CMG-3V / 3ESPV

Vertical Borehole Seismometers

Document template

Part No. MAN-BHO-0004

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1 Introduction

The CMG-3V and 3ESPV are single-axis seismometers whose components are housed in a sealed borehole sonde.

The two sensors are operated identically, the only differences being in the internal sensor mechanics, which affect the noise profile of the instrument and the available response options.



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 mass locking are carried out through a surface control box.

The 3V's sensor is sensitive to ground vibrations in the frequency range 0.0027 – 50 Hz, depending on the options you have specified. It 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

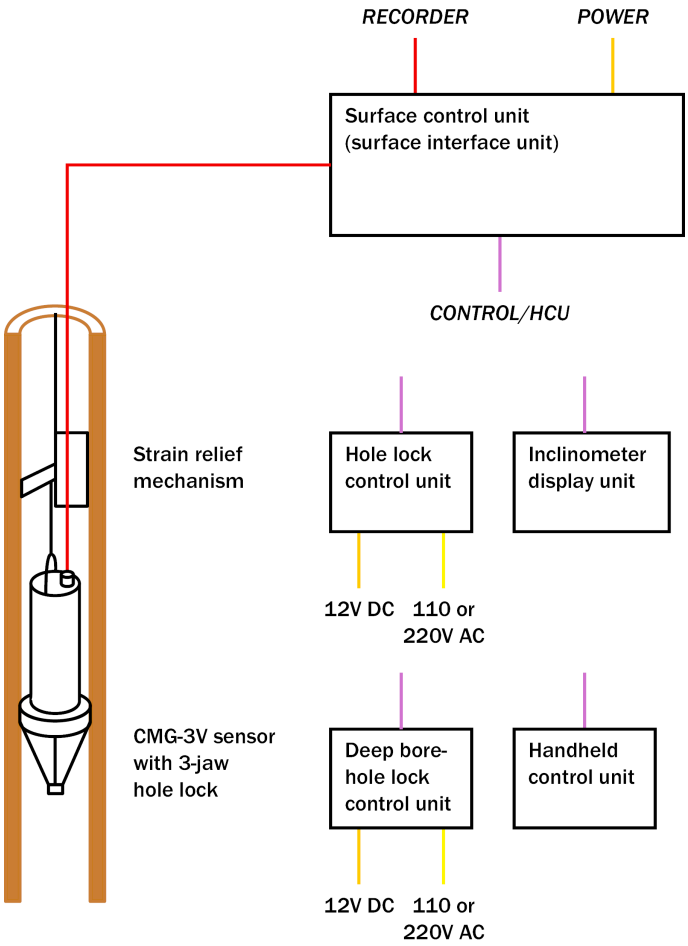
poles/zeros notation.

1.1 System configuration

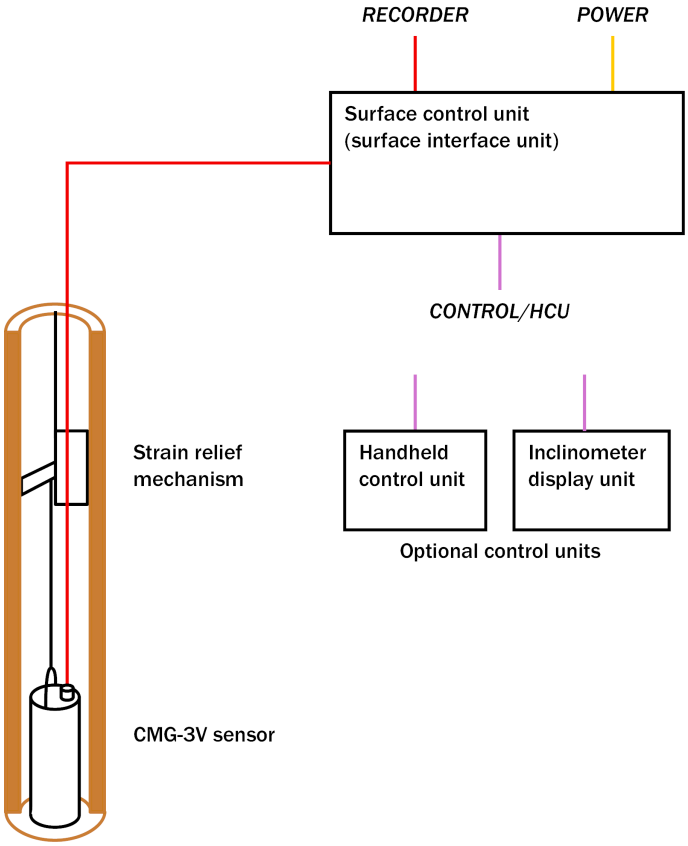
The CMG-3 series of seismic instruments share a number of features:

- 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 surface control unit, and
- a number of additional, optional control units which may be connected to the surface control unit to perform installation and maintenance tasks.

For example, a borehole or pit installation of a CMG-3V or 3ESPV instrument with a three-jaw hole lock has the following layout:



CMG 3-series instruments are also suitable for installing in boreholes with sand backfill. In this case no hole lock unit is necessary.



The CMG-3V sensor is identical to the vertical-component module of the 3TB instrument, allowing you to build mixed arrays of 3V and 3TB sensors with identical response characteristics. Likewise, the CMG-3ESPV and 3ESPB instruments use the same vertical component.

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 surface control unit.

1.3 The hole lock system

The hole lock clamp unit in a 3V or 3ESPV 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 to the seismic sensors.

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

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

The three-jaw hole 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.



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 single-jaw hole lock

A single-jaw hole lock is available which is smaller and lighter than the three-jaw lock, but does not grip the borehole casing with as much force. 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.

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.

1.4 Vault conversion base

As an alternative to borehole installation, the CMG-3V and 3ESPV can be supplied with a vault conversion base. This metal piece can be attached to the bottom of the sensor module to provide a stable three-point contact with a seismic pier.

The instrument can then be covered with an insulating box or backfilled with dry sand as in the photograph below.



The conversion base can easily be replaced with a hole lock module in the event that the instrument is later installed in a borehole.

2 First encounters

2.1 Unpacking and packing

The 3V and 3ESPV seismometers are 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 instrument and should be reused whenever you need to transport it. Please note any damage to the packaging when you receive the equipment, and unpack on a clean surface. The package should contain:

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

2.2 Handling notes

The 3V and 3ESPV are sensitive instruments, and is easily damaged if mishandled. It 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.

- Never lay the sonde horizontally whilst the sensors are unlocked. 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 instrument

The instrument is delivered in separate sections, which need to be assembled before it 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 top surface of the hole lock and the base of the sensor are clean.

2. Carefully lift the sensor, and connect the cable from the hole lock to the connector on the sensor base.

3. Gently lower the sensor onto the hole lock, making sure that it is properly aligned and no wires are trapped beneath the base.

4. Using the cap head screw provided, fasten the sensor base onto the hole lock.

2.4 Control units

The 3V and 3ESPV are operated from the surface through various control units. All the instrument 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, with 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.

For deep-borehole installations (over 50 m) we recommend that you use a breakout box with internal line drivers, to ensure that logic signals are reliably transmitted to the sensor. Contact Güralp Systems for advice.

Note: The breakout box looks very similar to other Güralp breakout boxes. However, its internal wiring is different from that used for some other instruments. For this reason, if you are using several instrument types, you should mark each breakout box clearly so that it is always used with the correct instrument.

Surface control units

Most newer 3V and 3ESPV units have state-of-health (SOH) electronics installed within the sensor housing, which manage the instrument's mass control functions. In some installations, however, these electronics are installed at the surface, in a dedicated control unit. This unit provides the same connectors as the breakout box, but is rather larger. In addition to the SOH electronics, it contains a differential input to differential output amplifier, and a fuse to protect the internal DC–DC converter against polarity reversal. Its connectors are the same as those on the breakout box, except that

- *POWER* and *HOLELOCK POWER* are brought out on separate 10-pin connectors, and

- the *SENSOR* connector is a 32-pin mil-spec plug, with a straight-through cable to the sensor.



The surface control unit is supplied with a 3 m cable as standard. This can be extended up to 100 m without compromising signal quality. The sensor uses amplifiers with high common mode rejection to ensure the signal to noise ratio is maintained over this distance. 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.

The push-button switches which operate the sensor's control commands (mass locking, unlocking, and centring) are housed beneath waterproof lids. You must release the fixing screws holding the lids down before you can initiate any commands.





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.

Mass locking and unlocking

The instrument is delivered with its sensor mass locked, so that they will not be damaged in transit. You should lock the mass whenever you need to move the instrument.

To unlock the instrument, hold down the *ENABLE* and *UNLOCK* buttons (or the *UNLOCK* switch on a surface control unit) for at least six seconds. The sensor's microcontroller will free the mass and ready it for use. Once this is done, the controller automatically starts a centring cycle. If you issue an *UNLOCK* command when the mass is already free, the instrument will attempt to lock the mass first, and then unlock it in sequence as normal.

To lock the instrument, hold down the *ENABLE* and *LOCK* buttons (or

the *LOCK* switch) for at least six seconds. The sensor's microcontroller will lock the vertical sensor mass. The instrument is now protected against accelerations up to 10*g*, and is ready for transportation.

Centring

To centre the instrument, hold down *ENABLE* and *CENTRE* buttons (or the *CENTRE* switch) for at least six seconds. If the masses are locked, the microcontroller will do nothing. Otherwise, it attempts to zero the output of the sensor. Inside, a motor-driven adjuster presses a small spring lever against the boom until the mass position output indicates an offset close to zero.

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, start another centring cycle. You will probably need to perform several rounds of centring before the masses are ready.

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.



Connections

The HCU provides

- two identical 26-pin connectors for attaching to the *HCU* or *RECORDER* connectors of the Surface Control Unit, and

- a 10-pin connector through which you can power the instrument, if desired. The power pins on this connector are directly connected to those on the *SENSOR POWER* connector of the Surface Control Unit. When using this alternative power connection, you should ensure you do not inadvertently connect two power supplies together.

Signal meter

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

- To monitor the velocity output, switch the dial to *V VEL*.

- To monitor the mass position output, switch the dial to *V MASS POS*.

- 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 and control

You can calibrate a 3V or 3ESPV sensor through the HCU by connecting a signal generator across the yellow and green *CALIBRATION SIGNAL* inputs and turning the *CAL ENABLE* dial to *V*. The sensor's response can now be monitored or recorded, and calibration calculations carried out.

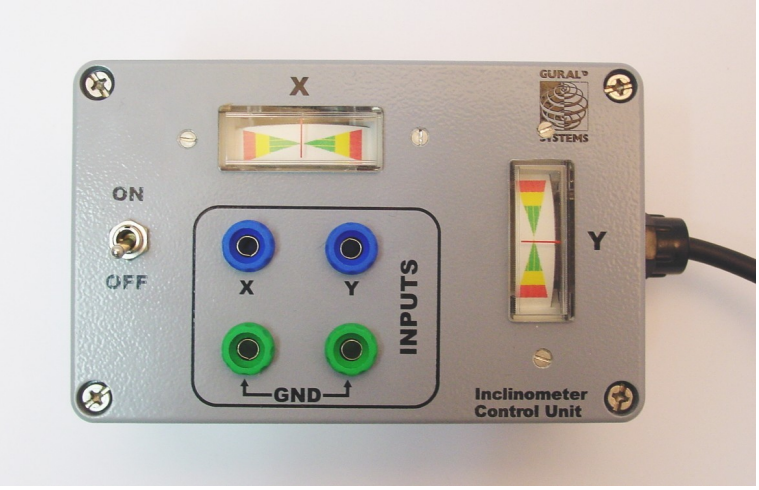
The section of the HCU below the calibration lines controls the instrument's mass control system. To initiate locking, unlocking, or centring, hold down the *ENABLE* switch on the HCU *together with* the appropriate switch for the command you want to issue for at least six seconds.

Banana sockets

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

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. You should check the inclination of the instrument *before* unlocking the sensor masses, since too great a tilt can damage the components.



To measure the attitude of a 3V or 3ESPV instrument:

1. Connect the inclinometer monitor unit to the *CONTROL* connector of the surface control unit.

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.

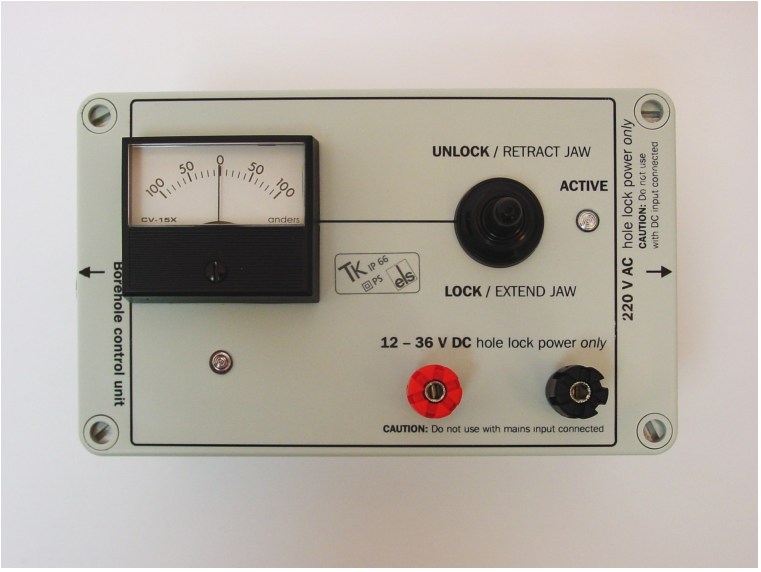
4. If both tilts are within the green shaded region, the instrument is close enough to vertical that it can be levelled and centred successfully. If either output is in the red shaded region, you should *not* attempt to unlock or centre the sensor masses. Instead, if possible, you should move the instrument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

2.5 Operating the hole lock

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



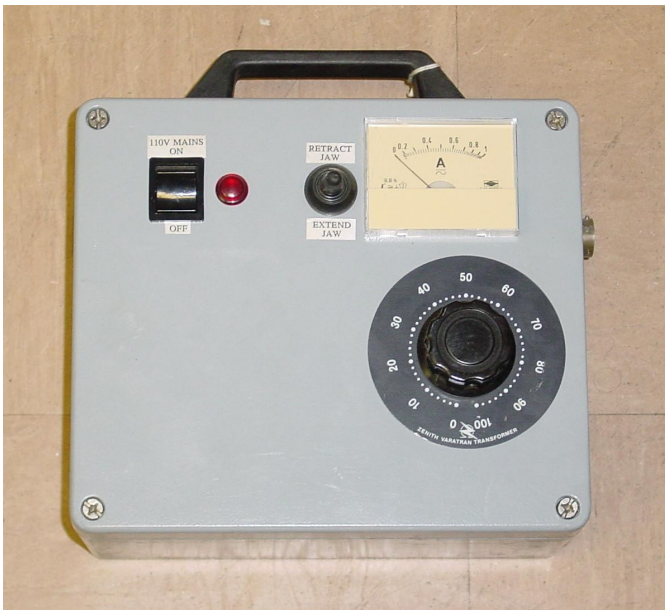
Caution: The hole lock may be using high-voltage mains (outlet) power.

1. Connect the hole lock control unit to the *HOLELOCK POWER* connector of the surface control unit, 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. If you are supplying power to the sensor through another connector, ensure that it is switched off whilst you operate the hole lock.

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 Surface Control Unit'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 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 surface Control Unit and Holelock Control Unit, and attempt to retract the hole lock arm (see Section 2.5, page 19.) 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.

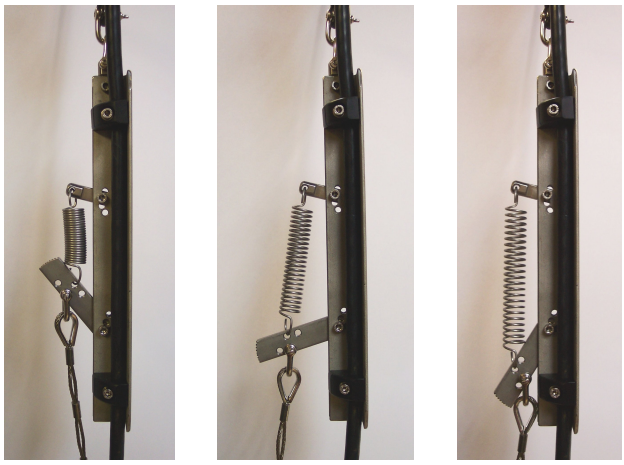


4. Attach the lifting loop to the sensor using four M5×16 screws (provided).



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 2.5, page 19) 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.

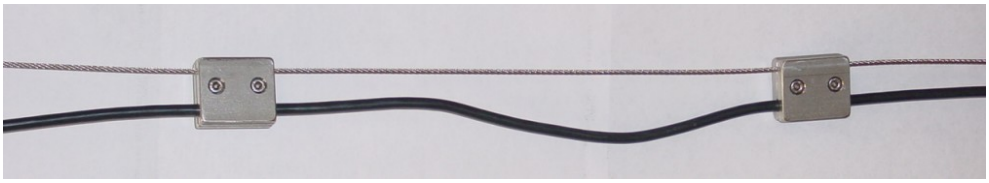
12. Power up the instrument from a suitable power supply.

13. Level and centre the sensor (see Section 3.5, page 39) 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. Lock the sensor masses once more, tension the load bearing cable and retract the hole lock arm.

16. 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.



17. Fix the sensor system into the borehole using the hole lock arm (see Section 2.5, page 19.)

    If you are installing the sensor 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.

18. 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.

19. 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.

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

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

22. The sensor can now be levelled and unlocked ready for use.

3.2 Installing a sensor using sand backfill

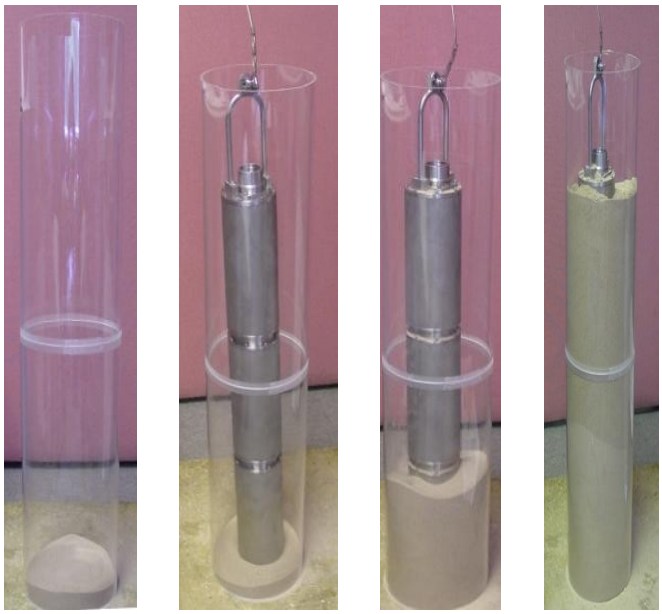
Dry sand backfill is a convenient and effective way of installing a borehole or posthole sensor in a time-stable environment. The presence of sand not only fixes the sensor in place at the bottom of the hole, but also reduces noise due to air convection.

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.

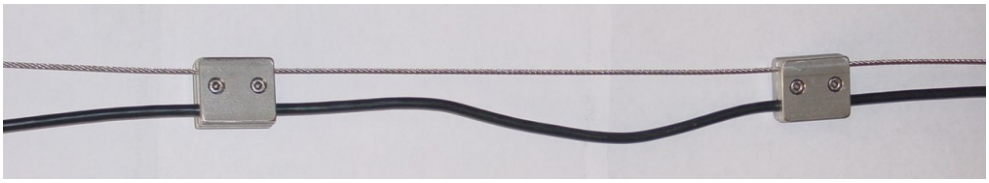
9. Position the assembly over the top of the borehole. Do not allow it to drag across the ground.

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.

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 2.4, page 18, 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 centred and unlocked (see Section 3.5, page 39)

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).



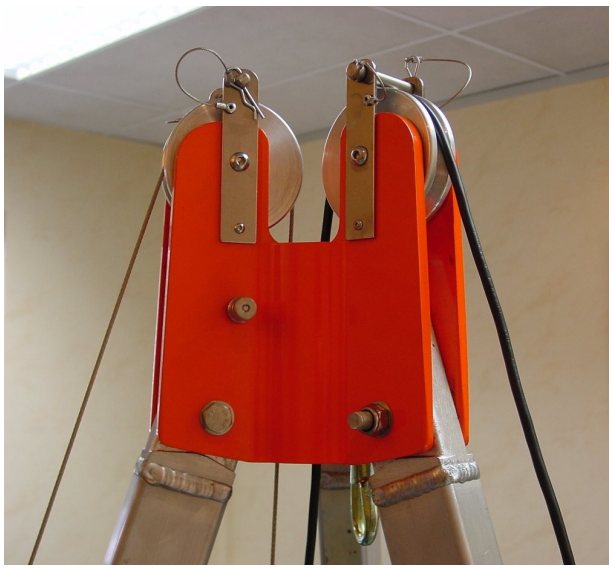


3. Erect the tripod above the borehole, and run the yellow retaining tape through the loops. Fasten together the ends of the tape.



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.

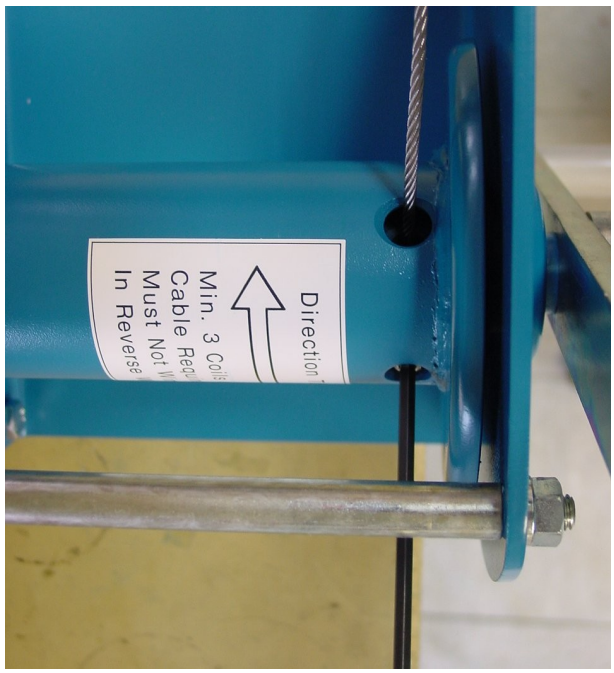
5. Run the sensor signal cable through the other pulley. Secure both cables in their pulleys by sliding the attached bolts into place.



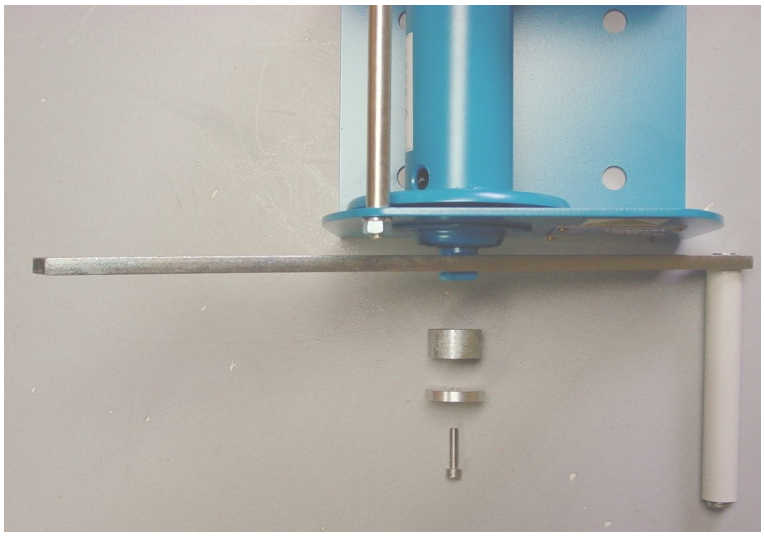
6. Extend each of the three legs in turn to the height you require, finishing at the leg with the winch attached.



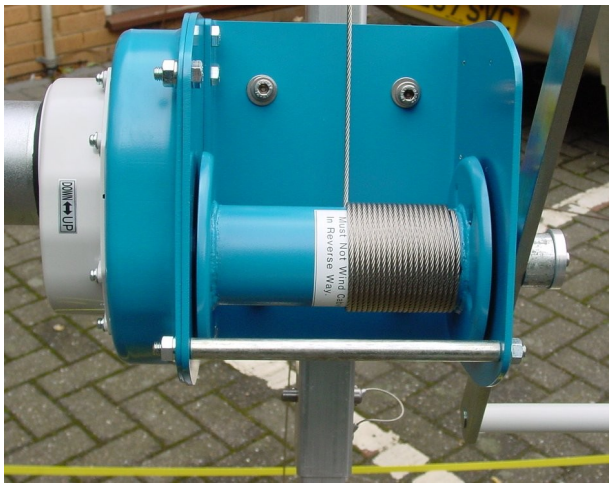
7. Take the end of the load-bearing cable without the loop, and screw it to the axle inside the winch using a 4 mm Allen key (provided) as shown.



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.

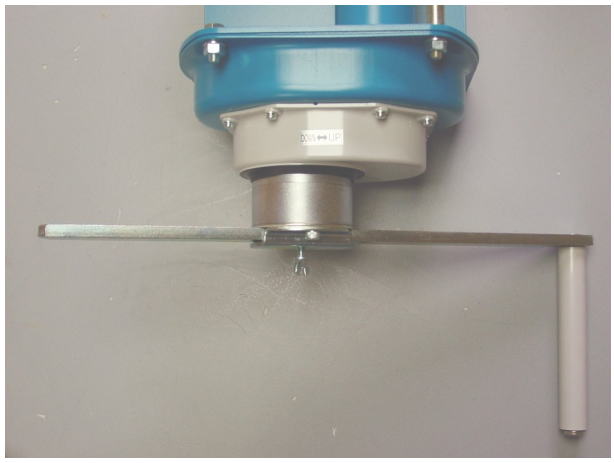


9. Wind the cable onto the winch by rotating the handle. Ensure that the cable builds up neatly across the drum. Continue winding until the loop on the other end is as high as you need it to install the equipment.



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 Levelling and centring

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

The 3V and 3ESPV instruments are less susceptible to tilt than instruments with horizontal components. However, to get the best performance you should still make sure the instrument is as close to vertical as possible.

1. Connect an inclinometer monitor unit to the borehole control unit.

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, 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 sensor control unit, if you have one.

6. Unlock the sensor masses, either by pushing the *UNLOCK* buttons of the borehole control unit, or by holding down the *ENABLE* and *UNLOCK* switches of the HCU together for at least six seconds.

7. When you press the switches, the *BUSY* LED will come on. After a while, the unlocking process will be completed, and the instrument will start centring itself. Whilst this happens, the *BUSY* LED will flash.

8. Monitor the mass position output, either using the HCU or your recording system. The microcontroller inside the unit will zero the output from the sensor. After successful centring, the mass position output should be in the range 0.1 – 0.8 V.

9. If the centring process leaves the mass position output above ±1.1 V, repeat steps 4 and 5. You will probably need to initiate the centring process several times before the mass is adequately centred.

4 Calibrating the 3V / 3ESPV

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 the sensor:

Velocity Output (Differential) : The sensitivity of each component to velocity at 1 Hz, in volts per m/s. Because the 3V 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 fm = 1 Hz, with $s = j f$m, where $j = \sqrt{-1}$.

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

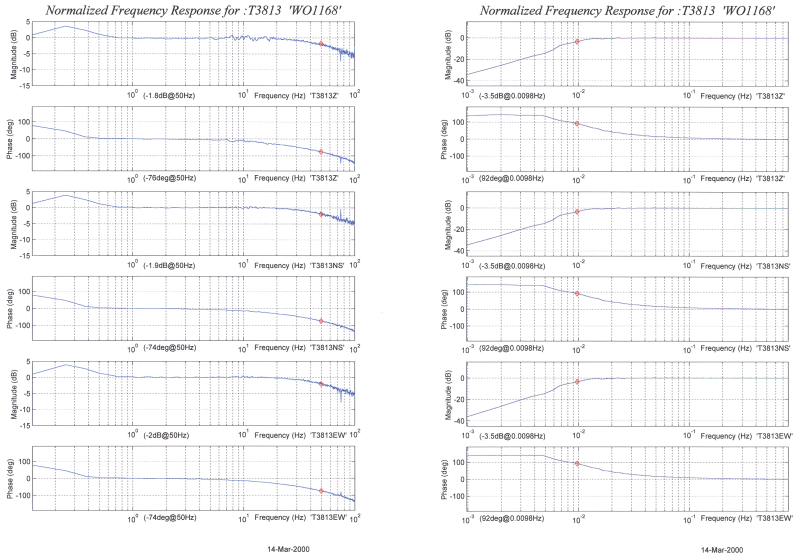
$$H(s) = N \frac{\prod_{i=1,n} s - Z_i}{\prod_{j=1,m} s - P_j}$$

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

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

Frequency response curves

The frequency response of each component of the instrument 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 3V and 3ESPV 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.

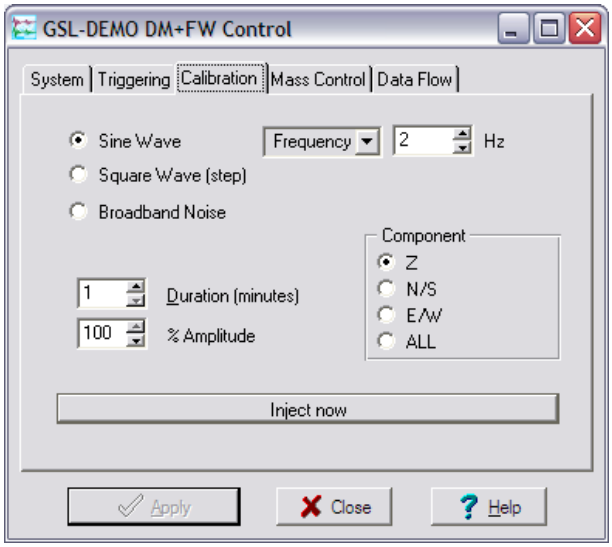
Before you can calibrate the instrument, its calibration relays need to be activated by pulling low the *CAL ENABLE* line on the instrument's connector for the component you wish to calibrate. Once enabled, a calibration signal provided across the *CAL SIGNAL* and *SIGNAL GROUND* lines will be routed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

4.3 Calibration with Scream!

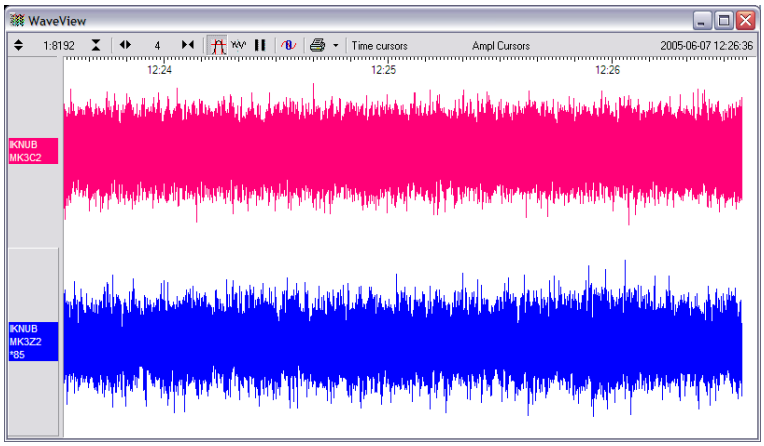
Güralp digitizers provide calibration signal generators to help you set up your sensors. Calibration is most easily done through a PC running Güralp's Scream! software.

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 *Z* component and a suitable duration and amplitude, and click **Inject now**. A new data stream, ending C*n* (*n* = 0 – 7) or MB, should appear in Scream!'s main window containing the returned calibration signal.



3. Open a Waveview window on the calibration signal and the returned streams by selecting them and double-clicking. The streams should display the calibration signal combined with the

sensors' own measurements. If you cannot see the calibration signal, zoom into the Waveview using the scaling icons at the top left of the window or the cursor keys.

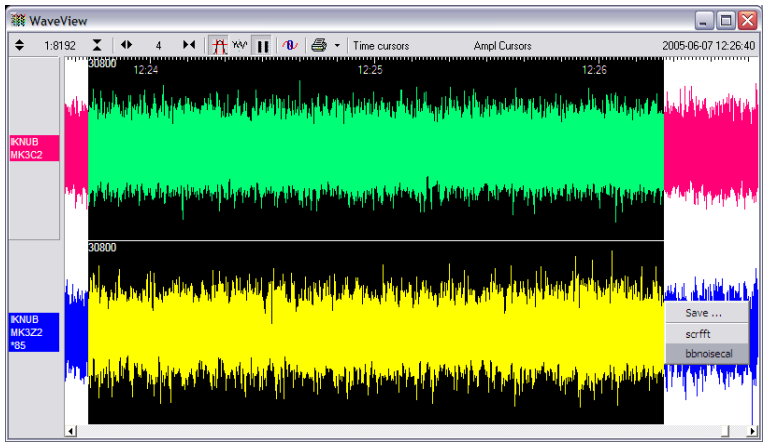
Drag the calibration stream `C`*`n`* across the Waveview window, so that it is at the top.

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

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

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

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

8. 

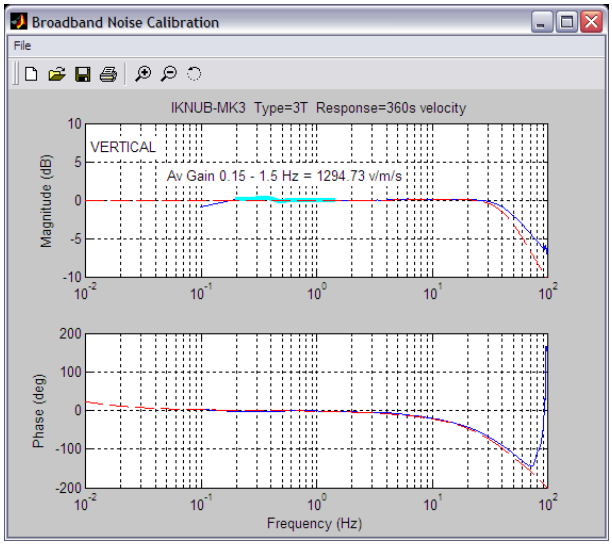
9. The script will ask you to fill in sensor calibration parameters.

   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! manual for details.

10. 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-3V / 3ESPV, 30 s – 50 Hz response	`CMG-3B_30S_50HZ`	`V`
CMG-3V / 3ESPV, 100 s – 50 Hz response	`CMG-3B_100S_50HZ`	`V`
CMG-3V / 3ESPV, 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 3V.

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 Inside the 3V / 3ESPV

5.1 The sensor

The inertial mass of the sensor 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; this spring is pre-stressed, with a natural period around 0.5 s.

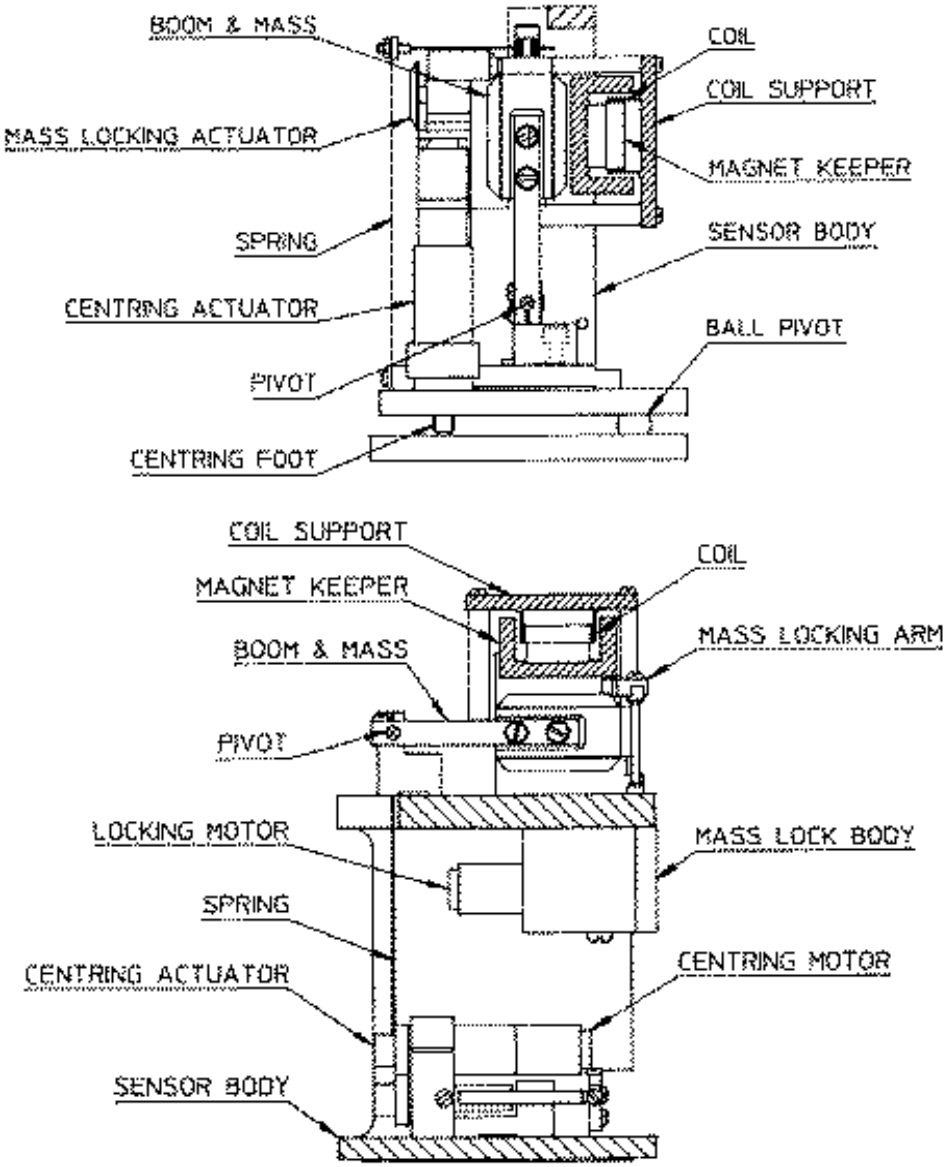
The sensor and hole lock units are stacked one on top of the other with a set of accurately-machined stacking tubes, which also form part of the sensor's pressure housing. Fixing holes provided on each end face allow for simple and accurate assembly. The base of each unit includes a double “O” ring to isolate the sensor from any pressure variations in the atmosphere.

The 3V and 3ESPV function by monitoring the position of the mass with a capacitative position sensor. Signals from the sensor 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 sensor mass is locked securely in its frame 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 sensor must be levelled so that its mass is centred in its equilibrium position. These adjustments are made by a small DC motor controlled remotely.

See Chapter 3, page 22, for detailed instructions on how to set up your installation.



The signal voltages output by the instrument are proportional to ground velocity, and are transmitted from the instrument on balanced differential lines. In addition, mass position signals are sent as single-ended circuits referred to analogue ground on the output plug. The 3V also receives control signals, which are used to clamp and unclamp 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.

5.2 The control system

The internal operations of the sensor are supervised by a control microprocessor, which drives the mass clamping and centring

adjustment motors. It responds to commands sent on three input lines by grounding for 0.2 – 7 seconds.

The signals you can send to the microprocessor are termed *LOCK*, *UNLOCK*, and *CENTRE*. 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 Handheld 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, Handheld Control Unit or digitizer. If you send control signals to the 3V manually, you must ensure that the lines are pulled high after sending the signal, or the equipment may be damaged. A "biased-OFF" type switch can be used for this purpose.

LOCK

This command locks the mass in position, ready for transportation.

If *LOCK* is activated when the mass is already locked, the processor will unlock it and attempt to lock again. This is useful if you suspect that the locking procedure has failed.

The *BUSY* LED is lit whilst locking is in progress.

UNLOCK

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

If *UNLOCK* is activated when the mass is already unlocked, the processor will lock it and attempt to unlock again. This is useful if you suspect that the locking procedure has failed.

During the *UNLOCK* procedure, the instrument automatically performs a round of centring. You can use the *BUSY* LED to monitor the progress of unlocking:

1. The instrument checks to see whether the mass is locked, and unlocks it if necessary.

2. The mass is centred by applying pulses to the motor. This stage

is often very short, since the vertical mass is locked near its central position.

CENTRE

This command re-centres the mass. If the mass is clamped, or if the sensor mass position does not exceed ± 1.2 V, the *CENTRE* command does nothing. Otherwise, it attempts to zero the output of the sensor. by exerting small extra forces on the boom. A motor-driven adjuster presses a small spring lever against the boom until the mass position sensor indicates an offset close to zero.

The *BUSY* LED will pulse whilst the mass is centred. The centring process is often very short, since the vertical mass is locked near its central position.

After successful centring, the mass position output should be in the range 0.1 – 0.8 V. If the centring process leaves the mass position output above ±1.1 V, you should start another centring cycle by activating the *CENTRE* command again.

5.3 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 CMG-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.

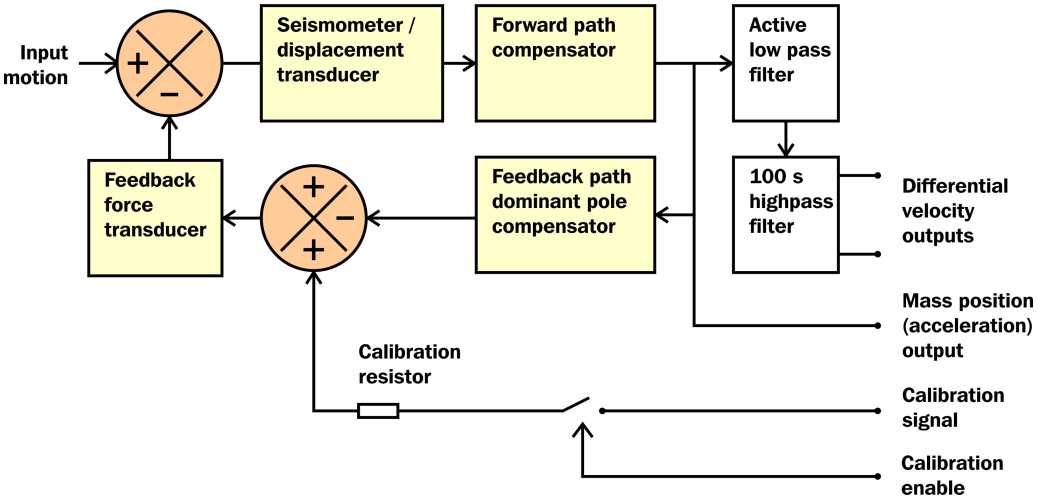
Force feedback seismometers of this type rely on the assumption that the force transducer produces a field of constant strength. The

magnetic circuit and magnet/pole assembly in the 3V and 3ESPV are designed so that the field strength from the feedback transducer is constant over large deflections and current levels. Tests have shown that the mechanical suspension system and electronics of a 3V 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 CMG-3 series instrument, known as *hybrid* and *conventional-response* feedback.

Hybrid feedback

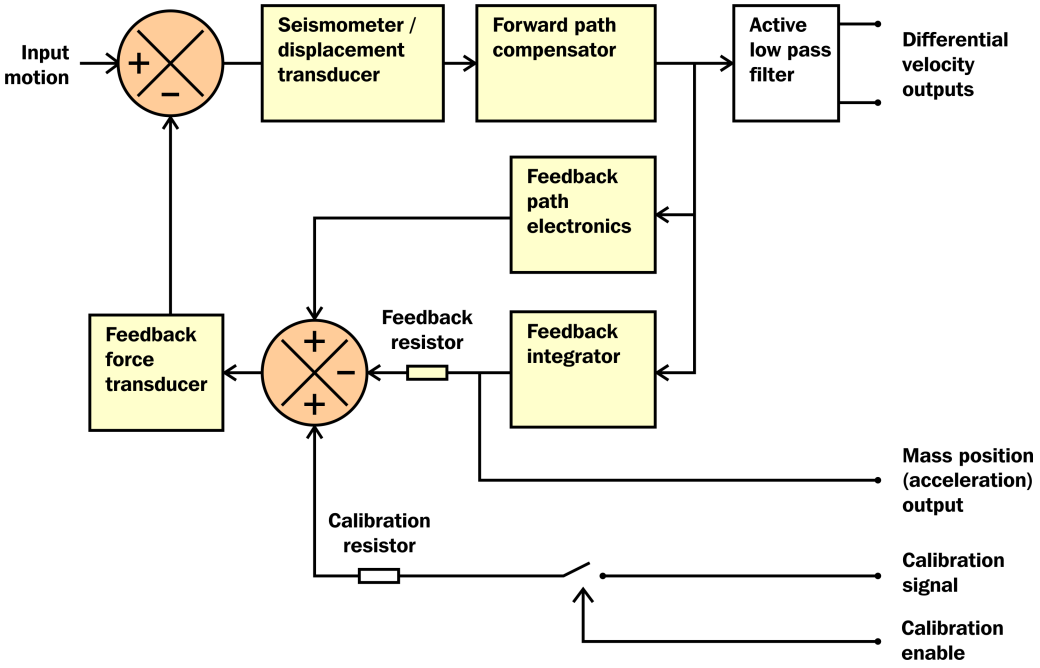


The *hybrid* feedback circuit contains a single capacitor in parallel with a resistor, resulting in a single dominant pole at 0.033 Hz (30 s). Below this frequency, the response of the seismometer is flat to ground acceleration; above it, the response is flat to velocity. (Other values for the acceleration-velocity corner can be provided upon request.) 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 cutoff 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.

Conventional-response feedback

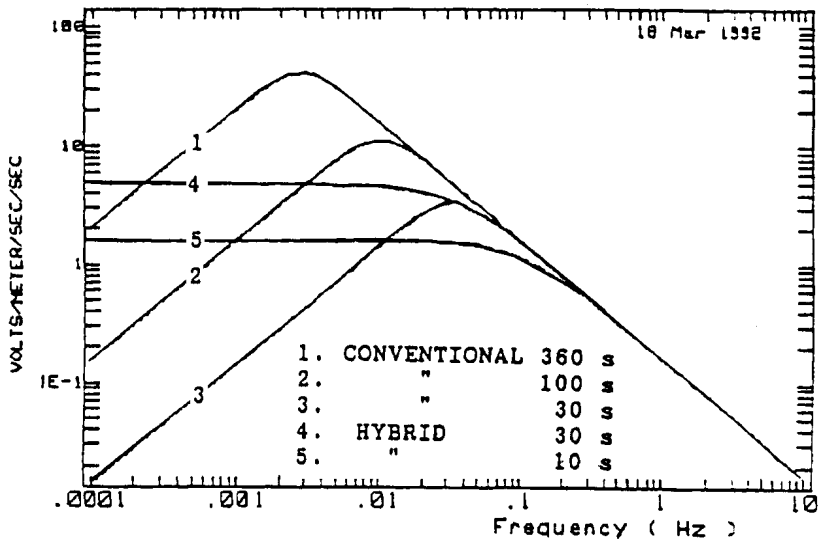


The *conventional-response* feedback system has an additional parallel feedback circuit, consisting of a non-inverting integrator in series with a resistor. This arrangement results in two poles at specified frequencies. The velocity response of a conventional-response system is defined by a transfer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

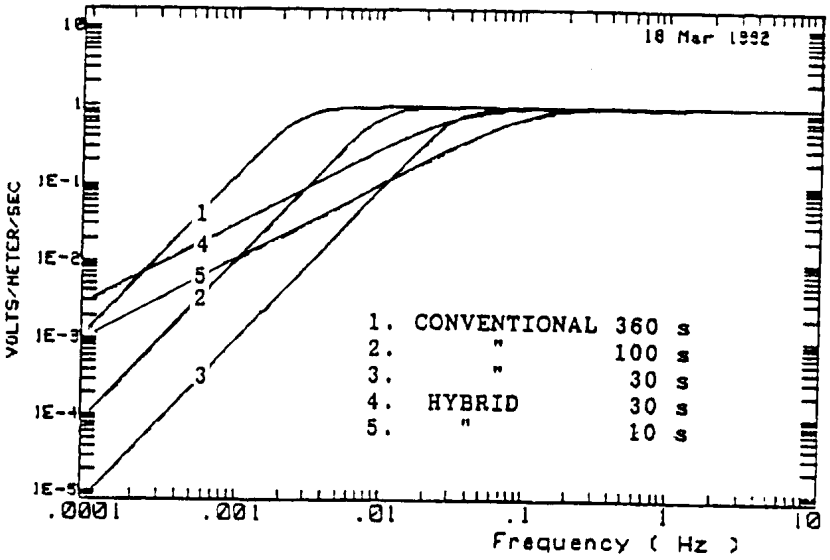
The seismometer can be supplied with an equivalent resonant frequency of 0.033 Hz (30 s), 0.01 Hz (100 s) or 0.0083 Hz (120 s) as required. An active low-pass filter provides a high-frequency cutoff point at a frequency you specify.

Comparisons

The figures below plot the comparative response of a conventional velocity output broadband sensor and a hybrid output broadband sensor. The upper graph shows the response in terms of output against input acceleration in units of V/m/s^2, whilst the lower graph is plotted in terms of output against input velocity, in V/m/s.



Relative Responses to Ground Acceleration.



Relative Responses to Ground Velocity.

6 Connector pinouts

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

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

Column (b): The *SENSOR* connector on the breakout box, a 32-way mil-spec plug (02E-19-32P).

Column (c): The *RECORDER* and *HCU* 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	A			Hole lock motor
B	B			Hole lock motor return
C	C	Z		Inclinometer power
D	D	c	B	+ V power (12 to 24 V)
E	E	b	A	0 V power
F	F	G		Mass position
		K		*BUSY* LED
J	J	A		Velocity +ve
K	K	B		Velocity –ve
R	R	P		Calibration signal
S	S	R		Calibration enable
		U		Centre
		V		Direct
		W		Unlock
		X		Lock
V	V			Centring motor (for offset zeroing)
Y	Y			Lock motor
b	b			Velocity / acceleration mode switch (see Note)

e	e	N	Signal ground
		Y	Control signal ground
f	f		Motor return (centring and lock motors)
	j		Case ground

Note: The “velocity / acceleration 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 surface control unit returns the sensor to its operational mode once the centring process is completed.

7 Specifications

Hybrid sensors	Velocity output bandwidth	0.1 – 50 Hz
	High pass filter output flat to acceleration	0.01 Hz – *spec**
	High pass filter output flat to velocity	*spec* – 50 Hz*
	Mass position output	DC – 0.1 Hz
	Velocity sensitivity	1400 V/m/s
	Acceleration sensitivity	2000 V/m/s^2
Velocity sensors	Velocity output bandwidth	*spec* – 50 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
	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	11 – 36 V DC
	Current at 24 V DC	75 mA†
	Current at 24 V DC during centring (average)	115 mA†
	Current at 24 V DC during locking and unlocking	200 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.

†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.

8 Revision history

2006-05-30	B	Added revision history and updated calibration
2004-12-23	A	New document