Trillium 240 Seismometer

User Guide

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Chapter 1 Introduction

Trillium Model 240 is a three-component, very broadband low-noise seismometer suitable for portable and fixed applications. Its extended low frequency range useful out to beyond 1000 seconds, low noise, and wide dynamic range make it ideal for teleseismic studies as well as for regional and local events.

The Trillium 240 has an internal fully-automatic mass recentring capability, which facilitates both local and remote recentring.

Trillium seismometers have a symmetric triaxial arrangement of the sensing elements. The use of three identical axis elements ensures the same frequency response for vertical and horizontal outputs, is less susceptible to rapid changes in temperature, and guarantees true orthogonality of the three outputs.

Data output of XYZ or UVW can be selected remotely, allowing calibration of the elements independently of the electronics. UVW data may also be used instead of XYZ for seismic signal recording, if desired.

Please read the appropriate sections of this manual before transporting, storing, installing, or operating the Trillium 240. 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. Before returning a unit for repair, contact Nanometrics Support to obtain an RMA number.

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

Chapter 2 Preparation

This chapter provides general preinstallation guidelines for the Trillium 240. These guidelines are intended to help achieve the best possible performance, but some guidelines may not be applicable for all types of site or study.

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 tall structures.

2.2 Pier construction

It is recommended that piers be rectangular (rather than round) whenever possible. Rigid foam thermal insulation boxes can be made to fit a rectangular pier more easily.

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; http://www.orfeus-eu.org/wg/wg2/guidelines/guidelines.htm). 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. These forces may cause the pier to tilt or twist and obscure the desired seismic signal. These signals are mostly long period, so vault wall decoupling is critical for quiet site long period studies.

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 localize and minimize 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 wrapping a layer of fibreglass batt insulation around the Trillium 240, and then installing a rigid foam insulation box. See Section 3.5, “Installing the thermal insulation,” on page 7.

2.4 Cable design

Cable design guidelines:

- 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 digitizer provides good electric field shielding, and a continuous outer shield provides good high-frequency RF shielding.
- The outer shield should be earthed at the digitizer for safety.
- The digital ground (DGND) must be used for the return currents of the control signals (U_CALEN, V_CALEN, W_CALEN, UVW/TX and MC/RX).
- The analog ground (AGND) must be used for the return currents of the analog signals (CAL_SIG, U_MP, V_MP, and W_MP).
- Note that AGND is connected to chassis ground (CHGND) inside the Trillium 240, so if these signals are already connected at the digitizer, AGND should not be connected through the cable or else a ground loop will be created.

See Appendix B for connector pinouts.

Chapter 3 Installation

Once the vault has been prepared, use the procedures described in this chapter to install the Trillium 240. Section 3.7 on page 11 provides a generic installation checklist.

3.1 Unpacking

Trillium 240 is shipped in a very sturdy triple-wall coated cardboard box with custom-cut cushioning foam.

- 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.
- Save the box and foam in case the sensor needs to be shipped again.

3.2 Optional thermal insulation

To maximize long period performance, we recommend wrapping fibreglass batt insulation around and under the Trillium 240, and then installing a rigid foam insulation box. For some installations, one or the other will be sufficient, or may not be required.

3.3 Orientation and levelling

Two methods of alignment are possible with the Trillium 240: vertically scribed marks on the East-West axis, and 5/16" diameter holes on the North-South axis. To level the Trillium 240, use the three adjustable-height feet with lock nuts and the levelling bubble on the cover.

For the most precise alignment possible two 5/16" diameter holes aligned to North-South are provided in the sensor base, into which 5/16" alignment rods can be fitted. However the East-West alignment marks will be precise enough for most installations. See Appendix D for top and bottom views of the Trillium 240 showing the relative orientation of the East-West and North-South alignment features.

1. Draw a line on the pier parallel to East-West.

   The East-West line (or North-South line, if you are using the alignment rods) drawn on the pier must be aligned to true East (North). If you are using a magnetic compass, account for the local magnetic declination when drawing the line.

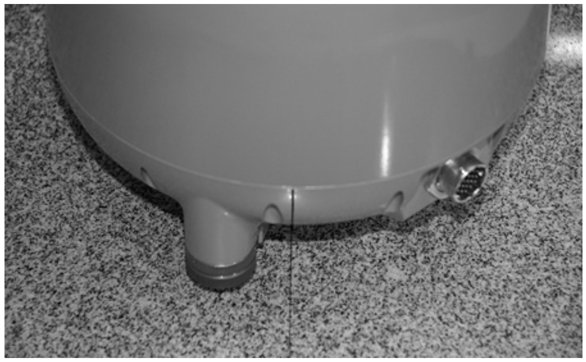
Caution Fibreglass insulation may irritate skin. Use gloves when handling fibreglass batt insulation.

2. Optional: Prepare the bottom layer of thermal insulation (Figure 3-1). This is to eliminate air currents between the pier and the underside of the Trillium 240.
   a) Place a layer (approximately 1" or 3 cm) of fibreglass batt insulation flat on the pier. The insulation should be thick enough to take up the air gap but should not be tightly compressed once the sensor is installed.
   b) Make holes in the insulation, spaced to accommodate the Trillium 240 levelling feet.

Figure 3-1 Fibreglass batt insulation under the Trillium 240

3. Take the Trillium 240 out of its box and place it gently down on the pier aligned approximately to East-West. The West marker line on the Trillium 240 base is the one just to the left of the sensor connector (Figure 3-2).
   - Ensure that no insulation is caught under the levelling feet of the sensor. All three levelling feet must rest directly on the surface of the pier.
4. 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. Note that the locknut has a mechanical stop that prevents it from loosening more than a third of a turn. 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.
   - Extend the levelling feet as little as possible to achieve a level sensor. Keep at least one of the feet (two, if possible) retracted fully into the sensor base.
5. Align the sensor precisely to East-West by aligning the line drawn on the pier with the vertical East-West lines on the base (Figure 3-2). Some care is required to avoid sighting at an angle and introducing a parallax error. (Pull the insulation back as required to see the alignment line on the pier.)
6. After you have aligned the sensor to East-West, the sensor may need to be relevelled due to unevenness in the pier. While the sensor will operate properly with the bubble anywhere inside the black ring on the level, the bubble should be centred as precisely as possible to ensure the Z output is measuring true vertical motion.
7. Check the alignment again after levelling.

Figure 3-2 Example of good sensor alignment



3.4 Installing the sensor cable

1. Connect the sensor cable. The cable should be strain-relieved to the pier at some point close to the sensor. Strain relief can be accomplished with tie-wraps and tie-wrap anchors, or with a heavy object.
2. Ensure that the digitizer case is solidly earthed, and that the outer shield of the cable and the sensor case are thereby earthed.

3.5 Installing the thermal insulation

3.5.1 Optional: Install the fibreglass batt insulation

Caution Fibreglass insulation may irritate skin. Use gloves when handling fibreglass batt insulation.

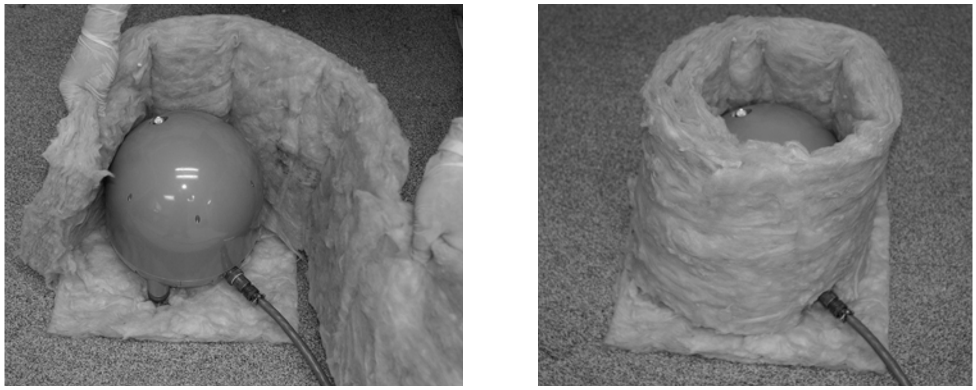
The Trillium 240 should be wrapped lightly on the sides and bottom (but not the top) with fibreglass batt style insulation (usually pink or yellow in colour). This eliminates residual convection air currents around the sensor which can disturb long period performance. The insulation works best when it is not tightly compressed, and when it is snugly but not tightly fitted around the sensor (see Figure 3-3).

- Wrap a layer of approximately 2" (5 cm), about 12" (30 cm) wide by 3' (1 m) long snugly around the Trillium 240, forming a vertical “pipe”. The fibreglass will adhere to itself at the overlap, so no adhesive or tape is needed to keep it in place.

  The fibreglass pipe should be snug enough so that there are no air gaps between the insulation and the sides of the sensor, but loose enough that it can be slid up off the sensor or replaced by sliding down over the sensor easily, without using force.

  - Do not cover the top, to ensure heat can be dissipated properly through the top of the sensor.

Figure 3-3 Wrapping the Trillium 240 with fibreglass batt insulation



3.5.2 Install the rigid foam insulation box

For the outer layer of insulation, we recommend a five-sided box constructed using rigid polystyrene or polyisocyanuratic foam insulation. Alternatively, rigid foam insulation with foil on one side can be used. There are two advantages to the foil-coated foam: it has a higher insulation resistance, and the joints can be made using packing tape which is quicker and less messy than glue.

Recommendations for constructing the thermal insulation box:

- Use insulation that is at least 2" (5 cm) thick. Depending on the temperature stability of the site, additional or thicker boxes may be used.
- Make the insulation box large enough that it is not touching the sensor, cables, or fibreglass insulation.
- Cut a groove in the bottom of one edge of the box to allow the sensor cable to exit at the appropriate point.
- Seal the box joints properly:
  - For rigid foam without a foil coating, glue the joints using polystyrene adhesive or polyurethane resin, taking care to leave no gaps.
  - For rigid foam with a foil coating, you can tape the joints with packing tape, taking care to leave no gaps.
- Ensure there is a good seal between the bottom edge of the box and the pier. Adhesive 0.5" (1.25 cm) thick weatherstripping can be used to ensure a good seal.
- Ensure the thermal insulation box is held firmly in place by setting a weight on top of the box. A brick works well for this purpose.

3.6 Mass centring

The Trillium 240 has an automated mechanical mass centring capability that uses a precision stepper motor to centre the boom of the pendulum of each axis exactly at the null point. The motor adjusts the tension on the spring which supports the boom, to compensate both for tilt from absolute level and for the ambient temperature in which the unit is operating.

As well, the sensor automatically recentres the masses electronically to compensate for gradual changes in temperature, up to a range of ±10°C difference from when mechanical mass centring was last initiated.

3.6.1 Tilt tolerance

The Trillium 240 is designed to tolerate a tilt within the range ±1° of level. If the unit is tilted beyond this range the mass centring may not be able to recentre the booms and the unit will not operate correctly.

3.6.2 Mechanical mass centring

The operation of mass centring typically takes less than 1 minute. It may take up to 5 minutes if the unit is compensating for substantially different tilt than it had when it was last centred.

3.6.2.1 Choosing when to initiate mass centring

- While mass centring can be done immediately after installing and levelling the Trillium 240, it is best to initiate mass centring again at least 6 hours after installation, when the temperature has fully equalized. This ensures the unit will then be able to tolerate up to ±10°C range variation in ambient temperature without requiring recentring.

  It is best to initiate mechanical mass centring when the ambient temperature is roughly in the centre of its expected range, rather that at one extreme or the other, to make the most of the usable 20°C range the unit can tolerate without mechanical recentring.
- Mass centring should only be done when interruption of good-quality seismic data can be tolerated, as there are temporary effects on the output signal. When the mass centring motors are operating, the sensor's transfer function is set to a "short period" mode, and the motion of the boom during the recentring is very evident in the output signal. When the mass centring operation is complete, the sensor reverts to the mode it was in before mass centring was initiated (generally "long period" mode). At this time, there may be a transient superimposed on the output signal that takes some minutes to decay.
- To determine whether mass centring needs to be done you can check the voltage readings on the mass position outputs for each of the three sensor channels (signals U_MP, V_MP, and W_MP, referenced to AGND):
  - If the values are outside the ±3.5V range the sensor may not be able to report seismic signals properly. For this condition, mass centring must be done.
  - If the values are within the range ±3.5V but not within ±2V range the sensor is sufficiently centred that it will report seismic signals properly. However, it is strongly recommended the masses be recentred.
  - If the values are within the range ±2V but not within the ±0.3V range the sensor is sufficiently centred that it will report seismic signals properly. However, the closer the mass positions are to 0V, the more room there is to tolerate further ambient temperature changes. For this condition, centring the masses is recommended if it is convenient to do so.

- If the mass positions are all within the range ±0.3V there is no need to recentre, although it can be done if desired.

3.6.2.2 How to initiate mass centring

You can initiate mass centring using either of these two methods:

- Pull the MC/RX pin high for at least 1 second (referenced to DGND).
- Issue a `Center` command using the RS-232 digital interface (see Section 4.9 on page 20).

3.6.3 Continuous electronic mass recentring

Continuous electronic mass recentring compensates for gradual changes in temperature, up to a range of ±10°C difference from when mechanical mass centring was last initiated. If the temperature changes more than 10°C, the unit may need to be mechanically mass centred.

3.6.3.1 Mass recentring status

The mass position status is reported via analog signals U_MP, V_MP, and W_MP, referenced to AGND (pins E, F, S, and V respectively) which operate roughly in the range ±4V. A 0V signal means the axis boom is perfectly centred. A signal exceeding ±2V indicates mechanical mass recentring should be initiated. These signals respond very slowly to changes in tilt, mass position, or temperature when the sensor is in the normal operating "long period" mode, but respond almost instantly (within a second) when the sensor is set to "short period" mode.

The mass position status is also reported digitally via the RS-232 serial interface (see Section 4.9 on page 20).

3.6.4 Mass centring procedure

When using a Nanometrics digitizer such as a Taurus or Trident that is connected to a network, you can read the mass position status and initiate mass centring remotely. For the Taurus, use options in the Sensor page either locally or on an external browser. The Taurus also provides a mass auto-centring feature. For the Trident, use options on the Nanometrics UI Trident > Operation > Instrument page, or use NaqsView.

1. Install and level the Trillium 240 as precisely as possible.
    - For best results, centre masses immediately after installing and levelling the Trillium 240, and again at least 6 hours after installation when the temperature has fully equalized. This ensures the unit will then be able to tolerate up to ±10°C range variation in ambient temperature without requiring recentring.
2. Check the voltage readings on the mass position outputs for each of the three sensor channels (signals U_MP, V_MP, and W_MP, referenced to AGND) to determine whether mass centring needs to be done (Table 3-1).

Table 3-1 Mass position output voltage indicating need for mass centring

Mass position output voltage	Need to centre the masses?
outside the ±3.5V range	yes
within the range ±3.5V but not within ±2V range	strongly recommended
within the range ±2V but not within the ±0.3V range	recommended, if it is convenient
mass positions are all within the range ±0.3V	no, although it can be done if desired

3. Initiate mass centring by pulling the MC/RX pin high, referenced to DGND (pin R), for at least 1 second.

   This will initiate mass centring on all three axes in sequence—first axis U, then V, then W. The time for the operation to complete varies from a few seconds to at most 5 minutes, but is typically less than 1 minute.

4. Observe the voltage readings on the mass position outputs to confirm they are now within the ±0.3V range.

   Note that the sensor is temporarily put into "short period mode" during the centring operation, and the previous mode is automatically restored when the centring operation is complete.

3.7 Installation checklist

This checklist can be used as an aid when installing Trillium 240:

- ❑ Pier is clear of debris
- ❑ Sensor is level
- ❑ Sensor is aligned to North-South or East-West
- ❑ Sensor feet are locked
- ❑ Sensor serial number is noted
- ❑ Cable is connected to the sensor and the digitizer
- ❑ Cable is strain-relieved to the pier
- ❑ Cable is not touching the sensor case
- ❑ Thermal insulating box and fibreglass insulation are in place
- ❑ Thermal insulating box is not touching the sensor, cables, or fibreglass insulation
- ❑ Thermal insulating box is weighted down
- ❑ Masses are centred after temperature equalization (at least 6 hours post-installation)

Chapter 4 Operation

This chapter provides operating parameters and instructions for the Trillium 240.

4.1 External connector

The Trillium 240 connector is a 19-pin male military circular type hermetic connector. The pinout is given in Appendix B.

4.2 Sensor power

The Trillium 240 can be powered using a DC source that can sustain 9 V to 36 V at the sensor connector. Voltage drops over the cable must be accounted for, and so the supply voltage at the source may need to be higher.

In normal operation (the sensor is level and well centred, there is a low seismic signal, the sensor has settled for at least 30 minutes, and serial transmit is disabled) the power consumption is typically 650 mW. On startup, the peak power surge may be up to 4.5 W briefly. Power consumption above normal quiescent after the initial power on in-rush is roughly proportional to the output signal. If the sensor is not centred or has not yet settled, the output signals will be at the maximum, and power consumption may be as high as 3 W. For a settled, centred, and level sensor, a seismic signal that approaches the sensor's maximum clip level may draw as much as 2 W peak (the average power consumption would be much lower).

The mass centring operation will draw additional power, up to an incremental 2 W while the motors are operating.

- For long cables, be sure to account for the resistive voltage drop due to the cable itself. For example, 50 m of 24 AWG wire has a resistance of 4.2 Ω in each direction. Therefore the voltage drop due to the possible 500 mA startup in-rush at 9 V would be 4.2 V, and the power supply such be able to briefly supply 13.2 V for this length of cable. The supply should also be able to sustain a 2 W peak output at a voltage that guarantees the sensor receives 9 V. For the 50 m cable example, the peak current would be 220 mA at 9 V, and the voltage drop would be 1.9 V, so the supply must be able to provide 220 mA at 10.9 V to reliably power the sensor for maximum seismic signals when using a 50 m cable.

4.3 Control signals

Trillium 240 has 5 digital control inputs: MC/RX, UVW/TX, U_CALEN, V_CALEN and W_CALEN.

All of these inputs are optically isolated from both the input voltage and the output and calibration input signals. Therefore, signals applied to these pins must be referenced to DGND rather than ±PWR or AGND.

All of these inputs are active-high. Specifically, any voltage greater than 3.5 V at a current greater than 0.1 mA enables the relevant functionality while any voltage less than 1 V or a high impedance disables it. All inputs can tolerate at least ±15 V except for UVW/TX which can tolerate voltages from –7 V to +15 V.

4.4 Output signals

The sensitivity specified in Table 4-2 on page 16 assumes an infinite input impedance at the digitizer. For digitizers with low input impedance it will become necessary to account for the fact that source impedance of the differential outputs is 300 Ω ±1% (150 Ω each output).

A control signal switches the Trillium 240 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

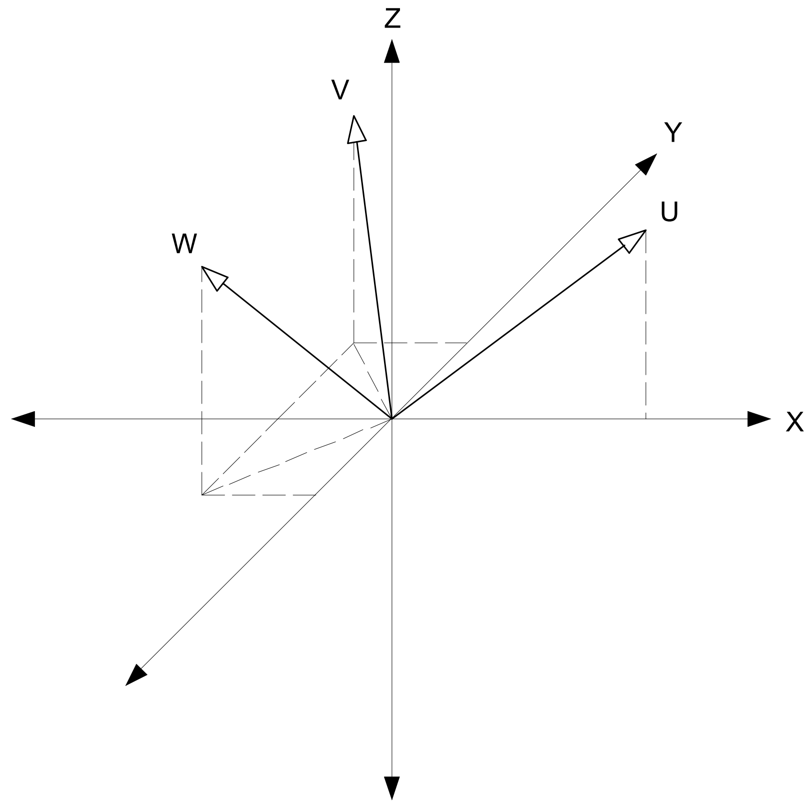
Axis	Orientation	Positive voltage represents ...
X	east-west	... case motion to east
Y	north-south	... case motion to north
Z	vertical	... case motion upwards

- To select the sensor outputs:
  - To select the UVW outputs, pull the UVW/TX pin high.
  - To select the XYZ outputs, either leave the UVW/TX pin floating or set it to 0 V.

  The sensor responds to changes on this control line within 4 seconds. Note that this input control signal is disabled when the sensor is transmitting on the serial port, since this pin is then used as the RS-232 serial TX output signal. (See Section 4.9, "Connecting and configuring the serial port," on page 20.)

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. 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 the Trillium 240's individual sensor axes. The second equation is implemented electronically when the Trillium 240 is in XYZ mode.

Alternatively, seismic data may be digitized with the Trillium 240 in UVW mode and the transformation to horizontal and vertical signals implemented optionally when the data are processed. This allows for studies and calibrations where both UVW and XYZ data are required.

4.5 Frequency response

The frequency response of the Trillium 240 can be measured using the calibration coil. The measured response is the product of the calibration system's (first-order low pass) response and the sensor's own response. The nominal Trillium 240 response is obtained by dividing the nominal sensor calibration result by the calibration system's transfer function; the three frequency response functions are shown in Figure 4-2. The calibration system's low-pass response cancels the zero at –161 rad/s in the sensor's transfer function when the sensor frequency response is measured using the calibration coil.

The nominal poles (p_n), zeroes (z_n), normalization factor (k), and normalization frequency of the Trillium 240 are shown in Table 4-2. These parameters define the transfer function according to this equation:

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

Where the normalization factor is defined as follows:

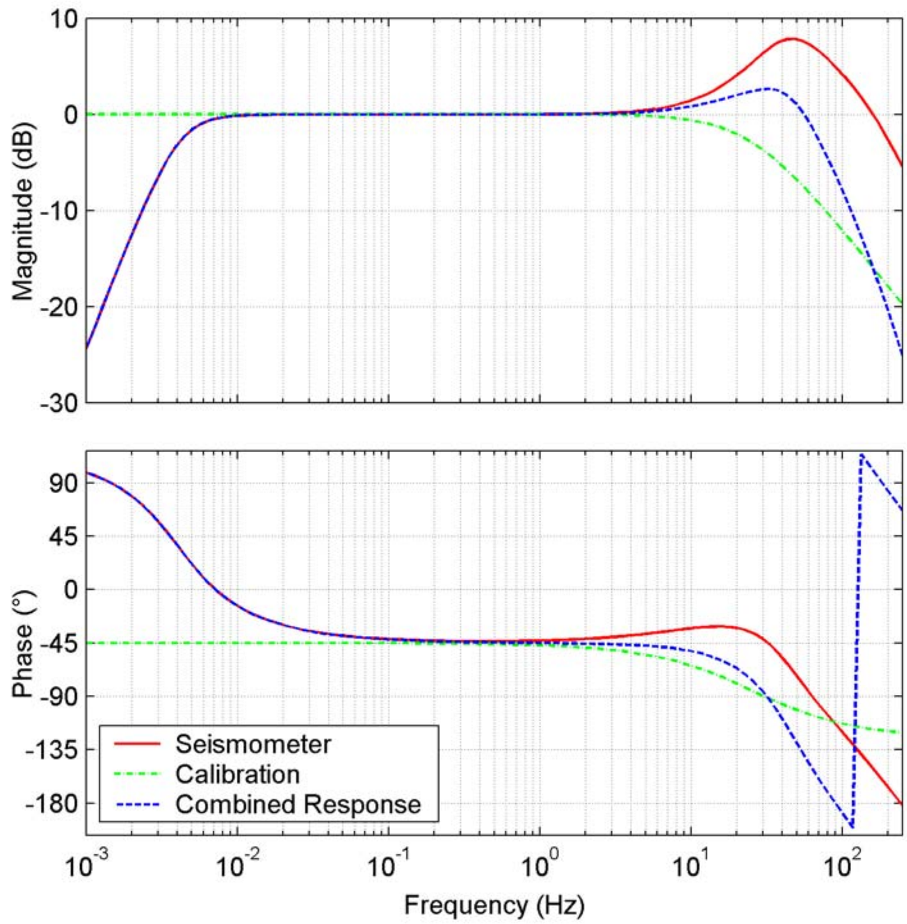
$$k = \frac{1}{\left| \frac{\prod_n (i \cdot 2 \cdot \pi \cdot f_0 + z_n)}{\prod_n (i \cdot 2 \cdot \pi \cdot f_0 + p_n)} \right|} \qquad \text{(EQ 4)}$$

Table 4-2 Poles and zeroes

	Parameter	Nominal values	Units
z_n	Zeroes	0 0 –108 –161	rad/s
p_n	Poles	–0.01815 ±0.01799i –173 –196 ±231i –732 ±1415i	rad/s
k	Normalization factor	2.316 x 10^9	
S_{sensor}	Passband sensitivity at 1 Hz	1196.5	V·s/m
f_0	Normalization frequency	1	Hz

The transfer function is approximately flat out to 240 s and rolls off at 40 dB/decade below the lower corner frequency, as shown in Figure 4-2.

Figure 4-2 Nominal frequency response



4.6 Self-noise

Typical Trillium 240 self-noise is plotted in Figure 4-3. Three curves are included for reference: Peterson's new low-noise model (NLNM) and new high-noise model (NHNM), and McNamara and Buland's PDF Mode Low Noise Model (MLNM).[1] The noise floor shown is the typical level of instrument self-noise assuming proper installation. To achieve best performance for any sensor, meticulous attention to detail must be paid to choice of site, vault design, and sensor installation. The New Manual of Seismological Observatory Practice (IASPEI 2002) has a good discussion of the relevant

1. See also:

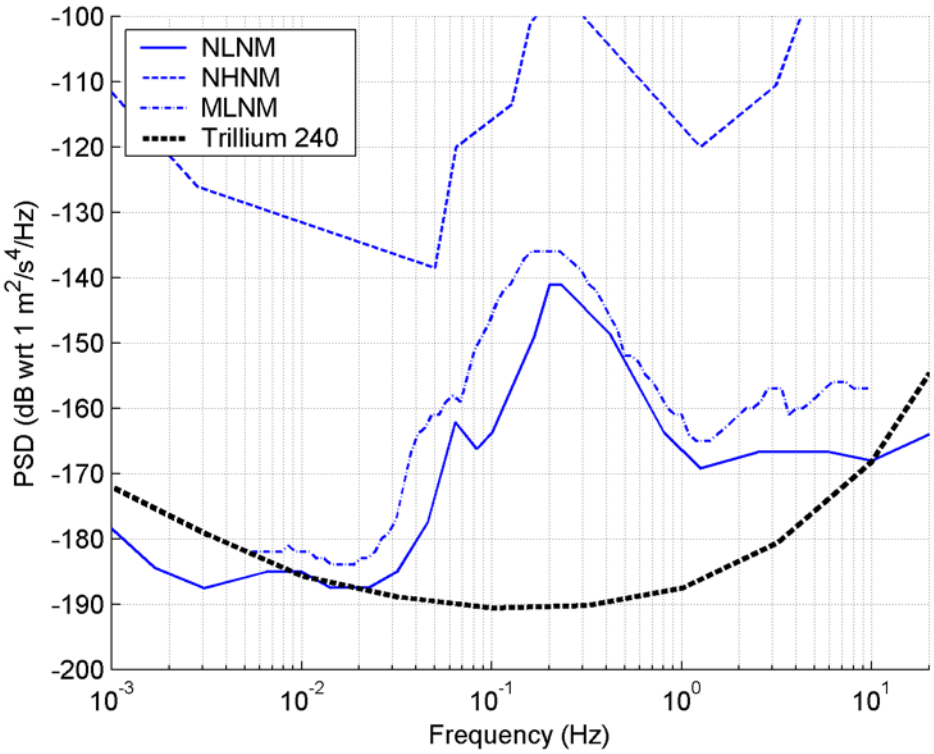
Peterson, J. (1993). *Observations and Modeling of Seismic Background Noise.* Open-file report 93-922, U. S. Geological Survey.

McNamara, D.E., and R. P. Buland (1994). Ambient Noise Levels in the Continental United States. *Bull. Seism. Soc. Am.*, **94**, 1517–1527.

Clinton, J. F., and T. H. Heaton (2002). Potential Advantages of a Strong-motion Velocity Meter over a Strong-motion Accelerometer. *Seism. Res. Lett.*, **73**, 332–342.

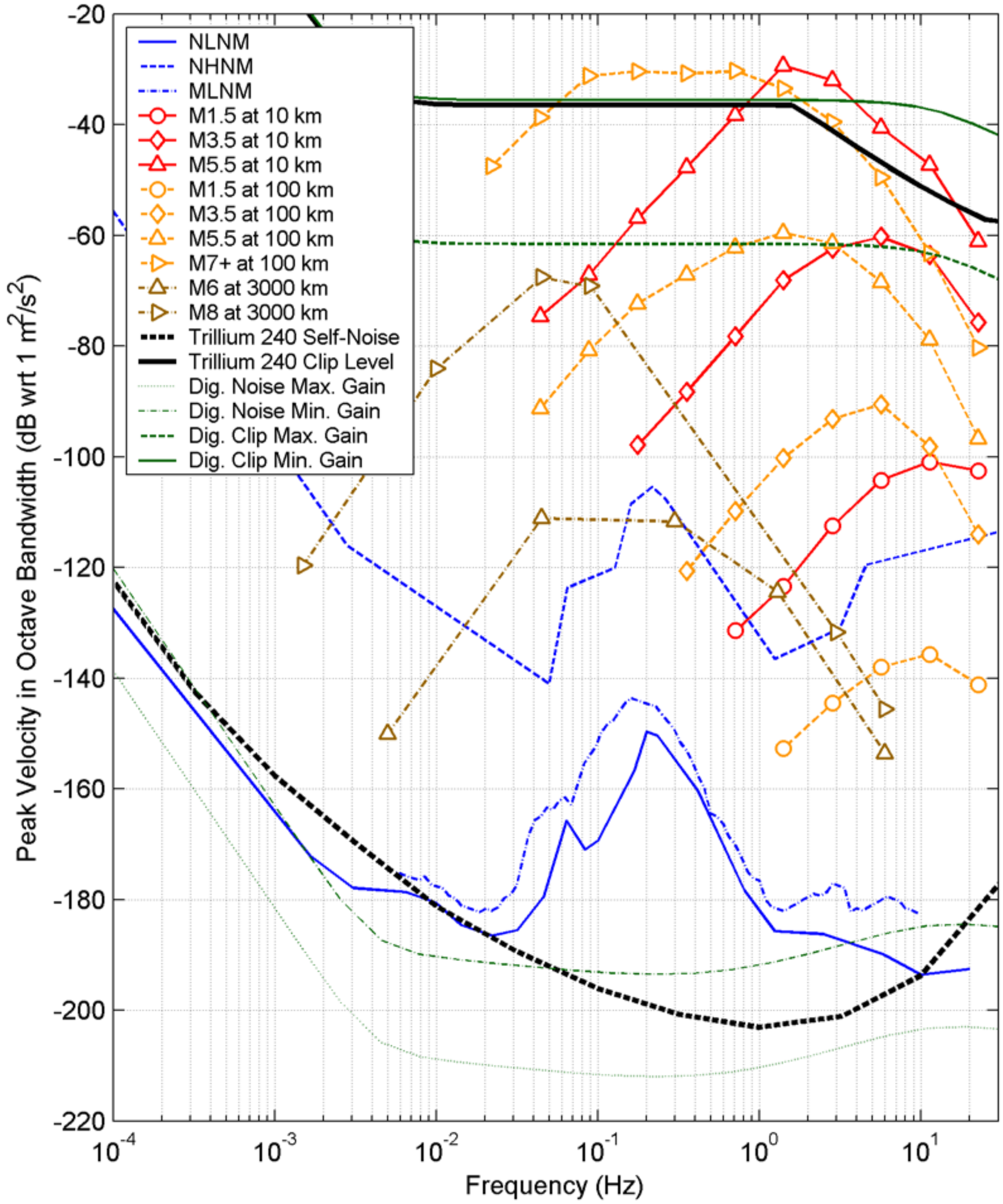
best practices (see the publisher's site http://www.gfz-potsdam.de/pb2/pb21/ for information on the NMSOP).

Figure 4-3 Trillium 240 self-noise



To determine the dynamic range at frequencies of interest for your application, compare the noise floor to the sensor clip level using Figure 4-4. In this figure, for comparison of noise floors to clip levels, we convert power spectral densities using octave bandwidths and an RMS-to-peak conversion factor of 1.253.

Figure 4-4 Trillium 240 performance



4.7 Calibration

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

Since the Trillium 240 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 (see Section 4.4).

Each axis has a separate calibration enable signal: U_CALEN, V_CALEN, W_CALEN. All axes use a common calibration input signal (CAL_SIG) which has a sensitivity of 0.010 $m/s^2 \cdot V$.

4.8 State-of-Health

Mass position output signals U_MP, V_MP, and W_MP 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 by initiating the automatic mass centring feature, which uses stepper motors to precisely tension the spring. (See Section 3.6 on page 8 for a discussion of these signals.)

If the mass positions are all within the range ±0.3 V, then there is no need for recentring. Otherwise follow the procedure in Section 3.6.4, “Mass centring procedure,” on page 10.

4.9 Connecting and configuring the serial port

1. Connect an appropriate RS-232 communications device (such as a PC serial port) to the sensor by connecting its TX pin to the MC/RX signal (pin C) and its RX pin to the UVW/TX signal (pin D).
   - Be sure to take appropriate precautions for signal shielding and grounding to avoid introducing unwanted noise into the sensor or onto adjacent signal wires in the cable, or the seismic signal from the sensor may become noisy.
2. Set the serial port on the communicating device to use this configuration:
   - Speed: 9600 baud
   - Data Bits: 8
   - Parity: None
   - Stop bits: 1
   - Flow Control: Xon/Xoff
3. If you are using a terminal emulator program, enable these settings:
   - Echo typed characters locally – The Trillium 240 serial port does not echo received characters on its transmit port.
   - “Send line ends with line feeds” or equivalent – The serial port expects all commands to be terminated with the “carriage return” character (ASCII 0x0D).
4. Once the sensor is powered up and an appropriate serial device connected as above, send the characters `Tx<CR>` (the `<CR>` denotes the “carriage return” character). Note that the serial commands are not case-sensitive; `Tx`, `TX`, and `tx` are equivalent. After a delay of 3 seconds the sensor will turn enable the UVW/TX output and transmit `Serial Transmit Enabled<LF><CR>`.
5. To view help on the commands, send the help command `Help<CR>` to get the sensor to transmit a help page, displaying the various commands and syntax. This is what would be displayed:

```
Nanometrics Trillium User Menu (Version 3.30) Program A
*********************************************************************
     Help     - Repeat this menu (also turns on Serial TX)
     Tx       - Enable the Serial Transmit Signal
     TxOff    - Disable the Serial Transmit Signal
     Upload   - Upload software to the alternate program
     Switch   - Switch to the alternate program
     Default  - Set the current program as default
     Reboot   - Reboot the instrument
     GetInfo  - Get factory configuration information
     ReadFC   - Read factory calibration parameters
     WriteUC  - Write user calibration parameters
     ReadUC   - Read the user calibration parameters
     Soh      - Report state-of-health
     ShortPer - Set sensor to short period mode
     LongPer  - Set sensor to long period mode
     SetXYZ   - Set sensor to XYZ mode
     SetUVW   - Set sensor to UVW mode
     Center   - Center all masses or (u/v/w)
     CheckSum - Print checksum value for both program A and B
*********************************************************************
Please type a command and hit return:
```

Each of the serial port commands is described in Table 4-3.

Table 4-3 Serial port commands

Command	Description
`Help` `- Repeat this menu (also turns on Serial TX)`	Use the `Help` command to view the list of commands. The first line identifies the firmware version in use, and whether it is Program A or Program B. The `Help` command also turns on the TX signal if it has not already been turned on (after a delay of 3 seconds). It is the only command besides `Tx` that will enable the sensor's serial transmit signal.
`Tx` `- Enable the Serial Transmit Signal`	The `Tx` command turns on the sensor's serial transmit signal (signal UVW/TX, pin D) after a delay of 3 seconds, and sends the message `Serial Transmit Enabled`<LF><CR>. The serial transmit port stays enabled until turned off by the `TxOff` command or by cycling the power to the sensor. In this mode, the UVW/TX pin must not be used as an input pin for UVW mode.
`TxOff` `- Disable the Serial Transmit Signal`	The `TxOff` command turns off the sensor's serial transmit signal (signal UVW/TX, pin D) and then waits 3 seconds. After the 3-second delay, this pin will be interpreted as the UVW mode input pin.
`Upload` `- Upload software to the alternate program`	**Caution** Please DO NOT use the `Upload` command unless specifically directed by Nanometrics Technical Support, as it erases the firmware in the alternate partition. The `Upload` command uploads a new version of firmware to the firmware partition (A or B) that is not currently running.

Table 4-3 Serial port commands (Continued)

Command	Description
Switch - Switch to the alternate program	There are two instances of firmware loaded in the Trillium 240, which can be the same version or different versions, one loaded in partition A, the other in partition B. The sensor will run the firmware from the default partition on power up. Use the `Switch` command to switch immediately to running the firmware in the other partition. It does not change which partition is the default, so that when the sensor is power cycled, it will start up in the original default partition. For example, if the default partition is "B" and the `Switch` command is executed, then partition A firmware is run immediately. When the sensor is powered off and then on again, it then switches back to running Partition B firmware. ▸ Use the `CheckSum` command to ensure there is valid code in both partitions before switching.
Default - Set the current program as default	Use the `Default` command to set the running firmware partition to be the default partition loaded at power up. For example, if the sensor is running partition A by default on power up, to change to running partition B instead, the procedure is: 1. Execute the `SOH` command to verify that partition A is running. 2. Use the `Checksum` command to verify that there is valid code in both partitions. 3. Execute the `Switch` command to change to running partition B, and the `SOH` command to verify that the new firmware is running. 4. Execute the `Default` command to set partition B to be the default on power up.
Reboot - Reboot the instrument	Use the `Reboot` command to restart the firmware.
GetInfo - Get factory configuration information **ReadFC** - Read factory calibration parameters	Use the commands `GetInfo` and `ReadFC` to read factory information stored in the Trillium 240. Factory configuration information includes model, version, and serial numbers; and other factory information for the unit, axes, and various circuit boards in the sensor. This information is primarily used by Nanometrics Technical support. Factory calibration parameters may include information regarding measured sensitivity, transfer function, and the like.
WriteUC - Write user calibration parameters	Use the command `WriteUC` to upload calibration information from a text file in Turtle format. (You can use `ReadFC` to view the factory calibration information for an example of the syntax. For information on Turtle, see http://www.ilrt.bris.ac.uk/discovery/2004/01/turtle/. For information on RDF in general, see http://www.w3.org/RDF/.)
ReadUC - Read the user calibration parameters	Use the `ReadUC` command to display calibration information stored using the `WriteUC` command.

Table 4-3 Serial port commands (Continued)

Command	Description

Soh - Report state-of-health	Use the SOH command to view state-of-health information as listed below.
	<SOH>
	<Manufacture>"Nanometrics, Inc."</Manufacture>
	<Product>"Trillium Firmware"</Product>
	<Version>3.30</Version>
	<Temperature>26.22</Temperature>
	<Mass>U=0.030 V=0.497 W=0.063</Mass>
	<Adc>U=14 V=225 W=29</Adc>
	<Modes>Period=Long Channel=XYZ</Modes>
	<Positions>U=380 V=-66 W=-110</Positions>
	<Zeros>U=0 V=0 W=0</Zeros>
	<Range>U=7043 V=7371 W=7151</Range>
	</SOH>
	• <Version> – The version of the firmware that is currently running.
	• <Temperature> – The temperature near the main electronics PCB, which is located in a chamber near the top of the unit. The temperature of the axes will likely be different from this.
	• The mass positions for each axis (U, V, W). These are reported in two forms:
	  • <Mass> – decimal numbers with a ±4.2 range that roughly corresponds to the output voltage at the U_MP, V_MP, and W_MP signals.
	  • <ADC> – proportional integer numbers with a range of ±1900. The <ADC> number is about 452 times the <Mass> decimal number.
	• <Modes> – The sensor modes are reported, including whether the sensor is in long period or short period mode, and whether the seismic signals are output in XYZ or UVW mode.
	• The <Range>, <Positions>, and <Zeros> numbers pertain to the mass recentring stepper motors:
	  • The <Range> number is the full range in steps the mass positioning stepper motor can traverse between the two optical limit switches. This is measured and set at the factory for each axis.
	  • The <Positions> number is the current position of the stepper motor relative to the midpoint of the total range. A number close to zero means the mass positioning mechanism is near the midpoint of the range and has lots of room for further adjustment. A positive or negative number close to half the <Range> number means the mass positioning mechanism is near to the limit of its adjustment range.
	  • The <Zeros> number is the position of the stepper motor which corresponds to the sensor being level. If the <Position> number is close to the <Zeros> number for all axes, the sensor is close to nominally level. The <Zeros> number is set at the factory for each axis.

Table 4-3 Serial port commands (Continued)

Command	Description
ShortPer - Set sensor to short period mode **LongPer** - Set sensor to long period mode	Use the ShortPer and LongPer commands to set the electronic mass centring response of the sensor to short period or to long period respectively. • Short period is used when mechanically recentring the masses, and is automatically invoked when the mass recentring is initiated. (The prior mode is restored when mass centring completes.) • Long period mode is the normal mode for collecting seismic data, and is essential to obtain the low frequency broadband performance. Short period mode is useful to see the mass positions respond quickly (signals U_MP, V_MP, W_MP, or the SOH <Mass> or <ADC> values) when the sensor is being levelled. In long period mode these numbers ramp very slowly, and so care must be taken to not be misled by apparently centred values when in fact the sensor is not centred. In short period mode, these numbers respond within a second. The sensor always powers up in long period mode. Long period is the normal response for a 240 second lower corner frequency.
SetXYZ - Set sensor to XYZ mode **SetUVW** - Set sensor to UVW mode	Use the SetXYZ and SetUVW commands to set the seismic output signals to the conventional XYZ (horizontals and vertical) mode, or to the “natural” UVW mode in which the output of each axis is given directly. XYZ mode is the default. Note that this mode is also set by the UVW/TX input line when the sensor is not in Serial Transmit mode. The sensor responds to whichever command (serial port or control line) last signalled a change.
Center - Center all masses or (u, v, w)	You can use the Center command with or without parameters: • Without parameters, Center initiates mass centring for all channels, which can also be initiated by pulling the MC/RX pin high for at least 1 second (referenced to DGND). • With a parameter (u, v, or w), Center will centre the specified axis without disturbing the other axes; for example, Center V centres the V axis only.
CheckSum - Print checksum values for both program A and B	Use the CheckSum command to check the firmware checksums of both partitions and what they should be. This is useful to ensure there is valid code in each partition (for example, before switching to the alternate firmware partition).

4.10 Troubleshooting and maintenance

The Trillium 240 mechanical and electronic elements have been designed to be robust and reliable, to ensure there is no need to open units for on-site maintenance. The internal reverse-voltage protection and over-current protection automatically resets when the fault is removed, so there are no fuses to replace. The automatic mass tensioner mechanism is designed to be jam-proof.

In the unlikely event the sensor does not operate correctly, please contact Nanometrics support (see Chapter 1, “Introduction”).

Appendix A Specifications

This section lists the specifications of the Trillium 240.

A.1 Technology

Topology	Symmetric triaxial
Feedback	Coil-magnet force feedback with capacitive transducer
Mass centring	Automatic mechanical recentring, can be remotely initiated
Levelling	Integrated bubble level, adjustable locking levelling feet
Alignment	Vertical scribe marks for East/West Precision holes for 5/16" alignment rods for North/South

A.2 Performance

Self-noise	See Figure 4-3 on page 18
Sensitivity	1196 V·s/m ±0.5%
Bandwidth	–3 dB points are 244 s and 207 Hz
Transfer function	Lower corner poles within ±0.5% of nominal provided High-frequency poles and zeros within ±5% of nominal provided
Clip level	15 mm/s peak-to-peak differential up to 1.5 Hz (see also Figure 4-4 on page 19)
Lower corner damping relative to critical	0.707
Output impedance	2·150 Ω ±1%
Temperature	±10 °C without recentring
Tilt	Operational tilt range ±1°

A.3 Interface

Connector	19-pin MIL-C-28642, mounted on base
Velocity output	Selectable XYZ (east, north, vertical) or UVW mode 40V peak-to-peak differential
Mass position output	Three independent ±4.5V outputs for UVW
Calibration input	Remote calibration in XYZ or UVW mode One voltage input for all channels Three separate control signals to enable U, V, or W channels
Control inputs	Isolated active-high referenced to DGND
Serial port	RS-232 compatible For instrument control and retrieval of configuration information

A.4 Power

Supply voltage	9V to 36V DC isolated output
Power consumption	650mW typical at 15V input
Protection	Reverse-voltage protected Self-resetting over-current protection No fuse to replace

A.5 Physical

Diameter	25cm
Height	• 26.5cm without levelling feet • 28.6cm with levelling feet at minimum extension • 29.5cm with levelling feet at maximum extension
Weight	14kg
Parasitic resonances	None below 150Hz

A.6 Environmental

Operating temperature	–20°C to 50°C
Storage temperature	–40°C to 70°C
Pressure	Enclosure optimized to be insensitive to atmospheric variations
Humidity	0 to 100%
Shock	20g half sine, 5ms without damage, 6 axes No mass lock required for transport
Weather resistance	Rated to IP68 and NEMA 6P for outdoor use, dust, and immersion resistance

Appendix B Connector Pinout

The Trillium 240 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	40V 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	9.2kΩ input impedance $0.010\,\mathrm{m/s^2 \cdot V}$ nominal
K	U_CALEN	calibration enable inputs	active-high 5 to 15V (low = open or 0V)
J	V_CALEN		
U	W_CALEN		
E	U_MP	mass position outputs	±4.5V single-ended
F	V_MP		
S	W_MP		
V	AGND	analog ground	N/A
H	+PWR	power input	9V to 36V DC isolated
G	–PWR	power return	
D	UVW/TX	• input: enable UVW instead of XYZ outputs • output: serial RS-232 transmit	• as UVW input: active-high 5 to 15V; (low = open or 0V) • as TX output: ±5V
C	MC/RX	• input: initiate mass centring • input: serial RS-232 receive	• as MC input: active-high 5 to 15V; (low = open or 0V) • as RX input: +5V/0V to ±15V
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 on page 30 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 digitizer connector.

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		CH1GND	DRAIN	1
P1	N	Y+/V+	P2		CH2+	WHT	2
P1	A	Y–/V–	P2		CH2–	BLK	2
P1			P2		CH2GND	DRAIN	2
P1	P	X+/U+	P2		CH3+	GRN	3
P1	B	X–/U–	P2		CH3–	BLK	3
P1			P2		CH3GND	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
P1	V	AGND	P1		CH1GND	BLK	7
P1		SHELL	P2		SHELL	DRAIN	7
P1	H	+PWR	P2		SEN+12V	RED	8
P1	G	–PWR	P2		SENRTN	WHT	8
P1		SHELL	P2		SHELL	DRAIN	8
P1	D	UVW/TX	P2		CTRL1	RED	9
P1	C	MC/RX	P2		CTRL2	GRN	9
P1	R	DGND	P2		DGND	DRAIN	9
P1		SHELL	P2		SHELL	BRAID	

Appendix D Alignment Features

See Figure D-1 and Figure D-2 for top and bottom views of the Trillium 240 showing the relative orientation of the East-West and North-South alignment features.

Figure D-1 Alignment features top view

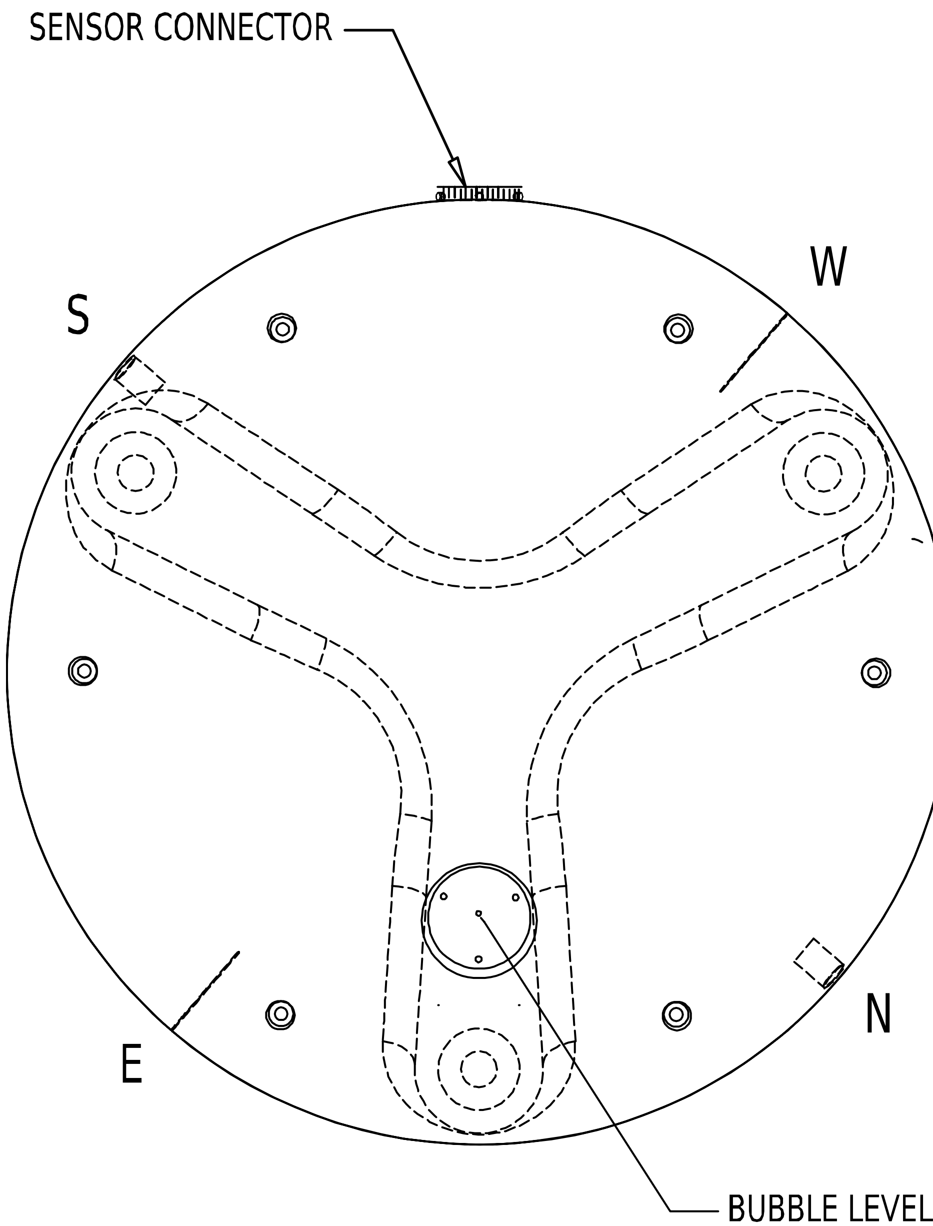
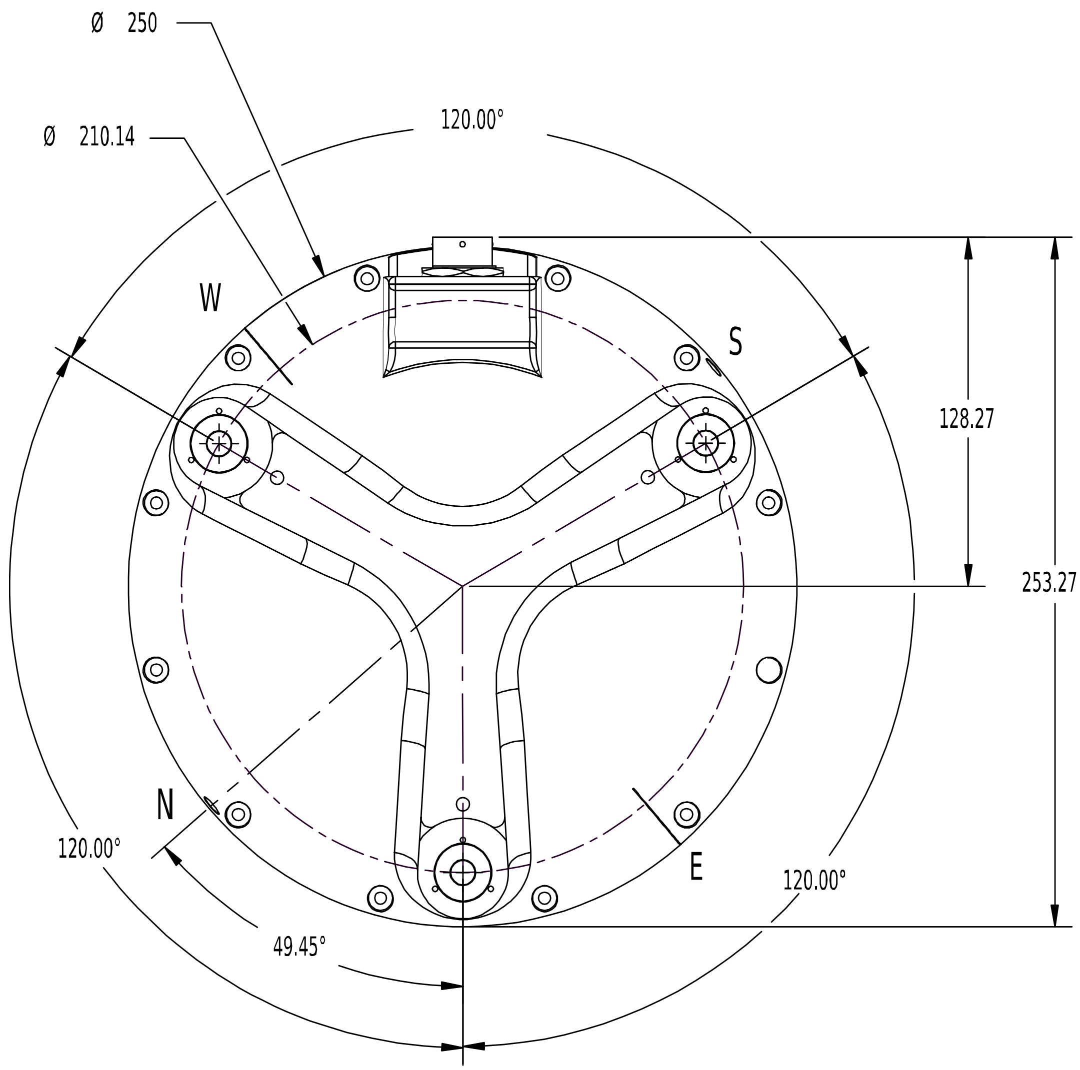


Figure D-2 Alignment features bottom view*



* All dimensions are in millimetres unless otherwise noted.