes total.

To replace the fuse:

1. Remove the connector jam nut.
2. Remove the 3 screws in the top of the cover. Inspect the O-rings for cuts or pitting and set them aside. Make sure the circuit board drops a short distance down onto 3 standoffs (not yet visible).
3. With the sensor standing on its feet at the edge of a benchtop, remove the 12 screws which fasten the base to the cover. Carefully lift the cover straight up.
4. The fuse is located beside the main connector. Using needle-nose pliers remove the blown fuse and insert the new one.
5. Inspect the connector and base O-rings for damage and make sure they are seated correctly.
6. Carefully lower the cover over the mechanics and electronics. Again with the sensor at the edge of a benchtop, thread the 12 base screws finger tight only. At this point it may be desirable to turn the sensor upside-down to make it easier to torque the screws so that the base O-ring is fully compressed.
7. Use the 3 cover screws to pull the electronics up against the inside of the cover and then tighten them until metal-to-metal contact is felt.
8. Replace the connector jam nut.

Apply power to the sensor and check that the current stays below 125 mA. When the sensor is level the power should be 0.6 W.

If the problem persists contact Nanometrics support (see Chapter 1, “Introduction”).

Appendix A Specifications

This section lists the specifications of Trillium.

Table A-1 Performance specifications

Parameter	Specification
Midband Generator Constant	1500 V·s/m
Clip Level	16 V peak-to-peak differential
Lower Corner Frequency	0.025 Hz
Lower Corner Damping relative to Critical	0.707
Upper Corner Frequency	50 Hz

Table A-2 Operation specifications

Parameter	Specification
Measurement Axis Orientation	symmetric triaxial
Output Axis Orientation	vertical, north, east
Displacement Transducer Type	capacitive
Feedback Type	coil-magnet
Mass Lock	none required
Mass Centring	optional manual
Calibration Enable	separate UVW enables
Control Inputs	open-drain active-low

Table A-3 Physical specifications

Parameter	Specification
Base Diameter	22 cm
Maximum Height Including Feet	18 cm
Total Weight	11 kg
Connector	19-pin military circular

Table A-4 Power specifications

Parameter	Specification
Input Voltage Range	9V to 36V
Maximum Power Consumption (when level)	0.6W
Overvoltage Protection	included
Short-circuit Protection	0.125A fuse (replaceable) 0.3A fuse (self-resetting)
Reverse Voltage Protection	series diode

Table A-5 Environmental specifications

Parameter	Specification
Operating Temperature Range	–20°C to 50°C
Operating Range Without Recentring	±35°C

Appendix B Connector Pinout

The Trillium connector is a 19-pin male military circular type hermetic connector. The pinout is given in Table B-1.

Table B-1 Connector pinout

Pin	Name	Function	Type
L	Z+/W+	vertical (W axis) output	16 V peak-to-peak differential
M	Z–/W–		
N	Y+/V+	north/south (V axis) output	
A	Y–/V–		
P	X+/U+	east/west (U axis) output	
B	X–/U–		
T	CAL_SIG	calibration signal input	13.6 kΩ input impedance
K	U_CALEN	calibration enable inputs	active-low open-drain
J	V_CALEN		
U	W_CALEN		
E	U_MP	mass position outputs	±4.5 V single-ended
F	V_MP		
S	W_MP		
V	AGND	analog ground	N/A
H	+PWR	power input	9 V to 36 V DC isolated
G	–PWR	power return	
D	UVW	enable single-ended UVW instead of differential XYZ outputs	active-low open-drain
C	ACC	enable short-period response for testing and mass centring	
R	DGND	digital ground	N/A
shell	CHASSIS	for shielding and safety	N/A

Appendix C Generic Sensor Cable

A generic sensor cable may have been shipped with your sensor. Table C-1 is the wiring key for the standard cable (Nanometrics part number CBL13942R2). This table can be used as a reference when wiring the generic sensor cable end to a digitiser connector.

Note If you are using the earlier version of the generic sensor cable (Nanometrics part number CBL13942R1), refer to Table C-2 for the wiring of the XYZ/UVW ± outputs; these are in inverse order to the standard cable. The rest of the wiring is the same as for CBL13942R2 shown in Table C-1.

Table C-1 Generic sensor cable wiring for CBL13942R2

From			To			Wire	Run
Conn	Pin	Name	Conn	Pin	Name	Colour	
P1	L	Z+/W+	P2		CH1+	RED	1
P1	M	Z–/W–	P2		CH1–	BLK	1
P1			P2		CH1 GND	DRAIN	1
P1	N	Y+/V+	P2		CH2+	WHT	2
P1	A	Y–/V–	P2		CH2–	BLK	2
P1			P2		CH2 GND	DRAIN	2
P1	P	X+/U+	P2		CH3+	GRN	3
P1	B	X–/U–	P2		CH3–	BLK	3
P1			P2		CH3 GND	DRAIN	3
P1	T	CAL_SIG	P2		CAL1+	BLU	4
P1	U	W_CALEN	P2		CAL1–/CTRL4	BLK	4
P1		SHELL	P2		SHELL	DRAIN	4
P1	J	V_CALEN	P2		CAL2–/CTRL5	YEL	5
P1	K	U_CALEN	P2		CAL3–/CTRL6	BLK	5
P1		SHELL	P2		SHELL	DRAIN	5
P1	S	W_MP	P2		EXT_SOH1	BRN	6
P1	F	V_MP	P2		EXT_SOH2	BLK	6
P1		SHELL	P2		SHELL	DRAIN	6
P1	E	U_MP	P2		EXT_SOH3	ORG	7

Table C-1 Generic sensor cable wiring for CBL13942R2 (Continued)

From			To			Wire	Run
Conn	**Pin**	**Name**	**Conn**	**Pin**	**Name**	**Colour**	
P1	V	AGND	P1		CH1 GND	BLK	7
P1		SHELL	P2		SHELL	DRN	7
P1	H	+BAT	P2		SEN +12V	RED	8
P1	G	–BAT	P2		SEN RTN	WHT	8
P1		SHELL	P2		SHELL	DRAIN	8
P1	D	UVW	P2		CTRL1	RED	9
P1	C	ACC	P2		CTRL2	GRN	9
P1	R	DGND	P2		DGND	DRAIN	9
P1		SHELL	P2		SHELL	BRAID	

Table C-2 Generic sensor cable wiring for XYZ/UVW ± outputs of CBL13942R1

From			To			Wire	Run
Conn	**Pin**	**Name**	**Conn**	**Pin**	**Name**	**Colour**	
P1	L	Z+/W+	P2		CH1+	BLK	1
P1	M	Z–/W–	P2		CH1–	RED	1
P1			P2		CH1 GND	DRAIN	1
P1	N	Y+/V+	P2		CH2+	BLK	2
P1	A	Y–/V–	P2		CH2–	WHT	2
P1			P2		CH2 GND	DRAIN	2
P1	P	X+/U+	P2		CH3+	BLK	3
P1	B	X–/U–	P2		CH3–	GRN	3
P1			P2		CH3 GND	DRAIN	3