CMG-40TB

Triaxial Borehole Seismometer

Operator's guide

Part No. MAN-BHO-0007

Designed and manufactured by
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1 Introduction

The CMG-40TB is a three-axis seismometer consisting of three sensors stacked vertically in a sealed borehole sonde, designed for use in cased boreholes with diameters between 5” / 89 mm and 9” / 229 mm.

The seismometer system is self-contained except for its 12 – 30 V power supply, which is provided through the same cable as the analogue data. Sensor functions such as levelling and centring are carried out through a breakout box.

A 40TB instrument with “30 s” response is sensitive to ground vibrations in the frequency range 0.033 – 100 Hz; one with a “1 s” response is sensitive in the range 1 – 100 Hz. The instrument outputs analogue voltage representing ground velocity on balanced differential lines.

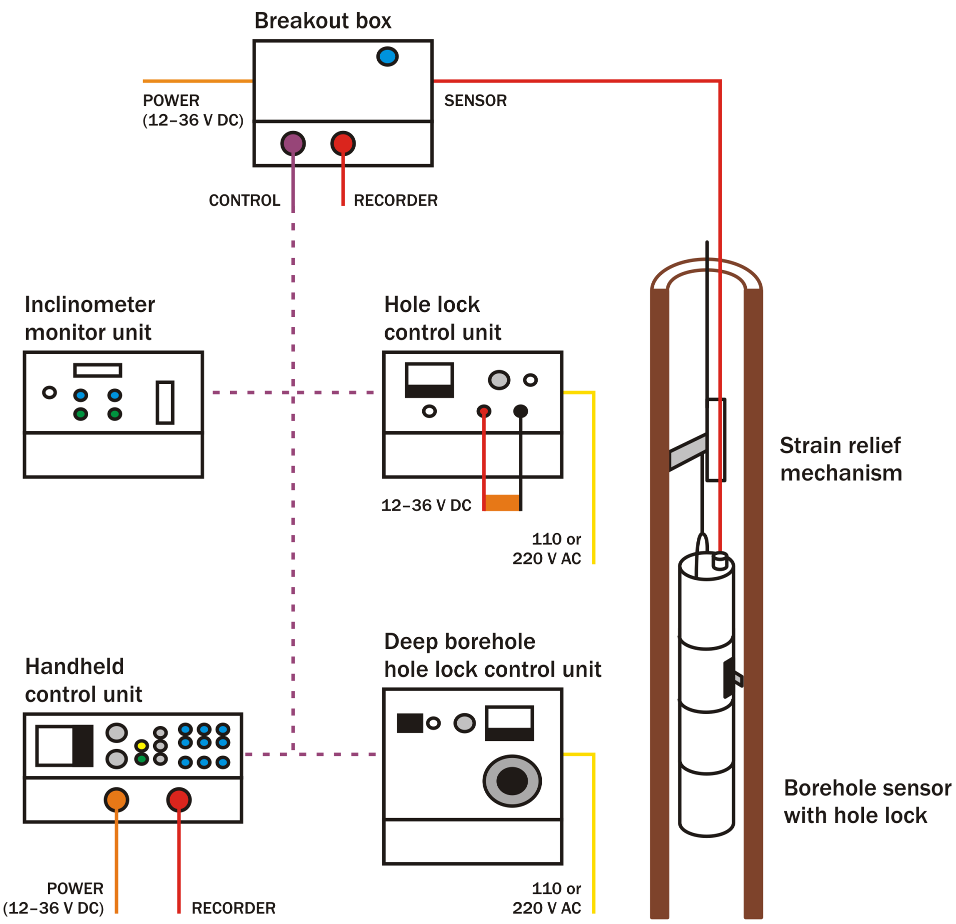
Each seismometer is delivered with a detailed calibration sheet showing its serial number, measured frequency response in both long and short period sections of the seismic spectrum, sensor DC calibration levels, and the transfer function in poles/zeros notation.

1.1 System configuration

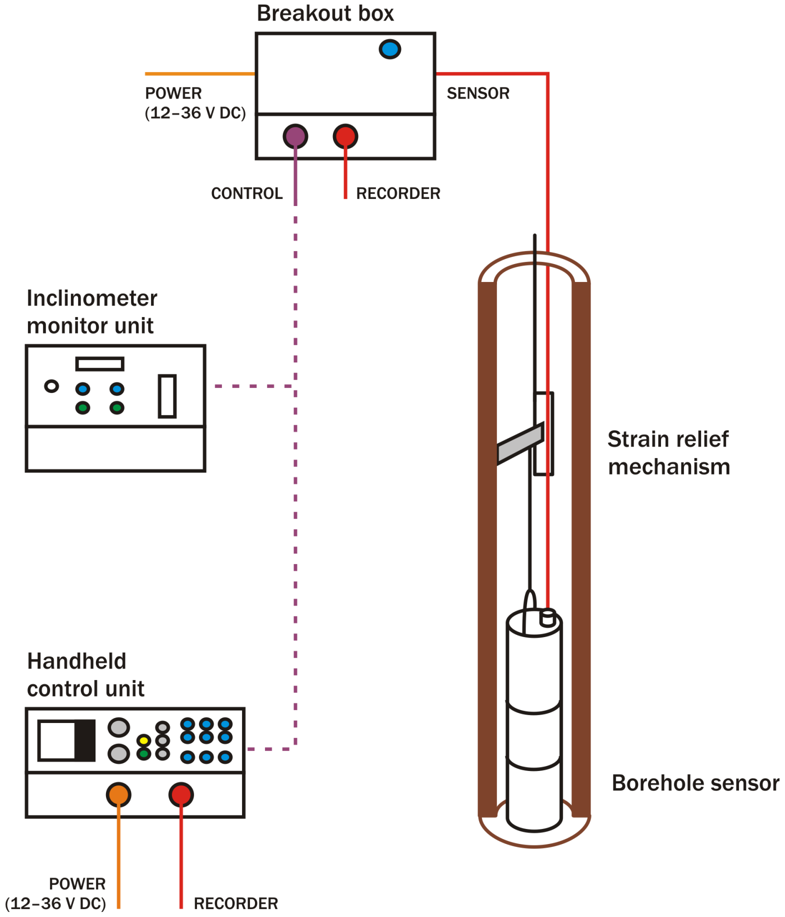
Güralp Systems borehole installations generally consist of the following components:

- a modular sensor sonde, which can be fitted with a single-jaw or three-jaw holelock mechanism as required,
- a pit head installation including a breakout box, and
- a number of additional, optional control units which may be connected to the breakout box to perform installation and maintenance tasks.

For example, a borehole or pit installation of a CMG-40TB instrument with a single-jaw hole lock has the following layout:



CMG 40-series instruments are also suitable for installing in boreholes with sand backfill. In this case no hole lock unit is necessary.



1.2 Digital borehole installations

The Güralp DM24 digitizer is available in a borehole sonde form. Connecting a Güralp borehole instrument to a downhole digitizer allows you to construct a true digital borehole installation. This has several advantages over a traditional borehole setup:

- Digital signals are not subject to attenuation as they travel up to the surface, so signals received are stronger and more reliable.
- Digitizing the data at source allows you to ensure that its origin can be reliably traced.
- The DM24 digitizer may also be combined with an Authentication Module within the borehole sonde, allowing you to generate cryptographically-signed data at the point of origin.

A digital borehole installation can be provided with RS232, RS422 or fibre-optic links to the surface, depending on the depth of the borehole.

When a downhole digitizer is present, it takes the place of the strain relief unit in the borehole. The surface unit also takes a slightly different form, with a serial connector allowing you to attach a modem or other communications link. In this type of installation, instead of using the surface unit to pass control signals to the sensor, all functions can be accessed remotely *via* the digitizer.

If you prefer to install a stand-alone digitizer at the surface, it should be connected to the 19-pin *RECORDER* socket of the breakout box.

1.3 The hole lock system

The hole lock clamp unit in a 40TB instrument provides a stable platform for the sensor modules mounted above and below it. It is designed to maintain a positive pressure on the borehole casing over a prolonged period of time without attention, and to fix the sonde in place whilst avoiding transmitting any stresses.

Güralp Systems hole locks are constructed to order from accurate measurements of your borehole at the depth you wish to install the instrument. Either single-jaw or three-jaw hole lock units can be manufactured.

In installations with sand backfill, or where the instrument rests on the bottom of the borehole, a hole lock may be unnecessary.

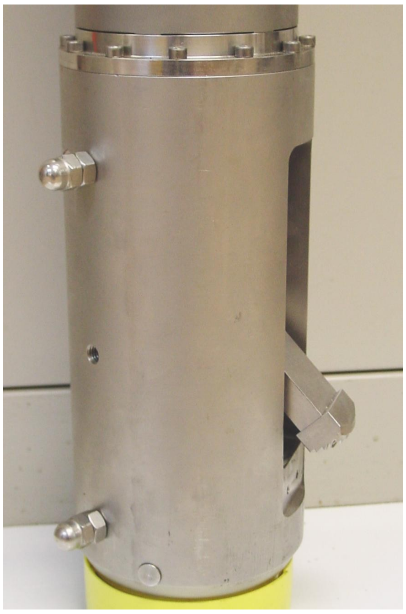
The single-jaw hole lock

The single jaw hole lock is the standard option for triaxial borehole instruments. It consists of an active clamp arm and a number of skids or studs on the sonde body. The arm is attached to a compression spring, which forces it to swing out from the sonde and wedge the body against the borehole wall. A serrated steel jaw at the end of the arm provides maximum grip against the borehole casing. The skids or studs and the locking arm together form a multi-point clamp, which aligns the sonde body parallel to the axis of the borehole and holds it firmly in place so that it cannot twist or slip under the influence of ground vibrations.

There are several configurations of skids and studs which can provide a suitable clamp. Either

- the locking jaw pushes two steel skids against the side of the borehole, providing two line contacts;

- only the tips of the skids come into contact with the borehole, providing three point contacts;
- a single skid is combined with a pad to provide one line and one point contact; or
- three studs provide three point contacts.



Studs have the advantage of being smaller than skids, but the contact points are very close to each other. You should evaluate the various locking methods available to see which works best in your borehole.

The spring inside the lock provides around 60 kg of force at its locking position. A DC actuator retracts the arm into the body of the lock so that the sensor mechanism can be installed and removed. The actuator consists of a 14 W DC motor with a planetary reduction gearhead, which drives the nut of a ball lead screw through the helical drive gears. The thread of the lead screw is prevented from turning, and so moves linearly when the nut turns.

The motor has a power system separate from that of the sensor, and can be controlled from the surface using a hole lock control unit. Once the sonde is installed, the hole lock control unit may be removed. Without power, the hole lock will not be able to retract, and the sensor will be secured.

The three-jaw hole lock

A three-jaw hole lock is available which gives better grip on the borehole casing, but is bulkier and heavier than the single-arm lock. This is the standard option for uniaxial instruments; it can be installed in boreholes between 3.5” / 89 mm and 7” / 178 mm in diameter.

The three-jaw hole lock consists of a set of three active clamp arms attached to a compression spring, which forces them to swing out from the sonde and wedge themselves against the borehole wall. Serrated steel jaws at the end of each arm provides maximum grip against the borehole casing. This configuration ensures that the sonde body is held parallel to the axis of the borehole and prevented from twisting or slipping under the influence of ground vibrations.

2 Assembling the instrument

2.1 Unpacking and packing

The 40TB seismometer is delivered in a single transportation case, with the sensor system and hole lock mechanism (if ordered) packed separately. The packaging is specifically designed for the 40TB and should be reused whenever you need to transport the sensor. Please note any damage to the packaging when you receive the equipment, and unpack on a clean surface.

The package should contain:

- the seismometer, in sections;
- a cable to join the sensor to the breakout box;
- the breakout box;
- the hole lock control unit;
- a cable strain relief mechanism;
- a Handheld Control Unit (HCU) for monitoring sensor outputs and calibration, if ordered;
- a calibration data sheet;
- this manual.

The sensor is securely packed, and you will need to remove most of the foam packing before it can be removed.

2.2 Handling notes

The 40TB is a sensitive instrument, and is easily damaged if mishandled. It will not stand vertically upwards without support, and should not be operated until it has been securely installed in a borehole casing. 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.
- Keep the sonde sections vertical wherever possible. Carry them by hand and store in a safe rack. Never drag or roll the sonde.
- When the sensor is vertical, keep it securely tied down. If the sensor system topples over, you must inform Güralp Systems.
- Keep all the parts of the sensor system protected and clean so that they can be joined together securely. Store in the original packaging if possible.
- 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.

2.3 Assembling the 40TB

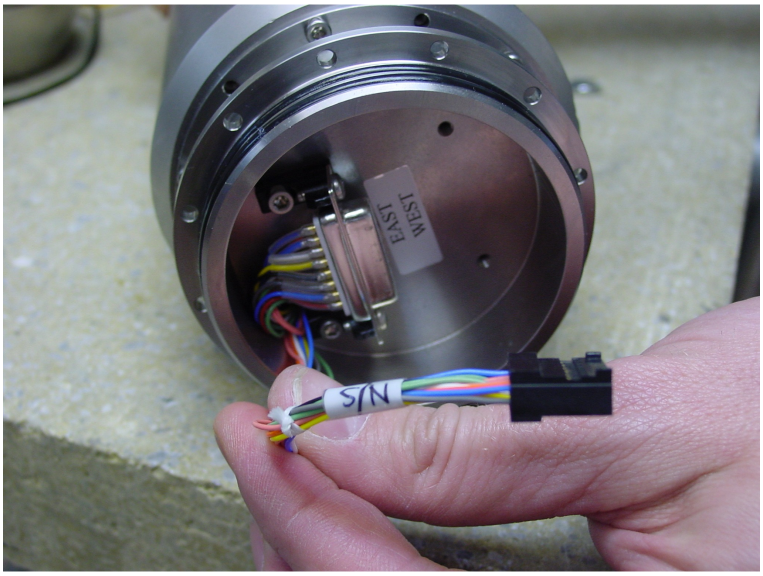
The 40TB is delivered in separate sections, which need to be assembled before the instrument can be installed in a borehole. It is recommended that you perform these steps with the help of at least one other person.

Important: Make sure your environment is clean and dust free before assembling the unit. Stray fibres or particles cause damage to the "O"-ring seals between the components and may render the sensor unusable. Do not remove the protective caps on the ends of each unit until you are ready.

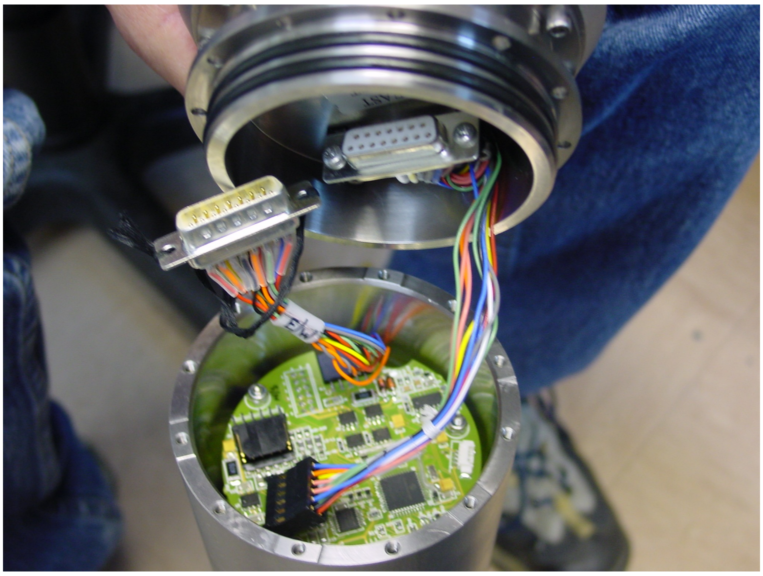
1. Ensure that the “O”-ring seals on the hole lock and sensor sections are clean and well greased.

2. Stand the horizontal sensor on the ground with the packing cap at the top, and support it to prevent it from falling over. This can be done either by using an assistant to hold the casing steady, or by strapping it to a support such as a bench leg.

3. Remove the packing caps from the top of the horizontal sensor and the bottom of the hole lock unit. Beneath the caps are connectors for the horizontal components.



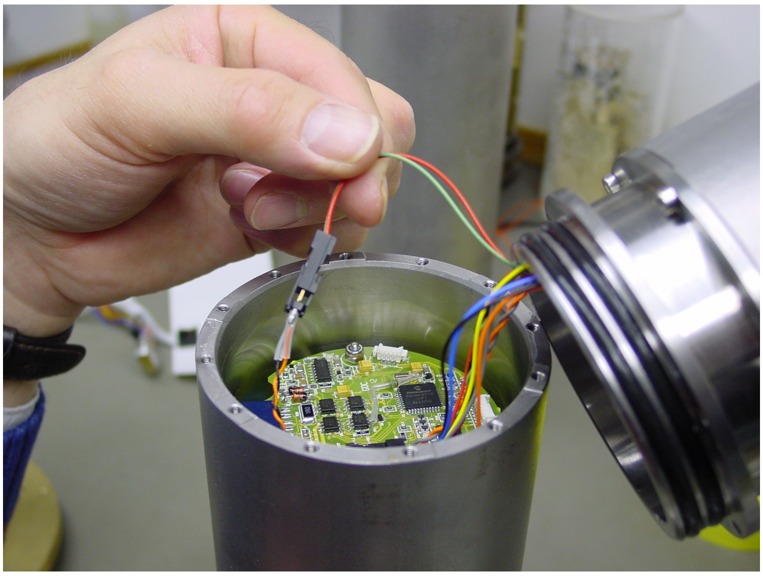
4. Hold the hole lock unit above the horizontal sensor and join the connectors. Ensure that each is connected to its correct counterpart. The wires are fairly short, so you will need a second person to hold the instrument whilst you connect them. Take care not to scratch the other components when attaching the connectors.



5. Align the hole lock unit with the *NORTH* mark on the horizontal sensor housing. Doing this will allow you to check the approximate orientation of the sensors at a glance.

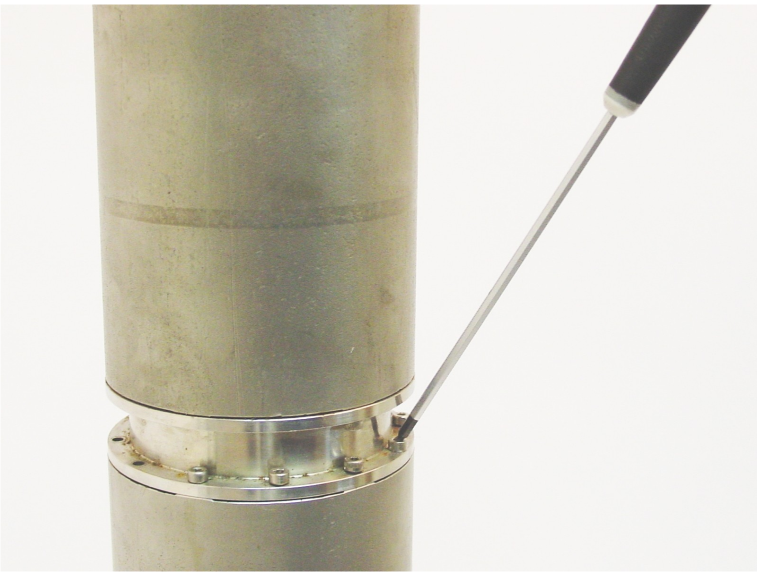
   The horizontal sensor consists of two distinct units (the north/south and east/west components), which are supplied already joined together with M3 × 8 cap screws. You should not need to undo this connection.

If you do separate the north/south and east/west components, make sure that both the signal cable and, if present, the pass-through to the key switch (red and green, held in the photograph below) are reconnected when you reassemble the instrument.



6. Push the hole lock unit into the horizontal sensor housing, twisting to align the holes.

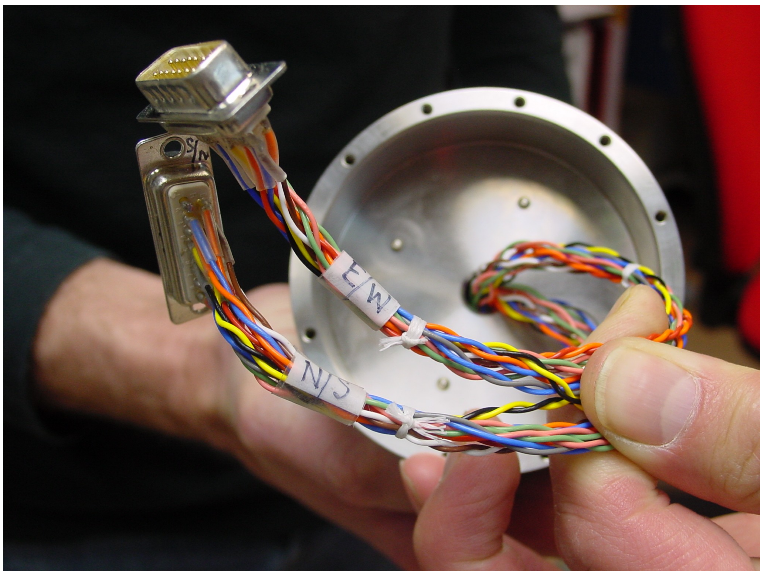
7. Fit twelve M3×8 cap screws into the holes in the joint flange.



8. When all twelve screws are fitted, begin to tighten them with a ball-ended Allen screwdriver. Tighten evenly, working round the instrument in several passes, until the two sections are securely joined together.

9. The vertical sensor now needs to be attached to the other end of the hole lock. Remove the packing caps from the top of the hole lock–actuator section and the vertical sensor.

10. Hold the vertical sensor above the hole lock–actuator section and connect the two 15-way “D”-type connectors, as before. Ensure that each is connected to its correct counterpart.



11. Push the vertical sensor housing into the hole lock–actuator section, twisting to align the holes.

12. Fit twelve M3×8 screws into the holes and tighten.

13. If you are using a single-jaw hole lock unit, attach skids or studs to the sonde as appropriate for your installation, using the fastenings provided.

2.4 Disassembling the instrument

When the instrument is recovered, you may want to disassemble it. To do this, reverse the steps above, bearing in mind the following points:

- Make sure you only undo the screws that are necessary to disassemble the instrument, and not the ones which hold each module together. Each joint has several sets of screws holding it together. Only one set from each joint needs to be undone—the set which was added during assembly. For the joint between the vertical sensor and the hole lock, this is the middle set of screws; for that between the hole lock and the horizontal sensors, it is the lower set. The joint between the two horizontal sensors should not be dismantled.

- When you detach one module from the next, do not yank them apart, since doing this will damage the connectors inside. Insert flat-head screwdrivers either side of the seal, and carefully lever both sides up simultaneously so that the modules remain parallel. You will need someone to support the upper module as you do this.

  When the two parts are separated, tilt the upper one to gain access to the connectors, and disconnect them without scratching the other components.

2.5 Control units

The 40TB is operated from the surface through various control units. All the 40TB's functions can be accessed through one or other unit. Most can be removed from the site once the instrument is ready for use.

Some of these control units are optional and may not have been supplied with your installation. Their functions can be duplicated either by applying voltages directly to control lines (see appendixes for pinout information) or through a connected Güralp digitizer such as the CMG-DM24. The DM24 digitizer is able to pass commands to the instrument from a Data Communications Module (DCM) or a computer running Güralp Systems' Scream! software, allowing you to access all of the instrument's functions remotely.

The breakout box

The breakout box is normally placed where the signal cable emerges from the borehole. It provides connectors for attaching the various other control units, supplies power to the instrument and relays output signals to a recorder or digitizer.

- The *SENSOR* connector is a 32-way mil-spec plug, and should be connected to the borehole instrument with the cable provided.

- The *RECORDER* connector is a 26-way mil-spec plug. This should be connected to an analogue data recorder or stand-alone digitizer. In systems using downhole digitizers, this is replaced by a 10-way mil-spec serial connector for attaching to a Data Communications Module (DCM), modem or other communications link.

- The *CONTROL* connector is a 26-way mil-spec plug intended for connecting to an external controller or Handheld Control Unit. It has the same pin out as the *RECORDER* connector.

- The *POWER* connector is a 10-way mil-spec plug, which should be connected to a source of 12 – 30 V DC power, for supplying to the borehole instrumentation. When operating the hole lock, you should connect the Holelock Control Unit to this connector. Because of the high voltages employed, the hole lock circuitry is entirely isolated from the rest of the electrical systems in the sensor and surface unit; it is not usual to power the sensor whilst using the hole lock.

Calibration

To calibrate the instrument, the *Calibration enable* line must be activated. This operates a relay which allows a calibration signal to flow through the transducer feedback coil. This provides an extra force acting on the sensor masses, producing a corresponding deflection in the output signal, which can be analysed by a control computer to extract the seismometer's response characteristics.

Most Güralp instruments are manufactured with active-low *Calibration enable* lines. However, instruments with active-high calibration can be manufactured on request.

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

- 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 the 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, page 22, for full details.

Remote null option

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.

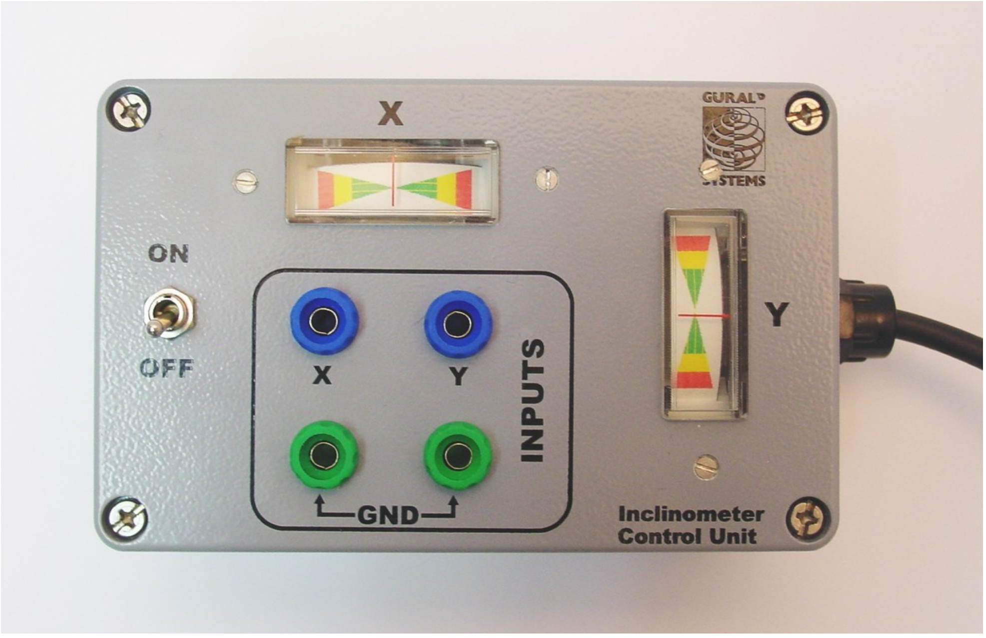
4. Press the *+/–* switch towards – to centre a mass from a positive value, or towards + to centre it from a negative value.

Banana plugs

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

The inclinometer monitor unit

The borehole sensor system can operate successfully in boreholes with a tilt angle up to 3.5 °. To check that the instrument is installed suitably close to the vertical, a two-axis inclinometer is installed within the sensor housing. The inclinometer monitor unit is used as a visual guide to the sensor's tilt only, and should not be used if precise attitude information is required.



To measure the attitude of a 40TB instrument:

1. Connect the inclinometer monitor unit to the *CONTROL* connector of the breakout box.

2. Switch the *ON/OFF* switch on the monitor unit to the *ON* position. The inclinometer is powered separately from other parts of the system; this switch provides power to the downhole circuitry as well as to the monitor unit. The inclinometer should not normally be powered up whilst the sensor is in use.

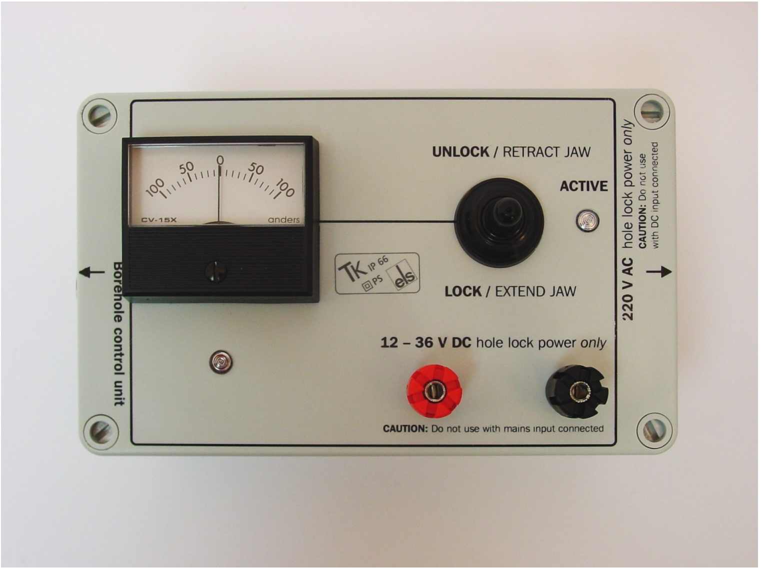
3. Read off the *X* and *Y* components of the tilt from the analogue meters.

4. If both tilts are within the green shaded region, the instrument is close enough to vertical that it can be levelled and centred successfully. If either output is in the red shaded region, you should not attempt to centre the sensor masses. Instead, if possible, you should move the instrument within the borehole to a place where it can lie closer to vertical.

If you need to use the outputs of the inclinometer for some other purpose, you can also connect a multimeter to the banana sockets on the inclinometer monitor unit.

2.6 Operating the hole lock

The hole lock, if fitted, can be extended and retracted using the hole lock control unit:



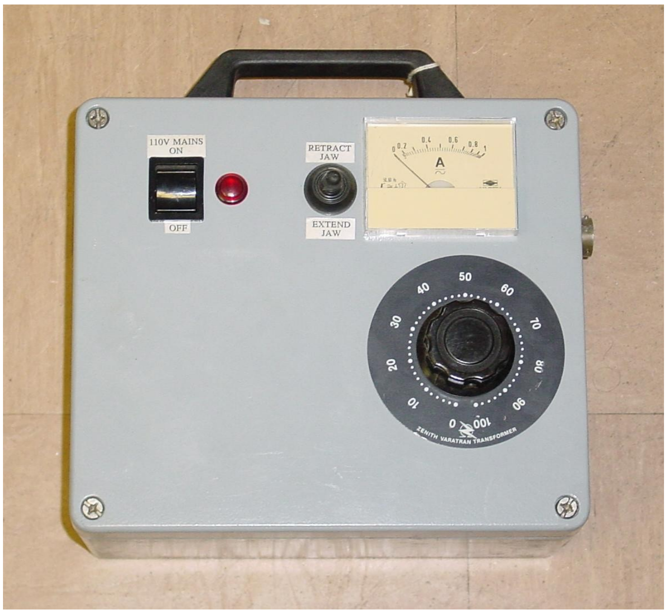
Caution: The hole lock may be using high-voltage mains (outlet) power.

1. Connect the hole lock control unit to the *HOLELOCK POWER* connector of the breakout box, and to a mains power supply. *Alternatively*, connect a 12 – 24 V DC power supply across the input terminals of the hole lock control unit. *Do not connect both DC and mains power at the same time.*

   The hole lock control unit supplied in regions with 220 V AC mains power differs from that supplied for 110 V AC mains power. You should ensure that you provide the correct voltage to the hole lock control unit, otherwise damage may result to the sensor.

2. Power down the sensor. The hole lock will only function whilst the power is off, to avoid injecting current transients from the mains power supply into the sensor electronics.

3. If you are using a deep-borehole hole lock control unit, set the dial to zero.



Engaging the hole lock

To extend the jaw of the hole lock:

1. Hold the switch on the hole lock control unit in the *EXTEND JAW* or + position. If you are using a deep-borehole control unit, there will be an additional dial compared to the unit pictured; turn this until the built-in ammeter reads around 0.1 A.

2. When the arm makes contact with the borehole casing, the current will drop slightly. Continue holding the switch in the *EXTEND JAW* position.

3. When the lock arm reaches its fully extended position, the motor will automatically stop and the current will drop to 0 A. If using a deep-borehole unit, return the dial to zero.

4. If the current has not dropped quite to zero after 30 – 40 s of operation, release the switch, wait a few seconds, and push it back to the *EXTEND JAW* position briefly. If the arm is not completely extended, you will see a surge of current. If the current remains constant, the jaw is at its maximum reach.

5. Once the sensor is locked in place, it is recommended that you remove the hole lock power cable and control unit from the site. Without power, the hole lock will not be able to retract, and the sensor will be secure.

Disengaging the hole lock

To retract the jaw of the hole lock:

1. Tension the load bearing cable, to take up any slack.

2. Hold the switch on the hole lock control unit in the *RETRACT JAW* or – position. If using a deep-borehole control unit, also turn the dial until the built-in ammeter indicates 0.3 – 0.5 A. More current is drawn retracting the arm, because the motor is now working against the spring.

3. When the lock arm reaches its fully retracted position, the motors will automatically stop and the current will drop to 0 A. If using a deep-borehole unit, return the dial to zero.

Manual operation

If you prefer, you can operate the hole lock by applying voltages directly to the sensor.

- To extend the jaw, connect the *Hole Lock Motor* pin on the sensor (or on the breakout box's *HCU* or *RECORDER* connectors) to a +12 V power source, and the *Hole Lock Motor Return* pin to 0 V.

- To retract the jaw, reverse the polarity so that the *Hole Lock Motor Return* pin is at +12 V and the *Hole Lock Motor* pin is at 0 V.

3 Installing the 40TB in a borehole

Before installing any instrument in a borehole, it is recommended that you prepare the installation site so there is clear access all around the hole.

- Keep the borehole capped at all times except when inserting or removing the instrument, so that debris and tools do not accidentally fall in.
- Lay out the cables beside the borehole, or set up a cable drum nearby, so that they do not become tangled.
- Ensure the tripod is tall enough to hang the entire installation (sensor and strain relief unit or digitizer) from it, with the sensor off the ground.
- Use a winch with a depth gauge if possible, or measure out the cable beforehand.

Most installations are equipped with a strain relief unit, which consists of a metal arm that swings out from the load-bearing cable to wedge against the side of the borehole. This removes any strain in the load-bearing cable and prevents vibrations from the surface from being transmitted to the instrument. In installations with a downhole digitizer, the strain relief arm is fitted to the base of the digitizer sonde; the phrase “strain relief unit” in the following instructions should be taken to refer to the digitizer's strain relief arm.

3.1 Installing a sensor with hole lock unit

1. Connect the signal cable to the connector on top of the sensor. Ensure that the “O”-rings inside the housing are clean, and tighten the knurled connector nut to its end stop.

2. If applicable, you should test the hole lock mechanism before installing the sensor. For safety reasons, the hole lock is normally supplied with the arm extended.

   To test the mechanism, connect the signal cable to a breakout box and Holelock Control Unit, and attempt to retract the hole lock arm (see Section 2.6, page 22.) If this fails, you should contact Güralp Systems. Extend the arm once more.

3. Fix the main lifting cable to the shackle on top of the strain relief mechanism, and run the signal cable through the mechanism using the built-in clamps (without tightening them.) Do not allow the signal cable to bear any of the sensor's weight.

4. Attach the lifting loop to the sensor using four M5×16 screws (provided).

5. Join the loop to the bottom of the strain relief mechanism using the linking cable provided.

6. Using a small winch, hoist up the sensor package and strain relief mechanism until both are hanging by the lifting cable, with the strain relief mechanism extended. Tighten the cable clamps on the strain relief unit, allowing a little slack in the signal cable.



7. Fix the signal cable to the main lifting cable about 1 m above the strain relief mechanism using a metal clamp (a nylon cable tie may be sufficient for shallow installations.) Leave a little slack in the signal cable between the clamp and the strain relief mechanism.

8. Position the assembly over the top of the borehole. Do not allow it to drag across the ground.

9. Lower the sonde so that its base is just level with the borehole mouth. If there is a depth gauge on the winch, set this to zero.

10. Continue to lower the sonde to a depth of about 1 m, so that the instrument is still visible.

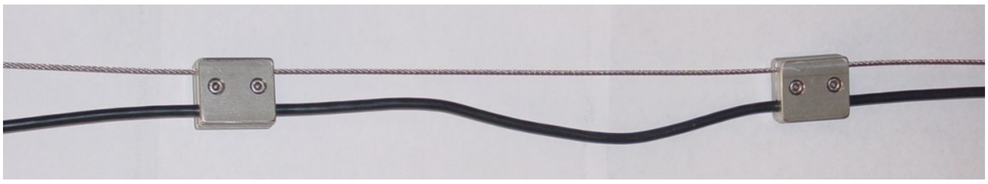
11. Extend the hole lock arm (see Section 2.6, page 22) to check that it fits your borehole. The current drawn should dip slightly as the arm touches the casing, then drop to zero when it is fully extended. Check that the sonde is firmly anchored to the borehole casing by attempting to slacken the load bearing cable. If it remains taut, the sonde is still loose within the borehole. Do not proceed with installation in this case. Instead, you should either move the instrument to a narrower section of the borehole and try again, or contact Güralp Systems to fit a longer hole lock, quoting accurate measurements of your borehole.

12. Power up the instrument from a suitable power supply.

13. Level and centre the sensor (see Section 3.5, page 44) so that it can be tested.

14. Check that the sensor is functioning correctly by connecting a meter or monitoring device to the sensor outputs. If the sensor fails to register ground movements, contact Güralp Systems.

15. Gently lower the sensor to the required depth. At approximately 20 m intervals, fix the signal cable to the load bearing cable using metal clamps (nylon cable ties every 5 m may be sufficient for shallow installations). This will ensure that the signal cable does not become kinked or trapped within the borehole. Leave a little slack on the signal cable each time, so that it does not bear any weight. Too much slack, however, will cause the cable to scrape against the borehole casing.



16. Fix the sensor system into the borehole using the hole lock arm (see section 2.6, page 22.)

    If you are installing a 40TB in a deep borehole, the weight of the sensor will stretch the load bearing cable slightly. Remember to allow for this when raising or lowering the cable in the following steps.

17. Use the winch to drag the assembly up within the borehole for a distance of 15 – 30 cm. This will ensure that the hole lock arm and the skids or studs on the sonde keep the sensor package vertical within the borehole. Do not drag too far, or you will damage the contact points.

18. Lower the load bearing cable by around 30 cm to engage the strain relief unit inside the borehole casing, and to provide some slack in the cables.

19. Clamp the load bearing cable to the top of the borehole.

20. Tie the lifting and signal cables together above the strain relief mechanism using tie wraps.

21. The sensor can now be levelled ready for use.

3.2 Installing a sensor using sand backfill

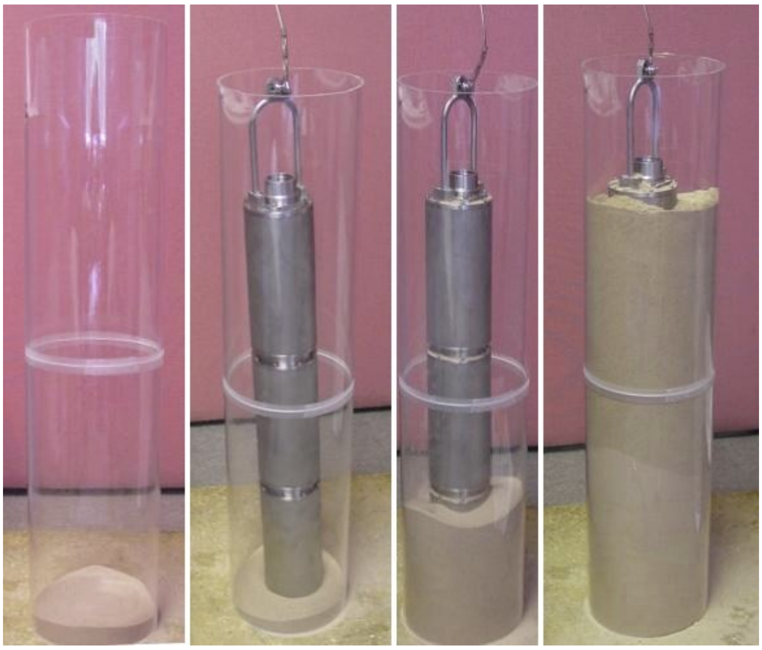
Dry sand backfill is a convenient and effective way of installing a borehole or posthole sensor in a time-stable environment. The presence of sand not only fixes the sensor in place at the bottom of the hole, but also reduces noise due to air convection.

The ideal type of sand to use is the fine, kiln-dried sand used for children's play sandpits. This is readily available in airtight bags, is thoroughly washed and clean, and will contain little sediment. (When dried out after wetting, sand containing foreign matter may solidify and “concrete” the sensor in position.) This sand is suitable for use in both dry and damp boreholes.

In the procedure outlined below, the sensor rests on a pad of sand around 300mm thick. This pad will absorb any residual moisture at the bottom of the borehole, and ensure that the surroundings of the instrument are kept dry.

After positioning the sensor, more sand is added to fill the space between it and the borehole casing, holding it firmly in place. The sand should reach within 30mm of the top of the instrument, but should not cover it. This way, the instrument can be more easily recovered when it requires maintenance or replacement. This is particularly important if the borehole is not completely dry, since moist sand does not flow well.

The following photographs show the steps involved in backfilling with sand:



Procedure

To install a sensor at the bottom of a borehole of known depth using sand backfilling:

1. Measure or calculate the physical volume of the unit which is to be installed in the borehole. (The volume of a cylinder $v = \pi r^2 h$.) Also measure the internal diameter of the borehole.

2. Measure and pour in a sufficient quantity of sand to fill the borehole to a depth of around 300mm.

3. Connect the signal cable to the connector on top of the sensor. Ensure that the “O”-rings inside the housing are clean, and tighten the knurled connector nut to its end stop.

4. Fix the main lifting cable to the shackle on top of the strain relief mechanism, and run the signal cable through the mechanism using the built-in clamps (without tightening them.) Do not allow the signal cable to bear any of the sensor's weight.

5. Attach the lifting loop to the sensor using four M5×16 screws (provided).

6. Join the loop to the bottom of the strain relief mechanism using the linking cable provided.

7. Hoist up the sensor package and strain relief mechanism until both are hanging by the lifting cable, with the strain relief mechanism extended. Tighten the cable clamps on the strain relief unit, allowing a little slack in the signal cable.

8. Fix the signal cable to the main lifting cable about 1 m above the strain relief mechanism using a metal clamp (a nylon cable tie may be sufficient for shallow installations.) Leave a little slack in the signal cable between the clamp and the strain relief mechanism.

9. Position the assembly over the top of the borehole. Do not allow it to drag across the ground.

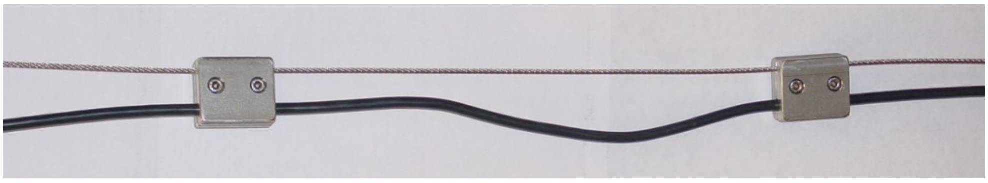
10. Lower the sensor so that its base is level with the borehole mouth. Set the depth gauge on the winch to zero.

11. Calculate how much lifting cable must be lowered into the borehole, taking into account the length of the sensor and the strain relief assembly or digitizer.

    If you are installing a 40TB in a deep borehole, the weight of the sensor will stretch the load bearing cable slightly. Remember to allow for this when raising or lowering the sensor in the following steps, since allowing the instrument to strike the bottom of the borehole will damage it.

12. Begin lowering the sensor down the borehole, keeping track of the depth reached.

13. At approximately 20 m intervals, fix the signal cable to the load bearing cable using metal clamps (nylon cable ties every 5 m may be sufficient for shallow installations). This will ensure that the signal cable does not become kinked or trapped within the borehole. Leave a little slack on the signal cable each time, so that it does not bear any weight. Too much slack, however, will cause the cable to scrape against the borehole casing.



14. Whilst monitoring the depth of the sensor, carefully approach the sand layer at the bottom of the borehole. The lifting cable will go slack when the sensor makes contact with the sand.

    If the lifting cable goes slack before the sensor has reached the sand layer, it may have become caught on a bad joint or lip in the borehole; carefully raise and lower the instrument to free it.

15. When you have reached the bottom, use the winch to lift the package slightly, taking the slack off the cable. This ensures that the sensor is hanging vertically within the borehole, and is no longer in contact with the sand bed.

    At this point, you may wish to use an inclinometer monitor unit to check that the instrument is sufficiently close to vertical to be properly centred. See Section 2.5, page 20, for details.

16. Calculate the volume of dry sand required to fill the gap between the sensor and the borehole liner to the level of the top of the sensor ($v = \pi r^2 h$ using the internal radius of the borehole, less the volume of the instrument determined in step 1.)

17. Pour this sand into the borehole. If you can, check how much of the sensor is covered with sand. Do not overfill the hole.

18. Carefully slacken the load bearing cable. This will engage the locking arm of the strain relief mechanism and secure the installation within the borehole.

19. Without pulling or lifting the sensor, lightly shake the cables to

remove any sand that may have fallen onto them or onto the strain relief mechanism.

20. Clamp the load bearing cable to the top of the borehole, and remove the winch.

21. The sensor can now be levelled (see Section 3.5, page 44) ready for use.

3.3 Assembling the winch

If required, Güralp Systems can provide a winch suitable for installing a borehole sensor. The winch and tripod are supplied as a set of parts which you can assemble on site:

There are two sections for each leg of the tripod. The upper sections are pre-attached to the head of the tripod; the lower sections are supplied detached.

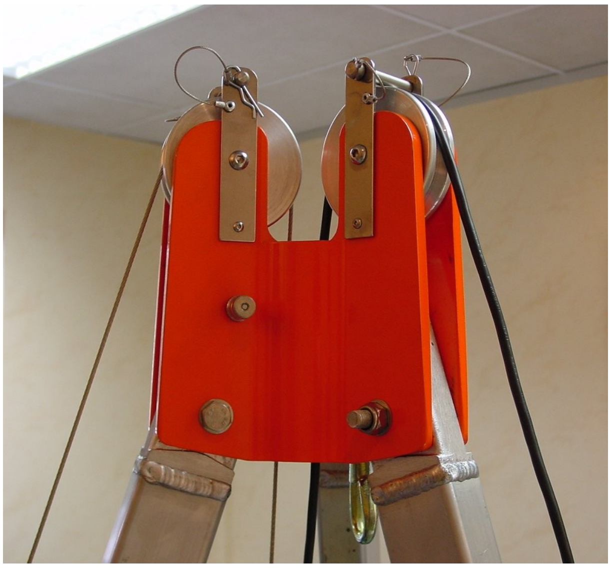
1. Slide the lower sections all the way into the head with the retaining tape loops facing outwards.

2. If you are working on a surface of *sand* or *soil*, rotate the feet so that the points face downwards (left). For *rock* or other hard surfaces, ensure the pads face downwards (right).

3. Erect the tripod above the borehole, and run the yellow retaining tape through the loops. Fasten together the ends of the tape.

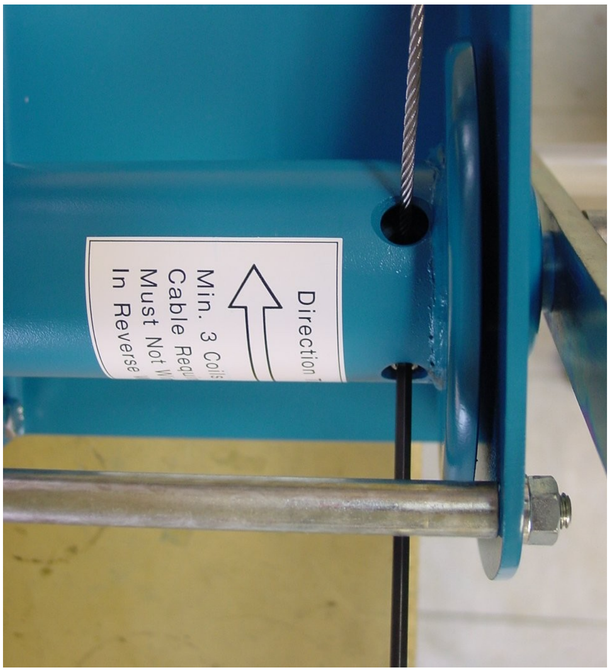
4. The lifting cable is supplied with a loop at one end. Run this over one of the pulleys at the top of the tripod, so that the loop hangs down between the legs. If the loop is not provided, you can make one by untwisting three outer strands from the (7-core) cable, crossing the two sets, and pleating the three outside strands back around the remaining four in the opposite direction. Secure the loop with a cable clamp.

5. Run the sensor signal cable through the other pulley. Secure both cables in their pulleys by sliding the attached bolts into place.

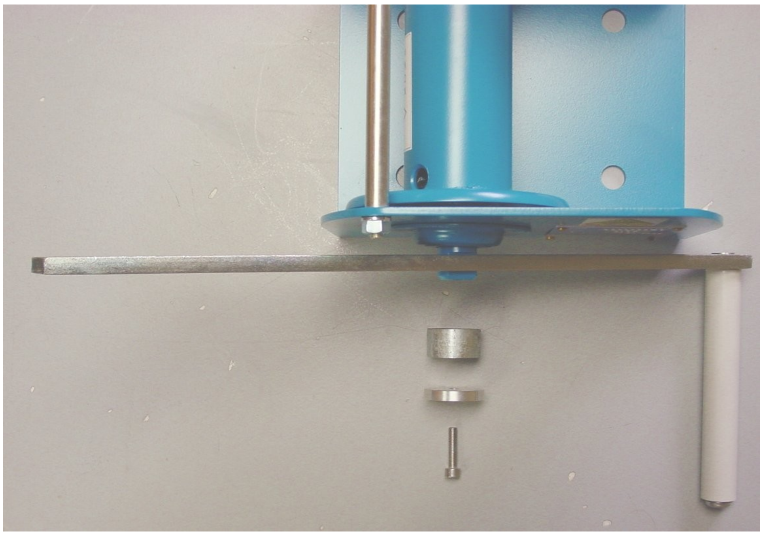


6. Extend each of the three legs in turn to the height you require, finishing at the leg with the winch attached.

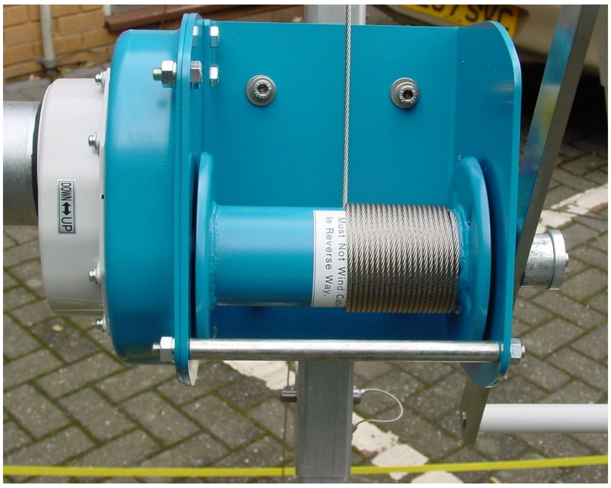
7. Take the end of the load-bearing cable without the loop, and screw it to the axle inside the winch using a 4 mm Allen key (provided) as shown.



8. Attach the handle to the side of the winch *opposite* the ratchet mechanism, and fasten it in place with a collar, washer and screw, using the larger Allen key.

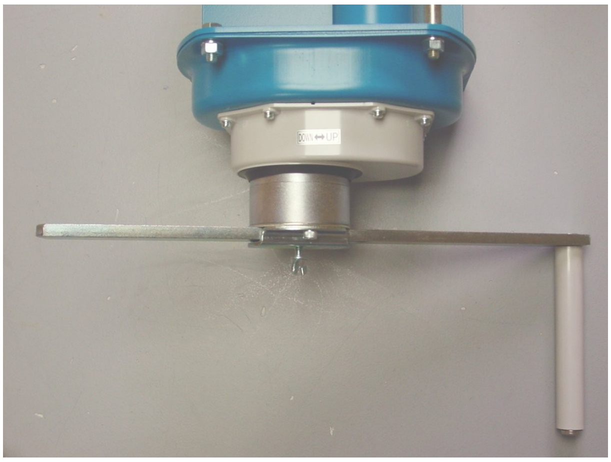


9. Wind the cable onto the winch by rotating the handle. Ensure that the cable builds up neatly across the drum. Continue winding until the loop on the other end is as high as you need it to install the equipment.



If the ratchet prevents you from winding the cable on, twist the metal boss in the *DOWN* direction to free the cable.

10. Remove the handle, and screw it onto the metal spool of the ratchet mechanism.



11. Hang the strain relief unit and instrument(s) from the loop at the other end of the cable. You are now ready to lower the assembly into the borehole as described above.

3.4 Earthing a borehole sensor

To achieve the best performance from any borehole instrument, you must make sure that the sensor electronics, its casing and the power supply share a common, local ground, and that all power and data lines are adequately protected against lightning and other transients.

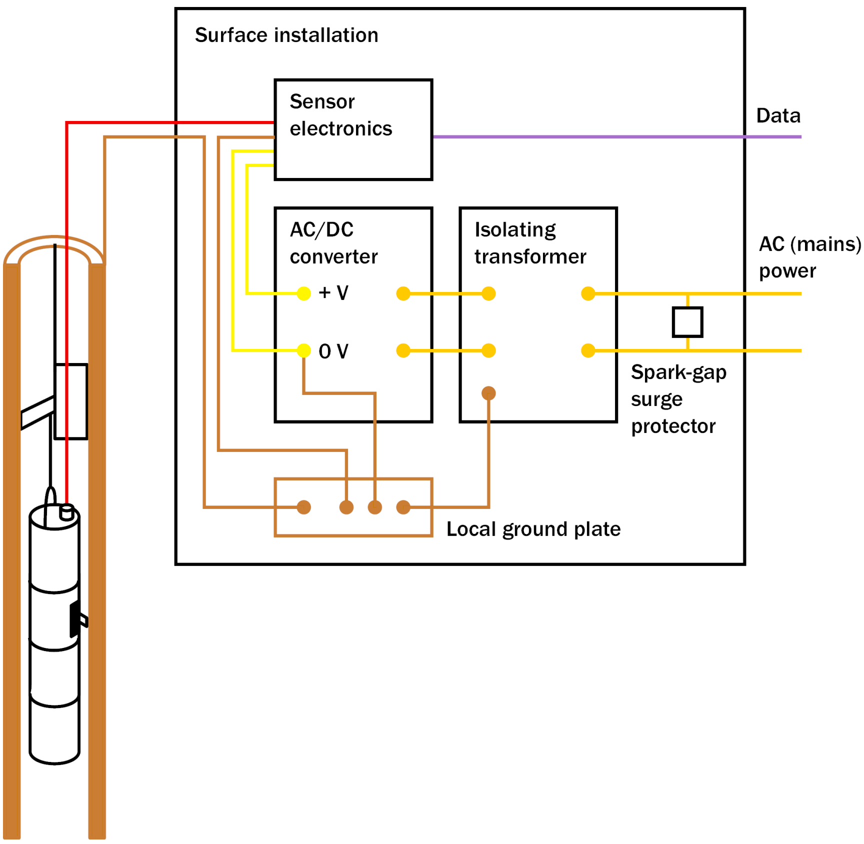
This section describes techniques for grounding sensor equipment which have proved effective in many installations. However, local conditions are always paramount, and you should design your installation with these in mind. Any regulations in force at your chosen location must also be followed.

Installations with AC power supplies

If you are using mains (outlet) power, or some other AC power distribution system, we recommend installing a fully isolating transformer between it and the power supply for the instrument. This will allow full control of the local grround.

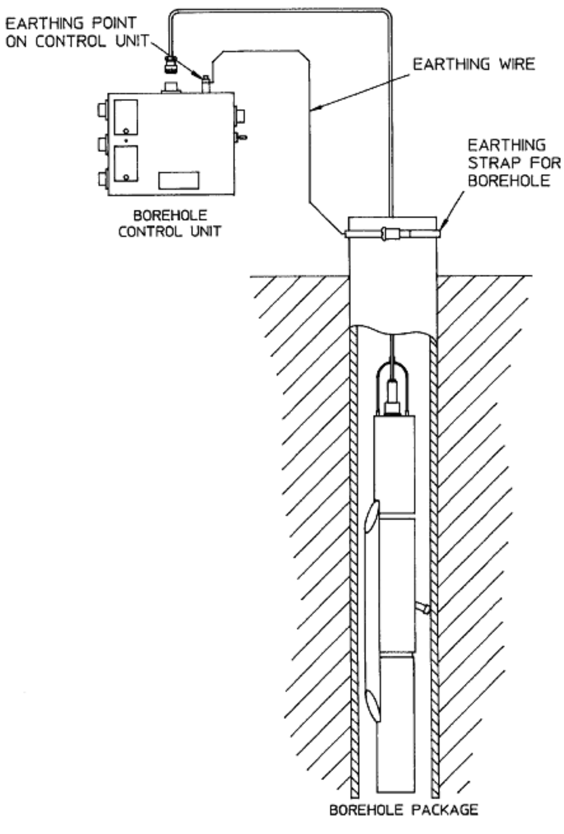
A spark-gap surge protector should also be installed on the mains side of the transformer, so that transient overvoltages are not transmitted across it. Suitable protectors are available off the shelf from several suppliers. On the sensor side, surge protection is installed as standard within all new Güralp borehole sensors and control equipment. If your surface installation includes third party electronics, digitizers, etc., you may need to install additional protection where power and data lines enter the surface enclosure. Contact Güralp Systems if you are unsure.

Within the installation, a single ground point should be established, which is connected to a local ground plate. All earth lines for equipment in the installation, such as the casings of the transformers and of the sensor electronics, as well as the signal ground line from the sensor, should be connected to this plate.



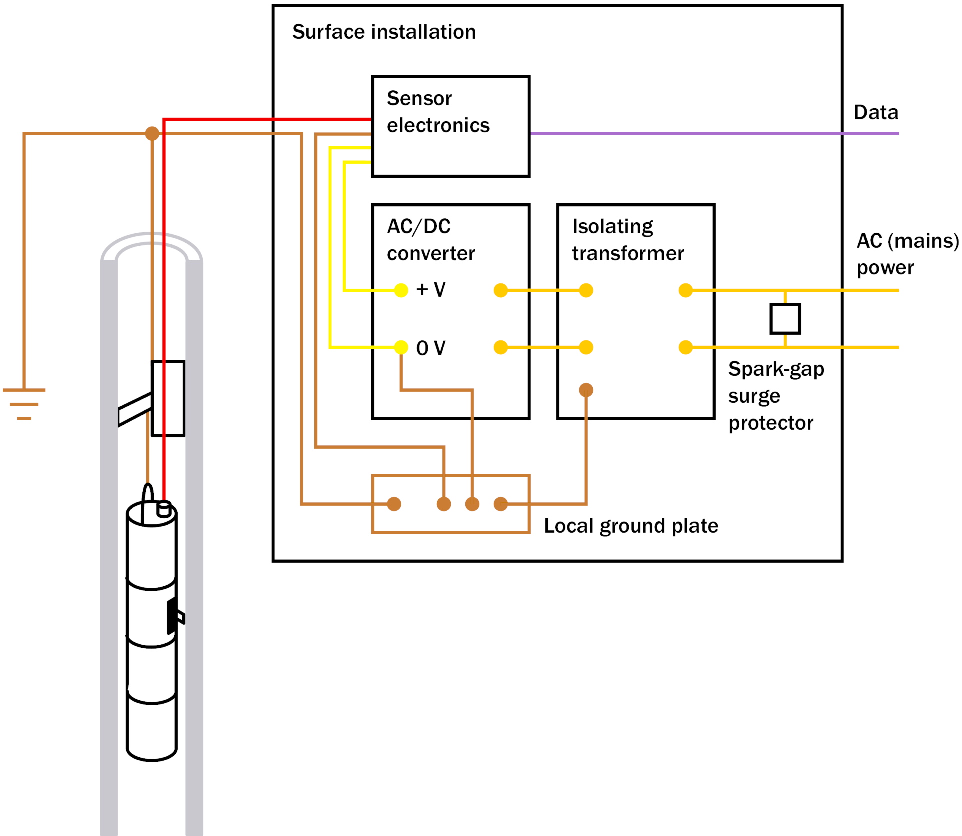
The best local earth point in many installations is the borehole itself. For this to work, the borehole must have a conductive casing and be situated close (<30 m) to the surface installation. In such an installation you need only connect a cable (green wire in the photograph below) from the local ground plate to the borehole casing.

An earth strap can be used to ensure a good connection.



If the lower borehole is filled with salt water, the instrument will be adequately grounded without any further action. Fresh water is an inferior conductor.

In a dry or sand-filled borehole, or one with a non-conducting casing, you will need to ensure the sonde is grounded by some other means. The best option is often to attach the sensor housing to an earth line brought out to the surface and attached to a metal stake driven into the ground nearby.



The sensor's load bearing cable is suitable for this purpose, provided it is secured to the sensor's lifting loop with a metallic clamp as shown below. This provides an additional firm contact between the sonde and the load-bearing cable. Installations with downhole digitizers will need similar arrangements at the top and bottom of the digitizer module, or a separate cable for this purpose.

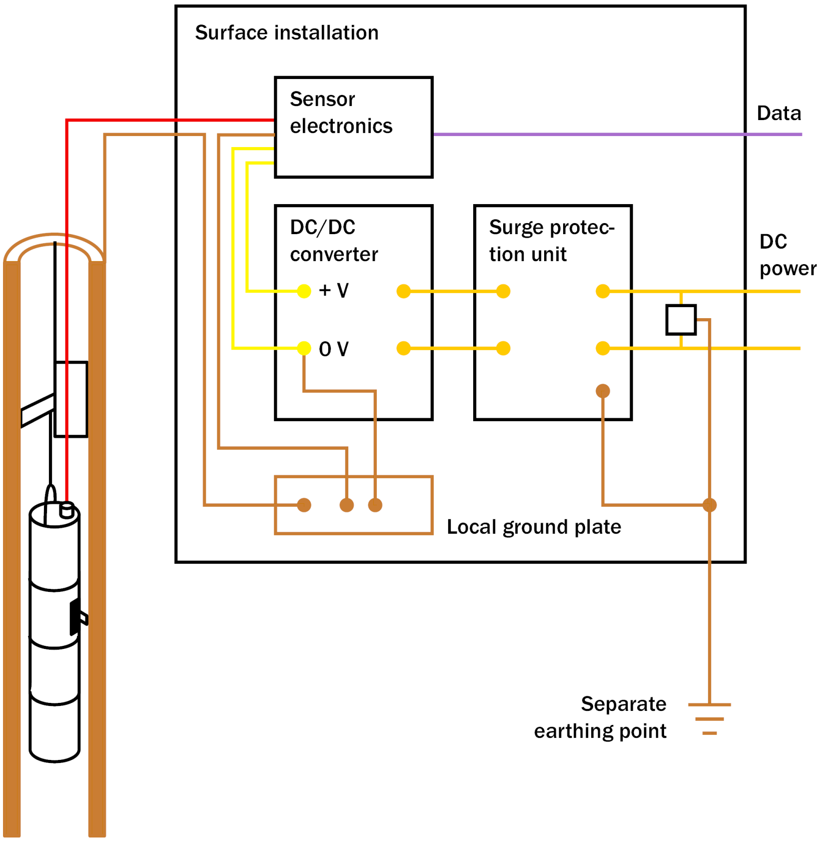
For boreholes with a metallic casing at the bottom and plastic above, we recommend connecting a cable between the sensor housing and the ground plate so that the lower borehole casing acts as the earthing point. Again, the

If there is a significant distance (>30 m) between the borehole and the surface installation, the resistance of the earth cable may make it impractical to use the borehole as an earthing point. In these cases, you will have to connect the local ground plate to an earth stake near to the enclosure; any coupling between this sensor-local earth line and ground lines for other parts of the system must be minimized.

Installations with DC power supplies

Güralp sensors require a 24 V DC power supply. In most cases, this is provided by an isolating DC/DC converter installed at the surface. This converter can be earthed to the local ground plate as above.

However, DC/DC converters contain sensitive electronics, which must be protected thoroughly. We recommend installing a full surge protection unit in addition to the spark gap protector. This protection is installed on the supply side of the isolator, so it must be earthed *separately* from the borehole installation. Otherwise, transients in the power supply will couple to the sensor.



As with AC installations, if the borehole is more than around 30 m from the surface enclosure, you will need to provide a second earthing point for the local ground plate.

DC power is most commonly available at self-contained installations with power supplied from batteries, solar panels, or a wind generator. In these cases, the power supply may already have protection from transients installed, in which case you may not need such comprehensive protection (although some form of protection is *always* necessary.)

External lightning protection

The surface installation building, and if possible the borehole also, should be protected by lightning conductors. These should lead to ground well away from the borehole. As a rule of thumb, a lightning mast provides a “zone of protection” within a 45 ° cone the height of the mast.

If you are using two earthing points, for example in the DC installation shown above, it may be convenient to connect the lightning conductor to the supply-side earthing point. In any case, the lightning earth must be well separated from the borehole (and its earth, if it needs one.)

3.5 Zeroing the instrument

Once it is installed, you should zero the instrument ready for use. This can be done using the various surface control units:

1. Connect an inclinometer monitor unit to the breakout box. If you do not have an inclinometer monitor unit, skip to step 5.

2. Turn on the borehole control unit using the *ON/OFF* switch under the transparent flap.

3. Turn on the inclinometer monitor unit using its *ON/OFF* switch, and read off the *X* and *Y* components of the tilt from the analogue meters.

4. If both tilts are within the green shaded region, the instrument is close enough to vertical that it can be levelled and centred successfully. If either output is in the red shaded region, you should *not* attempt to centre the sensor masses. Instead, if possible, you should move the instrument within the borehole to a place where it can lie closer to vertical.

5. Connect a handheld control unit (HCU) to the breakout box.

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

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

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

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

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

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

3.6 Downhole orientation

Once the sensor is installed inside the borehole, you will need to measure its orientation with respect to the compass points. There is no need to rotate the sensor itself, since the data can be rotated algorithmically after it is digitised.

A simple method for determining the orientation of a sensor package using the sensor's own horizontal component sensors, has been used effectively by the Blacknest Seismological Centre, UK, with downhole and surface equipment from Güralp Systems (*AWE Report O 10/93*, 1993.)

In this experiment, signals received by the N/S component of the reference sensor are correlated with those received at the N/S and E/W components of the sensor being studied, after different amounts of mathematical rotation. The highest correlation will occur when the N/S component of the reference sensor matches the rotated N/S component of the borehole sensor.

Once you know the deviation of the borehole components from the compass points, you can instruct the digitizer to rotate the signals algorithmically.

Installing the Scream! extension

The *Relative Orientation* extension is supplied in the standard Windows distribution of Scream! 4.2 and later.

The extension uses Matlab libraries, which are currently only available for Windows. However, you do not need the full Matlab package to use the extension. The Matlab runtime libraries are also included in the Scream! distribution.

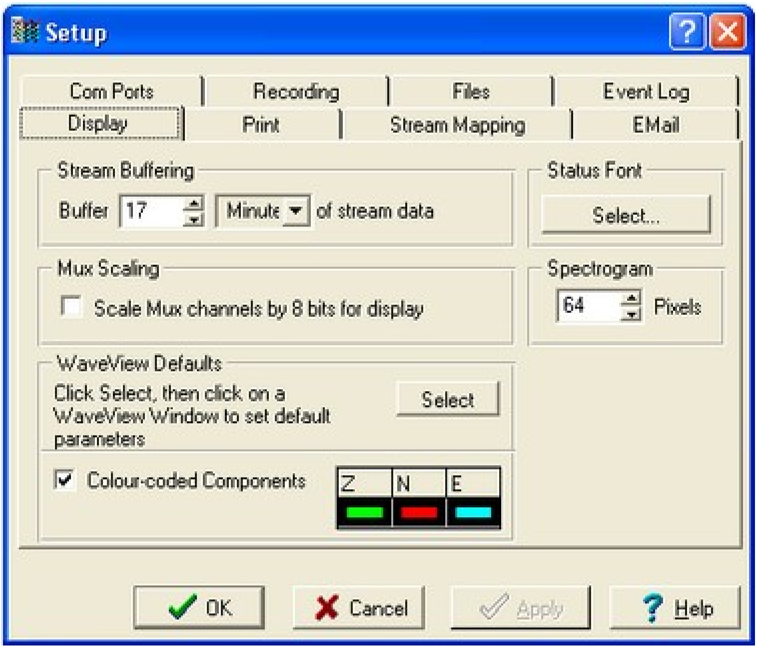
Installing the reference instrument

To measure the orientation of a sensor, you will need a second instrument which is known to point precisely North. It should be located on a solid surface as close to the other instrument as possible. Most boreholes are constructed with a concrete base around the top of the borehole. If this is present, we recommend installing the reference sensor there.

Ideally, the two sensors will be directly connected to the same 6-channel digitizer. If you are using separate digitizers, you will need to ensure they are *exactly* synchronized. This can be done by connecting GPS receivers to both digitizers and waiting for the control system of each one to settle. This process takes at least 12 hours.

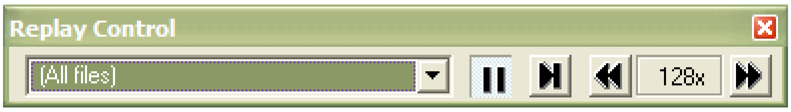
Measuring the orientation

1. Run Scream!. Open the *File – Setup* window, and select the *Display* tab.



2. Under *Stream Buffering*, increase the buffer size to an amount which will hold all your experimental data. Click **OK**.

3. Drag the data files you have recorded into Scream!. A *Replay Control* window will open.



4. Click the *Increase Speed* icon  until the legend (*128x* in the picture above) reads *Max*.

5. Click the *Pause* icon  to begin replaying.

   Scream! will be able to replay data faster if you are not currently displaying it. When Scream! has finished, the *Replay Control* window will disappear.

6. Hold down `CTRL` and select the N, E, and X streams from the digitizer at the correct sample rate.

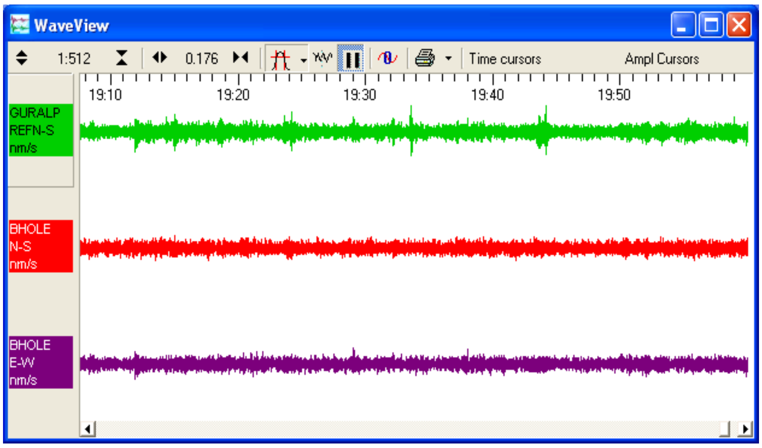
   The N and E streams are the "North/South" and "East/West" components of the downhole instrument. The X stream is the North/South component of the reference instrument.

   If you are using a separate digitizer, the reference instrument will appear on the North/South component of the other digitizer, instead of the X stream. To select this at the same time as the other streams, make sure *Network* is selected in the left-hand pane of Scream!'s main window, to display all the streams from your seismic network.

7. Double-click on one of the selected streams, or press ENTER. A *WaveView* window will open.

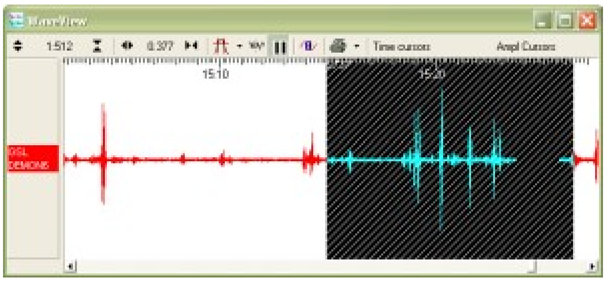
8. Drag the streams across the window so that the reference stream is at the top, the N stream in the middle, and the E stream at the bottom.

9. Click the *Pause* icon to stop the traces moving, and zoom in and out until you can see a suitable data range. You should use a period of at least an hour, and preferably longer.



10. Hold down the SHIFT key and drag across the *WaveView* window with the left button until all three streams are selected for the whole range.

 Make sure there are no gaps in the data you select. In Scream! 4.3 and later, the selection will be shown with hatched lines if there is a gap:



 When you are happy with the selection, release the mouse button, but keep SHIFT held down.

11. When the menu appears, release the `SHIFT` key. Select *Relative Orientation* from the menu that appears.

    Two small windows will appear: a small progress window, and a warning with a legend like

    ```
    Assuming DEMOX3 is reference N/S
    ```

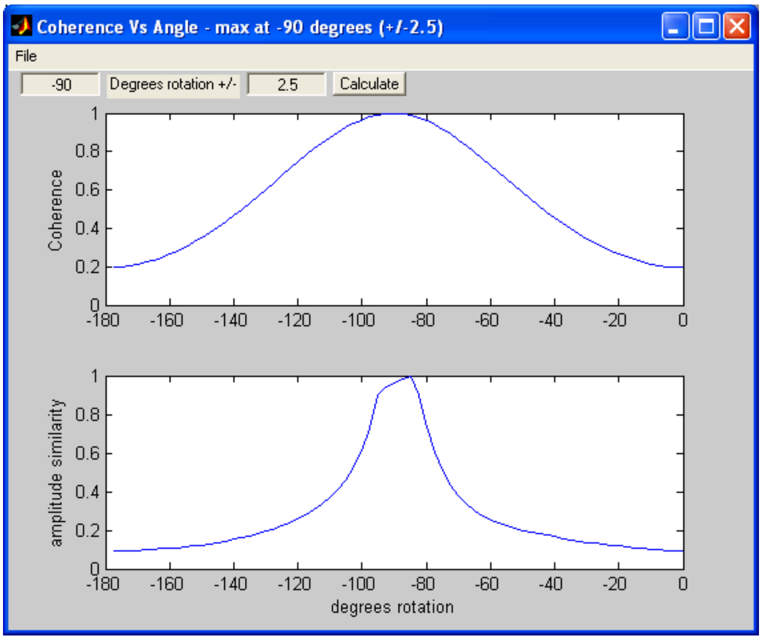
    Scream! produces this warning because the reference sensor is not using a standard N/S channel, but the auxiliary (X) channel.

    If you are using a separate digitizer, the warning will not appear.

    If you get an error, make sure the streams are in the right order in the *WaveView* window. If you still have problems, you may have selected too few data points for it to be confident about the orientation; you should try again with a larger selection, or when more data is available.

12. After a few seconds, the calculation should finish and two windows will appear. (One may obscure the other.)

    The top window is a graph of *Coherence vs Angle*:



    The two-stage algorithm rotates the N/S and E/W components of the sensor being tested in small steps.

    It measures first the amplitude similarity, and then the coherence between this new N/S component and the reference

N/S component, for a number of rotation angles.

The error in the final calculation is around 2.5 °.

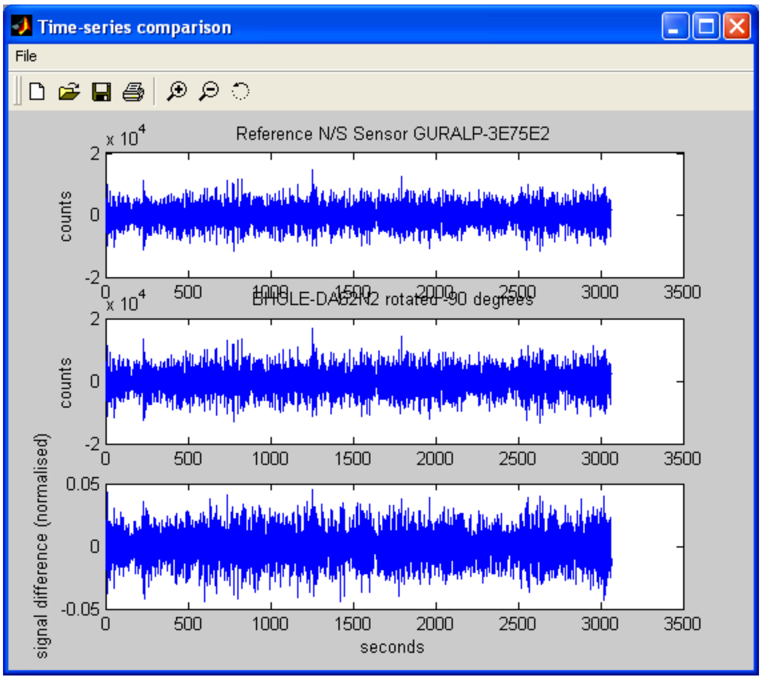
The peak of the coherence curve (upper graph) therefore corresponds to the angle of rotation which best matched the reference component. This angle is shown in the title bar, together with an estimated error.

You should see a coherence curve which is smooth and symmetrical. If the curve is distorted, either the surface data is too noisy or the data selection is too short.

The lower graph shows the overall amplitude similarity of the rotated signal. This provides an idea of the sign of the coherence (since signals in perfect antiphase have a high coherence as well as those in phase). If there are two peaks in the coherence graph, the correct one is where the amplitude similarity is most positive.

The sample plots show that the borehole instrument is installed with its N/S axis at a bearing of –90 ° from true North.

13. The second window shows the result of applying the rotation to the signal, *i.e.* the time series that a sensor in perfect N/S orientation would have produced:

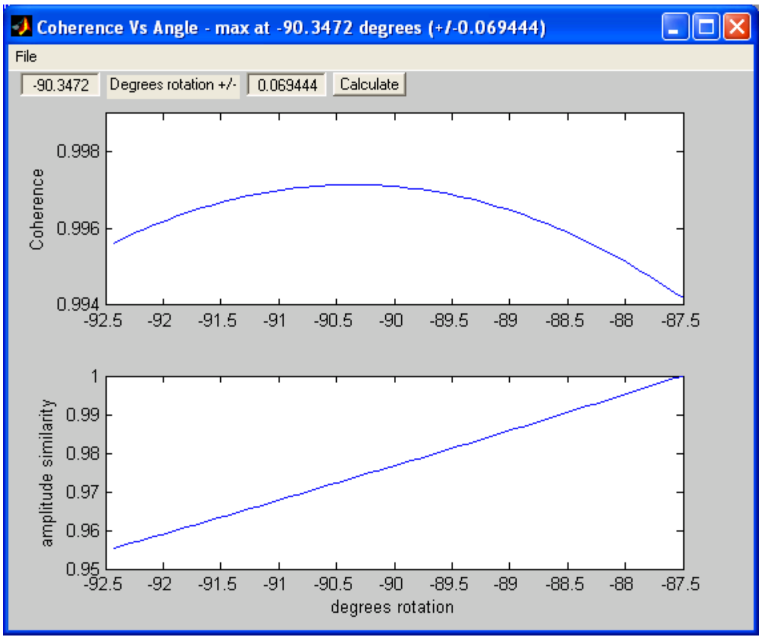


14. You can perform more accurate calculations by narrowing the

search range. This is done in the two entry boxes on the *Coherence vs Angle* window: the first denotes the centre of the new search, and the second its range.

The program suggests suitable values for you, so in most cases you can just click *Calculate* to perform another iteration.

15. A new graph will be displayed showing the results.



Our sample instrument is thus aligned at –90.35 ± 0.07 °.

16. The error given is only a rough estimate.

You should repeat the orientation experiment several times using different data sets.

The true error in the computed orientation can be determined by observing the spread of the results.

The Blacknest orientation method generally provides a reliable indication of the sensor's orientation. In most cases, the greatest source of error is in the installation of the reference sensor.

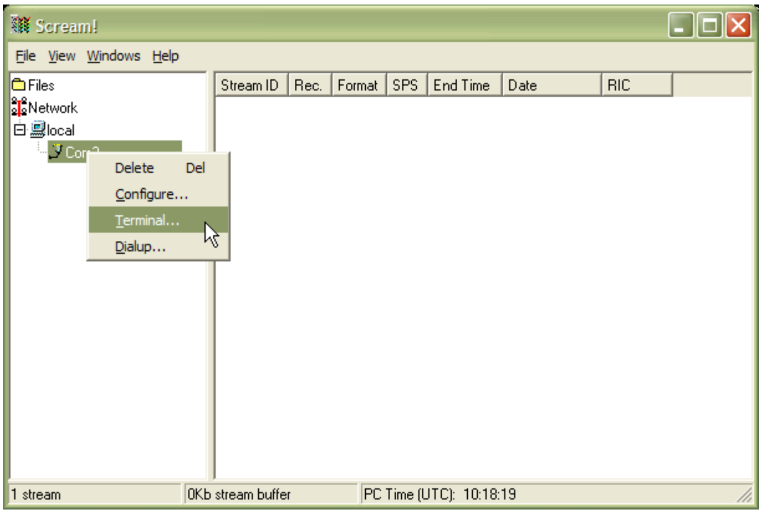
Applying automatic rotation

You can configure a DM24 mk3 digitizer to apply an automatic rotation to the digitized data and output streams representing ground motion on true North/South and East/West axes.

This is done within the DSP to minimize the reduction in data quality.

To set up the rotation:

1. Open a terminal session with the digitizer. You can do this with a program such as `minicom` (for Linux) or `hypertrm` (for Microsoft Windows). Alternatively, you can access the digitizer's console through Scream! by right-clicking on its icon and selecting **Terminal...**.



You should see an `ok` prompt, indicating that the digitizer is ready to receive commands.

2. Type

`0 rotation AZIMUTH`

where *rotation* is the angle of deviation from true North that you measured earlier, as a whole number of tenths of a degree. This is the same angle (with the same sign) as that given by the orientation program.

The `0` tells the digitizer to apply the rotation to instrument number 0 (the first, or only instrument.)

Thus in the example above, you would type `0 -903 AZIMUTH` to make the digitizer rotate signals by –90.3 degrees.

3. Reboot the digitizer with the command `re-boot`.

4. Collect some more data with the transformation active, and carry out another orientation calculation. The data from the

downhole instrument should now have a maximum coherence with the reference sensor at 0 °. Check in particular that the sign of the rotation you have applied is correct.

4 Calibrating the 40TB

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 40TB 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 $s = j f\text{m}$, where $j = \sqrt{-1}$.

- $H(s)$ is the transfer function of the sensor, which can be expressed in factored form:

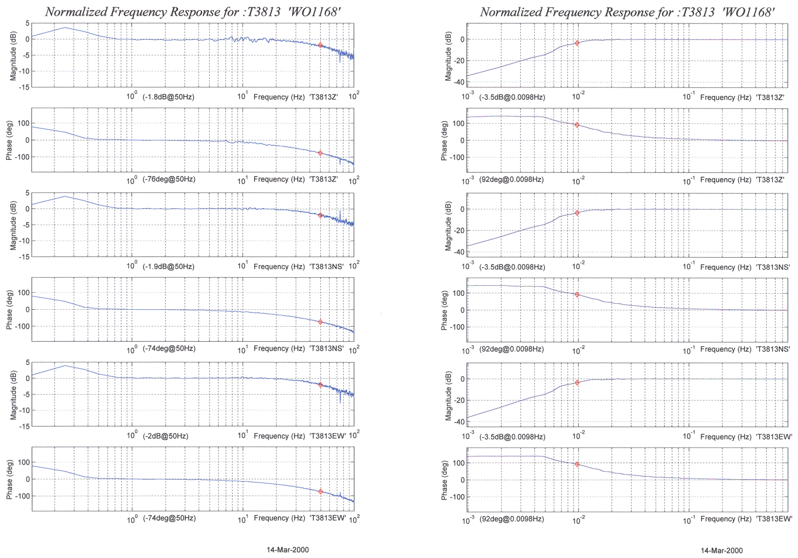
$$H(s) = N \frac{\prod_{i=1,n} s - Z_i}{\prod_{j=1,m} s - P_j}$$

  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 40TB 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 40TB 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.

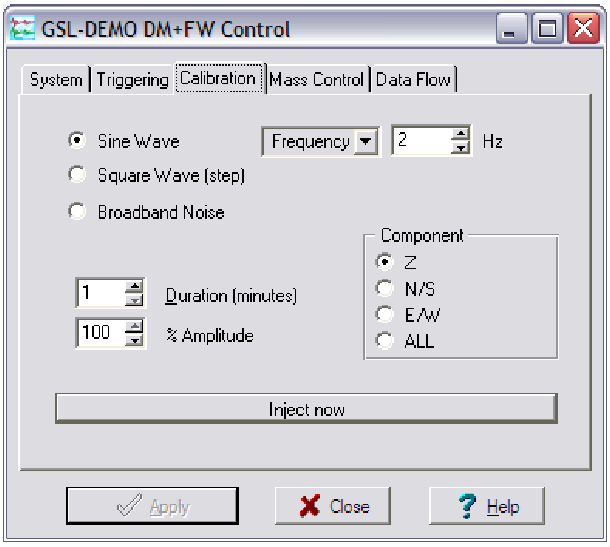
Before you can calibrate the instrument, its calibration relays need to be activated by pulling low the *CAL ENABLE* line on the instrument's connector for the component you wish to calibrate. Once enabled, a calibration signal provided across the *CAL SIGNAL* and *SIGNAL GROUND* lines will be routed 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!

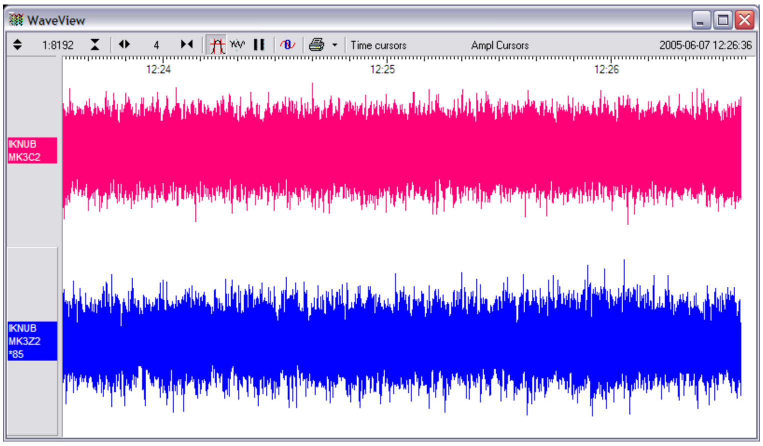
Güralp digitizers provide calibration signal generators to help you set up your sensors. Calibration is most easily done through a PC running Güralp's Scream! software.

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.

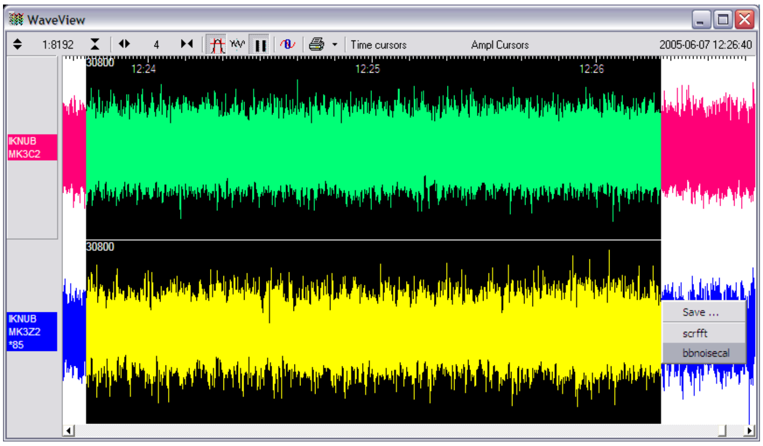
Drag the calibration stream C<u>n</u> across the Waveview window, so that it is at the top.

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.

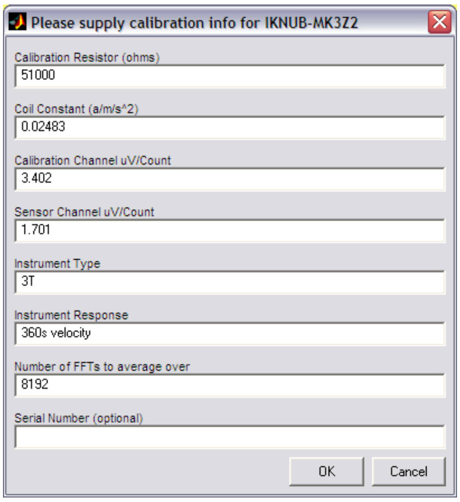
5. If you need to scale one, but not another, of the traces, right-click on the trace and select **Scale…**. You can then type in a suitable scale factor for that trace.

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.

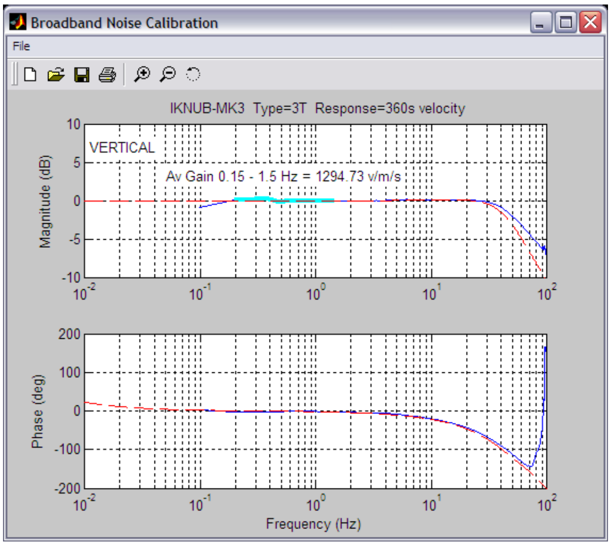


Most data can be found on the calibration sheet for your sensor. Under *Instrument response*, you should fill in the sensor response code for your sensor, according to the table below. *Instrument Type* should be set to the model number of the sensor.

If the file `calvals.txt` exists in the same directory as Scream!'s executable (`scream.exe`), Scream! will look there for suitable calibration values. See the Scream! documentation for more information.

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-40TB, 30 s – 50 Hz response	`CMG-3B_30S_50HZ`	V
CMG-40TB , 100 s – 50 Hz response	`CMG-3B_100S_50HZ`	V
CMG-40TB, 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 40TB.

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 a mounting harness for the sonde and 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 $a = g \sin \phi$, whilst for the horizontal sensor, it is $a = g(1 - \cos \phi)$.

   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.

5 Connector pinouts

6 Connector pinouts

This table combines the pinouts for all connectors on the borehole sensor and breakout box. Control signals are normally active low, but active high versions can be supplied on request.

Column (a): The single connector on a 40TB sensor, a 32-way mil-spec waterproof plug (02E-19-32P).

Column (b): The *SENSOR* connector on a breakout box, a 26-way mil-spec plug (02E-16-26P)

Column (c): The *RECORDER* and *CONTROL* connectors on the breakout box, both 26-way mil-spec plugs (02E-16-26P).

Column (d): The *POWER* connector on the breakout box, a 10-way mil-spec socket (02E-12-10S).

(a)	(b)	(c)	(d)	Function
A	H		F	Hole lock motor
B	b		K	Hole lock motor return
C	Z	Z		Inclinometer power
D	c	c	B	+ 12 to 24 V DC power
E	b	b	A	0 V power
F	G	G		Mass position, vertical channel
G	J	J		Mass position, N/S channel
H	L	L		Mass position, E/W channel
J	A	A		Velocity +ve, vertical channel
K	B	B		Velocity –ve, vertical channel
L	C	C		Velocity +ve, N/S channel
M	D	D		Velocity –ve, N/S channel
N	E	E		Velocity +ve, E/W channel
P	F	F		Velocity –ve, E/W channel
R	P	P		Calibration signal (all channels)
S	R	R		Calibration enable (all channels)
T	T	T		Y tilt
U	S	S		X tilt
W	K	K		*BUSY* LED

V	U	U		1 s response mode (Centre)
X	V	V		Direct
Z	W	W		(Unlock)
Y	X	X		(Lock)
b				*Acc/Vel* mode switch*
e	N	N		Signal ground
f	Y	Y	E	Control signal ground
j				Case ground

*The *Acc/Vel* mode switch pin is used by the automatic centring process to switch the instrument temporarily into a mode where its response at normal frequencies is flat to acceleration, and thus in linear proportion to the mass position. The sensor returns to its operational mode once the centring process is completed.

7 Specifications

Velocity sensors	Velocity output bandwidth	*spec* – 100 Hz*
	Mass position output	DC – *spec* Hz*
	Velocity sensitivity	2 × 1000 V/m/s**
	Mass position sensitivity	1000 V/m/s^2
Controls	Mass locking and unlocking	remotely operated
	Mass centring	automatic, microprocessor controlled
Mechanics and electronics	Sensors	3 orthogonal sensors, each 0.180 kg
	Lowest spurious resonance	above 140 Hz
	Sensor transducer type	capacitive displacement
	Feedback transducer type	magnet/coil
	Connector	pressure tight, waterproof
	Borehole diameter	89 – 229 mm
	Temperature range with masses locked	–20 to +75 °C
	Operational temperature range	–10 to +65 °C
Power	Supply requirements	12 – 30 V DC
	Current at 24 V DC	75 mA†

**spec* refers to the quoted frequency response value, *e.g.*, for a “30 s” sensor, the value of *spec* would be 30 s = 0.033 Hz.

**Sensors are available with a range of sensitivities between 2 × 750 and 2 × 10,000 V/m/s.

8 Revision history

2006-11-15	C	Corrections and clarifications
2006-10-06	B	Updated borehole orientation method
2006-03-27	A	New document