Trillium 40

Seismometer

User Guide

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SEISMOLOGICAL INSTRUMENTS
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Trillium 40 Seismometer User Guide

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About This Document

Document Conventions

Essential and Supplementary Information		
	Warning	Explains a risk of irreversible damage to data, software, or equipment and provides recommendations for preventive action.
	Caution	Explains a risk of damage to data, software, or equipment where recovery is likely to be troublesome and provides recommendations for preventive action.
	Note	Provides additional information related to the current text.
	Tip	Explains a best practice or provides helpful information related to the current text.
	Example	Provides an example related to the current text.
Text Conventions		
	bold text	Identifies referenced elements in the graphical user interface (GUI) (for example, "click **Cancel** to discard the changes").
	italic text	Identifies variables such as parameter names and value placeholders (for example, "select Configuration > *Sensor Name*").
	`courier text`	Identifies commands that must be entered exactly as shown (for example, "type `mkdir $APOLLO_LOCATION/config`").

Changes Included in This Revision

Revision number 13912R11 includes the following changes:

- A correction to the transfer function calculation
- Updates to the poles and zeros information
- Included the output impedances in the specifications section
- Corrected the alignment rod dimension reference
- Details on both the original enclosure (serial numbers 1 to 902) and the new enclosure model (serial numbers 903 and above), including illustrations
- A warning in Section 7.3 "Centring the Masses in Trillium 40 Seismometers" on page 32 stating that the mass position adjustment screws for units with serial numbers 1 to 902 should not be completely loosened

- A warning in Section 3.2 "Best Practices for Aligning and Levelling a Trillium 40" on page 12 stating that static electricity can affect the accuracy of the levelling bubble that provides suggestions for eliminating the static electricity
- New information on unpacking and handling your Trillium 40
- New information on how to prepare for your installation, including lists of the tools and materials needed
- A list of optional equipment to accompany your Trillium 40
- A site selection and preparation section that includes descriptions of common types of installations and a site record for recording information about your installation
- Expanded information on insulating your Trillium 40
- A section on using a Nanometrics digitizer with a Trillium 40
- A glossary of abbreviations and terms and a list of unit abbreviations and symbols commonly used in Nanometrics documentation
- A reorganization of the content and formatting changes with the introduction of a new document template

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Chapter 1
Getting Started

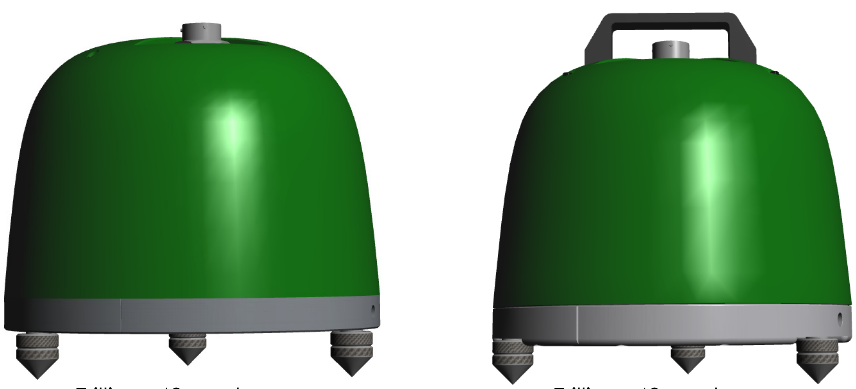
1.1 About Trillium 40 Seismometers

Trillium 40 seismometers are three-component, force-balance broadband seismometers that operate over a wide temperature range without manual recentring. Suitable for both portable and fixed applications, the extended response of Trillium 40 seismometers at higher frequencies makes these seismometers ideal for local and regional networks as well as volcano hazard monitoring and aftershock studies.

The symmetric triaxial arrangement of the sensing elements in Trillium 40 seismometers ensures uniformity between vertical and horizontal outputs. The ability to remotely select either the raw (UVW) or resulting horizontal-vertical (XYZ) outputs allows for the calibration of each axis separately. For some studies, it may be preferable to use UVW mode instead of XYZ mode for recording seismic data.

The enclosure design of the Trillium 40 was updated in 2008 (serial numbers 903 and above). Leaving the performance and functionality of the Trillium 40 unchanged, the new enclosure replaces the stainless steel base with a lighter, fully aluminum design and also features a removable lifting handle. See Table 8-4 "Physical specifications" on page 38 for specific physical differences.

Figure 1-1 Trillium 40 enclosure designs



Trillium 40 enclosure: Serial numbers 1 to 902

Trillium 40 enclosure: Serial numbers 903 and above

1.2 Unpacking and Handling a Trillium 40

The shipping box and packing foam for Trillium 40 seismometers have been designed and tested to protect the seismometers against the impact of accidental drops during hand-carrying and from vibration and shock during shipping. To maintain warranty protection, Trillium 40 seismometers must always be transported in packaging approved by Nanometrics. Save the original packaging and reuse it any time you are transporting a Trillium 40. If custom packaging is required for a particular application, please consult Nanometrics (see Contacting Nanometrics on page 55).

After delivering a Trillium 40 to its installation site, you can safely remove it from the packaging and handle it without any special precautions other than taking care not to drop it or bang it against hard surfaces. Trillium 40 seismometers do not require any mass lock mechanisms. The seismometer is ready to operate right out of the box and can withstand shocks of up to 20 *g* with no degradation in performance or service life.

Trillium 40 seismometers (serial numbers 903 and above) come with a removable lifting handle. Do not use this handle to carry your seismometer over long distances. The handle should only be used to help lift or carry the seismometer at the installation site. For more information on using the handle, see Section 3.1 "Alignment, Levelling, and Placement Features" on page 11.

Remove the handle when transporting the Trillium 40 seismometer in the shipping container to maintain adequate shock absorbing protection.

1.3 Preparing to Install a Trillium 40

Advanced planning and preparation for the installation of your Trillium 40 seismometer will ensure that you have a properly prepared site and the tools and materials you need readily available. Follow these recommendations when preparing for your installation:

- Select and prepare your site.

  If the site requires the construction of a pier or other time-consuming labour, factor this time into your installation schedule. See Chapter 2 "Selecting and Preparing a Site" for more information.

- Prepare your insulation materials.

  It is recommended practice to thermally insulate your seismometer by making a freestanding cover out of rigid insulation. For more information on insulating your seismometer, see Section 3.3 "Theory and Practice of Insulation" on page 13 and Section 3.4 "Insulating Trillium 40 Seismometers" on page 14.

- Gather your installation tools and materials. At a minimum you should have the following on-site when installing your seismometer:
  - Thermal insulation
  - Power source
  - Digitizer and cable (see Table 1-1 "List of Trillium 40 optional equipment" on page 5 for information on Nanometrics digitizers and cables)

- Compass and drawing utensils for alignment (see See Section 3.2 “Best Practices for Aligning and Levelling a Trillium 40” on page 12)

◆ Gather any optional tools and materials you may need. Your installation may also require:

- A laptop with software and cables required to connect to and communicate with the digitizer if using a digitizer without a display screen.
- Alignment rods if you are aligning the seismometer to the east-west using the 5/16 in. diameter holes in the seismometer base. Using the north-south scribe lines is preferred. See Section 3.1 “Alignment, Levelling, and Placement Features” on page 11.
- Lifting handle if you are installing the seismometer in a vault that is only accessible from the top.

1.4 Trillium 40 Optional Equipment

Nanometrics offers optional equipment that add convenience to the installation and use of your Trillium 40 seismometer. The table below describes a number of these options.

Table 1-1 List of Trillium 40 optional equipment

Name	Part Number	Description
Cable – Trillium seismometer to Nanometrics digitizer	16169–3M 16169–5M 16169–10M 16169–15M 16169–25M	Double-shielded, ultra-flexible cable with a 19-pin right-angled connector at one end for connecting to a Trillium seismometer and a 26-pin connector at the other end for connecting to a Taurus or Trident. Standard cable lengths are 3 m, 5 m, 10 m, 15 m, and 25 m. Custom cable lengths are available upon request.
Cable – Trillium seismometer to open end	16170–3M 16170–5M 16170–10M 16170–15M 16170–25M	Double-shielded, ultra-flexible cable with a 19-pin right-angled connector at one end for connecting to a Trillium seismometer and open-ended at the other end for attaching the connector of a third-party digitizer. Standard cable lengths are 3 m, 5 m, 10 m, 15 m, and 25 m. Custom cable lengths are available upon request.
Cable – Trillium seismometer to third party digitizer	Contact Nanometrics	Double-shielded, ultra-flexible cable with a 19-pin right-angled connector at one end for connecting to a Trillium seismometer and a connector for a common third party digitizer, such as a Q330 or REFTEK D130, on the other end. Contact Nanometrics (see Contacting Nanometrics on page 55) for a full listing of cables with connectors to third party digitizers.
Alignment rods	Contact Nanometrics	Rods that fit into the 5/16 in. diameter holes on the base of a Trillium 40 seismometer. Used for aligning the seismometer to east-west. Contact Nanometrics (see Contacting Nanometrics on page 55) for more details.

Table 1-1 List of Trillium 40 optional equipment

Name	Part Number	Description
Taurus Portable Seismograph	14977	Compact, self-contained, 24-bit digitizer and data logger with low power consumption, and 142 dB dynamic range. Use as a stand-alone time-series data logger or as a component in a data acquisition network. Incorporates a three-channel 24-bit digitizer, GPS receiver and system clock, removable data storage, and remote communication options. Can be installed in the seismometer vault, requiring only a short cable. Configurable locally using the colour display screen and integrated browser or remotely using any Web browser over a TCP/IP connection.
Trident 305 Digitizer	14072	A 24-bit digitizer with 142 dB dynamic range and Nanometrics NMX-bus for connecting to Taurus, Cygnus satellite transceiver, or other NMX-bus enabled device. The NMX-bus host device, such as a Taurus, supplies GPS timing and power to the Trident. Can be installed in the seismometer vault, requiring only a short cable. Weather-sealed enclosure also allows outdoor installations. Configurable locally using the host Taurus or remotely using any Web browser over a TCP/IP connection.

1.5 Technical Support and Maintenance

If you need technical support, please submit your request by email or fax. Include a full explanation of the problem and any supporting information (such as mass position readings, photographs of the site, operating input voltage and current) to help us direct your request to the most knowledgeable person for reply. Before returning a unit for repair, contact Nanometrics Technical Support (see Contacting Technical Support on page 55) to obtain an RMA number.

1.5.1 Recording Your Serial Number

The serial number of your Trillium 40 is located on the cover of the seismometer, near the connector. Record the serial number and keep it accessible. You need to reference this number when contacting Technical Support.

Chapter 2

Selecting and Preparing a Site

2.1 Selecting a Site

There is no substitute for a geological survey when it comes to site selection. A survey provides knowledge of the structures over which the seismometer will be installed.

Where possible, seismometers should be installed on bedrock and as far away as possible from sources of cultural noise such as roads, dwellings, and tall structures. 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.

Use the worksheet in Section 2.4 "Site Record" on page 10 to record information about the structure, cultural environs, and climatic conditions of the site; as well as information about the type and length of the installation. Section 2.2.1 "Common Types of Installations" on page 8 provides recommendations for some common installation types.

2.2 Planning Your Installation

Before deploying your seismometer, you should have an understanding of the type of installation you will use and how you will insulate your seismometer. Your installation must be designed to provide a stable base for the seismometer without any forces or disturbances acting on it.

The installation methods described in this section incorporate installation design guidelines that aim to reduce the possibility of installation-related noise. Horizontal spikes in the signal are indicative of installation-related issues, and it is normal to see horizontal spikes following installation. However, if the spikes do not diminish after a few days, there may be a problem with the installation. See Section 4.4 "Troubleshooting Your Installation" on page 18 for more information.

2.2.1 Common Types of Installations

Following are three common methods for installing and insulating a seismometer (see Section 3.3 “Theory and Practice of Insulation” on page 13 and Section 3.4 “Insulating Trillium 40 Seismometers” on page 14 for more information on insulation):

a) Vault installation

Vault installations can be at or below the surface and usually include a pier that provides a level platform for the seismometer to sit on and good coupling to the ground.

The pier must be insulated from air currents to prevent tilt noise caused by the thermal expansion or contraction of its surface. For a pier solidly connected to the ground (such as a poured cement pad on top of bedrock), a useful technique is to place a thick quilt over the surface of the pier. Cutting a hole out of the quilt allows it to drop over the insulating cover of the seismometer and cover the pier.

Thoroughly insulate the roof of the vault and any exposed sides. Seal the door and any other openings. Do not use a thermostat-controlled heating or cooling system because the temperature cycling will show up as periodic noise in the seismic signal.

b) Temporary deployment on rock

Install the seismometer on the flattest available surface and lay sand in a ring around it to create a flat sealing surface for the rigid insulation that will cover it.

c) Temporary deployment in sediment

Dig a pit to bury the seismometer. A depth of 2 ft. is sufficient to ensure the seismometer and cover will be completely buried and not disturbed. If possible, place a metal plate or paving stone at the bottom of the pit to create a hard, flat surface. Install the seismometer in the pit and cover it with a rigid insulating cover. The cover will prevent the seismometer from being disturbed by sediments shifting and settling against it. Hold the cover down while piling sediment around it to ensure that it does not shift as it is buried.

A simpler but less optimal method is to place the seismometer directly in the ground and bury it. This method provides good insulation, but horizontal noise spikes may be observed due to instability of the soil.

2.3 Recommendations for Pier Construction

If your installation involves the construction of a pier, use Table 2-1as a guide to constructing your pier:

Table 2-1 Recommended pier design specifications

Material	Concrete. Homogeneous, 50% Portland cement and 50% sieved sand (see Section 2.3.1 “Choosing the Right Concrete” on page 9).
Size	Large enough to fit all required seismometers, cables, and insulation.
Thickness	Within the range of 2 in. to 4 in. on top of bedrock.
Surface	Smooth, level, and clear of debris.
Decoupling	Decouple the pier from the vault walls (see Section 2.3.2 “Decoupling the Pier and Vault Walls” on page 9).

2.3.1 Choosing the Right Concrete

The concrete used in a seismic pier should be as homogeneous as possible to avoid inducing tilts from differing thermal coefficients of expansion. To create a homogeneous concrete mixture do not use any aggregates and ensure the concrete is free of air bubbles. Steel reinforcement is not necessary as strength is not a concern in seismic piers.

The recommended concrete mixture is 50 percent Portland cement and 50 percent sieved sand.[1] After pouring the concrete, shake it to allow trapped bubbles to escape. Allow 24-hours for the concrete to harden before positioning the seismometer on the pier.

The pier may generate spurious signals as the concrete cures, which can take two to four weeks.

2.3.2 Decoupling the Pier and Vault Walls

When setting up the concrete forms for the pier, include a gap between the edge of the concrete and the walls of the vault. Decoupling the pier and the vault walls prevents the transfer of non-seismic forces, such as those generated by surface winds, from the vault walls to the pier. Such forces can 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.

1. Bob Uhrhammer and Bill Karavas, *Guidelines for Installing Broadband Seismic Instrumentation* (Berkeley: The Regents of the University of California, 1997), http://seismo.berkeley.edu/bdsn/instrumentation/guidelines.html.

2.4 Site Record

Use the following table to record information about the site, including its structure, cultural environs, and climatic conditions. This information will be helpful in identifying changes to the site over time and for determining when mass recentring may be necessary due to temperature change.

Table 2-2 Record of installation site details

Site name (full name / station code / network code, for example, Yellowknife / YKN / CN):	**Latitude:**
	Longitude:
	Elevation:
	Date of installation (mm/dd/yyyy):
Type of installation (for example, vault, surface, other): __________ Depth below surface (m) __________ Height above sea level (m)	**Length of installation:** Permanent or temporary: If temporary, expected time frame (mm/dd/yyyy to mm/dd/yyyy):
Ground surface type (for example, rock, soil, sand, clay, other):	**Distance to potential noise sources (km):** __________ Airport or air traffic __________ Railway __________ Roads __________ Tall structures ________ Height (m) __________ Trees ________Height (m) __________ Dwellings __________ Industrial site __________ Others (describe):
Seasonal temperature ranges (°C): ________________ January 1 to March 31 ________________ April 1 to June 30 ________________ July 1 to September 30 ________________ October 1 to December 31	
Notes:	

Chapter 3

Installing a Trillium 40

3.1 Alignment, Levelling, and Placement Features

To aid in the proper alignment of your seismometer, each Trillium 40 has:

- Vertically-scribed marks on the north-south axis.
- Two 5/16 in. diameter holes on the east-west axis for fitting alignment rods.

For convenience and accuracy, use of the north-south scribe marks is the preferred method of alignment. Alternatively, for an east-west alignment, alignment rods are available from Nanometrics that you can fit into the 5/16 in. diameter holes on the east-west axis of the seismometer base. Chapter 11 "Alignment Features and Dimensions" provides illustrations that show the relative orientation of the north-south and east-west alignment features in top, bottom, and side views.

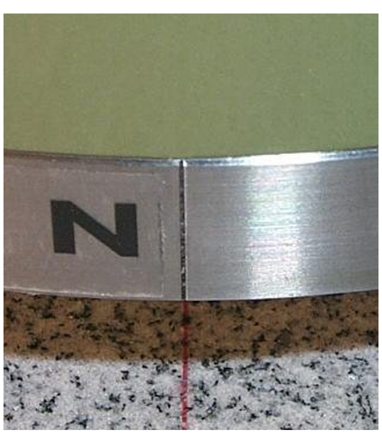
For levelling purposes, each Trillium 40 seismometer is equipped with:

- Three adjustable-height feet with lock nuts.
- A levelling bubble on the cover.

Trillium 40 seismometers also come with a lifting handle (serial numbers 903 and above) that can be screwed into the top of the seismometer cover. The handle is provided to facilitate the placement of these seismometers in vaults that are only accessible from the top, or to carry the seismometer over short distances.

Figure 3-1 shows the north scribe line on a Trillium 40 aligned with a line drawn on the pier that is parallel to north-south.

Figure 3-1 Example of seismometer alignment using vertically scribed marks



3.2 Best Practices for Aligning and Levelling a Trillium 40

Following are best practices for aligning and levelling a Trillium 40 using the vertically scribed marks on the north-south axis:

If you are using an east-west alignment with the alignment rods, continue with these best practices, but substitute north-south with east-west and fit the alignment rods into the 5/16 in. diameter holes in the base of the seismometer instead of aligning the Trillium 40 with the vertically scribed marks.

- Draw a line on the pier or other installation surface parallel to north-south.

  The north-south line must be aligned to true north. If you are using a magnetic compass, account for the local magnetic declination when drawing the line. For underground installations, you can transfer north measured at the surface to below ground by traversing with survey equipment.

- When you are ready to remove the Trillium 40 seismometer from the box, gently place it on the installation surface in an approximate north-south alignment.

- Use the adjustable feet, as required, and the levelling bubble on the cover to level the seismometer.

  Extend the levelling feet as little as possible to achieve a level seismometer. Try to keep one of the feet fully retracted into the seismometer base for greatest stability.

  Centre the bubble as precisely as possible inside the black ring to ensure that the Z output is measuring true vertical motion.

Static electricity can affect the accuracy of the levelling bubble in Trillium 40 seismometers with serial numbers 1 to 902. Measures must be taken to eliminate static electricity around the seismometer or, if this is not possible, mass positions must be used to determine whether the seismometer is level instead of the levelling bubble.

Methods for eliminating static electricity around a seismometer include

1. Earthing the seismometer and the installer, while the installer is physically levelling the seismometer with the levelling bubble.
2. Misting water on the seismometer, installer, and any structure around the seismometer.

- When the Trillium 40 is level, lock the feet by turning the lock nut up until it engages firmly with the base of the seismometer. A foot that is properly locked will not turn easily when touched.

- Precisely align the Trillium 40 to north-south by aligning the vertical north-south lines on the base of the seismometer (see Figure 3-1 "Example of seismometer alignment using vertically scribed marks" on page 11) with the line drawn on the installation surface.

  Some care is required when aligning the seismometer to avoid sighting at an angle and introducing a parallax error.

- After aligning the seismometer, verify that it is still level. It may need to be adjusted due to unevenness of the installation surface.

- If you relevelled the Trillium 40, ensure the feet are locked when finished.

3.3 Theory and Practice of Insulation

It is recommended practice to thermally insulate Trillium 40 seismometers to achieve optimal performance, particularly at long periods. Continue with this section to understand why and when thermal insulation is required and to determine the degree of insulation needed at your installation site.

There are two broad categories of thermal effects that can cause unwanted noise:

a) Direct thermal sensitivity.

Like all seismometers, Trillium 40 seismometers have some residual temperature sensitivity. There are several components in a seismometer that are temperature sensitive, for example the springs that suspend the inertial masses. The effect of direct thermal sensitivity typically shows up as very long period noise on the vertical channel, in particular, a periodic diurnal variation in response to the day-to-night temperature cycle.

b) Thermally induced tilt.

All seismometers are susceptible to thermally induced tilt. Tilt converts the strong vertical acceleration of gravity into an apparent horizontal acceleration. There are many mechanisms for the conversion of temperature into tilt. For example:

- Movement of air surrounding the seismometer can cause non-uniform thermal expansion or contraction of the pier and the seismometer. Such effects typically have an apparent ground-motion spectrum that is peaked at long periods.
- Movement of anything touching the seismometer, including the digitizer cable and insulation materials, can cause forces to develop that change with temperature. Stick-slip effects typically transform these forces into sudden step changes in tilt. The apparent ground-motion power spectral density is, therefore, inversely proportional to the square of frequency.

Seismometers that are improperly installed may exhibit spurious low frequency signals on the horizontal channels due to thermally induced tilt. Furthermore, due to the natural convection of air, thermally induced tilt is even observable in sealed underground vaults where the temperature is very stable.

Therefore, the objectives of a good installation are to:

- Insulate the seismometer from temperature changes.
- Prevent the movement of air on the surface of the seismometer.
- Insulate the pier from temperature changes.
- Prevent the movement of air on the surface of the pier, including the sides and underside of piers that consist of a slab raised above the vault floor.
- Prevent anything from touching and thereby applying a mechanical force to the seismometer.

To meet these objectives and achieve the best possible performance, observe the following practices:

- The vault (the space or room where the seismometer is installed) must provide a stable thermal environment. This environment is typically achieved through careful site selection (see Chapter 2 "Selecting and Preparing a Site") and by installing the seismometer below ground.
- The digitizer cable must be flexible enough to bend without applying significant forces to the seismometer. Nanometrics provides ultra-flexible cables designed for this purpose (see Section 1.4 "Trillium 40 Optional Equipment" on page 5).
- The insulation surrounding the seismometer must:
  - Have low thermal conductivity to insulate the seismometer from temperature changes.
  - Form a nearly airtight seal against the pier to block drafts.
  - Fit closely around the seismometer, eliminating space that may cause convection inside the cover.
  - Not touch the seismometer or the cable. The insulation is subject to temperature expansion and can exert measurable forces on the seismometer.

3.4 Insulating Trillium 40 Seismometers

It is recommended that you insulate a Trillium 40 seismometer with a rigid foam box. This box should be a freestanding cover made of rigid insulation that is sealed against air drafts, does not touch the seismometer, and minimizes the volume of air trapped between the insulating box and the seismometer.

Use the following recommendations as a guide when constructing the box:

When installing a Trillium 40 in a rigid insulating box, follow the best practices for aligning and levelling the seismometer that are outlined in Section 3.2 "Best Practices for Aligning and Levelling a Trillium 40" on page 12.

- Construct a five-sided box that is large enough to house the seismometer without touching the sides of the seismometer or the cable.

  Preferably, use rigid foam insulation with foil on one or both sides. There are two advantages to the foil-coated foam: it has a higher insulation resistance, and you can make the joints with aluminium tape, which is quicker and cleaner than glue.
- Use insulation that is at least 5 cm (2 in.) thick. Depending on the temperature stability of the site, additional or thicker boxes can be used.
- Cut a groove at the appropriate point in the bottom of the box to allow the seismometer cable to exit.

- Seal the box joints properly:
  - For rigid foam without a foil coating, glue the joints using polystyrene adhesive or polyurethane resin, taking care not to leave any gaps.
  - For rigid foam with a foil coating, tape the joints with aluminium tape, taking care not to leave any gaps.
- Ensure there is a good seal between the bottom edge of the box and the pier. Adhesive weatherstripping that is 1.25cm (0.5 in.) thick creates a good seal.
- Ensure the thermal insulation box is held firmly in place by setting a weight on top of it. A brick works well for this purpose.
- Strain relieve the cable to the pier, close to the seismometer. Tie-wraps with tie-wrap anchors or a heavy object are effective tools for achieving strain relief.

Chapter 4

Post-Installation Activities

4.1 Grounding the Digitizer and Trillium 40

The digitizer and seismometer cases must have a low-resistance path to ground for safety. However, directly earthing both instruments will result in a ground loop. When the digitizer and seismometer are far apart, differences in ground potential may cause spurious signals to appear unless the loop is broken. The solution is to earth the digitizer case and isolate the seismometer case.

Trillium seismometers have stainless steel adjustable feet which, when mounted directly onto dry rock or concrete, provide a relatively high resistance to ground. In wet environments it may be necessary to mount the seismometer on a plate of glass embedded in sand. For more details on earthing the digitizer and seismometer, refer to the user guide for your digitizer.

4.2 Centring the Masses after Installation

For best results, centre the masses in your Trillium 40 seismometers immediately after installing and levelling the seismometer.

For more information on how and when to centre the masses in your Trillium 40 seismometer, see Chapter 7 "Centring the Masses."

4.3 Installation Checklist

Use the following checklist to help you verify that you have completed all of the necessary steps in the installation of your Trillium 40.

- ❑ Installation surface is clear of debris.
- ❑ Trillium 40 is level.
- ❑ Trillium 40 is aligned to north-south or east-west.
- ❑ The feet of the Trillium 40 are locked.
- ❑ Trillium 40 serial number is noted.
- ❑ Cable is connected to the Trillium 40 and the digitizer.
- ❑ Cable is strain-relieved to the installation surface.
- ❑ Cable is not touching the Trillium 40 case.
- ❑ Thermal insulation is in place.

❑ Thermal insulation is not touching the Trillium 40 or cables.

❑ Rigid-foam insulating box is weighted down.

❑ Masses are centred.

4.4 Troubleshooting Your Installation

It is normal to see spikes in the horizontal channels of a Trillium 40 as the seismometer settles after installation. However, if these spikes do not diminish after a few days, there may be a problem with the installation and the site should be visited to determine the cause of the spikes.

Table 4-1 lists common types of noise, including horizontal spikes, that may occur with a Trillium 40 seismometer and reasons why the noise may be present.

Table 4-1 Types of noise and possible causes

Noise Type	Possible Cause
Spikes on the horizontal channels	◆ The feet of the seismometer are not locked. ◆ There is a force pulling on the cable. ◆ There is something touching the sides of the seismometer.
Continuous low frequency wander (random noise, larger on horizontal channels)	◆ Insulation is missing or not well sealed, allowing drafts to blow over the seismometer. ◆ There are forces, such as wind, acting on the installation.
Spikes on the vertical channel	◆ Usually due to electrical system noise. For example, power supply noise from a battery charging circuit, or interference from a strong magnetic or radio source that is nearby.

4.5 Fuse Replacement (Applies to Serial Number Range 0 to 179 Only)

The electronics on Trillium 40 seismometers with serial numbers in the range of 0 to 179 are protected by a replaceable input fuse. Replacement fuses are provided in the maintenance kit that shipped with the seismometer.

Trillium 40 seismometers with serial numbers 180 and above are equipped with a self-resetting fuse that does not need to be replaced.

When the fuse is blown in a Trillium 40 it will not produce any output on any channel and there will be zero power consumption. To verify that the fuse is blown, apply 12 V across the input terminals using a power supply with a built-in current meter. If the seismometer does not draw any current the fuse needs to be replaced.

Before proceeding with the fuse replacement, ensure you can adhere to the following best practices:

- Broadband seismometer mechanics are very sensitive to the presence of contamination such as dust. Perform the fuse replacement in a clean room. If a clean room is not available, return the seismometer to the factory for maintenance.
- There is a desiccant inside the sensor case that must be replaced after exposure to moisture in the atmosphere. To limit exposure to moisture, fuse replacement must be done quickly, taking no more than a total of 15 minutes.

To replace the fuse:

1. Remove the connector jam nut.
2. Remove the three screws in the top of the cover.
   a) Inspect the O-rings for cuts or pitting and set these aside.
   b) Make sure the circuit board drops a short distance down onto three standoffs (not yet visible).
3. With the sensor standing on its feet at the edge of a bench top, remove the twelve screws that fasten the base to the cover. Carefully lift the cover straight up.
4. Locate the fuse beside the main connector and remove it using needle-nose pliers.
5. Insert the new fuse.
6. Inspect the connector and base O-rings for damage and ensure all are properly seated.
7. Carefully lower the cover over the mechanics and electronics.
8. With the sensor at the edge of the bench top, thread the twelve base screws finger tight only.

> At this point you may want to turn the seismometer upside-down to make it easier to torque the screws until the base O-ring is fully compressed.

9. Use the three cover screws to pull the electronics up against the inside of the cover and then tighten each until metal-to-metal contact is felt.
10. Replace the connector jam nut.
11. Apply power to the sensor and check that the current stays below 125 mA. When the seismometer is level the power should be 600 mW.

If the problem persists, contact Nanometrics technical support. See Contacting Technical Support on page 55.

Part 2

Operation

Chapter 5

Input and Output Signals

5.1 Digital Control Input Signals

Trillium 40 seismometers have five digital control input signals: MC, UVW, U_CALEN, V_CALEN, and W_CALEN.

Each input is optically isolated from the input voltage, the output signals, and the calibration input signals. Therefore, signals applied to these pins must be referenced to DGND rather than ±PWR or AGND.

All of the control input signals are active-low. Activate the input signals by shorting the line to DGND.

5.2 UVW and XYZ Output Signals

To account for the source impedance, see Table 9-1 "Ground motion response nominal parameters" on page 40. A control signal switches the Trillium 40 output signal to either UVW output mode or XYZ output mode. The "natural" output is UVW where the outputs represent the actual motion of the three sensor component masses. The "conventional" seismometer output is XYZ where the outputs represent horizontal and vertical motion.

See Table 5-1 for the polarities of the XYZ outputs and the correspondence of each to the directions of the compass.

Table 5-1 Axis orientation and polarity of XYZ outputs

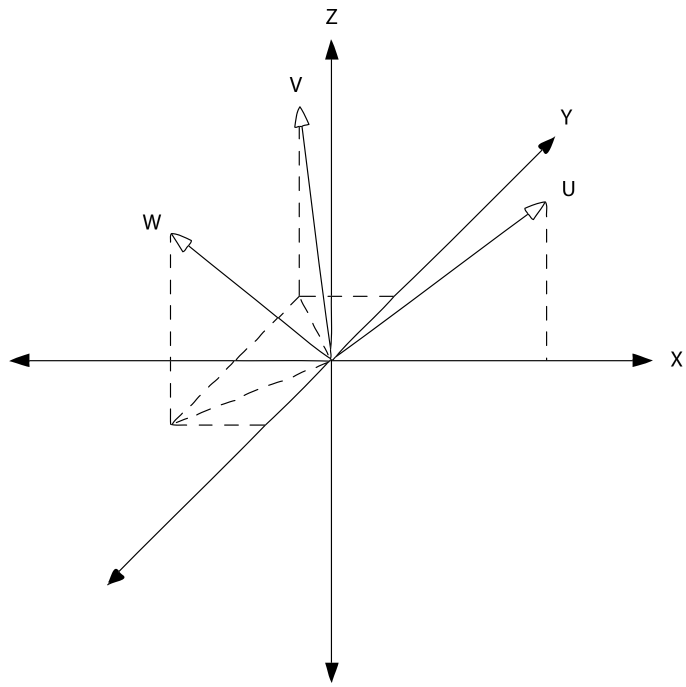
Axis	Orientation	Positive Voltage
X	east-west	represents case motion to the east
Y	north-south	represents case motion to the north
Z	vertical	represents upward case motion

The seismometer will respond to changes in the type of output signal within 4 s. To select the

- UVW outputs, pull the UVW pin low.
- XYZ outputs, leave the UVW pin floating.

To understand the difference between the UVW and XYZ outputs, see Figure 5-1. By design, the Trillium 40 axes are identical and sense motion in orthogonal directions. The U axis is aligned with the east-west axis when projected into the horizontal plane.

Figure 5-1 Trillium 40 axis orientation



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 Trillium 40 through the orientation of the individual axes. The second equation is implemented electronically when the Trillium 40 is in XYZ mode.

Alternatively, seismic data can be digitized with the Trillium 40 seismometer in UVW mode and the transformation to horizontal and vertical signals being implemented when the data are processed. For example, UVW mode is particularly useful for the calibration of the transfer function of individual axes.

5.3 Calibration Input Signals

Calibration input signals are provided to allow for relative calibration of the Trillium 40 across frequency and over time.

Since the Trillium 40 is a symmetric triaxial seismometer, calibration is best performed on the individual axes (UVW) rather than the horizontal and vertical outputs (XYZ). Individual axis outputs can be digitized by placing the seismometer in UVW mode. For instruction on how to set a Trillium 40 to UVW mode, see Section 5.2 "UVW and XYZ Output Signals" on page 23.

Each axis has a separate calibration enable signal: U_CALEN, V_CALEN, W_CALEN. All of the axes use a common calibration input signal, CAL_SIG. See Table 9-2 "Calibration input response nominal parameters" on page 41 for sensitivity information. To enable calibration, pull the pin low. to disable calibration, leave the pin floating.

5.4 State-of-Health Output Signals

Mass position output signals U_MP, V_MP, and W_MP are provided to monitor the effect of tilt and temperature on the spring that sets the rest position of the boom. As with the calibration signals, these signals represent the state of the individual axes (UVW) rather than the horizontal and vertical outputs (XYZ). See Section 7.2 "Choosing When to Initiate Mass Centring" on page 32 for more information on centring the masses based on the status of these signals.

If any of the mass positions are approaching ±3.5 V, mechanical recentring should be initiated. Follow the procedure in Section 7.3 "Centring the Masses in Trillium 40 Seismometers" on page 32.

5.5 Power Consumption

Following are power consumption scenarios typical of Trillium 40 seismometers:

- Under normal operation (the Trillium 40 is level and well centred, the seismic signal is well below the clip level, and the Trillium 40 has settled for at least 30 minutes), power consumption is approximately 600 mW.
- On start-up, power consumption may briefly surge to 4.5W.
- If the Trillium 40 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 Trillium 40, a seismic signal that approaches the maximum clip level of the seismometer may draw as much as a 2 W peak (the average power consumption would be much lower).

- Power consumption does not increase significantly with mass position.

For long cables, account for the resistive voltage drop due to the cable length and, if necessary, increase the voltage at the source.

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 inrush at 9 V would be 4.2 V, and the power supply should 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 seismometer receives 9 V.

In the example above, 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 seismometer for maximum seismic signals when using a 50 m cable.

Chapter 6

Using a Nanometrics Digitizer with a Trillium 40

True 24-bit digitizers such as the Taurus or Trident should be set to 16 Vpp input range (1 count/μV) sensitivity. This setting matches the clip level of the seismometer and digitizer, allowing the digitizer to record the full dynamic range of the Trillium 40. See Section 6.4 "Changing System Sensitivity" on page 29 for information on other sensitivity settings and what to expect if using a sensitivity setting other than 16 Vpp.

6.1 Using a Version 3.x Taurus or Taurus-attached Trident 305 with a Trillium 40

Version 3.x Taurus includes a sensor library with the default configurations for all Trillium seismometers. For a Trillium 40 connected to a version 3.x Taurus or Taurus-attached Trident 305, use the Taurus display or Web interface to apply the default Trillium 40 configuration to the instrument (Taurus or Trident 305) that is connected to the seismometer.

Refer to the Taurus user guide for full instructions on configuring a Taurus or Trident 305 for a Trillium 40 seismometer. Nanometrics cable 16169-nM (where n is the length of the cable in metres) can be used to connect a Trillium seismometer to a Taurus or Trident 305. See Table 1-1 "List of Trillium 40 optional equipment" on page 5 for a description of this cable.

6.2 Using a Version 2.x Taurus with Trillium 40

The instructions that follow are a guide to using the Taurus display or Web interface to select the default configuration for a Trillium 40 on your version 2.x Taurus. Refer to the Taurus user guide for full instructions on configuring a version 2.x Taurus for a Trillium 40 seismometer. Nanometrics cable 16169-nM (where n is the length of the cable in metres) can be used to connect a Trillium seismometer to a Taurus. See Table 1-1 "List of Trillium 40 optional equipment" on page 5 for a description of this cable.

Use the following steps to load the default configuration for the Trillium 40 into the Taurus:

1. Log into the Taurus with either the tech or central user account.
2. Select **Advanced Configuration** from the **Status** menu.
3. Select **Browse** and navigate to the Trillium40.cfg file in the **sensors** folder of the Taurus software CD.
4. Select **Upload**.
5. When the upload is complete, select **Apply**.
6. Select **Commit**.

6.3 Using a Trident Digitizer with a Trillium 40

Refer to the user guide for your Trident digitizer for complete instructions on using it with a seismometer. Nanometrics cable 16169-nM can be used to connect a Trillium seismometer to a Trident digitizer. See Table 1-1 “List of Trillium 40 optional equipment” on page 5 for a description of this cable.

Following are instructions for configuring your Trident and NaqsServer to work with a Trillium 40 seismometer.

1. Match the settings on the **Configuration** tab of Nanometrics UI to those in the following table.

Nanometrics UI Configuration Tab		Value	Notes
Section	**Setting**		
Front End	Input Range	16 Vpp	
Sensor Control	High Voltage Level	High Z	
	Calibration Mode	Voltage (active low)	
	Line 1 Level	High	Low is equivalent to UVW mode and High is equivalent to XYZ mode.
	Line 2 Level	High	Low is equivalent to SP mode and High is equivalent to LP mode.
	Line 3 Level	Not used	

2. Ensure the NaqsServer Naqs.stn file contains the following information:

```
[ Sensor ]                  // predefined sensor - all fields mandatory
TypeName = Trillium40       // name of this prototype - may be same as model
Model = Trillium40          // sensor model name
SensitivityUnits = M/S      // units of ground motion: M, M/S or M/S**2
Sensitivity = 1.553e+9      // counts per unit of ground motion
SensitivityFreq = 1.0       // Frequency at which sensitivity is correct
CalibrationUnits = VOLTS    // calibration input units: VOLTS or AMPS
CalCoilResistance = 13600   // calibration coil resistance in ohms
CalCoilConstant = 100       // Calibration units per m/s/s
CalEnable = -1              // digital enable signal for calibration
CalRelay = 0                // analog relay for calibration (0 = use channel number)
MassCenterEnable = -1       // digital enable signal for mass centering
MassCenterDuration = 1      // duration of mass centering signal (optional)
CalSource = Trident         // gives the source of the Cal signal
```

6.4 Changing System Sensitivity

True 24-bit digitizers such as the Taurus or Trident should be set to 16 Vpp input range (1 count/μV) sensitivity. This setting matches the clip level of the seismometer and digitizer, allowing the digitizer to record the full dynamic range of the Trillium 40.

A system sensitivity lower than 16 Vpp degrades the system noise floor without improving the system clip level. A system sensitivity higher than 16 Vpp degrades the system clip level without improving the system noise floor. With this in mind, if a different system sensitivity is required for either the Taurus or Trident, change the digitizer input range and the sensitivity, using Table 6-1 as a guide.

Table 6-1 Increasing system sensitivity

Digitizer Input Range	Digitizer Software Gain	Digitizer Sensitivity	Trillium 40 Sensitivity	System Sensitivity (Counts/(m/s))
40 Vpp	1	0.4 count /μV	1500 $V \cdot s/m$	6.000e+8
*16 Vpp	1	1 count /μV	1500 $V \cdot s/m$	1.500e+9
8 Vpp	1	2 count /μV	1500 $V \cdot s/m$	3.000e+9
4 Vpp	1	4 count /μV	1500 $V \cdot s/m$	6.000e+9
2 Vpp	1	8 count /μV	1500 $V \cdot s/m$	1.200e+10

* Recommended setting

Chapter 7

Centring the Masses

7.1 About Mass Centring

Trillium 40 seismometers have three analog voltage outputs representing the DC currents applied to each of the three channel feedback coils. These are the mass position outputs, which cover a range of ±4 V. Zero volts means the moving mass would be perfectly balanced even if there was no force feedback. An offset in the mass position voltage means that the equilibrium position of the mass has moved off centre and a small DC feedback current is being applied to hold the mass at its centre operating point. The Trillium 40 is not subject to any significant degradation in performance until one or more mass positions exceed approximately ±3.5 V. This value represents the limit of available current to the force feedback coil. When this limit is exceeded, the main velocity output signal will drift to the rail and cease to provide useful information about ground motion.

The mass centring process itself introduces large glitches with the ground motion signal for about 1 minute while the axes are rebalanced. Therefore, to prevent data loss, you should only recentre the seismometer when necessary. The recommended best practice regarding mechanical mass centring is to periodically check the three axis mass positions (analog signals U_MP, V_MP, and W_MP, referenced to AGND) and initiate mass centring if any are approaching ±3.5 V.

Mass positions in seismometers can drift over time for two reasons:

a) Tilt

   Circumstances such as compaction of soil, changes in moisture, frost heaving, or the expansion of structures in hot sun may cause the ground under the seismometer to tilt.

b) Temperature

   Some climates experience vast temperature changes between seasons. Such drastic changes in temperature can cause seismometer masses to become decentred.

These two phenomena are easily distinguished. Simply speaking, the effects of temperature appear in the sum of all of the mass positions, while the effects of tilt appear in the differences between mass positions. You can use the equations in Section 5.2 “UVW and XYZ Output Signals” on page 25 to convert UVW to XYZ mass positions. Changes in the Z mass position correspond to changes in internal temperature, while changes in the X and Z mass positions correspond to tilt towards the east and north, respectively.

The mass positions in Trillium 40 seismometers have low sensitivity to both tilt and temperature and usually do not require recentring after the initial installation:

- The tilt range of a Trillium 40 before recentring is required is ±0.65°. This tilt range is enough to accommodate instability of the ground, even in a temporary field deployment, as long as basic care is taken to ensure a stable mounting surface for the seismometer.

- Trillium 40 seismometers have a temperature range of ±35 °C without requiring recentring. This temperature range is wide enough that the seismometer can endure significant seasonal temperature changes without requiring recentring.

As one or more of the masses in a Trillium 40 seismometer approach the range limit of ±4 V, the seismometer is subject to some degradation in performance. Low frequency self-noise increases by approximately 3 dB per V of mass position. Below ±1 V, the effect on noise is negligible. However, as the mass positions approach ±4 V, the noise level goes up to –150 dB m^2/s^4/Hz at 100 s period. Depending on the site and the type of study being conducted, this increase in the noise level may or may not be an issue.

Although it is unlikely that recentring will be required in Trillium 40 seismometers after the initial installation, it is good practice to check mass positions when visiting the installation site. You can also use Nanometrics systems and software to remotely monitor the mass positions in Trillium 40 seismometers.

7.2 Choosing When to Initiate Mass Centring

Following are circumstances when you should mechanically centre the masses in Trillium 40 seismometers:

- Immediately following installation and levelling.
- When the voltage of any of the three axis mass positions (analog signals U_MP, V_MP, and W_MP, referenced to AGND) approach ±3.5 V.

7.3 Centring the Masses in Trillium 40 Seismometers

Use the following procedure to centre the masses on a Trillium 40 seismometer. This procedure requires a 2.0 mm hex screwdriver with a long shaft and a 2.5 mm hex screwdriver. Both screwdrivers are supplied in the Trillium Maintenance Kit that ships with the seismometer.

Trillium 40 seismometers with serial numbers 903 and above use a 2.0 mm hex screwdriver for mass centring. Trillium 40 seismometers with serial numbers 1 to 902 may need a 1.5 mm or 2.0 mm hex screwdriver. Use the screwdriver that came in your maintenance kit or make sure you have a 1.5 mm and a 2.0 mm hex screwdriver available when visiting the site.

All Trillium 40 seismometers use the same 2.5 mm hex screwdriver to remove the access seal screws. A 2.5 mm hex screwdriver is also included in the Trillium Maintenance Kit.

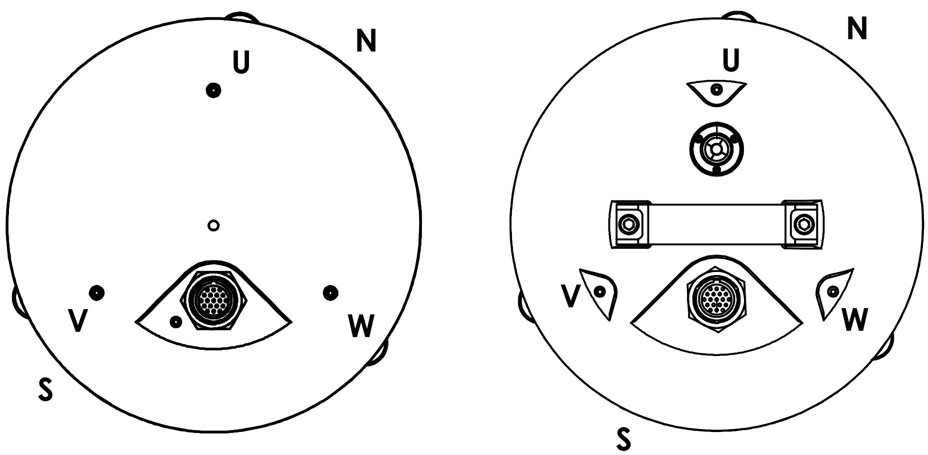
1. Check the voltage readings on the mass position outputs for each of the three channels (signals U_MP, V_MP, and W_MP, referenced to AGND) to determine whether mass centring is required. If any of the mass position outputs exceed ±3.5 V, continue with the mass centring procedure.

If you have a Taurus (or Taurus-attached Trident 305), check the mass position status on the **Sensor** page. If you have a networked Trident, check the mass position status on the Nanometrics UI **Trident** > **Operation** > **Instrument** page or on the NaqsView **View** > **Mass Position and Centering** page. See the user guides for these products for more information.

2. Set the Trillium 40 to SP mode using one of the following methods:
   a) Short the MC control signal to ground.
   b) Use the interface for a connected Taurus or Trident.
      i. If you have a Taurus or Trident 305, go to the **Sensor** page and select SP mode.
      ii. If you have a networked Trident with Nanometrics UI, set Line 2 Level to Low and pull the MC pin low, referenced to DGND (pin R), for at least 1 s. See the Trident and Nanometrics UI user guides for more information.
3. Locate and remove the access seal screw (see U, V, W labelled screws for the enclosure matching your serial number in Figure 7-1) corresponding to the channel of interest (a channel where the mass position voltage is approaching or above ±3.5 V):

Do not remove more than one access seal screw at a time during mass centring.

Figure 7-1 Location of access seal screws for mass centring



Trillium 40 enclosure:
Serial numbers 1 to 902

Trillium 40 enclosure:
Serial numbers 903 and above

   a) Using the 2.5 mm hex screwdriver, remove the appropriate seal screw.
   b) Inspect the O-ring for damage such cuts or pitting and replace the seal screw with a new one from the maintenance kit if there appears to be damage.
   c) Place the seal screw where it will remain clean during the mass centring procedure.

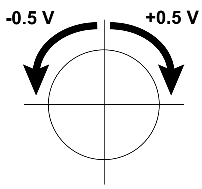
4. With the seal screw removed centre the mass for the selected channel:

   For units with serial numbers 1 to 902, do not loosen the mass position adjustment screws completely. If any of these screws become unseated, the unit will require factory repair to replace the screw. Should the screw become unthreaded but remain in place, you can carefully rethread it by turning the screw clockwise.

   For units with serial numbers 903 and above, there is a retention device that prevents the screw from being completely removed. Do not force the screw beyond this stop.

   a) Insert the 2.0 mm hex screwdriver (as noted at the beginning of this section, units with serial numbers 1 to 902 may use a 1.5 mm hex screwdriver) straight into the hole until it engages with the mass position adjustment screw head.

   b) Monitor the mass position output while adjusting the screw by small increments.



   Clockwise adjustments of a mass position adjustment screw results in positive changes in the mass position output, and counter-clockwise adjustments result in negative changes. One quarter turn is approximately equal to ±0.5 V. When the mass position output is less than ±0.3 V, the adjustment is complete.

   If the mass position output voltage does not change when you turn the screw, check the following three conditions:

   i. Ensure you are adjusting the channel corresponding to the mass position output you are monitoring.

   ii. Ensure the seismometer is in SP mode. In LP mode the mass position outputs change too slowly to be useful in mass centring.

   iii. If the mass position output is greater than ±3.5 V, ensure the seismometer is precisely levelled and that you are turning the screw in the correct direction.

5. Using the 2.5 mm hex screwdriver, replace the seal screw, tightening it to hand-tight, or 9 pound-force inches (10 kilogram-force centimetres).

6. Return the seismometer to LP mode using one of the following methods:

   a) Set the MC control signal (pin C) to float, referenced to DGND (pin R).

   b) Use the interface for a connected Taurus or Trident.

   i. If you have a Taurus (or Taurus-attached Trident 305), go to the **Sensor** page and select LP mode.

   ii. If you have a networked Trident with Nanometrics UI, set Line 2 Level to High. See the Trident and Nanometrics UI user guides for more information.

Part 3
Reference

- Specifications
- Transfer Function
- Connector and Cables
- Alignment Features and Dimensions
- Glossary

Chapter 8
Specifications

8.1 Technology

Table 8-1 Technology specifications

Topology	Symmetric triaxial
Feedback	Coil-magnet force feedback with capacitive transducer
Mass Centring	Operates over full temperature range without manual recentring Manual centring control included
Levelling	Integrated bubble level Adjustable locking levelling feet
Alignment	Vertical scribe marks for north-south 5/16 in. diameter holes on east-west axis for alignment rods

8.2 Interface

Table 8-2 Interface specifications

Connector	19-pin MIL-C-26482, mounted in cover
Velocity output	Selectable XYZ (east, north, vertical) or UVW mode 16 Vpp differential
Mass position output	Three independent ±4.0 V outputs for UVW
Calibration input	Remote calibration in XYZ or UVW mode Single voltage input with one open-drain active-low control signal per channel
Control input	Isolated active-low referenced to DGND

8.3 Power

Table 8-3 Power specifications

Supply voltage	9 V to 36 V DC isolated intput at connector
Power consumption	See Section 5.5 "Power Consumption" on page 25 for typical power consumption scenarios
Protection	Reverse-voltage protection Fuse: • Serial number 0 to 179: 0.125 A replaceable fuse • Serial number 180 and beyond: 0.3 A self-resetting fuse

8.4 Physical

Table 8-4 Physical specifications

	Serial numbers 1 to 902:	Serial numbers 903 and above:
Enclosure	Machined aluminum top with stainless steel base	Machined aluminum
Diameter	22 cm	22 cm
Height	17.4 cm without levelling feet 20.1 cm with levelling feet fully retracted 21.4 cm with levelling feet fully extended	17.8 cm without levelling feet 20.1 cm with levelling feet fully retracted 21.4 cm with levelling feet fully extended
Weight	11 kg	7.1 kg
Handle	None	Detachable handle on case
Parasitic resonances	None below 200 Hz	None below 200 Hz

8.5 Performance

Table 8-5 Performance specifications

Self-noise	See Figure 9-2 "Trillium 40 self-noise" on page 42
Sensitivity	Within ±0.5% of nominal. See Table 9-1 "Ground motion response nominal parameters" on page 40
Bandwidth	–3 dB points are 40.2 s and 85.5 Hz
Transfer function	◆ Lower corner poles within ±0.5% of nominal provided ◆ See Figure 9-1 "Bode plot for Trillium 40 seismometers" on page 39
Clip level	> 5 mm/s
Lower corner damping relative to critical	0.707
Output impedance	2 x 100Ω ±1%
Temperature	±35 °C without recentring
Tilt	Operational tilt range is ±2°
Dynamic tilt	Maximum tilt without recentring is ±0.65°

8.6 Environmental

Table 8-6 Environmental specifications

Operating temperature	–20 °C to 50 °C
Storage temperature	–40 °C to 70 °C
Pressure	Enclosure designed 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

Chapter 9
Transfer Function

9.1 Frequency Response

Figure 9-1 "Bode plot for Trillium 40 seismometers" on page 39 is a bode plot that shows the nominal ground motion, calibration input circuit, and combined calibration response for Trillium 40 seismometers.

In this figure:

- The nominal ground motion frequency response of the seismometer is a solid red line.
- The calibration input circuit response is a dash-dotted green line and behaves effectively as a simple low-pass circuit in series with the ground motion response.
- During calibration, the sensor calibration response is the combination of the two lines referenced above and is a dashed blue line.

Figure 9-1 Bode plot for Trillium 40 seismometers

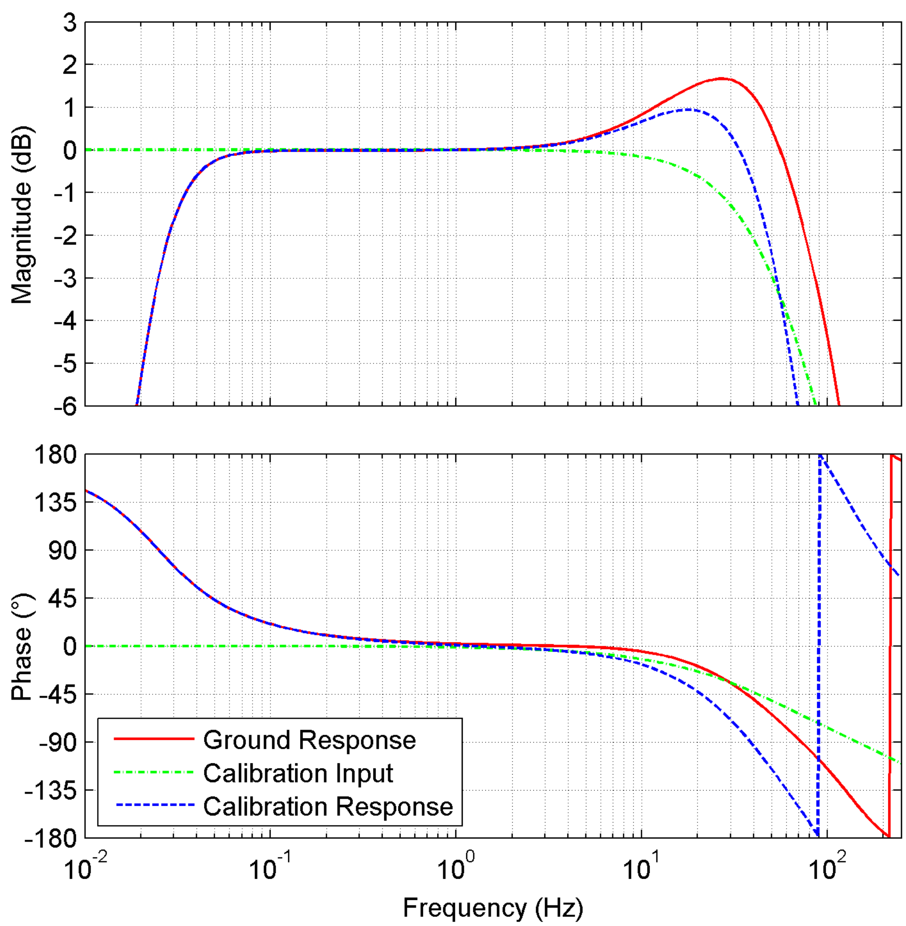


Table 9-1 provides the ground motion response nominal parameters. The ground motion response has –3 dB corners at 40.2 s and 85.5 Hz. The ground motion sensitivity at f_0 specified in Table 9-1 assumes an infinite input impedance at the digitizer. For digitizers with low input impedance, it will become necessary to account for the fact that source impedance of the differential outputs is 300 Ω, ±1 percent (150 Ω for each output).

Table 9-1 Ground motion response nominal parameters

Symbol	Parameter	Nominal Values	Units
z_n	Zeros	0 0 –68.8 –323 –2530	rad/s
p_n	Poles	–0.1103 ±0.1110i –86.3 –241 ±178i –535 ±719i	rad/s
k	Normalization factor	1.104×10^5	$(\text{rad/s})^2$
f_0	Normalization frequency	1	Hz
S	Ground motion sensitivity at f_0	1553	V·s/m

The seismometer sensitivity (S), poles (p_n), and zeros (z_n) define the transfer function according to this equation:

$$F(s) = S \cdot k \cdot \frac{\prod_n (s - z_n)}{\prod_n (s - p_n)} \qquad \text{(EQ 1)}$$

Where the normalization factor (k) is defined by

$$k = \frac{1}{\dfrac{\prod_n (i2\pi f_0 - z_n)}{\prod_n (i2\pi f_0 - p_n)}} \qquad \text{(EQ 2)}$$

and is given for informational purposes only.

The calibration input response nominal parameters are given in Table 9-2.

Table 9-2 Calibration input response nominal parameters

Symbol	Parameter	Nominal Values	Units
z_n	Zeros		rad/s
p_n	Poles	–323 –2530	rad/s
k	Normalization factor	8.172 x 10^5	$(rad/s)^2$
f_0	Normalization frequency	1	Hz
S	Calibration input sensitivity at f_0	0.00976	$(m/s^2)/V$

The calibration input poles effectively cancel the corresponding zeros in the ground motion response during calibration. Thus the nominal parameters of the combined calibration response are as shown in Table 9-3.

Table 9-3 Combined calibration response nominal parameters

Symbol	Parameter	Nominal Values	Units
z_n	Zeros	0 0 –68.8	rad/s
p_n	Poles	–0.1103 ±0.1110i –86.3 –241 ±178i –535 ±719i	rad/s
k	Normalization factor	9.025 x 10^{10}	$(rad/s)^4$
f_0	Normalization frequency	1	Hz
S	Combined calibration sensitivity at f_0	15.15	rad/s

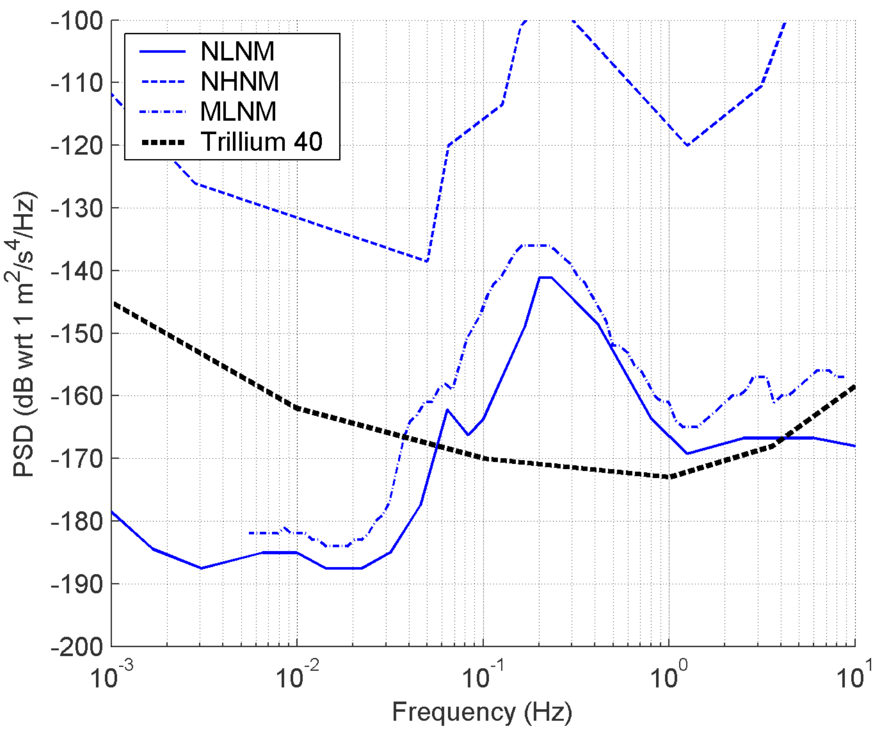
When a measured electrical calibration result is to be used to convert the seismometer output signals to ground motion, the result must be divided by the nominal calibration input. In practice this means simply adding the nominal poles from Table 9-2 “Calibration input response nominal parameters” on page 41 to the set of measured zeros.

The units of the combined calibration response are rad/s because the calibration input produces an equivalent acceleration, while the seismometer passband is flat to velocity. Therefore, to determine the expected gain for a sinusoidal calibration, you must divide the sensitivity listed in Table 9-3 “Combined calibration response nominal parameters” on page 41 by 2π*f*, where *f* is the frequency of the sinusoid.

9.2 Self-Noise

Figure 9-2 plots typical self-noise for Trillium 40 seismometers. Three curves are included for reference: Peterson's new low-noise model (NLNM) and new high-noise model (NHNM), and McNamara and Buland's probability density function (PDF) mode low noise model (MLNM).[1] The noise floor shown is the typical level of instrument self-noise given proper installation. To achieve best performance for any seismometer, careful attention to detail must be paid to choice of site, vault design, and seismometer installation. See Chapter 2 "Selecting and Preparing a Site" and Chapter 3 "Installing a Trillium 40."

Figure 9-2 Trillium 40 self-noise



1. See also:
Jon Peterson, *Observations and Modeling of Seismic Background Noise, Open-File Report* 93-922 (Albuquerque, New Mexico: U.S. Department of Interior Geological Survey, 1993).
Daniel E. McNamara and Raymond P. Buland, "Ambient Noise Levels in the Continental United States," *Bulletin of the Seismological Society of America* 94, 4 (August 2004): 1517–1527.
John F. Clinton and Thomas H. Heaton, "Potential Advantages of a Strong-motion Velocity Meter over a Strong-motion Accelerometer," Seismological Research Letters 73, 3 (May/June 2002): 332–342.

Chapter 10
Connector and Cables

10.1 Connector Pinout

The Trillium 40 connector is a 19-pin male military circular type hermetic connector. Table 10-1 provides the connector pinout.

Table 10-1 Connector pinout

Pin	Name	Function	Type
L	Z+/W+	Vertical (W axis) output	16 Vpp 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	±4.0 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 UVW instead of XYZ outputs	Active-low open drain
C	MC	Enable short period mode	
R	DGND	Digital ground	N/A
shell	CHASSIS	For shielding and safety	N/A

10.2 Seismometer Cable Pinout

A seismometer cable may be included with your Trillium 40. A label with the part number is located on the cable. Use the appropriate pinout table for the appropriate cable as a reference when wiring the seismometer cable to a digitizer connector.

Table 10-2 provides the pinout for part number 16169–nM (where n is the length of the cable in metres). This is a cable with a Trillium right-angled connector on one end and Nanometrics digitizer connector on the other end for connecting a Taurus or Trident.

Table 10-2 Seismometer cable wiring for cable 16169–nM (for Nanometrics digitizers)

Nanometrics Digitizer			Seismometer			Wire Colour	Run
Connector	Pin	Name	Connector	Pin	Name		
P1	U	CH1+	P2	L	Z+/W+	Brown	1
P1	C	CH1-	P2	M	Z-/W-	Black	1
P1	B	CH1 GND				DRAIN	1
P1	A	CH2+	P2	N	Y+/V+	Orange	2
P1	S	CH2-	P2	A	Y-/V-	Black	2
P1	T	CH2 GND				DRAIN	2
P1	a	CH3+	P2	P	X+/U+	Yellow	3
P1	P	CH3-	P2	B	X-/U-	Black	3
P1	R	CH3 GND				DRAIN	3
P1	N	CAL1+	P2	T	CAL_SIG	White	
P1	Z	CAL1-/CTRL4	P2	U	W_CALEN	Black	
P1	c	CAL2-/CTRL5	P2	J	V_CALEN	Brown	
P1	Y	CAL3-/CTRL6	P2	K	U_CALEN	Red	
P1	K	EXT_SOH1	P2	S	W_MP	Orange	
P1	X	EXT_SOH2	P2	F	V_MP	Yellow	
P1	J	EXT_SOH3	P2	E	U_MP	Green	
P1	B	CH1 GND	P2	V	AGND	Pink	
P1	F	SEN +12V	P2	H	+PWR	Red	4
P1	D	SEN RTN	P2	G	-PWR	Black	4
P1	b	CHGND				DRAIN	4
P1	H	CTRL1	P2	D	UVW	Blue	
P1	W	CTRL2	P2	C	MC	Purple	
P1	V	DGND	P2	R	DGND	Grey	
P1	M	CAL2+	P1	N	CAL1+	Yellow	
P1	L	CAL3+	P1	M	CAL2+	Yellow	
P1		SHELL	P2		SHELL/BAND	Overall/Shield	
P1	G	CTRL3					
P1	E	SEN -12V					

Table 10-3 provides the pinout for part number 16170–nM (where n is the length of the cable in metres). This is a cable with a Trillium right-angled connector on one end and open-ended at the other end for attaching the connector of a third-party digitizer. Use Table 10-3 as a worksheet for attaching your digitizer connector to the cable.

Table 10-3 Seismometer cable wiring for cable 16170–nM (open-ended cable)

Seismometer			Digitizer			Wire Colour	Run
Connector	Pin	Name	Connector	Pin	Name		
P1	L	Z+/W+	P2		CH1+	Brown	1
P1	M	Z-/W-	P2		CH1-	Black	1
P1					CH1 GND	DRAIN	1
P1	N	Y+/V+	P2		CH2+	Orange	2
P1	A	Y-/V-	P2		CH2-	Black	2
P1					CH2 GND	DRAIN	2
P1	P	X+/U+	P2		CH3+	Yellow	3
P1	B	X-/U-	P2		CH3-	Black	3
P1					CH3 GND	DRAIN	3
P1	T	CAL_SIG	P2		CAL1+	White	
P1	U	W_CALEN	P2		CAL1-	Black	
P1	J	V_CALEN	P2		CAL2-	Brown	
P1	K	U_CALEN	P2		CAL3-	Red	
P1	S	W_MP	P2		EXT_SOH1	Orange	
P1	F	V_MP	P2		EXT_SOH2	Yellow	
P1	E	U_MP	P2		EXT_SOH3	Green	
P1	V	AGND	P2		CH1 GND	Pink	
P1	H	+PWR	P2		SEN +12V	Red	4
P1	G	-PWR	P2		SEN RTN	Black	4
P1			P2		CHGND	DRAIN	4
P1	D	UVW	P2		CTRL1	Blue	
P1	C	MC	P2		CTRL2	Purple	
P1	R	DGND	P2		DGND	Grey	
P1		Shell/Band	P2		Shell	Overall/Shield	

10.3 Cable Design Guidelines

If you are designing your own cable, use the following cable design guidelines:

- Include effective EMI shielding in the cable design.

Double-shielded twisted-pair cable is a good choice for EMI shielding as 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 radio-frequency shielding.

- Use the DGND for the return currents of the control signals (U_CALEN, V_CALEN, W_CALEN, UVW and MC).
- Use the AGND for the return currents of the analog signals (CAL_SIG, U_MP, V_MP, and W_MP).

AGND is connected to CHGND inside the seismometer. If AGND is connected through the cable, the case of the Trillium 40 should be isolated from earth ground to prevent a ground loop.

- Ensure that the cable capacitance does not exceed 10 nF. For Nanometrics cables, this corresponds to 25 m.
- Ensure the cable length is sufficient to allow for strain relief.
- Ensure that the peak current requirement of the Trillium 40 does not result in a voltage drop along the cable which takes the power supply voltage below the minimum required at the Trillium 40. See Table 8-3 "Power specifications" on page 37.
- Ensure the cable is watertight.
- Check the cable electrically after assembly. In particular, ensure that the individual and overall shields are not shorted together unless so specified.
- Make sure cables are labelled with correct drawing numbers and revisions.
- Make sure the digitizer is configured so that the default states of the control lines put the Trillium 40 in the desired state.

Chapter 11

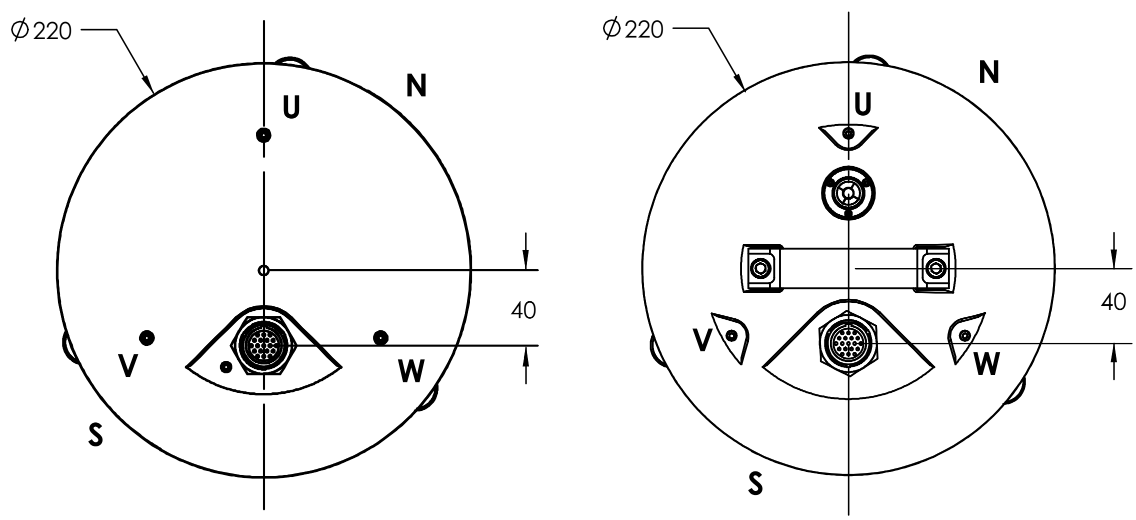
Alignment Features and Dimensions

11.1 Top View of Alignment Features

Figure 11-1 is an illustration that shows the relative orientation of the east-west and north-south alignment features on the enclosure for Trillium 40 seismometers with serial numbers 1 to 902 and on the enclosure for Trillium 40 seismometers with serial numbers 903 and above.

Dimensions in Figure 11-1 are in millimetres unless otherwise stated.

Figure 11-1 Top view of alignment features



Trillium 40 enclosure:
Serial numbers 1 to 902

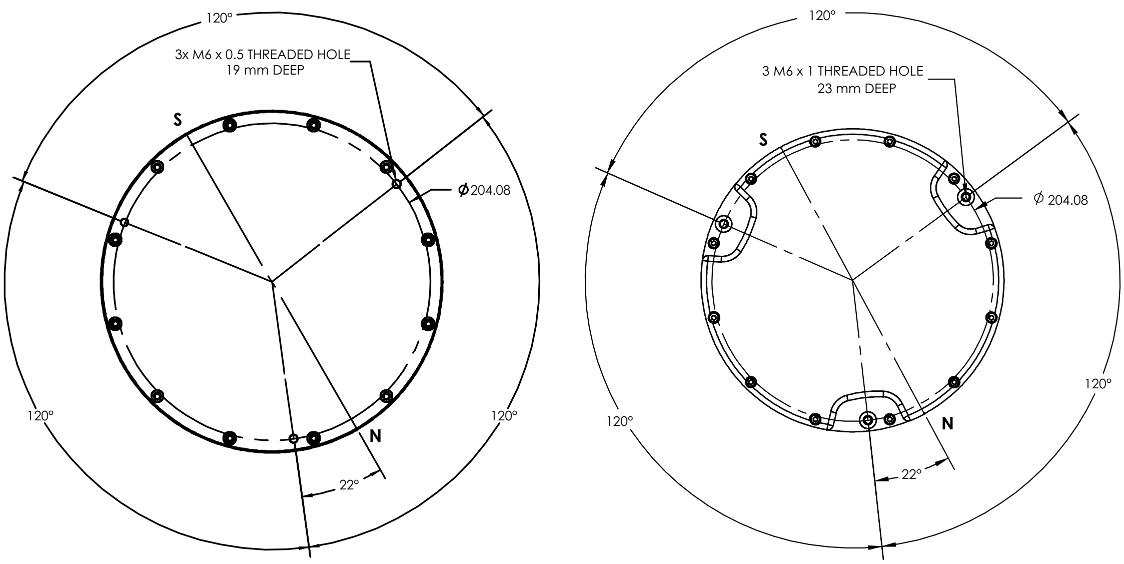
Trillium 40 enclosure:
Serial numbers 903 and above

11.2 Bottom View of Alignment Features and Dimensions

Figure 11-2 is an illustration that shows the relative orientation of the east-west and north-south alignment features and dimensions on the enclosure for Trillium 40 seismometers with serial numbers 1 to 902 and on the enclosure for Trillium 40 seismometers with serial numbers 903 and above.

Dimensions in Figure 11-2 are in millimetres unless otherwise stated.

Figure 11-2 Bottom view of alignment features and dimensions



Trillium 40 enclosure:
Serial numbers 1 to 902

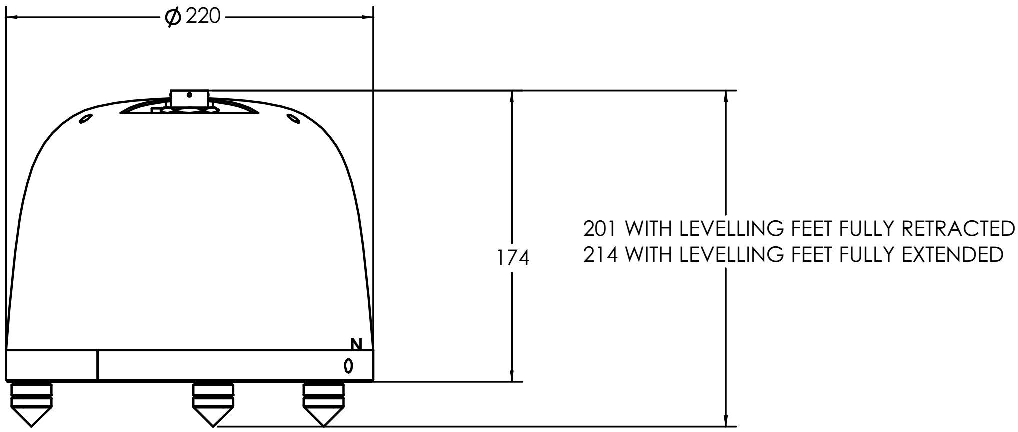
Trillium 40 enclosure:
Serial numbers 903 and above

11.3 Side View of DImensions

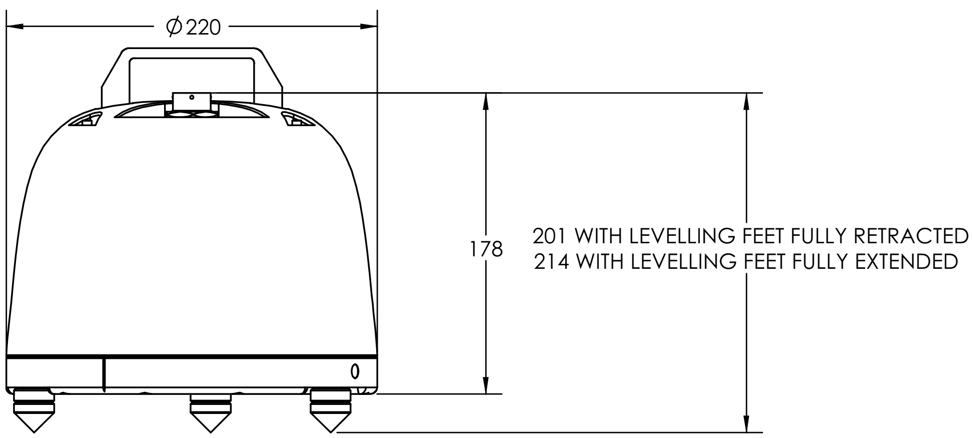
Figure 11-3 is an illustration that shows a side view of the alignment features and dimensions on the enclosure for Trillium 40 seismometers with serial numbers 1 to 902 and on the enclosure for Trillium 40 seismometers with serial numbers 903 and above.

Dimensions in Figure 11-3 are in millimetres unless otherwise stated.

Figure 11-3 Side view of alignment features and dimensions



Trillium 40 enclosure: Serial numbers 1 to 902



Trillium 40 enclosure: Serial numbers 903 and above

Appendix A
Glossary

A.1 Glossary of Abbreviations and Terms

A

AGND

Reference to analog ground in Nanometrics cable designs.

AWG

American Wire Gauge

C

CHGND

Reference to chassis ground in Nanometrics cable designs.

D

DGND

Reference to digital ground in Nanometrics cable designs.

E

EMI

Electromagnetic Interference

G

GPS

Global Positioning System

M

MLNM

Mode Low Noise Model

N

NEMA

National Electrical Manufacturers Association

NHNM

New High-Noise Model

NLNM

New Low-Noise Model

P

PDF

Probability Density Function

PWR

Power

R

RMA

Return Merchandise Authorization

T

TCP/IP

Transmission Control Protocol/Internet Protocol

A.2 List of Unit Abbreviations and Symbols

Table A-1 provides a list of unit abbreviations and symbols commonly used in Nanometrics documentation.

Table A-1 Unit Abbreviations and Symbols

Abbreviation or Symbol	Definition
°	degree
Ø	diameter
µ	micro
Ω	ohm
A	ampere
AC	alternating current
b	bit
B	byte
bps	bits per second
C	Celsius
cm	centimetre
dB	decibel
DC	direct current
F	farad
ft.	foot
g	gram
g	gravity
GB	gigabyte
GHz	gigahertz
Hz	hertz
in.	inch
KB	kilobyte
kg	kilogram
kHz	kilohertz
kΩ	kiloohm
kW	kilowatt
L	litre

Abbreviation or Symbol	Definition
lb	pound
m	metre
m/s	metre per second
m/s^2	metre per second, squared
mA	milliampere
MB	megabyte
MΩ	megaohm
MHz	megahertz
mi.	mile
mL	millilitre
mm	millimetre
ms	millisecond
MTU	maximum transmission unit
mV	millivolt
mW	milliwatt
N	Newton
nF	nanofarad
ns	nanosecond
rad	radian
rad/s	radian per second
s	second
sps	samples per second
U	rack unit
V	volt
Vpp	Volts peak-to-peak
W	watt

About Nanometrics

Nanometrics is a world leader in the development of precision instrumentation, network technology, and software applications for seismological and environmental studies. Using Nanometrics technology, our customers establish and grow research networks that are often located in extreme environments such as the frozen Arctic and Antarctic, the arid deserts of the Middle East, the jungles of South America, and the depths of the world's oceans. Many of these are mission-critical national and regional networks that demand the highest possible data quality and availability.

Nanometrics provides end-to-end solutions that include a growing portfolio of broadband and strong motion seismometers, dataloggers and digitizers, satellite ground station systems for remote site data collection, and software applications for data and network analysis and management. To support this portfolio, Nanometrics also provides global systems engineering services for design, installation, and support of complete networks.

Our head office, research and development centre, and production facility are located in the Kanata North Business Park of Ottawa, the high-technology heart of Canada's capital region.

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Contacting Technical Support

If you need technical support please submit a request on the Nanometrics technical support site or by email or fax. Include a full explanation of the problem and related information such as log files.

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