GURALP SYSTEMS

CMG-40T

Triaxial Broadband Seismometer

Operator's guide

Part No. MAN-040-0001

Designed and manufactured by
Güralp Systems Limited
3 Midas House, Calleva Park
Aldermaston RG7 8EA
England

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1 Introduction

The CMG-40T is an ultra-lightweight seismometer consisting of three sensors in a sealed case, which can measure the north/south, east/west and vertical components of ground motion simultaneously.

The 40T has a rugged, waterproof stainless steel design for ease of installation. The lightweight sensor elements are designed so that no mechanical clamping is required. Because of this, the 40T is ready to record ground movements as soon as you provide it with power. In addition, the sensor does not have to be levelled or centred as long as the base is within 3 ° of horizontal. For the best results, however, you should install where possible on a hard, near-horizontal surface well coupled to the bedrock.

Each seismometer is delivered with a detailed calibration sheet showing its serial number, measured frequency response in both the long period and the short period sections of the seismic spectrum, sensor DC calibration levels, and the transfer function in poles/zeros notation.

1.1 Response options

The 40T can be supplied with a response which is flat to velocity from 50 Hz to any of 0.1 Hz (10 s), 0.050 Hz (20 s) or 0.033 Hz (30 s).

If you do not require high-frequency data, a low-pass filter may be installed at a frequency (below 50 Hz) that you specify.

Standard 40T instruments output signals representing ground velocity on three pairs of balanced differential lines. An option is available which provides a second, parallel set of outputs at higher gain. The high-gain outputs have a sensitivity nominally 10 times higher than the standard (low-gain) outputs.

2 First encounters

2.1 Handling notes

Although the 40T has a rugged design, it is still a sensitive instrument, and can be damaged if mishandled. If you are at all unsure about the handling or installation of the device, you should contact Güralp Systems for assistance.

- Avoid bumping or jolting the sensor when handling or unpacking.
- Do not kink or walk on the data cable (especially on rough surfaces such as gravel), nor allow it to bear the weight of the sensor.
- Do not connect the instrument to power sources except where instructed.
- Do not ground any of the signal lines from the sensor.

All parts of the 40T are waterproof.

2.2 Connections

The instrument has an integrated cable ending in a 26-pin mil-spec socket which carries both power and output signals. This is suitable for connecting directly to a Güralp digitizer.

The breakout box, if ordered, provides individual signal and power connectors, or you can make up your own cable if you prefer.

The breakout box

If you are using a Güralp breakout box, it should be attached to the sensor through its *SENSOR* connector. Connectors are also provided at the *CONTROL* and *RECORDER* outputs, for attaching to a handheld control unit or a Güralp digitizer. If you have ordered a 40T with optional high gain outputs, you will need to make up a suitable cable to expose these outputs.

The breakout box also provides a standard Güralp power connector on a 10-pin mil-spec plug. The 40T draws a nominal current of 48 mA from a 12 V supply when in use; thus, using a 12 V, 25 Ah sealed heavy-duty lead-acid battery, you should expect the instrument to operate for around a week without recharging.

The *CENTRE* button switches the instrument into *ACC/VEL* mode whilst it is pressed. This mode allows you to monitor the mass positions whilst you adjust the offsets manually. If you prefer, you can use the equivalent switch on a Handheld Control Unit (see below.)

The handheld control unit

This portable control unit provides easy access to the seismometer's control commands, as well as displaying the output velocity and mass position (*i.e.* acceleration) on an analogue meter.

Signal meter

The upper section of the HCU contains a simple voltmeter for monitoring various signals from the instrument.

- To monitor the low-gain outputs, switch the dial to *V*, *N/S* or *E/W LOW VEL* according to the component you want to monitor.

- To monitor the high-gain outputs (on a 40T with that option), switch the dial to *V*, *N/S* or *E/W HIGH VEL*.

- To monitor the mass position outputs, switch the dial to *V*, *N/S* or *E/W MASS POS*. Whilst you are adjusting mass position offsets, you should also switch the instrument out of broadband mode by switching the rightmost *CENTRING SELECT* switch to *1 SEC VEL*, or by holding down the *CENTRE* button on a breakout box.

- You can set the range of the meter with the *RANGE* switch. When switched to 10 V, the meter ranges from –10 to + 10 V (as marked.) When switched to 1 V, the range is –1 to +1 V.

Calibration

You can calibrate a 40T sensor through the HCU by connecting a signal generator across the yellow and green *CALIBRATION SIGNAL* inputs and setting the adjacent switch to *ON*. The sensor's response can now be monitored or recorded, and calibration calculations carried out. See Chapter 4, “Calibrating the 40T” for full details.

Control commands

If you have ordered a 40T with the remote null facility, you can zero its mass position offsets from the HCU.

1. Select the component you want to centre from the *CENTRING SELECT* dial.

2. Switch the signal meter dial to one of the *MASS POS* settings.

3. Switch the rightmost switch to *1 SEC VEL* to enable the centring lines.

4. Press the +/– switch towards – to centre a mass from a positive value, or towards + to centre it from a negative value.

Banana plugs

The remainder of the HCU provides useful connections for each of the signal lines from the instrument, for attaching to your own equipment as necessary.

2.3 Zeroing the instrument

Before installing the 40T, you should check that the mass positions are not significantly offset from zero. The mass position offsets can be affected by any tilt to the instrument, as well as handling during transportation. The normal range of the mass positions is ±10 V; you should zero the instrument if any mass reads more than around ±3.5 V when the sensor is stationary.

The velocity outputs of the 40T are set at the factory to a nominal value below ±3 mV. Once the instrument is installed and has reached thermal equilibrium with its environment, these outputs should be similar to the factory-set value.

Adjusting the mass position offsets manually

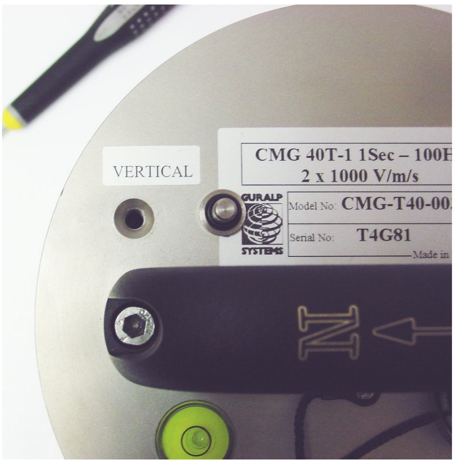
The 40T has three potentiometers (“pots”) accessible within its casing, which should be used to remove any DC offsets electronically:

1. Bring the instrument into 1 second response mode by applying a voltage across the *Acc/Vel* and *Signal Ground* pins of the input. If you are using

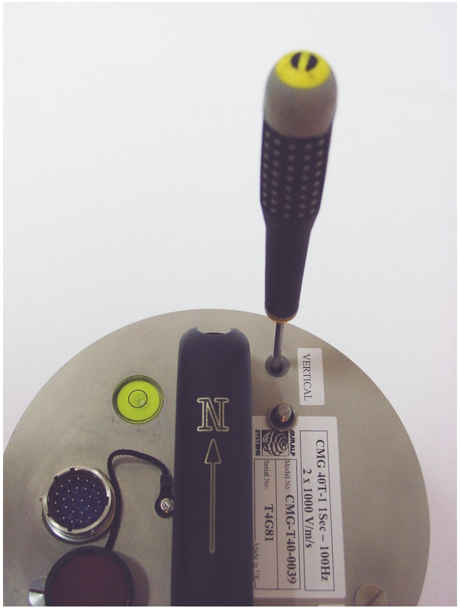
a DM24, you can do this by sending a `CENTRE` command. If you are using a Handheld Control Unit, you should select *1 SEC VEL* from the *Velocity Select* switch.

2. Measure the vertical mass position output with a 10 V voltmeter (see Appendix A, "Connector pinouts") or by selecting *MASS POS*, *V* from a Handheld Control Unit's *Display Select* knob. If using a HCU, also check that the *Centring Select* knob is set to *OFF*.

3. If the vertical component needs adjusting, remove the cap on the lid which protects the *Vertical*pot with a flat-bladed screwdriver (provided).



4. Insert the screwdriver through the opening, and engage the pot. An LED flashlight may be useful for locating the head.



5. Turn the pot either way until the offset readout is as close to 0 V as possible.

6. Repeat steps 2 – 5 for the north/south and east/west components.

Adjusting the mass position offsets with a Handheld Control Unit

Some 40T units are equipped with a remote mass centring option, which allows you to adjust the internal potentiometers by applying voltages across control lines to the sensor:

1. Bring the instrument into 1 second response mode by selecting *1 SEC VEL* from the *Velocity Select* switch.

2. Measure the vertical mass position output by selecting *MASS POS, V* from the Handheld Control Unit's *Display Select* knob.

3. Set the *Centring Select* knob to *V*.

4. Press the spring-loaded switch towards + or – to bring the mass position offset from negative or positive values towards zero.

5. Repeat steps 3 and 4 for the *N/S* and *E/W* components.

6. Return the instrument to broadband mode by selecting *BB VEL* from the *Velocity Select* switch.

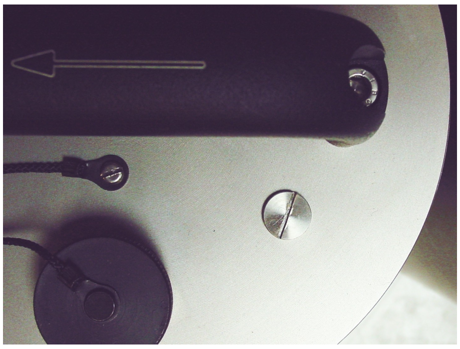
Zeroing a 40TD digital instrument

The offset potentiometers in a 40TD are in the same place as on the 40T. To access them, you will need to remove the digitizer module, which lies on top of the sensor itself. You can monitor the mass position outputs of the sensor using a Handheld Control Unit and an adapter cable, available from Güralp Systems.

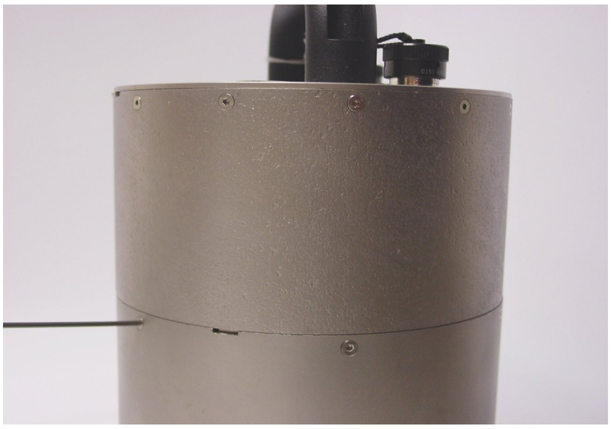
To change the offsets of a 40TD without digital centring:

1. Check the bubble level on the lid of the instrument, to ensure it is not tilted. If necessary, re-level the instrument by adjusting its feet.

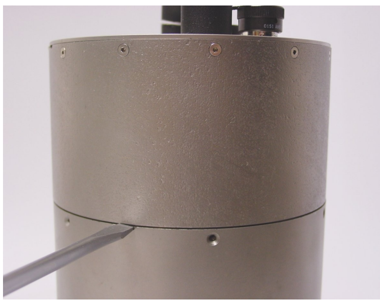
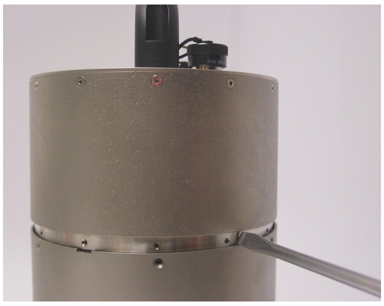
2. Unscrew the vent cap on the lid to allow the air pressure to equalise.



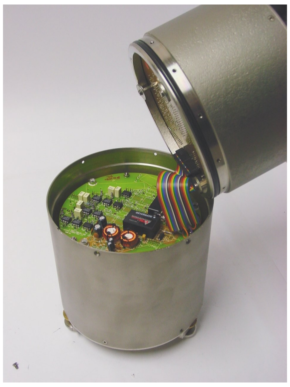
3. Using an Allen key, remove the screws holding the digitizer module onto the sensor.



4. Place a flat-head screwdriver in the notches provided, and twist to lever off the digitizer module.

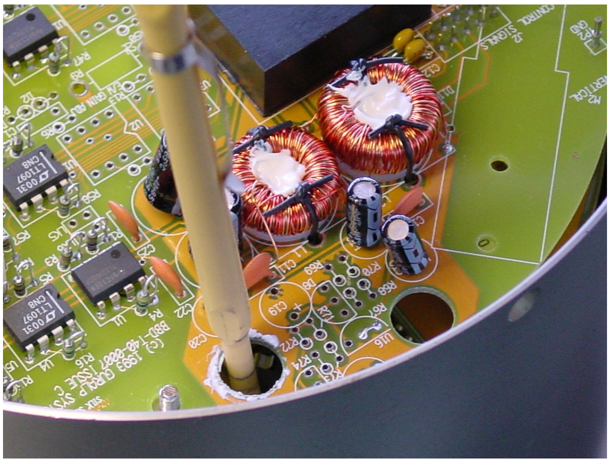
5. Carefully lift off the digitizer module, and unplug the ribbon cable from the sensor electronics.

6. Attach a Handheld Control Unit and adapter cable to the ribbon connector, and power up the sensor through the control unit.

7. Set the *CENTRING SELECT* switch on the Handheld Control Unit to *1 SEC VEL*, and the monitoring dial to *V MASS POS.*

8. There are three holes in the topmost electronics board, which provide access to the offset potentiometers. Insert a screwdriver through the appropriate hole, and engage the potentiometer for the vertical component.



9. Adjust the potentiometer until the mass position output reads close to zero.

10. Repeat steps 4 – 6 for the north/south and east/west components.

Alternatively, you can adjust the mass postions and monitor the output digitally.

1. Remove the vent cap, and use an Allen key to remove the screws holding the digitizer module onto the sensor as above.

2. Carefully lift off the digitizer module, and support it nearby, leaving the ribbon cable connected. Extension cables can be obtained from Güralp

Systems; otherwise, you can use the casing of the sensor itself as a support.

The steel sensor housing can be removed with an Allen key.

3. Whilst monitoring the mass position outputs (channels `M8`, `M9` and `MA`), adjust the potentiometers as above.

2.4 Installation notes

For the best possible results, a seismometer should be installed on a seismic pier in a specially-built vault, where conditions are near perfect. Here, wave-trains arriving at the instrument reflect very well the internal motion of subsurface rock formations. However, this is not always feasible. For example,

- instruments may need to be deployed rapidly, perhaps to monitor the activity of a volcano showing signs of rejuvenation, or to study the aftershocks of a major earthquake;

- installations may be required in remote locations, or otherwise in circumstances where it is unfeasible to build a vault.

In these situations, the seismometer and its emplacement need to be considered as a mechanical system, which will have its own vibrational modes and resonances. These frequencies should be raised as high as possible so that they do not interfere with true ground motion: ideally, beyond the range of the instrument. This is done by

- standing the sensor on bedrock where possible, or at least deep in well-compacted subsoil;

- clearing the floor of the hole of all loose material; and

- using as little extra mass as possible in preparing the chamber.

In temporary installations, environmental factors are also important. The sensor needs to be well protected against

- fluctuations in temperature,
- turbulent air flow around walls or trees, or around sharp corners or edges in the immediate vicinity of the sensor;
- vibration caused by heavy machinery (even at a distance), or by overhead power lines.

This can be done by selecting a suitable site, and placing the instrument in a protective enclosure. An open-sided box of 5 cm expanded polystyrene slabs, placed over the instrument and taped down to exclude draughts, makes an excellent thermal shield.

After installation, the instrument case and mounting surface will slowly return to the local temperature, and settle in their positions. This will take around four hours from the time installation is completed.

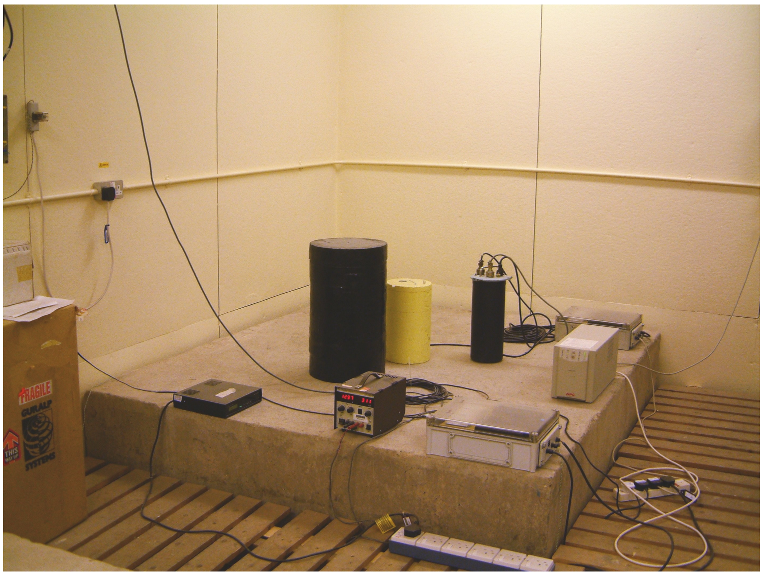
3 Installing the 40T

3.1 Installing in vaults

The 40T is a sensitive instrument designed to measure extremely small movements of the ground. These movements are the sum of all the vibrations arriving at the instrument: as well as distant earthquakes and nearby tremors, the ground responds to surf on nearby beaches, quarry blasts, heavy machinery, traffic, and even people moving around the building. Temperature changes and air currents in the same room as the sensor can also affect its output.

Choosing a location

When studying natural earth movements, any other effects introduce unwanted noise into the system. It is therefore important to choose an appropriate site for the instrument, ideally in an underground vault with the sensor installed on a concrete pier that is in direct contact with the bedrock.



This setup has a number of advantages:

- It is installed below ground. Most man-made noise tends to travel along the surface, and natural microseisms (tiny natural flexings of the Earth's crust) also occur near the surface.

- Good contact with bedrock means that the signals accurately reflect earth motions; seismic waves do not have to travel through layers of soft soil and sediment.

- If the vault is inside a larger structure, its foundations are separated from the pier, so that nearby vibrations are not transmitted to the sensor.

A high-quality seismic vault can be incorporated into the construction plans of a new building at relatively low cost. However, if you are not in a position to build a dedicated vault, you can still reduce noise to a satisfactory level by

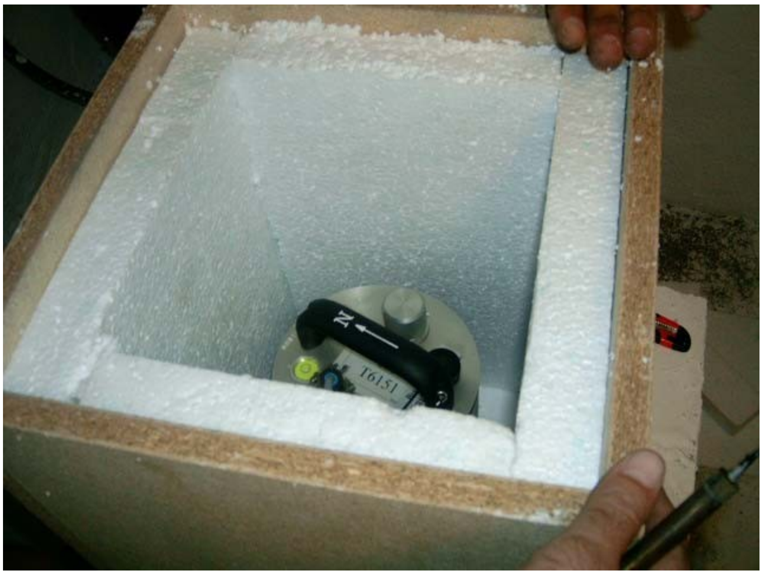
- installing below ground, in the basement or sub-basement of an existing building;
- placing the sensor directly on a cement floor to improve contact; and
- locating the sensor in a quiet corner away from people and machinery (*e.g.* air conditioning and heating systems, elevators, *etc.*)

Installation on higher floors is not recommended, especially for horizontal sensors, since any “give” in the floor near the sensor will cause it to tilt slightly and register a signal.

Temperature stability

The 40T can operate over a wide temperature range (–10 °C to +75 °C). However, the sensor mass is sensitive to fluctuations in local temperature. This affects the response of the instrument at long periods. Sunlight and other bright lights can also cause small mechanical stresses that will be detected by the sensor. You can minimise these effects by

- installing in a basement, where the temperature is normally more stable than above ground;
- locating the sensor in a dark, protected corner, and
- enclosing it in an insulated box (expanded polystyrene works very well). This also helps protect the sensor from air currents.



Other considerations

- The sensor and cables should be situated well away from other electical cables and appliances. Stray radiation from these sources may interfere with the sensor's electronics.

- The sensor should be placed on a smooth, level surface free from cracks. Small cracks tend to open and close slightly with changes in humidity and temperature, causing the surface to move slightly.

- All three of the sensor's metal feet must make good contact with the floor.

- The signal cable from the sensor should rest loosely on the ground nearby, so that vibrations are not transmitted along it.

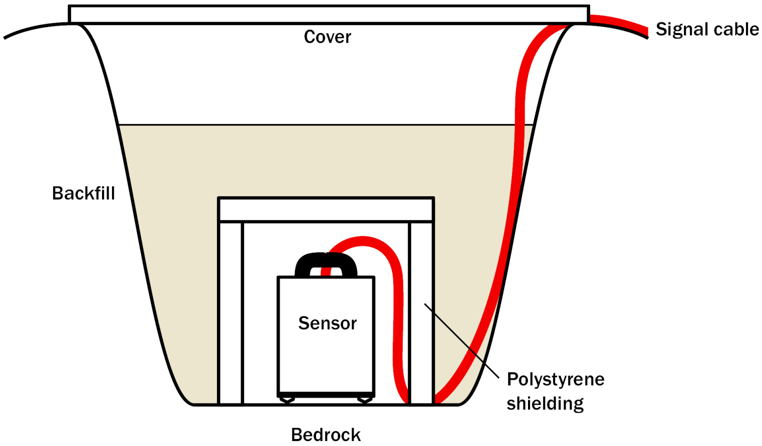
- If your recording or digitizing equipment has front-panel indicators or connectors, make sure it can be reached without disturbing the sensor.

- The GPS unit needs to be in a location where it can see as many satellites as possible. A location with a good view of the sky, preferably down to the horizon, is recommended. If you are in the Northern Hemisphere, make sure as much of the southern sky as possible is visible. Conversely, in the Southern Hemisphere, make sure the GPS can see a large area of sky to the north.

  The GPS unit is supplied with a 15 m cable to the digitizer.

3.2 Installing in pits

For outdoor installations, high-quality results can be obtained by constructing a seismic pit.



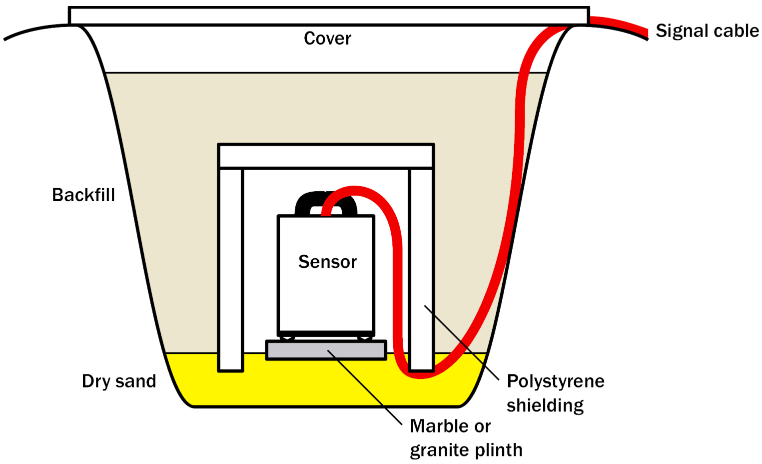
Depending on the time and resources available, this type of installation can suit all kinds of deployment, from rapid temporary installations to medium-term telemetered stations.

Ideally, the sensor should rest directly on the bedrock for maximum coupling to surface movements. However, if bedrock cannot be reached, good results can be obtained by placing the sensor on a granite pier on a bed of dry sand.

1. Prepare a hole of 60 – 90 cm depth to compacted subsoil, or down to the bedrock if possible.

2. *On granite or other hard bedrock*, use an angle grinder to plane off the bedrock at the pit bottom so that it is flat and level. Stand the instrument directly on the bedrock, and go to step 7.

3. *On soft bedrock or subsoil*, you should install a pier as depicted below.



4. Pour a layer of loose, fine sand into the pit to cover the base. The type of sand used for children's sand-pits is ideal, since the grains are clean, dry and within a small size range. On top of the sand, place a smooth, flat granite plinth around 20 cm across, and shift it to compact the sand and provide a near-level surface.

Placing a granite plinth on a sand layer increases the contact between the ground and the plinth, and improves the performance of the instrument. There is also no need to mix concrete or to wait for it to set, as in step 4.

5. *Alternatively*, if time allows and granite is not available, prepare a concrete mix with sand and fine grit, and pour it into the hole. Agitate ("puddle") it whilst still liquid, to allow it to flow out and form a level surface, then leave to set. Follow on from step 7.

   Puddled concrete produces a fine-textured, level floor for emplacing the seismometer. However, once set hard, the concrete does not have the best possible coupling to the subsoil or bedrock, which has some leeway to shift or settle beneath it.

6. *Alternatively*, for the most rapid installation, place loose soil over the bottom of the pit, and compact it with a flat stone. Place the seismometer on top of this stone. This method emulates that in step 3, but can be performed on-site with no additional equipment.

7. Set up the instrument as described in Section 3.1, "Installing in vaults" (steps 4 to 9).

8. The instrument must now be shielded from air currents and temperature fluctuations. This is best done by covering it with a thermal shield.

   An open-sided box of 5 cm expanded polystyrene slabs is recommended. If using a seismic plinth on sand (from steps 3–4 or 5), ensure that the box is firmly placed in the sand, without touching the plinth at any point.

In other installations, tape the box down to the surface to exclude draughts.

9. *Alternatively*, if a box is not available, cover the instrument with fine sand up to the top.

   The sand insulates the instrument and protects it from thermal fluctuations, as well as minimizing unwanted vibration.

10. Ensure that the sensor cable is loose and that it exits the seismometer enclosure at the base of the instrument. This will prevent vibrations from being inadvertently transmitted along the cable.

11. Cover the pit with a wooden lid, and back-fill with fresh turf.

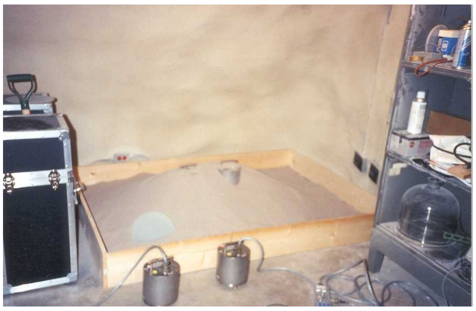
Other installation methods

The recommended installation methods have been extensively tested in a wide range of situations. However, past practice in seismometer installation has varied widely.

Some installations introduce a layer of ceramic tiles between a rock or concrete plinth and the seismometer (left):


However, noise tests show that this method of installation is significantly inferior to the same concrete plinth with the tiles removed (right). Horizontal sensors show shifting due to moisture trapped between the concrete and tiling, whilst the vertical sensors show pings as the tile settles.

Other installations have been attempted with the instrument encased in plaster of Paris, or some other hard-setting compound (left):

Again, this method produces inferior bonding to the instrument, and moisture becomes trapped between the hard surfaces. We recommend the use of fine dry sand (right) contained in a box if necessary, which can also insulate the instrument against convection currents and temperature changes. Sand has the further advantage of being very easy to install, requiring no preparation.

Finally, many pit installations have a large space around the seismometer, covered with a wooden roof. Large air-filled cavities are susceptible to currents which produce lower-frequency vibrations, and sharp edges and corners can give rise to turbulence. We recommend that a wooden box is placed around the sensor to protect it from these currents. Once in the box, the emplacement may be backfilled with fresh turf to insulate it from vibrations at the surface, or simply roofed as before.

By following these guidelines, you will ensure that your seismic installation is ready to produce the highest quality data.

4 Calibrating the 40T

4.1 The calibration pack

All Güralp sensors are fully calibrated before they leave the factory. Both absolute and relative calibration calculations are carried out. The results are given in the calibration pack supplied with each instrument:

Works Order : The Güralp factory order number including the instrument, used internally to file details of the sensor's manufacture.

Serial Number : The serial number of the instrument

Date : The date the instrument was tested at the factory.

Tested By : The name of the testing engineer.

There follows a table showing important calibration information for each component of the instrument, *VERTICAL*, *NORTH/SOUTH*, and *EAST/WEST*. Each row details:

Velocity Output (Differential) : The sensitivity of each component to velocity at 1 Hz, in volts per m/s. Because the 40T uses balanced differential outputs, the signal strength as measured between the +ve and –ve lines will be twice the true sensitivity of the instrument. To remind you of this, the sensitivities are given as 2 × (single-ended sensitivity) in each case.

Mass Position Output : The sensitivity of the mass position outputs to acceleration, in volts per m/s^2. These outputs are single-ended and referenced to signal ground.

Feedback Coil Constant : A constant describing the characteristics of the feedback system. You will need this constant, given in amperes per m/s^2, if you want to perform your own calibration calculations (see below.)

Power Consumption : The average power consumption of the sensor during testing, given in amperes and assuming a 12 V supply.

Calibration Resistor : The value of the resistor in the calibration circuit. You will need this value if you want to perform your own calibration calculations (see below.)

Poles and zeroes

Most users of seismometers find it convenient to consider the sensor as a "black box", which produces an output signal *V* from a measured input *x*. So long as the relationship between *V* and *x* is known, the details of the internal mechanics and electronics can be disregarded. This relationship, given in terms of the Laplace variable *s*, takes the form

$$(V/x)(s) = G \times A \times H(s)$$

In this equation

- *G* is the acceleration output sensitivity (gain constant) of the instrument. This relates the actual output to the desired input over the flat portion of the frequency response.
- *A* is a constant which is evaluated so that $A \times H(s)$ is dimensionless and has a value of 1 over the flat portion of the frequency response. In practice, it is possible to design a system transfer function with a very wide-range flat frequency response.

  The normalising constant *A* is calculated at a normalising frequency value *f*m = 1 Hz, with $s = j\,f$m, where $j = \sqrt{-1}$.
- $H(s)$ is the transfer function of the sensor, which can be expressed in factored form:

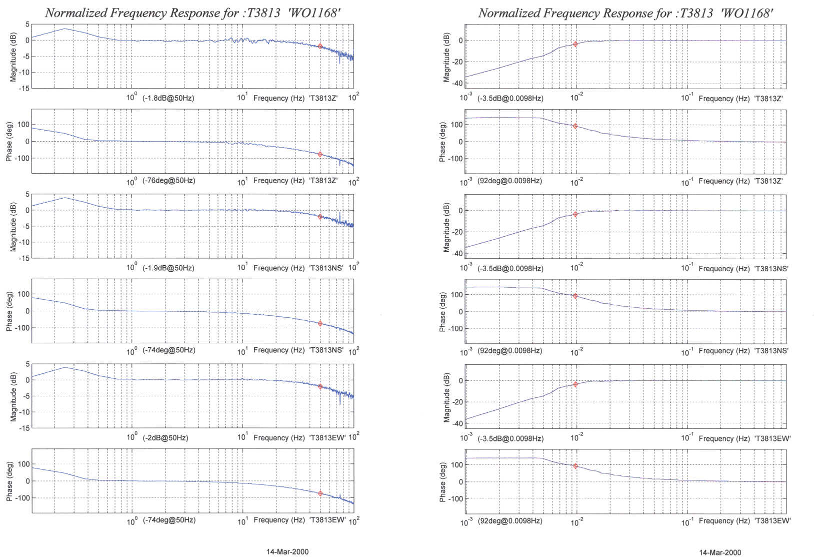
$$H(s) = N \frac{\prod_{i=1,n} s - Z_i}{\prod_{j=1,m} s - P_j}$$

  In this equation z_n are the roots of the numerator polynomial, giving the zeros of the transfer function, and p_m are the roots of the denominator polynomial giving the poles of the transfer function.

In the calibration pack, *G* is the sensitivity given for each component on the first page, whilst the roots z_n and p_m, together with the normalising factor *A*, are given in the *Poles and Zeros* table. The poles and zeros given are measured directly at Güralp Systems' factory using a spectrum analyser. Transfer functions for the vertical and horizontal sensors may be provided separately.

Frequency response curves

The frequency response of each component of the 40T is described in the normalised amplitude and phase plots provided. The response is measured at low and high frequencies in two separate experiments. Each plot marks the low-frequency and high-frequency cutoff values (also known as –3 dB or half-power points).



If you want to repeat the calibration to obtain more precise values at a frequency of interest, or to check that a sensor is still functioning correctly, you can inject calibration signals into the system using a Güralp digitizer or your own signal generator, and record the instrument's response.

Obtaining copies of the calibration pack

Our servers keep copies of all calibration data that we send out. In the event that the calibration information becomes separated from the instrument, you can obtain all the information using our free e-mail service. Simply e-mail caldoc@guralp.com with the serial number of the instrument in the subject line, *e.g.*

```
From: your@email.net
To: caldoc@guralp.com
Subject: T3A15
```

The server will reply with the calibration documentation in Word format. The body of your e-mail will be ignored.

4.2 Calibration methods

Velocity sensors such as the 40T are not sensitive to constant DC levels, either as a result of their design or because of an interposed high-pass filter. Instead, three common calibration techniques are used.

- Injecting a step current allows the system response to be determined in the time domain. The amplitude and phase response can then be calculated using a Fourier transform. Because the input signal has predominantly low-frequency components, this method generally gives poor results. However, it is simple enough to be performed daily.

- Injecting a sinusoidal current of known amplitude and frequency allows the system response to be determined at a spot frequency. However, before the calibration measurement can be made the system must be allowed to reach a steady state; for low frequencies, this may take a long time. In addition, several measurements must be made to determine the response over the full frequency spectrum.

- Injecting white noise into the calibration coil gives the response of the whole system, which can be measured using a spectrum analyser.

You can perform calibration either using a Güralp DM24 digitizer, which can generate step and sinusoidal calibration signals, or by feeding your own signals into the instrument through a handheld control unit.

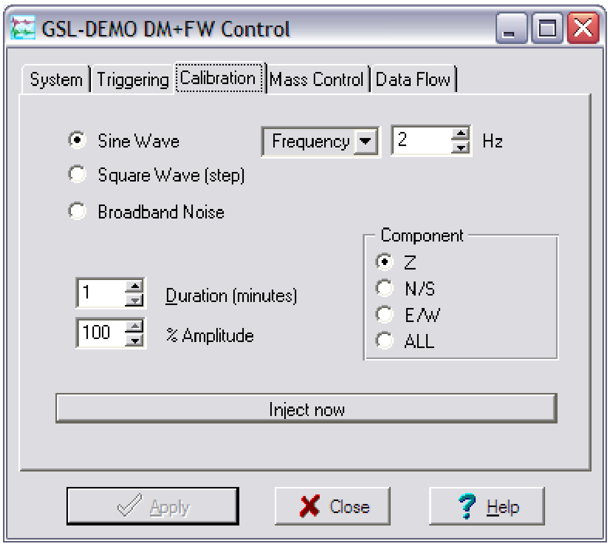
Before you can calibrate the instrument, its calibration relays need to be activated by pulling low the *CAL ENABLE* line on the instrument's connector for the component you wish to calibrate. Once enabled, a calibration signal provided across the *CAL SIGNAL* and *SIGNAL GROUND* lines will be routed through the feedback system. You can then measure the signal's equivalent velocity on the sensor's output lines. Güralp Handheld Control Units provide a switch for activating the *CAL ENABLE* line.

4.3 Calibration with Scream!

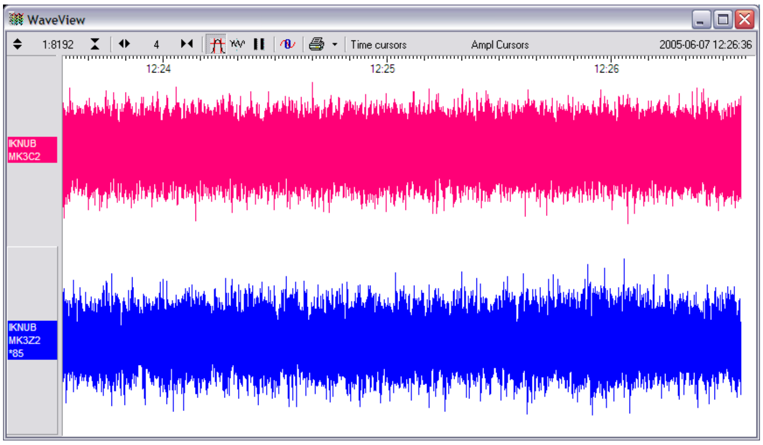
Güralp digitizers provide calibration signal generators to help you set up your sensors. Calibration is most easily done through a PC running Güralp's Scream! software.

Depending on the digitizer type, sine-wave, step and broadband noise signal generators may be available. In this section, broadband noise calibration will be used to determine the complete sensor response in one action. Please refer to the digitizer's manual for information on other calibration methods.

1. In Scream!'s main window, right-click on the digitizer's icon and select **Control...**. Open the *Calibration* pane.



2. Select the calibration channel corresponding to the instrument, and choose **Broadband Noise.** Select the component you wish to calibrate, together with a suitable duration and amplitude, and click **Inject now**. A new data stream, ending `C`*n* (*n* = 0 – 7) or `MB`, should appear in Scream!'s main window containing the returned calibration signal.



3. Open a Waveview window on the calibration signal and the returned streams by selecting them and double-clicking. The streams should display the calibration signal combined with the sensors' own measurements. If you cannot see the calibration signal, zoom into the Waveview using the scaling icons at the top left of the window or the cursor keys.

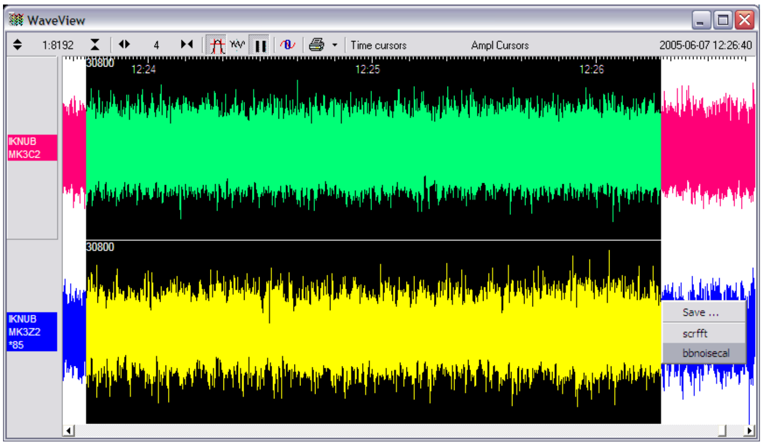
   Drag the calibration stream `C`*n* across the Waveview window, so that it is at the top.

4. If the returning signal is saturated, retry using a calibration signal with lower amplitude, until the entire curve is visible in the Waveview window.

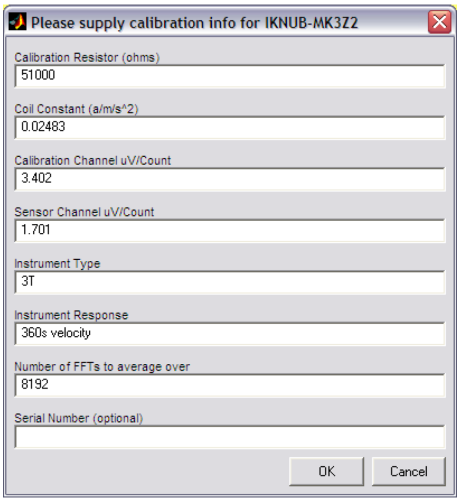
5. If you need to scale one, but not another, of the traces, right-click on the trace and select **Scale...**. You can then type in a suitable scale factor for that trace.

6. Pause the Waveview window by clicking on the  icon.

7. Hold down `SHIFT` and drag across the window to select the calibration signal and the returning component(s). Release the mouse button, keeping `SHIFT` held down. A menu will pop up. Choose **Broadband Noise Calibration.**



8. The script will ask you to fill in sensor calibration parameters for each component you have selected.



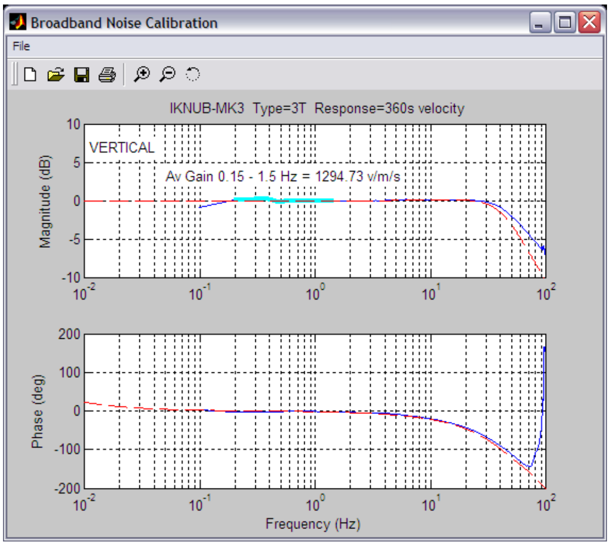
Most data can be found on the calibration sheet for your sensor. Under *Instrument response*, you should fill in the sensor response code for your sensor, according to the table below. *Instrument Type* should be set to the model number of the sensor.

If the file `calvals.txt` exists in the same directory as Scream!'s executable (`scream.exe`), Scream! will look there for suitable calibration values. A sample `calvals.txt` is supplied with Scream!, which you can edit to your requirements. Each stream has its own section in the file, headed by the line `[`***instrument-id***`]`. The ***instrument-id*** is the string which identifies the digitizer in the left-hand pane, *e.g.* `GURALP-DEMO`. It is always 6 characters (the system identifier) followed by a dash, then 4 characters (the serial number.) For example:

```
[instrument-id]
Serial-Nos=T3X99
VPC=3.153,3.147,3.159
G=1010,1007,1002
COILCONST=0.02575,0.01778,0.01774
CALVPC=3.161
CALRES=51000
TYPE=sensor-type
RESPONSE=response-code
```

9. Click `OK`. The script will return with a graph showing the responsivity of the sensor in terms of amplitude and phase plots for each component (if appropriate.)

   The accuracy of the results depends on the amount of data you have selected, and its sample rate. To obtain good-quality results at low frequency, it will save computation time to use data collected at a lower sample rate; although the same information is present in higher-rate streams, they also include a large amount of high-frequency data which may not be relevant to your purposes.



The `bbnoisecal` script automatically performs appropriate averaging to reduce the effects of aliasing and cultural noise.

Sensor response codes

Sensor	Sensor type code	Units (V/A)
CMG-5T or 5TD, DC – 100 Hz response	CMG-5_100HZ	A
CMG-40T-1 or 6T-1, 1 s – 100 Hz response	CMG-40_1HZ_50HZ	V
	CMG-40_1S_100HZ	V
CMG-40T-1 or 6T-1, 2 s – 100 Hz response	CMG-40_2S_100HZ	V
CMG-40T-1 or 6T-1, 10 s – 100 Hz response	CMG-40_10S_100HZ	V
CMG-40, 20 s – 50 Hz response	CMG-40_20S_50HZ	V
CMG-40, 30 s – 50 Hz response	CMG-40_30S_50HZ	V
CMG-3T or 3ESP, 30 s – 50 Hz response	CMG-3_30S_50HZ	V
CMG-40, 60 s – 50 Hz response	CMG-40_60S_50HZ	V
CMG-3T or 3ESP, 60 s – 50 Hz response	CMG-3_60S_50HZ	V
CMG-3T or 3ESP, 100 s – 50 Hz response	CMG-3_100S_50HZ	V
CMG-3T or 3ESP, 120 s – 50 Hz response	CMG-3_120S_50HZ	V
CMG-3T, 360 s – 50 Hz response	CMG-3_360S_50HZ	V
CMG-3TB or 3V / 3ESP borehole, 30 s – 50 Hz response	CMG-3B_30S_50HZ	V
CMG-3TB or 3V / 3ESP borehole, 100 s – 50 Hz response	CMG-3B_100S_50HZ	V
CMG-3TB or 3V / 3ESP borehole, 120 s – 50 Hz response	CMG-3B_120S_50HZ	V

4.4 Calibration with a handheld control unit

If you prefer, you can inject your own calibration signals into the system through a handheld control unit. The unit includes a switch which activates the calibration relay in the seismometer, and 4 mm banana sockets for an external signal source. As above, the equivalent input velocity for a sinusoidal calibration signal is given by

$v = V / 2 \pi f R K$

where *V* is the peak-to-peak voltage of the calibration signal, *f* is the signal frequency, *R* is the magnitude of the calibration resistor and *K* is the feedback coil constant. *R* and *K* are both given on the calibration sheet supplied with the 40T.

The calibration resistor is placed in series with the transducer. Depending on the calibration signal source, and the sensitivity of your recording equipment, you may need to increase *R* by adding further resistors to the circuit.

4.5 The coil constant

The feedback coil constant *K* is measured at the time of manufacture, and printed on the calibration sheet. Using this value will give good results at the time of installation. However, it may change over time.

The coil constant can be determined by tilting the instrument and measuring its response to gravity. To do this, you will need apparatus for measuring tilt angles accurately.

1. Measure the acceleration due to gravity, *g*, at your location.

2. Tilt the instrument slightly, and measure its attitude and the gain of the *mass position* output for the component you wish to calibrate.

3. Repeat this measurement for several tilt angles.

4. For the vertical sensor, the input acceleration is given by $a = g \sin \varphi$, whilst for the horizontal sensor, it is $a = g (1 - \cos \varphi)$.

   Calculate the input acceleration for each of the tilt angles used, and plot a graph of mass position output against input acceleration.

5. The gradient of the line obtained gives the sensitivity of the coil (in $V/m/s^2$, if *g* was measured in m/s^2 and the mass position in V.)

6. The coil constant *K* is equal to this sensitivity divided by the value of the displacement feedback resistor, given on the calibration sheet.

Appendix A Connector pinouts

Appendix A.1 Output port and breakout box RECORDER connector

Models with a 26-pin mil-spec plug (02E-16-26P) have the following pin assignments.

Pin	Function
A	Velocity +ve, vertical channel
B	Velocity –ve, vertical channel
C	Velocity +ve, N/S channel
D	Velocity –ve, N/S channel
E	Velocity +ve, E/W channel
F	Velocity –ve, E/W channel
G	Mass position, vertical channel
J	Mass position, N/S channel
L	Mass position, E/W channel
M	– 12 V DC supply (3-way power option)
N	Signal ground
P	Calibration signal (all channels)
R	Calibration enable (all channels)
U	Acc/Vel
V	N/S centring motor (remote centring option)
W	E/W centring motor (remote centring option)
X	Vertical centring motor (remote centring option)
Y	Motor return (remote centring option)
b	Power ground
c	+ 12 V DC supply

These outputs are compatible with the CMG-3ESP, so you can use CMG-3ESP handheld control units and breakout boxes to monitor the low-gain velocity outputs and calibrate. *Note:* 40T units with the optional additional high-gain outputs cannot be used with a CMG-3ESP breakout box. The pinouts for these sensors are given in the next section.

Pin R, *Calibration enable*, is equivalent to the vertical calibration enable line on a CMG-3ESP, so you can calibrate all channels by setting up Scream! or a handheld control unit to calibrate the vertical channel.

Pressing *ENABLE* and *CENTRE* on a CMG-3ESP handheld control unit activates pin U and switches the 40T into 1 second mode. You must do this before you can monitor mass position outputs, *e.g.* for offset zeroing.

Appendix A.2 Output port and breakout box RECORDER connector (high gain option)

These models have a 26-pin mil-spec plug (02E-16-26P) with the following pin assignments.

Pin	Function
A	Velocity +ve, vertical channel
B	Velocity –ve, vertical channel
C	Velocity +ve, N/S channel
D	Velocity –ve, N/S channel
E	Velocity +ve, E/W channel
F	Velocity –ve, E/W channel
G	Mass position, vertical channel
H	High gain velocity –ve, E/W channel
J	Mass position, N/S channel
K	High gain velocity +ve, E/W channel
L	Mass position, E/W channel
M	– 12 V DC supply (3-way power option)
N	Signal ground
P	Calibration signal (all channels)
R	Calibration enable (all channels)
S	High gain velocity –ve, vertical channel
T	High gain velocity +ve, vertical channel
U	Acc/Vel
V	N/S centring motor (remote centring option)
W	E/W centring motor (remote centring option)

X	Vertical centring motor (remote centring option)
Y	Motor return (remote centring option)
Z	High gain velocity –ve, N/S channel
a	High gain velocity +ve, N/S channel
b	Power ground
c	+ 12 V DC supply

Appendix A.3 Breakout box power connector

This is a standard 10-pin mil-spec plug (02E-12-10P).

Pin	Function
A	0 V
B	+12 V DC supply
H	–12 V DC supply (3-way power option)

Appendix B Specifications

Outputs and response	Sensitivity	2 × 160 V/m/s or 2 × 400 V/m/s
	Sensitivity (optional high gain outputs)	2 × 1600 V/m/s or 2 × 4000 V/m/s
	Dynamic range	> 145 dB
	Flat velocity response	0.033 Hz, 0.05 Hz or 0.1 Hz – 50 Hz
	Flat acceleration response	DC – 0.33 Hz, 0.05 Hz or 0.1 Hz
	High-frequency roll-off	See calibration sheet
	Output impedance	47 Ω
	Differential output	± 10 V
Physical	Lowest spurious resonance	450 Hz
	Operating temperature range	–10 to +60 °C
	Base diameter	168 mm
	Sensor height	210 mm (including handle)
	Sensor weight	5.0 kg
Power	Voltage requirements	10 – 36 V using internal 12 V DC/DC converter
	Current at 12 V DC	48 mA