Güralp 3T

Operator's guide

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Designed and manufactured by
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1 Preliminary Notes

1.1 Proprietary Notice

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1.2 Warnings, Cautions and Notes

Warnings, cautions and notes are displayed and defined as follows:

Warning: A black cross indicates a chance of injury or death if the warning is not heeded.

Caution: A yellow triangle indicates a chance of damage to or failure of the equipment if the caution is not heeded.

Note: A blue circle indicates indicates a procedural or advisory note.

1.3 Manuals and Software

All manuals and software referred to in this document are available from the Güralp Systems website: www.guralp.com unless otherwise stated.

2 Introduction

The Güralp 3T is a three-axis seismometer consisting of three sensors in a sealed case, which can measure the north/south, east/west and vertical components of ground motion simultaneously. Each sensor is sensitive to ground vibrations in the frequency range 0.003 – 50 Hz, a broadband frequency response made possible by advanced force-balance feedback electronics. Because of this wide response range, the 3T can replace many of the instruments conventionally used in a seismic observatory; it also produces true pulse-shape records suitable for modern earthquake mechanism analysis.

The 3T is designed for mounting on a hard, near-horizontal surface well coupled to the bedrock. After levelling and orienting the case, you can perform accurate adjustments internally by sending the instrument control signals. These electronics allow it to compensate for a tilt of up to 3 ° from horizontal.

Once levelled and centred, the 3T will begin operating automatically. It outputs analogue voltages representing ground velocity on balanced differential lines. These voltages can be recorded using a separate logging device or digitiser. For testing and installation purposes, a hand-held control unit is supplied which can monitor the instrument's output.

The seismometer unit is self-contained apart from its 12 Volt power supply. Centring and mass locking can be carried out by sending control signals to the instrument, either through the hand-held control unit or through an attached Güralp digitiser.

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.

2.1 Options

2.1.1 Form factors

The Güralp 3T can be supplied in several forms, besides its standard configuration:

- The Güralp 3T Compact is internally identical to the standard 3T, but has a different arrangement of components allowing it to fit in a smaller casing.
- The 3T can also be supplied in a slimline form factor, with vertically-stacked sensors, suitable for installation in post-holes (see Section 3.5 on page 22.).
- The 3T is also available as a fully-fledged borehole instrument, the Güralp 3TB.

Any of these can be supplied with integral digitisers and data modules, allowing the 3T to form a complete, integrated seismic installation. For example, the 3TD is a full-height 3T with an integrated Güralp DM24 digitiser. As an additional option, the 3TD can be ordered with an Integrated State-of-Health Controller, which provides the mass-control functions (normally accessed via the break-out box) directly from controls mounted on the instrument. See section 5.3 on page 36 for more details.

2.1.2 Output types

The standard 3T has a single 26-pin military-specification waterproof connector for signals, control and power:

Alternatively, the 3T can be supplied with a 100 Bar (10 MPa) waterproof connector of the type used in our borehole instruments. The pin-out for this is given in section 7.3 on page 51.

2.1.3 Sensor control interface

3T instruments can be fitted with an optional RS232 control interface. The control interface can be used to lock, unlock, and centre the sensor masses, and query mass positions. See section 6.3 on page 43, for more details.

2.1.4 Sensor response

The 3T can be supplied with a response which is flat to velocity from 100 Hz to any of 0.1 Hz (10 seconds), 0.033 Hz (30 seconds), 0.016 Hz (60 seconds), 0.01 Hz (100 seconds), 0.0083 Hz (120 seconds) or 0.0027 Hz (360 seconds). Alternatively, a *hybrid* response function may be provided. See Chapter 6 for more details.

If you do not require high-frequency data, a low-pass filter may be installed at any frequency (below 100 Hz) that you specify.

3 Installing the 3T

3.1 First encounters

3.1.1 Unpacking

The 3T seismometer is delivered in a single transportation case. The packaging is specifically designed for the 3T and should be reused whenever you need to transport the sensor. (The softer, low-density foam should be on the outside and the stiffer, high-density foam should be placed next to the instrument when re-packing, in order to prevent the instrument from damaging the soft foam while still providing the necessary shock-absorption.) Please note any damage to the packaging when you receive the equipment, and unpack on a safe, clean surface. The package should contain:

- the seismometer;

- a cable to join the sensor to a digitiser or breakout box; and

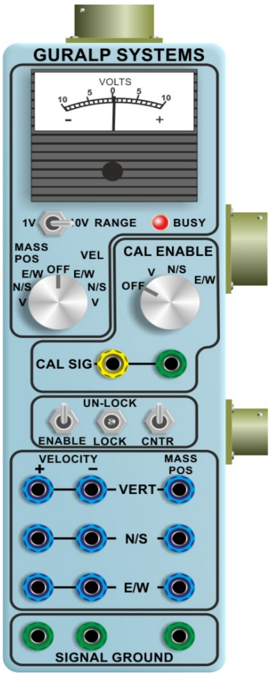
- a calibration and installation sheet.

If you have ordered the optional break-out box, you will also have received:

- the breakout box (which provides separate connections for the signal, control and power lines); and

- a 10-pin connector for your power lead (see below).

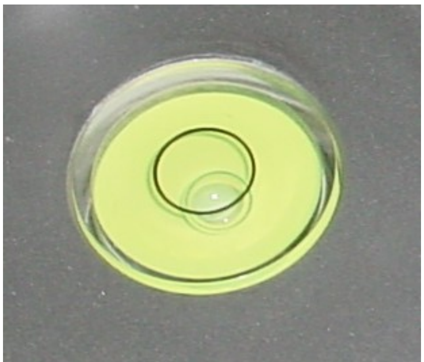
You will also have received, if ordered, a Hand-held Control Unit (HCU) for monitoring sensor outputs and calibration



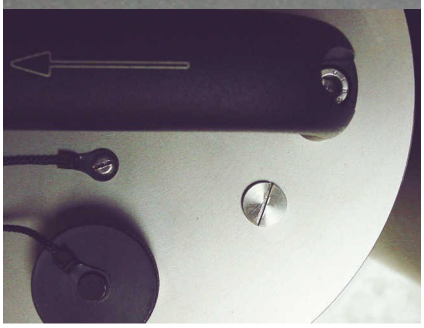
Assuming all the parts are present, stand the seismometer in the centre of a bench and identify its external features:

- a handle with North indication

- a multi-pole socket for input and output
- other optional connectors as ordered

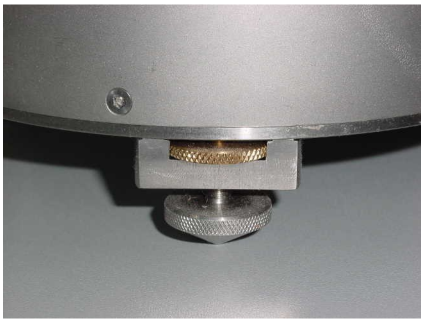


- a bubble level



- an air vent port

Warning: Instruments are assembled at sea level. If working at altitude, there may be a considerable pressure difference between inside and outside the casing. Never remove this screw unless instructed to do so by GSL support staff.



- three adjustable feet

- two accurate orientation pins, one brass and one steel. The steel stud is opposite the brass stud, pictured here.

3.1.1.1 Serial number

The sensor's serial number is stamped onto the side of the sensor base, next to the N/S indicator (seen to the right of the photograph above). It can also be found on the label on the top lid of the sensor. You should quote this serial number if you need assistance from Güralp Systems.

3.1.1.2 Handling notes

The 3T is a sensitive instrument, and is easily damaged if mishandled. If you are at all unsure about the handling or installation of the device, you should contact Güralp Systems for assistance.

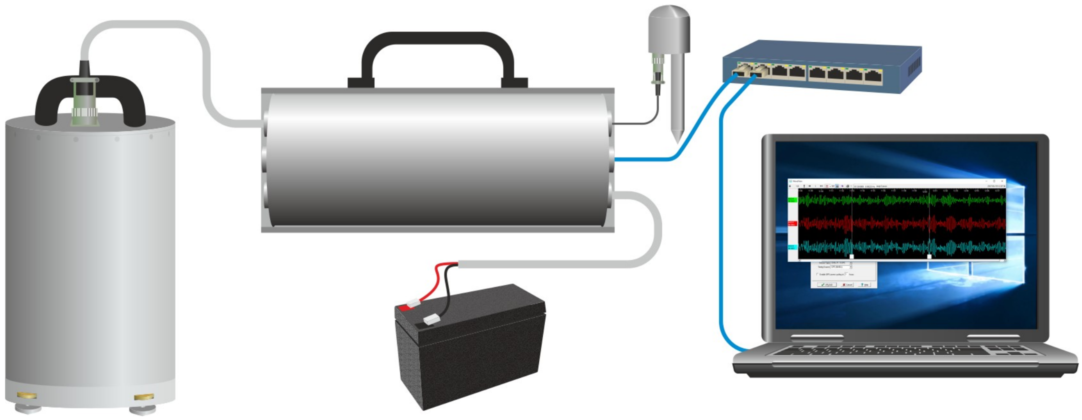
- Do not bump or jolt any part of the sensor when handling or unpacking.
- Do not kink or walk on the data cable (especially on rough surfaces such as gravel), nor allow it to bear the weight of the sensor.
- Do not connect the instrument to power sources except where instructed.
- Do not ground any of the signal lines from the sensor.
- Do not move the instrument whilst the masses are unlocked. You should report any sign of loose components, or any sound of parts moving inside the instrument, to Güralp Systems.

3.1.2 Connections

The instrument has a single connector, which can be joined using the cable provided to a digitiser or breakout box. Individually shielded twisted-pair cabling *must* be used for the sensor outputs, control lines and power supply. If you need to make up a suitable cable, you should confirm the cable type with Güralp Systems.

3.1.2.1 Using a digitiser

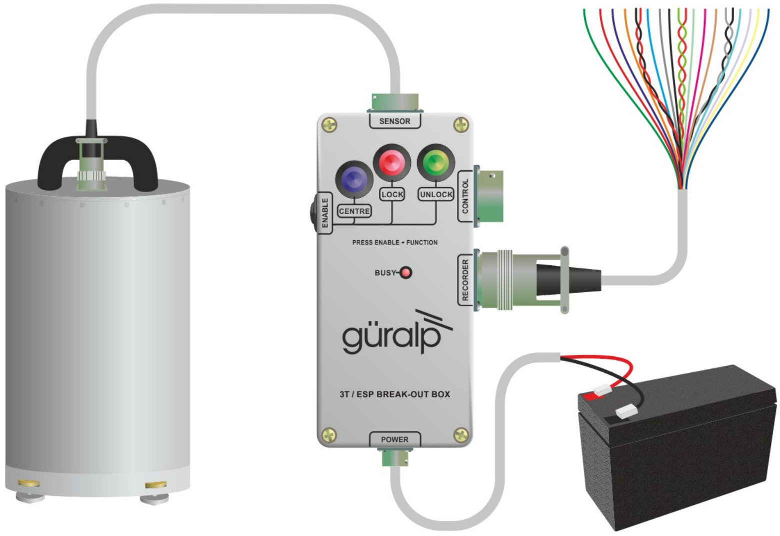
The 3T can be connected directly to any Güralp Systems digitiser using the signal cable provided. This is the simplest way to use a 3T instrument. All the instrument's functions are available through the digitiser - including centring, locking and unlocking - and the instrument takes its power from the digitiser, along the single connection cable.



We recommend that you keep the digitiser near the instrument if at all possible, to minimize the length of analogue cable required. Once digitized, the signal is robust to degradation by noise or attenuation. Keeping the digitiser in the quiet, stable conditions of a seismic installation also provides it with an optimum environment for the on-board ADCs.

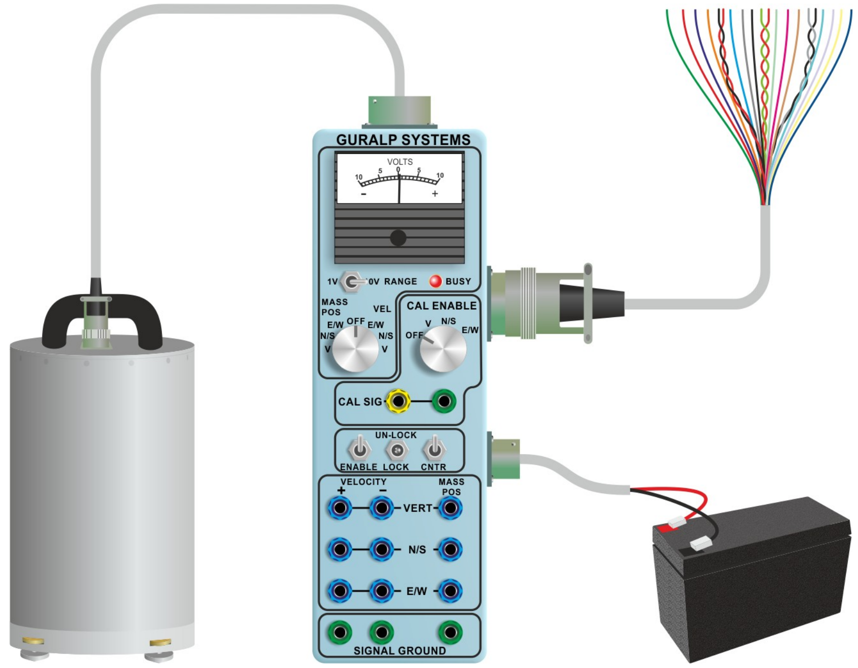
3.1.2.2 Breakout box and hand-held control unit

The 3T can be supplied with an optional breakout box, which provides mass control functions in installations which do not use compatible digitisers.



"Pig-tail" sensor cables, which terminate in bare ends, are available, to aid connection to third-party digitisers.

A hand-held control unit is also available which can control calibration lines and monitor sensor outputs in addition to mass control. See Chapter 5 on page 33, for more details.



The digitiser can be connected either to the break-out box, as in the previous illustration, or to the hand-held control unit, as shown above.

3.1.2.3 Power supply

or

The sensor requires a DC power supply of between 10 and 36 Volts, connected via the socket on the breakout box, hand-held control unit or digitiser. If you are powering the instrument via the break-out box or hand-held controller, you will need to make up a suitable cable to connect your power source to the 10-pin connector (spare 10pin bayonet connectors are provided for this purpose). Using a 12 Volt, 25 Ampere-hour, sealed, heavy-duty, lead-acid battery, you should expect the instrument to operate for around a week without recharging.

If you prefer, you can power the 3T directly from the connector on the top panel (see Chapter 7 on page 49.)

The 3T draws a nominal current of 75 milliamps from a 12 Volt supply when in use. During locking and unlocking of the sensor masses, this current rises briefly to

600 milliamps. It is recommended that you carry a spare 12 Volt battery when visiting a battery-powered installation for maintenance, in case the sensor needs to be moved and the on-site batteries no longer have sufficient charge to perform the locking procedure.

3.1.2.4 Signal output

The sensors output voltages representing ground velocity on floating differential lines. The breakout box provides a *RECORDER* connector for attaching to a recording system or digitiser. You can use any multi-channel recording system, provided that it has high-impedance floating differential inputs that can accept ±10 Volt signals on each leg of each input.

If you are using a Güralp Systems digitiser, you can connect the instrument directly to the digitiser without using the breakout box; power will be supplied through the digitiser. The digitiser can also activate the sensor control lines under software control.

The breakout box also provides a *CONTROL* output, which can be connected to the Hand-held Control Unit. This device lets you monitor output signals from the instrument, and perform on-site calibration. For more information, see Chapter 7 on page 49.

3.2 Installation notes

The goal of any seismic installation is to ensure that wave-trains arriving at the instrument accurately reflect the internal motion of subsurface rock formations. To achieve this, 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.

In particular, the sensor needs to be protected against environmental factors such as:

- 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 equipment in or near the installation, particularly computer equipment; and
- vibration caused by heavy machinery (even at a distance), or by overhead power lines.

In seismic vaults, instruments are often installed on piers. It is important to ensure that the interface between the pier and the floor does not introduce noise, and that the pier itself does not have resonant frequencies within the passband. Ideally, a seismic pier will be significantly wider than it is high (to minimize flexing) and will form a single piece with the floor, *e.g.* by moulding a poured concrete floor within a wooden frame.

Many situations do not allow for the construction of a seismic vault. For example, you may need to deploy quickly to monitor the activity of a volcano showing signs of rejuvenation, or to study the aftershocks of a major earthquake. In other cases the site itself may be too remote to ship in construction equipment.

Temporary installations can be protected against spurious vibrations by:

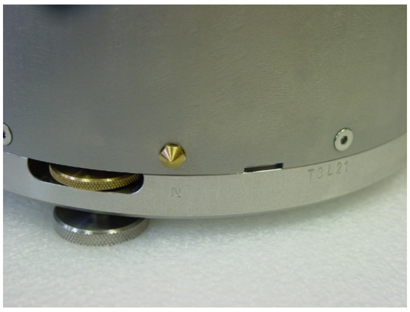
- selecting a suitable site,
- placing the instrument in a protective enclosure (an open-sided box of 5 cm expanded polystyrene slabs, placed over the instrument and taped down to exclude draughts, makes an excellent thermal shield),
- standing the sensor on bedrock where possible, or at least deep in 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.

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. If you require long-period recording, you should re-centre the instrument after this time.

3.3 Installing in vaults

You can install a 3T in an existing seismic vault with the following procedure:

1. Unpack the sensors from their container, saving the shipping boxes for later transportation.
2. Prepare the mounting surface, which should be smooth and free of cracks. Remove any loose particles or dust, and any pieces of loose surfacing. This ensures good contact between the instrument's feet and the surface.
3. If it is not already present, inscribe an accurate North-South line on the mounting surface.
4. Place the sensor over the scribed line, so that the brass and steel pointers are aligned with the marked directions, with the brass pointer facing North. This can be done by rotating the base of the sensor whilst observing it from above. The brass pointer can be found next to one of the feet.

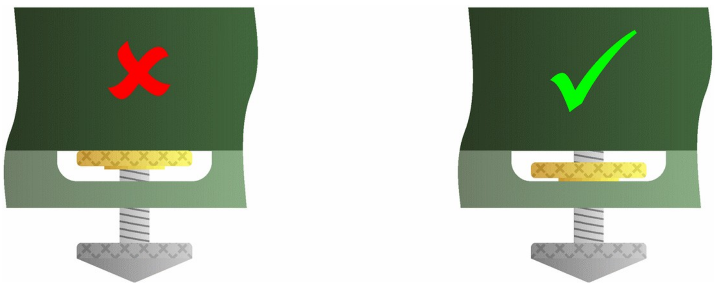


If you cannot easily see the pointers, you should align the sensor using the north arrow on the handle. However, the alignment of the handle with the sensors inside is less accurate than the metal pointers.

5. The top panel of the 3T includes a spirit level.

Level the sensor using the adjustable feet of the instrument, until the bubble in the spirit level lies entirely within the inner circle. (The instrument can operate with up to 2° of tilt, but with reduced performance.)

The feet are mounted on screw threads. To adjust the height of a foot, turn the brass locking nut anticlockwise to loosen it, and rotate the foot so that it screws in or out. When the instrument is level, tighten each brass locking nut clockwise to secure the foot. When locked, the nut should be at the *bottom* of its travel for optimal noise performance.



6. Connect the sensor to a breakout box, or to a Güralp digitiser if you are using one.

7. Connect a 12 Volt DC power supply, either directly or through the breakout box or digitiser.

8. Unlock the sensor. If you have a breakout box or hand-held control unit, you can do this by holding the *ENABLE* and *UNLOCK* buttons on the unit down together for 7 seconds. The *BUSY* LED will start flashing, and then go out.

   Alternatively, if you are using a DM24 digitiser and Scream!, right-click on the digitiser's entry in Scream! and select **Control...**. Click on the **Mass control** tab, followed by **Unlock**. (If the *Mass control* tab is unavailable, check the sensor type in the *Sensor type* tab, apply, and open a new *Control* window.)

   Alternatively, if you are using an EAM, navigate to the Control→Instruments page, select the instrument and click on the **Unlock masses** button.

   Caution: After unlocking the masses, you should be careful not to move the instrument at all or you may damage it.

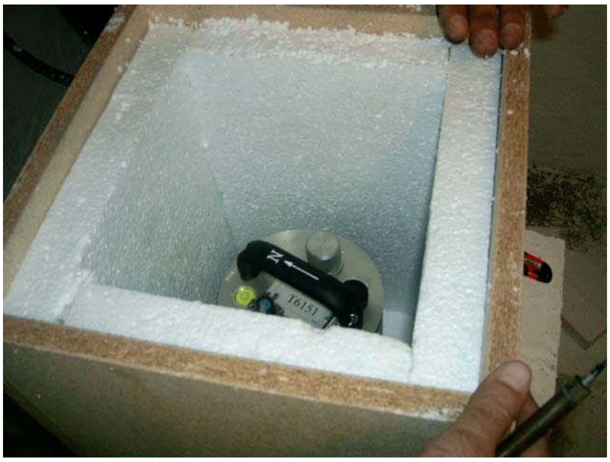
9. Check the mass position outputs using a digital multimeter, digitiser or hand-held control unit.

   Re-centre the masses if required. If you have a breakout box or hand-held control unit, you can do this by holding the *ENABLE* and *CENTRE* buttons on the unit down together for seven seconds. The *BUSY* LED will start flashing, and then go out

   Alternatively, if you are using a DM24 digitiser and Scream!, right-click on the digitiser's entry in Scream! and select **Control...**. Click on the **Mass control** tab, followed by **Centre**.

   Alternatively, if you are using an EAM, navigate to the Control→Instruments page, select the instrument and click on the **Centre masses** button.

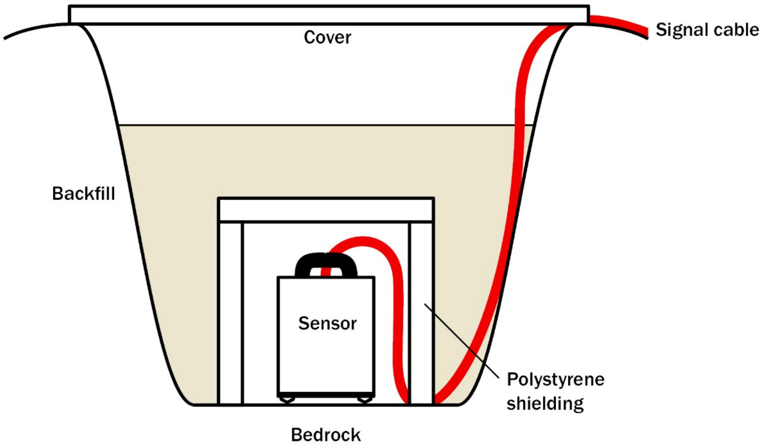
10. Cover the instrument with thermal insulation - for example, a 5 cm expanded polystyrene box. This will shield it from thermal fluctuations and convection currents in the vault. It also helps to stratify the air in the seismometer package. Position the thermal insulation carefully so that it does not touch the sensor package.



11. 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.

3.4 Installing in pits

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



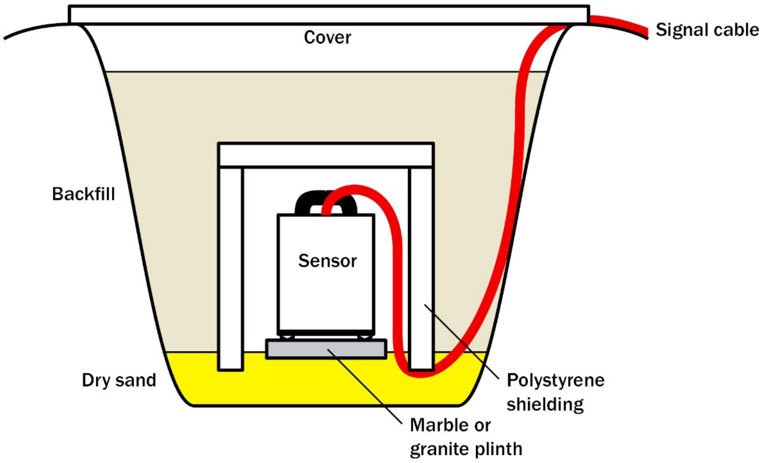
Depending on the time and resources available, this type of installation can suit all kinds of deployment, from rapid temporary installations to medium-term telemetered stations.

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 5.

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 situating 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 for a vault installation (Section 3.3 on page 16, 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.

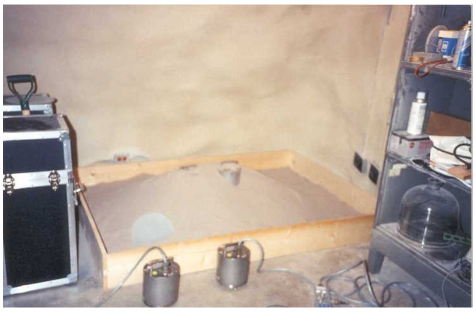
3.4.1 Other installation methods

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 introduced 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.

3.5 Installing in post-holes

The 3T is suitable for installation in post-holes. In soft subsoil, a hole two to four metres deep and 20 cm wide can be conveniently excavated using a tractor-mounted or hand-operated post-hole auger. To minimize surface effects, you should ensure that the hole is one metre deeper than the length of the instrument or, preferably, somewhat more.

Since the hole has no lining, it may occasionally flood. However, most soil types are sufficiently permeable to allow water to soak away, leaving the packing material moist.

A slim-profile 3T instrument is available with vertically stacked sensors and built-in inclinometer, specifically designed for post-hole installations. Digitisers or other recording equipment can be placed either within the hole or in a separate enclosure; alternatively, the Güralp DM24 is available in modular form, allowing you to attach the digitiser directly to the instrument.

To install a 3T in a post-hole:

1. Clean the post-hole, making sure there is no loose material around the mouth of the hole or on its base.
2. Prepare the instrument package, making sure the inclinometer is visible, and attach it to a winch or hoist by clamping a light steel cable to the centre of the handle so that the package hangs vertically. Connect the signal cable to the instrument.
3. Add packing material to the hole to about 15 cm depth. Fine crushed rock, with a high proportion of rock flour and fine particles, makes excellent packing material. Alternatively, a mixture of 3 mm grade angular coarse grit with around 30% medium grit gives good results. Moisten the packing material in the hole and ram firm.
4. Lower the instrument to the bottom of the hole, but without slackening the lifting cable.
5. Fill more packing material around the instrument for about 30 cm, moisten, and ram firm.
6. Use the inclinometer to check that the instrument remains within its tilt tolerance (± 2°).
7. Continue filling, moistening and packing until the instrument is buried, checking that the tilt remains within tolerance.
8. Release the strain on the lifting cable, and allow the packing material to settle for 24 hours.
9. If all is well after the settling period, release the lifting tackle, coil a tail of the lifting wire into the top of the hole and backfill almost to the surface.
10. Ensure that the signal cable is slack and fix it to a support at the top of the hole.
11. Ram a split wooden bung into the top of the hole, and cover with sandbags.
12. Attach the signal cable to your recording equipment or breakout box. Power the sensor, and unlock it. Carry out preliminary tests using a hand-held control unit, if required.

4 Calibrating the 3T

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 3T 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 ms^{-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 ms^{-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.)

4.1.1 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

$$\left(\frac{V}{x}\right)(s)=G\times A\times H(s)$$

In this equation

- s is the Laplace variable, equal to $j\ \omega$ (where ω is the angular frequency in radians per second and $j = \sqrt{-1}$) and, hence, equal to to $2\ \pi\ j\ f$ (where f is the frequency in Hertz).
- G is the velocity output sensitivity (gain constant) of the instrument. This relates the actual output to the desired input over the flat portion of the frequency response. It is expressed in units of V / ms^{-1}.
- A is a real constant which is chosen such that $A \times H(s)$ is dimensionless and has unity magnitude over the flat portion of the frequency response. It is calculated at a defined normalising frequency value fm (almost always 1 Hz) such that

  $$A\times\Re[H(2\pi j f_m)]=1$$

  where $\Re[x]$ denotes taking the real part of complex number x.

  In practice, it is possible to design a system transfer function with a very wide-range flat frequency response.
- $H(s)$ is the transfer function of the sensor, which can be expressed in factored form:

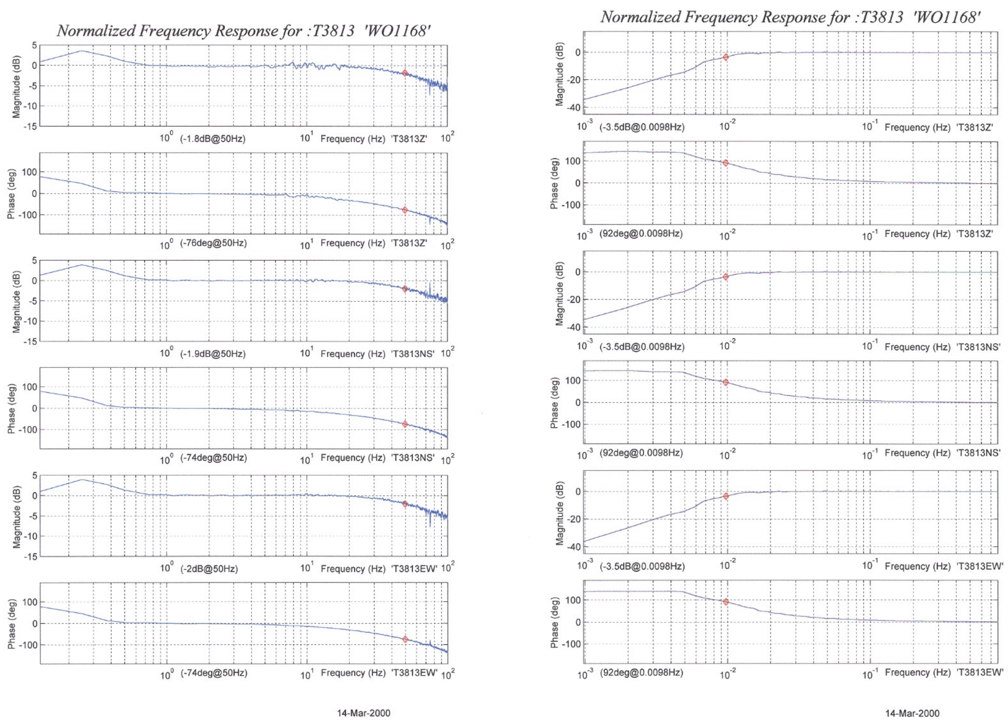
  $$H(s)=\frac{\prod_{i=1,n}(s-Z_i)}{\prod_{j=1,n}(s-P_j)}$$

  In this equation Z_i are the roots of the numerator polynomial, giving the zeros of the transfer function, and P_j 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_i and P_j, 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.

4.1.2 Frequency response curves

The frequency response of each component of the 3T 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 cut-off values (also known as –3 dB or half-power points).

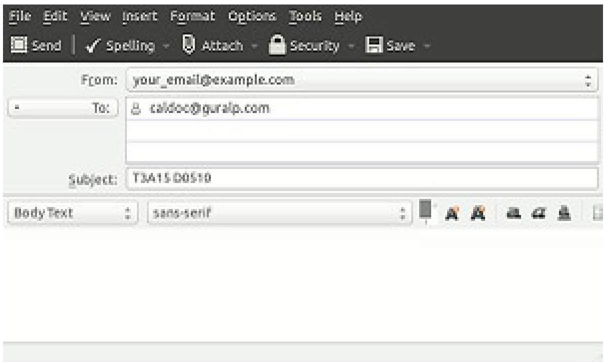


If you want to repeat the calibration to obtain more precise values at a frequency of interest, or to check that a sensor is still functioning correctly, you can inject calibration signals into the system using a Güralp digitiser or your own signal generator, and record the instrument's response.

4.1.3 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.*



The server will reply with the calibration documentation in Word format. The body of your e-mail will be ignored. If you want data for several sensors, put their serial numbers together on the subject line, separated by commas.

4.2 Calibration methods

Velocity sensors such as the 3T 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 digitiser, which can generate step and sinusoidal calibration signals, or by feeding your own signals into the instrument through a hand-held control unit.

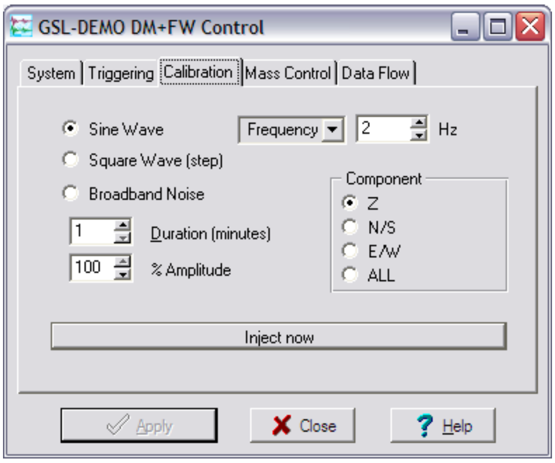
Before you can calibrate the instrument, its calibration relays need to be activated by pulling low the *CAL ENABLE* line on the instrument's connector for the component you wish to calibrate. Once enabled, a calibration signal provided across the *CAL SIGNAL* and *SIGNAL GROUND* lines will be routed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

4.3 Calibration with Scream!

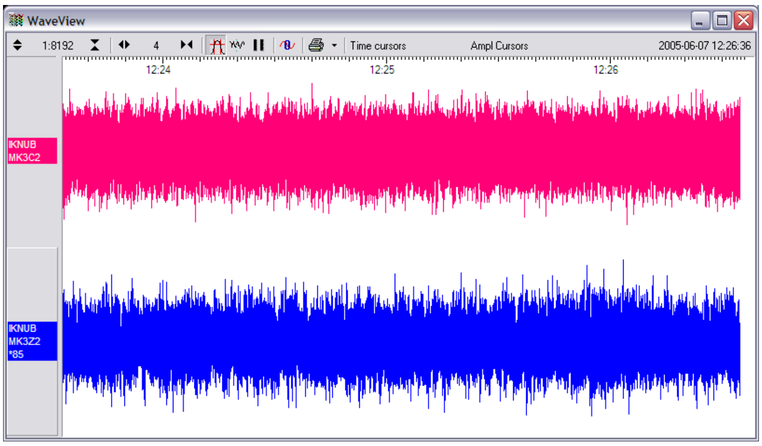
Güralp digitisers provide calibration signal generators to help you set up your sensors. Calibration is most easily done through a PC running Güralp's Scream! software.

Depending on the digitiser 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 digitiser's manual for information on other calibration methods.

1. In Scream!'s main window, right-click on the digitiser'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.

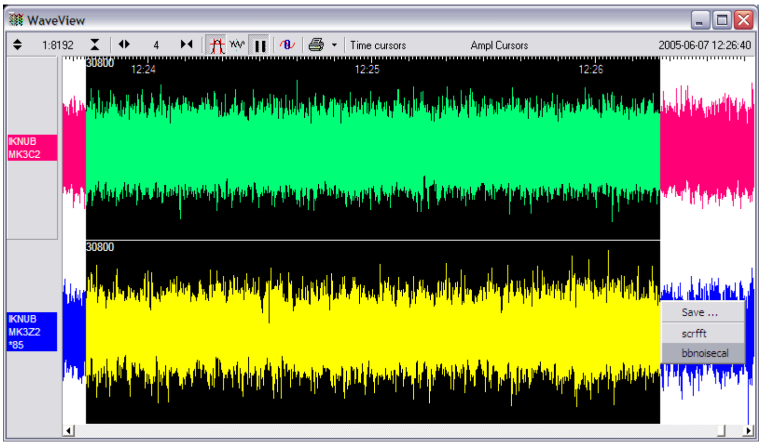
   Drag the calibration stream C*n* up the WaveView window, so that it is at the top.

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

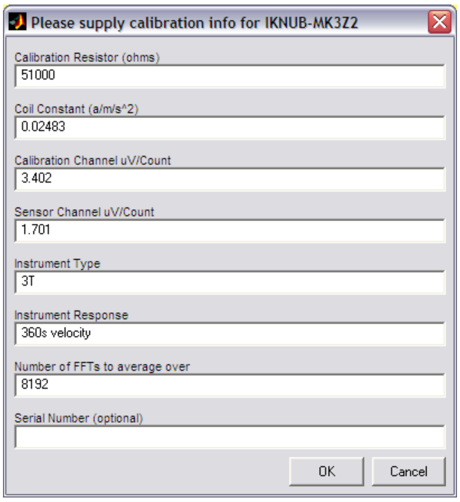
5. If you need to scale one, but not another, of the traces, right-click on the trace and select **Scale…**. You can then type in a suitable scale factor for that trace.

6. Pause the WaveView window by clicking on the ❚❚ icon.

7. Hold down the shift key (⇧)and drag across the window to select the calibration signal and the returning component(s). Release the mouse button, keeping the shift key held down. A menu will pop up. Choose **Broadband Noise Calibration.** This option runs a script called bbnoisecal which automatically performs appropriate averaging to reduce the effects of aliasing and cultural noise.



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



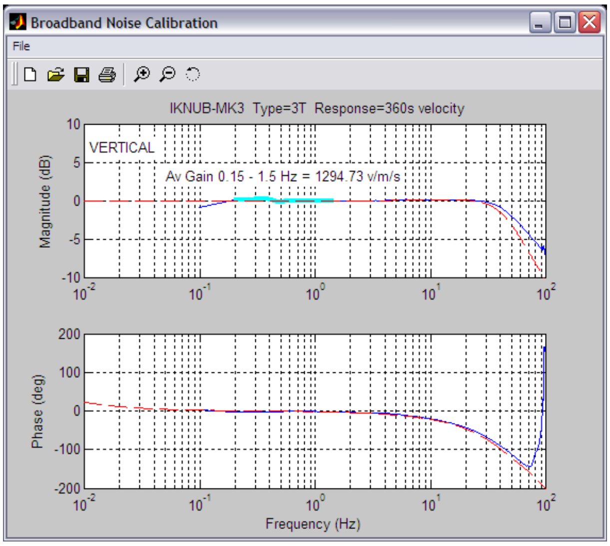
Most data can be found on the calibration sheet for your sensor. Under *Instrument response*, you should fill in the sensor response code for your sensor, according to the table below. *Instrument Type* should be set to the model number of the sensor.

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 digitiser in the left-hand pane, *e.g.* `GURALP-DEMO`. It consists of the System Identifier (up to six characters) followed by a dash and then the Serial Number (up to 4 characters). 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=CMG-3T
RESPONSE=CMG-3_100s_50Hz
```

9. Click OK. The script will return with a graph showing the response 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.

4.3.1 Sensor response codes

Sensor	Sensor type code	Units (V/A)
3T or 3ESP, 30s – 50 Hz response	`CMG-3_30S_50HZ`	V
3T or 3ESP, 60s – 50 Hz response	`CMG-3_60S_50HZ`	V
3T or 3ESP, 100s – 50 Hz response	`CMG-3_100S_50HZ`	V
3T or 3ESP, 120s – 50 Hz response	`CMG-3_120S_50HZ`	V
3T, 360s – 50 Hz response	`CMG-3_360S_50HZ`	V
3TB or 3V / 3ESP borehole, 30s – 50 Hz response	`CMG-3B_30S_50HZ`	V
3TB or 3V / 3ESP borehole, 100s – 50 Hz response	`CMG-3B_100S_50HZ`	V
3TB or 3V / 3ESP borehole, 120s – 50 Hz response	`CMG-3B_120S_50HZ`	V

4.4 Calibration with a hand-held control unit

If you prefer, you can inject your own calibration signals into the system through a hand-held 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 the equation

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

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

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/ms^{-2}, if g was measured in ms^{-2} and the mass position is in Volts).
6. The coil constant K is equal to this sensitivity divided by the value of the displacement feedback resistor, as given on the calibration sheet.

5 Accessories

5.1 The breakout box

This unit separates the lines in the signal cable, so you can connect a power supply, a recording system, and the hand-held control unit:

You can also use the breakout box to centre, lock and unlock the sensor masses. You will need to provide power through the breakout box's *POWER* connector to do this (see below.)

- To unlock the sensor masses, hold down the *ENABLE* and *UNLOCK* buttons simultaneously for 7 seconds. The *BUSY* LED will light. All three masses are unlocked, each in turn. The sensor then automatically moves on to centre the masses, during which time the *BUSY* LED will flash. When the *BUSY* LED goes out, the instrument is ready for use.

Caution: After unlocking the masses, you should be careful not to move the instrument at all or you may damage it.

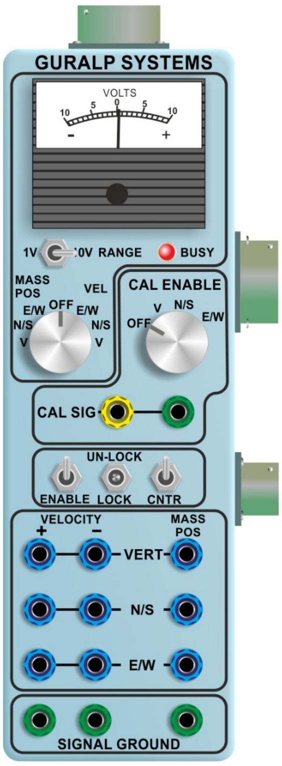
- To lock the sensor masses, hold down the *ENABLE* and *LOCK* buttons simultaneously for 7 seconds. When the *BUSY* LED goes out, the instrument is ready for transportation.

- To re-centre the sensor masses, hold down the *ENABLE* and *CENTRE* buttons simultaneously for 7 seconds. When the *BUSY* LED stops flashing, the centring process has finished. You may need to initiate several rounds of centring before the instrument is ready; when no more centring is required, pressing the *ENABLE* and *CENTRE* buttons has no effect.

For more details on the control system, see Section 6.2 on page 40.

The standard breakout box is rain resistant but *not* waterproof. If you intend to use a breakout box in your installation, you should site it away from potential flooding. If this is not possible, a larger unit is optionally available which can be immersed in water. (The 3T itself is, however, completely waterproof.)

5.2 The hand-held 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. It takes input from the 26-pin connector at the bottom, and repeats it at the connector on the side for connection to further equipment.

The hand-held control unit can be sited up to fifty metres from the breakout box.

5.2.1 The meter

The meter at the top of the unit allows you to monitor the voltage outputs of the instrument. You can use the knob below to select, for each of the three components, either the mass position output or the velocity output. There is also a *RANGE* switch allowing you to alter the sensitivity of the meter.

5.2.2 Calibration

The hand-held control unit can be used to calibrate the 3T. To activate the calibration relays, turn the knob to the component you wish to calibrate, and introduce a calibration signal on the *CAL SIG* banana sockets.

5.2.3 Control commands

You can use the hand-held control unit to centre, lock and unlock the sensor masses.

- To unlock the sensor masses, press the *ENABLE* switch down, and the *LOCK/UNLOCK* switch up simultaneously. The *BUSY* LED will light. All three masses are unlocked, each in turn. The sensor then automatically moves on to centre the masses, during which time the *BUSY* LED will flash. When the *BUSY* LED goes out, the instrument is ready for use.

> **Caution:** After unlocking the masses, you should be careful not to move the instrument at all, especially if unpowered, or you may damage it.

- To lock the sensor masses, press the *ENABLE* and *LOCK/UNLOCK* switches down simultaneously. When the *BUSY* LED goes out, the instrument is ready for transportation.

- To re-centre the sensor masses, press the *ENABLE* and *CENTRE* switches down simultaneously. When the *BUSY* LED stops flashing, the centring process has finished. You may need to initiate several rounds of centring before the instrument is ready. When no more centring is required, pressing the *ENABLE* and *CENTRE* buttons has no effect.

> **Note:** The *ENABLE*, *LOCK*, *CENTRE* and *UNLOCK* switches require only a single quick press to initiate the processes. Do not hold them down.

For more details on the control system, see Section 6.2 on page 40.

5.2.4 Outputs

The remaining banana sockets provide easy access to the output voltages of the instrument. For each component (vertical, N/S and E/W):

- the left-hand two sockets expose the balanced differential outputs representing ground velocity, and
- the right-hand socket exposes the mass position (acceleration) output.

Ground references for each of these voltages are provided at the bottom of the unit. Ensure that you do not connect either side of a differential output to ground.

5.3 Integrated State-of-Health Controller

The Güralp 3TD variant (a Güralp 3T with an integrated DM24 digitiser) is also available with an optional, in-built state-of-health controller.

This option provides a simple means to centre, lock and unlock the masses without the need for a hand-held control unit.

The lid of the device is fitted with four momentary, colour-coded push-buttons, labelled “ENABLE” (black), “CENTRE” (blue), “UNLOCK” (green) and “LOCK” (red) - together with a red LED, labelled “BUSY”.

These buttons are used in a similar manner to those on the break-out box with the exception that it is not necessary to hold the buttons down for seven seconds - one second is adequate.

- To unlock the sensor masses, hold down the *ENABLE* and *UNLOCK* buttons simultaneously for one second. The *BUSY* LED will light. All three masses are unlocked, each in turn. The sensor then automatically moves on to centre the masses, during which time the *BUSY* LED will flash. When the *BUSY* LED goes out, the instrument is ready for use.

  Caution: After unlocking the masses, you should be careful not to move the instrument at all or you may damage it.

- To lock the sensor masses, hold down the *ENABLE* and *LOCK* buttons simultaneously for one second. When the *BUSY* LED goes out, the instrument is ready for transportation.

- To re-centre the sensor masses, hold down the *ENABLE* and *CENTRE* buttons simultaneously for one second. When the *BUSY* LED stops flashing, the centring process has finished. You may need to initiate several rounds of centring before the instrument is ready; when no more centring is required, pressing the *ENABLE* and *CENTRE* buttons has no effect.

For more details on the mass control system, see Section 6.2 on page 40.

6 Inside the 3T

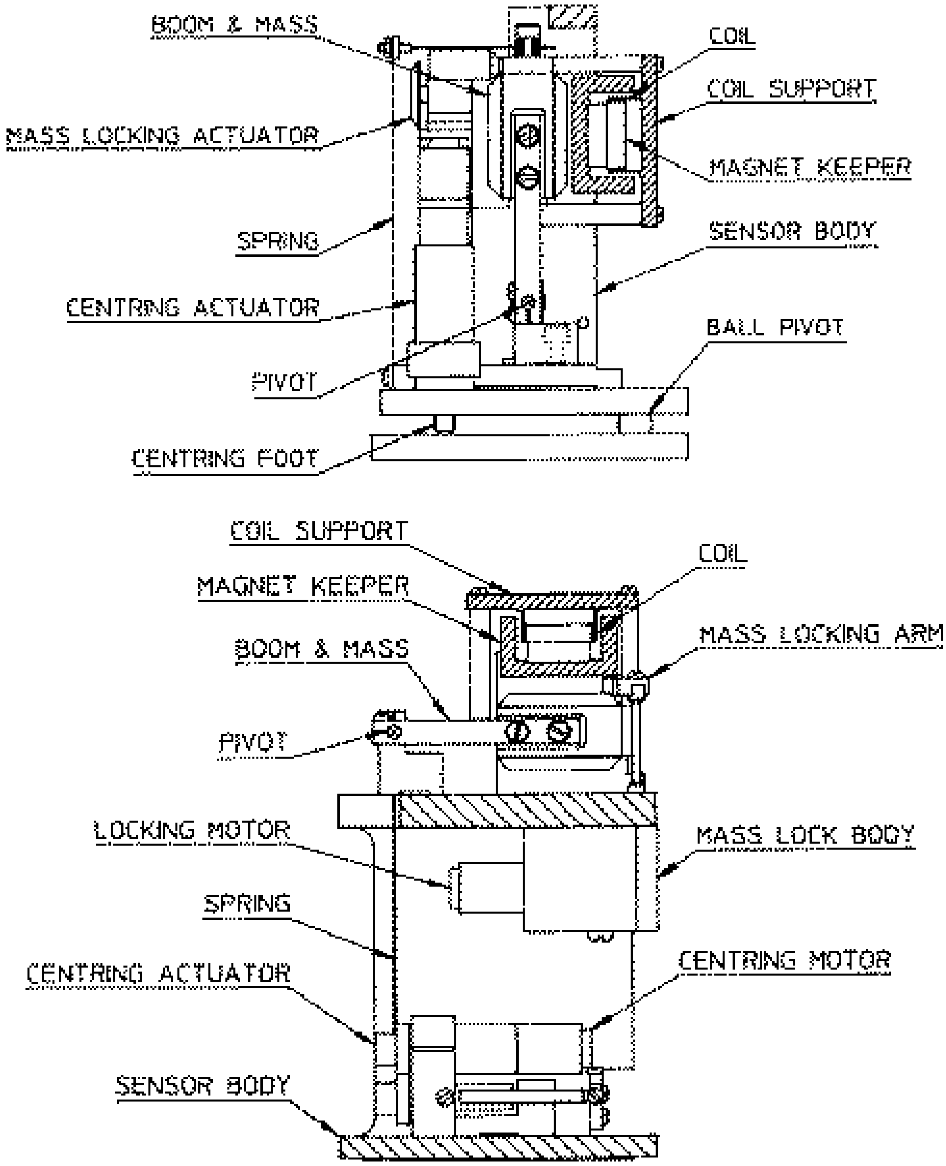
6.1 The sensors

The horizontal and vertical sensors are similar in design. The inertial mass in both cases consists of a transducer coil and a leaf-spring suspended boom which swings on a frictionless hinge. A triangular spring supports the weight of the mass; in the vertical sensor this spring is pre-stressed with a natural period of around 0.5 seconds, whilst the horizontal sensor has an unstressed flat spring with a natural period of around 1 second. Güralp 3T sensors have no spurious resonances below 140 Hz, and weigh around 180 g. The small boom size and stiff springs allow three independent instruments to be mounted within the casing, together with all the associated feedback electronics.

The 3T functions by monitoring the position of each mass with a capacitative position sensor. The three sensors are identical. Signals from the sensors are fed into an electronic processing unit, which is mounted in a screened compartment above the mechanical components (see below for details on the feedback circuitry.)

When the instrument is being transported, the masses are locked securely in their frames so as to relieve strain on the support hinges. This locking is performed by a small motor-driven clamp in response to a signal from the surface controller unit.

Before using the instrument, the boom of the vertical sensor must be levelled and the bases of the horizontal sensors tilted, so that the masses are centred in their equilibrium positions. These adjustments are made by small DC motors controlled remotely.



The signal voltages output by the 3T are proportional to ground velocity and are transmitted from the instrument on balanced differential lines. In addition, mass position signals are sent on single-ended lines, referred to analogue ground on the output plug. The 3T also receives control signals, which are used to lock (clamp) and unlock the masses and to run the motors which level and centre the instrument once in position. Finally, a line is provided for you to apply a calibrating voltage to the force transducers, thereby measuring the deflection sensitivity, along with three control lines which operate relays to isolate the feedback loops from the calibration signal input when not in use..

6.2 The control system

The internal operations of the 3T are supervised by a control microprocessor, which drives the mass clamping and centring adjustment motors. It responds to commands sent on three input lines, any of which is activated by connecting it to digital ground for seven seconds.

The signals you can send to the microprocessor are termed *LOCK*, *UNLOCK*, and *CENTRE*. Each command acts on the vertical, N/S and E/W masses in turn. The microprocessor prevents the system from attempting incompatible actions (*e.g.* centring when the masses are clamped).

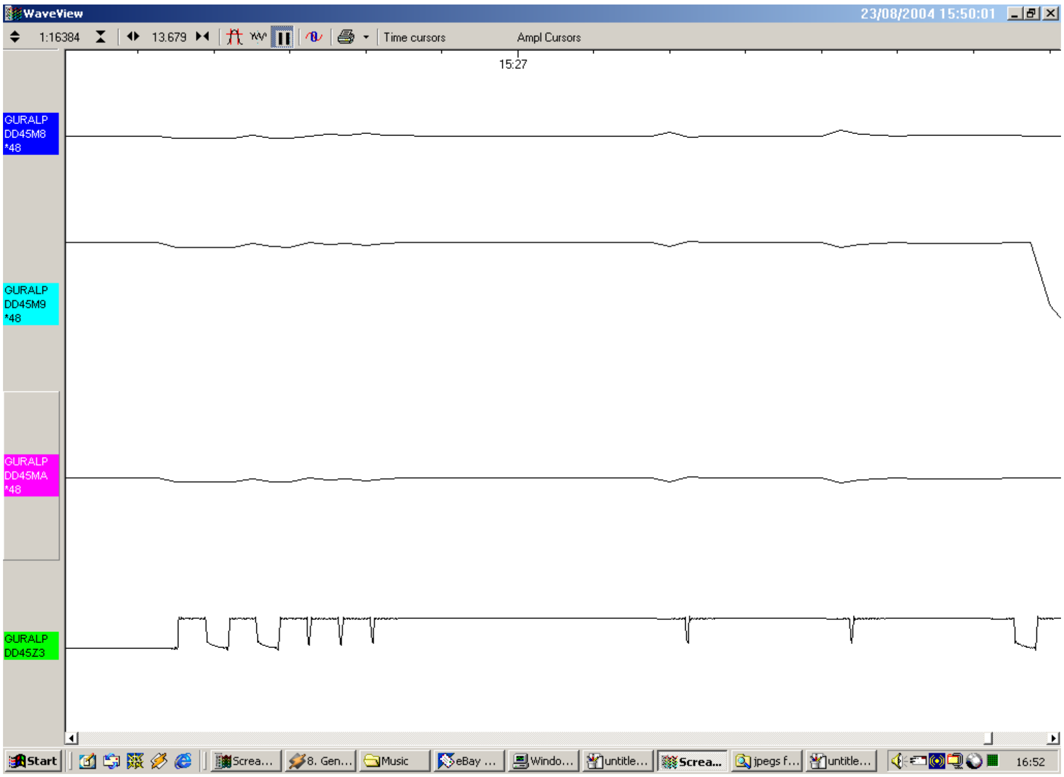
While a command is taking place, if you are using a Break-out box or Hand-held Control Unit, its *BUSY* LED will flash; you can use this for diagnostic purposes. See the description of each command for full details.

When no command is active, *i.e.* all three lines are high, the control microprocessor goes into a power-saving mode. In routine operation, the lines are controlled from the breakout box, Hand-held Control Unit or digitiser. If you send control signals to the 3T manually, you must ensure that the lines are allowed to float high after sending the signal, or the equipment may be damaged. A "biased-OFF" type switch can be used for this purpose.

6.2.1 LOCK

This command locks the masses and clamps the horizontal sensors by tilting them up to their end stops.

In detail, the process acts as shown in the following graph. The top three streams are the *mass position* outputs of each component (Z, N/S and E/W, respectively), whilst the bottom one represents the state of the *BUSY* LED (up = on).



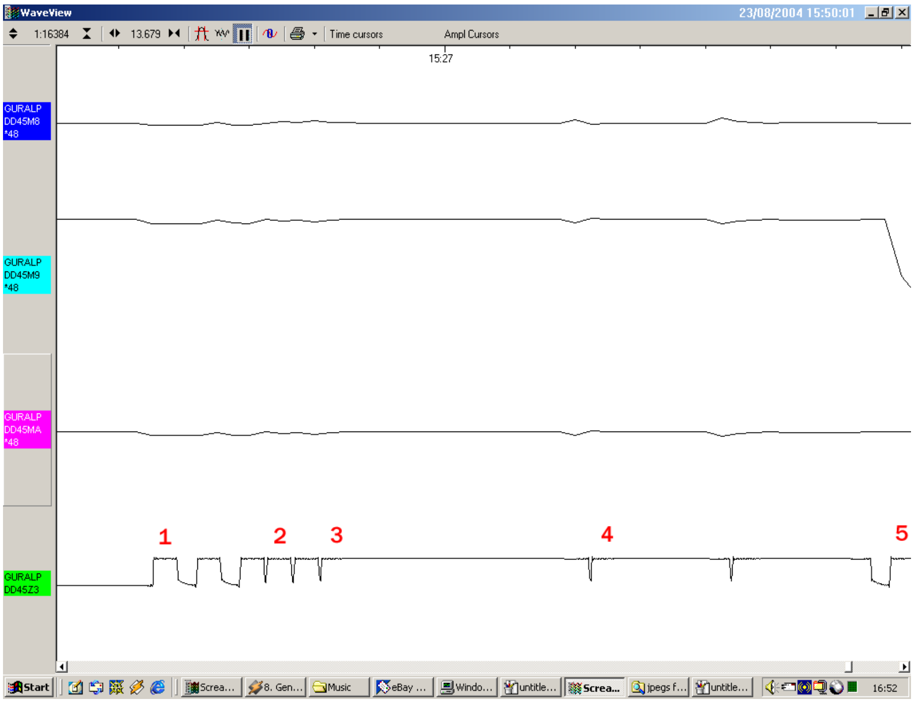
The five-stage process comprises locking the *Z*, *N/S* and *E/W* masses, followed by longer periods tilting the *N/S* and *E/W* sensor base to their end stops. During the latter two periods, the position of the *N/S* and *E/W* masses will “flip” to one side.

The *BUSY* LED is lit during each stage, but goes out briefly between stages, allowing you to follow the progress of the lock.

6.2.2 UNLOCK

This command unlocks the sensor masses and prepares the instrument to begin operating.

On earlier models, if *UNLOCK* is activated when the masses are already unlocked, the processor will lock them and attempt to unlock again. This is useful if you suspect that the locking procedure has failed. Later models are fitted with limit switches so this is no longer necessary.



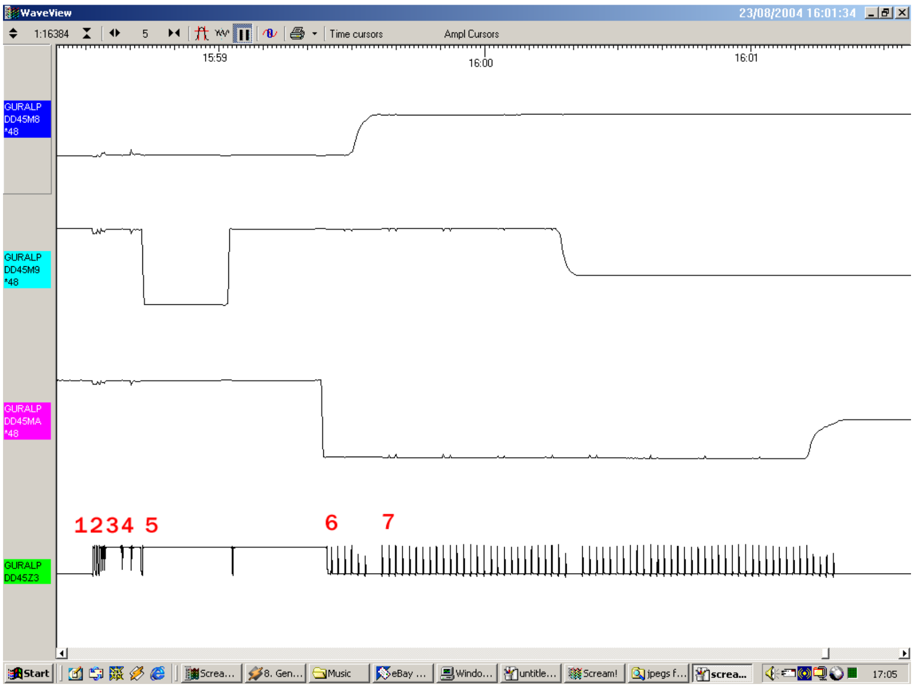
Again, you can use the *BUSY* LED to monitor the progress of unlocking.

1. The instrument checks to see whether the *Z*, *N/S* and *E/W* masses are locked.
2. The instrument checks the *N/S* and *E/W* sensor bases.
3. The *Z* component is unlocked.
4. The *N/S* and *E/W* components are unlocked. These are quicker than the *Z* component.
5. (see graph below) The *N/S* sensor base is unlocked, followed by the *E/W* base. These processes take longer still.

- After unlocking, the instrument automatically performs a round of centring (see below).

6.2.3 CENTRE

This command re-centres the masses. If the masses are clamped, or if the sensor mass positions do not exceed ± 1.2 V, the *CENTRE* command does nothing. Otherwise, it attempts to zero the output of the vertical, N/S and E/W sensors in sequence by exerting small extra forces on the boom. For the vertical sensor, a motor-driven adjuster presses a small spring lever against the boom until the mass position sensor indicates an offset close to zero. In the case of the horizontal sensors, the sensor frame is tilted on its base plate. Again, the controller monitors the mass position sensor and stops the centring process once it reaches its lowest offset.



This graph shows the entire process of unlocking and centring:

1 – 5. The unlocking process as described above.

6. The *BUSY* LED pulses to indicate that it is centring the *Z* component. The mass position output does not change for a while, as it is beyond the range of the output. However, after a few pulses, the position of the *Z* component comes within range and is centred. The pulses become more brief as this goes on, until a pulse is missed (signifying that no corrective impulse is needed.)

7. The *N/S* and *E/W* components follow in the same way, until all three masses are centred and the process completes. The first round of centring has to move the *N/S* and *E/W* components all the way from their end stops, whilst the *Z* component is often closer to the proper position. Because of this, the first *Z* centring operation takes much less time than the others, and you may not notice it.

After successful centring, the mass position outputs should be in the range 0.1 – 0.8 V. If the centring process leaves the mass position outputs above ±1.1 V, you should start another centring cycle by activating the *CENTRE* command again. You will probably need to initiate the centring process several times before the masses are adequately centred.

6.3 RS232 control interface

As an option, the 3T can be supplied with an RS232 control interface, which uses three additional pins on the sensor output connector.

The control electronics save power by switching off the sensor feedback electronics whilst the masses are locked. When you unlock the masses, either using the standard logic lines (see above) or over the RS232 interface, the control electronics automatically “wake up” the rest of the sensor.

To connect to the RS232 control interface, attach the sensor to a PC's serial port using the cable supplied, and use a terminal program such as minicom (on Linux) or PuTTY (on Windows) to connect to the port. Set the baud rate to 4800, with 8 data bits, no parity bit, 0 stop bits and no flow control.

Now power up the sensor. You should see the message `PWR OK` indicating that it is ready to receive commands. Each command is a single character. When you enter a command character, the controller will echo it back to your terminal so you can see it.

After around 10 seconds of inactivity, the control electronics will go into power-saving mode. You will need to wake up the controller by sending any character before you can issue commands. This character will not be interpreted as a command, and the controller will not echo it back to your terminal.

6.3.1 H Help

Sending H causes the controller to reply with a short list of available commands.

```
[U]nlock [C]entre [L]ock [S]tatus [Q]uit [H]elp
```

6.3.2 U Unlock

Sending U will start an unlock sequence, exactly as if you had activated the *Unlock* line on the output port. The sensor will automatically perform one round of centring after it has been unlocked, and the electronics will be fully activated.

If the unlocking process finishes normally, the controller will reply with `OK`. If there was a problem, such as one or more components failing to unlock or centre, the controller will report `NG` (“no good”.)

6.3.3 L Lock

Sending L will start a lock sequence, as if you had activated the *Lock* line on the output port (including unlocking the sensor before locking, if necessary.) The sensor electronics will be placed in power saving mode as soon as the masses are successfully locked.

If the locking process finishes normally, the controller will reply with `OK`. If there was a problem, the controller will report `NG`.

6.3.4 C Centre

Sending C will start a centring sequence, as if you had activated the *Centre* line on the output port. When the process finishes, the controller will reply with `OK`, or `NG` if there was a problem. You may need to issue the command several times before the masses are adequately centred.

If you try to centre the masses when they are locked, the controller will reply with `OK` immediately but take no action.

6.3.5 S Status

Sending S causes the controller to reply with the current instantaneous mass positions, *e.g.*:

```
V: +5 N: +8 E: -10
```

The mass positions are measured by the controller's on-board ADC, which has a nominal range of ±127 counts. For accurate mass position information, you should use the analogue lines provided elsewhere on the output connector.

6.3.6 Q Quit

Sending Q ends your command session, and puts the controller into power-saving mode. To issue further commands, you will need to wake up the controller by sending any character. This character will not be treated as a command, and will not be echoed back to your terminal.

6.4 The feedback system

The output from a modern broadband seismometer does not depend on the natural characteristics of the instrument. Instead, the period and damping of the sensor is completely determined by a feedback loop which applies a force to the sensor mass opposing any motion. The force required to *restrain* the movement of the mass can then be used to measure the inertial force which it exerts as a result of ground motion.

All Güralp 3 series units are based on these general principles. The capacitative position sensor for each mass produces a voltage proportional to the displacement of the mass from its equilibrium position. After amplification, this voltage generates a current in the force transducer coil which tends to force the mass back toward equilibrium. The feedback loop has a sufficiently high gain to cancel the motion of the mass. Since the mass is not moving, the forces acting on it must be balanced; the feedback voltage then directly measures the force, and hence the acceleration, which is being applied to the mass. The feedback loop introduces a phase shift, which must be carefully controlled if the instrument is to remain stable over its entire frequency range. This is achieved using compensation components in the forward and feedback paths.

Force feedback seismometers of this type rely on the assumption that the force transducer produces a field of constant strength. The magnetic circuit and magnet/pole assembly in the 3T are designed so that the field strength from the feedback transducer is constant over large deflections and current levels. Independent tests have shown that the mechanical suspension system and electronics of a 3T instrument are linear to better than 107 dB (source: measurements made at ASL during evaluation for the USGS National Network.)

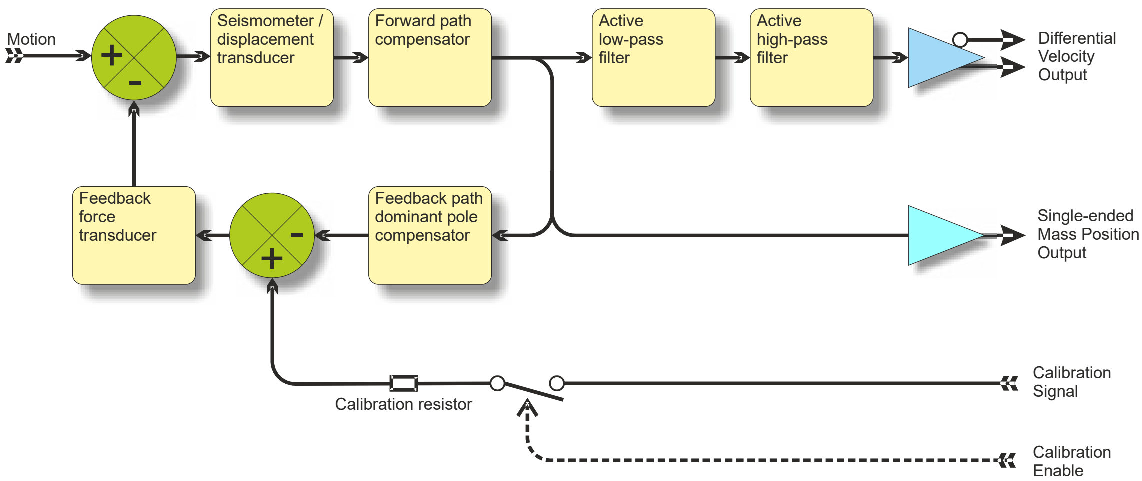
In a feedback seismometer with a displacement transducer, it is essential to monitor the acceleration output. This provides the position of the displacement transducer and therefore also the mass position, as the displacement transducer is attached to the sensor inertial mass. The sensor should always be operated with the displacement transducer centred or nulled, so that the response to input acceleration is linear.

There are two types of feedback system which can be used in a 3T instrument, known as *hybrid* and *conventional-response* feedback.

These are both described below.

6.4.1 Hybrid feedback

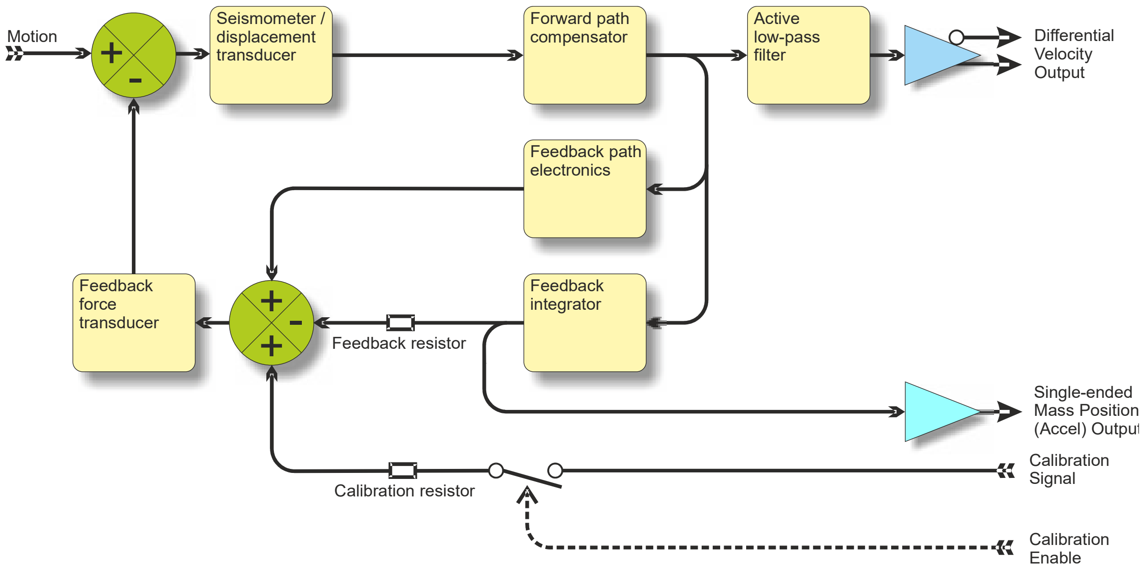
The hybrid feedback method of operation is illustrated by the following schematic diagram:



The *hybrid* feedback circuit contains a single capacitor in parallel with a resistor, resulting in a single dominant pole. Below this frequency, which can be varied from the standard 30 seconds, the response of the seismometer is flat to ground acceleration. Above it, the response is flat to velocity. Hybrid-feedback systems provide a stable response, particularly for portable systems, with a high saturation level at high frequencies and a high dynamic range at long periods.

An active low-pass filter provides a high-frequency cut-off point at a frequency you specify. Without the filter, the velocity response is flat up to 100 Hz. Outside the feedback loop there is an active high-pass filter with a corner frequency of 0.01 Hz (100 s) or 0.005 Hz (200 s), which serves to remove any DC offsets.

6.4.2 Conventional-response feedback

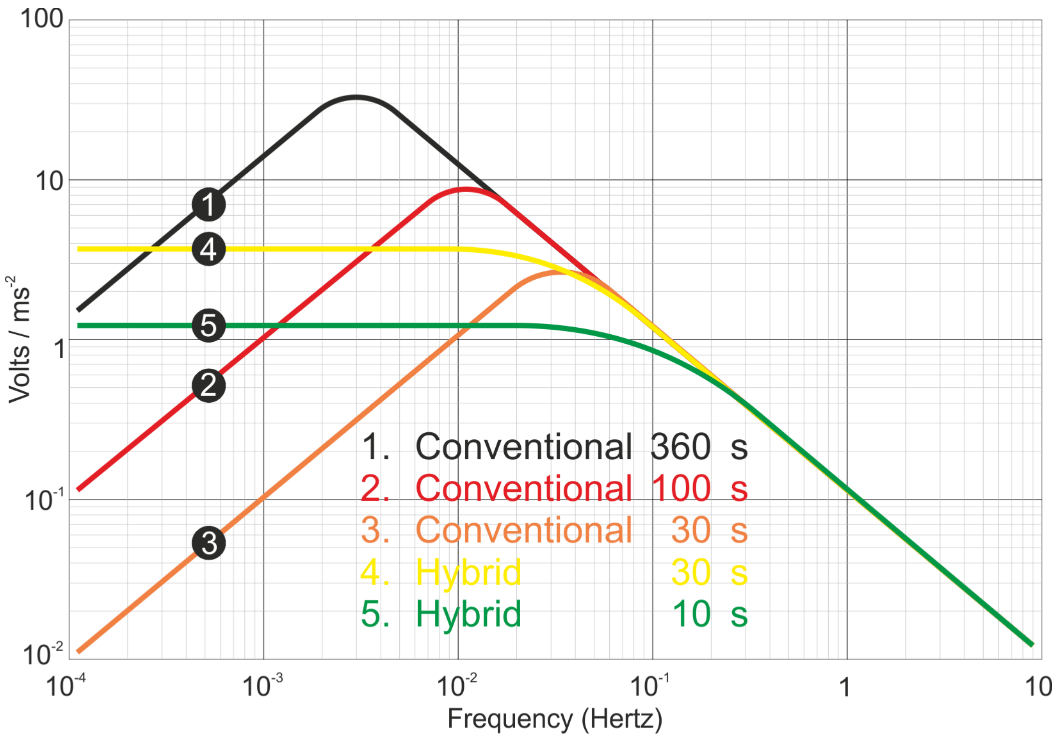


The *conventional-response* feedback system has an additional parallel feedback circuit, consisting of a non-inverting integrator in series with a resistor. This arrangement results in two poles at specified frequencies. The velocity response of a conventional-response system is defined by a transfer function identical to that of a conventional long-period sensor with a damping constant ζ of 0.707 (1/√2)

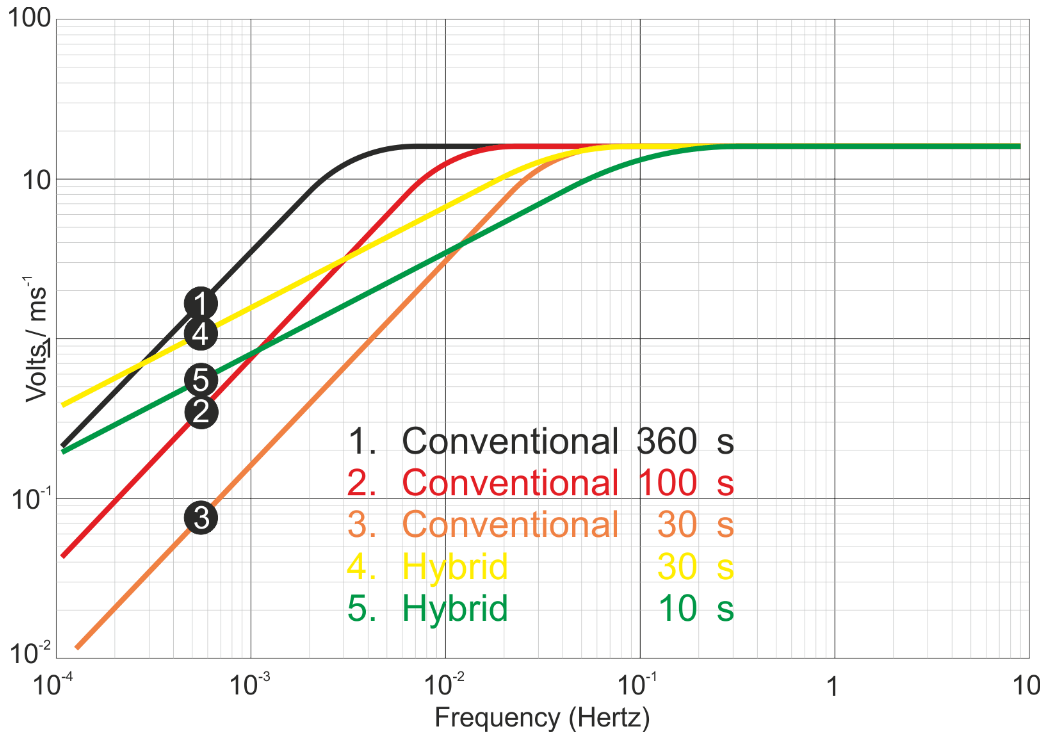
The seismometer can be supplied with an equivalent resonant frequency of 0.033 Hertz (30 seconds), 0.01 Hertz (100 seconds) or 0.0083 Hertz (120 seconds) as required. An active low-pass filter provides a high-frequency cut-off point at a frequency you specify.

6.4.3 Comparisons

The figures below plot the comparative response of a conventional velocity output broadband sensor and a hybrid output broadband sensor. The first graph shows the response in terms of output against input acceleration in units of V/ms^{-2}, whilst the second is plotted in terms of output against input velocity, in V/ms^{-1}.



Relative responses to ground acceleration.



Relative responses to ground velocity.

7 Connector pin-outs

7.1 Sensor and control unit pin output

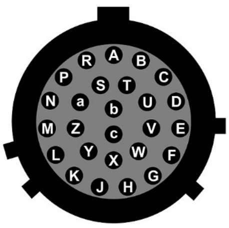
Models with a 26-pin bayonet plug have the pin assignments below. The *RECORDER* and *HCU* connectors on the breakout box are connected directly to the *SENSOR* connector, and behave identically.

This is a standard 26-pin military-specification plug, conforming to MIL-DTL-26482 (formerly MIL-C-26482). A typical part-number is 02E-16-26P although the initial “02E” varies with manufacturer.

Suitable mating connectors have part-numbers like ***-16-26S and are available from Amphenol, ITT Cannon and other manufacturers.

Pin	Function	Pin	Function
A	Velocity +ve, vertical channel	**P**	Calibration signal (all channels)
B	Velocity −ve, vertical channel	**R**	Calibration enable, Z channel
C	Velocity +ve, N/S channel	**S**	Calibration enable, N/S channel
D	Velocity −ve, N/S channel	**T**	Calibration enable, E/W channel
E	Velocity +ve, E/W channel	**U**	Centre
F	Velocity −ve, E/W channel	**V**	*not connected*
G	Mass position, vertical channel	**W**	Unlock
H	* RS232 ground	**X**	Lock
J	Mass position, N/S channel	**Y**	Logic ground
K	*BUSY* LED	**Z**	* RS232 TxD (from instrument)
L	Mass position, E/W channel	**a**	* RS232 RxD (to instrument)
M	Power −ve (optional)	**b**	Power ground
N	Signal ground	**c**	Power +ve

* Optional lines for sensors with the RS232 control option. The RS232 ground is isolated from pins a and Z using 10 nF decoupling capacitors.

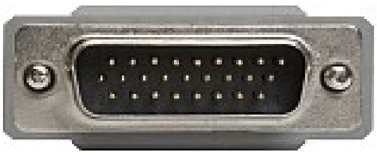


Wiring details for the compatible socket, ***-16-26S, as seen from the cable end, i.e. during assembly.

7.2 Sensor output (“D”-type connector option)

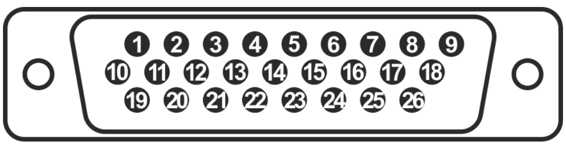
Some sensors were provided with a high-density “D”-connector in place of the standard bayonet connector.

These are standard DA26 sub-miniature (D-sub) plugs, conforming to DIN 41652 and MIL-DTL-24308. They are very widely available, as are suitable mating connectors.



Pin	Function	Pin	Function
1	Mass position, N/S component	**14**	Velocity –ve, Z component
2	Lock	**15**	Calibration enable, E/W component
3	*BUSY* LED	**16**	Velocity +ve, Z component
4	Logic ground	**17**	+ 10 – 36 V power
5	Mass position, E/W component	**18**	Velocity –ve, N/S component
6	*not connected*	**19**	Centre
7	*RS232 RxD (from instrument)	**20**	Velocity +ve, N/S component
8	Signal ground	**21**	Factory use only, do not connect
9	*RS232 TxD (to instrument)	**22**	Velocity –ve, E/W component
10	Calibration signal	**23**	Velocity +ve, E/W component
11	Calibration enable, N/S component	**24**	Unlock
12	Calibration enable, Z component	**25**	Mass position, Z component
13	0 V power	**26**	*RS232 ground

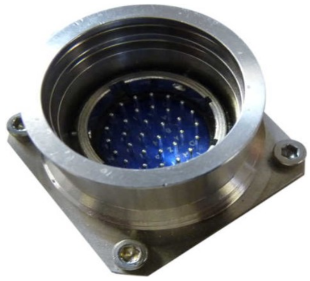
* Optional lines for sensors with the RS232 control option. The RS232 ground is isolated from the other ground lines (pins 4 and 8) using 10 nF decoupling capacitors.



Wiring details for the compatible socket, DA26F, as seen from the cable end, i.e. during assembly

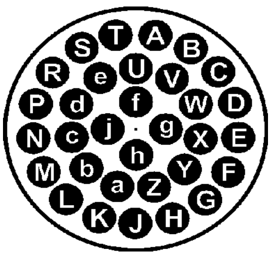
7.3 Sensor output (waterproof connector option)

Waterproofed models have a custom 32-pin plug with pin spacing and layout conforming to MIL-DTL-26482 (formerly MIL-C-26482). The GSL part number is ELM-32P-18FX+MEC-GEN-1002-32W. These instruments are supplied with an adapter cable for connecting to a standard digitiser input.



Pin	Function	Pin	Function
A	Velocity +ve, vertical channel	**T**	Calibration enable, E/W channel
B	Velocity −ve, vertical channel	**U**	Centre
C	Velocity +ve, N/S channel	V	*not connected*
D	Velocity −ve, N/S channel	**W**	Unlock
E	Velocity +ve, E/W channel	**X**	Lock
F	Velocity −ve, E/W channel	**Y**	Logic ground
G	Mass position, vertical channel	**Z**	* RS232 TxD (from instrument)
H	Hole lock / *RS232 ground	**a**	* RS232 RxD (to instrument)
J	Mass position, N/S channel	**b**	Power ground
K	*BUSY* LED	**c**	Power +ve
L	Mass position, E/W channel	d	*not connected*
M	Power −ve (split power option)	e	*not connected*
N	Signal ground	f	*not connected*
P	Calibration signal (all channels)	g	*not connected*
R	Calibration enable, Z channel	h	*not connected*
S	Calibration enable, N/S channel	j	*not connected*

* Optional: sensors with the RS232 control option. The RS232 ground line (pin H) is decoupled from the other ground lines (pins N and Y) using 10 nF capacitors.



Wiring details for the compatible socket, MEC-GEN-2002-32W, as seen from the cable end (*i.e.* when assembling).

7.4 Breakout box POWER connector

This is a standard 10-pin “mil-spec” plug, conforming to MIL-DTL-26482 (formerly MIL-C-26482). A typical part-number is 02E-12-10P although the initial “02E” varies with manufacturer.

Suitable mating connectors have part-numbers like ***-12-10S and are available from Amphenol, ITT Cannon and other manufacturers.

Pin	Function
A	0 volts (power ground)
B	+12 V DC supply
C	*not connected*
D	*not connected*
E	*not connected*
F	*not connected*
G	*not connected*
H	−12 V DC supply
J	*not connected*
K	*not connected*

Wiring details for the compatible socket, ***-12-10S, as seen from the cable end.

8 Specifications

SYSTEM	Technology	Force feedback (force-balance) velocity sensor
	Configuration / Topology	Triaxial orthogonal (ZNE)
PERFORMANCE	Velocity output band	(flat response within -3 dB crossing points) 120 s (0.0083 Hz) to 50Hz standard 360 s (0.0017 Hz) to 50 Hz option available Contact Güralp to discuss other frequency response options
	Output sensitivity	1500 V/ms^{-1} (2 x 750 V/ms^{-1}) differential standard output (full-scale clip level of 13 mm/s) Contact Güralp to discuss alternative high sensitvity (high gain) options
	Peak full-scale output voltage	Differential: ±20 V (40 V peak-to-peak) Single-ended (e.g. mass positions): ±10 V (20 V peak-to-peak)
	Self-noise below NLNM	(New Low Noise Model; Peterson, 1993, USGS) 100 s (0.01 Hz) to 10 Hz*
	Sensor dynamic range (at standard output sensitivity)	161 dB @ 1 Hz 157 dB @ 5 Hz
	Cross axis rejection	65 dB
	Linearity	>90 dB
	Lowest spurious resonance	>140 Hz
	Damping	70% of critical
	Operating tilt range	±2.5°
MASS / MONITORING CONTROL	Sensor Mass positions	Three independent sensor mass position outputs (single-ended)
	Mass locking	Remote auto mass lock/unlock for transportation
	Mass centring / offset zeroing	Remotely controlled automatic mass centring
CALIBRATION	Calibration input	Independent signal and enable lines exposed on sensor connector

CONNECTORS	Analogue output	26-pin Mil-spec (military specification bayonet) connector Optional 1500 psi waterproof connector for posthole deployment
POWER	Power supply voltage	10–36 V DC
	Power consumption	0.75 W at 12 V DC *
PHYSICAL / ENVIRONMENTAL	Operating temperature range	-20 to +75 °C **
	Operating humidity range	0-100% relative humidity
	Enclosure ingress protection	IP68 - protection against prolonged effects of immersion under pressure (tested under 3 metres of water for 72 hours)
	Enclosure material	Stainless steel case O-ring seals throughout
	Diameter	167 mm
	Height with handle	340 mm
	Weight	14.6 kg
	Alignment	Bubble level on lid; north arrow on handle and base; adjustable feet

* Because centring, locking, and unlocking consume varying amounts of power, it is recommended that you use a power supply capable of delivering 1 A at 12 V.

** Temperatures below –20 °C may be accommodated with additional care. Please consult Güralp Systems for advice.

9 EU Declaration of Conformity

We

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Declare under our sole responsibility that the following product

Equipment name: 3T
Model Number: 3T-MSV500121402L and appropriate variants

Is in conformity with the

Electromagnetic Compatibility Directive 2014/30/EU
Low Voltage Directive 2014/35/EU
Restriction of Hazardous Substances (RoHS) Directive 2011/65/EU

by applying the following harmonised standards and technical specifications:

EN 61000-4-2:2009 – Electrostatic Discharge Immunity
EN 61000-4-3:2006 +A1:2008 +A2:2010 – Radiated RF Immunity
EN 61000-4-4:2012 – Electrical Fast Transients Immunity
EN 61000-4-5:2014 – Voltage Surge Immunity
EN 61000-4-6:2014 – Conducted RF Immunity
EN 61000-4-8:2010 – Power Frequency Magnetic Field Immunity
EN 61000-4-11:2004 – Voltage Dips and Short Interruptions Immunity
EN 55011:2009 +A1:2010 – Radiated Emissions
EN 55011:2009 +A1:2010 – Conducted Emissions
IEC 61010-1 3rd Edition – Low voltage safety
2011/65/EU – RoHS

Signed for and on behalf of
Guralp Systems Ltd
on 25 February 2020

Systems Director

10 Revision history

2023-01-12	U	Corrected descriptions in pin-out of 32-way connector (TxD v RxD)
2021-02-17		Minor correction to transfer function and description. No up-issue.
2021-09-07	T	Added EU Declaration of Conformity
2019-10-31	S	Corrected description of LOCK and UNLOCK actions.
2019-01-23		Minor changes, mostly to graphics. No up-issue.
2016-06-30	R	Specifications aligned with data-sheet. Images updated. New branding.
2015-07-25	P	Corrected 1500psi connector pin-out. Updated SoH description.
2010-02-26	O	New diagrams and improved connector information
2009-07-06	N	Added integrated SoH controller
2006-10-19	M	Added waterproof connector pin-out
2006-08-14	L	Added RS232 command interface
2006-06-06	K	Moved BoB to “Accessories”
2006-02-20	J	Corrections; added revision history
2004-10-29	H	New document