Trillium 360 GSN

SEISMOMETERS FOR GLOBAL SEISMIC MONITORING

User Guide

June 14, 2022

nanometrics

Strategic Intelligence Fueled by Science

 The Trillium 360 GSN User Guide applies to the following model numbers:

Product Name	Model Number	Part Number
Trillium 360 GSN Borehole	T360-BH1-GSN	18995
Trillium 360 GSN Posthole	T360-PH1-GSN	18998
Trillium 360 GSN Vault	T360-SV1-GSN	19013
Trillium 360 GSN Posthole, Polar Environment	T360-PH1-GSN-XC	18998-01
Trillium 360 GSN Vault, Polar Environment	T360-SV1-GSN-XC	19013-01
Trillium Holelock Controller	T-BHL-C	17465

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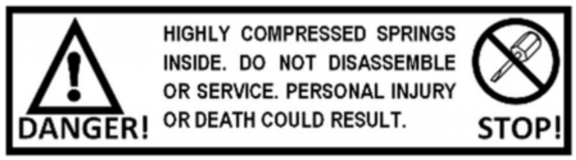
The Trillium Borehole Holelock on the Trillium 360 GSN Borehole seismometer is used to hold and clamp the seismometer against the side of the borehole casing. The holelock is encased in a stainless steel tube and consists of a high-tension, spring loaded pin, three side-mounted clamping studs, and an actuator that controls the pin. The holelock, particularly the springs, must not be disassembled or serviced outside of the factory as releasing the springs could result in personal injury or death. If you require assistance with the Trillium Borehole Holelock, contact see "Contact Technical Support " on page 140. The following warning label is affixed to the holelock assembly:



Part number: 19307R2
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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.

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`”).

Revision number 19307R2 includes the following changes:

- Updated sensitivity values for all form factors. See "Frequency Response" on page 111
- Added details throughout the guide that are specific to the new models T360-PH1-GSN-XC and T360-SV1-GSN-XC for use in Polar environments.
- Added recommendations for installation in saline groundwater environments. See "Selecting a Site for a Posthole Installation " on page 40
- Provided further details for seismometer installation. See Installing a Borehole on page 22, Installing a Posthole on page 39 and Installing a Vault on page 55.
- Updated product service warnings. See "Technical Support and Maintenance" on page 20.
- Provided further details for " Configuring the Centaur for the Trillium 360 GSN" on page 84
- General updates to specifications. See "Specifications" on page 102
- Formatting and typographical changes.

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Chapter 1 - Getting Started

1.1 About the Trillium 360 GSN

Building on the proven technologies of the Trillium 360, the Trillium 360 GSN is a next-generation seismometer providing full bandwidth coverage for global seismology, regional and local monitoring with a single instrument. The Trillium 360 GSN seismometer is available as a Borehole, a Posthole or a Surface Vault, offering a Trillium 360 GSN to suit any application. If you are recapitalizing a global seismic network, the Trillium 360 GSN allows you to replace long and short-period instruments with one that will provide the entire bandwidth. In addition, if the site is encroached upon by development, the Posthole and Borehole options help to limit cultural noise.

The advantages of the different form factors are as follows:

- Trillium 360 GSN Borehole allows emplacement deep into bedrock and thereby provides the best possible noise performance for permanent teleseismic observatory stations.
- Trillium 360 GSN Posthole is a versatile instrument requiring the minimum of site preparation, enabling high performance in temporary or remote installation sites. Also in permanent networks its low logistical costs enable a larger number of stations for a given budget, potentially maximizing performance of the total seismic network.
- Trillium 360 GSN Vault is suitable to replace older instruments within an existing infrastructure of seismic vaults, or for new installations in underground structures such as tunnels or mines.

Features of the Trillium 360 GSN product line include:

- Very broadband, exceptional performance that meets operational requirements for the USGS/IRIS Global Seismic Network (GSN)
    - Meets USGS Class A+ Requirements
    - An extended low frequency range useful out to beyond a 10 000-second time period
    - The ability to resolve below Peterson's new low-noise model (NLNM)
    - A wide bandwidth of 0.0027 Hz (360 s) to 80 Hz

    - A wide dynamic range with a clip level of ±10 mm/s
    - Lowest magnetic sensitivity of any broadband seismometer
- Additional Trillium 360 GSN Vault features include:
    - Automatic motorized recentering, can be remotely initiated
    - Patented thermal stability system
- Additional Trillium 360 GSN Posthole features include:
    - Robust, waterproof, stainless steel enclosure to protect from hostile environments
    - Automatic leveling and mass centering, can be remotely initiated
- Additional Trillium 360 GSN Borehole features include:
    - Designed for cased boreholes
    - Robust holelock with fail-safe release mechanism

1.2 Unpacking and Handling a Trillium 360 GSN seismometer

The shipping box and packing material for the Trillium 360 GSN 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 360 GSN seismometers must always be transported in packaging approved by Nanometrics. Save the original packaging and reuse it any time you are transporting a Trillium 360 GSN seismometer. If custom packaging is required for a particular application, please consult Nanometrics (see "Contact Us" on page 140).

After delivering a Trillium 360 GSN seismometer 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 360 GSN seismometers do not require any mass lock mechanisms. These seismometers are 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.

For the Trillium 360 GSN Borehole, after unpacking, attach the bottom end pipe (actuator guard) by screwing it into the threaded hole in the bottom of the Trillium 360 GSN Borehole seismometer until it is tight. This pipe protects the actuator shaft that extends through this hole when the Trillium Borehole Holelock is operated.

When re-packaging the unit for shipment, be sure to retract the actuator shaft and remove the bottom end pipe from the Trillium 360 GSN Borehole.

The Trillium Borehole Holelock should always be stored or shipped in the locked state (locking pin fully extended) to minimize the stress on the internal mechanics.

1.3 Cables and Accessories

Nanometrics offers optional equipment, that can be purchased separately, that add convenience to the installation and use of your Trillium 360 GSN seismometer. This section describes a number of these options. Table 1-1, Table 1-2, and Table 1-3 list the cables and accessories available for the Trillium 360 GSN Posthole, Trillium 360 GSN Borehole, and Trillium 360 GSN Vault respectively. Table 1-4 lists the contents of the lifting cable kit.

Table 1-1 - List of cables and accessories for the Trillium 360 GSN Borehole

Name	Part Number	Description
Cable, Seismometer, Borehole to Nanometrics Digitizer	17442-xxM where xx refers to the length in meters.	Double-shielded, heavy duty cable with a straight connector at one end for connecting to a Trillium 360 GSN Borehole seismometer and a 26-pin connector at the other end for connecting to a Centaur digitizer or to the Trillium Holelock Controller. Suitable for buried deployments to depths of 65 m with a 12 V power system or depths of up to 300 m with a 24 V power system. In addition to connecting the analog inputs, power, and control line signals to the digitizing and data logging features of the digitizer, this cable provides access to the Web interface of the seismometer through the Web interface of the digitizer. This cable is also compatible with the Trillium 360 GSN Posthole variant.

Table 1-1 - List of cables and accessories for the Trillium 360 GSN Borehole (Continued)

Name	Part Number	Description
Cable, Trillium Posthole/Borehole seismometer to Serial Port and Power	17280-xxM where xx refers to the cable length in meters.	This cable, which is used for lab testing, provides serial communications and power to the Trillium 360 GSN seismometer. On one end, the cable has a 20-pin connector that attaches to the connector of the Trillium 360 GSN seismometer. From this connector, the cable splits into two 3 m lengths; one with a DB-9 serial connector that connects to the serial port of a computer, and the other with a two-prong banana plug for power. This cable is used for accessing the Web interface of the Trillium 360 GSN seismometer using a SLIP connection. For more information, refer to the Nanometrics technical note *Accessing Your Nanometrics Smart Sensor Web Interface*, or go to support.nanometrics.ca. The standard length of this cable is 3 m. This cable is also compatible with the Trillium 360 GSN Posthole variant.
Cable, seismometer to open-end or third party digitizer	Contact Nanometrics	Contact Nanometrics for a full listing of open-ended cables and cables with connectors to third party digitizers. See "Contact Us" on page 140.
Trillium Holelock Controller	17465	A control unit used on the surface at the installation site to control the Trillium Borehole Holelock (lock/unlock).
Power Cable, Power source to Trillium Holelock Controller	14268-xxM	A shielded 18 AWG power cable xxM=length in meters.
Clamping stud extender kit, Trillium Holelock, 152-156 mm	18150-152	Use to allow you to install a Trillium 360 GSN Borehole in cased hole with an inside diameter of 152 to 156 mm. See "Changing the Clamping Diameter of the Trillium Borehole Holelock" on page 31 for more detail.
Clamping stud extender kit, Trillium Holelock, 191-199 mm	18150-191	Use to allow you to install a Trillium 360 GSN Borehole in cased hole with an inside diameter of 191 to 199 mm. See "Changing the Clamping Diameter of the Trillium Borehole Holelock" on page 31 for more detail.

Table 1-1 - List of cables and accessories for the Trillium 360 GSN Borehole (Continued)

Name	Part Number	Description
Clamping stud extender kit, Trillium Holelock, 201-209 mm ID	18150-205	Use to allow you to install a Trillium 360 GSN Borehole in cased hole with an inside diameter of 201 to 209 mm. See "Changing the Clamping Diameter of the Trillium Borehole Holelock" on page 31 for more detail.
Trillium Cascadia PH/BH Integration Kit for Trillium PH or Trillium BH to Titan PH	18411	The integration bracket kit enables you to connect the Titan Posthole accelerometer with either a Trillium 360 GSN Borehole or a Trillium 360 GSN Posthole seismometer for simultaneous installation in the same borehole or posthole.
Lifting Cable Kit, Trillium/Meridian Posthole and Borehole, 3/16" 316SS Cable, Harsh Env	18276-xxM where xx refers to the cable length in meters.	For use when installing the Trillium 360 GSN Borehole or Trillium 360 GSN Posthole. This kit includes a lifting cable, cable clamps, cable ties. When the cable is more than 50 m in length the kit also includes a magnetic cable strain relief and borehole cable clamp. See Table 1-4 for a detailed component list.

Table 1-2 - List of cables and accessories for the Trillium 360 GSN Posthole

Name	Part Number	Description
Cable, Seismometer, Posthole to Nanometrics digitizer	17782-xxM where xx refers to the cable length in meters.	A cable that connects the Trillium 360 GSN Posthole to a Nanometrics digitizer. It has 20 AWG power wires and can be used in lengths up to 65 m with a 12 V power system or up to 300 m with a 24 V power system. This cable has a rugged polyurethane jacket suitable for direct burial.

Table 1-2 - List of cables and accessories for the Trillium 360 GSN Posthole (Continued)

Name	Part Number	Description
Cable, Seismometer, Borehole to Nanometrics Digitizer	17442-xxM where xx refers to the length in meters.	Double-shielded, heavy duty cable with a straight connector at one end for connecting to a Trillium 360 GSN Borehole seismometer and a 26-pin connector at the other end for connecting to a Centaur digitizer or to the Trillium Holelock Controller. Suitable for buried deployments to depths of 65 m with a 12 V power system or depths of up to 300 m with a 24 V power system. In addition to connecting the analog inputs, power, and control line signals to the digitizing and data logging features of the digitizer, this cable provides access to the Web interface of the seismometer through the Web interface of the digitizer. This cable is also compatible with the Trillium 360 GSN Borehole variant.
Cable, Seismometer, Trillium Posthole to Open-end, polyurethane jacket	17852-nM where n is the length in meters	A cable with a glass reinforced epoxy connector on one end that connects to the Trillium 360 GSN connector and is open-ended at the other end. This cable has a rugged polyurethane and 20 gauge power wires. In addition to connecting the analog outputs, power, and control line signals to the digitizing and data logging features of the digitizer, this cable also provides access to the Web interface of the seismometer through the Web interface of the digitizer.

Table 1-2 - List of cables and accessories for the Trillium 360 GSN Posthole (Continued)

Name	Part Number	Description
Cable, Trillium Posthole/Borehole seismometer to Serial Port and Power	17280-xxM where xx refers to the cable length in meters.	This cable, which is used for lab testing, provides serial communications and power to the Trillium 360 GSN seismometer. On one end, the cable has a 20-pin connector that attaches to the connector of the Trillium 360 GSN seismometer. From this connector, the cable splits into two 3 m lengths; one with a DB-9 serial connector that connects to the serial port of a computer, and the other with a two-prong banana plug for power. This cable is used for accessing the Web interface of the Trillium 360 GSN seismometer using a SLIP connection. For more information, refer to the Nanometrics technical note *Accessing Your Nanometrics Smart Sensor Web Interface*, or go to support.nanometrics.ca. The standard length of this cable is 3 m. This cable is also compatible with the Trillium 360 GSN Borehole.
Trillium Cascadia PH/BH Integration Kit for Trillium PH or Trillium BH to Titan PH	18411	The integration bracket kit enables you to connect the Titan Posthole accelerometer with either a Trillium 360 GSN Borehole or a Trillium 360 GSN Posthole seismometer for simultaneous installation in the same borehole or posthole.
Lifting Cable Kit, Trillium/Meridian Posthole and Borehole, 3/16" 316SS Cable, Harsh Env	18276-xxM where xx refers to the cable length in meters.	For use when installing the Trillium 360 GSN Borehole or Trillium 360 GSN Posthole. This kit includes a lifting cable, cable clamps, cable ties. When the cable is more than 50 m in length the kit also includes a magnetic cable strain relief and borehole cable clamp. See Table 1-4 for a detailed component list.

Table 1-3 - List of cables and accessories for the Trillium 360 GSN Vault

Name	Part number	Description
Cable, Seismometer, Trillium 19-Pin Right-angle to Nanometrics Digitizer	16169-xxM where xx refers to the length in meters	Double-shielded, ultra-flexible cable with Trillium 360 GSN Vault seismometer right-angled connector on one end and Nanometrics digital recorder connector on the other end for connecting a Centaur. Standard cable lengths are 3 m, 5 m, 10 m, 15 m and 25 m. Custom cable lengths are available upon request.

Table 1-3 - List of cables and accessories for the Trillium 360 GSN Vault (Continued)

Name	Part number	Description
Cable, Trillium Vault, 19-Pin Right-angle to Nanometrics Digitizer, Polar, PU Jacket	19870-xxM	Double-shielded, flexible polyurethane cable with one connector at each end. The right-angled connector on one end connects to a Trillium 360 GSN Vault seismometer and the other end connects to a Nanometrics digital recorder. Suitable for vault or buried deployments in ultra-low temperature installations. xxM refers to the length of the cable in meters.
Cable, Trillium VBB Power/Serial	CAB15766	Cable to provide power to the Trillium 360 GSN Vault seismometer and enable serial communications between the seismometer and a laptop. Standard cable length is 3 m. Custom cable lengths are available upon request.
Cable, seismometer to open-end or third party digitizer	Contact Nanometrics	Contact Nanometrics for a full listing of open-ended cables and cables with connectors to third party digitizers. See "Contact Us" on page 140.
Alignment rods	Contact Nanometrics	Rods that fit into the 5/16 in. diameter holes on the base of a Trillium 360 GSN Vault seismometer that are used for aligning the seismometer to north-south. Contact Nanometrics for more details. See "Contact Us" on page 140.
Trillium 240/360 Insulating Cover	16060	Easily installed system that provides thermal insulation and protection from external air currents, including a foam base gasket and a rigid form-fitting cover matched to the Trillium 360 GSN Vault. Properly installed, the cover attenuates temperature-induced long period noise by up to 40 dB. Requires a flexible cable with a right-angle connector.

Table 1-4 - List of Contents for Lifting Cable Kit 18276

Qty	Part Number	Description
1	18279-xxM	Lifting cable, T120 Borehole, 316SS, Harsh Env xxM=length in meters.

Table 1-4 - List of Contents for Lifting Cable Kit 18276 (Continued)

Qty	Part Number	Description
1	17313	Wellhead Cable Clamp, for 3/16” Stainless Steel Lifting Cable
1	15251	Wellhead Cable Clamp for seismometer Cable
1	HDW1301	Shackle, 1000 lbs load, SS
*	MSC0360	Cable Tie, Harsh Env, 8” *Quantity depends on cable length. 1 tie wrap around seismometer cable and wire rope every 5 m.
If the cable is 50 m or longer the following items are also included with 18276-xxM		
1	18277	Magnetic Cable Strain Relief, T-120 Borehole, Harsh Env Included with kit, but not required for sand installations.
*	18274	Cable Clamp, Trillium Borehole, Harsh Env *Not required for cables less than 40 m in length. For cables over 40 m in length, quantity depends on cable length. 1 clamp every 20 to 25 m.

1.4 Technical Support and Maintenance

If you need technical support, please submit your request by email. Include a full explanation of the problem and any supporting information (such as a screen capture of the observed problem, 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 to obtain an RMA (Return Merchandise Authorization) number. Email us at techsupport@nanometrics.ca or see "Contact Technical Support " on page 140.

The mechanical and electronic elements of the Trillium 360 GSN seismometers 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 auto-leveling and mass centering mechanism is designed to be jam-proof.

Contents may become pressurized under normal use and handling. Do not attempt to open the seismometer as this may cause severe personal injury if not handled correctly. Please return seismometers to Nanometrics for servicing.

Seismometers are sealed using security screws to prevent unauthorized opening and tampering. Unauthorized opening of the unit may cause damage to the seismometer and will void the warranty. Please return the seismometer to Nanometrics for servicing.

1.4.1 Recording Your Serial Number and IP Address

Before installing your Trillium 360 GSN seismometer, it is important to record both the serial number and the IP address of the unit. Both numbers are located on the label.

Keep this information readily available. You will need to reference the serial number when contacting Technical Support. You will need the IP address of the unit to access its Web interface. See "Configuring Serial Communications" on page 93 for more information.

If the IP address of the unit is not recorded, it can be calculated later using the serial number. See "Calculating the IP Address" on page 94.

Chapter 2 - Installing a Trillium 360 GSN Borehole Seismometer

2.1 Borehole Installation Overview

The following steps for installing a Trillium 360 GSN Borehole in a borehole are described throughout this guide:

1. "Selecting a Site for a Borehole Installation" on the next page
2. "Best Practices for Borehole Installations" on page 24
3. "Preventative Maintenance of Connectors" on page 41
4. "Installing a Trillium 360 GSN Borehole seismometer" on page 26
5. "Connecting the Digitizer to the Trillium 360 GSN Borehole " on page 33
6. "Verifying connection with the Centaur digital recorder" on page 43
7. "Aligning the Trillium 360 GSN Borehole using a Surface Seismometer" on page 32

Once you have completed the installation of your Trillium 360 GSN Borehole, you can proceed to configure the digital recorder. See "Configuring Your System" on page 84 and refer to the *Centaur User Guide (17935)*

2.2 Tools and equipment for a Borehole installation

The following tools and equipment are required for installing a Trillium 360 GSN Borehole. See "Cables and Accessories" on page 14 for more detail.

2.2.1 Contents of a Typical Trillium 360 GSN Borehole Shipment

The Trillium 360 GSN Borehole seismometer shipment is comprised of 3 boxes that include the following typical contents:

- 1 - Trillium 360 GSN Borehole model T360-BH1-GSN seismometer
- 1 - Borehole seismometer to digitizer cable (Ordered separately)
- 1 - Lifting Cable Kit (See Table 1-4 for a full listing of the kit contents)

2.2.2 Additional tools and equipment

In addition to the contents of the shipment, you will need the following tools and equipment:

- A tripod and winch or another means for lowering the Trillium 360 GSN Borehole seismometer down the hole in a controlled manner
- Trillium Holelock Controller (See Table 1-1 for more detail)
- Power cable for Trillium Holelock Controller (See Table 1-1 for more detail)
- A 24 VDC 10 A power source for the Trillium Holelock Controller
- 3 mm (7/64 in.) Allen key for securing magnetic cable strain relief in place

2.3 Selecting a Site for a Borehole Installation

A hole bored into bedrock can provide excellent low frequency noise performance even in urban areas. High frequency performance will also be better at depth than at the surface although the best performance will be attained at remote sites. Consider the following factors when selecting a site:

- Accessibility to the site for both the drilling equipment and maintenance personnel
- Availability of power and some form of communication capability (if desired)
- Cultural activity near the site
- Ability to provide adequate security for the site
- Proximity to a coastline (should be at least several km away)
- Depth to bedrock (borehole should extend down into bedrock for best performance)

The borehole seismometer is designed to withstand long-term immersion in fresh water. However it can be corroded by salt, which may be encountered in groundwater near sea coasts and in some desert environments. In environments with saline groundwater we recommend that the seismometer should either be installed at a depth above the water table or in a sealed plastic casing.

2.4 Best Practices for Borehole Installations

Refer to the Nanometrics technical note on *Borehole Drilling Requirements* and the following best practices to minimize potential installation issues.

A Trillium 360 GSN Borehole seismometer is designed to be installed in a dry, cased borehole with a minimum diameter greater than or equal to 152 mm (5.98 in.). The standard version includes clamping studs to fit a borehole casing with an inner diameter of 156 to 170 mm (6.14 to 6.69 in.). See "Changing the Clamping Diameter of the Trillium Borehole Holelock" on page 31 for instructions on installing the clamping studs. For diameters outside of this range, contact Nanometrics to purchase an alternate clamping stud kit.

Although the Trillium 360 GSN Borehole seismometer is designed for immersion up to 300 m, the Trillium Borehole Holelock motor is only designed for up to 30 m immersion. If the holelock motor fails, the seismometer can easily be extracted using the instructions in "Retrieving the Instruments from a Borehole Manually" on page 75.

- Ensure that the local driller you hire to construct the borehole is aware of the requirements of the Trillium 360 GSN Borehole seismometer and make sure that they are provided with detailed drilling and construction specifications to ensure that the finished borehole will be suitable for a seismic observatory installation. These specifications should include diameter, working depth, type of casing, verticality, and water-tightness.
- To prevent dirt and tools from falling into the hole, keep it capped or covered as often as possible during installation.
- Since the total length of the Trillium 360 GSN Borehole seismometer and Trillium Borehole Holelock is 1050 mm and since the wellhead will be 0.5 to 1 m in height, we recommend that you use a tripod that is at least 2.7 m high to ensure that the winch can raise the instrument above the wellhead.

The winch should only be operated by persons suitably trained to do so and who are familiar with any local regulations for this type of a device.

The stall force of the winch must be less than the rated load of the tripod and lifting cable to prevent breakage if the equipment becomes jammed or snagged during lifting.

- To help you determine the depth of the installation, you should measure out the cable before lowering it and mark it so you know when you have reached the targeted depth. Alternatively, you could use a winch with a depth gauge.

2.5 Preventative Maintenance of Connectors

Prior to each deployment, inspect the O-rings on the seismometer and cable connectors and replace them if necessary. Once greased and mated the O-rings will be well protected and will not need to be serviced during the course of a field deployment.

To prolong the life of the O-rings, follow the guidelines in this section:

- **Unpacking**. Nanometrics seismometers and cables ship with protective dustcaps on the connectors. For best protection of the connectors, keep and re-use the dustcaps for later transport or storage of the equipment.
- **Storage.** Nitrile O-rings are vulnerable to ozone damage in air and therefore have a limited shelf life of 1 year in open air or 5 years in their original packaging. Greasing the O-rings will extend their life. Mating the connectors will also extend the life of the O-rings.
- **Inspecting the connector O-rings**
  - Prior to mating, verify that both O-rings are present, undamaged, clean, and lightly greased.
  - If the O-ring is dry, lightly stretch it to inspect for cracks. If cracks are present, discard the O-ring and obtain an equivalent replacement of the same size and material from any O-ring supply company.
  - If an O-ring is missing or damaged, obtain an equivalent replacement of the same size and material from any O-ring supply company.

- If the O-rings are dirty, remove them gently with tweezers, wipe them clean without stretching them, re-grease and replace them. They may be greased with a small amount of any standard O-ring or vacuum grease.

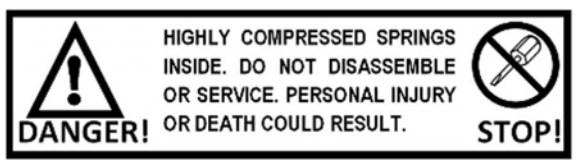
If you need to replace a connector O-ring, use one of the following:

- **Instrument connector O-ring:** size 2-016 neoprene or nitrile rubber
- **Cable connector O-ring:** size 2-017 neoprene or nitrile rubber

2.6 Installing a Trillium 360 GSN Borehole seismometer

Use the instructions in this section and Lifting cable kit (18276) to deploy a Trillium 360 GSN Borehole seismometer in a cased borehole.

The Trillium Borehole Holelock on the Trillium 360 GSN Borehole seismometer is used to hold and clamp the seismometer against the side of the borehole casing. The holelock is encased in a stainless steel tube and consists of a high-tension, spring loaded pin, three side-mounted clamping studs, and an actuator that controls the pin. The holelock, particularly the springs, must not be disassembled or serviced outside of the factory as releasing the springs could result in personal injury or death. If you require assistance with the Trillium Borehole Holelock, contact see "Contact Technical Support " on page 140. The following warning label is affixed to the holelock assembly:



1. Prepare the hole for the installation. Refer to the Nanometrics technical note *Borehole Drilling Requirements* and "Best Practices for Borehole Installations" on page 24 for further information.
2. If required, change the clamping diameter of the Trillium Borehole Holelock as specified in "Changing the Clamping Diameter of the Trillium Borehole Holelock" on page 31.
3. Ground the system using the guidelines in "Grounding guidelines " on page 132.
4. Connect the Trillium Holelock Controller. If the locking pin of the Trillium Borehole Holelock is in a locked state (extended), you have to unlock it before you can lower it

down the hole. The Trillium Holelock Controller is used on the surface at the installation site to control the Trillium Borehole Holelock (lock/unlock). To unlock the pin:

   a. Connect the seismometer end of the seismometer cable to the Trillium 360 GSN Borehole seismometer.
   b. Connect the digitizer end of the seismometer cable and a 24 VDC 10 A power source to the Trillium Holelock Controller.
   c. Press and hold the **Holelock Enable** button and then move the **Holelock Control** toggle switch on the Trillium Holelock Controller in the direction of **Unlock** and hold it there until the Unlocked LED on the Trillium Holelock Controller turns green (approximately 10 seconds).
      - The Unlocking LED comes on first and then the Unlocked LED comes on when the Trillium Borehole Holelock is unlocked.
      - You can then release the **Holelock Control** toggle switch and the **Holelock Enable** button.

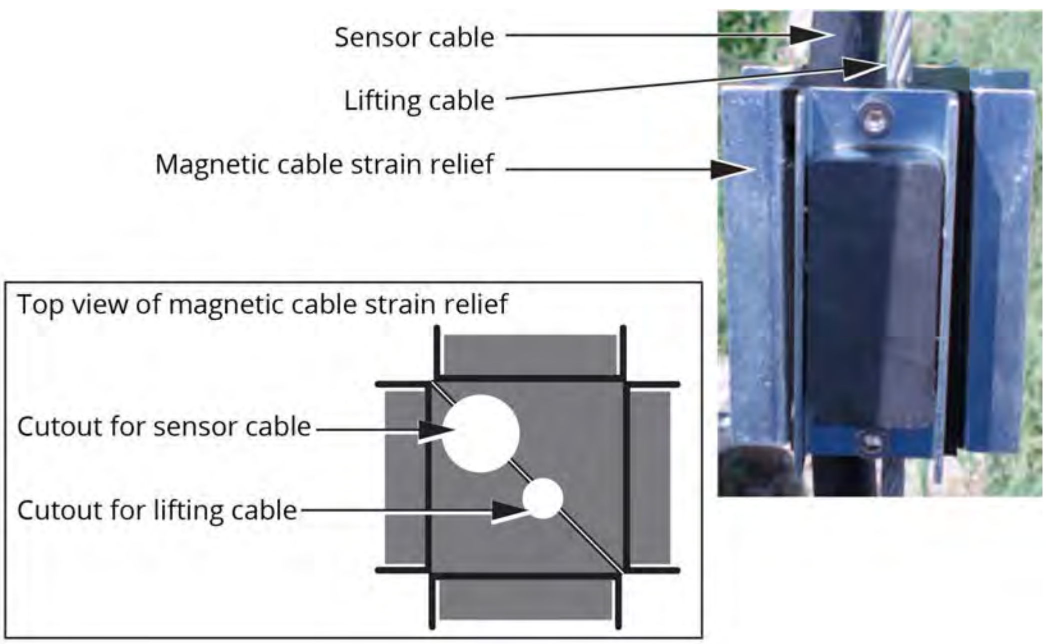
The winch should only be operated by persons who are suitably trained to do so and who are familiar with any local regulations for this type of a device. The stall force of the winch must be less than the rated load of the tripod and lifting wire rope to prevent breakage if the equipment becomes jammed or snagged during lifting. Failure to follow safety instructions may result in severe personal injury, death or damage to property.

5. Lay out, in a straight line if possible, the sensor cable and the lifting cable (also known as a wire rope).
6. Attach the load-bearing lifting cable to the on the top of the seismometer.
7. To prevent vibrations on the cable, attach the magnetic strain relief (see the tip "Preventing vibrations on cable"):
   a. Attach the magnetic cable strain relief to both the sensor cable and the lifting cable 2.0 meters above the top of the seismometer (see Figure 2-1). Ensure that you allow a little slack in the sensor cable when you attach the magnetic cable strain relief so that the weight of the seismometer is supported by the load-bearing lifting cable.

b. Insert the thicker sensor cable into the wider cutout in the magnetic cable lock and insert the thinner load-bearing lifting cable into the narrower cutout. Use a screwdriver to securely tighten the screws (1 N•m or 9 inch-pounds).

> **Preventing vibrations on cable.** The magnetic cable strain relief is used to prevent any vibrations that travel down the lifting cable and the sensor cable from being transferred to the seismometer. When the Trillium Borehole Holelock is locked and the tension is removed from the lifting cable and sensor cable, the magnetic cable strain relief uses magnetic force to attach itself to the side of the cased hole. This ensures that the 2.0 m of sensor cable and lifting cable between it and the top of the seismometer are not under any strain and are isolated from vibration or motion of the cable and lifting cable that occurs above the magnetic cable strain relief.

Figure 2-1 - Magnetic cable strain relief



8. Use the tripod and winch to lift the seismometer and holelock off of the ground and position it over the hole.
9. Lower the Trillium 360 GSN Borehole seismometer and Trillium Borehole Holelock into the hole to the targeted depth ensuring that cable tie wraps are tied around both the sensor cable and the lifting cable approximately every 5 meters to keep

them together and ensure that the load is placed on the load-bearing lifting cable and not on the sensor cable.

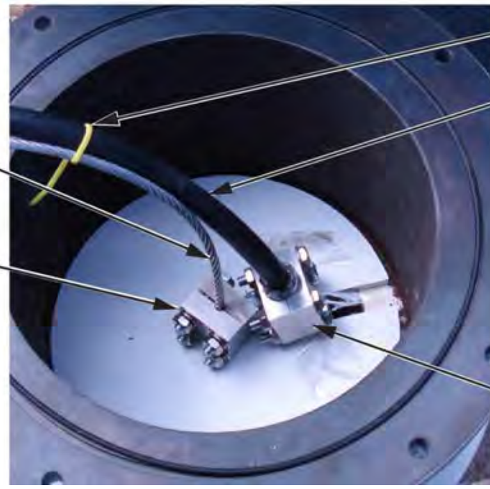
10. Using the Trillium Borehole cable clamps, secure the electrical cable together with the lifting cable, allowing the lifting cable to bear the weight of the electrical cable. After 40 m, place one cable clamp every 20 to 25 m.

Never unlock the Trillium Borehole Holelock while the load-bearing lifting cable has some slack. If this happens, the Trillium 360 GSN Borehole seismometer and Trillium Borehole Holelock will drop down suddenly and possibly be damaged.

Before you unlock it, you must remove all slack in the cables by raising them slowly (by winch) until the cable is drawn tight.

11. Lock the Trillium Borehole Holelock by pressing and holding the **Holelock Enable** button on the Trillium Holelock Controller and then moving the **Holelock Control** toggle switch in the direction of **Lock** and holding it there until the Locked LED turns green (approximately 10 seconds). The Locking LED comes on first and then the Locked LED comes on when the Trillium Borehole Holelock is locked. After you release the toggle switch, it will return to the middle position and the Locked LED will turn off. You can then release the **Holelock Enable** button.
12. Now that the Trillium Borehole Holelock is locked, you can engage the magnetic cable strain relief by lowering the cables another 40 cm (approximately).
13. Optionally, if you have serial communications to the sensor (a Centaur digitizer or SLIP appliance is recommended for this), access the State of Health page and verify that the case tilt is within the leveling range of the instrument (±5° for the standard version). If not, it may be possible to correct this by pulling up on the cable to move the seismometer to a shallower depth where the hole may be more vertical. If excessive tilt cannot be corrected, it is likely because the hole is non-vertical at the bottom end.
14. Inside the wellhead box, attach the wellhead cable clamp to the lifting cable and the seismometer cable clamp to the seismometer cable to hold them in place when the winch is removed (See Figure 2-2).

Figure 2-2 - Cable clamps at wellhead



15. Disconnect the Trillium Holelock Controller from the seismometer cable.
16. Connect the seismometer to a digitizer (see "Connecting the Digitizer to the Trillium 360 GSN Borehole " on page 33) and verify the connection ("Verifying connection with the Centaur digital recorder" on page 43).
17. Initiate auto-leveling. For more information, "About Leveling and Mass Centering" on page 88. It may take up to 20 minutes for the leveling operation to complete.
18. Verify a level installation by checking that the mass positions are within an acceptable range (within ±1 V of zero). Auto-leveling should result in mass positions that are within ±1 V of zero for all three U, V, and W axes. See "Viewing the Real-time Mass Position" on page 97.
19. Close and seal the hole.

> A cased hole must be covered at the top to prevent it filling with water. This cover must secure and stabilize the load-bearing and seismometer cables. The cables should enter the wellhead box through a waterproof gland and a waterproof cover or shed should be positioned over the wellhead to provide long-term security, watertightness, and thermal insulation.

20. Check the mass positions to verify that the Trillium 360 GSN Borehole seismometer and Trillium Holelock Controller are undisturbed. If necessary, initiate auto-leveling again.

You might want to perform auto-leveling again one to two days after installation because the temperature down in the borehole will likely be significantly different than the temperature at the surface.

2.6.1 Changing the Clamping Diameter of the Trillium Borehole Holelock

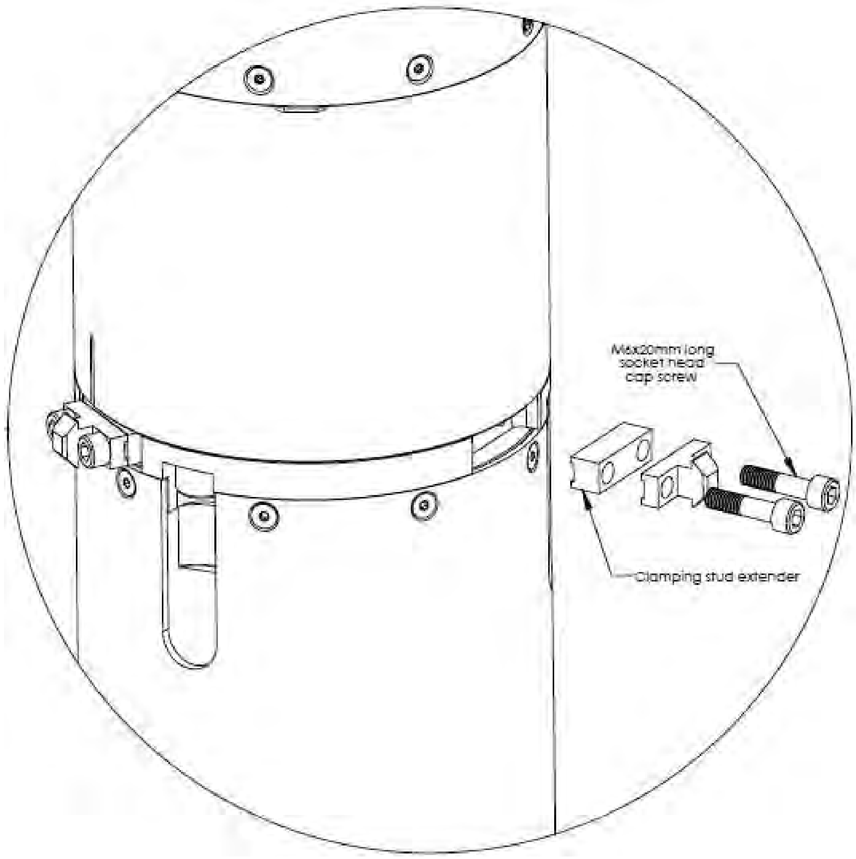
The standard version of the Trillium 360 GSN Borehole seismometer includes three clamping studs to fit a borehole casing with an inner diameter of 156 to 170 mm (6.14 to 6.69 in.). Table 2-1 provides information on how to install the optional extenders to change the clamping diameter of the Trillium Borehole Holelock to fit different borehole casing diameters (see also Figure 2-3). For further information, please refer to *Nanometrics Instruction Sheet 18150, Trillium 120 Borehole Holelock Extender Kit Assembly Instructions*.

Table 2-1 - Trillium Borehole Holelock clamping diameter ranges

Borehole casing diameter range		**Clamping stud extender kit (P/N)**
in mm	**in inches**	
152 to 156	5.98 to 6.14	18150-152
156 to 162	6.14 to 6.38	Included with the Holelock
162 to 170	6.38 to 6.69	Included with the Holelock along with 3 clamping stud extenders
191 to 199	7.52 to 7.83	18150-191
201 to 209	7.91 to 8.23	18150-205

In all instances, torque the screws to 9 N•m (80 inch-pounds)

Figure 2-3 - Extending the Trillium Borehole Holelock clamping studs



2.7 Aligning the Trillium 360 GSN Borehole using a Surface Seismometer

You can use a seismometer installed at the surface to determine the orientation of the horizontal (X and Y) components of the Trillium 360 GSN seismometer once it has been installed in the hole. This method involves comparing the recorded output of both seismometers and computing the relative direction of seismic wave motion to determine the relative azimuth of the down-hole seismometer compared to the surface seismometer.

When you install the reference seismometer on the surface, ensure that you align it carefully in a known orientation. After both seismometers have been installed, leave the installations undisturbed for at least one hour while collecting data from both. When you are ready to perform your data analysis, ensure that your post-processing software is equipped to apply a rotation transformation, allowing it to measure and correct the relative azimuth. Take note of the values and enter them on the Centaur in the Digitizer Orientation Correction configuration feature. See the *Centaur user guide (17935)* for instructions.

> **Orientation correction.** You should record the actual azimuth. This value can be used to perform field data rotation to correct the sensor orientation for instances where the physical orientation of a deployed three-component geophysical sensor is different than what is desired, resulting in output X, Y and Z signals that do not represent the desired directions of sensitivity (typically East, North and Vertical). See the *Orientation correction* sections in the *Centaur User Guide (17935)* for more detail.

One advantage of this method of alignment is that it allows you to verify the performance of the down-hole instrument: it should be quieter than the surface instrument.

Contact Nanometrics (see "Contact Technical Support " on page 140) for more information on using this method of alignment.

2.8 Connecting the Digitizer to the Trillium 360 GSN Borehole

Use the guidelines in this section to connect the Centaur digital recorder and the Trillium 360 GSN.

1. Power up the digital recorder. You can continue with the steps in this procedure while the digital recorder is booting up.
2. Using the appropriate seismometer to digitizer cable, see "Cables and Accessories" on page 14, attach the seismometer connector to the Trillium 360 GSN making sure that the guides on the cable connector align with the notches on the Trillium 360 GSN.
3. Attach the other end of the cable to the digital recorder, making sure that the guides on the cable connector align with the notches on the digital recorder.

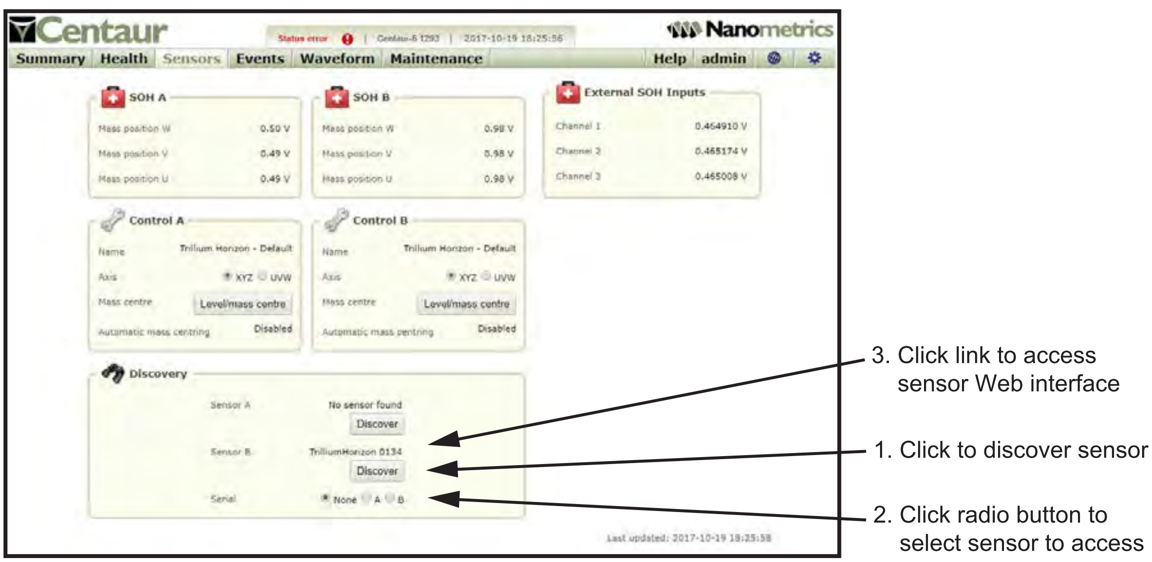
Once powered up, the digital recorder will provide pass-through power to the seismometer as well as feedback regarding seismometer operation.

2.9 Verifying connection with the Centaur digital recorder

Use the guidelines in this section to verify that the connection between the Centaur digital recorder and the Trillium 360 GSN was successful.

1. Once the Centaur has booted up, using a Web-enabled device such as a laptop, login to the Centaur and Discover the seismometer as follows, see Figure 2-4:
   a. Navigate to the **Sensors** page.
   b. For each sensor, click on the **Discover** button.
   c. Once a sensor has been discovered, a link will display above the **Discover** button. You can access the sensor's web page by clicking on the appropriate Serial radio button, then clicking on the link.
2. Return to "Installing a Trillium 360 GSN Borehole seismometer" on page 26 to initiate auto-leveling.

Figure 2-4 - Centaur Web interface Sensors page



2.10 Retrieving the Instruments from a Borehole

Never unlock the Trillium Borehole Holelock when the load-bearing wire rope has some slack. If this happens, the Trillium 360 GSN Borehole seismometer and Trillium Borehole Holelock will drop down suddenly and possibly be damaged. Before you unlock it, you must remove all slack in the wire rope by raising it with the winch.

To retrieve the Trillium 360 GSN Borehole seismometer and Trillium Borehole Holelock from a borehole:

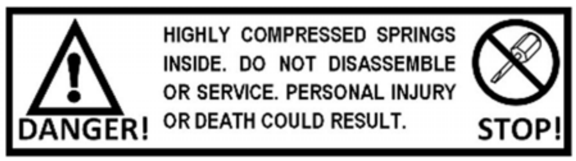
1. Disconnect the seismometer cable from the digitizer and reconnect the Trillium Holelock Controller to the seismometer cable at the surface of the installation.
2. Remove the borehole cover/seal.
3. Raise the wire rope slowly with the winch to take up all slack and put tension on the wire rope.
4. Press and hold the **Holelock Enable** button on the Trillium Holelock Controller and then move the **Holelock Control** toggle switch in the direction of **Unlock** and hold it there until the Unlocked LED on the Trillium Holelock Controller turns green. (This takes approximately 10 seconds.)
5. Raise the Trillium 360 GSN Borehole seismometer and Trillium Borehole Holelock out of the borehole.

Although the Trillium 360 GSN Borehole seismometer is designed for immersion up to 300 m, the Trillium Borehole Holelock motor is only designed for up to 30 m immersion.

In the event that the Trillium Borehole Holelock unlocking procedure fails or the Trillium Holelock Controller or appropriate power to operate the Trillium Holelock Controller is not available, see "Retrieving the Instruments from a Borehole Manually" on page 75 for instructions on how to retrieve the Trillium 360 GSN Borehole seismometer and Trillium Borehole Holelock.

2.11 Attaching the Trillium Borehole Holelock to the Trillium 360 GSN Borehole seismometer

The Trillium Borehole Holelock on the Trillium 360 GSN Borehole seismometer is used to hold and clamp the seismometer against the side of the borehole casing. The holelock is encased in a stainless steel tube and consists of a high-tension, spring loaded pin, three side-mounted clamping studs, and an actuator that controls the pin. The holelock, particularly the springs, must not be disassembled or serviced outside of the factory as releasing the springs could result in personal injury or death. If you require assistance with the Trillium Borehole Holelock, contact see "Contact Technical Support " on page 140. The following warning label is affixed to the holelock assembly:



The Trillium 360 GSN Borehole seismometer and the Trillium Borehole Holelock are normally shipped preassembled. If they were shipped separately, you have to attach the Trillium Borehole Holelock to the Trillium 360 GSN Borehole seismometer before you install it in the borehole. To do this, you will need the following:

- Shipped with the Trillium Borehole Holelock:
    - O-ring with an inner diameter of 1.0625 in. and an outer diameter of 1.25 in.
    - Three M10X1.5X16 hex socket cap screws
- One 8 mm (5/16 in.) Allen key (for the M10X1.5X16 screws)
- O-ring or vacuum grease

The Trillium Borehole Holelock is shipped in a locked state. If you want to try unlocking it before you attach it to the Trillium 360 GSN Borehole seismometer, connect the plus terminal of a +24 V power supply to pin 2 of the 2-pin male connector on top of the Trillium Borehole Holelock and the negative terminal to pin 1. You can lock it again by connecting the plus terminal to pin 1 and the negative terminal to pin 2 of the connector.

Use the following steps to attach the Trillium Borehole Holelock to the Trillium 360 GSN Borehole seismometer:

1. Lay the Trillium Borehole Holelock and the Trillium 360 GSN Borehole seismometer horizontally on a clean and flat surface, align them with each other so that the locking pin on the side of the Trillium Borehole Holelock lines up with the south line on the Trillium 360 GSN Borehole seismometer, and place the top of the Trillium Borehole Holelock close to the bottom of the Trillium 360 GSN Borehole seismometer.
2. Apply a thin layer of O-ring or vacuum grease to the Trillium Borehole Holelock O-ring and insert it into the O-ring groove on the top of the Trillium Borehole Holelock.
3. Take the 2-pin male connector out of the hole at the top of the Trillium Borehole Holelock and extend it enough that you can connect it to the female connector on the bottom of the Trillium 360 GSN Borehole seismometer.
4. Once connected, slide the Trillium 360 GSN Borehole seismometer closer to the Trillium Borehole Holelock so that the 2-pin male connector goes all the way back in the hole at the top of the Trillium Borehole Holelock.
5. Align the M10x1.5 screw holes in the bottom of the Trillium 360 GSN Borehole seismometer with the clearance holes in the top of the Trillium Borehole Holelock.
6. Insert three M10 screws into the holes in the Trillium Borehole Holelock and use the 8 mm Allen key to torque them to 20 N•m (180 inch-pounds).
7. Continuing with 2 people, stand the seismometer upright and have one person holding the seismometer for the remaining steps.
8. Slide the magnetic shield onto the holelock/seismometer assembly.
9. Align the holes in the shield with the clamping stud screw holes on the Trillium 360 GSN Borehole.
10. Attach the topmost two clamping studs to the holelock. See "Changing the Clamping Diameter of the Trillium Borehole Holelock" on page 31.

The Trillium Borehole Holelock is now securely attached to the Trillium 360 GSN Borehole seismometer and you are ready to start the installation (see "Installing a Trillium 360 GSN Borehole seismometer" on page 26).

2.12 Installation Checklist for the Trillium 360 GSN Borehole seismometer

Use the following checklist to help you verify that you have completed all of the necessary steps in the installation of your Trillium 360 GSN Borehole .

	Check that connector O-rings are present, undamaged, clean, and lightly greased.
	Borehole is prepared according to best practices.
	Trillium 360 GSN Borehole is auto-leveled and mass centered.
	The holelock is properly locked.
	Trillium 360 GSN Borehole serial number and IP address is noted.
	If alignment was accomplished using the surface seismometer method, ensure that Orientation Correction values have been entered on the Centaur.
	Cable is connected to the Trillium 360 GSN Borehole and the digitizer.
	Cable is clamped at the wellhead.
	System is correctly grounded according to guidelines in grounding section.

Chapter 3 - Installing a Trillium 360 GSN Posthole Seismometer

3.1 Posthole Installation Overview

The following steps for installing a Trillium 360 GSN Posthole seismometer are described throughout this guide:

1. "Selecting a Site for a Posthole Installation " on the next page
2. "Pre-Installation Preparation" on page 41
3. "Preventative Maintenance of Connectors" on page 41
4. "Grounding guidelines " on page 132
5. "Connecting the Centaur digital recorder and the Trillium 360 GSN" on page 42
6. "Verifying connection with the Centaur digital recorder" on page 43
7. Installing, aligning a Trillium 360 GSN Posthole either by:
    a. "Installing a Trillium 360 GSN Posthole in an Uncased Hole (Direct Burial)" on page 44 or by
    b. "Installing a Trillium 360 GSN Posthole in a Cased Hole" on page 47

Once you have completed the installation of your Trillium 360 GSN Posthole, you can proceed to configure the digital recorder. See "Configuring Your System" on page 84 and refer to the *Centaur User Guide (17935)*

3.2 Tools and equipment for a Posthole installation

The following tools and equipment are required for installing a Trillium 360 GSN Posthole seismometer. See "Cables and Accessories" on page 14 for a listing of cables and accessories associated with this product.

3.2.1 Contents of a Typical Trillium 360 GSN Posthole Shipment

The Trillium 360 GSN Posthole seismometer shipment may include the following typical contents:

- 1 - Trillium 360 GSN seismometer, model T360-PH1-GSN or T360-PH1-GSN-XC
- 1 - Seismometer to digitizer cable (Ordered separately)
- 1 - Lifting Cable Kit (Ordered separately. See Table 1-4 for a full listing of the kit contents)

3.2.2 Additional tools and equipment

In addition to the contents of the shipment, you may need the following tools and equipment:

- For deeper installations, a tripod and winch or another means for lowering the Trillium 360 GSN Posthole seismometer down the hole in a controlled manner
- For deeper installations, 3 mm (7/64 in.) Allen key for securing magnetic cable strain relief in place
- Trillium Holelock Controller (See Table 1-1 for more detail)
- Power cable for Trillium Holelock Controller (See Table 1-1 for more detail)
- A 24 VDC 10 A power source for the Trillium Holelock Controller
- 3 mm (7/64 in.) Allen key for securing magnetic cable strain relief in place

3.3 Selecting a Site for a Posthole Installation

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, the Trillium 360 GSN Posthole should be installed on bedrock and as far away as possible from sources of cultural noise such as roads, dwellings, and tall structures.

The posthole seismometer is designed to withstand long-term immersion in fresh water. However it can be corroded by salt, which may be encountered in groundwater near sea coasts and in some desert environments. In environments with saline groundwater we recommend that the seismometer should either be installed at a depth above the water table or in a sealed plastic casing.

Use the worksheet "Site Record" on page 130 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.

3.4 Pre-Installation Preparation

Advanced planning and preparation for the installation of your Trillium 360 GSN 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:

- Gather your installation tools and materials. At a minimum you should have the following on-site when installing your Trillium 360 GSN:
    - Digging tools for a direct burial installation
    - Power source
    - Digitizer and cable. See "Cables and Accessories" on page 14 for information on cables and other accessories.
    - Compass for alignment.
    - A laptop or mobile device with software and cables required to connect to and communicate with the digitizer.

To save time during installation, the Trillium 360 GSN and the Nanometrics digital recorder can be pre-configured for deployment. See "Configuring Your System" on page 84.

3.5 Preventative Maintenance of Connectors

> Prior to each deployment, inspect the O-rings on the seismometer and cable connectors and replace them if necessary. Once greased and mated the O-rings will be well protected and will not need to be serviced during the course of a field deployment.

To prolong the life of the O-rings, follow the guidelines in this section:

- **Unpacking**. Nanometrics seismometers and cables ship with protective dustcaps on the connectors. For best protection of the connectors, keep and re-use the dustcaps for later transport or storage of the equipment.
- **Storage.** Nitrile O-rings are vulnerable to ozone damage in air and therefore have a limited shelf life of 1 year in open air or 5 years in their original packaging. Greasing the O-rings will extend their life. Mating the connectors will also extend the life of the O-rings.
- **Inspecting the connector O-rings**
  - Prior to mating, verify that both O-rings are present, undamaged, clean, and lightly greased.
  - If the O-ring is dry, lightly stretch it to inspect for cracks. If cracks are present, discard the O-ring and obtain an equivalent replacement of the same size and material from any O-ring supply company.
  - If an O-ring is missing or damaged, obtain an equivalent replacement of the same size and material from any O-ring supply company.
  - If the O-rings are dirty, remove them gently with tweezers, wipe them clean without stretching them, re-grease and replace them. They may be greased with a small amount of any standard O-ring or vacuum grease.

If you need to replace a connector O-ring, use one of the following:

- **Instrument connector O-ring:** size 2-016 neoprene or nitrile rubber
- **Cable connector O-ring:** size 2-017 neoprene or nitrile rubber

3.6 Connecting the Centaur digital recorder and the Trillium 360 GSN

Use the guidelines in this section to connect the Centaur digital recorder and the Trillium 360 GSN.

1. Ground the system using the guidelines in "Grounding guidelines " on page 132.
2. Power up the digital recorder. You can continue with the steps in this procedure while the digital recorder is booting up.
3. Using the appropriate seismometer to digitizer cable, see "Cables and Accessories" on page 14, attach the seismometer connector to the Trillium 360 GSN making sure

that the guides on the cable connector align with the notches on the Trillium 360 GSN.

4. Attach the other end of the cable to the digital recorder, making sure that the guides on the cable connector align with the notches on the digital recorder.

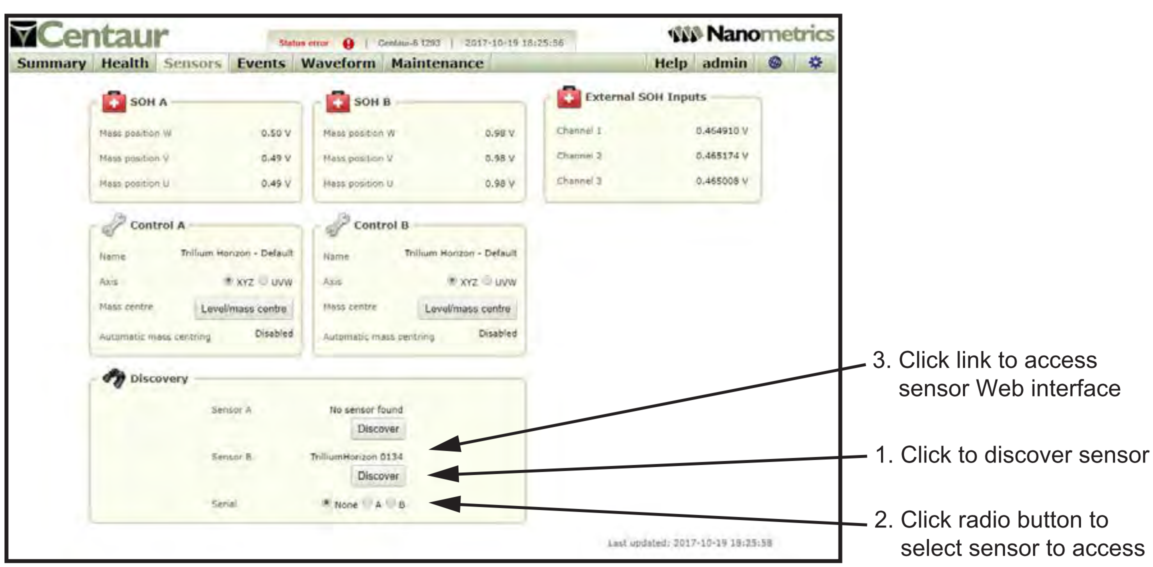
Once powered up, the digital recorder will provide pass-through power to the seismometer as well as feedback regarding seismometer operation.

3.7 Verifying connection with the Centaur digital recorder

Use the guidelines in this section to verify that the connection between the Centaur digital recorder and the Trillium 360 GSN was successful.

1. Once the Centaur has booted up, using a Web-enabled device such as a laptop, login to the Centaur and Discover the seismometer as follows, see Figure 3-1:
   a. Navigate to the **Sensors** page.
   b. For each sensor, click on the **Discover** button.
   c. Once a sensor has been discovered, a link will display above the **Discover** button. You can access the sensor's web page by clicking on the appropriate Serial radio button, then clicking on the link.
2. Proceed to "Installing the Trillium 360 GSN Posthole Seismometer" on the next page.

Figure 3-1 - Centaur Web interface Sensors page



3.8 Installing the Trillium 360 GSN Posthole Seismometer

A Trillium 360 GSN Posthole seismometer may be installed in an uncased or cased hole, to a maximum immersion depth of 300 m. Units will self-level as long as the seismometer is within ±5° of vertical, making deployment simple.

Direct burial (Uncased hole) installation method

The direct burial (also known as uncased hole) method is used for a shallow, low-cost deployment. It is used for temporary installations or for installations in remote areas that are inaccessible to a drill truck, or simply to save on installation costs. Saving cost on installation allows you to install more stations within a similar budget. This is important because the size and density of the network is just as important as the quality of each individual station. See "Installing a Trillium 360 GSN Posthole in an Uncased Hole (Direct Burial)" below.

Cased hole installation method

The cased hole method is used for deeper installations in bedrock. This type of installation improves noise performance but it costs more and requires access by a drill truck. This method of installation is applicable to permanent seismic observatory stations. See "Installing a Trillium 360 GSN Posthole in a Cased Hole" on page 47.

3.8.1 Installing a Trillium 360 GSN Posthole in an Uncased Hole (Direct Burial)

The hole can be up to 10 meters deep and have a diameter large enough to accommodate the instrument. The recommended minimum hole depth is one meter, which will allow the instrument to be covered by 0.6 m (2 ft.) of fill once the installation is complete. This backfill creates a buffer between the installation and the surface, shielding it from temperature change and weather. In general, greater depth produces better results with all other things being equal.

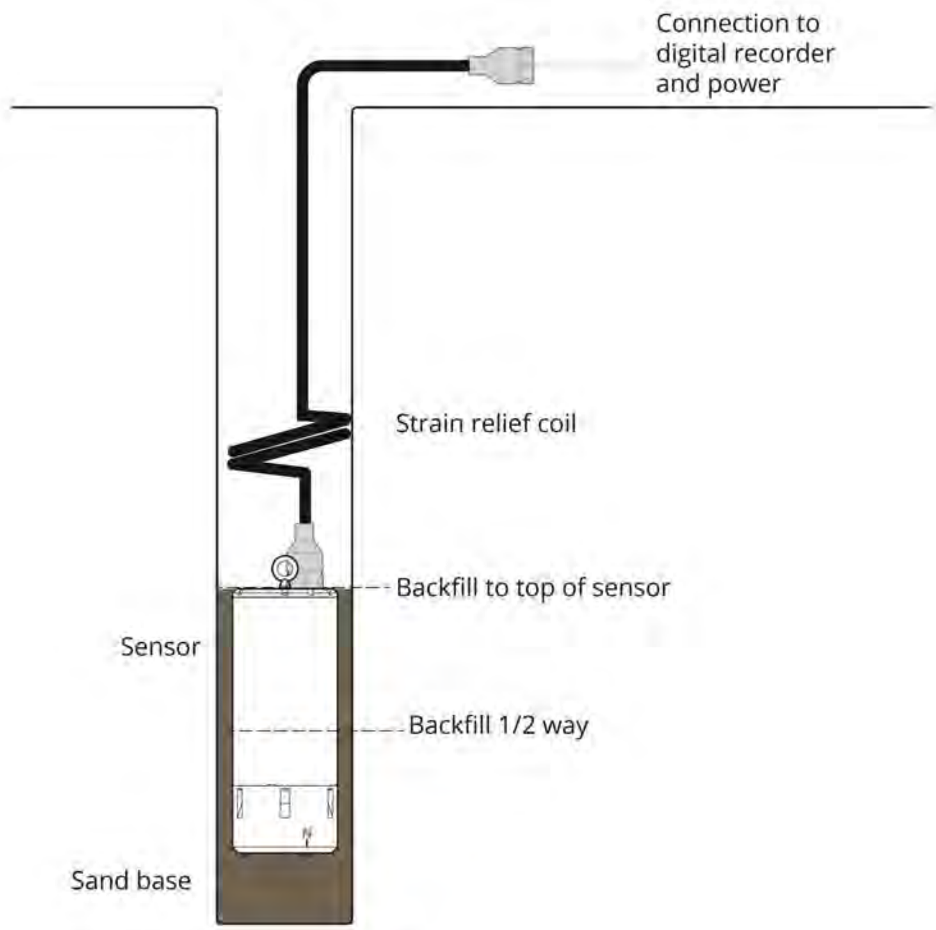
Use the following steps to install a Trillium 360 GSN Posthole seismometer in an uncased hole:

1. Prepare the hole by tamping the bottom surface of the hole with a flat-ended pole such as a pickaxe handle.
2. Pour a small volume of sand into the hole to act as a base for the sensor, so that there will be no air spaces underneath the seismometer.
3. Lower the seismometer into the hole and stand it upright, not touching the sides of the hole. The seismometer should stand approximately vertical, but it does not need to be precisely leveled since it has an internal self-leveling mechanism. The top end of the seismometer should be at least 60 cm (2 feet) below the ground surface so that it will be well insulated once it is buried.
4. Align the seismometer to North. See the **Methods for aligning** notes and "Aligning the Trillium 360 GSN Posthole to North" on page 52.

> **Methods for aligning.** The recommended practices for aligning a Trillium 360 GSN Posthole vary based on the depth of the hole where the unit is installed.
>
> - For recommendations on aligning a Trillium 360 GSN Posthole in a shallow hole of 2 m or less, see "Aligning the Trillium 360 GSN Posthole using a Surface Line" on page 52.
> - For recommendations on aligning a Trillium 360 GSN Posthole in a deeper hole, see "Aligning the Trillium 360 GSN Posthole using a Surface Seismometer" on page 53.

5. Stabilize the instrument by compacting sand or other fill material to ensure that the instrument is solidly coupled to the surrounding substrate and will not shift or move. It is preferable to use clean dry sand since it will tend to flow easily. Leave the top of the seismometer uncovered for the time being for easy removal in case of any problem. (See Figure 3-2.)
6. Initiate auto-leveling. This process will take from 5 to 20 minutes depending on how far the leveling mechanism has to travel.
7. Once auto-leveling is complete, confirm that mass positions are leveled within ±1 V. For more information, see "About Leveling and Mass Centering" on page 88. It may take up to 20 minutes for the operation to complete.
8. To provide strain relief to the cables, leave a coil of cable near the top of the seismometer.

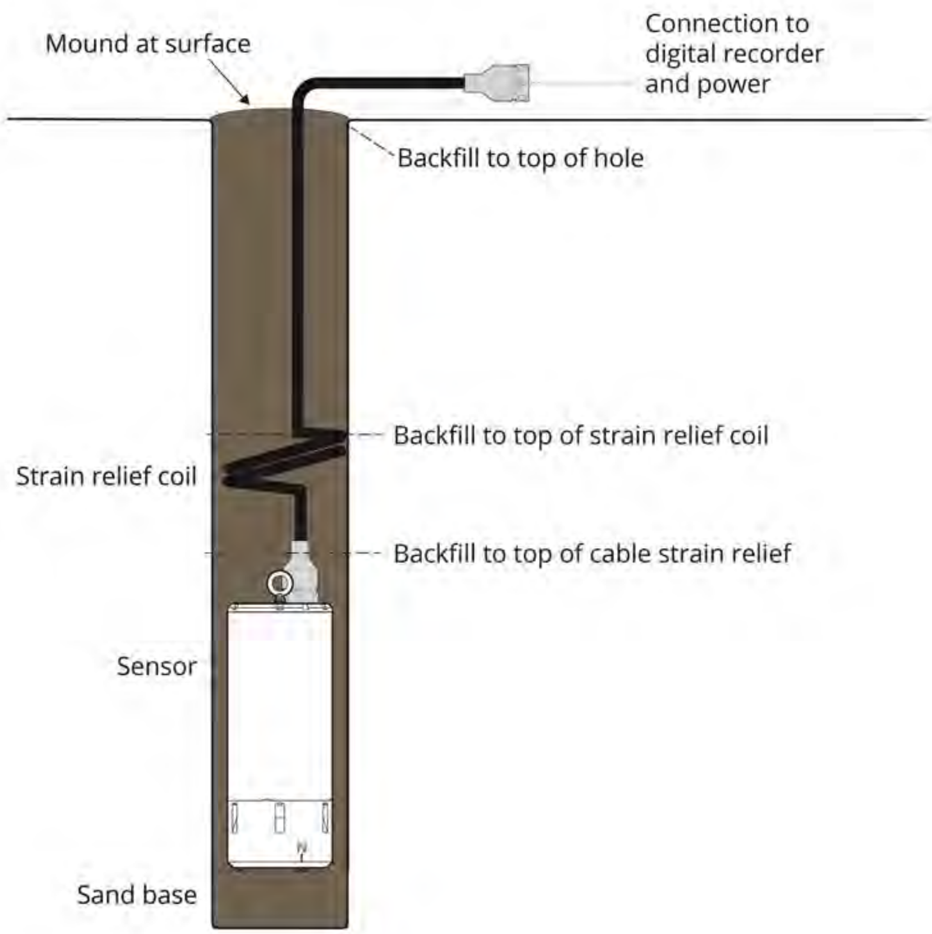
Figure 3-2 - Stabilize the Instrument



9. Fill the hole to the surface and mound additional material on the hole so that water will run off and not collect in the hole. Optionally, if the surrounding soil is wet, pour water after filling to saturate the compacted fill material and bring it more rapidly to equilibrium with the surrounding soil. (See Figure 3-3.)
10. Optionally, cover the installation with a plastic ground sheet to maintain a more constant moisture level in the sediment around the seismometer.
11. Pile additional soil or rocks on top of the ground sheet to secure it.
12. Check the seismic outputs to verify that the unit is undisturbed. If necessary, initiate auto-leveling again.
13. Place the digitizer in its final location.

14. Install any remaining station equipment such as additional batteries, and solar equipment.
15. Proceed to configure the Centaur for use with the Trillium 360 GSN, see "Configuring Your System" on page 84.

Figure 3-3 - Complete Backfilling



3.8.2 Installing a Trillium 360 GSN Posthole in a Cased Hole

Use the following steps to install a Trillium 360 GSN Posthole in a cased hole:

For best results, make sure that the cased hole is dry and the bottom is sealed. If you are using an existing cased hole, make sure that the hole is not flooded. Additionally, the inner diameter of the casing should be at least 10 mm larger than the seismometer to allow clearance for casing joints and to allow space for sand to flow all around the seismometer when it is installed. See the *Nanometrics technical note 18093 Borehole Drilling Requirements* for details on preparing a cased hole."

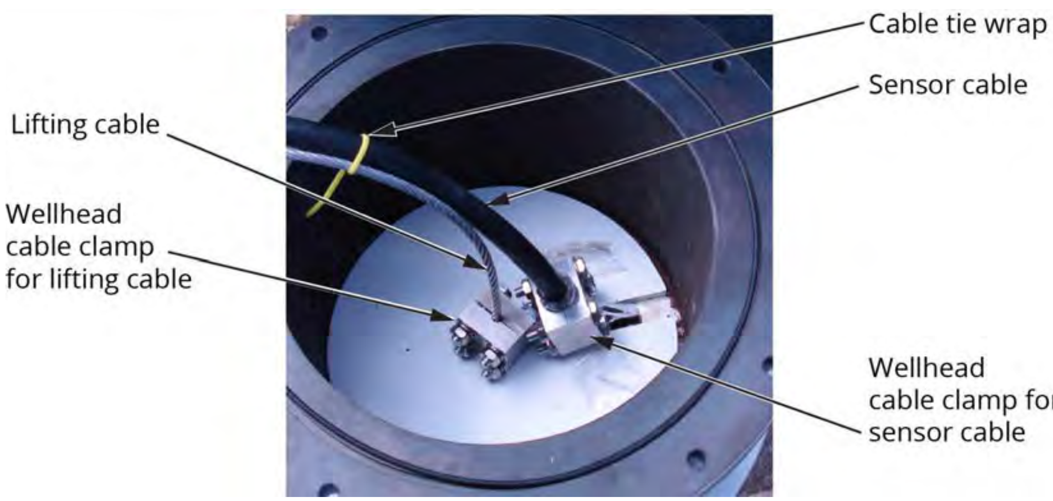
A cased hole must be covered at the top to prevent it filling with water. This cover must secure and stabilize the load-bearing and seismometer cables. The cables should enter the wellhead box through a waterproof gland and a waterproof cover or shed should be positioned over the wellhead to provide long-term security, watertightness, and thermal insulation.

1. Prepare the hole for the installation.
   The hole diameter must be large enough to accommodate the seismometer. The hole must be covered at the top to protect the seismometer from the elements such as wind and rain. This cover must secure and stabilize the electrical and lifting cables, allowing some slack to avoid strain on the seismometer.
2. Obtain very clean dry sand material that will flow easily and not solidify over time. Aluminum oxide sandblasting material with a coarse grain size is recommended. A more easily available substitute is washed play sand, however it must be dried prior to use so that it will flow easily and not leave any air spaces.
3. Pour 1 liter of sand down the hole to provide a base for the sensor.
4. Lower the seismometer until it reaches the bottom of the hole. A winch is required for deep holes. In very deep holes it may not be obvious when the seismometer has reached the bottom. In this case, continue to lower the cable until it goes slack at the top end. (It will eventually go slack because the cable is too stiff to fall down a narrow borehole, it will stand wedged between the sides of the hole and not slide down more than a small amount.) (See "Lowering the Seismometer into a Deep Cased Hole" on page 50.)
5. Optionally, if you have serial communications to the seismometer (a Centaur digitizer or SLIP appliance is recommended for this), access the **State of Health** page and verify that the case tilt is within the leveling range of the instrument. If not, it may be possible to correct this by pulling up on the cable to move the seismometer around, and if need be, maintain some tension on the cable while

sand is poured down to stabilize it. If excessive tilt cannot be corrected, it is likely because the hole is non-vertical at the bottom end.

6. Pour a measured volume of sand down the hole, sufficient to cover the sides plus 15 cm (6 inches) on top. This is enough to stabilize the seismometer, while still allowing it to be easily extracted if necessary.
7. Slacken the cable.
8. Initiate auto-leveling. This process will take from 5 to 20 minutes depending on how far the leveling mechanism has to travel. Afterwards confirm that mass positions are leveled within ±1 Volt. For more information, see "About Leveling and Mass Centering" on page 88.
9. Optionally, in a shallow hole (less than 10 m depth) there may be a benefit to filling the top end of the hole (from the top of the wellhead to slightly below ground level) with insulating material such as bags of polyester wool to mitigate the effect of temperature changes at surface.
10. Inside the wellhead box, attach the wellhead cable clamp to the lifting cable and the sensor cable clamp to the sensor cable to hold them in place when the winch is removed (See Figure 3-4).
11. Close and seal the wellhead to prevent any water or moist air from entering the cased hole.

Figure 3-4 - Cable clamps at wellhead



12. Proceed to configure the Centaur for use with the Trillium 360 GSN, see "Configuring Your System" on page 84.

3.8.3 Lowering the Seismometer into a Deep Cased Hole

Use the instructions in this section and Lifting Cable Kit (18276) to deploy the Trillium 360 GSN Posthole in a deep cased hole using a tripod and winch or another similar method.

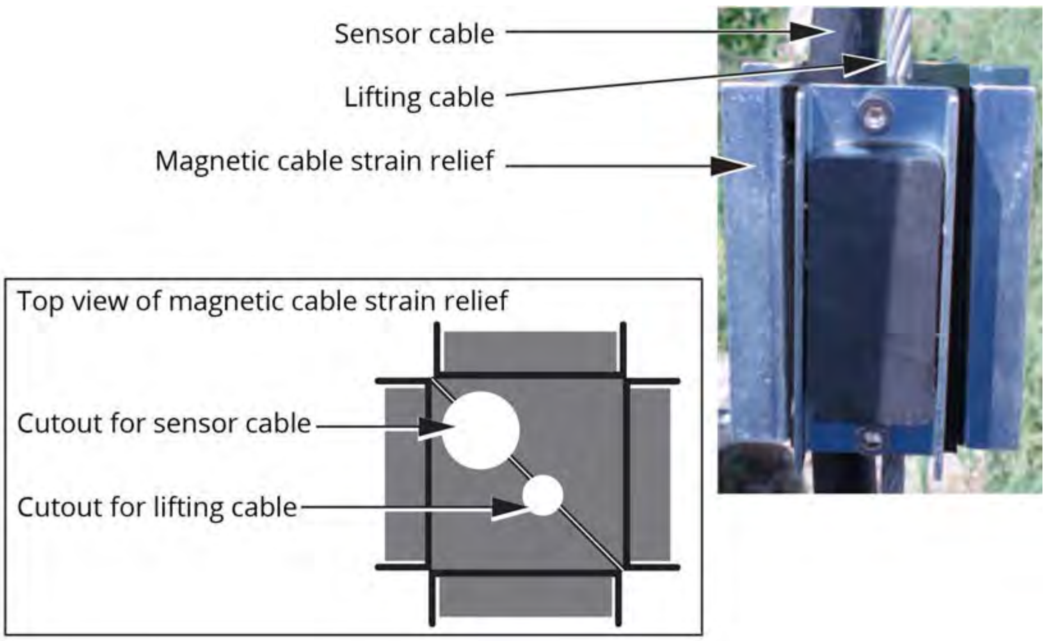
> The winch should only be operated by persons who are suitably trained to do so and who are familiar with any local regulations for this type of a device. The stall force of the winch must be less than the rated load of the tripod and lifting wire rope to prevent breakage if the equipment becomes jammed or snagged during lifting. Failure to follow safety instructions may result in severe personal injury, death or damage to property.

1. Lay out, in a straight line if possible, the sensor cable and the lifting cable (also known as a wire rope).
2. Attach the load-bearing lifting cable to the eyebolt located on the top of the seismometer.
3. (Optional for posthole installations) To prevent vibrations on the cable, attach the magnetic strain relief (see the tip "Preventing vibrations on cable"):
   a. Attach the magnetic cable strain relief to both the sensor cable and the lifting cable 0.6 meter above the top of the seismometer (see Figure 3-5). Ensure that you allow a little slack in the sensor cable when you attach the magnetic cable strain relief so that the weight of the seismometer is supported by the load-bearing lifting cable.
   b. Insert the thicker sensor cable into the wider cutout in the magnetic cable lock and insert the thinner load-bearing lifting cable into the narrower cutout. Use a screwdriver to securely tighten the screws (1 N•m or 9 inch-pounds).

> **Preventing vibrations on cable.** The magnetic cable strain relief is included with the lifting cable kit, however it is not required for sand installations. This device is used to prevent any vibrations that travel down the lifting cable and the sensor cable from being transferred to the seismometer. When the tension is removed from the lifting

cable and sensor cable, the magnetic cable strain relief uses magnetic force to attach itself to the side of the cased hole. This ensures that the 0.6 m of sensor cable and lifting cable between it and the top of the seismometer are not under any strain and are isolated from vibration or motion of the cable and lifting cable that occurs above the magnetic cable strain relief.

Figure 3-5 - (Optional for posthole installations) Magnetic cable strain relief



4. Use the tripod and winch to lift the seismometer off of the ground and position it over the hole.
5. Lower the seismometer into the hole to the targeted depth ensuring that cable tie wraps are tied around both the sensor cable and the lifting cable approximately every 5 meters to keep them together and ensure that the load is placed on the load-bearing lifting cable and not on the sensor cable.
6. Return to "Installing a Trillium 360 GSN Posthole in a Cased Hole" on page 47 to complete the installation.

3.9 Aligning the Trillium 360 GSN Posthole to North

There are two typical methods for aligning a Trillium 360 GSN Posthole to north. The method used is usually determined by the depth of the hole where the unit is installed.

For shallow holes,

- Where the top of the seismometer is visible and can be reached by hand, you can align the north-south guide on the top of the pressure vessel to a surface line. See "Aligning the Trillium 360 GSN Posthole using a Surface Line" below for details.

For deeper holes,

- Correlate the output of the seismometer with that of a temporarily installed surface-based seismometer that is aligned to true north to calculate their relative orientation. See "Aligning the Trillium 360 GSN Posthole using a Surface Seismometer" on the next page.

3.9.1 Aligning the Trillium 360 GSN Posthole using a Surface Line

If you are installing the Trillium 360 GSN Posthole in a shallow hole (usually 2 m or less) where the top of the seismometer pressure vessel is visible and the unit can be turned by hand after being lowered into the hole, you can use the surface line method to align the instrument.

To align a Trillium 360 GSN Posthole to north with a surface line.

1. Place a ruler, or stake a line, aligned to true north across the hole.

> If you are using a magnetic compass, account for the local magnetic declination when making the line across the hole.

2. Turn the seismometer until the north-south guide on the top of the pressure vessel is parallel to the line at the top of the hole.

3.9.2 Aligning the Trillium 360 GSN Posthole using a Surface Seismometer

You can use a seismometer installed at the surface to determine the orientation of the horizontal (X and Y) components of the Trillium 360 GSN seismometer once it has been installed in the hole. This method involves comparing the recorded output of both seismometers and computing the relative direction of seismic wave motion to determine the relative azimuth of the down-hole seismometer compared to the surface seismometer.

When you install the reference seismometer on the surface, ensure that you align it carefully in a known orientation. After both seismometers have been installed, leave the installations undisturbed for at least one hour while collecting data from both. When you are ready to perform your data analysis, ensure that your post-processing software is equipped to apply a rotation transformation, allowing it to measure and correct the relative azimuth. Take note of the values and enter them on the Centaur in the Digitizer Orientation Correction configuration feature. See the *Centaur user guide (17935)* for instructions.

Orientation correction. You should record the actual azimuth. This value can be used to perform field data rotation to correct the sensor orientation for instances where the physical orientation of a deployed three-component geophysical sensor is different than what is desired, resulting in output X, Y and Z signals that do not represent the desired directions of sensitivity (typically East, North and Vertical). See the *Orientation correction* sections in the *Centaur User Guide (17935)* for more detail.

One advantage of this method of alignment is that it allows you to verify the performance of the down-hole instrument: it should be quieter than the surface instrument.

Contact Nanometrics (see "Contact Technical Support " on page 140) for more information on using this method of alignment.

3.10 Installation Checklist for the Trillium 360 GSN Posthole Seismometer

Use the following checklist to help you verify that you have completed all of the necessary steps in the installation of your Trillium 360 GSN Posthole.

	Check that connector O-rings are present, undamaged, clean, and lightly greased.
	System is correctly grounded according to guidelines in grounding section.
	Installation hole is prepared according to best practices.
	Trillium 360 GSN Posthole is aligned to east-west or north-south.
	Cable is connected to the Trillium 360 GSN Posthole and the digitizer.
	Trillium 360 GSN Posthole is auto-leveled and mass centered.
	Trillium 360 GSN Posthole serial number and IP address is noted.
	If alignment was accomplished using the surface seismometer method, ensure that Orientation Correction values have been entered on the Centaur.
	For installations in a cased hole, cable is clamped at the wellhead.

Chapter 4 - Installing a Trillium 360 GSN Vault Seismometer

4.1 Vault Installation Overview

The following steps for installing a Trillium 360 GSN in a vault are described throughout this guide:

1. "Preparing to Install a Trillium 360 GSN Vault seismometer" on the next page
2. "Selecting a Site for the Trillium 360 GSN Vault " on page 57
3. "Planning Your Installation" on page 57
4. "Grounding guidelines " on page 132
5. Aligning, leveling and placing the seismometer, see:
   a. "Alignment, Leveling, and Placement Features" on page 60
   b. "Best Practices for Aligning and Leveling" on page 61
6. Insulating the seismometer, see:
   a. "Theory and Practice of Insulation" on page 62
   b. "Insulation Options" on page 64

Once you have completed the installation of your Trillium 360 GSN Posthole, you can proceed to configure the digital recorder. See "Configuring Your System" on page 84 and refer to the *Centaur User Guide (17935)*

4.2 Tools and equipment for a Vault installation

The following tools and equipment are required for installing a Trillium 360 GSN Vault seismometer. See "Cables and Accessories" on page 14 for a listing of cables and accessories associated with this product.

4.2.1 Contents of a Typical Trillium 360 GSN Vault Shipment

The Trillium 360 GSN Vault seismometer shipment may include the following typical contents:

- 1 - Trillium 360 GSN Vault seismometer, model T360-SV1-GSN or T360-SV1-GSN-XC
- 1 - Seismometer to digitizer cable (Ordered separately)

4.2.2 Additional tools and equipment

In addition to the contents of the shipment, you may need the following tools and equipment:

- Trillium 240/360 Insulating Cover, see "Cables and Accessories" on page 14.

4.3 Preparing to Install a Trillium 360 GSN Vault seismometer

Advanced planning and preparation for the installation of your Trillium 360 GSN Vault 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 "Installing a Trillium 360 GSN Borehole seismometer" on page 26 or "Installing a Trillium 360 GSN Posthole Seismometer" on page 39 for more information.
- **Select your insulation method.** You can thermally insulate your Trillium 360 GSN Vault seismometer with the insulating cover (recommended) or make a free-standing cover out of rigid plastic foam. Determine which method you will use before your installation so that you have the necessary materials on-site. For more information on insulating your seismometer, see "Theory and Practice of Insulation" on page 62 and "Insulation Options" on page 64.
- **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 "Cables and Accessories" on page 14 for information on cables and other accessories.
  - Compass for alignment. See "Best Practices for Aligning and Leveling" on page 61.
- **Gather any optional tools and materials you may need.** Your installation may also require:

    - A laptop or mobile device with software and cables required to connect to and communicate with the digitizer if using one without a display screen.
    - 5/16 in. alignment rods if you are using the east-west alignment holes. Using the north-south scribe lines is preferred. See "Alignment, Leveling, and Placement Features" on page 60.
    - Lifting handle if you are installing the seismometer in a vault that is only accessible from the top.
- **Ground the system** using the guidelines in "Grounding guidelines " on page 132.
- Note that there are no special handing requirements for connectors for the Trillium 360 GSN Vault.

4.4 Selecting a Site for the Trillium 360 GSN Vault

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 "Site Record" on page 130 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. "Common Types of Surface Installations" on the next page provides recommendations for some common installation types.

4.5 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 "Troubleshooting Your Installation" on page 73 for more information.

4.5.1 Common Types of Surface Installations

Following are two common methods for installing and insulating a seismometer (see "Theory and Practice of Insulation" on page 62 and "Insulation Options" on page 64 for more information):

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. See "Recommendations for Pier Construction" below.

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.

4.6 Recommendations for Pier Construction

If your installation involves the construction of a pier, use Table 4-1 as a guide to constructing your pier:

Table 4-1 - Recommended pier design specifications

Material	Concrete. Homogeneous, 50% Portland cement and 50% sieved sand (see "Choosing the Right Concrete" below).
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 "Decoupling the Pier and Vault Walls" below).

4.6.1 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.

4.6.2 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.

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[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.

4.7 Alignment, Leveling, and Placement Features

To aid in the proper alignment of your seismometer, each Trillium 360 GSN Vault has:

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

For convenience and accuracy, use of the east-west scribe marks is the preferred method of alignment. Alternatively, for a north-south alignment, alignment rods are available from Nanometrics that you can fit into the 5/16 in. diameter holes on the north-south axis of the seismometer base. "Features and Dimensions" on page 124 provides illustrations that show the relative orientation of the east-west and north-south alignment features in top, bottom and side views.

For leveling purposes, each Trillium 360 GSN Vault seismometer is equipped with:

- Three adjustable-height feet with lock nuts.

> If a sufficiently flat and level installation surface is available, the feet can be removed and the seismometer will rest on three raised bosses that are located on the bottom of the seismometer base.

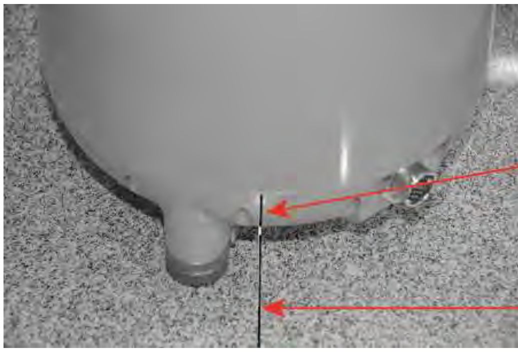
- A leveling bubble on the cover.

Trillium 360 GSN Vault seismometers also come with a lifting handle 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. Remove the handle when the seismometer installation is complete to allow for close-fitting insulation.

> Do not use the lifting handle to carry your Trillium 360 GSN Vault seismometer over long distances as the seismometer could gradually rotate and fall off of the handle.

Figure 4-1 shows the west scribe line on a Trillium 360 GSN Vault aligned with a line drawn on the pier that is parallel to east-west. One of the leveling feet to the left of the alignment marker is also visible.

Figure 4-1 - Example of seismometer alignment using vertically scribed marks



4.8 Best Practices for Aligning and Leveling

Following are best practices for aligning and leveling a Trillium 360 GSN Vault using the vertically scribed marks on the east-west guide axis:

> If you are using an north-south alignment with the alignment rods, continue with these best practices, but substitute east-west with north-south and fit the alignment rods into the 5/16 in. diameter holes in the base of the seismometer instead of aligning the Trillium 360 GSN Vault seismometer with the vertically scribed marks.

1. Draw a line on the pier or other installation surface parallel to east-west. The east-west line must be aligned to true east. 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.
2. If you are insulating the seismometer using the Trillium 360 GSN Vault insulating cover, see "Installing a Trillium 360 GSN Vault in the Insulating Cover" on page 67 for instruction on aligning the foam base gasket of the cover and for placing the seismometer on the base.
3. When you are ready to remove the Trillium 360 GSN Vault from the box, gently place it on the installation surface in an approximate east-west alignment.
4. Use the adjustable feet, as required, and the leveling bubble placed on the cover to level the seismometer. Center the bubble as precisely as possible inside the black ring to ensure that the Z output is measuring true vertical motion:

a. Extend the leveling 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.
b. When the Trillium 360 GSN Vault is level, lock each foot using a 2.5 mm Allen key, by inserting Allen key into one of the lock nut holes and turning the lock nut until it engages firmly with the base of the seismometer. A foot that is properly locked will not turn easily when touched.

5. Precisely align the Trillium 360 GSN Vault to east-west by aligning the vertical east-west lines on the base of the seismometer (see Figure 4-1 on the previous page) 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.

6. After aligning the seismometer, verify that it is still level. It may need to be adjusted due to unevenness of the installation surface.
7. If you re-leveled the Trillium 360 GSN Vault ensure the feet are locked when finished.

4.9 Theory and Practice of Insulation

Seismometer installations must be thermally insulated to achieve optimal performance, particularly at long periods. There are two broad categories of thermal effects that can cause unwanted noise:

- **Direct thermal sensitivity.** The Trillium 360 GSN Vault is designed to minimize temperature sensitivity; however, like all seismometers, it has some residual thermal response. There are several components in a seismometer that are temperature sensitive, such as 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.
- **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.

For seismometers that are well temperature-compensated, such as the Trillium 360 GSN Vault, but are improperly installed, thermally induced tilt on the horizontal channels will be more significant than direct thermal sensitivity on the vertical channel. 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 installation 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 and by installing the seismometer below ground.
  The site must have good drainage to prevent flooding of an underground vault. Passive drainage is better than pumps which cause vibration. Roof and wall surfaces

that are directly exposed to the sun and wind may require up to 30 cm (1 foot) of insulation to completely stabilize the inside temperature. The door and any other openings must be fully sealed to prevent air drafts.

- 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 "Cables and Accessories" on page 14.
- 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.

4.10 Insulation Options

There are two options for insulating a Trillium 360 GSN Vault:

- **Recommended method.** Use the Nanometrics Trillium 240/360 Insulating Cover (Nanometrics part number 16060). See also "Insulating a Trillium 360 GSN Vault with the Insulating Cover" on the next page.
- Make a freestanding cover using rigid foam 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. See also "Insulating a Trillium 360 GSN Vault with a Rigid Foam Box" on page 69.

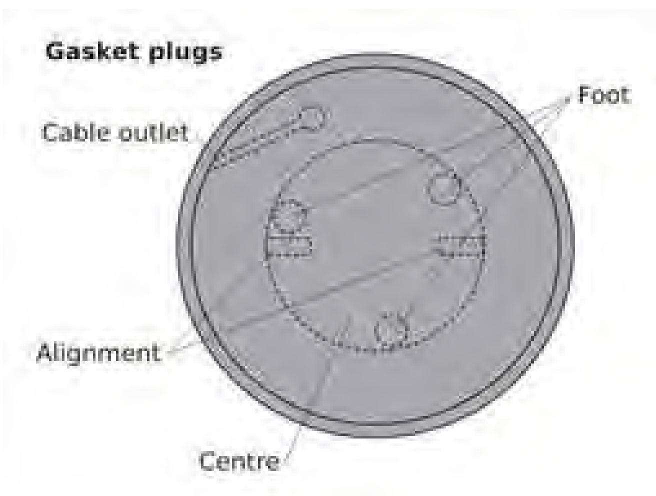
Before proceeding with the implementation of thermal insulation, there are many aspects you must consider in the context of the particular site and type of installation. See "Planning Your Installation" on page 57.

4.10.1 Insulating a Trillium 360 GSN Vault with the Insulating Cover

The Trillium 240/360 Insulating Cover (Nanometrics part number 16060) is a rugged and form-fitting cover that is made of rigid plastic filled with an insulating foam core. This cover can be used with the Trillium 360 GSN Vault seismometer. The cover encloses the seismometer without touching it, eliminates convection by minimizing the air volume trapped under the cover, and provides a race for a coiled cable that minimizes heat and conduction through the cable. Properly installed, the insulated cover can attenuate temperature-induced long-period noise by up to 40 dB.

The included foam base gasket of the cover has precut plugs that provide flexibility in how the cover is used.

Figure 4-2 - Location of gasket plugs



A standard installation retains the original position of the cable outlet and leads the cable around the base of the gasket, enclosing approximately 1 m of cable in the cover. Enclosing the cable in the cover helps attenuate temperature variations conducted by the cable.

If your installation requires a different exit point for the cable, you can separate the center plug from the outer main gasket and rotate the outer gasket to move the cable outlet as required. This type of modified installation provides less insulation for the cable.

Figure 4-3 - Insulating cover installation options

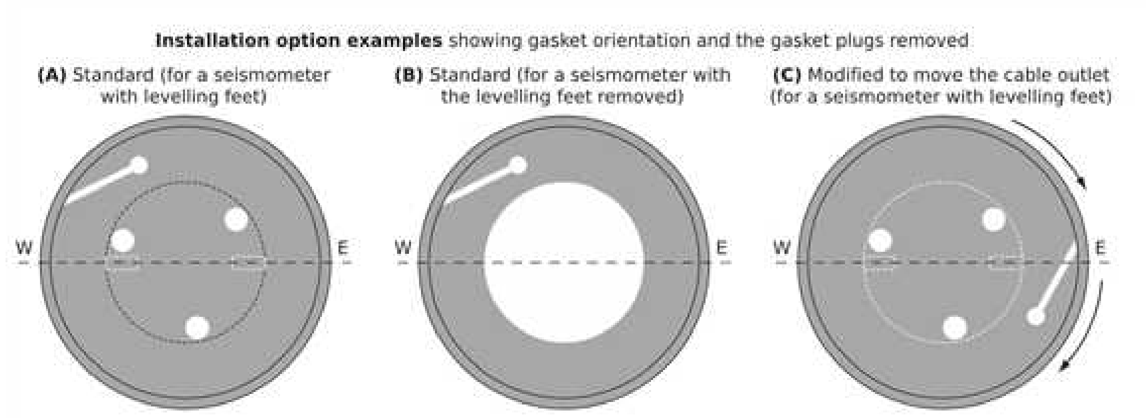
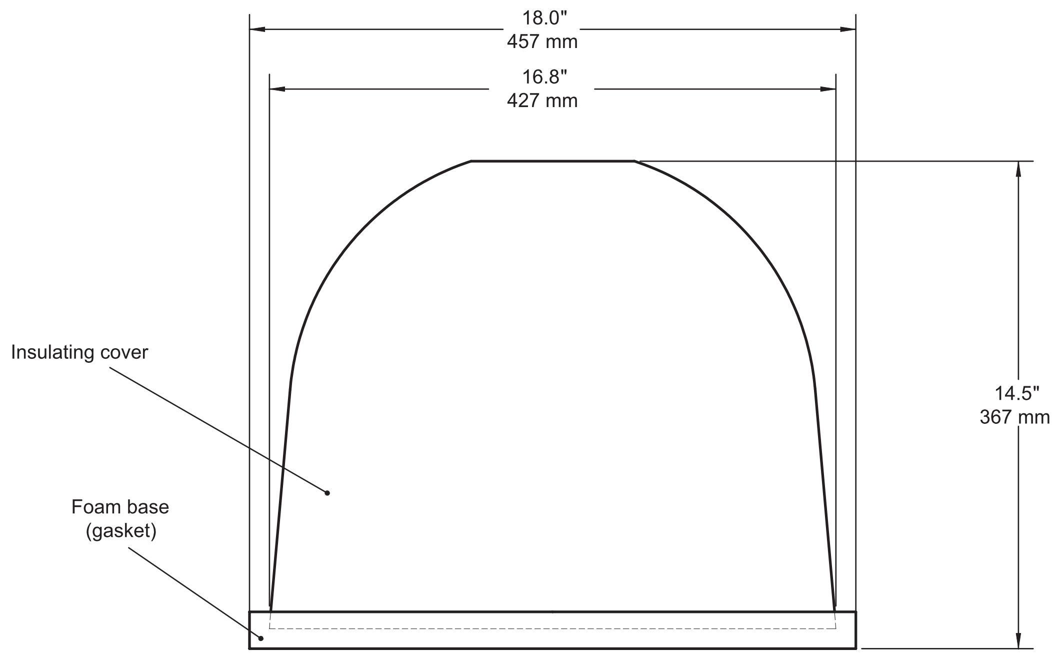


Figure 4-4 provides the dimensions of the insulating cover.

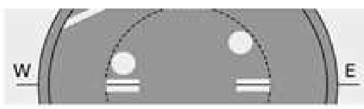
Figure 4-4 - Trillium 360 GSN Vault insulating cover dimensions



4.10.2 Installing a Trillium 360 GSN Vault in the Insulating Cover

Use the following steps to install and align a Trillium 360 GSN Vault in the insulating cover:

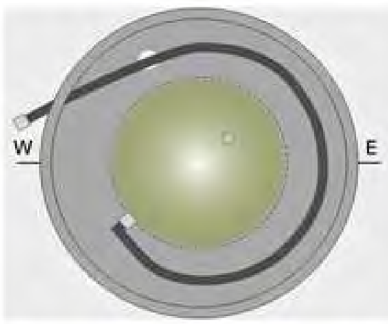
1. Remove the pre-cut gasket plugs as required for your installation (see the examples in "Insulating cover installation options" on the previous page.
    - For standard installations, keep the alignment plugs as in example (A).
    - For modified installations, keep the center plug and the alignment plugs as in example (C).
2. Draw a line on the installation surface parallel to east-west.
3. Place the gasket on the installation surface with the gasket alignment holes roughly centered over the east-west alignment line.



4. Place the seismometer in the gasket and align it (see "Best Practices for Aligning and Leveling" on page 61.
5. Connect the cable to the seismometer. The connector on all standard cables for Trillium seismometers is angled downward by about 30º, bringing the cable directly onto the gasket and preventing it from touching the cover.

> If you are connecting your Trillium 360 GSN Vault to a third-party digitizer, contact Nanometrics for a full listing of cables with connectors to third party digitizers. See "Contact Us" on page 140. See "Configuring Your System" on page 84 for information on configuring your Nanometrics digitizer for a Trillium 360 GSN Vault and also refer to the digitizer manual.

6. Pull the cable end through the cable outlet.
7. Place the cable on the gasket so it aligns to the V-groove in the bottom edge of the cover, approximately centering it between the edge of the gasket and the center plug line.



8. Orient the connector groove in the cover to the connector and place the cover over the seismometer.

> It is very important that the cover and gasket do not touch the seismometer or cable connector. A continuous air gap is required for the cover to work properly.

9. To properly position the cover so that it is not touching the connector:
   a. Lift the cover slightly above the gasket so that it does not drag when rotated.
   b. Gently rotate the cover until it lightly touches the connector.
   c. Rotate the cover by about 1 cm in the opposite direction and place it on the gasket.
10. 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.

4.10.3 Insulating a Trillium 360 GSN Vault with a Rigid Foam Box

If you are not using the recommended Trillium 360 GSN Vault insulating cover, insulate the seismometer with a rigid foam box. Use the following recommendations as a guide when constructing the box:

> When installing a Trillium 360 GSN Vault in a rigid foam insulating box, follow the best practices for aligning and leveling the seismometer that are outlined in "Best Practices for Aligning and Leveling" on page 61.

- 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 aluminum tape, which is quicker and cleaner than glue.
- Use insulation that is at least 5 cm (2.0 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 weather-stripping that is 1.25 cm (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.

4.11 Connecting the Centaur digital recorder and the Trillium 360 GSN

Use the guidelines in this section to connect the Centaur digital recorder and the Trillium 360 GSN.

1. Ground the system using the guidelines in "Grounding guidelines " on page 132.
2. Power up the digital recorder. You can continue with the steps in this procedure while the digital recorder is booting up.
3. Using the appropriate seismometer to digitizer cable, see "Cables and Accessories" on page 14, attach the seismometer connector to the Trillium 360 GSN making sure that the guides on the cable connector align with the notches on the Trillium 360 GSN.
4. Attach the other end of the cable to the digital recorder, making sure that the guides on the cable connector align with the notches on the digital recorder.

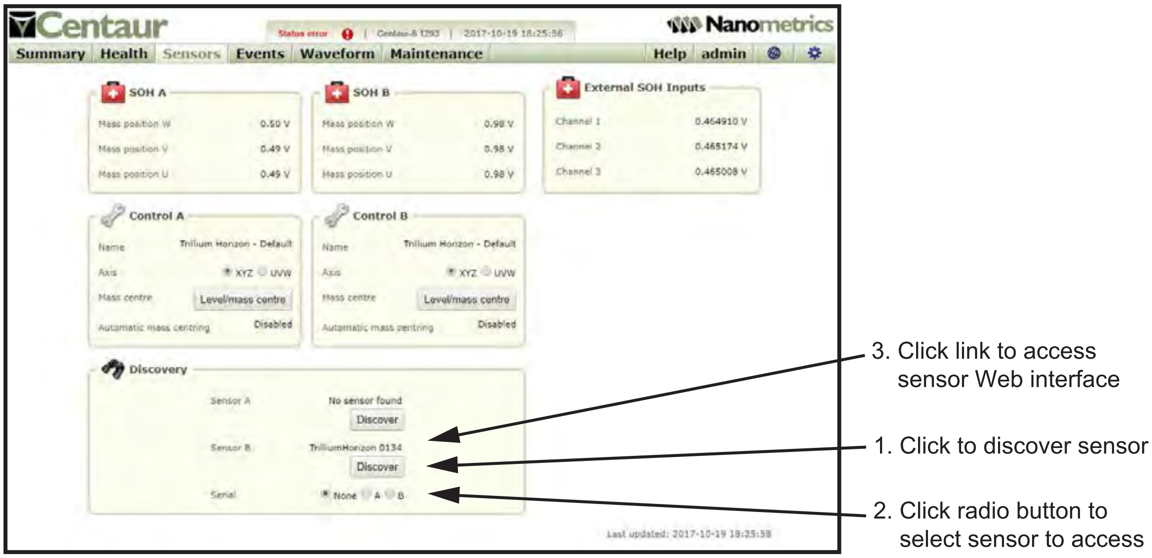
Once powered up, the digital recorder will provide pass-through power to the seismometer as well as feedback regarding seismometer operation.

4.12 Verifying connection with the Centaur digital recorder

Use the guidelines in this section to verify that the connection between the Centaur digital recorder and the Trillium 360 GSN was successful.

1. Once the Centaur has booted up, using a Web-enabled device such as a laptop, login to the Centaur and Discover the seismometer as follows, see Figure 4-5:
   a. Navigate to the **Sensors** page.
   b. For each sensor, click on the **Discover** button.
   c. Once a sensor has been discovered, a link will display above the **Discover** button. You can access the sensor’s web page by clicking on the appropriate Serial radio button, then clicking on the link.
2. Proceed to "Centering the Masses after Installation" on the next page.

Figure 4-5 - Centaur Web interface Sensors page



4.13 Centering the Masses after Installation

For best results, center the masses in your Trillium 360 GSN Vault:

- Immediately after installing and leveling the seismometer.
- Again, at least 12 hours after installation, when the temperature of the Trillium 360 GSN Vault has fully equalized to the ambient temperature. Centering the masses after temperature equalization allows the seismometer to tolerate subsequent ±10ºC variations in ambient temperature without requiring recentering

For more information on how and when to center the masses in your Trillium 360 GSN Vault, see "About Leveling and Mass Centering" on page 88. See also "About Serial Communications" on page 93 for information on using the serial interface. This interface can be used to monitor mass position status and to center the masses.

4.14 Installation Checklist for the Trillium 360 GSN Vault seismometer

Use the following checklist to help you verify that you have completed all of the necessary steps in the installation of your Trillium 360 GSN Vault.

	Installation surface is clear of debris.
	Trillium 360 GSN Vault is level.
	Trillium 360 GSN Vault is aligned to east-west or north-south.
	The feet of the Trillium 360 GSN Vault are locked.
	Trillium 360 GSN Vault serial number is noted.
	Cable is connected to the Trillium 360 GSN Vault and the digitizer.
	Cable is strain-relieved to the installation surface.
	Cable is not touching theTrillium 360 GSN Vault case.
	Thermal insulation is in place.
	Thermal insulation is not touching the Trillium 360 GSN Vault or cables.
	If using a rigid-foam insulating box, it is weighted down.
	Masses are centered.

Chapter 5 - Post-Installation Activities

5.1 Troubleshooting Your Installation

It is normal to see noise spikes in the horizontal channels of a Trillium 360 GSN seismometer as the instrument 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.

It is normal to see thermal drift in the data as the seismometer comes to equilibrium temperature. This should stabilize after approximately 24 hours.

The following tables list common types of noise that may occur and the reasons why the noise may be present.

Table 5-1 - Types of noise and possible causes for borehole deployments

Noise Type	Possible Cause
Spikes on horizontal channels	• The holelock is not properly clamped (Check that the length of clamping studs is correct for the hole diameter and that they are screwed on tightly.). • The cable does not have slack. • Poor surface quality inside the casing. For example, flaking rust. • Poor cementation of casing or other borehole construction issue. Refer to the Nanometrics technical note on *Borehole Drilling Requirements*.
Continuous low frequency wander (random noise, larger on horizontal channels)	• The hole is not sealed and air drafts are causing temperature fluctuations. • The cable lock is not installed. • The hole may be flooded with water. Since rain leakage or condensation of moist air can cause water to accumulate, check the seal at the top of the hole. If the water is only present at the bottom end of the hole, raise the sensor higher and reclamp.
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.

Table 5-2 - Types of noise and possible causes for posthole deployments

Noise Type	Possible Cause
Spikes on horizontal channels	• There is a force pulling on the cable. • There is unstable soil around the seismometer. Note that deploying in unstable soil may be a deliberate choice for a posthole installation if that is the only way to place a seismometer at that location, for example a marsh or flood plain. • In a cased hole installation, the casing may be loose in the ground. Refer to the Nanometrics technical note on *Borehole Drilling Requirements*.
Continuous low frequency wander (random noise, larger on horizontal channels)	• The hole is not sealed and air drafts are causing temperature fluctuations. • There is unstable soil around the seismometer. Horizontal noise may be expected at a low level for temporary installations in challenging environments where the seismometer must be installed in unstable ground.
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.

Table 5-3 - Types of noise and possible causes for vault deployments

Noise Type	Possible Cause
Spikes on 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. • There is unstable soil underneath the seismic pier. Horizontal noise levels will generally be somewhat higher in loose sediment environments as compared to bedrock.
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.

5.2 Retrieving the Instruments from a Borehole Manually

If the Trillium Borehole Holelock unlocking procedure fails or if the Trillium Holelock Controller or appropriate power to operate the Trillium Holelock Controller is not available, use the following steps to retrieve the instruments from the borehole.

1. Remove the borehole cover/seal.
2. Lift the cables up enough that all slack is gone.
3. Apply 300 kg (700 lb) of force to raise the cables approximately 2.5 cm (1 in.).
4. If the winch is not strong enough, this can be done by looping the wire rope around a crowbar or pipe and prying upwards using the edge of the hole as a fulcrum.
   This amount of force over that distance will engage the fail-safe mechanism on the locking pin and cause it to retract back into the body of the Trillium Borehole Holelock.

> Operation of the fail-safe retraction mechanism does not damage the Trillium Borehole Holelock. The mechanism is spring loaded and automatically resets when free of the borehole.

5. Lift the seismometer and Trillium Borehole Holelock out of the borehole.
   It should be easy to lift because the locking pin has been retracted back inside the Trillium Borehole Holelock.

Part 2 - Operation

- Input & Output Signals
- Configuring Your System
- Leveling and Centering the Masses
- Configuring Serial Communications
- Using the Web Interface

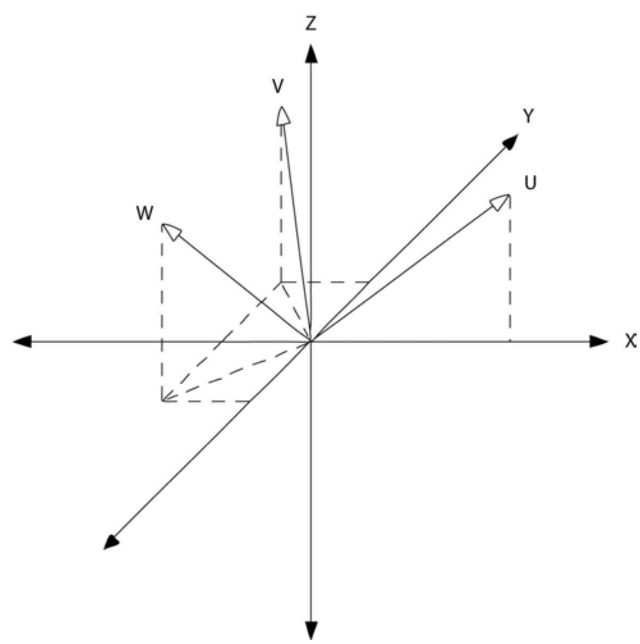
Chapter 6 - Input & Output Signals

6.1 UVW and XYZ Output Signals

The Trillium 360 GSN can be configured to output either XYZ or UVW signals. The “natural” output is UVW where the outputs represent the motions in the direction of sensitivity of the three sensor components. The “conventional” seismometer output is XYZ where the outputs represent horizontal and vertical motion of the seismometer. When you change the output mode, the seismometer will respond within 4 s.

To understand the difference between the UVW and XYZ outputs, see Figure 6-1. By design, the Trillium 360 GSN axes are identical and sense motion in orthogonal directions. The U axis is aligned with the X axis when projected into the horizontal plane.

Figure 6-1 - Trillium 360 GSN axis orientation



This arrangement results in the following transformation equations:

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

(EQ1)

$$\begin{bmatrix} x \\ y \\ z \end{bmatrix} = \frac{1}{\sqrt{6}} \cdot \begin{bmatrix} 2 & -1 & -1 \\ 0 & \sqrt{3} & -\sqrt{3} \\ \sqrt{2} & \sqrt{2} & \sqrt{2} \end{bmatrix} \cdot \begin{bmatrix} u \\ v \\ w \end{bmatrix}$$ (EQ2)

The first equation (EQ1) is implemented mechanically in the Trillium 360 GSN through the orientation of the individual axes. The second equation (EQ2) is implemented electronically when the Trillium 360 GSN is in XYZ mode.

Alternatively, seismic data can be digitized with the Trillium 360 GSN 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.

To account for the source impedance, see Table 12-1 "Ground motion response nominal parameters for T360-BH1-GSN, T360-PH1-GSN, and T360-SV1-GSN models" on page 114

Table 6-1 shows the polarities of the XYZ outputs and the correspondence of each to the directions of the compass.

Table 6-1 - Axis orientation and polarity of XYZ outputs on the Trillium 360 GSN

Axis	Orientation	Voltage
X	east-west	A positive voltage (+) indicates case motion to the east
Y	north-south	A positive voltage (+) indicates case motion to the north
Z	vertical	A positive voltage (+) indicates an upward case motion

To select the

- UVW outputs, apply a constant 5 to 15 VDC to the UVW/TX pin
- XYZ outputs, leave the UVW/TX pin floating or set it to 0 V

The UVW/TX input control signal is disabled when the seismometer is transmitting through a serial port because this pin is used as the RS-232 serial TX output signal. For more information on serial port communication with a Trillium 360 GSN seismometer, see "About Serial Communications" on page 93.

6.2 Serial RS-232 Communications

The 9600 baud serial communications interface is provided on the Rx and Tx signals of the serial connector or the main connector, where DGND serves as the ground reference for the serial link. Use this interface to access the unit's integrated Web server that presents a series of Web pages with unit information and configuration options. View these pages using one of the following methods:

- through the Sensor Web page of a Nanometrics digitizer such as a Centaur, see "Connecting through a Nanometrics Digitizer" on page 93.
- through a direct serial connection to a computer using a serial communications breakout cable (Nanometrics part number 17280-3M) and a Serial Line Internet Protocol (SLIP) connection on the computer (see "Calculating the IP Address" on page 94).

The digital control lines share the same pins as the serial lines, and so, are only functional when serial communications are not in use. The two serial/control pins are provided on the connector.

The Rx, Tx, and DGND signals implement a 9600 baud RS-232 communications interface. The Trillium 360 GSN automatically senses when valid serial communication on the Rx line is being received, and turns on the Tx line to transmit. The Rx and Tx signals share pins with the MC (mass centering) and UVW control inputs. Care must be taken to ensure that the UVW/TX line is not being simultaneously driven by the digitizer. When serial communications are occurring on the Rx and Tx lines, the control line signals MC and UVW that share these pins are not effective. For more details, see "Digital Control Input Signals" on the next page and "Connectors" on page 120.

Serial communication should not be active when the highest quality seismic signal is desired because it may cause low levels of noise on the analog output signals.

6.3 Digital Control Input Signals

Trillium 360 GSN seismometers have the following digital control input signals:

- All Trillium 360 GSN seismometers have MC/RX and UVW/TX control input signals
    - UVW changes the output mode. The output modes are XYZ (default) and UVW.
    - **For the Trillium 360 GSN Borehole and Trillium 360 GSN Posthole seismometers,** MC initiates auto-leveling. In a single operation, auto-leveling levels the internal seismometer to true vertical and centers the axis mass positions. See "About Leveling and Mass Centering" on page 88 for a detailed description.
    - **For the Trillium 360 GSN Vault seismometers,** MC initiates mass centering but not auto-leveling. See "About Leveling and Mass Centering" on page 88.
- Trillium 360 GSN Borehole and Trillium 360 GSN Posthole both have a single calibration enable signal that is used by each of the U, V, and W axes (CALEN).
- Trillium 360 GSN Vault has calibration enable signals for each of the axes (U_CALEN, V_CALEN, and W_CALEN).

See "Calibration Input Signal" below for more information.

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-high signals. See "Connectors" on page 120 for details. All inputs can tolerate at least ±15 V except for UVW/TX which can tolerate voltages from -7 V to +15 V.

6.4 Calibration Input Signal

The Calibration Input Signals are provided to allow for relative calibration of the Trillium 360 GSN seismometer across frequency and over time.

Since the Trillium 360 GSN 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 instructions on how to set a Trillium 360 GSN to UVW mode, see "UVW and XYZ Output Signals" on page 77.

The calibration enable signals are as follows:

- Trillium 360 GSN Borehole and Trillium 360 GSN Posthole have a single calibration enable signal that is used by each of the U, V, and W axes (CALEN).
- Trillium 360 GSN Vault has a separate calibration enable signal for each axis (U_CALEN, V_CALEN, and W_CALEN).

All of the axes use a common calibration input signal, CAL_SIG. See "Calibration input response nominal parameters for T360-BH1-GSN, T360-PH1-GSN, and T360-SV1-GSN models " on page 115.

6.5 State-of-Health Output Signal

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 signal, these signals represent the state of the individual axes (UVW) rather than the horizontal and vertical outputs (XYZ).

For the Trillium 360 GSN Borehole and the Trillium 360 GSN Posthole, the mass positions are zeroed at the factory at room temperature with the seismometer perfectly level. If any of the mass positions are approaching ±3.5 V, mechanical recentering should be initiated. Follow the mass centering procedure for your seismometer in "About Leveling and Mass Centering" on page 88.

For the Trillium 360 GSN Vault, zero the mass positions by initiating automated mass centering, which uses stepper motors to precisely tension the spring. See "Choosing When to Center the Masses" on page 90 for more information on centering the masses based on the status of these signals.

6.6 Power Consumption

A 24 VDC, 10 A power system is recommended to supply the requirements for both the Trillium 360 GSN Borehole Seismometer and the Trillium Borehole Holelock and to allow for cable losses.

Following are power consumption scenarios typical for a Trillium 360 GSN seismometer:

- Under normal operation, (the unit is level and well centered, there is a low seismic signal, the unit has settled for at least 30 minutes, and the RS-232 serial port is not transmitting), power consumption is approximately 820 mW
- On start-up, power consumption may briefly surge to 4 W
- Any additional power consumption above normal quiescent, after the power-on inrush, is roughly proportional to the output signal and is largely independent of mass position
- If the unit is not centered or has not yet settled, the output signals will be at the maximum, and power consumption may be as high as 2.4 W
- For a unit that is settled, centered and level, a seismic signal that approaches the maximum clip level of the seismometer may draw as much as 2 W peak

(The average power consumption would be much lower.)

- **For the Trillium 360 GSN Borehole and Trillium 360 GSN Posthole**, the auto-leveling operation draws up to 5.6 W while the motors are operating. The time for the operation to complete may be up to 20 minutes. See "Leveling and Centering the Masses" on page 88 for more information on the auto-leveling operation.
- **For the Trillium 360 GSN Vault**, mass centering can momentarily draw up to 3.8 W while the motors are operating.

6.6.1 Voltage Drop Considerations

For long cables, account for the resistive voltage drop due to the cable length and, if necessary, increase the voltage at the source. See "Cables and Accessories" on page 14 for a description of the cables.

Table 6-2 - Voltage Drop Considerations

Seismometer type	Cable type (Nanometrics part number)	Power wire gauge	Power supply voltage	Maximum cable length
Trillium 360 GSN Vault	16169	24	12 V	25 m
			24 V	130 m
Trillium 360 GSN Borehole Trillium 360 GSN Posthole	17442, 17782	20	12 V	65 m
			24 V	300 m

6.6.2 Power Consumption for the Trillium Borehole Holelock

- The current consumption of the Trillium Borehole Holelock DC motor is largely independent of the applied voltage. It can operate on as little as 9 V but 24 V power is recommended to overcome any voltage drop in the cable.
- On start-up, current consumption may briefly surge to 10 A.
- The locking operation typically draws 0.5 A. The unlocking operation typically draws 2 A. The time for each operation to complete is approximately 10 seconds at 24 V (takes longer at a lower voltage since motor speed is proportional to voltage).
- No power is consumed when the Trillium Borehole Holelock is in a fully locked or unlocked state, even when voltage is applied.
- The motor DC resistance is 1.3 Ω. The Trillium Borehole Holelock power wires in the sensor cable are 12 AWG with a DC resistance of 0.52 Ω each way per 100 m cable length. Therefore, the worst case stall current would be 10 A at 24 V for a 100 m cable.

Chapter 7 - Configuring Your System

7.1 Configuring the Centaur for the Trillium 360 GSN

Using the following paragraphs as a guideline, configure the Centaur for use with the Trillium 360 GSN.

1. Verify that the connections displayed in the **Discovery** panel on Centaur Web interface match the connections on the Centaur digital recorder, see "Verifying connection with the Centaur digital recorder" on page 43.
2. Select the sensor type from the sensor library. See " Selecting the Sensor" below.

> Make sure that the selected seismometer is compatible with the actual seismometer. For example, if you have the posthole variant of the Trillium 360 GSN seismometer, select Trillium 360 Posthole GSN - Default from the Centaur Sensor Library.

3. Configure the digitizer sensitivity, typically this will be 40 V peak-to-peak. See "Configuring the Sensitivity of the Centaur Digitizer" on the next page.

7.2 Selecting the Sensor

The current generation Nanometrics digitizer, Centaur, features an on-board sensor library that contains the default configurations for all Nanometrics sensors. Use the following instructions to configure the Centaur digitizer to use with the Trillium 360 GSN seismometers.

1. Log on to the Centaur Web Interface, access the Configuration window and navigate to the **Sensor Library** menu item.
2. Expand the Sensor Library menu item and click on the appropriate default sensor type as follows:
   - Trillium 360 Borehole - Default
   - Trillium 360 Posthole - Default
   - Trillium 360 Vault - Default

> If your Sensor Library does not include the sensor definitions for the Trillium 360 GSN,

> upgrade your Centaur firmware to the latest version, or contact Nanometrics for further assistance. See "Contact Us" on page 140.

3. Click on the **Apply** button. While the system is processing the configuration change the configuration window will be greyed out. This may take approximately 1 minute.
4. Once the message ***INFO****: changes applied* appears at the bottom of the configuration window, click on the **Commit** button.

   > If you do not Commit the configuration, you risk losing the sensor configuration if the device restarts.

5. Click on the **Close** button.

7.3 Configuring the Sensitivity of the Centaur Digitizer

Use these instructions to change the sensitivity of the Centaur digitizer.

1. Log into the Centaur.

> The 6-channel Centaur has a Sensor port A and a Sensor port B.

2. Click on the Configuration icon to access the drop-down menu and click on **Configuration**. The configuration window will display.
3. In the left pane,
   a. Select **Configuration** > **Digitizer A** or **Digitizer B**.
   b. Select **Front End A** or **Front End B**. The Front End window will be displayed in the right pane.
   c. Select the appropriate value from the Input range drop-down. Most commonly, the 40 Vpp range is used to match the seismometer clip level.
   d. If a lower system noise floor is desired, configure a higher sensitivity (lower input range). See "Seismometer System Sensitivity Guidelines " on the next page for more information.
4. Click on the **Apply** button. While the system is processing the configuration change the configuration window will be greyed out. This will take approximately 1 minute.

5. Once the message **INFO:** *changes applied* appears at the bottom of the configuration window, click on the **Commit** button.
6. Click on the **Close** button.

7.4 Seismometer System Sensitivity Guidelines

If increased system sensitivity is desired, decrease the digitizer input range and increase the sensitivity. Use Table 7-1, Table 7-2 and Table 7-3 as a guide.

> Increasing the sensitivity of a digitizer by decreasing the input range below the 40 Vpp output range of the Trillium 360 GSN seismometer can cause the digitizer to clip during strong events.

Table 7-1 - Clip Level versus Gain Range for Models T360-PH1-GSN and T360-BH1-GSN (all S/Ns), & model T360-SV1-GSN (S/N 200 and above)

Digitizer Input Range (Vpp)	Digitizer Sensitivity (count /µV)	Sensitivity (V/(m/s))	Clip Level (mm/s)
40	0.4	1998.4	10.01
20	0.8	1998.4	5.00
10	1.6	1998.4	2.50
4	4	1998.4	1.00
2	8	1998.4	0.50
1	16	1998.4	0.25
0.5	32	1998.4	0.125

Table 7-2 - Clip Level versus Gain Range for model T360-SV1-GSN (S/N to 199)

Digitizer Input Range (Vpp)	Digitizer Sensitivity (count /µV)	Sensitivity (V/(m/s))	Clip Level (mm/s)
40	0.4	1999.5	10.00
20	0.8	1999.5	5.00
10	1.6	1999.5	2.50
4	4	1999.5	1.00
2	8	1999.5	0.50
1	16	1999.5	0.25
0.5	32	1999.5	0.125

Table 7-3 - System Sensitivity versus Gain Range

	Models T360-PH1-GSN and T360-BH1-GSN (all S/Ns), & model T360-SV1-GSN (S/N 200 and above)		Model T360-SV1-GSN (S/N to 199)	
Digitizer Input Range (Vpp)	**Centaur System Sensitivity (Counts/(m/s))**	**Pegasus System Sensitivity (Counts/(m/s))**	**Centaur System Sensitivity (Counts/(m/s))**	**Pegasus System Sensitivity (Counts/(m/s))**
40	7.93E+08	7.93E+08	7.94e+08	7.94e+08
20	1.59E+09	1.60E+09	1.59e+09	1.60e+09
10	3.17E+09	3.20E+09	3.18e+09	3.20e+09
4	7.93E+09	7.99E+09	7.94e+09	8.00e+09
2	1.59E+10	1.60E+10	1.59e+10	1.60e+10
1	3.17E+10	3.20E+10	3.18e+10	3.20e+10
0.5	NA	6.39E+10	NA	6.40e+10

Note that the exact nominal system sensitivity will vary depending on the normalization frequency (typically 1 Hz) and the lower corner period. The exact nominal sensor sensitivity for a particular type of Trillium 360 GSN seismometer can be taken from the appropriate table in "Frequency Response" on page 111.

Chapter 8 - Leveling and Centering the Masses

8.1 About Leveling and Mass Centering

For the Trillium 360 GSN Borehole and the Trillium 360 GSN Posthole automatic motorized leveling and mass centering are completed in a single operation called auto-leveling. The internal seismometer is leveled to true vertical and the mass positions of the three axes are zeroed. In the case of the Trillium 360 GSN Vault, the seismometer must be leveled manually using the bubble and feet before initiating the automatic mass centering procedure.

> In the context of this user guide, unless otherwise noted, mass centering refers to auto-leveling in the case of the Trillium 360 GSN Borehole and Trillium 360 GSN Posthole or mass centering in the case of the Trillium 360 GSN Vault.

Trillium 360 GSN 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 nominal range of ±4 V and in practice a usable range of at least ±3.5 V, allowing for tolerances in components, power supplies, and variation with temperature. 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 center and a small DC feedback current is being applied to hold the mass at its center operating point. The Trillium 360 GSN seismometer is not subject to any significant degradation in performance until one or more of the mass positions reaches the limit of its range (±3.5 V or higher). 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 process of auto-leveling and mass centering introduces large glitches in the ground motion signal while the axes are rebalanced.

- **For the Trillium 360 GSN Borehole and Trillium 360 GSN Posthole seismometers**, this time may be between 5 and 20 minutes depending on how far the mechanism has to move to reach level.
- **For the Trillium 360 GSN Vault seismometer**, this time is approximately 1 minute.

Therefore, to prevent data loss, you should only recenter the seismometer when necessary. The recommended best practice regarding mechanical mass centering is to periodically check the three axis mass positions (analog signals U_MP, V_MP, and W_MP, referenced to AGND) and initiate mass centering if any are approaching ±3.5 V.

Mass positions in seismometers can drift over time for two reasons: tilt and temperature.

These two phenomena are easily distinguished. 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 "UVW and XYZ Output Signals" on page 77 to convert UVW to XYZ mass positions. X, Y, and Z mass positions do not correspond to an actual voltage within the seismometer. They are calculated parameters that can be used to roughly measure the cumulative changes in tilt and to distinguish that from changes in temperature. Changes in the Z mass position correspond roughly to changes in internal temperature, while changes in the X and Y mass positions correspond to tilt towards the east and north, respectively. Significant temperature change and therefore a change in Z mass position is to be expected within the first 24 hours after installation. Some tilt is also to be expected in the first few days, especially due to soil settling in a direct burial installation. Tilt that occurs later, once the installation is settled, may have geological significance indicating uplift or subsidence of soil slopes or rock structures.

Table 8-1 - Tilt Sensitivity and Range

	Sensitivity	**Range**
Tilt	150 V per degree	±0.026 degrees
Corresponding values for X, Y, and Z may be calculated from the UVW to XYZ transformation matrix on page 77.		

We recommend that you check and if necessary re-center mass positions one to two days after installation to allow for initial temperature change and settling.

The noise performance is not sensitive to mass position offset as long as it is in the operational range.

Mass positions should be monitored on a monthly basis to check for long-term, typically seasonal, drift as follows:

- **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. The Trillium 360 GSN has a tilt range of ±0.026º without recentering. This is more than sufficient for a bedrock installation. Typically this is sufficient for direct burial or for vault installations that are not in bedrock, however care must be taken to ensure that the fill material is well compacted and that the ground is not subject to excessive movement such as frost heaving or flood erosion.
- **Temperature.** Some climates experience vast temperature changes between seasons. Such drastic changes in temperature can cause seismometer masses to become decentered. The Trillium 360 GSN has a temperature range of at least ±10 ºC without recentering. Since the seismometer itself has a large heat capacity (thermal mass) and is normally installed below ground level, with insulation, it will not become decentered due to day-to-night temperature cycling. However, seasonal temperature changes can cause the seismometer to become decentered. Therefore, mass positions may need to be checked on a monthly basis, depending on the climate.

> Nanometrics systems and software allow the mass positions to be monitored and recentered remotely. Alternatively the Centaur can be configured to automatically recenter the seismometer whenever the mass position exceeds a preset threshold. See the *Centaur User guide (17935)* for instructions.

8.2 Choosing When to Center the Masses

Following are circumstances when you should initiate mass centering:

- Immediately following installation, and one to two days later if necessary
- 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
- When an interruption of good-quality seismic data can be tolerated, as auto-leveling may affect the output signal for approximately 20 minutes
- When ambient temperature is roughly in the center of its expected range, allowing the seismometer to use the full ±10°C range before auto-leveling may be required

due to temperature change. For example, if temperature extremes are reached in summer and winter, it is best to auto-level in spring or fall

8.3 Centering the Masses in Trillium 360 GSN Seismometers

Mass centering is initiated via the MC/RX control line or the serial RS-232 interface on the connector. Most commonly a standard cable and digitizer will be used to initiate mass centering; however, it can also be initiated using the on-board Web interface. For the Trillium 360 GSN Borehole and Trillium 360 GSN Posthole, allow up to 20 minutes for the operation to complete. For the Trillium 360 GSN Vault, this operation will take approximately 1 minute to complete.

> This operation may fail and need to be re-initiated if the seismometer is moved or tilted during the procedure.

See "Initiating Mass Centering Using a Standard Cable and a Digitizer" below for instructions on initiating auto-leveling using a standard cable and digitizer. For information on using the Web interface, see "Using the Web Interface" on page 95.

8.3.1 Initiating Mass Centering Using a Standard Cable and a Digitizer

The following instructions explain how to initiate mass centering using a standard cable (see "Cables and Accessories" on page 14) and a Nanometrics Centaur digital recorder, or a third party digitizer.

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 centering is required.

> If you have a Centaur, check the mass position status on the **Sensor** page. See the *Centaur User Guide (17935)* for more information.

2. Initiate mass centering using the option that best meets your hardware and software configuration:

   a. If you are using a Centaur, either configure the Centaur for auto mass centering, or click **Mass centre** on the **Sensor** page using the Centaur Web interface. See the *Centaur user guide (17935)* for more information.
   b. If you are using a third-party digitizer, pull the MC/RX pin high, referenced to the DGND pin for at least 1 s. See "Connectors" on page 120.
3. For the Trillium 360 GSN Borehole or the Trillium 360 GSN Posthole, allow up to 20 minutes for the operation to complete. For the Trillium 360 GSN Vault, this operation will take approximately 1 minute to complete.
4. Check the voltage readings on the mass position outputs again to confirm that the masses are now within the ±1 V range.

> The Trillium 360 GSN seismometer automatically changes to short period (SP) mode during the auto-leveling operation, and is automatically returned to its previous state when the operation is complete.

8.3.2 Initiating Mass Centering using a Serial Cable and Laptop

If you are not using a Nanometrics digitizer, you will need an appliance that converts Ethernet to Serial Line Internet Protocol (SLIP). A SLIP appliance is required to access the sensor's Web Interface to initiate mass centering. For more information, see "About Serial Communications" on page 93.

Chapter 9 - Configuring Serial Communications

9.1 About Serial Communications

The Trillium 360 GSN has an integrated Web server that is accessible using a standard Web browser and the RS-232 serial interface. The sensor web page can be used to retrieve sensor information, access state-of-health information and control features, and to configure the sensor.

The simplest way to connect to the sensor's web page is to use a Nanometrics digitizer, such as Centaur (see "Connecting through a Nanometrics Digitizer" below.) The web page is accessed through the Web interface of the digitizer. The Web Interface is a series of Web pages that retrieve information about the seismometer, access state-of-health (SOH) information and control features, and allow you to configure the seismometer. See "Using the Web Interface" on page 95.

If you are not using a Nanometrics digitizer, connecting to a Trillium 360 GSN seismometer requires an IP connection over a Serial port. Most modern PCs, laptops, and handheld devices do not include a physical serial port. In addition, currently supported Microsoft Windows operating systems do not support Serial Line Internet Protocol (SLIP) connections.

Nanometrics has developed a simple, low-cost appliance that converts Ethernet to SLIP to allow IP communication with sensors from PCs or laptops. Alternatively, advanced Linux users can build their own SLIP appliance. For more information about the Nanometrics SLIP appliance, instructions on building your own SLIP appliance, and other methods of accessing your Nanometrics smart sensor web interface, refer to the Nanometrics technical note *Accessing Your Nanometrics Smart Sensor Web Interface (18105)*, or go to support.nanometrics.ca

9.2 Connecting through a Nanometrics Digitizer

Nanometrics digitizers, such as the Centaur, support the Web interface of the Trillium 360 GSN family, allowing you to access the Web-based features of the seismometer through the Web interfaces of those instruments. This allows you to access the unit remotely, even while it is in service, without requiring a breakout cable and a SLIP connection on a co-located computer.

See the documentation for your Nanometrics digitizer for details on how to access the Trillium 360 GSN Web interface through these instruments. See "About the Web Interface" on page 95 for descriptions of each page.

9.3 Calculating the IP Address

You will need the IP address if you are not using a Nanometrics digitizer to access the sensor's Web interface (see "About the Web Interface" on page 95). The IP address was provided with the unit. However, if you cannot locate the IP address, you can calculate it using the method described below.

The IP addresses of the Trillium 360 GSN variants are as follows:

- 2.58.x.y for the Trillium 360 GSN Borehole,
- 2.58.x.y for the Trillium 360 GSN Posthole, and
- 2.57.x.y for the Trillium 360 GSN Vault,

where x and y are calculated from the serial number of the unit.

To calculate the values for x and y in the serial number:

- x = SerialNumber / 256

Use the resulting whole number for the value of x and discard any decimal amounts.

- y = SerialNumber *modulo* 256

The reference to *modulo* 256 in the equation for y means that it is the remainder after 256 is divided into the serial number.

For the Trillium 360 GSN Borehole which has an IP address of 2.58.x.y and assuming a serial number of 800, you can use the above equations to determine that:

- x = 800 / 256, which results in a value of 3.125. Only the whole number is required, leaving x equal to 3.
- y = 800 *modulo* 256, which results in a value of 32.

Therefore, having solved for x and y, the IP address of a Trillium 360 GSN Borehole with a serial number of 800 is 2.58.3.32.

Chapter 10 - Using the Web Interface

10.1 About the Web Interface

Each Trillium 360 GSN has an integrated Web server that is available using a standard Web browser and the RS-232 serial interface (see "About Serial Communications" on page 93). This interface is provided through either the serial connector or the main connector. Use the Web interface to retrieve information about the sensor, access state-of-health information and control features, and to configure the sensor.

> Ensure that the proxy server is disabled when using a Web browser with a Trillium 360 GSN seismometer.

The simplest way to access the sensor’s Web Interface is to use a Nanometrics digitizer, such as the Centaur. See "Connecting through a Nanometrics Digitizer" on page 93.

If you are not using a Centaur digitizer, you will need to acquire a Nanometrics appliance that converts Ethernet to Serial Line Internet Protocol (SLIP) or build your own SLIP device. For more information, see "About Serial Communications" on page 93.

Use this interface to retrieve information about the seismometer, access state-of-health information and control features, and configure the seismometer. Access the seismometer Web interface through the Web interface of the Nanometrics digitizer, such as the Centaur or by connecting the optional cable to a SLIP appliance. (For the Trillium 360 GSN Borehole and Trillium 360 GSN Posthole use the optional cable 17280-3M. For the Trillium 360 GSN Vault use the optional cable CAB15766.)

> The serial port should not be accessed when the highest quality seismic signal is desired as serial port traffic may cause low levels of noise on the analog output signals of the Trillium 360 GSN.

The home page provides links to other pages which are described in the following sections:

- "Viewing the Current State-of-Health" below
- "Viewing the Real-time Mass Position" on the next page
- "Viewing Seismometer Control" on page 98
- "Performing Auto-Leveling and Mass Centering " on page 99
- "Calibrate Bubble Level" on page 99
- "Upgrading the Seismometer Firmware" on page 100
- "Managing and Viewing Unit Information" on page 100

10.2 Accessing Trillium 360 GSN Web pages

Proceed as follows to access the Trillium 360 GSN Web pages through the Centaur digitizer:

> You can connect two sensors to the 6-channel Centaur. Each sensor is accessed from one of the Serial radio buttons.

1. Login to the Centaur.
2. Navigate to the **Sensors** page.
3. For each seismometer,
   a. If the Discovery section of the Sensors page indicates “No sensor found”, click on the **Discover** button.
   b. Click on the **Serial** radio button (**A** or **B**). A link to the sensor Web home page will display.
   c. Click on the link located above the **Discover** button to access the Trillium 360 GSN Web pages.

10.3 Viewing the Current State-of-Health

The **SOH** page provides detailed information that indicates the health and status of the Trillium 360 GSN seismometer, including the following:

- **Output Mode.** Displays the current settings for the output mode (XYZ or UVW) and long or short period mode (Long Period or Short Period). You can edit these settings on the **Seismometer Control** page. See "Viewing Seismometer Control" on the next page.

- **Temperature.** Displays the approximate internal temperature of the Trillium 360 GSN Borehole seismometer in Celsius and Fahrenheit.
- **Case tilt angle.** Displays the tilt of the case from vertical in degrees.

> The axes are automatically leveled so the Z output represents the true vertical regardless of the tilt of the case.

- **Mass Positions.** Displays the current mass positions for the U, V, and W channels. The mass position range is ±4 V and the color of the table cells change based on the mass position voltage.
  The color thresholds for the table cells are as follows:
  - Green when the mass position voltage is between -2.5 V and +2.5 V.
  - Yellow when the mass position voltage is between -2.5 V and -3.5 V or between +2.5 V and +3.5 V.
  - Red when the mass position voltage is greater than +3.5 V or less than -3.5 V.

  See "Viewing the Real-time Mass Position" below.

Together these values provide the health of the Trillium 360 GSN seismometer.

10.4 Viewing the Real-time Mass Position

The **Real-time Mass Position** page provides real-time mass position voltage readings for the U, V, and W channels. When the page loads, the U, V, and W mass positions will be changing as the Web interface receives data from the Trillium 360 GSN seismometer in real-time. When receiving data from the Trillium 360 GSN seismometer, the button below the table will be labelled **Streaming** and the color of the table cells may change based on the mass position voltage.

The color thresholds for the table cells are as follows:

- Green when the mass position voltage is between -2.5 V and +2.5 V.
- Yellow when the mass position voltage is between -2.5 V and -3.5 V or between +2.5

V and +3.5 V.

- Red when the mass position voltage is greater than +3.5 V or less than -3.5 V.

The real-time stream of data will continue for approximately 60 s to 90 s. When streaming stops, the color of the table cells will turn to grey. Click the **Resume streaming** button to begin streaming data again.

> If you want to navigate to another page before the data finishes streaming, click the **Home** link at the bottom of the page.

10.5 Viewing Seismometer Control

The **Seismometer Control** page allows you to change the XYZ/UVW output mode, and to change the long/short period mode for the seismometer. Click **Apply** to save your settings. These settings will reset to the factory default settings when the firmware is rebooted or the unit is power cycled.

> Changes made on the Seismometer Control page are temporary. The Trillium 360 GSN seismometer will return to its default values when rebooted.

The sections on the page are as follows:

- **Output Mode.** Choose the output mode of XYZ or UVW (see "UVW and XYZ Output Signals" on page 77 for a detailed explanation of the output signals). Select **Use control line** to permit the control line input to select between XYZ and UVW modes. The default is **Use control line**.
- **Long or Short Period Mode.** The lower corner of the seismometer response can be changed from the normal operating mode of 360 s period to a “short period” response of approximately 1 s period. This may be useful when leveling the seismometer, allowing you to see the mass positions quickly respond to changes in tilt, or once the seismometer is leveled, to allow the mass positions to quickly settle. Be sure to set the seismometer to **Long period** mode when recording seismic signals. The default setting is **Long period**.

- Trillium 360 GSN seismometers are automatically placed into short period mode when auto-leveling begins and returned to long period mode when finished. Short period mode allows the mass positions to respond quickly (signals U_MP, V_MP, W_MP, or the SOH <Mass> or <ADC> values) when the Trillium 360 GSN is being leveled. In long period mode these numbers ramp very slowly, and so, care must be taken to not be misled by apparently centered values when in fact the Trillium 360 GSN is not centered. In short period mode, these numbers respond within a second. The Trillium 360 GSN seismometer always powers up in long period mode.

10.6 Performing Auto-Leveling and Mass Centering

For the Trillium 360 GSN Borehole and Trillium 360 GSN Posthole, use the **Level and Mass Centre** page to initiate auto-leveling and center the masses. **For the Trillium 360 GSN Vault,** use the **Mass Centre** page to center the masses.

After centering the masses, a table is displayed that shows the mass position and the status of each channel. Once the process has started, you cannot navigate away from the page until the process is complete. For the Trillium 360 GSN Borehole and Trillium 360 GSN Posthole the process may take between 5 and 20 minutes depending on how far the mechanism has to move to reach level.

10.7 Calibrate Bubble Level

The **Calibrate Bubble Level** page allows you to calibrate the digital bubble level display for the Trillium 360 GSN. The Trillium 360 GSN digital bubble level is calibrated at the factory, so there is no need to run calibration prior to installing the instrument.

If you do wish to verify the digital bubble level display prior to installing the instrument, do so only when advised by Nanometrics and only in a lab setting using a perfectly level slab. Once the Trillium 360 GSN is physically level, then click on the **Calibrate** button.

10.8 Upgrading the Seismometer Firmware

Use the **Firmware** page to upgrade the unit with a new firmware file provided by Nanometrics.

Use the following steps to upload new firmware:

1. Copy the new firmware file (*nmx_trillium_vbb-5.x.x.nbf*) provided by Nanometrics to a local or network accessible location.
2. From a browser on this PC, access the Trillium 360 GSN seismometer web interface.
3. Click the **Firmware** link on the Home page. Verify the current firmware Version is shown as *5.x.x*.
4. Click **OK** and continue to the next page.
5. Browse to the firmware file provided by Nanometrics.
6. Click **Choose file** to navigate to the new firmware file.
7. Click **Upload** to begin the firmware upgrade.

> When the firmware upload begins, the Upload button becomes disabled and its label changes to “Uploading...”

8. When the firmware upgrade is complete a message indicates that the unit must be rebooted or power cycled for the new firmware to become active.
   Restart the unit using one of the following methods:
   a. Click the **Back** button and click **Reboot** on the previous page to reboot the firmware.
   b. Manually power-cycle the unit.
9. Confirm that the version has been updated by verifying the version at the bottom of the **Home** page after rebooting.

10.9 Managing and Viewing Unit Information

The **Unit Information** page allows you to upload your own user information about the unit in a text file. This information can then be viewed or exported.

Part 3 - Reference

- Specifications
- Performance
- Connectors
- Features and Dimensions
- Site Record
- Grounding guidelines
- Open Source Attributions
- Glossary

Chapter 11 - Specifications

11.1 Common Specifications for Trillium 360 GSN Seismometers

Table 11-1 - Common Specifications for Trillium 360 GSN seismometers

Performance	
Self-noise	At or below the NLNM for all frequencies. See "Noise floor figure" on page 118.
Sensitivity	**For models T360-PH1-GSN and T360-BH1-GSN (all S/Ns), & model T360-SV1-GSN (S/N 200 and above)** 1998.4 V-s/m **For model T360-SV1-GSN (S/N to 199)** 1999.5 V-s/m
Precision	±0.5%
Bandwidth	-3 dB points at 360 s and 79 Hz
Clip level	10 mm/s up to 12 Hz See "Trillium 360 GSN seismometer performance" on page 119.
Dynamic range	169 dB @ 1 Hz
Lower corner damping relative to critical	0.707
Transfer function	• Lower corner poles within ±0.5% of nominal provided • High-frequency response within ±1 dB of nominal up to 50 Hz • See Figure 12-1 on page 112 and Figure 12-2 on page 113.
Output impedance	2 x 150 Ω±1%
Calibration input impedance	8.87 kΩ
Temperature sensitivity	±10°C without recentering
Magnetic sensitivity	less than 0.03 (m/s^2)/T
Technology	
Topology	Symmetric triaxial
Feedback	Force balance with capacitive transducer
Hardware interface	
Velocity output	• 40 V peak-to-peak differential • Selectable XYZ (east, north, vertical) or UVW mode
Mass position output	Three independent ±4 V outputs for UVW

Table 11-1 - Common Specifications for Trillium 360 GSN seismometers (Continued)

Power	
Supply voltage	9 V to 36 V DC isolated input at connector **Note: For the Trillium 360 GSN Borehole**, a 24 V power system is recommended to allow for cable losses.
Protection	• Reverse-voltage protected • Self-resetting over-current protection • No fuse to replace
Environmental	
Shock	20 *g* half sine, 5 ms without damage, 6 axes No mass lock required for transport
Pressure	Enclosure optimized to be insensitive to atmospheric variations

11.2 Specifications for Trillium 360 GSN Borehole Seismometers

Table 11-2 - Specifications for Trillium 360 GSN Borehole Seismometers

Technology	
Mass centering	Motorized recentering automatically initiated during leveling sequence, can be remotely initiated
Self-leveling	Internal automated leveling
Leveling range	±5°
Dynamic tilt	Maximum tilt without auto-leveling ±0.026°
Leveling initiation	Control line or serial port command
Alignment	North line on top cap; optional alignment rod for downhole orientation
Hardware interface	
Connector	**Top end:** SEA CON®, XSL-20-BCR 20-pin male, glass reinforced epoxy Recommended mating connector: SEA CON, XSL-20-CCP **Bottom end:** Subconn MCBH2F, 2-socket micro bulkhead female for connecting to a Trillium Borehole Holelock Recommended mating connector: Subconn MCBH2M or MCIL2M

Table 11-2 - Specifications for Trillium 360 GSN Borehole Seismometers (Continued)

Calibration input	• Single voltage input for all channels • Remote calibration in XYZ or UVW mode
Calibration enable	Single calibration enable for all channels
Control lines	Auto-level, Mass Center, Calibration Enable, XYZ/UVW mode
Serial port	RS-232 compatible For instrument control and retrieval of configuration information.
Power	
Power consumption	820 mW typical at 12 V typical, under normal operating conditions For power consumption under other operating conditions such as startup and mass centering, see "Power Consumption" on page 82.
Environmental	
Operating temperature	-20ºC to +60ºC
Storage temperature	-40ºC to +70ºC
Ingress protection	Seismometer is rated to IP68 and NEMA6P to 300 m for prolonged immersion. A dry hole is recommended for best seismic performance. Holelock motor is rated to IP68 and NEMA6P to 30 m for prolonged immersion. NOTE: In the event of holelock motor failure, see "Retrieving the Instruments from a Borehole Manually" on page 75.
Humidity	0% to 100% (submersible)
Maximum depth	300 m
Physical	
Diameter	146 mm (5.75 in.), including external magnetic shield
Height	886 mm (34.88 in.), not including connector or actuator guard pipe 1050 mm (41.34 in.) including connector and actuator guard pipe
Weight	31 kg
Parasitic resonances	None below 100 Hz

Table 11-2 - Specifications for Trillium 360 GSN Borehole Seismometers (Continued)

Handling (Hoisting attachment point)	One eyebolt, centered, in the top end cap for lifting cable • Stainless steel, 3/8 in.-16, 1 in. inner diameter • Maximum load of 1300 lbf (5800 N) rated
Case design (Enclosure)	Stainless steel pressure vessel Threaded holes in top end cap: • Six retaining screw holes • Six M4 x 0.7 threaded utility holes for use as custom attachment points • Three M10X1.5 holes for attaching the Trillium Borehole Holelock • Three M10X1.0 holes for installing optional leveling feet for testing the seismometer on a pier 20-pin male connector Dual O-Ring seal in each end cap
Minimum borehole diameter	• 152 mm (5.98 in.) for ideal casing. • 156 mm (6.15 in.) is the minimum recommended diameter, allowing for typical irregularities in welded casings.
Alignment features	• Case-top north-south guide for straight-edge, line, or laser level • Vertical scribe marks for north and south on base
Maintenance	Factory maintenance only. Seismometer is only to be serviced by Nanometrics personnel.

11.3 Specifications for Trillium Borehole Holelock

Table 11-3 - Specifications for Trillium Borehole Holelock

Technology	
Topology	Motorized, single pin locking, non-jamming
Fail-safe features	Spring-based locking immune to motor failure, safe release mechanism for locking pin
Waterproofing	Motor sealed in pressure vessel
Hardware interface	

Table 11-3 - Specifications for Trillium Borehole Holelock (Continued)

Connector	SubConn® MCBH2M 2-pin micro bulkhead male for connecting to a Trillium 360 GSN Borehole seismometer Recommended mating connector: SubConn® MCBH2F
Power	
Power supply requirements	10 A at 24 V recommended (see "Power Consumption for the Trillium Borehole Holelock" on page 83.)
Power consumption	• 10 A at 24 V startup inrush current • 2 A at 24 V during locking or unlocking
Environmental	
Operating temperature	–20°C to +60°C
Storage temperature	–40°C to +70°C
Ingress protection	Holelock motor is rated to IP68 and NEMA6P to 30 m for prolonged immersion. NOTE: In the event of holelock motor failure, see "Retrieving the Instruments from a Borehole Manually" on page 75. A deepwater version is also available; however, a dry hole is recommended for best seismic performance.
Physical	
Height	438.4 mm (17.26 in.) (not including actuator guard)
Diameter	143 mm (5.64 in.) (excluding clamping studs and locking pin)
Weight	17 kg
Enclosure	• Stainless steel vessel • Extendable and retractable locking pin • 3 removable and extendable clamping studs • 3 holes in top end cap for attaching the Trillium Borehole Holelock to the Trillium 360 GSN Borehole seismometer • 2-pin Subconn® MCBH2M male connector in top end cap for connecting the Trillium Borehole Holelock to the Trillium 360 GSN Borehole seismometer
Locking force	3000 N (300 kgf)
Maintenance	Stainless steel body can be washed with a hose

11.4 Specifications for Trillium Holelock Controller

Table 11-4 - Specifications for Trillium Holelock Controller

Power	
Supply voltage	24 VDC (10 A) for the Trillium Borehole Holelock actuator motor
Environmental	
Weather resistance	Rated to IP67 and NEMA 6P for outdoor use, dust, and immersion resistance
Physical	
Length	200 mm (8 in.)
Width	150 mm (6 in.)
Height	44 mm (1.73 in.) (including connectors)
Enclosure	Aluminium case Sensor connector • 26-socket, shell size 16, MIL-C-26482 Series 1 • Mating connector MS3116J16-26P Power connector • 3-pin, shell size 8, MIL-C-26482 Series 1 • Mating connector MS3116J8-3S Holelock enable button Holelock lock/unlock toggle switch 4 LEDs (unlocked, unlocking, locking, locked)
Controls	Lock/unlock

11.5 Specifications for Trillium 360 GSN Posthole

Table 11-5 - Specifications for Trillium 360 GSN Posthole Seismometers

Technology	
Mass centering	Motorized recentering automatically initiated during leveling sequence, can be remotely initiated
Self-leveling	Internal automated leveling
Leveling range	±5°
Dynamic tilt	Maximum tilt without auto-leveling ±0.026°

Table 11-5 - Specifications for Trillium 360 GSN Posthole Seismometers (Continued)

Leveling initiation	Control line or serial port command
Alignment	North line on top cap; optional alignment rod for downhole orientation
Hardware interface	
Connector	20-pin male Glass reinforced epoxy Recommended mating connector: SEA CON, XSL-20-CCP
Calibration input	Single voltage input for all channels Remote calibration in XYZ or UVW mode
Calibration enable	Single calibration enable for all channels
Control lines	Auto-level, Mass Center, Calibration Enable, XYZ/UVW mode
Serial port	RS-232 compatible For instrument control and retrieval of configuration information
Power	
Power consumption	820 mW at 12 V typical, under normal operating conditions For power consumption under other operating conditions such as startup and mass centering, see "Power Consumption" on page 82.
Environmental	
Operating temperature	-20°C to +60°C (Standard Model T360-PH1-GSN) -50°C to +60°C (Polar Certified Model T360-PH1-GSN-XC)
Storage temperature	-40°C to +70°C (Standard Model T360-PH1-GSN) -60°C to +70°C (Polar Certified Model T360-PH1-GSN-XC)
Ingress protection	Rated to IP68 and NEMA6P to 300 m for prolonged immersion. A dry hole is recommended for best seismic performance
Humidity	0% to 100% (submersible)
Maximum depth	300 m
Physical	
Diameter	148 mm (5.83 in.), including external magnetic shield
Height	444 mm (17.48 in.) not including connector, eyebolt, or feet 451 mm (17.76 in.) including feet 500 mm (19.69 in.) including feet and eyebolt

Table 11-5 - Specifications for Trillium 360 GSN Posthole Seismometers (Continued)

Weight	18 kg
Case design (Enclosure)	Stainless steel pressure vessel Threaded holes in top end cap: • Six retaining screw holes • Six utility holes to use as custom attachment points Removable feet (3) in base 20-pin male connector Dual O-Ring seal in each end cap
Handling (Hoisting attachment point)	One eyebolt, centered, in the top end cap for lifting cable Stainless steel, 3/8 in.-16, 1 in. inner diameter Maximum load of 1300 lbf (5800 N)
Alignment features	Case-top north-south guide for straight-edge, line, or laser level Vertical scribe marks for north and south on base
Maintenance	Factory maintenance only. Vessel is only to be serviced by Nanometrics personnel.
Parasitic resonances	None below 100 Hz

11.6 Specifications for Trillium 360 GSN Vault Seismometers

Table 11-6 - Specifications for Trillium 360 GSN Vault Seismometers

Technology	
Leveling	Integrated bubble level, adjustable locking leveling feet
Mass centering	Automatic motorized recentering, can be remotely initiated Mass centering capability up to ±1.5º tilt
Dynamic tilt	Maximum tilt range without recentering ±0.026º
Leveling initiation	Control line or serial port command
Alignment	Vertical scribe marks for east-west, precision holes for 5/16 in. alignment rod for north-south
Hardware interface	
Connector	19-pin MIL-C-26482, mounted on base
Calibration input	Remote calibration in XYZ or UVW mode Three separate control signals to enable U, V, or W channels

Table 11-6 - Specifications for Trillium 360 GSN Vault Seismometers (Continued)

Calibration enable	Isolated active-high referenced to DGND Three independent calibration enable inputs.
Serial port	RS-232 compatible For instrument control and retrieval of configuration information
Power	
Power consumption	820 mW at 12 V typical, under normal operating conditions For power consumption under other operating conditions such as startup and mass centering, see "Power Consumption" on page 82.
Environmental	
Operating temperature	-20ºC to 60ºC (Standard Model T360-SV1-GSN) -50ºC to 60ºC (Polar Certified Model T360-SV1-GSN-XC)
Storage temperature	-40ºC to 70ºC (Standard Model T360-SV1) -60°C to +70°C (Polar Certified Model T360-SV1-GSN-XC)
Ingress protection	Rated to IP68 and NEMA 6P to 2 m for prolonged immersion
Insulating cover	Optional insulating cover available for quick and convenient installation
Humidity	0% to 100%
Physical	
Case design (Enclosure)	Powder-coated aluminum pressure vessel
Diameter	250 mm (9.84 in.)
Height	270 mm (10.63 in.) without leveling feet 290 ±0.5 mm (11.42 ± 0.2 in.) depending on leveling feet extension
Weight	14 kg
Parasitic resonances	None below 150 Hz
Handling Hoisting attachment point	Detachable carrying handle on case

Chapter 12 - Performance

12.1 Frequency Response

The following sections provide frequency response information for Trillium 360 GSN seismometers.

You can obtain response files from the following sources:

- Directly from a configured Centaur in RESP, Dataless SEED, or StationXML formats
- From the IRIS DMC Library of Nominal Responses for Seismic Instruments at http://ds.iris.edu/NRL/.

Figure 12-1 and Figure 12-2 are bode plots that show the nominal ground motion and calibration response for T360-BH1-GSN, T360-PH1-GSN, and T360-SV1-GSN models of the Trillium 360 GSN.

In these figures:

- The nominal ground motion frequency response of the seismometer is shown as a solid red line.
- The calibration input circuit response is shown as 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 shown as a dashed blue line.

Figure 12-1 - Bode plot showing nominal ground response for models T360-BH1-GSN and T360-PH1-GSN (all S/Ns), and model T360-SV1-GSN (S/N 200 and above)

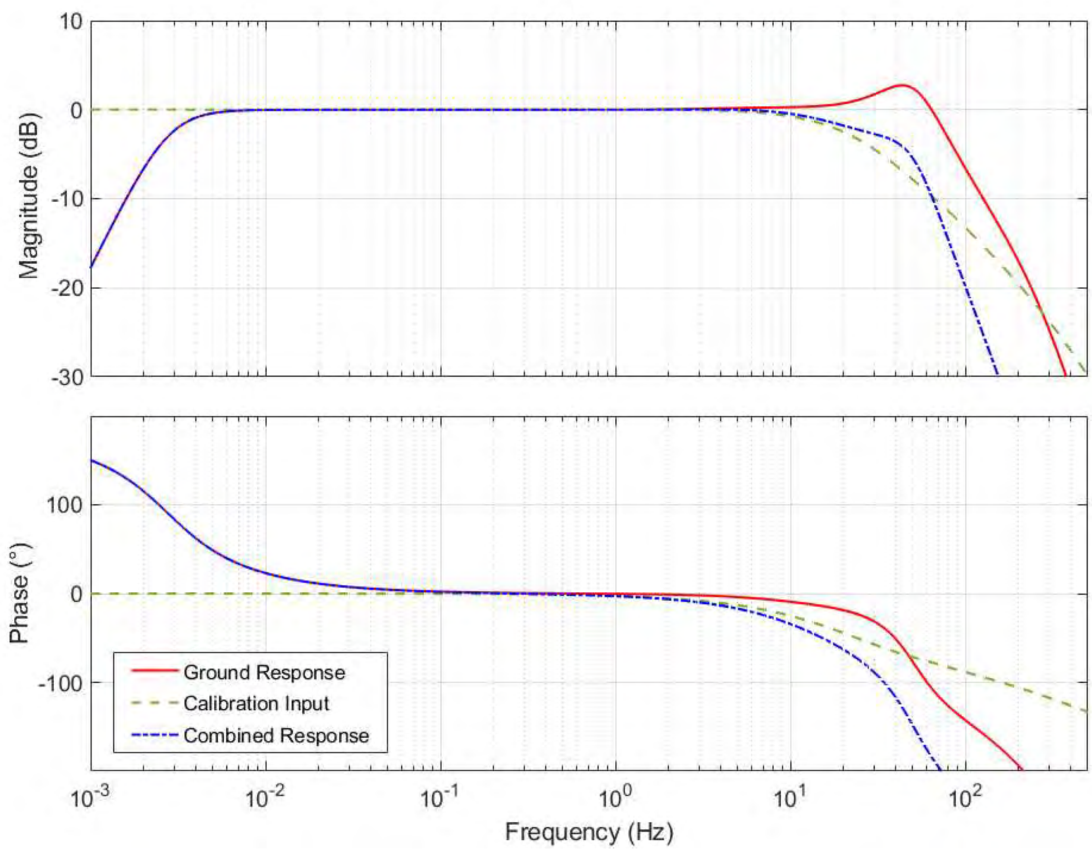


Figure 12-2 - Bode plot showing nominal ground response for model T360-SV1-GSN (S/N to 199)

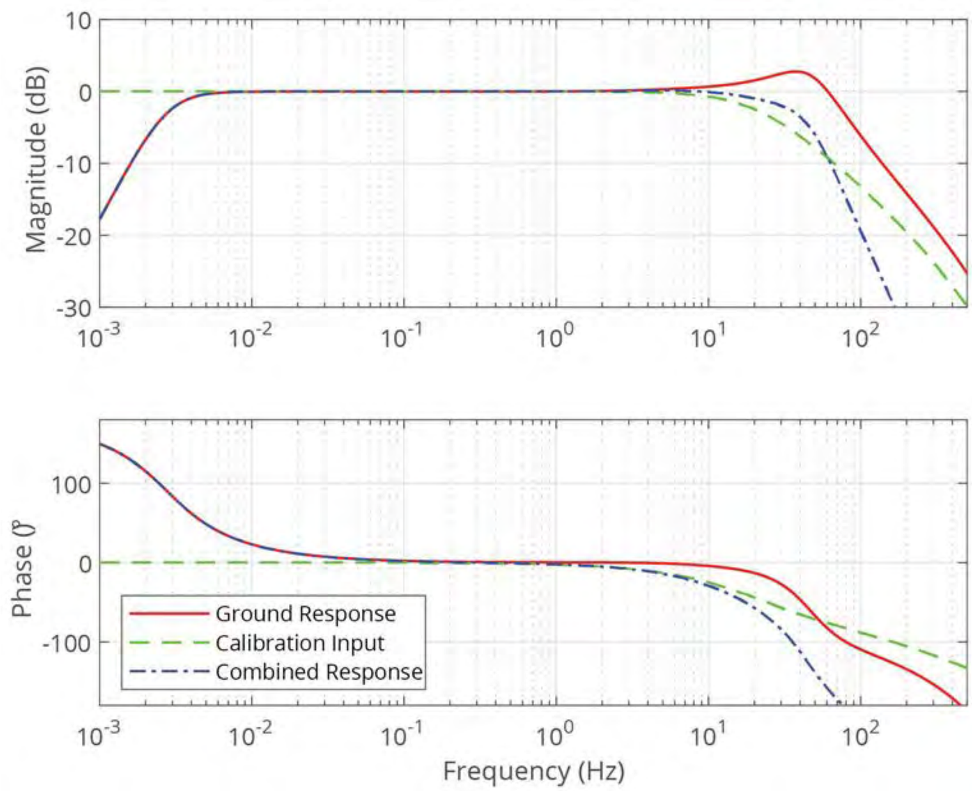


Table 12-1 provides the ground motion response nominal parameters. The ground motion response has –3 dB corners at 360 s and 79 Hz. The ground motion sensitivity at f_0 assumes an infinite input impedance at the digitizer. For digitizers with low input impedance, it will become necessary to account for the source impedance of the seismometer outputs as listed in Table 11-1.

Table 12-1 - Ground motion response nominal parameters for T360-BH1-GSN, T360-PH1-GSN, and T360-SV1-GSN models

Symbol	Parameter	Nominal Values models T360-PH1-GSN and T360-BH1-GSN (all S/Ns), & model T360-SV1-GSN (S/N 200 and above)	Nominal Values model T360-SV1-GSN (S/N to 199)	Units
z_n	Zeros	0 0 -31.6 -143.4 -350 -3100	0 0 -31.6 -143.4 -350 -3100	rad/s
p_n	Poles	-0.012293 ± 0.012315i -33.4 -112.9 -137.3 ± 286.6i -1420 ± 900i -2400 -6300 ± 300i	-0.012293 ± 0.012315i -33.4 -142 -155.8 ± 252.8i -2120 -4900 ± 5100i -6700 ± 1300i	rad/s
k	Normalization factor	$2.0863e\times10^{16}$	$4.1919e\times10^{17}$	$(rad/s)^5$
f_0	Normalization frequency	1	1	Hz
s	Ground motion sensitivity at f_0	1998.4	1999.5	V•s/m

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

$$F(s) = S \cdot k \cdot \frac{\prod_n (s - z_n)}{\prod_n (s - p_n)} \qquad \text{(EQ1)}$$

Where the normalization factor (k) is defined by

$$k = \left| \frac{\prod_n (i2\pi f_0 - p_n)}{\prod_n (i2\pi f_0 - z_n)} \right| \qquad \text{(EQ2)}$$

and is given for informational purposes only.

The calibration input response nominal parameters for T360-BH1-GSN, T360-PH1-GSN, and T360-SV1-GSN models are given in Table 12-2.

Table 12-2 - Calibration input response nominal parameters for T360-BH1-GSN, T360-PH1-GSN, and T360-SV1-GSN models

Symbol	Parameter	Nominal Values models T360-PH1-GSN and T360-BH1-GSN (all S/Ns), & model T360-SV1-GSN (S/N 200 and above)	Nominal Values model T360-SV1-GSN (S/N to 199)	Units
z_n	Zeros			rad/s
p_n	Poles	-143.4 -3100	-143.4 -3100	rad/s
k	Normalization factor	4.4497 x 10^5	4.4497 x 10^5	$(rad/s)^2$
f_0	Normalization frequency	1	1	Hz
s	Calibration input sensitivity at f_0	–0.0057	–0.0057	$(m/s^2)/V$

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 12-3.

Table 12-3 - Combined calibration response nominal parameters for T360-BH1-GSN, T360-PH1-GSN, and T360-SV1-GSN models

Symbol	Parameter	Nominal Values models T360-PH1-GSN and T360-BH1-GSN (all S/Ns), & model T360-SV1-GSN (S/N 200 and above)	Nominal Values model T360-SV1-GSN (S/N to 199)	Units
z_n	Zeros	0 0 -31.6 -350	0 0 -31.6 -350	rad/s
p_n	Poles	-0.012293 ± 0.012315i -33.4 -112 -137.3±286.6i -1420±900i -2400 -6300±300i	-0.012293 ± 0.012315i -33.5 -142 -159 ± 251i -2100 -4900 ± 5100i -6724 ± 1271i	rad/s
k	Normalization factor	9.2834×10^{21}	1.8650×10^{23}	$(rad/s)^7$
f_0	Normalization frequency	1	1	Hz
s	Combined calibration sensitivity at f_0	-11.4	–11.4	rad/s

When a measured electrical calibration result is to be used to convert the Trillium 360 GSN 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 12-2 to the set of measured zeros.

The combined calibration response units 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 12-3 by $2\pi f$, where f is the frequency of the sinusoid.

12.2 Self-Noise

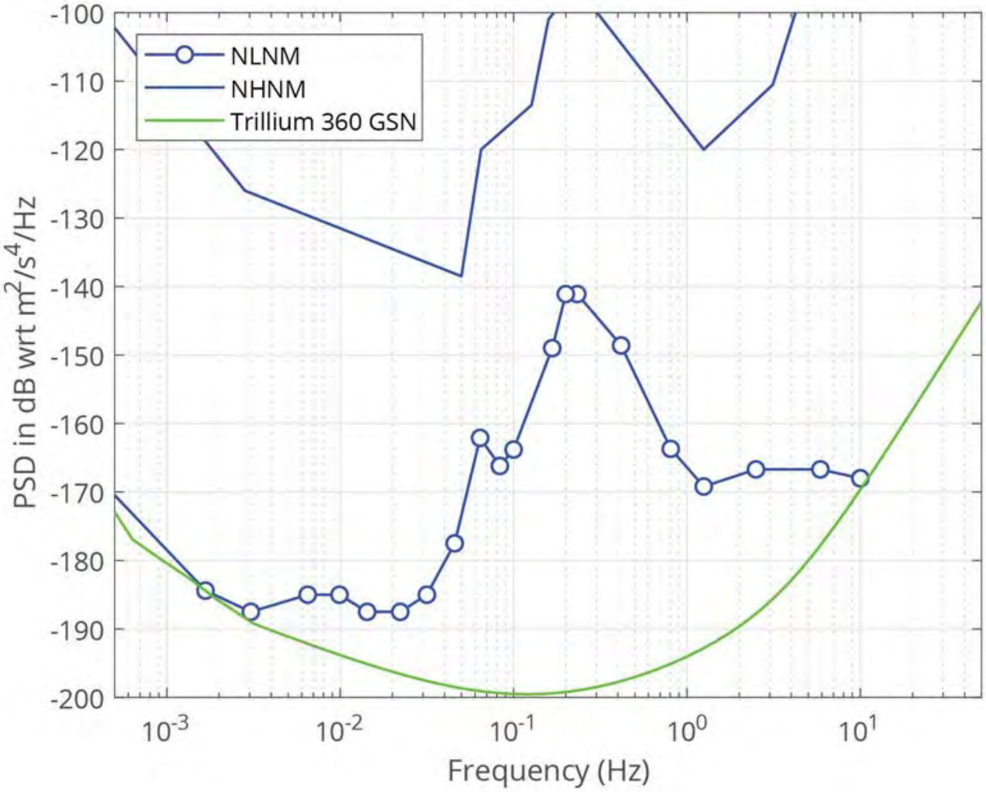
Figure 12-3 plots typical self-noise for Trillium 360 GSN seismometers. Three curves are included for reference: Peterson's new low-noise model (NLNM) and new high-noise model (NHNM), and McNamara and Buland's probability density function (PDF) mode low noise model (MLNM).[1]

The noise floor shown is the typical level of instrument self-noise in an ideal installation. To achieve best performance for any seismometer, careful attention to detail must be paid to choice of site and to the seismometer installation."Installing a Trillium 360 GSN Borehole Seismometer" on page 22, "Installing a Trillium 360 GSN Posthole Seismometer" on page 39 or "Installing a Trillium 360 GSN Vault Seismometer" on page 55.

1See also:

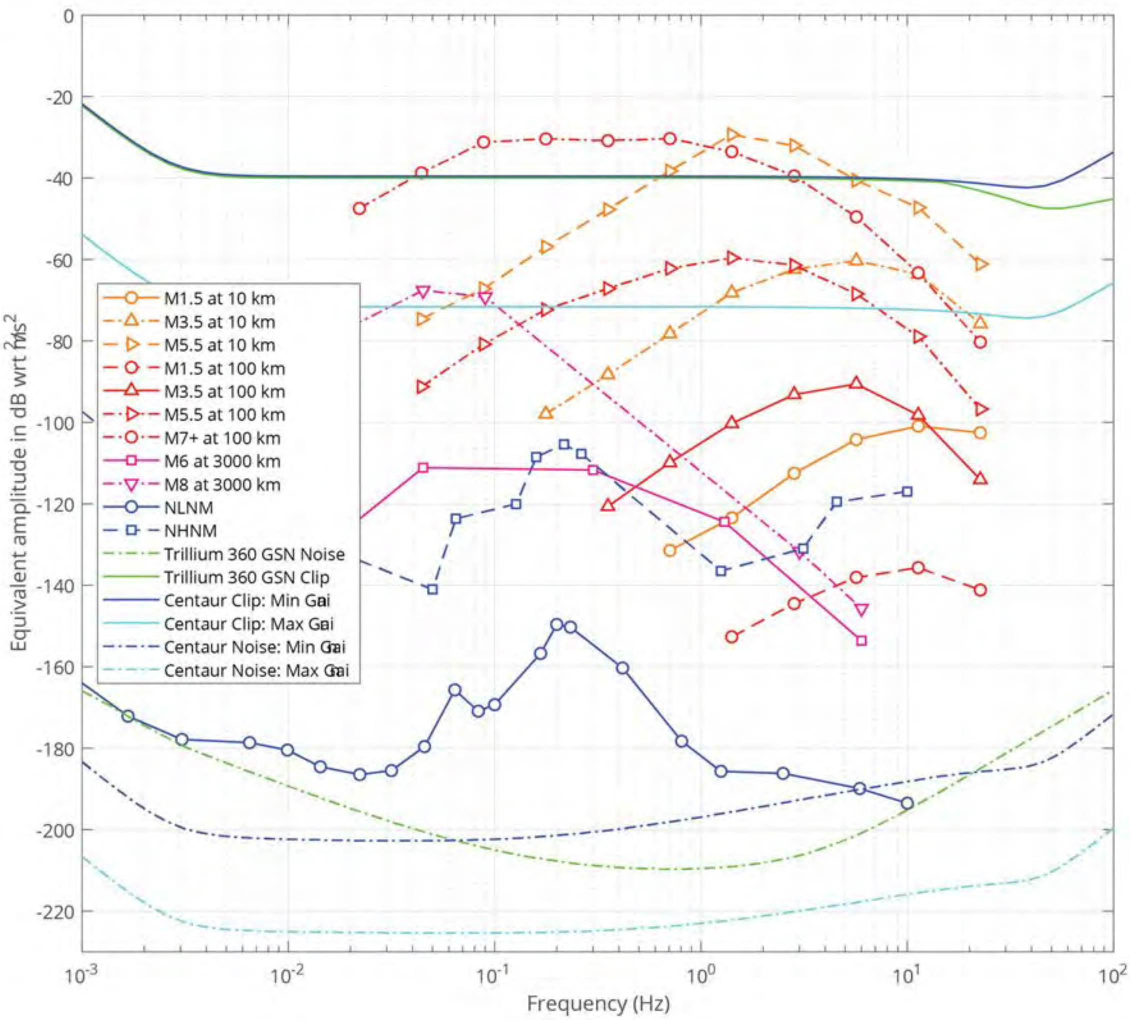
Jon Peterson, *Observations and Modeling of Seismic Background Noise, Open-File Report 93-922* (Albuquerque, New Mexico: U.S. Department of Interior Geological Survey, 1993).
Daniel E. McNamara and Raymond P. Buland, "Ambient Noise Levels in the Continental United States," *Bulletin of the Seismological 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.

Figure 12-3 - Noise floor figure



To determine the dynamic range at frequencies of interest for your application, compare the noise floor to the Trillium 360 GSN seismometer clip level using Figure 12-4. For the purpose of comparing noise floors to clip levels, Figure 12-4 converts power spectral densities using octave bandwidths and an RMS-to-peak conversion factor of 1.253.

Figure 12-4 - Trillium 360 GSN seismometer performance



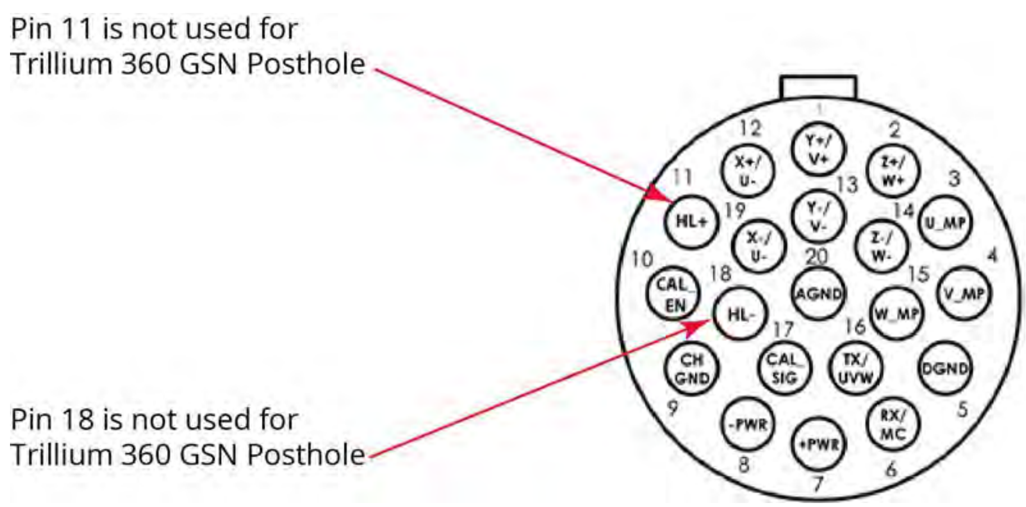
Chapter 13 - Connectors

13.1 Connector Pinout for the Trillium 360 GSN Borehole and Posthole

The Trillium 360 GSN Borehole and Trillium 360 GSN Posthole seismometers both have a 20-pin male connector. See Table 13-1 for the connector pinout table that provides a description for each pin.

For the Trillium 360 GSN Borehole seismometer, this connector allows you to connect to the Trillium Holelock Controller or to a digitizer.

Figure 13-1 - Connector for the Trillium 360 GSN Borehole or the Trillium 360 GSN Posthole Seismometer



Connector:

- Manufacturer: SEA CON®
- Part number: XSL-20-BCR

Recommended mating connector:

- Manufacturer: SEA CON®
- Part number: XSL-20-CCP

Cable:

- Manufacturer: Nanometrics "Cables and Accessories" on page 14

Table 13-1 - Connector pinout for the Trillium 360 GSN Borehole and Trillium 360 GSN Posthole

Pin	Name	Function	Type
12	X+/U+	East or U axis output	40 Vpp differential
19	X-/U-		
1	Y+/V+	North or V axis output	
13	Y-/V-		
2	Z+/W+	Vertical or W axis output	
14	Z-/W-		
17	CAL_SIG	Calibration signal input	8.87 kΩ input impedance
10	CAL_EN	Calibration enable input	Active-high 5 V to 15 V (low is equal to 0 V or open)
11	HL+	Trillium Borehole Holelock power **Note:** Pins 11 and 18 are not used for the Trillium 360 GSN Posthole	Apply 12 to 24 VDC power to lock. Reverse voltage to unlock. A voltage supply that is capable of delivering at least 5 A is recommended.
18	HL-		
3	U_MP	Mass position outputs	±4 V single-ended
4	V_MP		
15	W_MP		
20	AGND	Analog ground	N/A
7	PWR+	Power input	9 V to 36 VDC isolated
8	PWR-		
9	CHGND	Shielding and safety	
6	MC/RX	Initiate leveling and mass centering -OR- Serial RS-232 receive input	MC: active-high 5 V to 15 V (low is equal to 0 V or open) RX: +5/0 V to +15/-15 V
16	UVW/TX	Enable UVW outputs instead of the factory default XYZ outputs Serial RS-232 transmit output	UVW: active-high 5 V to 15 V (low is equal to 0 V or open) TX: ±3.7 V
5	DGND	Digital ground	N/A

13.2 Connector Pinout for the Trillium 360 GSN Vault

The Trillium 360 GSN Vault connector is a 19-pin male military circular type hermetic connector. Table 13-2 for the connector pinout table that provides a description for each pin.

Table 13-2 - Connector pinout for the Trillium 360 GSN Vault

Pin	Name	Function	Type
L	Z+/W+	vertical (W axis) output	40 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	8.87 kΩ input impedance
K	U_CALEN	calibration enable inputs	active-high 5 V to 15 V (low = open or 0 V)
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/TX	input: enable UVW instead of XYZ outputs output: serial RS-232 transmit	as UVW input: active-high 5 V to 15 V; (low = open or 0 V) as TX output: ±5 V
C	MC/RX	input: initiate mass centering input: serial RS-232 receive	as MC input: active-high 5 V to 15 V; (low = open or 0 V) as RX input: ±3 V to ±15 V
R	DGND	digital ground	N/A
shell	CHASSIS	for shielding and safety	N/A

13.3 Connector Pinout for the Trillium Holelock Controller

The Trillium Holelock Controller for the Trillium 360 GSN Borehole seismometer has two connectors one each for Sensor and Power In.

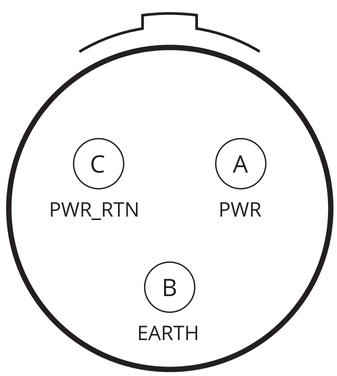
13.3.1 Sensor Connector Pinout for the Trillium Holelock Controller

Table 13-3 - Sensor connector pinout for the Trillium Holelock Controller

Pin	Name	Function	Details
Z	HL–	Trillium Holelock power	Power passed from power input connector; 24V recommended.
C	HL+		

13.3.2 Power In Connector Pinout for the Trillium Holelock Controller

Figure 13-2 - Power In connector receptacle on the Trillium Holelock Controller



Connector:

3-pin, shell size 8, MIL-C-26482 Series 1

Recommended mating connector:

MS3116J8-3S

Table 13-4 - Power In Connector Pinout for the Trillium Holelock Controller

Pin	Function
A	Raw (battery) power in (9V to 36VDC); 24V recommended
B	Raw power supply earth
C	Raw power return

Chapter 14 - Features and Dimensions

14.1 Trillium 360 GSN Borehole Features and Dimensions

Figure 14-1 - Top view of the Trillium 360 GSN Borehole

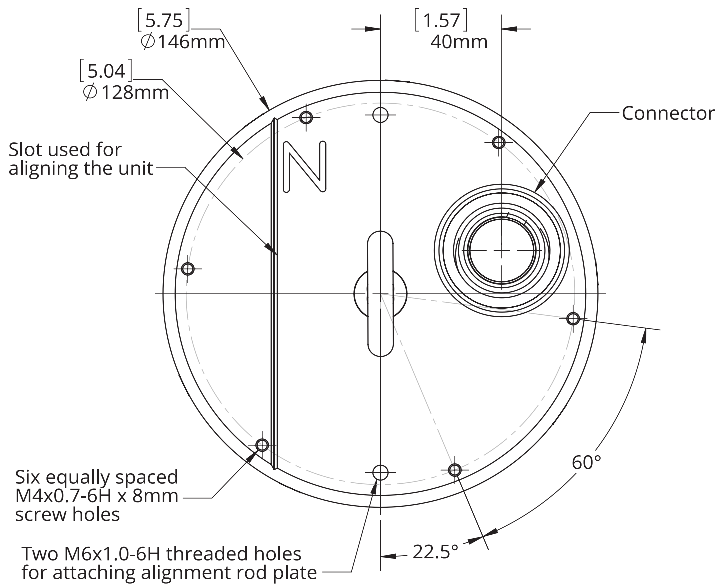


Figure 14-2 - Bottom view of the Trillium Borehole Holelock

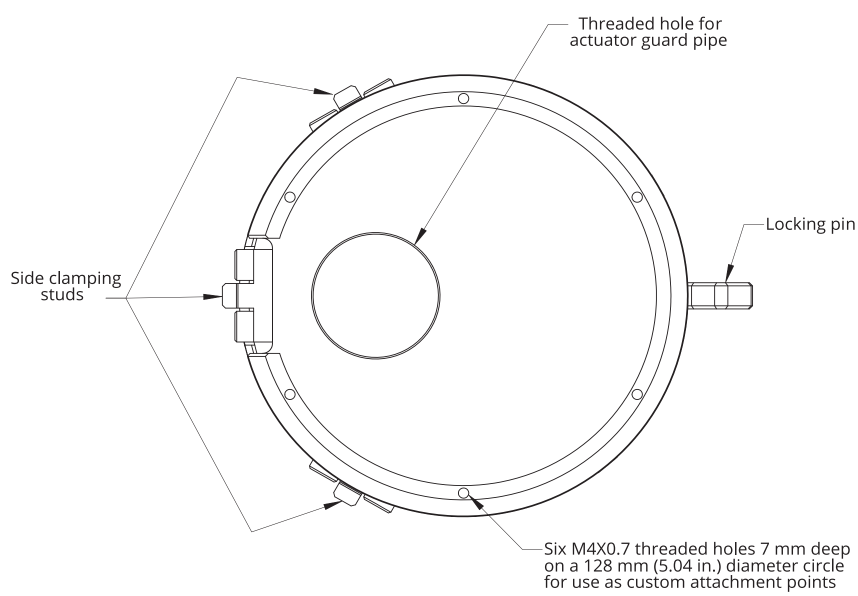
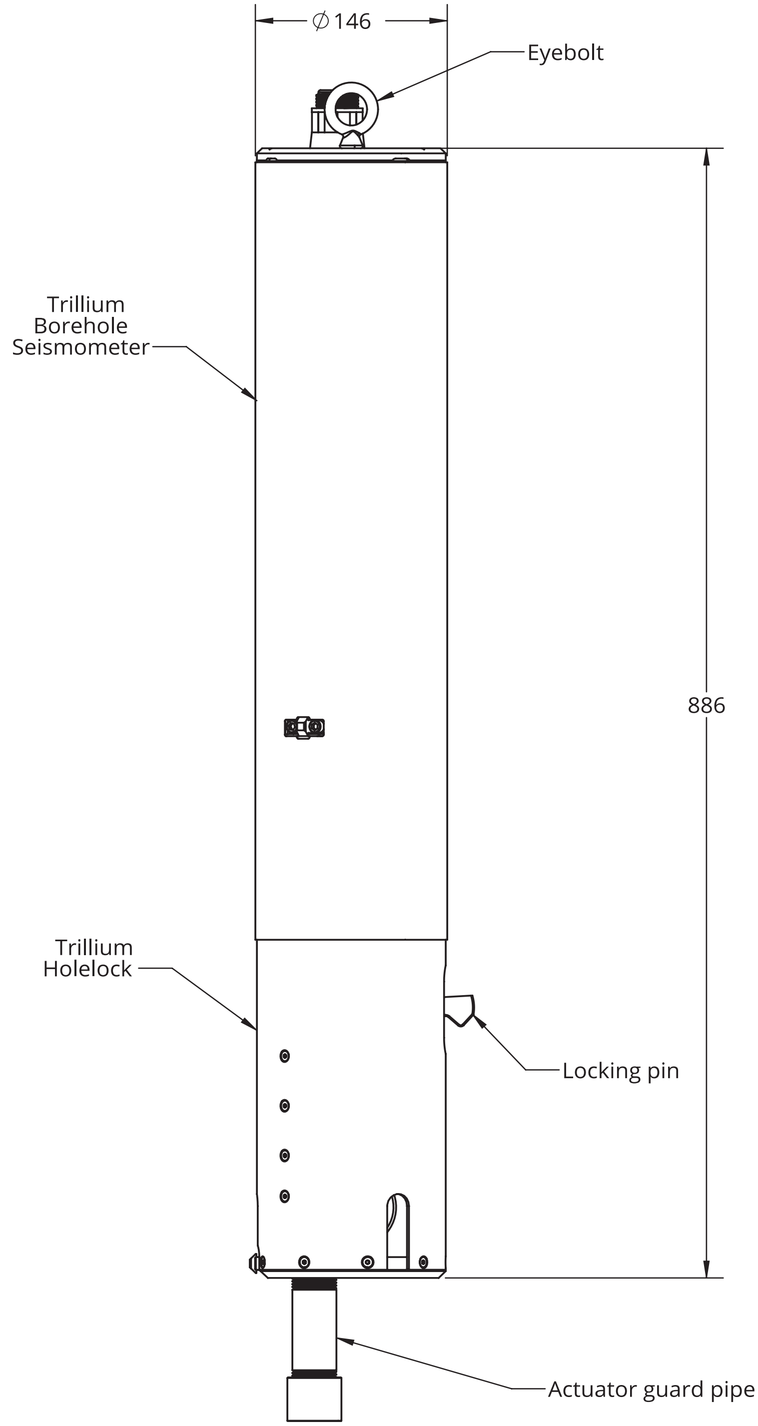
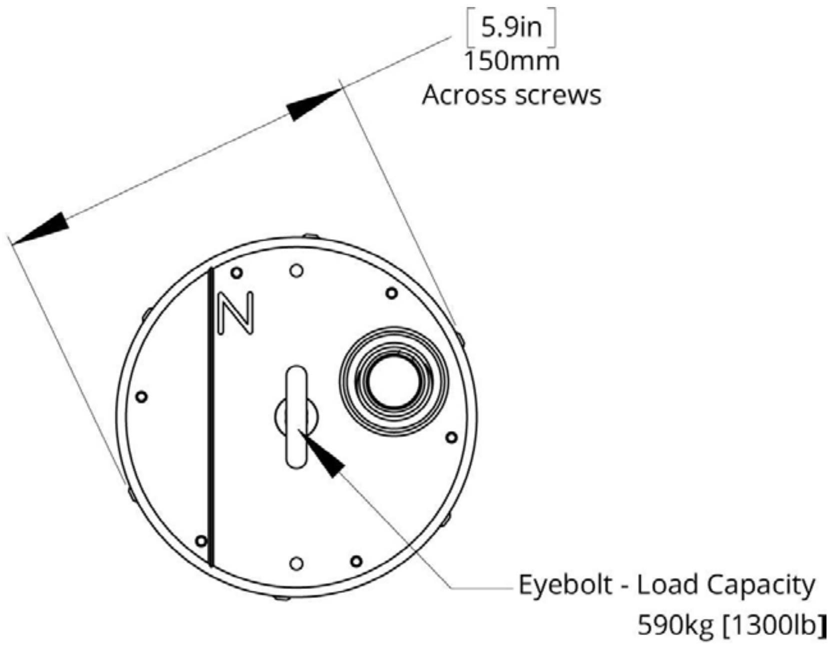


Figure 14-3 - Side view of the Trillium 360 GSN Borehole seismometer and Trillium Borehole Holelock



14.2 Trillium 360 GSN Posthole Features and Dimensions

Figure 14-4 - Top view Trillium 360 GSN Posthole



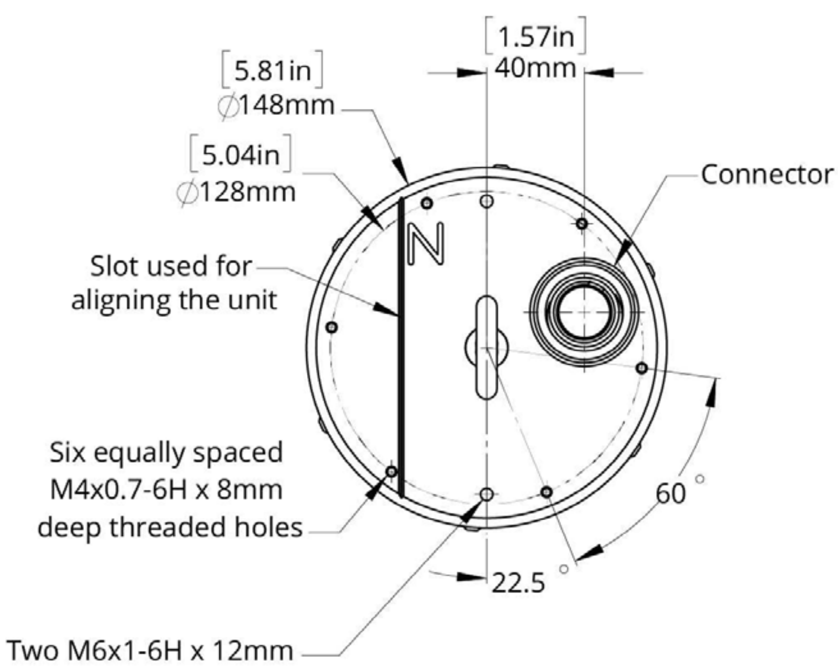


Figure 14-5 - Bottom view of the Trillium 360 GSN Posthole

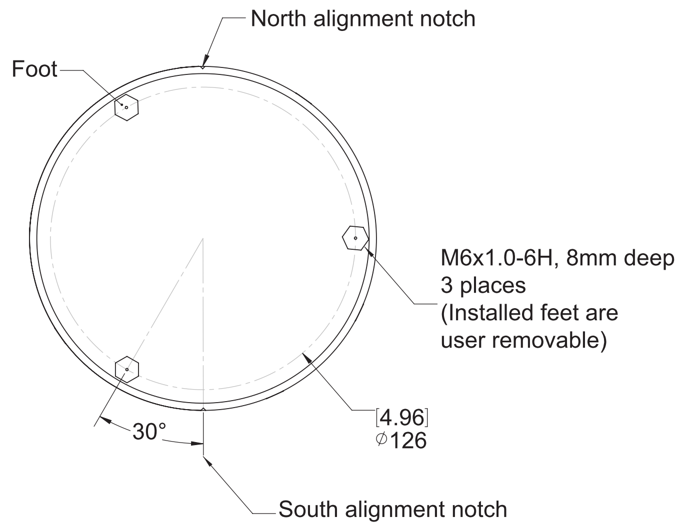
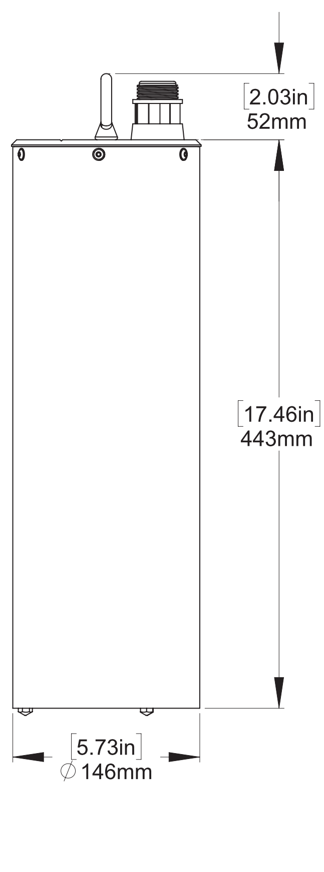


Figure 14-6 - Side view of the Trillium 360 GSN Posthole



14.3 Trillium 360 GSN Vault Features and Dimensions

Figure 14-7 - Side view of Trillium 360 GSN Vault

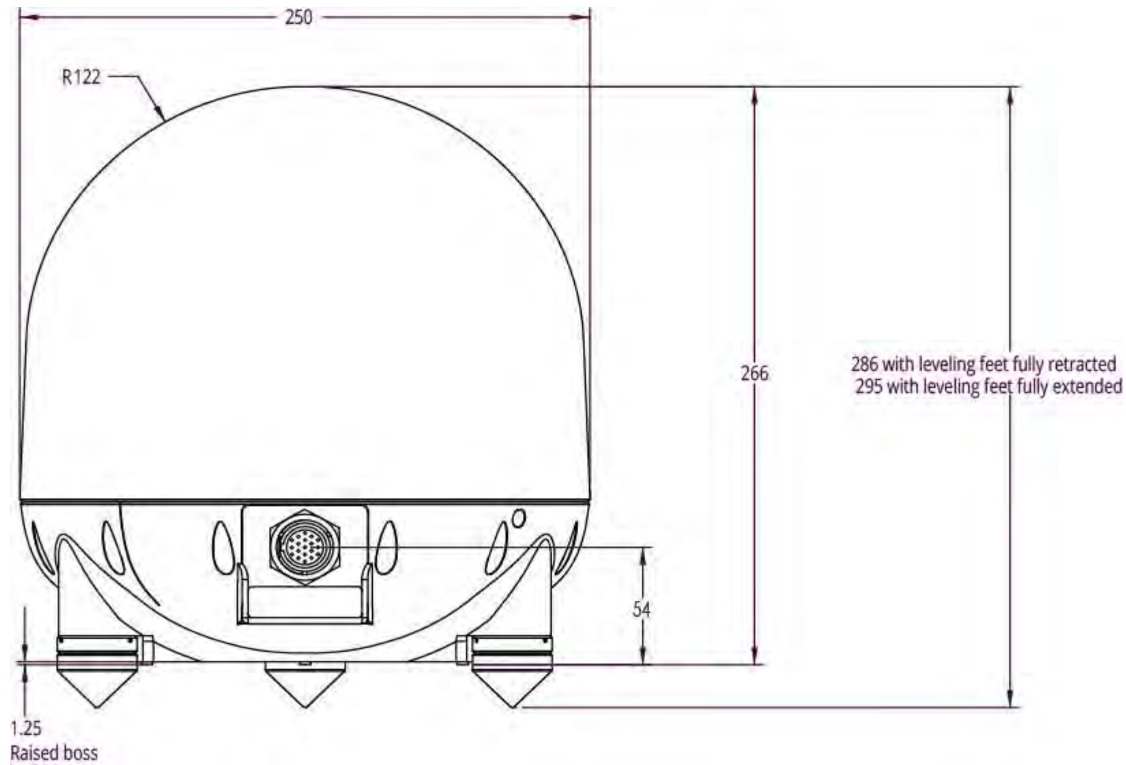


Figure 14-8 - Bottom view of Trillium 360 GSN Vault

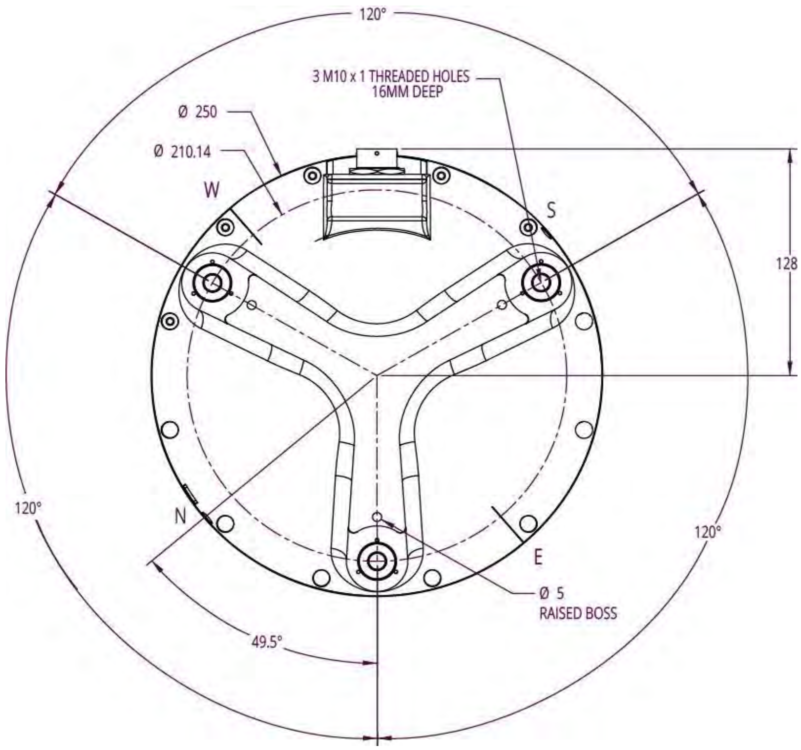
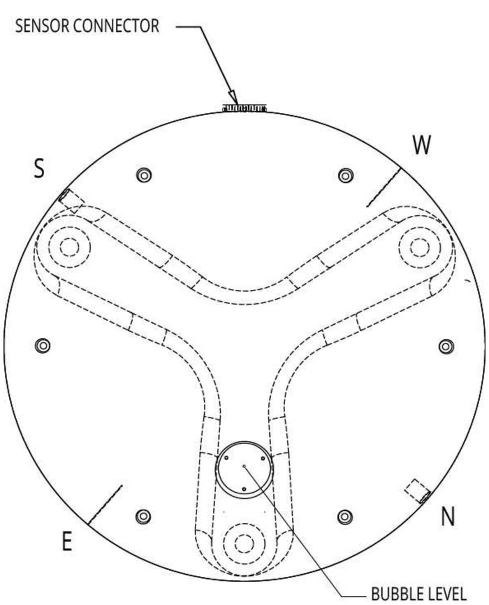


Figure 14-9 - Top view of Trillium 360 GSN Vault



Appendix A - Site Record

Use the following table to record information about the installation and site, including its structure, cultural environs, and climatic conditions. This information will be helpful in identifying changes to the site over time.

<table>
<tr><td colspan="2">Site Record</td></tr>
<tr><td rowspan="3">Site name (full name / station code / network code, for example, Yellowknife / YKN / CN):</td><td>Latitude:</td></tr>
<tr><td>Longitude:</td></tr>
<tr><td>Elevation:</td></tr>
<tr><td rowspan="2">Description of installation site (for example, name of building, location of seismometer within building, depth of hole, other):</td><td>Date of installation (mm/dd/yyyy):</td></tr>
<tr><td>Duration of installation:

Permanent or temporary:

If temporary, expected time frame (mm/dd/yyyy to mm/dd/yyyy):</td></tr>
<tr><td>Type of installation (for example, uncased or cased hole):

Depth of sensor installation (m) ________________

Ground surface elevation above sea level (m) ____________________________

Depth to bedrock (m)___________________

Orientation in hole (±°)___________________

Seismometer azimuth ___________ (° from north)</td><td></td></tr>
</table>

<table>
<tr><td colspan="2">Site Record</td></tr>
<tr><td>Ground surface type (for example, soil, sand, clay, other):</td><td rowspan="2">Distance to potential noise sources (km):
_________ Airport or air traffic
_________ Coastline
_________ Railway
_________ Roads
_________ Tall structures _____ Height (m)
_________ Trees _______Height (m)
_________ Dwellings
_________ Industrial site
_________ Others (describe):</td></tr>
<tr><td>Seasonal temperature ranges (°C):
____________ January 1 to March 31
____________ April 1 to June 30
____________ July 1 to September 30
____________ October 1 to December 31</td></tr>
<tr><td>Orientation of unit:
Orientation of X arrow _____________
Orientation of Y arrow _____________
Orientation of vertical (Z) _____________</td><td>Expected range of motion at the site:
_________ g to _________ g</td></tr>
<tr><td colspan="2">List of equipment at site (include model, serial number and IP addresses):</td></tr>
<tr><td colspan="2">Notes:</td></tr>
</table>

Appendix B - Grounding guidelines

In a station system consisting of multiple pieces of equipment with power, signal, and ground connections running between them, the differences in ground potential must be considered and managed to minimize noise and to minimize the risk of damage due to lightning surge.

Trillium 360 GSN seismometers and Centaur digitizers are designed for high immunity to ground voltages, with isolated power inputs, differential signalling for noise immunity, and internal surge protection circuitry. The protection circuitry has been tested to withstand a simulated lightning surge applied between the case grounds of the sensor and digitizer, with a peak voltage of 1000 Volts and a pulse duration of 50 microseconds. In addition, the power input to the Centaur is surge protected up to 2000 Volts for 50 microseconds.

Nevertheless, it is important to set up a correct grounding scheme that minimizes ground potential differences to ensure the best possible noise performance and highest immunity to lightning surge.

This section provides a general grounding scheme and guidelines for grounding a Trillium 360 GSN seismometer in a metal-cased hole, an uncased hole, or in a vault installation or test lab.

B.1 Grounding Scheme

All electronic devices at the site should have a low-impedance (1 ohm or less) ground connection to a single earth ground point. Nanometrics cables provide a low-impedance connection from the case ground of each piece of equipment to the digitizer via the cable shield braid. The case of the digitizer should be connected to earth ground via a short, low-impedance cable. The earth ground may be a ground stake or buried screen, a metal borehole casing, or the sensor itself in a direct burial installation.

This grounding scheme minimizes ground voltage differences between separate pieces of equipment. As long as there is a low-impedance connection to a single main earth ground, incidental contact of equipment with the earth at other points is usually of little or no consequence. However, additional isolation and surge protection measures may be needed in exceptional circumstances such as if pieces of equipment at the surface are too widely separated to allow a low-impedance connection, or if equipment or support structures are at high risk of a direct lightning strike.

In very dry desert or in polar environments with no liquid water, a true earth ground connection may not be possible. The system can function well in isolation as long as there is a low-impedance connection between the case grounds of all pieces of equipment.

For safety reasons, equipment should be connected to earth ground wherever possible.

B.2 Grounding the Sensor in a Direct Burial Installation

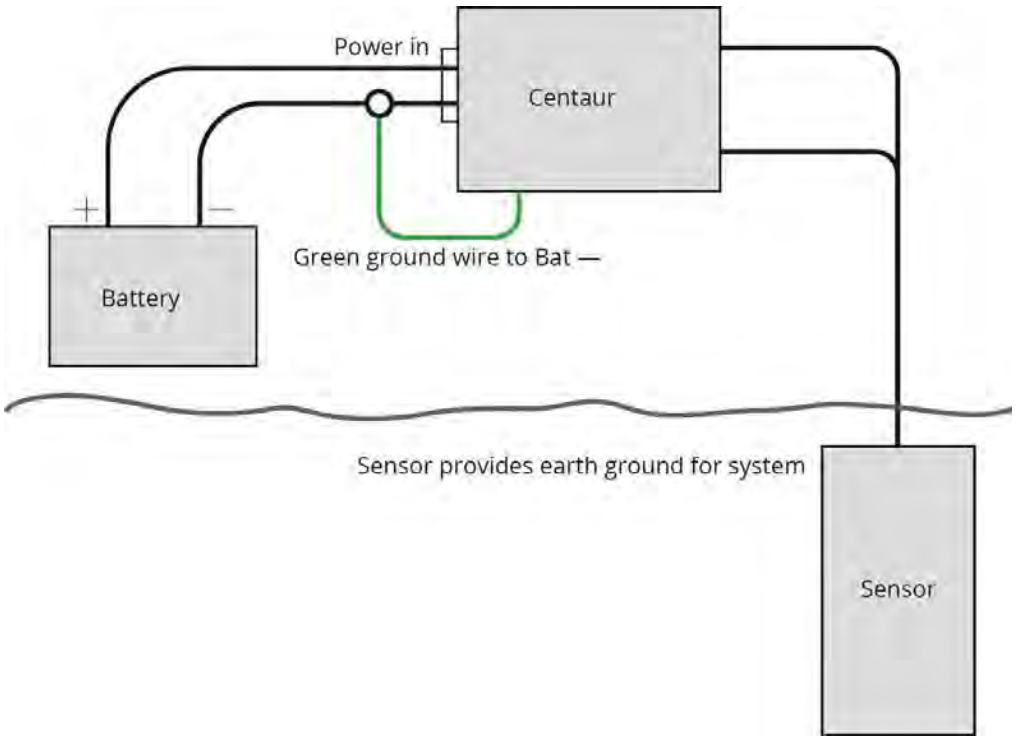
Use the guidelines in this section to ground a Trillium 360 GSN Posthole that is installed in an uncased hole.

In a direct burial installation the Trillium 360 GSN Posthole seismometer itself provides the system earth ground. When the case of the Trillium 360 GSN Posthole seismometer and all other equipment is connected to the case ground of the digitizer via shielded cables as provided by Nanometrics, this implements a correct grounding scheme as described in "Grounding Scheme" on the previous page. See Figure B-1.

If the Trillium 360 GSN Posthole seismometer is installed in a cased hole, ground the system as described in "Grounding the Sensor in a Metal-cased Hole Installation" on the next page.

In a vault or test lab installation, a Trillium 360 GSN Posthole system should be grounded as described in "Grounding the Sensor in a Vault or Test Lab Installation" on page 136.

Figure B-1 - System grounding for burial in uncased hole (direct burial)



B.3 Grounding the Sensor in a Metal-cased Hole Installation

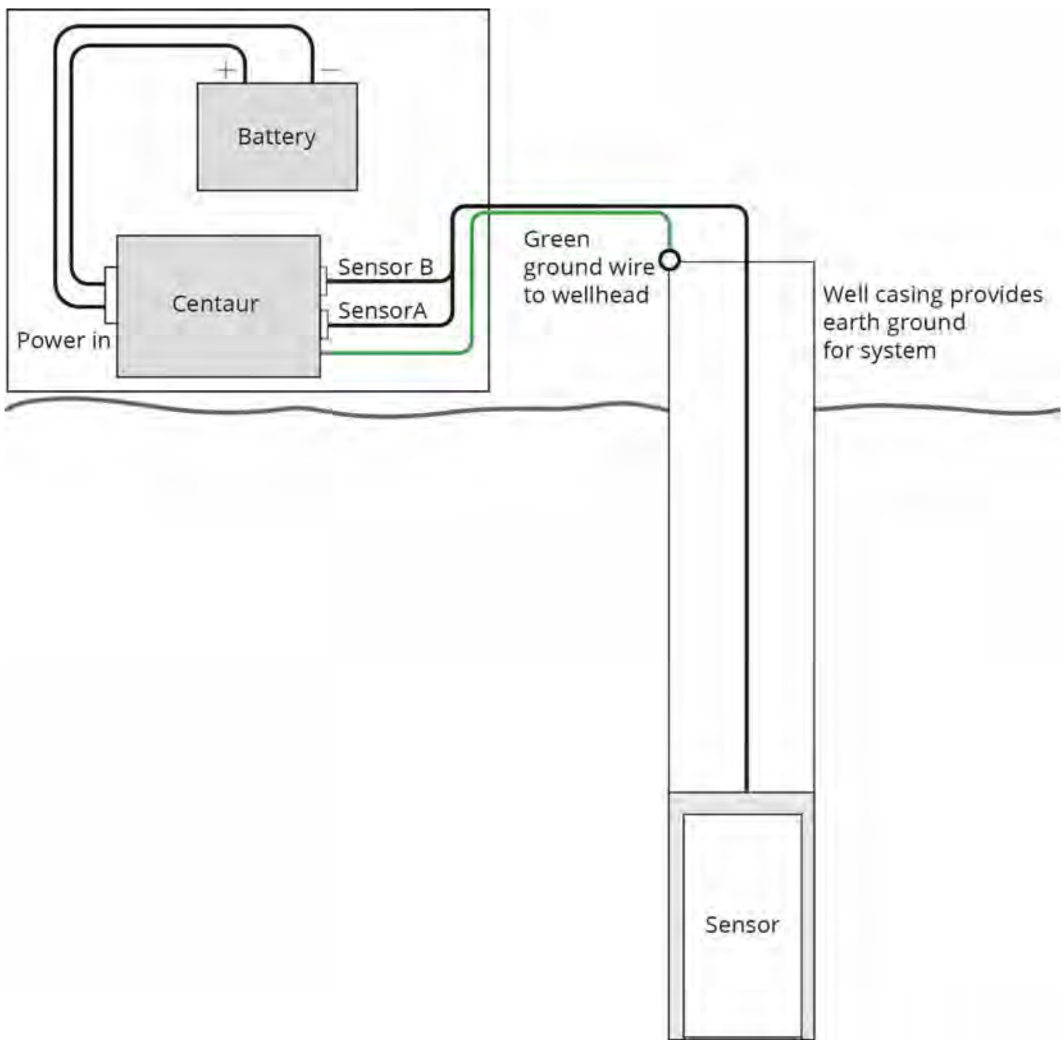
Use the guidelines in this section to ground a Trillium 360 GSN Borehole or Posthole seismometer that is installed in a metal-cased hole.

Lightning surge failures can occur at improperly grounded metal-cased hole installation sites when the digitizer's earth ground at the surface becomes charged to a high voltage while the Trillium 360 GSN seismometer is connected to a more neutral voltage at depth.

To minimize this voltage difference, connect the digitizer chassis ground to the borehole casing at the wellhead. A steel borehole casing provides an excellent earth ground for all equipment at the station, as well as a ground shield around the seismometer itself. Surge currents will travel down the outside surface of a steel casing but will not penetrate significantly to the inside, due to the small skin depth for fast surge transients. See Figure B-2.

A non-conductive plastic casing is another option, although this option is usually not preferred due to poorer mechanical properties (thermal expansion and creep) which may cause low-frequency horizontal noise effects. However a plastic casing may be used in special circumstances, for example if the site includes highly saline groundwater that would attack steel, or if there is a weight limit for transporting materials to the site. In these instances, a separate earth ground should be constructed via a suitable ground stake or buried screen. Connect the case ground of the digitizer to the earth ground, and connect the case ground of the Trillium 360 GSN seismometer and all other equipment to case ground of the digitizer via cable ground shields as described above.

Figure B-2 - System grounding for burial in a metal-cased hole



B.4 Grounding the Sensor in a Vault or Test Lab Installation

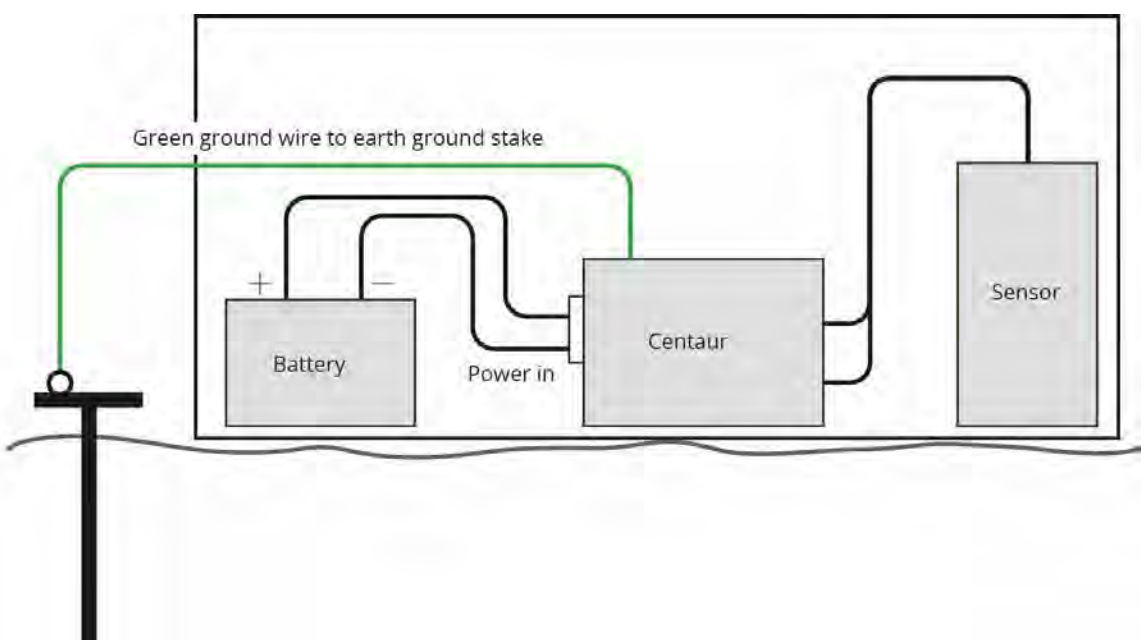
Use the guidelines in this section to ground a Trillium 360 GSN Vault that is installed in a vault or in a test lab.

In a vault installation, connect the case of the digitizer to a suitable earth ground such as a ground stake or buried screen. Connect the case ground of the seismometer and other equipment to case ground of the digitizer via shielded cables as provided by Nanometrics. See Figure B-3.

In a test lab or other building with mains power, connect the case of the digitizer to the safety ground of the mains power system (typically via the case ground of an AC-DC power supply). Connect case ground of the seismometer and all other equipment to case ground of the digitizer via shielded cables as provided by Nanometrics.

In a dry vault or test lab installation it is possible (but not recommended) to keep the entire instrument system isolated or with only a high-impedance connection to earth ground. The equipment can perform well in this configuration, however this is not recommended for safety reasons. Connecting the case ground of all equipment to earth ground will maintain a safe ground potential on accessible parts of the equipment.

Figure B-3 - System grounding for a vault or test lab installation



Appendix C - Open Source Attributions

Discrete portions of the Nanometrics software product may include open source software code. Please see the attribution notices below.

Contiki

Glossary

ADC	Analog to Digital Converter
AGND	Analog Ground
Auto-leveling	Automatic motorized leveling and mass centering of a seismometer where the internal seismometer is leveled to true vertical and the mass positions of the three axes are zeroed.
AWG	American Wire Gauge
CHGND	Chassis Ground
DGND	Digital Ground
EMI	Electromagnetic Interference
GPS	Global Positioning System
GSN	Global Seismic Network
IRIS	Incorporated Research Institutions for Seismology
MLNM	Mode Low Noise Model
NEMA	National Electrical Manufacturers Association
NHNM	New High-Noise Model
NLNM	New Low-Noise Model
PDF	Probability Density Function
PWR	Power
RF	Radio Frequency
RMA	Return Merchandise Authorization
RMS	Root Mean Squared
SLIP	Serial-Over-IP
TCP/IP	Transmission Control Protocol/Internet Protocol
USGS	United States Geological Survey

Unit Abbreviations and Symbols

Abbreviation or Symbol	Definition	Abbreviation or Symbol	Definition
°	degree	lb	pound
Ø	diameter	m	meter
μ	micro	m/s	meter per second
Ω	ohm	m/s^2	meter per second, squared
A	ampere	mA	milliampere
AC	alternating current	MB	megabyte
b	bit	MΩ	megaohm
B	byte	MHz	megahertz
bps	bits per second	mi.	mile
C	Celsius	mL	milliliter
cm	centimeter	mm	millimeter
dB	decibel	ms	millisecond
DC	direct current	MTU	maximum transmission unit
F	farad	mV	millivolt
ft.	foot	mW	milliwatt
g	gram	N	Newton
g	gravity	nF	nanofarad
GB	gigabyte	ns	nanosecond
GHz	gigahertz	rad	radian
Hz	hertz	rad/s	radian per second
in.	inch	s	second
KB	kilobyte	sps	samples per second
kg	kilogram	U	rack unit (1.75 inches)
kHz	kilohertz	V	volt
kΩ	kiloohm	Vpp	Volts peak-to-peak
kW	kilowatt	W	watt
L	liter		

About Us

Nanometrics is an award winning company providing monitoring solutions and equipment for studying man-made and natural seismicity. Headquartered in Ottawa, Ontario, with offices and representatives world-wide, Nanometrics has over 30 years' experience, delivering solutions to customers across the globe. Nanometrics real-time and portable systems are utilized by the world's leading scientific institutions, universities and major corporations. Our pedigree is founded on precision instrumentation, network technology and software applications for seismological and environmental research. We specialize in collecting and analyzing critical real time data for global, regional and local seismic networks. We deliver world-class network design, installation and training services throughout the globe in a safety conscious environment.

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Contact 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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Email: techsupport@nanometrics.ca