3ESPCD – DM24 Versions

Users' Guide

Document No: MAN-C3E-0002

Issue D: June, 2016

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

Table of Contents

1 Preliminary Notes

1.1 Proprietary Notice

The information in this document is proprietary to Güralp Systems Limited and may be copied or distributed for educational and academic purposes but may not be used commercially without permission.

Whilst every effort is made to ensure the accuracy, completeness and usefulness of the information in the document, neither Güralp Systems Limited nor any employee assumes responsibility or is liable for any incidental or consequential damages resulting from the use of this document.

1.2 Warnings, Cautions and Notes

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

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

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

1.3 Manuals and Software

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

1.4 Conventions

Throughout this manual, examples are given of command-line interactions. In these examples, a fixed-width typeface will be used:

`Example of the fixed-width typeface used.`

Commands that you are required to type will be shown in bold:

`Example of the fixed-width, bold typeface.`

Where data that you type may vary depending on your individual configuration, such as parameters to commands, these data are additionally shown in italics:

`Example of the fixed-width, bold, italic typeface.`

Putting these together into a single example:

`System prompt:` **`user input with`** ***`variable parameters`***

2 Introduction

The Güralp 3ESPCD is a full-featured three-axis digital seismometer consisting of three sensors in an ultra-lightweight case, which can measure the north/south, east/west and vertical components of ground motion simultaneously, and a built-in digitiser.

Note: The Güralp 3ESPCD is available with one of two alternative built-in digitisers: the Güralp DM24 and the Güralp CD24. The DM24 version offers greater functionality at the cost of increased power consumption. This document describes the DM24 versions of the instrument. For CD24 versions, please see MAN-C3E-0005.

Each sensor is sensitive to ground vibrations in the frequency range 0.003 Hz to 50 Hz, a broadband frequency response made possible by advanced force-balance feedback electronics. Because of this wide response range, the 3ESPCD can replace many of the instruments conventionally used in a seismic observatory; it also produces true pulse-shape records suitable for modern earthquake mechanism analysis. Its small size and low weight make it an ideal choice for rapid deployment of low-noise installations.

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

The seismometer unit is self-contained apart from its 12 V power supply. Once levelled and centred, it will begin operating automatically. Its output is digitised within the sensor by the internal DM24 digitiser, which provides data streams in GCF format. The instrument can be connected to a PC's serial port or to a Güralp Systems data module using the cable supplied. The digitiser also controls the instrument's centring and mass locking processes.

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

2.1 Sensor response

The 3ESPCD can be supplied with a response which is flat to velocity from 100 Hz to any of 0.1 Hz (10 s), 0.033 Hz (30 s), 0.016 Hz (60 s), 0.01 Hz (100 s) or 0.0083 Hz (120 s). Alternatively, a hybrid response function may be provided. See section 7.1.1 on page 76 for more details.

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

3 Installing the 3ESPCD

3.1 First encounters

3.1.1 Unpacking

The 3ESPCD seismometer is delivered in a single transportation case. The packaging is specifically designed for the 3ESPCD 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 safe, clean surface. The package should contain:

- the seismometer;
- a GPS unit, if ordered, with cable;
- a 10-pin connector for your power/data lead (see below); and
- a calibration and installation sheet.

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

- a handle with North indication,
- DATA OUT and GPS connectors;
- a mil-spec FireWire connector;
- other optional connectors as ordered;
- a bubble level,
- an air vent port,
- two adjustable feet, and
- two accurate orientation pins (one brass and one steel).

3.1.2 Serial number

The sensor's serial number can be found on the label stuck to the top lid of the sensor. You should quote this serial number if you need assistance from Güralp Systems.

3.1.3 Handling notes

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

- Avoid bumping or jolting any part of the sensor when handling or unpacking.
- Do not kink or walk on the data cable (especially on rough surfaces such as gravel), nor allow it to bear the weight of the sensor.
- Do not connect the instrument to power sources except where instructed.
- Do not ground any of the signal lines from the sensor.
- Avoid moving the instrument whilst the masses are unlocked. The 3ESPCD is designed to tolerate a certain amount of motion with the sensor masses unlocked, e.g. over short distances carried by hand. For example, if the remote locking procedure fails, removing the instrument for diagnostics is unlikely to damage it. However, you should always lock the sensor masses before shipping or transporting the sensor over longer distances.

3.1.4 Connections

The instrument has the following connectors:

- The DATA OUT connector outputs RS232 data to your PC or data module, and also provides power to the instrument.
- The GPS connector is intended for connection to a Güralp GPS module.
- The FIREWIRE connector can be attached to any IEEE.1394 (FireWire) hard disk or data storage unit using the cable provided.

3.1.5 Power supply

The sensor requires a 12 V power supply, which it obtains through the DATA OUT port. You may wish to terminate the supplied power cable in order to connect a 12 V power source to this connector: it is supplied with bare ends. Using a 12 V, 25 Ah sealed heavy-duty lead-acid battery, you should expect the instrument to operate for around a week without recharging.

A power management module can be installed as an option, which allows the 3ESPCD to operate from a 10 – 15 V supply range. This module also cuts the input power to the sensor electronics if it drops below 10.5 V, to minimize discharge from battery-operated installations.

The 3ESPCD draws a nominal current of 200 mA from a 12 V supply when in use. During locking and unlocking of the sensor masses, this current rises briefly to 750 mA. It is recommended that you carry a spare 12 V battery when visiting an installation for maintenance, in case the sensor needs to be moved and the on-site batteries no longer have sufficient charge to perform the locking procedure.

3.1.6 FireWire

The digitiser has an IEEE.1394 (“FireWire”) port, which you can use to download data onto a compatible hard disk.

Before you can use the disk, you will need to erase/format it. The digitiser saves data on the hard disk in raw mode, so you cannot use a PC's standard software to reset the disk.

To erase/format a FireWire disk for use with the 3ESPCD:

- Power up the digitiser, and connect it to your computer's serial port.
- Open its terminal console. To do this using Güralp Systems' Scream! software, right-click on the digitiser's icon (once it appears) and select `Terminal...`.

  or

  From a Güralp EAM, issue the command `data-terminal` and select the appropriate data source from the menu.
- Issue the command `DISKMENU`. You will see the message

  `Plug in FireWire cable`
- Plug in your disk. The digitiser will display information about the disk as soon as it is detected. Within the next seven seconds, press any key to bring up the disk menu.
- Key R to reset the disk.
- When the reset is complete, remove the disk.

You will now be able to download data onto the disk when required.

3.2 Installation notes

The goal of any seismic installation is to ensure that wave-trains arriving at the instrument accurately reflect the internal motion of subsurface rock formations. To achieve this, the seismometer and its emplacement need to be considered as a mechanical system, which will have its own vibrational modes and resonances. These frequencies should be raised as high as possible so that they do not interfere with true ground motion: ideally, beyond the range of the instrument.

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

- fluctuations in temperature,
- turbulent air flow around walls or trees, or around sharp corners or edges in the immediate vicinity of the sensor;

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

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

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

Temporary installations can be protected against spurious vibrations by

- selecting a suitable site,
- placing the instrument in a protective enclosure (an open-sided box of 5 cm expanded polystyrene slabs, placed over the instrument and taped down to exclude draughts, makes an excellent thermal shield),
- standing the sensor on bedrock where possible, or at least deep in well-compacted subsoil;
- clearing the floor of the hole of all loose material; and
- using as little extra mass as possible in preparing the chamber.

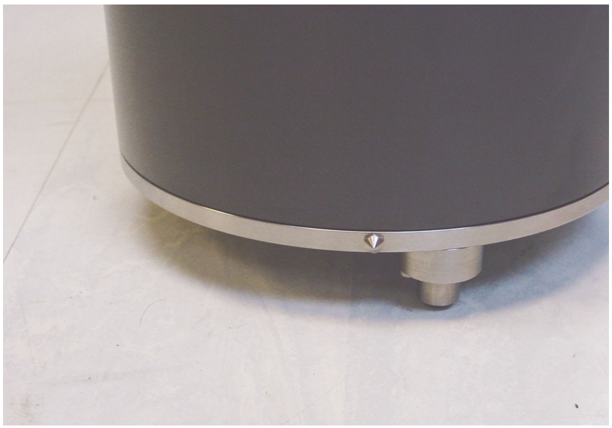
After installation, the instrument case and mounting surface will slowly return to the local temperature, and settle in their positions. This will take around four hours from the time installation is completed. If you require long-period recording, you should re-zero the instrument after this time.

3.3 Installing in vaults

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

1. Unpack the sensor from its container, saving the shipping box for later transportation.
2. Prepare the mounting surface, which should be smooth and free of cracks. Remove any loose particles or dust, and any pieces of loose surfacing. This ensures good contact between the instrument's feet and the surface.
3. If it is not already present, inscribe an accurate North-South line on the mounting surface.

4. Place the sensor over the scribed line, so that the brass and steel pointers are aligned with the marked directions, with the brass pointer facing North. This can be done by rotating the base of the sensor whilst observing it from above. The brass pointer can be found next to one of the feet.



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

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

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

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

6. Plug the grey/blue power/data cable into the ten-pin connector on the instrument's lid and connect a 12 V power supply to the ends of the grey cable. Connect the DE9 connector to a PC running scream, using a USB-to-RS232 converter, if required.

   Note: GSL strongly recommend USB/RS232 convertors based on the FTDI chipset. Numerous problems have been found with convertors based on the other common chip-set.

   Alternatively, connect the ten-pin connector on the instrument's lid to a Güralp EAM using cable CAS-DCM-0001 (green).

7. Plug in the GPS cable and connect the GPS receiver.

8. In Scream's set-up dialogue, select the “COM Ports” tab and set the Baud rate of the appropriate COM port to 38,400 Baud. Click OK and wait for the instrument to appear in Scream's source tree.

   Right-click on the digitiser's entry in the source tree and select Control.... Click on the Mass control tab, followed by Unlock. (If the Mass control tab is unavailable, check the sensor type in the Sensor type tab, apply, and open a new Control window.)

   Alternatively, if you are using an EAM, navigate to the Control → Instruments → Port X Instrument... page and click on the Unlock instrument button.

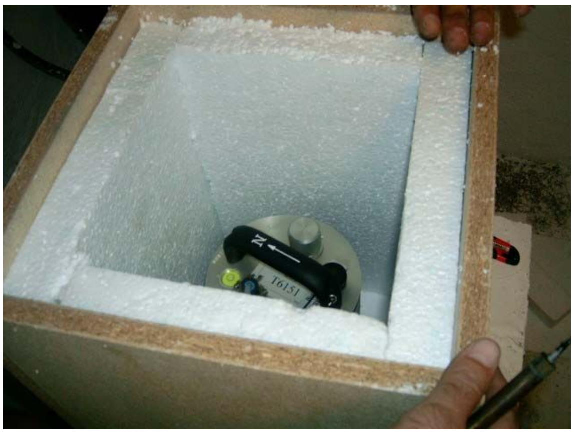
   Caution: After this point, you should be careful not to tilt the instrument or you may damage it.

9. Right-click on the digitiser's entry in Scream's source tree and select Control.... Click on the Mass control tab, followed by Centre.

   Alternatively, if you are using an EAM, navigate to the Control → Instruments → Port X Instrument... page and click on the centre button.

   Monitor the mass positions during the centring operation. You may need to initiate several rounds of centring before the mass positions reach an acceptable value.

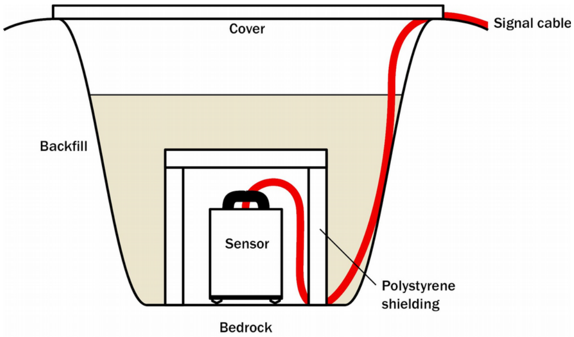
10. Cover the instrument with thermal insulation, for example, a 5 cm expanded polystyrene box. This will shield it from thermal fluctuations and convection currents in the vault. It also helps to stratify the air in the seismometer package. Position the thermal insulation carefully so that it does not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



11. Ensure that the cables are loose and that they exit the seismometer enclosure at the base of the instrument. This will prevent vibrations from being inadvertently transmitted along the cables.

3.4 Installing in pits

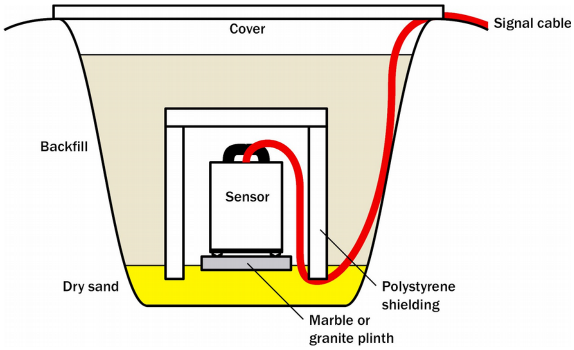
For outdoor installations, high-quality results can be obtained by constructing a seismic pit.



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

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

1. Prepare a hole of 60 – 90 cm depth to compacted subsoil, or down to the bedrock if possible.
2. On granite or other hard bedrock, use an angle grinder to plane off the bedrock at the pit bottom so that it is flat and level. Stand the instrument directly on the bedrock, and go to step 7.
3. On soft bedrock or subsoil, you should install a pier as depicted below.



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

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

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

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

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

7. Set up the instrument as described in Section 3.3 on page 12.

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

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

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

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

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

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

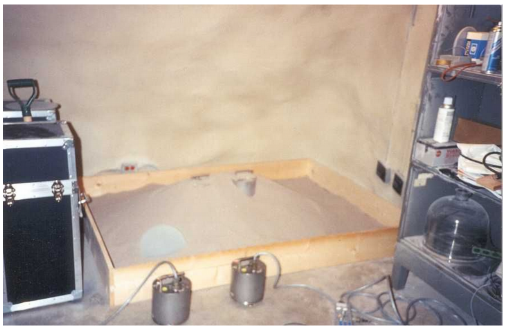
3.5 Other installation methods

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

Some installations introduce a layer of ceramic tiles between a rock or concrete plinth and the seismometer, as shown in the left-hand picture below:

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

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



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

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

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

3.6 Rapid installation

This section details a method of deploying 3ESPCD instruments with the minimum of additional equipment. This is recommended for situations where seismic instrumentation needs to be installed very quickly, e.g. to study a resumption of volcanic activity, or where difficulty of access to the site prevents you from constructing a full seismic pit. You should always construct a pit if possible (see Section 3.4 on page 15), since the data produced will be of significantly higher quality.

3.6.1 Deployment

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

2. Clean the hole down to the bottom, and remove any loose material from the mouth. Ensure that the bottom of the hole is relatively flat.

3. If the bottom of the hole is made of hard rock, you may need to put in some loose sand or soil so that the sensor can be levelled.

4. Connect the sensor to cables for the GPS unit and power source.

5. Carefully insert the instrument into the hole, protected by a tough plastic bag to keep water out. Use a bag strong enough to bear the weight of the sensor and breakout box, so that it can be recovered easily.

6. Press the sensor down firmly into the soil, without tapping or hitting it.

7. Check the bubble level on top of the instrument package. Adjust the instrument's position if necessary so that the bubble lies entirely within the black circle.

8. Pack soil or sand around the instrument to hold it steady. Make sure the soil or sand is firmly compacted and not at all loose.

9. Recheck the bubble level. If you cannot adjust the soil packing at this stage and the sensor is not level, you will need to clear the hole and restart from step 3.

10. Power the sensor and connect it to a laptop. Unlock the masses using Scream's Control window.

11. Place the breakout box and any excess cable on top of the sensor, inside the plastic bag.

12. Group the cables coming from the bag for a distance of about 1 m, and keep them together with insulating tape.

13. Tie the top of the package and fold it over so that water cannot get in. Leave any excess cable within the bag.

14. Cover the installation with soil or sand until it is no longer visible.

15. Attach a GPS unit to the cable coming from the sensor. Seal the connection between the data cable and the GPS unit's IEEE 1394 cable inside a plastic bag to protect it from moisture.

16. Position the GPS unit so that it has a good view of the sky. Bury the cable and connector package so that they cannot be seen.

17. If possible, place the GPS near the instrument so that it can be found more easily, and the connector package near the GPS so you can retrieve data from the instrument without affecting the installation.
18. If you are using a battery as a power source, dig a second hole for it. This hole does not need to be as deep as the pit for the instrument—perhaps 10 cm plus the height of the battery.
19. Attach the sensor power cable to the battery, and wrap it in another plastic bag. Place the bag in the hole.

20. Tie the bag and fold over, to make the battery as waterproof as possible.
21. Bury the power cable between the battery and the instrument, and compact soil or sand around the bag.
22. Fill in and cover the hole so that it is not visible.

3.6.2 Recovery

Care should be taken when recovering the 3ESPCD, since tapping or banging it can cause damage to the sensors inside. The following instructions assume that you have installed the instrument following the steps above.

1. Find the GPS receiver, which will be the only feature visible from the surface, and follow the buried data cable from it to the instrument.

2. Carefully remove earth from the hole until you find the power cable coming from the instrument.
3. Follow the power cable to the battery pit, and carefully dig away the soil to reveal the battery about 10 cm from the surface.
4. Connect a laptop to the data connector and, using Scream's Control dialogue, lock the masses.
5. Disconnect the power cable from the battery. (With the power off, the sensor is less likely to suffer electrical damage during recovery.)
6. Return to the location of the sensor, and dig down to it. You should be able to remove a spade's head depth of soil without hitting the instrument. Beyond that, using a small hand shovel, follow the wires and carefully remove the remaining soil until you can see the plastic bag. Take special care not to damage the wires, which should be tied together in the vicinity of the bag.
7. Carry on removing soil, either with your hands or (very carefully!) with the shovel, until the whole bag is uncovered to about half the height of the instrument.
8. If the hole is relatively dry, open the bag and lift the instrument out by its handle.

   Caution: Do not lift the instrument by any of the attached cables. Straining the cables may result in invisible damage, making future installations unreliable.

9. Alternatively, if the hole is waterlogged, carefully lift out the entire bag in one piece, and remove the contents at the surface.

3.7 Installing in post-holes

The 3ESPCD is suitable for installation in potholes. In soft subsoil, a hole 2 – 4 metres deep and 20 cm wide can be conveniently excavated using a tractor-mounted or hand-operated pothole auger. To minimize surface effects, you should ensure that the hole is at least 1 metre deeper than the length of the instrument, and preferably somewhat more.

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

To install a 3ESPCD in a pothole:

1. Clean the pothole, making sure there is no loose material around the mouth of the hole or on its base.
2. Prepare the instrument package, making sure the inclinometer is visible, and attach it to a winch or hoist by clamping a light steel cable to the centre of the handle so that the package hangs vertically. Connect the signal cable to the instrument.

3. Add packing material to the hole to about 15 cm depth. Fine crushed rock, with a high proportion of rock flour and fine particles, makes excellent packing material. Alternatively, a mixture of 3 mm grade angular coarse grit with around 30% medium grit gives good results. Moisten the packing material in the hole and ram firm.
4. Lower the instrument to the bottom of the hole, but without slackening the lifting cable.
5. Fill more packing material around the instrument for about 30 cm, moisten, and ram firm.
6. Use the bubble level to check that the instrument remains within its tilt tolerance (± 2 °).
7. Continue filling, moistening and packing until the instrument is buried, checking that the tilt remains within tolerance.
8. Release the strain on the lifting cable, and allow the packing material to settle for 24 hours.
9. If all is well after the settling period, release the lifting tackle, coil a tail of the lifting wire into the top of the hole and backfill almost to the surface.
10. Ensure that the signal cable is slack, and fix it to a support at the top of the hole.
11. Ram a split wooden bung into the top of the hole, and cover with sandbags.
12. Attach the signal cable to your laptop. Power the sensor, and unlock it. Carry out preliminary tests using Scream!, if required.

3.8 Using the 3ESPCD

Once the 3ESPCD is powered, it will start producing data immediately. You can now start configuring it for your own needs. There are three ways you can do this:

- using the graphical interface provided by Scream! (see section 5 on page 39);
- using the web interface of a Güralp EAM (see MAN-EAM-0003); or
- over a terminal connection (see section 6 on page 59).

All three methods provide full access to the configuration options of the digitiser.

3.8.1 Retrieving data

You can configure the digitiser to operate in a number of transmission modes. These modes determine whether the unit stores data in its on-board Flash memory, sends it over the serial link in GCF format, or does some combination of these. See “Data flow ” in Section 5.2.5 on page 54 for more details.

If you choose a transmission mode where some data are stored in Flash memory, you will need to recover this data at a later date. You can do this either over the serial link, or using the digitiser's FireWire interface.

To download data over FireWire, simply plug the disk in. If there are enough new data waiting to be transferred (by default 128 Mb), they will immediately be downloaded onto the disk. The internal pointers will be updated to mark the data as downloaded.

Alternatively, for more downloading options, issue the command DISKMENU from the digitiser's console before attaching the disk. See Section 6.7 on page 70 for more information. You can use DISKMENU to download any section of data, whether or not it has already been transferred.

While the FireWire interface is active, it will consume about 200 mA of power (from a 12 V supply). If you interrupt a transfer whilst in progress, the digitiser will re-boot, but the data held in memory will not be affected.

To download data over the serial link:

1. Open the digitiser's console. To do this using Güralp Systems' Scream! software, right-click on the digitiser's icon (once it appears) and select Terminal....

   Alternatively, from a Güralp EAM, issue the command

   `data-terminal`

2. If you want to download all data held in the Flash memory, issue the command

   `ALL-FLASH ALL-DATA DOWNLOAD`

3. Alternatively, select a particular set of streams, sample rates and times to download using the `STREAM`, `S/S`, `FROM-TIME` and `TO-TIME` commands, and finish with `DOWNLOAD`. See Section 6.7 on page 70 for more information.

4. Close the terminal session. If you are using Scream! or an EAM, the digitiser should start transmitting immediately. Otherwise, you may need to issue the command `GO` to start transferring data.

3.8.2 Reading digitiser disks

The digitiser uses a special disk format, DFD, for recording data. You can read this data into a PC using Scream! or the GCFXtract utility, which is freely available from the Güralp Systems Web site.

Note: The DFD format is not the same as that used by the Güralp Systems EAM data modules, which use a FAT32-compatible or extn journalling file system.

Güralp Systems can provide fully-tested disks with FireWire and USB connectors. Alternatively, a third-party FireWire disk may be used (although compatibility is not guaranteed.)

3.8.2.1 Reading disks with GCFXtract

To read a disk using GCFXtract:

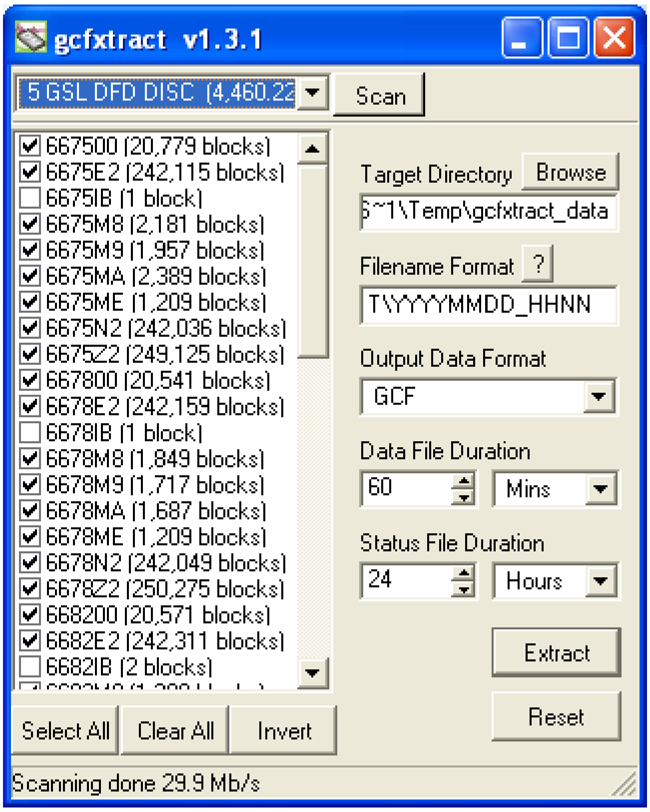
1. Attach the disk to your computer. You can use FireWire, USB, or any other interface supported by your computer and the disk.

> **Caution:** Some operating systems, not recognising the DFD format, will offer to re-format the disk when it is attached. Always say NO: reformatting the disk will make the recorded data unreachable and may over-write some of it. If you accidentally allow the operating system to format a drive containing valuable recorded seismic data, please contact support@guralp.com for help.

2. Start GCFXtract

> **Note:** As GCFXtract requires raw disk device access, it must be run with elevated privileges. On Windows 7 and Windows Vista, it needs to "Run as Adminsitrator". On Windows XP, you need to be logged in as administrator. On Linux, you need to run as root, or a user with read/write permissions for raw disk devices. On most Linux systems, you can grant these permissions with the command
>
> **sudo adduser *user_name* disk**

The following screen is displayed:



The program will first search for non-DOS disks on all the interfaces it understands. If it does not find your disk, check that it is properly connected and that any relevant drivers have been installed, then click the Scan button.

3. When you start up GCFXtract, the program searches all SCSI interfaces and devices for DM24-format disk drives. The ID of each disk is displayed in the drop-down list at the top of the window. Under each disk, GCFXtract lists the transfer sessions it has found on the disk. The DM24 creates a new transfer session each time it saves data to the disk. You can extract data either from a single transfer session, or from the entire disk.

4. Select the required disk or transfer session from the drop-down list, and click Scan. GCFXtract will scan the disk and display all the streams it finds in the selection area below. For each stream, the Stream ID and the number of blocks found are shown. This operation requires roughly 12 Mb of available memory for every Gb of space on the disk. If you have a very large disk, your computer may have to use its hard disk to make enough space. This will slow down scanning considerably.

5. By default, all streams containing more than 100 blocks are selected for extraction. You can change which streams to extract by ticking or clearing the check-box beside each stream. You can tick or clear all of the boxes using the Select All and Clear All buttons. Clicking Invert ticks all cleared boxes, and clears all ticked boxes.

6. Enter a path name into the Target Directory field, or use the Browse button to find a directory. This will be used as the root directory for extracted data. If it does not exist, GCFXtract will create it.

7. Enter a format string into the Filename Format field. The syntax is the same as the format string in Scream! and full documentation is available by pressing the ? button beside the format entry field in interactive mode.

8. Normally, GCFXtract outputs GCF files, to ensure all the information in the original data are retained. If you want to convert to a different format, select it from the Output Data Format drop-down box. GCFXtract can output in most of the formats supported by Scream!.

9. Data are automatically placed in time order and saved in multiple files, each file containing a contiguous segment of data. By default, data streams are recorded in files 60 minutes long. To change this to some other number of minutes, alter the value in the Data File Duration (mins) box. For data streams, if there is a gap in the data, GCFXtract will start a new file anyway.

10. Status streams are also saved in multiple files, but have a default length of 24 hours. To change this, alter the value under Status File Duration (hours).

11. When you are happy with the settings, click Extract to begin extracting the data.

12. Clicking Reset sets a flag on the disk which marks it as empty. Next time a digitiser wants to transfer data, it will begin at the beginning of the disk, overwriting the old data. When this happens, none of the old data can be extracted with GCFXtract. Until then, however, you will still be able to retrieve all the data.

3.8.2.2 Reading disks with Scream!

You can also read disks with Scream!. This allows you to view data in the process of being transferred, but is slightly slower, because Scream! does not read data in strict order. To read a disk with Scream!:

1. Attach the disk to your computer. You can use FireWire, USB, or any other interface supported by your computer and the disk.

2. Run Scream!, and select File → Setup... from the main menu. Select the Files tab.

3. Set the Base Directory, Filename Format and Data Format as required. Also, if required, set the Post-processor and Granularity options to your preference. Consult the Scream! documentation for details.

4. Select the Recording tab, and tick the Auto Record—Enable for Data Streams and Auto Record—Enable for Status Streams check-boxes. Click OK. Scream! will remember the recording options you set in steps 3 and 4 for later occasions.

5. Select File → Read SCSI disk... from the main menu. Scream! will search for attached disks, and open a window with a list of all the streams it has found.

6. Select the streams you want to replay, and click Open. The disk will appear in the left-hand pane of Scream!'s main window, and the streams you have selected will start playing into the stream buffer, as well as being recorded.

7. When you have finished transferring the data, if you want to reset the disk, select File → Reset SCSI disk... from Scream!'s main menu. Select the disk you want to reset, and click OK.

More information is contained in the Scream! Manual, MAN-SWA-0001.

4 Calibrating the 3ESPCD

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 3ESPCD uses balanced differential outputs, the signal strength as measured between the +ve and –ve lines will be twice the true sensitivity of the instrument. To remind you of this, the sensitivities are given as 2 × (single-ended sensitivity) in each case.
- **Mass Position Output** : The sensitivity of the mass position outputs to acceleration, in volts per ms^{-2}. These outputs are single-ended and referenced to signal ground.
- **Feedback Coil Constant** : A constant describing the characteristics of the feedback system. You will need this constant, given in amperes per ms^{-2}, if you want to perform your own calibration calculations (see below.)
- **Power Consumption** : The average power consumption of the sensor during testing, given in amperes and assuming a 12 V supply.
- **Calibration Resistor** : The value of the resistor in the calibration circuit. You will need this value if you want to perform your own calibration calculations (see below.)

4.1.1 Poles and zeroes

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

```
( V / x ) (s) = G × A × 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 × H (s) is dimensionless and has a value of 1 over the flat portion of the frequency response. In practice, it is possible to design a system transfer function with a very wide-range flat frequency response.

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

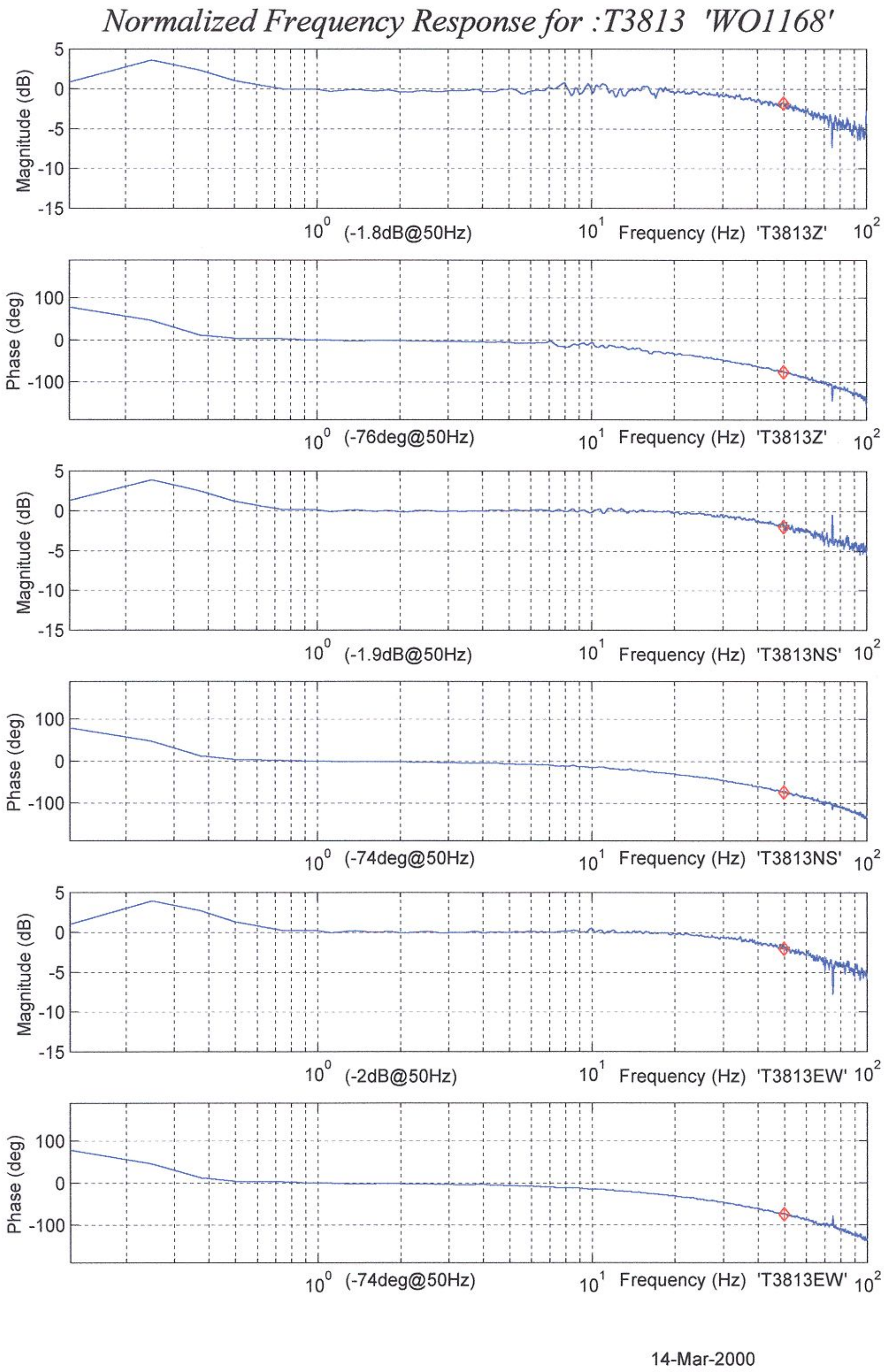
$$H(s) = N \frac{\prod_{i=1,n} s - Z_i}{\prod_{j=1,m} s - P_j}$$

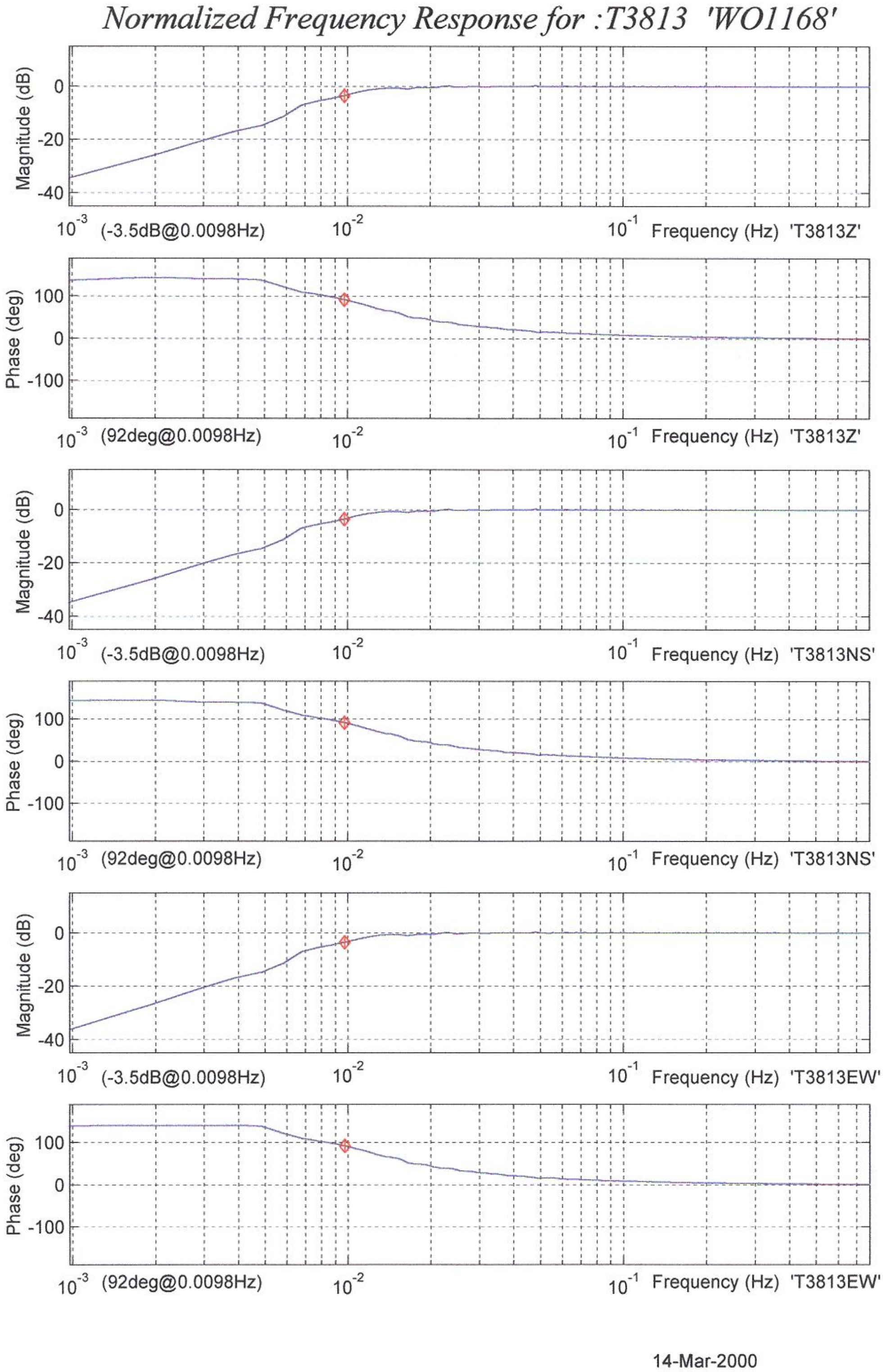
  In this equation, z_n are the roots of the numerator polynomial, giving the zeros of the transfer function, and p_m are the roots of the denominator polynomial giving the poles of the transfer function.

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.

4.1.2 Frequency response curves

The frequency response of each component of the 3ESPCD 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).

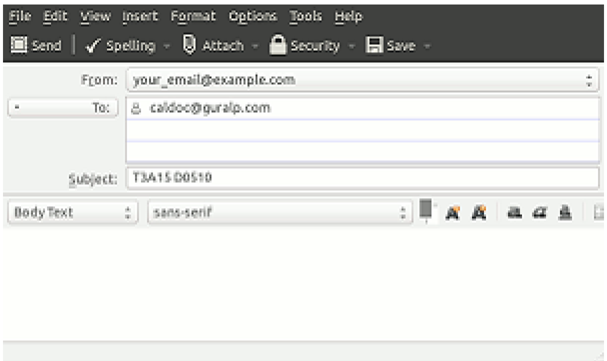

Normalized Frequency Response for :T3813 'WO1168'
Magnitude (dB)
(-1.8dB@50Hz)
Frequency (Hz) 'T3813Z'
Phase (deg)
(-76deg@50Hz)
Frequency (Hz) 'T3813Z'
Magnitude (dB)
(-1.9dB@50Hz)
Frequency (Hz) 'T3813NS'
Phase (deg)
(-74deg@50Hz)
Frequency (Hz) 'T3813NS'
Magnitude (dB)
(-2dB@50Hz)
Frequency (Hz) 'T3813EW'
Phase (deg)
(-74deg@50Hz)
Frequency (Hz) 'T3813EW'
14-Mar-2000



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

4.1.3 Obtaining copies of the calibration pack

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



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

4.2 Calibration methods

Velocity sensors such as the 3ESPCD are not sensitive to constant DC levels, as a result both of their design and because of the 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 will take a long time. In addition, several measurements must be made to determine the response over the full frequency spectrum.
- Injecting broadband noise into the calibration coil gives the response of the whole system, which can be measured using a spectrum analyser.

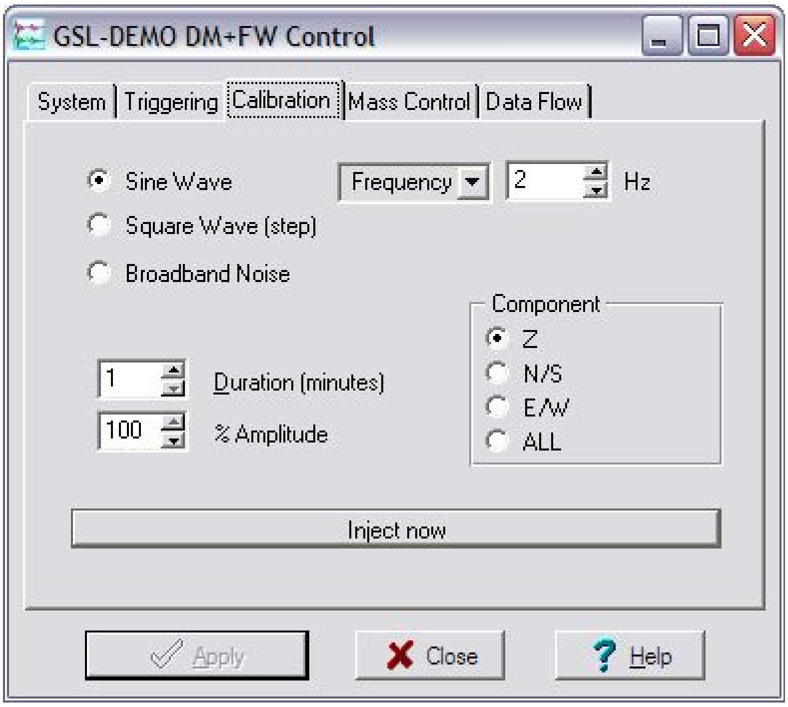
Calibration is performed using the built-in DM24 digitiser, which can generate step and sinusoidal calibration signals as well as broadband noise, and integrated scripts within Güralp Systems' Scream! software.

Initiating a calibration closes a relay which normally isolates the feedback electronics from the calibration signal generator and causes signals of the specified nature to be generated and routed through the feedback system. You can then measure the signal's equivalent velocity using Scream!

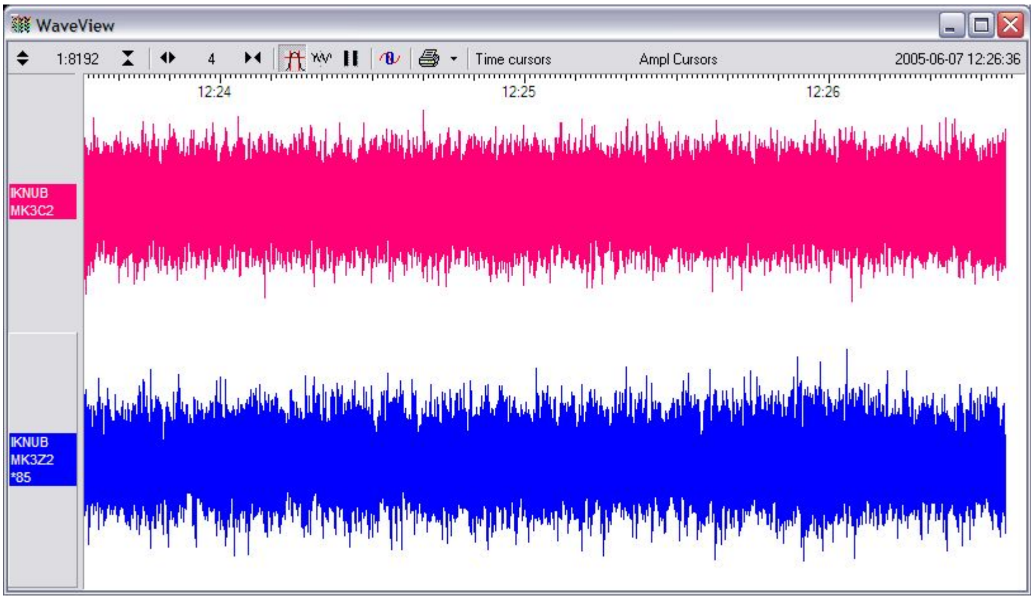
4.3 Calibration with Scream!

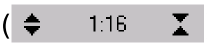
Sine-wave, step and broadband noise calibrations are available. In this section, broadband noise calibration will be used to determine the complete sensor response in one action.

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



2. Select the calibration channel corresponding to the instrument, and choose Broadband Noise. Select the component you wish to calibrate, together with a suitable duration and amplitude, and click Inject now. A new data stream, ending Cn (n = 0 – 7) or MB, will 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.

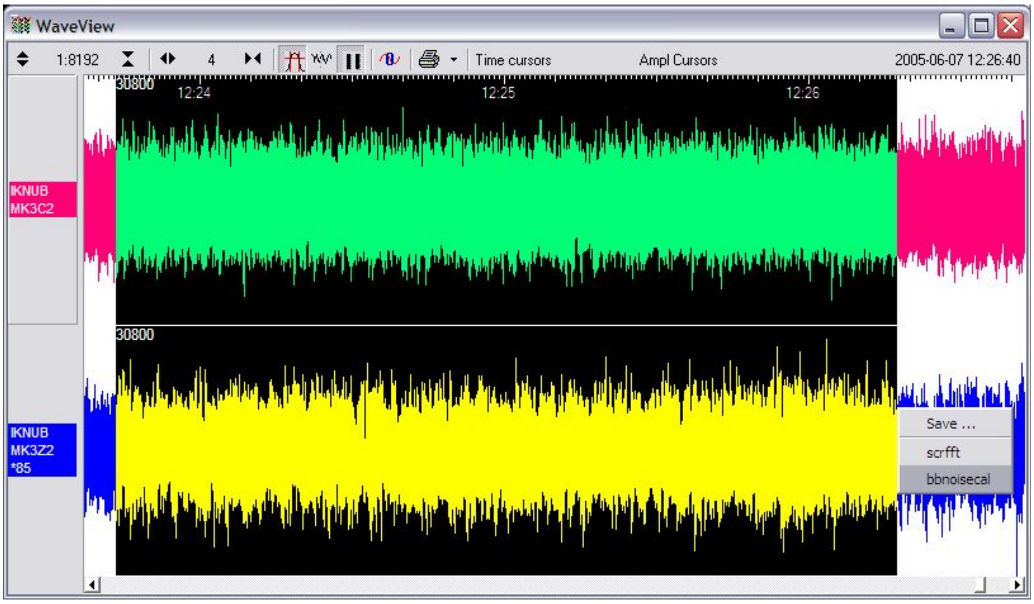
   If necessary, drag the calibration stream Cn up the Waveview window, so that it is at the top.

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

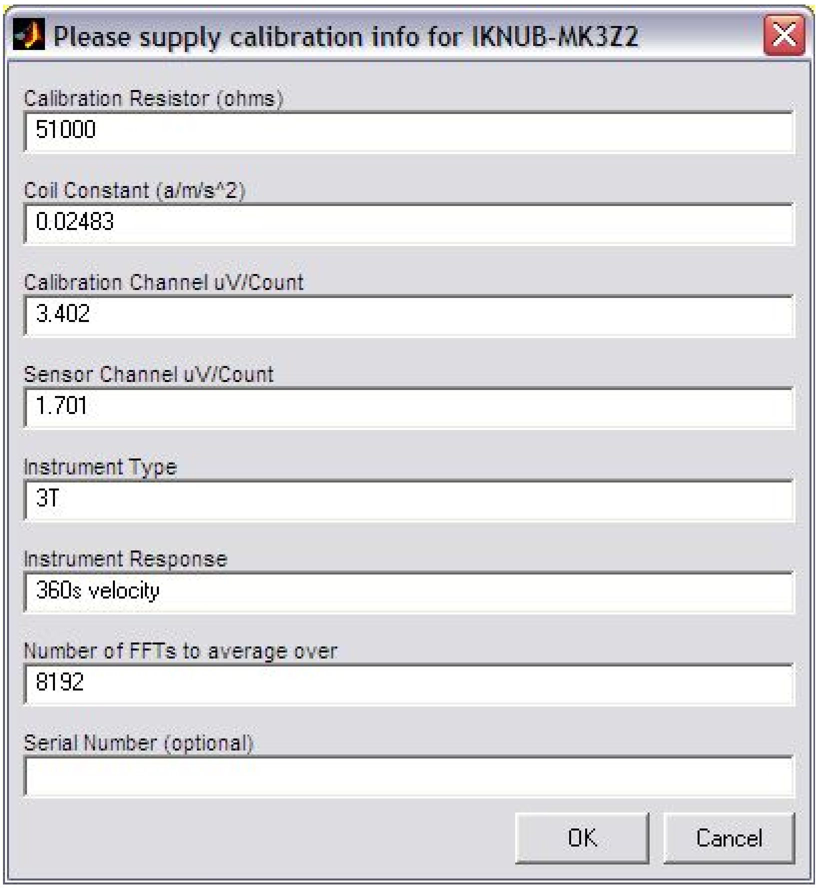
5. If you need to scale one, but not another, of the traces, right-click on the trace and select Scale.... You can then type in a suitable scale factor for that trace.

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.



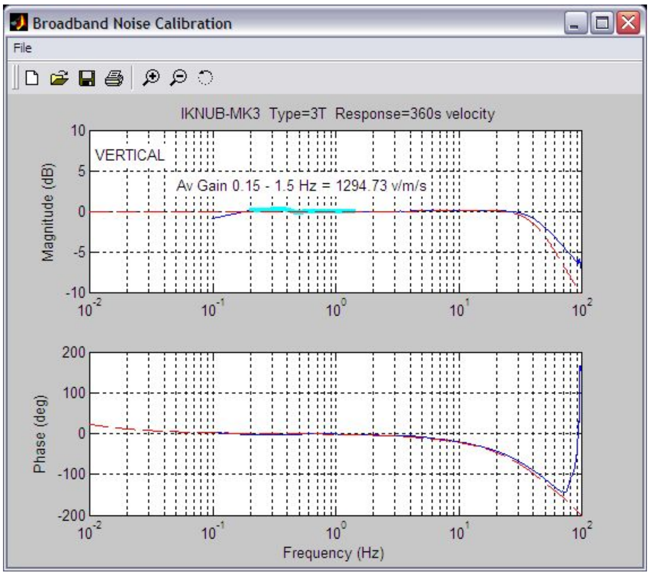
Most data can be found on the calibration sheet for your sensor. Under Instrument response, you should fill in the sensor response code for your sensor, according to the table below. Instrument Type should be set to the model number of your instrument and Instrument Response should be set to correct code, as given in section 4.3.1 on page 38, followed by eirther “v” or “velocity”.

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

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

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

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



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

4.3.1 Sensor response codes

Sensor	Sensor type code	Units (V/A)
3T or 3ESP, 30 s – 50 Hz response	CMG-3_30S_50HZ	V
3T or 3ESP, 60 s – 50 Hz response	CMG-3_60S_50HZ	V
3T or 3ESP, 100 s – 50 Hz response	CMG-3_100S_50HZ	V
3T or 3ESP, 120 s – 50 Hz response	CMG-3_120S_50HZ	V
3T or 3ESP, 360 s – 50 Hz response	CMG-3_360S_50HZ	V
3TB/3V/3ESP borehole, 30 s – 50 Hz	CMG-3B_30S_50HZ	V
3TB/3V/3ESP borehole, 100 s – 50 Hz	CMG3B_100S_50HZ	V
3TB/3V/3ESP borehole, 120 s – 50 Hz	CMG3B_120S_50HZ	V

4.4 The coil constant

The feedback coil constant K is measured at the time of manufacture, and printed on the calibration sheet. Using this value will give good results at the time of installation. However, it may change over time. The coil constant can be determined by tilting the instrument and measuring its response to gravity. To do this, you will need apparatus for measuring tilt angles accurately.

1. Measure the acceleration due to gravity, g, at your location.
2. Tilt the instrument slightly, and measure its attitude and the gain of the mass position output for the component you wish to calibrate.
3. Repeat this measurement for several tilt angles.
4. For the vertical sensor, the input acceleration is given by

   $a = g \sin \varphi$

   whilst for the horizontal sensor, it is

   $a = g (1 - \cos \varphi)$

   Calculate the input acceleration for each of the tilt angles used, and plot a graph of mass position output against input acceleration.
5. The gradient of the line obtained gives the sensitivity of the coil (in V/ms^{-2}, if g was measured in ms^{-2} and the mass position 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 Using Scream!

Scream! is a versatile seismic data visualisation program for Güralp instruments, and is available for free download from Güralp Systems. See http://www.guralp.com/scream/ for details about how to obtain Scream!.

5.1 Configuring digitisers

Scream! distinguishes between configuration and control of digitisers. The most important difference is that a digitiser may be controlled through Scream! at any time whilst it is acquiring data, whereas configuration options only take effect after a reboot (with consequent loss of data). To change the configuration of any connected digitiser:

1. Locate the digitiser you want to configure. All connected digitisers have an entry in the tree on the left of Scream!'s main window. If the digitiser is transmitting data through a remote server or EAM, you may need to “unroll” the entry for that server (by clicking on the ⊞ icon) to see the digitisers connected to it.

2. Right-click on the digitiser's entry (not the icon for the server or any Comxx icon). digitisers are shown with icons depicting a coloured cylinder ().

3. Click Configure.... Scream! will then contact the digitiser and retrieve its current configuration, a process which will take a few seconds. This done, the Configuration set-up window will be displayed.

4. Once you are happy with any changes you have made in the Configuration Set-up window, click UPLOAD to send them to the digitiser and reboot. This will take a short while.

To control a digitiser whilst it is running, either right-click on the digitiser's entry in the list and click Control..., or double-click the entry. In either case Scream! will contact the digitiser to retrieve control information and display the Control window. The options you can control immediately are:

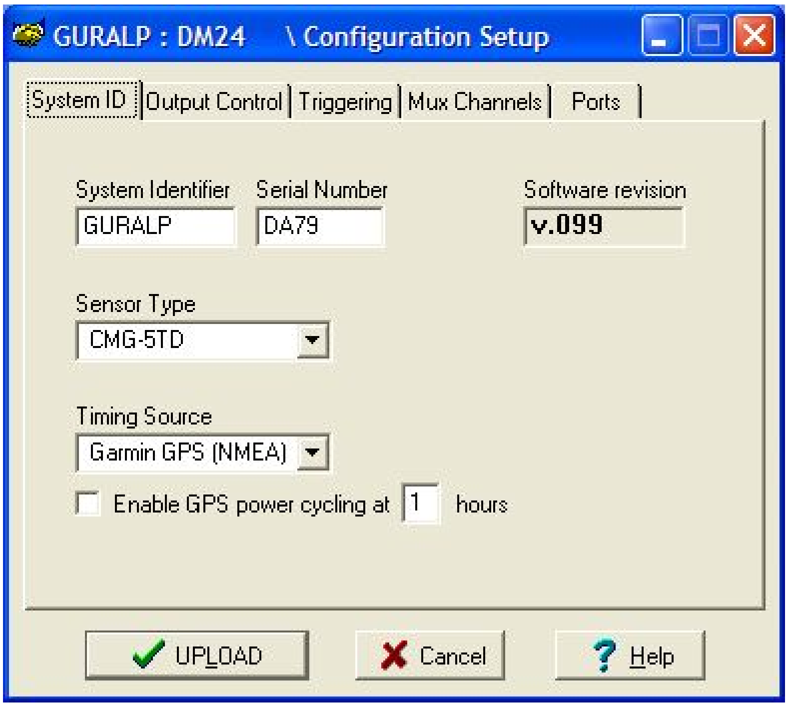
- the type of sensor you are using,
- GPS power cycling options,
- the short-term and long-term average values for triggering (but not which streams perform the trigger, or which are output by it - see “Triggering” in section 5.1.3 on page 44),
- the length of pre-trigger and post-trigger periods,
- calibration signal options, and
- mass control functions.

Some of these options can also be altered in the Configuration set-up window. For more information on the Control window, see section 5.2 on page 52.

If you need a more powerful interface to the digitiser, you can also issue commands to it directly using Scream!'s terminal mode. A terminal window is opened by right-clicking on the digitiser's entry in the list and selecting Terminal.... The digitiser will stop collecting data while you have a terminal window open. The remaining sections of this chapter describe in detail the configuration options available for the digitiser. Many of these options will also be available for other Güralp digitisers

5.1.1 System ID

The System ID pane gives information about the digitiser and its internal software, and allows you to change GPS timing parameters.



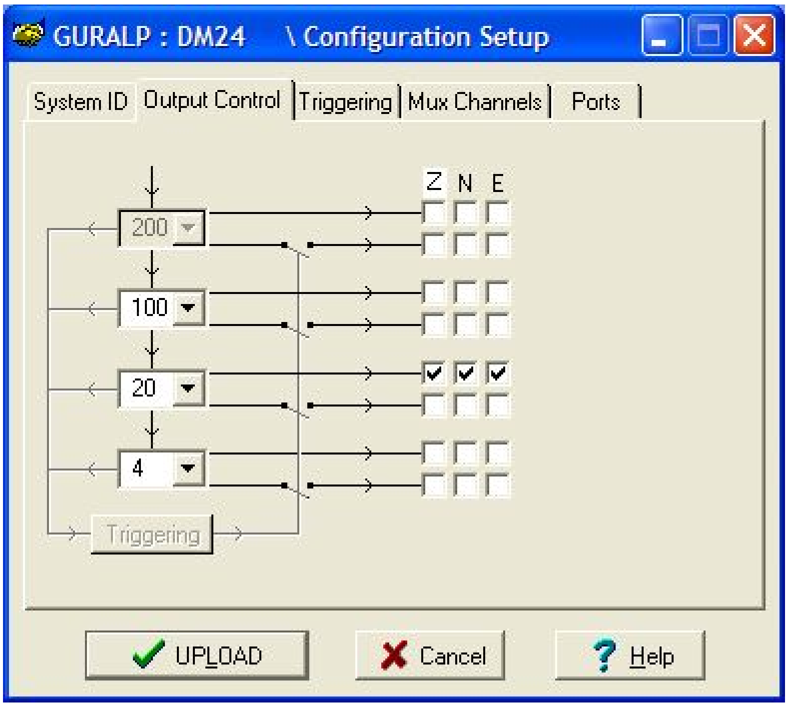
- **System Identifier and Serial Number** : The digitiser type is identified by its system identifier and serial number. Every data and status block generated by the digitiser includes these two fields at the beginning, so that the block's origin can be identified. On delivery from the factory, the system identifier and the serial number are set to the GSL works order number and the digitiser's serial number, but any combination of letters A-Z and numbers can be used, such as an abbreviation of your institution's name, etc. The system identifier can be up to 6 characters long, whilst the serial number cannot be longer than 4.

- **Sensor Type** : If the sensor attached to the digitiser is a Güralp velocity sensor, useful seismometer functions (such as sensor locking, centring, and calibration) may be controlled through the digitiser. The Sensor Type you set here determines which functions will be available through the Scream! digitiser configuration set-up interface or through interactive commands. The correct value for your 3ESPCD is "`CMG-3T / ESPC`"

- **GPS Type** : The digitiser needs to be able to time-stamp accurately all data that passes through it. It can set its clock either by receiving time signals from the GPS satellite network using an attached Garmin-compatible (NMEA output) unit, or by taking time information from a central site (stream sync mode). In stream sync mode, the digitiser expects to receive two-byte packets from the central timing source, which may have its own GPS unit, or take signals from one of the radio time standards. Choose the mode you require from the drop-down menu.
- **Enable GPS power cycling** : If you are using a GPS unit to receive time signals, but do not experience significant drift in the system's clock (for example, in a stable-temperature environment), you can save power by selecting Enable GPS power cycling. With this option in use, the GPS time is only checked at intervals of a specified number of hours. Disabling this option keeps the GPS unit running constantly; if you have ample power, this will give the most accurate results. You can choose any whole number of hours for the interval.

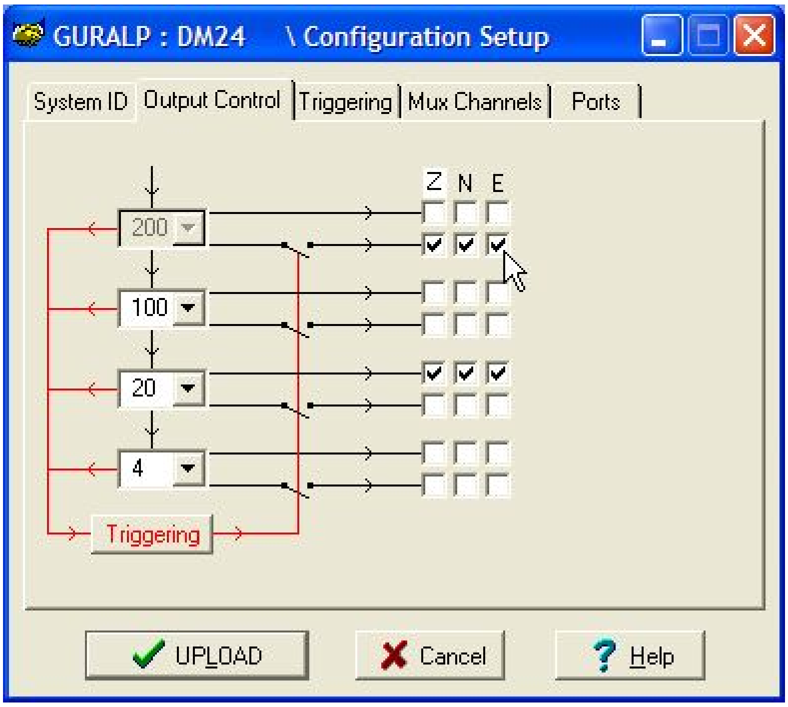
5.1.2 Output control

The Output control tab allows you to configure which data streams are sent to Scream! from the digitiser.



Güralp digitisers initially sample incoming data at a high rate (e.g. 512,000 Hz for the DM24), which is then filtered and reduced to a lower rate (decimated) using an on-board digital signal processing unit, or DSP. The DSP has several filtering-decimation stages, which run one after the other. Stages which can produce output are called taps. The Güralp DM24 can output 4 taps simultaneously. The input to the tap chain is fixed at 2,000 samples per second.

Each configurable tap can be set to a different decimation factor by choosing values from the drop-down menus on the left. Decimation factors of 2, 4, 5, 8, and 10 are available. The numbers visible in the drop-down menu of each tap are the data rates that each of the possible decimation factors will provide, given the settings of the taps above it. Only integer (Hz) data rates are allowed: thus, for example, if one tap emits data at 25 Hz, the only possible further decimation factor is 5.



To the right of each decimation factor menu is a grid of check-boxes. These boxes mark which streams of data to generate at each sample rate. The screen-shot above shows a possible configuration for a triaxial instrument. Every channel of the digitiser may be output at any tap; currently, all three axes are being output at Tap 2 (20Hz).

Note: If you want to change the names used for the channels, click in the white box containing a Z in the above picture, and type a letter or number. It will name the channels with a sequence of letters or numbers beginning with the one you choose (e.g. A, B, C; 2, 3, 4; 9, A, B), unless you type Z in which case they will revert to Z, N, and E.

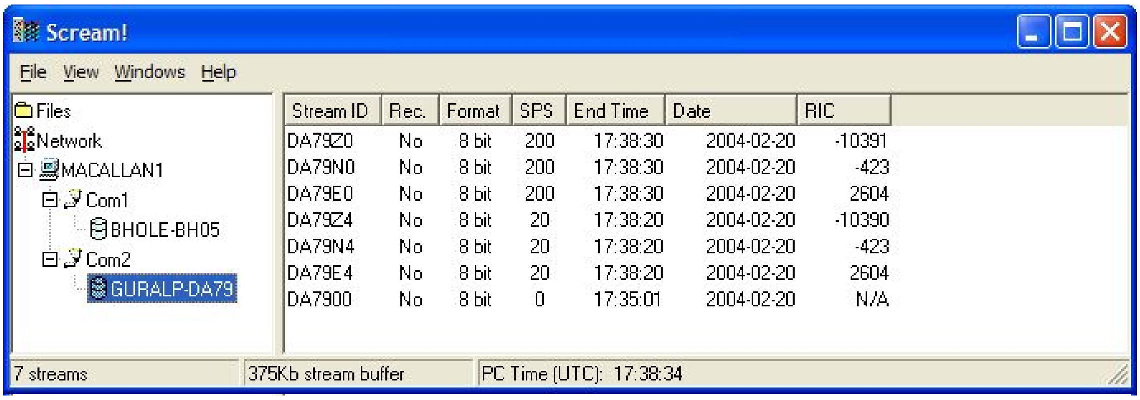
Each combination of channel and tap has two check-boxes. The upper check-box of each pair activates continuous output, whilst the lower activates triggered output. In the example above, the digitiser will output data continuously for all three channels at Tap 2, but never for any other taps. If you do not need all the streams to output at all rates, you should leave boxes clear to save communications capacity. You cannot tick both continuous and triggered output for the same channel and tap.

When you enable a triggered stream, the digitiser will output data in that stream only when a particular set of trigger criteria are met. This is shown diagrammatically as data passing through a switch. In the example above, we might want the high-rate data from Tap 0 to be generated only when an event registers at some other tap. To do this, the lower check-boxes of Tap 0 should be ticked.

With this configuration uploaded, Tap 2 will continue to produce output at all times, but Tap 0 will also emit data whenever the trigger criteria are met. The Triggering button is now shown in red to remind you that the trigger is active.

Every ticked box in this window will give rise to a data stream coming from the digitiser, which will be displayed in Scream!'s main window when Scream! first receives some data from it. Every stream is identified by a 6-character code, where the first four characters identify the digitiser, and the last two characters identify the individual stream. The first four characters are set by default to the serial number of the digitiser; you can change this on the System ID pane (see section 5.1.1 on page 40) or from the digitiser's console.

Using the example above, there are three data streams, Z, N and E, which each output data at 20 samples/s (continuously) and 200 samples/s (occasionally).



In this example: •

- **DA79** is the serial number of the digitiser.
- **Z0**, **N0**, **E0** correspond to input channels Z, N, and E, output through Tap 0.
- **Z4**, **N4**, **E4** correspond to input channels Z, N, and E, output through Tap 2. A six-channel digitiser connected to two triaxial instruments will use Z0, N0, E0, Z1, N1, E1 for tap 0; Z2, N2, E2, Z3, N3, E3 for tap 1; Z4, N4, E4, Z5, N5, E5 for tap 2; and Z6, N6, E6, Z7, N7, E7 for tap 3. The digitiser in the example has only one triaxial instrument connected to it, so Z/N/E1, 3, 5 and 7 are unused.
- **00** is the digitiser status stream (notice: zero sample rate).

Other streams you may see include •

- **M8**, **M9**, **MA**: slow-rate Mux channels reporting the sensor mass positions for the Z, N, and E components ("Mux Channels" in Section 4.1).
- **ME**: another Mux channel, normally used for reporting the digitiser's internal temperature.
- **CD**, **BP**, **IB**: digitiser streams for specialised use.

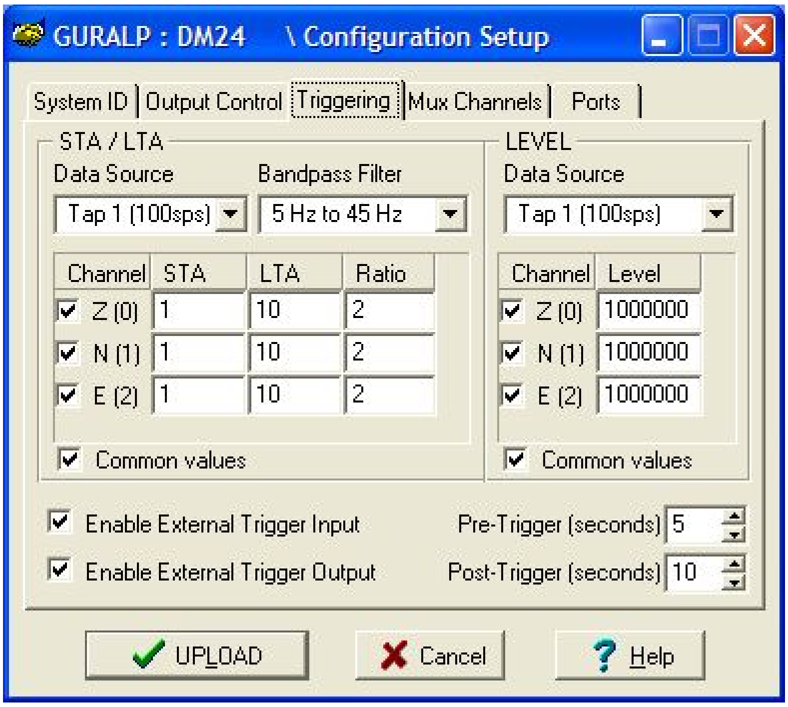
5.1.3 Triggering

In its standard configuration, the digitiser outputs continuous data at a sample rate you specify. In addition to this, Güralp digitisers can run a triggering algorithm on the data they acquire. This allows you to record data continuously at a relatively low sample rate, but record at a much higher sample rate during short periods when the trigger is active. The parameters controlling the triggering algorithm, and controlling the data output once the system is triggered, are all selectable by the user, permitting maximum flexibility of operation and the most efficient use of available storage space.

The digitiser can be set up for triggered output, that is, to output certain data streams only when a particular trigger criterion is met. The trigger criterion can be tested with data from the same or some other stream. For example, you could use a later tap (with a lower sample rate) as a trigger for output from an earlier, more detailed tap. Scream! also allows you to configure each digitiser to receive triggers from other digitisers.

To create a new stream with a trigger, open Scream!'s digitiser configuration window for the relevant digitiser, and click on the Output control tab. In the Output control pane, a tap which gives rise to a triggered stream has a tick in the lower row of its grid of check-boxes. You cannot configure the trigger criteria until you have selected at least one stream to be affected by the trigger.

Once you have decided which streams should be output when the trigger is activated, you will be able to click on the Triggering button to describe the trigger condition. Alternatively, click on the Triggering tab at the top of the window. Either action will open the Triggering pane:



There are two triggering algorithms which Güralp digitisers can use: STA/LTA and level-triggering. In addition, software and external triggering options are available.

5.1.3.1 STA/LTA

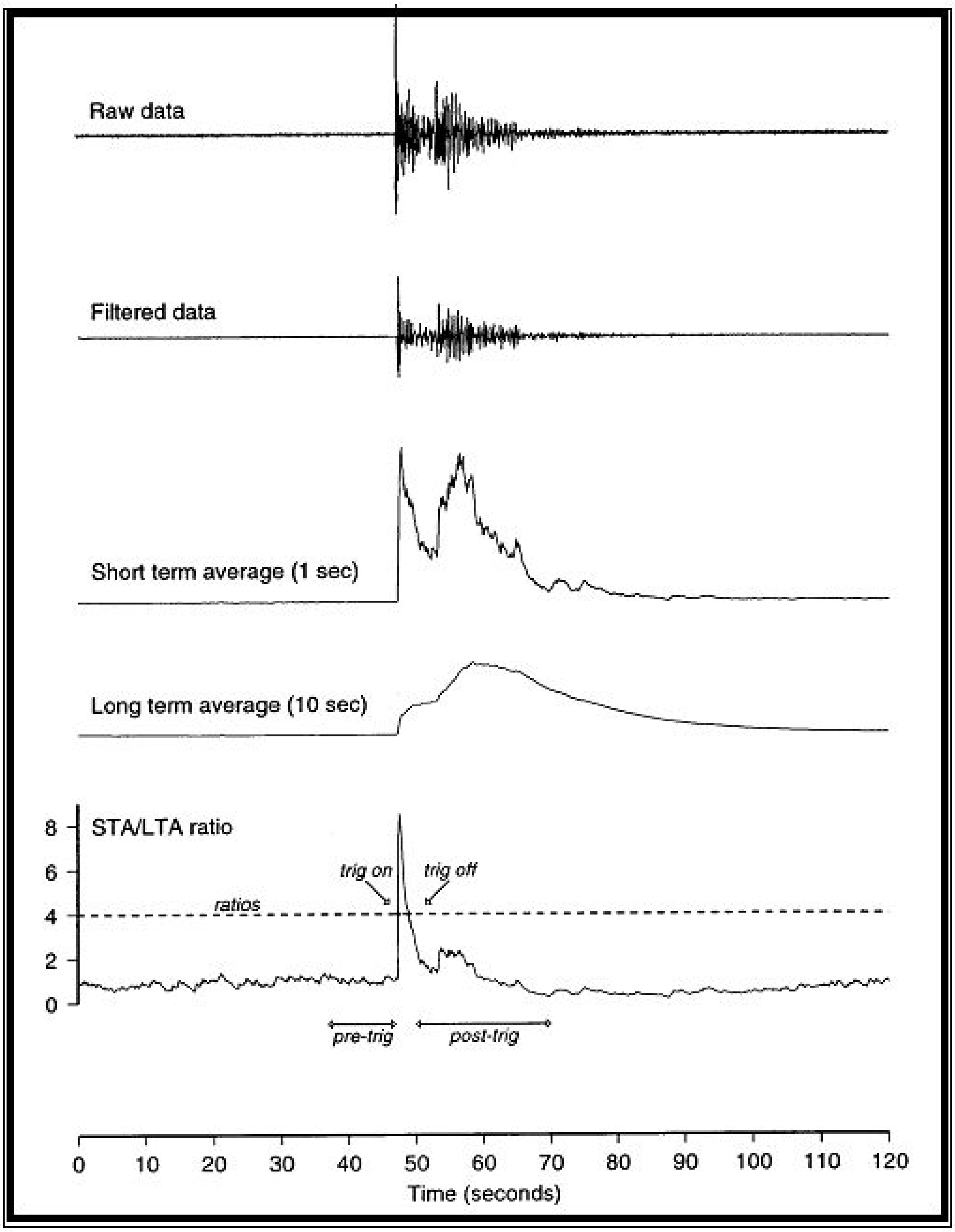
The STA/LTA algorithm applies a simple (short-term average ÷ long-term average) calculation to the triggering stream. It works by identifying sections of an incoming data stream when the signal amplitude increases. The purpose of taking a short term average, rather than triggering on signal amplitude directly, is to make it less likely that spurious spikes will trigger the device. Averaging also introduces an element of frequency selectivity into the triggering process.

You can select which tap is tested for the trigger from the Data source drop-down menu. The tap does not have to output data to Scream! for you to be able to use it here.

Any or all of the channels available at that tap may be used to determine a trigger. You can select which channels are considered by ticking the boxes in the Channel column of the table. If any of the ticked channels passes the trigger condition, the trigger will activate, and will not de-trigger until all of the ticked channels have fallen below their respective ratio values.

The STA and LTA columns allow you to set the intervals over which the two averages are calculated, in seconds. Typically, the time interval for the short term average should be about as long as the signals you want to trigger on, while the long term average should be taken over a much longer interval. Both the STA and LTA values are recalculated continually, even during a trigger. The Ratio column determines by what factor the STA and LTA must differ for the trigger to be passed. Finding the ratio most suited to your needs is best done by experiment. Too high a value will result in events being missed, while too low a value will result in spurious non-seismic noise triggering the system. Like the averages, their ratio is continuously recalculated for all components. Note that none of the boxes are allowed to be empty, and so you will need to enter the new value before removing the old one. Alternatively, you can use the up and down cursor keys to change the values.

For example, setting the STA to 1 second, the LTA to 10 seconds and the Ratio to 4 would give rise to the following trigger behaviour:



Usually, the values of the STA and LTA periods, and of the Ratio, will be the same for all selected channels. For convenience, Scream! will automatically fill in other values to match ones you enter. If you want to use different values for some channels, you should clear the “Common values” check-box before altering them.

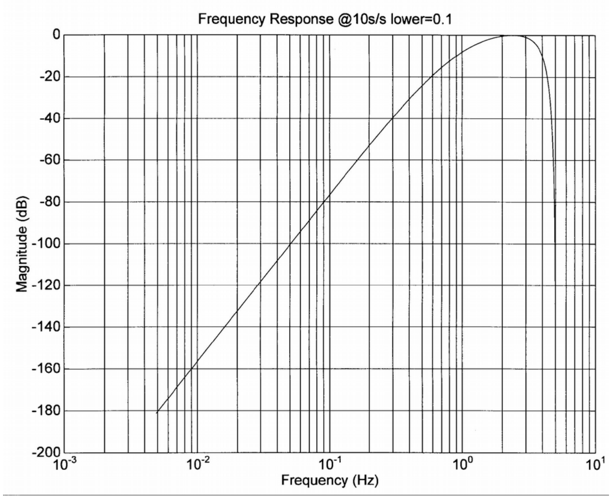
Once you have enabled the STA/LTA triggering method on a particular channel, you can use the Control window to change the values of the STA and LTA periods, together with the Ratio, without restarting the digitiser (see section 5.2 on page 52).

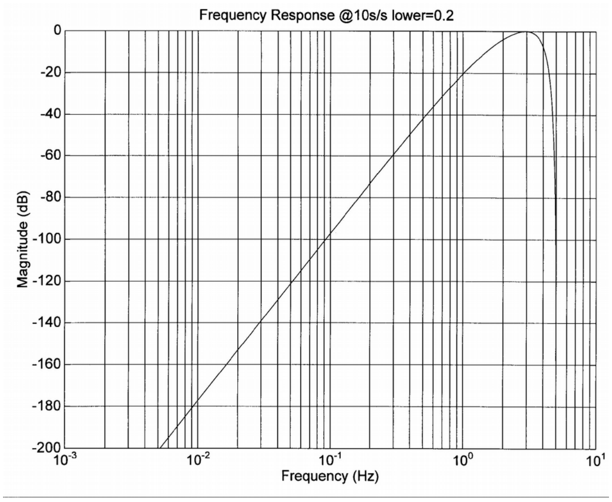
Since it is not generally advisable to trigger from broadband data, the digitiser provides a set of standard bandpass filters to apply to the data streams before they are tested for the trigger condition. This filtering serves to maximise sensitivity within the frequency band of interest, and filter out noise outside this band. You can select which bandpass filter to use from the Bandpass filter drop-down menu. The corner frequencies of the pass band of the filter are determined by the Nyquist frequency, which is given by the sampling rate of the triggering data. The three filter options have pass bands between 10% and 90%, between 20% and 90% and between 50% and 90% of the data's Nyquist frequency, respectively.

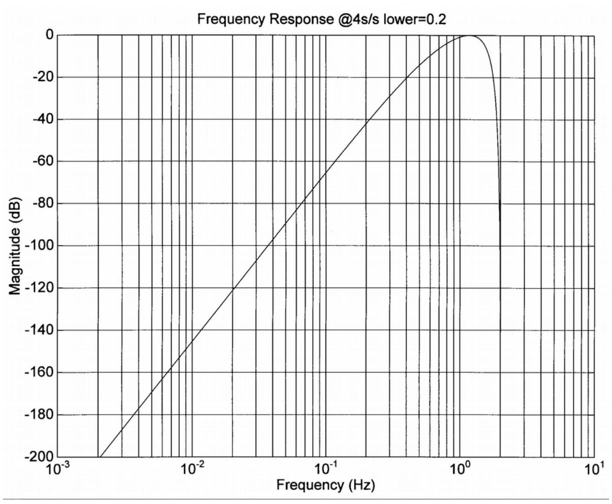
The possible filter configurations are shown in the following table:

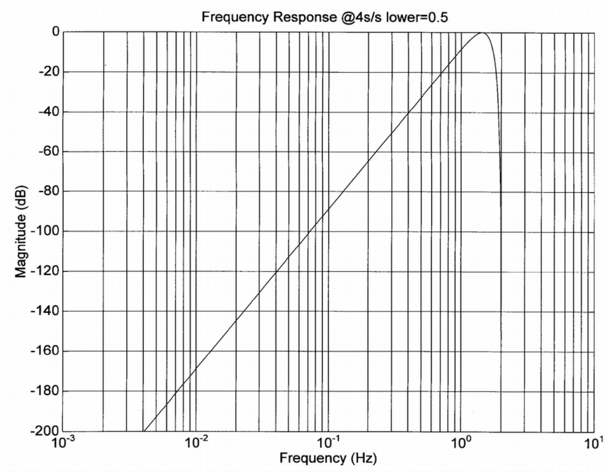
Tap #	Rate (samples/s)	Bandwidth 1 (Hz)	Bandwidth 2 (Hz)	Bandwidth 5 (Hz)
0	200	10 – 90	20 – 90	50 – 90
1	100	5 – 45	10 – 45	25 – 45
	50	2.5 – 22.5	5 – 22.5	12.5 – 22.5
	40	2 – 18	4 – 18	10 – 18
	25	1.25 – 11.25	2.5 – 11.25	6.25 – 11.25
	20	1 – 9	2–9	5–9
2	50	2.5 – 22.5	5 – 22.5	12.5 – 22.5
	25	1.25 – 11.25	2.5 – 11.25	6.25 – 11.25
	20	1 – 9	2–9	5–9
	10	0.5 – 4.5	1 – 4.5	2.5 – 4.5
	8	0.4 – 3.6	0.8 – 3.6	2 – 3.6
	5	0.25 – 2.25	0.5 – 2.25	1.25 – 2.25
	4	0.2 – 1.8	0.4 – 1.8	1 – 1.8
	2	0.1 – 0.9	0.2 – 0.9	0.5 – 0.9
3	25	1.25 – 11.25	12.5 – 11.25	6.25 – 11.25
	10	0.5 – 4.5	1 – 4.5	2.5 – 4.5
	5	0.25 – 2.25	0.5 – 2.25	1.25 – 2.25
	4	0.2 – 1.8	0.4 – 1.8	1 – 1.8
	2	0.1 – 0.9	0.2 – 0.9	0.5 – 0.9
	1	0.05 – 0.45	0.1 – 0.45	0.25 – 0.45

As can be seen, the filter you choose defines the set of permissible sample rates. The spectral amplitudes for the various frequency responses available are shown in the figures below.


Frequency Response @10s/s lower=0.1
Magnitude (dB)
0
-20
-40
-60
-80
-100
-120
-140
-160
-180
-200
10^{-3}
10^{-2}
10^{-1}
10^{0}
10^{1}
Frequency (Hz)


Frequency Response @10s/s lower=0.2
Magnitude (dB)
0
-20
-40
-60
-80
-100
-120
-140
-160
-180
-200
10^{-3}
10^{-2}
10^{-1}
10^{0}
10^{1}
Frequency (Hz)


Frequency Response @4s/s lower=0.2
Magnitude (dB)
0
-20
-40
-60
-80
-100
-120
-140
-160
-180
-200
10^{-3}
10^{-2}
10^{-1}
10^{0}
10^{1}
Frequency (Hz)



5.1.3.2 Level

Using the Level triggering method, a trigger is generated whenever one of the selected components reaches a certain level above the baseline. You can select which tap is monitored from the Data source drop-down menu, and the channel(s) to be considered from the Channel column of the table. The values in the Level column are the number of counts above the baseline that channel must reach before a trigger is generated.

As with the STA/LTA method, the values of the Level will often be the same for all selected channels. If you want to use different values for some channels, you should clear the Common values check-box before altering them.

Once you have enabled the Level triggering method on a particular channel, you can use the Control window to change the level at which the system triggers without restarting the digitiser (see section 5.2 on page 52).

5.1.3.3 External triggering

When a digitiser or digital sensor triggers, it sends the trigger itself to connected devices, as well as any extra data that it has been configured to record. You can configure other digitisers to respond to this signal by triggering in turn. This is an option which you can specify at the time of manufacture. For further details, please contact support@guralp.com.

5.1.3.4 Pre-trigger and post-trigger recording

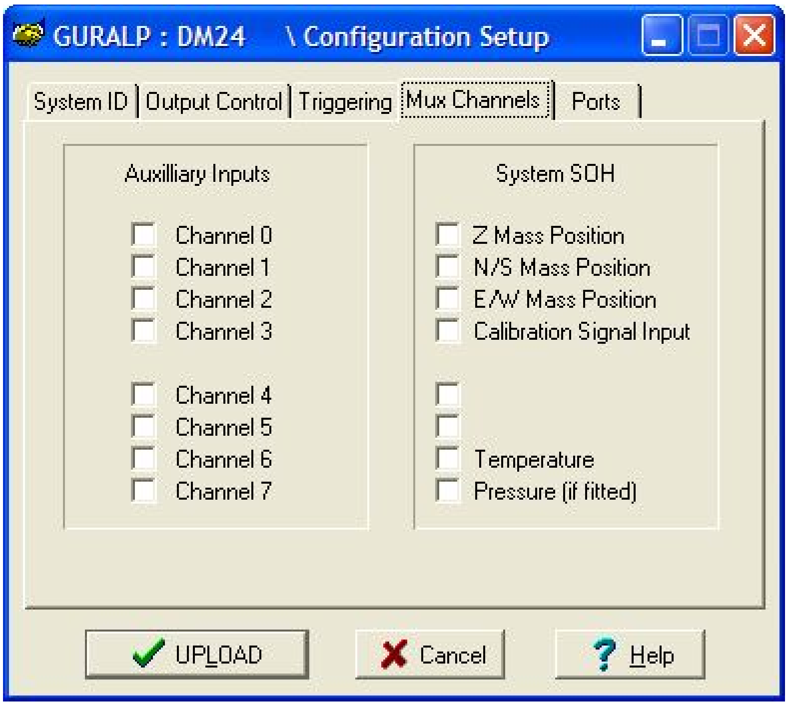
In order to capture all of a seismic event, it is often useful to be able to record data immediately preceding the trigger. Güralp digitisers have an internal buffer of some seconds which allows this data to be added to the triggered stream. Pre-trigger data are particularly useful for emergent-type signals, where the system does not trigger until one phase after the first arrival. In addition, to ensure that the coda of each event is included, some seconds of data are recorded after the system de-triggers.

The two boxes at bottom right of the Triggering pane allow the user to set the pre-trigger and post-trigger data intervals, in seconds. These values determine the minimum length of time during which data will be saved before the trigger condition occurs, and after it has lapsed. Regardless of the intervals chosen, the data in the triggered streams will begin on a whole second.

5.1.4 Mux Channels

The digitiser provides a range of slow-rate auxiliary channels for reporting the system's state of health and other diagnostic information, known as multiplexed ("Mux") channels. In the 3ESPCD configuration, three of these are used to report the sensor mass position and another is used for measuring the internal temperature of the digitiser.

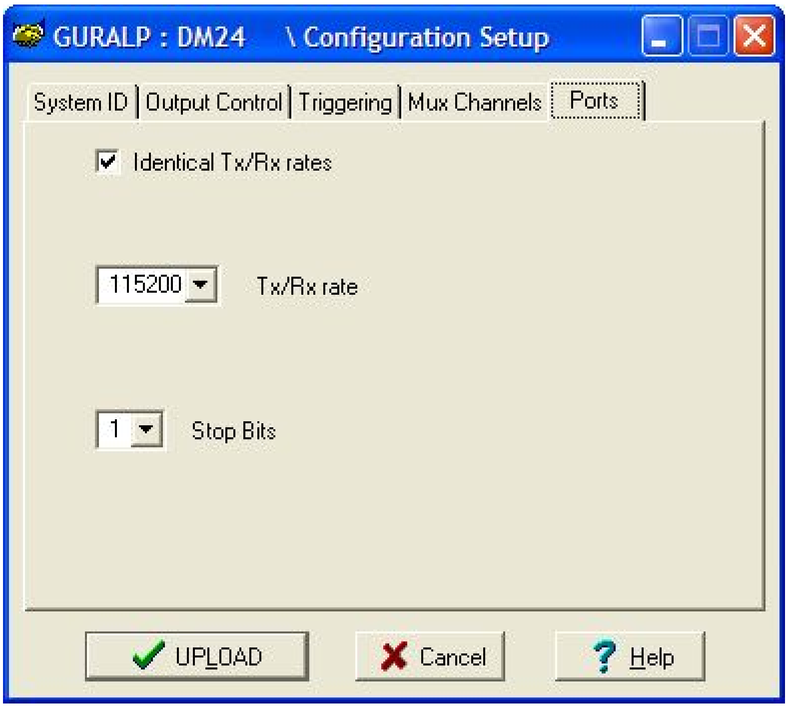
The collection and transmission of these environmental channels is controlled using the Mux Channels pane:



If a tick is placed in the box next to a channel, its data will be collected and transmitted as a data stream in GCF format, just as with the normal data channels. To indicate that the data comes from a Mux channel, the Stream ID will take the form `****Mx`, where `M` stands for Mux and *x* is a hexadecimal integer (i.e. 0 – 9, and A – F for 10 through 15). Z, N/S and E/W Mass Position Mux channels appear as `M8`, `M9` and `MA` respectively. The digitiser also monitors its internal temperature, which is reported on channel `ME`.

5.1.5 Ports

The Baud Rates pane of the Configuration set-up window allows you to program the baud rate and stop bits for the digitiser's output port.



The baud rate you choose must satisfy two conditions:

- It must be high enough to allow all the transmission of all data generated by the digitiser at the sampling rates you have chosen. For three streams of data at 100 Hz, for example, 9,600 baud will usually be sufficient. If you wish to transmit 200 Hz data, however, the baud rate must be at least 19,200.
- It must be low enough to fit within the operating range of the telemetry equipment you are using. While modern modems often offer transfer rates up to 56 kBaud, the telephone or transmission lines may not support these rates. The same holds true for radio telemetry.

Usually, the transmit and receive rates of the data port will be the same. If not, you may select different data rates by removing the tick in the check-box marked **Identical TX/RX rates**.

The **Stop Bits** option allows you to choose whether the serial link uses 1 or 2 stop bits. In most cases this can be left at 1, although 2 may be required if you are sending data over 'difficult' transmission lines (for example, some types of radio link). Using 2 stop bits will add a 10% overhead to the data.

You will also need to set the data rate for Scream's local serial port, as well as for the EAM or other communications device (if you are using one). In Scream!, you can configure a serial port by right-clicking on its icon (not that of the digitiser) and selecting Configure... from the pop-up menu: for more details, consult the on-line help or user guide for Scream!. If you are using an additional communications device, you should consult its documentation to learn how to set its baud rate.

5.2 Controlling digitisers

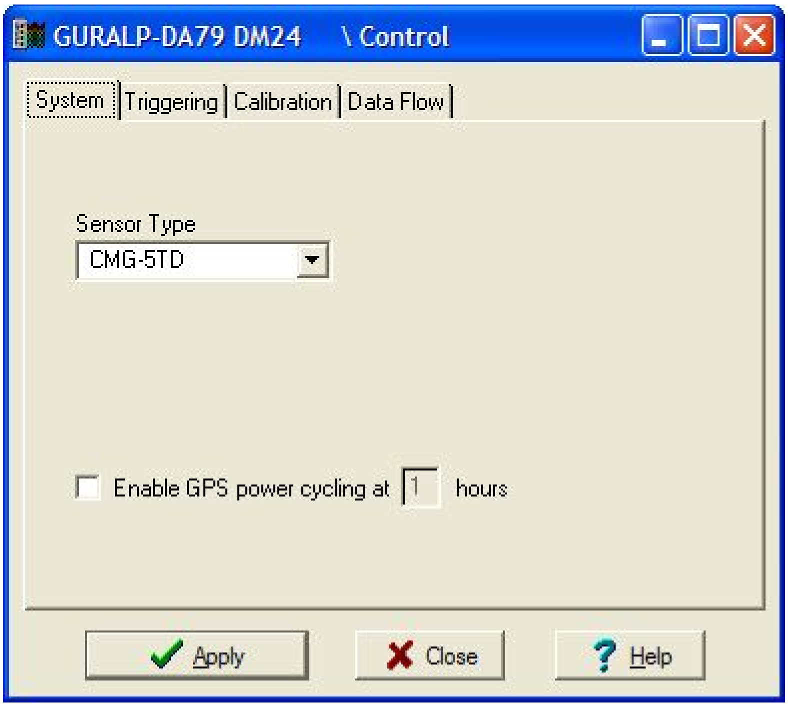
To control a digitiser whilst it is running, either right-click on the digitiser's entry in the list to the left of Scream!'s main window (not the Local or Comxx icons) and click Control..., or simply double-click the entry. Scream! will then contact the digitiser and retrieve its current status, a process which will take a few seconds, after which the Control window will be displayed. Once you are happy with any changes you have made in the Control window, click 

to send them to the digitiser, where they will take effect immediately.

This chapter describes the control options available to you for the digitiser. Many of these options will also be available for other Güralp digitisers. For the most accurate information, you should consult the Operator's Guide for the digitiser or sensor you connect.

5.2.1 System

When the Control window is first opened, it will be showing the System pane.

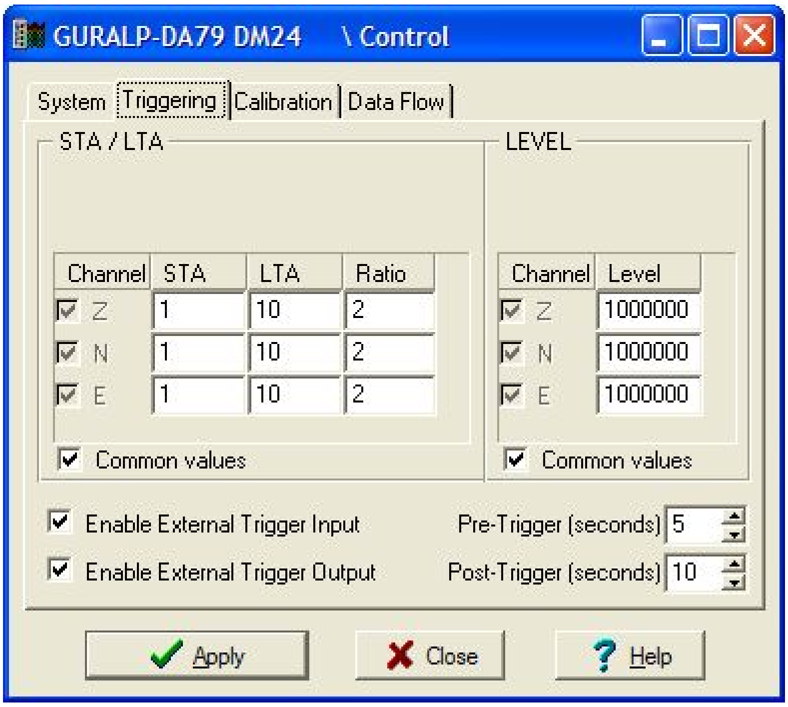


Sensor Type: If the sensor attached to the digitiser is a Güralp velocity sensor, you can send control commands to it from the Mass Control tab (see below). Which functions are available on this tab depends on the Sensor Type you have set here. The correct value for your 3ESPCD is “CMG-3T / ESPC”

If you change the Sensor Type, you may have to Apply the change, close the Control window, and open a new one to access the Mass Control options.

Enable GPS power cycling: If you are using a GPS unit to receive time signals, but do not experience significant drift in the system's clock (for example, in a stable-temperature environment), you can save power by selecting Enable GPS power cycling. With this option in use, the GPS time is only checked at intervals of a specified number of hours.

5.2.2 Triggering



The Triggering pane is very similar to the corresponding pane of the Configuration set-up window although not all options are available, since some require rebooting the digitiser. See “Triggering” in section 5.2.2 on page 53 for more details.

5.2.3 Calibration

You can check that your instrumentation is correctly calibrated by injecting known signals into the sensor's feedback loop. The Calibration pane allows you to do this once the sensors are installed. See section 4 on page 29 for details.

5.2.4 Mass Control

The controls on this tab are used to centre, unlock, and lock the sensor masses.

Note: Whether or not this tab is visible depends on the “Sensor type” setting on the “System” tab. See section 5.2.1 on page 52.

See section 7.1.2 on page 76 for more information.

5.2.5 Data flow

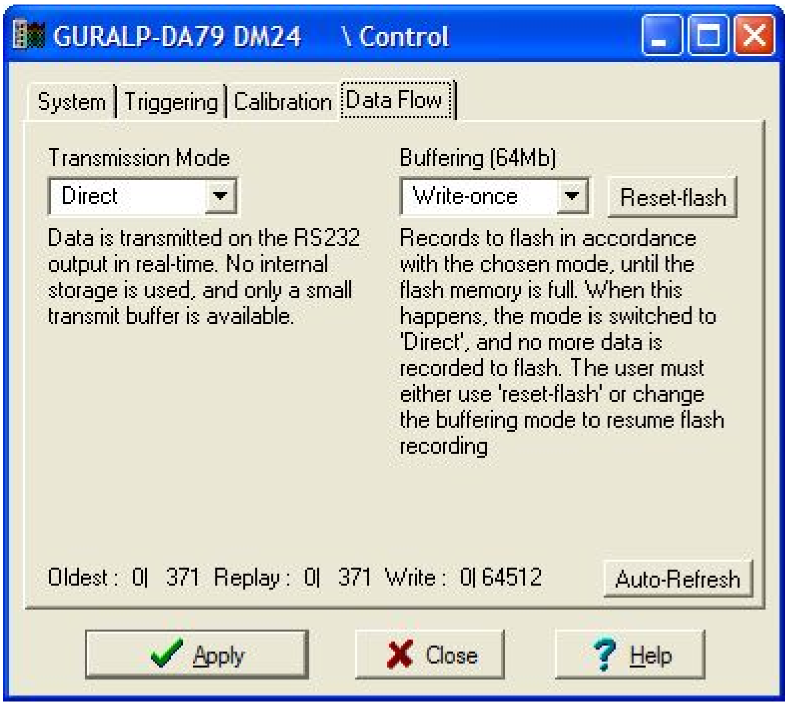
The digitiser operates in one of several transmission modes. These modes relate to how the unit uses its Flash memory:

- as a simple data store, from which you can request data (FILING and DUAL modes);
- as a buffer holding unacknowledged blocks, which are transmitted in preference to real-time data (FIFO mode);
- as a buffer holding unacknowledged blocks, which are transmitted whenever the channel is free but no real-time data blocks are ready (ADAPTIVE mode);
- not at all (DIRECT mode).

Separate from these modes are buffering modes, which tell the unit what to do when its Flash memory becomes full: either

- carry on, overwriting the oldest data held (RECYCLE), or
- stop writing and switch the digitiser transmission mode to DIRECT (WRITE-ONCE).

You can switch between transmission modes in Scream! by right-clicking on the digitiser and clicking on Control..., then navigating to the Data Flow pane:



Clicking Apply in this window immediately activates the transmission mode you have selected—there is no need to reboot. If you prefer, you can use the digitiser terminal to switch between transmission modes. The commands to use, which take effect immediately, are given below.

5.2.5.1 DIRECT

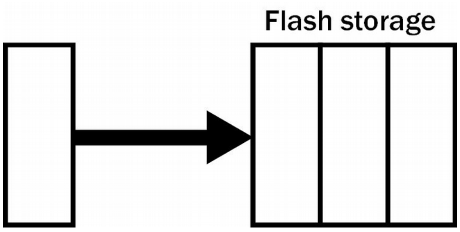
Syntax: `DIRECT`

Instructs the digitiser not to use Flash memory for storage. Instead, all data are transmitted directly to clients. An instrument in DIRECT mode still honours the GCF Block Recovery Protocol: a temporary RAM buffer always holds the last 256 blocks generated and, if a client fails to receive a block, it can request its retransmission. If you expect breaks in communication between the instrument and its client to last more than 256 blocks, or if you want the instrument to handle breaks in transmission (rather than relying on the client to request missed blocks), you should use

- ADAPTIVE mode, if you want data to stay as near to real time as possible (but do not mind if blocks are received out of order); or
- FIFO mode, if you need blocks to be received in strict order (but do not mind if the instrument takes a while to catch up to real time.)

5.2.5.2 FILING

Syntax: `FILING`

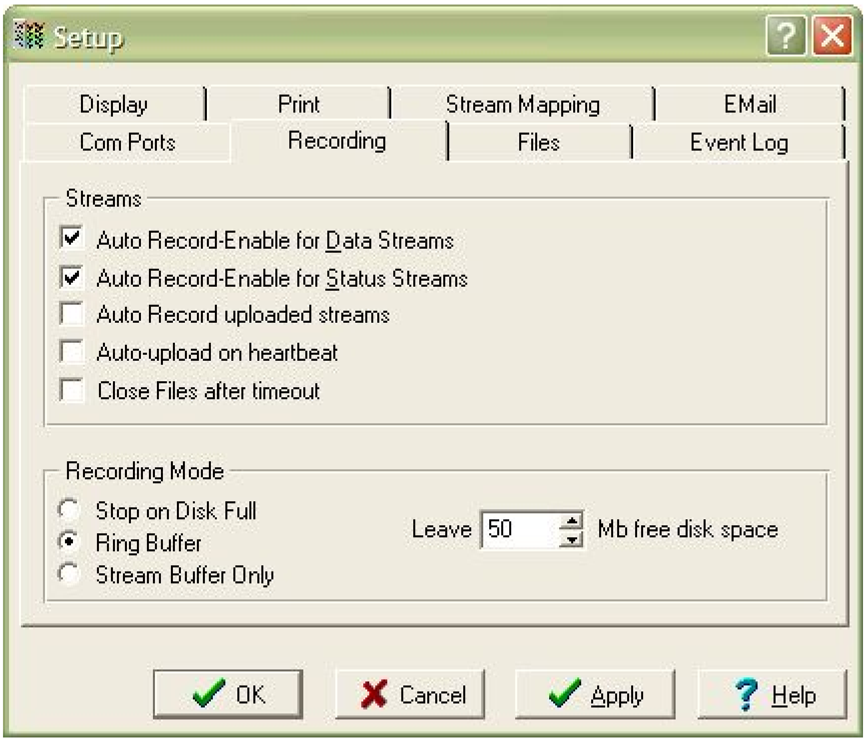


Instructs the digitiser not to transmit blocks to clients automatically, but to store all digitised data in the Flash memory. If you have chosen the RECYCLE buffering mode (see below), the memory is used in circular fashion, i.e. if it becomes full, incoming blocks begin overwriting the oldest in memory. If the WRITE-ONCE mode is active, the instrument will switch to DIRECT mode (see above) when the memory becomes full. You can retrieve blocks from an instrument in FILING mode by connecting to its terminal interface and issuing commands such as FLUSH, or through Scream! (see below).

5.2.5.3 Heartbeat messages

When in FILING mode, an instrument transmits “heartbeat” messages over its data port. These short messages take the place of data blocks, and ensure that programs such as Scream! know that an instrument is present. You can change the frequency of heartbeat messages from Scream!'s Control window, or with the command HEARTBEAT. You can tell Scream! to download new data automatically whenever it receives a heartbeat message from an instrument in FILING mode. This is useful, for example, in autonomous installations connected by intermittent modem links. To enable this feature:

1. Choose File → Setup... from Scream!'s main menu, and navigate to the Recording pane.

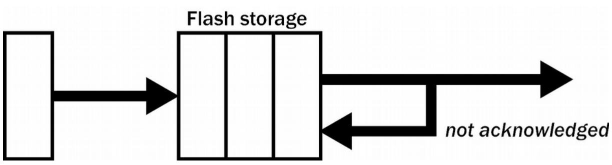


2. Tick the Auto-upload on heartbeat check-box.

3. Click OK. Using FILING mode with Auto-upload on heartbeat ensures that Scream! receives all new data whenever it can, regardless of the configuration of any devices between you and the instrument.

5.2.5.4 FIFO (First In First Out)

Syntax: `FIFO`



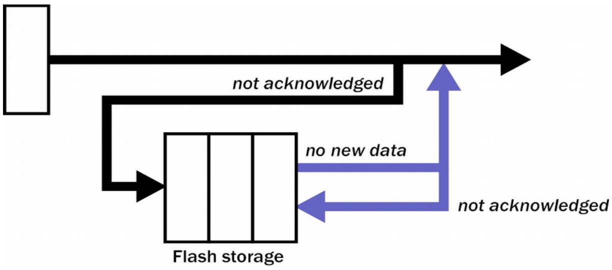
Instructs the digitiser to begin writing blocks to Flash memory as for FILING mode, but also to transmit data to clients. Data are transmitted in strict order, oldest first; the digitiser will only transmit the next block when it receives an explicit acknowledgement of the previous block. If the communications link is only marginally faster than the data rate, it will take some time to catch up with the real-time data after an outage.

If you want data to be transmitted in real-time where possible, but are worried about possible breaks in communication, you should use ADAPTIVE mode instead. FIFO mode will consider a data block successfully transmitted once it has received an acknowledgement from the next device in the chain. If there are several devices between you and the instrument, you will need to set up the transmission mode for each device (if applicable) to ensure that data flow works the way you expect.

Like all the transmission modes, FIFO mode does not delete data once it has been transmitted. You can still request anything in the Flash memory using Scream! or over the command line. The only way data can be deleted is if they are overwritten (in the RECYCLE buffering mode, see below) or if you delete it manually.

5.2.5.5 ADAPTIVE

Syntax: `ADAPTIVE`

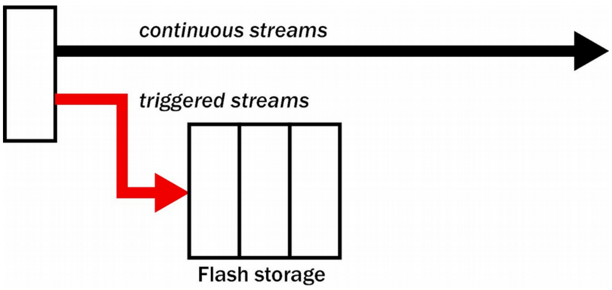


Instructs the digitiser to transmit current blocks to clients if possible, but to store all unacknowledged blocks in the Flash memory and resend them, oldest first, when time allows. ADAPTIVE mode is best suited for “real-time” installations where the link between digitiser and client is intermittent or difficult to access. If the communications link is only marginally faster than the data rate, it will usually be busy transmitting real-time data. Thus, it may take a while for the instrument to work through the missed blocks. In this case, and if your client supports it, you may prefer to use the Block Recovery Protocol to request missed blocks where possible.

Some software packages (most commonly Earthworm) cannot handle blocks being received out of time order. If you are using such a package, ADAPTIVE mode will not work, and may crash the software.

5.2.5.6 DUAL

Syntax: `DUAL`



Instructs the digitiser to transmit any continuous streams directly to clients as for DIRECT mode, but to store triggered data into Flash storage as for FILING mode. If you choose DUAL mode but do not select any continuous streams for output, the instrument will send heartbeat messages as for FILING mode. Scream! can pick these up and download new data as necessary.

5.2.5.7 RE-USE / RECYCLE

Syntax: `RE-USE`

Instructs the digitiser to carry on using the current filing technique when the Flash memory becomes full, overwriting the oldest data held. This buffering mode is called RECYCLE in Scream!. For example, in DUAL mode with RECYCLE buffering, the latest continuous data will be transmitted to you as normal, and the latest triggered data may be retrieved from the Flash memory using Scream! or the command line. However, if you do not download data regularly from the Flash memory, you may lose older blocks. This mode thus lets you define the end point of the data held by the instrument.

5.2.5.8 WRITE-ONCE

Syntax: `WRITE-ONCE`

Instructs the digitiser to stop writing data to the Flash memory when it is full, and to switch to DIRECT mode automatically. For example, in FIFO mode with WRITE-ONCE buffering, the station will transmit data to you continuously, but also save it in the Flash memory until it is full. Once full, the instrument will switch to DIRECT mode and continue transmitting, though no further data will be saved. This mode thus lets you define the start point of the data held by the instrument.

6 Command line interface

6.1 Introduction

You can connect to the internal software of the digitiser over its output serial port and communicate with it. To enter command mode from Scream!, right-click on the digitiser's icon and select Terminal... from the menu that pops up. A window will open, and once the digitiser and computer are communicating properly you will see the prompt

```
ok
```

If you prefer, you can use a terminal program on your computer (such as minicom on Linux, or PuTTY on Microsoft Windows) to connect to the digitiser.

Whilst you are in terminal mode, data transfer will be interrupted; the digitiser may use any Flash memory as a temporary store, depending on how you have configured it. Some commands, such as `SET-TAPS`, require a reboot to take effect.

Güralp EAM and AM modules also allow you to send commands directly to the digitiser using command-line and/or web-based tools. For more information, please see the manual for your data module.

If you have problems connecting to the digitiser's console, you should check that the serial port's options and baud rate are set correctly in Scream! or your terminal program. As supplied, the digitiser expects connections at 19200 baud, with 8 data bits, no parity bit and 1 stop bit. No flow control is used.

6.1.1 FORTH

The digitiser uses FORTH to implement its features. To issue a command in FORTH, you must supply the arguments *before* the command, for example:

```
3 SENSOR-TYPE
```

In FORTH, anything you enter is termed a “word”. New words (case insensitive) are placed on a stack. Some words are known to the system, and may represent commands; if a command finds itself at the top of the stack (e.g. because it is the last thing you typed), they will execute, remove themselves from the stack, and then remove further items from the stack to use as arguments. Thus, in the command

```
3 SENSOR-TYPE
```

the `3` has no immediate effect, so stays on the stack; `SENSOR-TYPE` takes itself and the previous item (here `3`) off the stack, then performs its action on the `3` (here, setting the configured sensor type to 3, representing a Güralp 3T sensor.)

If a command completes with nothing remaining on the stack, the digitiser will show the prompt `ok`. Otherwise, the prompt will remind you that the digitiser is waiting for you to complete the command. Some commands, such as SAMPLES/SEC, clear the stack automatically after they execute.

Some commands are interactive, and will ask you to provide extra information after you execute them. In the following sections, interactive commands are shown as example sessions, using the typographical conventions given in section 1.4 on page 6.

6.2 General configuration

The following commands set the general configuration of the digitiser.

6.2.1 SET-ID

Syntax: `SET-ID` (interactive)

Sets the system identifier and serial number of the digitiser to values you supply:

> **SET-ID**
> System Identifier ? (e.g. ALPHA,) **DM24ID**, Serial # ? (e.g. 1234,00) **4507,00**

The system identifier that you supply may contain up to 6 alphanumeric (0-9A-Z) characters, and must have a comma after it. 6-character strings lexically greater than ZIK0ZJ are not permitted. The serial number you supply must contain exactly 6 alphanumeric (09A-Z) characters, and must have a comma after the fourth character.

6.2.2 SENSOR-TYPE

Syntax: *type* `SENSOR-TYPE`

Tells the digitiser which kind of sensor is attached to it. This affects whether or not the digitiser exposes commands such as locking and centring. The argument *type* can be one of

- 1, for 40T sensors,
- 2, for 3ESP sensors,
- 3, for 3T analogue sensors, or
- 4, for 3TD sensors.

6.2.3 GPS-TYPE

Syntax: *type* `GPS-TYPE`

Tells the digitiser which kind of GPS is attached to it. The argument *type* can be one of

- 0, if no GPS is available,

- 1, for attached Trimble GPS equipment,
- 2, for attached Garmin GPS equipment, or
- 3, if GPS information should be obtained from upstream units (stream sync mode.)

6.2.4 BAUD

Syntax: *`port baud-rate`* `BAUD`

Sets the baud rate for one of the serial ports on the digitiser, in bytes per second. The argument *`port`* is a small integer specifying the port: Most units have port 0 assigned to data output and communication, port 1 to GPS input, and port 2 to the DATA IN port. For example,

```
0 38400 BAUD
1 4800 BAUD
2 38400 BAUD
```

This will reset a standard single-sensor digitiser to its default configuration. The allowable values for baud-rate are 4800, 7200, 9600, 14400, 19200, 38400, 57600 and 1152 (for 115200 baud). GPS inputs should remain set at 4800 baud.

6.2.5 AZIMUTH

Syntax: *`instrument angle`* `AZIMUTH`

Some borehole digitisers can rotate incoming signals algorithmically as they are digitised. This feature allows you to compensate for an instrument being out of alignment with the North/South axis. To use it, first measure the orientation of the sensor, then connect to the digitiser and issue an AZIMUTH command, giving the angle you have measured.

The argument *`instrument`* tells the digitiser which instrument to apply the rotation to; 0 for a 4-channel digitiser.

The argument *`angle`* is the measured angle of deviation from the North/South axis, in tenths of a degree. The angle of deviation is the negative of the angle by which you want incoming signals to be rotated. Like all other parameters, it must be an integer (i.e. a whole number of tenths of a degree).

You can measure the orientation of a borehole sensor by placing a reference sensor nearby and carrying out coherence calculations. An extension to Scream! is available which can do this for you. For details, see the manual for Scream!, MAN-SWA-0001.

The AZIMUTH command only alters the digitiser's CMOS settings. You will need to re-boot the digitiser to transfer them to the DSP.

6.2.6 CROSS

Syntax: *`channel`* `CROSS`

Alters the DSP's transformation matrix to invert one of the digitiser channels.

The argument *`channel`* is one of 0 (vertical), 1 (N/S), 2 (E/W) and 3 (auxiliary).

The CROSS command only alters the digitiser's CMOS settings. You will need to re-boot the digitiser to transfer them to the DSP. If you need to set both `AZIMUTH` and `CROSS`, you must issue `AZIMUTH` first, since it overwrites the matrix.

6.3 Output configuration

The commands in this section control the serial data output.

6.3.1 SAMPLES/SEC

Syntax: *`tap-0 tap-1 tap-2 tap-3`* `samples/sec`

The DSP software on the digitiser supports up to seven cascaded filter/decimation stages. At each stage, the sample rate can be decimated by a factor of 2, 4 or 5. The fixed decimation stages output data at 2,000 samples/sec, so decimated data streams are available from 1,000, 500 and 400 samples/sec down to 1 sample/sec.

You can specify the sample rate to use at four of these stages, known as taps. You can also take output from any of these four stages. The digitiser will arrange the remaining stages according to your settings.

The arguments *`tap-0`* to *`tap-3`* are the sample rates at each tap in turn, starting with the highest. You must ensure that each rate is lower than the previous one by a factor of 2, 4, 5, 8 (= 2 then 4), 10 (= 2 then 5) or 16 (= 4 then 4). Non-integer values are not allowed. The following four examples are all valid settings:

```
1000  125   25    5     samples/sec
1000  500   100   10    samples/sec
500   100   20    4     samples/sec
400   40    10    5     samples/sec
```

As long as you specify the initial taps, you can omit later ones. The command fills in the value of the missing taps, using a decimation factor of 2 where possible. Thus, the following commands are equivalent:

```
400 40 20 10 samples/sec
400 40 samples/sec
```

6.3.2 CONTINUOUS

Syntax: *tap components* `CONTINUOUS`

Sets which components are output under normal conditions, and at which tap(s).

The argument *tap* is the tap number at which to output the triggered stream. You can set which taps output which sample rates using the `SAMPLES/SEC` command, described above.

The argument *components* is an integer below 16, whose binary bits represent the Z (1), N (2), E (4) and auxiliary (8) components respectively. Thus, for example,

- `0 1 CONTINUOUS` will output the Z component only (1) at the first tap;
- `0 2 CONTINUOUS` will output the N component only (2);
- `0 4 CONTINUOUS` will output the E component only (4);
- `0 7 CONTINUOUS` will output all three directional components (1 + 2 + 4 = 7);
- `0 12 CONTINUOUS` will output the E component and the auxiliary component (4 + 8 = 12);
- `0 0 CONTINUOUS` will output nothing at this tap.

6.3.3 SET-TAPS

Syntax: *tap-0 tap-1 tap-2 tap-3* `SET-TAPS`

This is an alternative to the `CONTINUOUS` command, which allows you to set the outputs for all taps simultaneously.

The arguments *tap-0* to *tap-3* are integers below 16, whose binary bits represent the Z (1), N (2), E (4) and auxiliary (8) components respectively. Each one sets which components are output at that tap under normal conditions. For example, if you issue

```
9 7 0 15 SET-TAPS
```

then

- tap 1 will output Z and the auxiliary component (1 + 8 = 9);
- tap 2 will output all three directional components (1 + 2 + 4 =7);
- tap 3 will not output anything; and
- tap 4 will output all four components (1 + 2 + 4 + 8 = 15).

To set triggered output streams, you should use the `TRIGGERED` command detailed below.

6.4 Triggering

This section describes the commands which affect triggering.

6.4.1 TRIGGERS

Syntax: *`components`* `TRIGGERS`

Selects which component or components can generate a trigger. Only these components will be examined by the triggering algorithm.

The argument *`components`* is an integer below 16, whose binary bits represent the Z (1), N (2), E (4) and auxiliary (8) components respectively as described above. Issuing 0 TRIGGERS will disable the triggering system.

6.4.2 TRIGGERED

Syntax: *`tap components`* `TRIGGERED`

Selects which component or components will be output when a trigger is generated, and at which tap (sample rate).

The argument *`tap`* is the tap number at which to output the triggered stream. You can set which taps output which sample rate using the SAMPLES/SEC command, described above.

The argument *`components`* is an integer below 16, which represents which components to output in the same fashion as in the CONTINUOUS command, above.

(This command and the previous one have similar names; remember that a component TRIGGERS the system, whilst taps and components are TRIGGERED.)

6.4.3 STA

Syntax: *`Z-secs N-secs E-secs X-secs`* `STA`

Sets the length of the “short-term” averaging period in the STA/LTA triggering algorithm.

The arguments *`Z-secs`*, *`N-secs`*, *`E-secs`* and *`X-secs`* are the time period over which to calculate the average for the Z, N, E, and auxiliary components respectively. If a component is not considered by the triggering algorithm (see `TRIGGERS`, above), the value you specify here will be ignored. For example,

```
1 1 2 2 STA
```

will calculate short-term averages for 1 second of the Z and N components, and 2 seconds of the E and auxiliary components.

6.4.4 LTA

Syntax: *`Z-secs N-secs E-secs X-secs`* `LTA`

Sets the length of the "long-term" averaging period in the STA/LTA triggering algorithm.

The arguments *`Z-secs`*, *`N-secs`*, *`E-secs`* and *`X-secs`* are the time period over which to calculate the average for the Z, N, E, and auxiliary components respectively. If a component is not considered by the triggering algorithm (see `TRIGGERS`, above), the value you specify here will be ignored. For example,

```
15 20 20 20 STA
```

will calculate long-term averages for 15 seconds of the Z component and 20 seconds of the N, E and auxiliary components.

6.4.5 RATIOS

Syntax: *`Z-ratio N-ratio E-ratio X-ratio`* `RATIOS`

Sets the ratio of STA to LTA above which a trigger will be declared in the STA/LTA triggering algorithm.

The arguments *`Z-ratio`*, *`N-ratio`*, *`E-ratio`* and *`X-ratio`* are the time period over which to calculate the average for the Z, N, E, and auxiliary components respectively. If a component is not considered by the triggering algorithm (see `TRIGGERS`, above), the value you specify here will be ignored. For example,

```
4 10 10 10 RATIOS
```

will cause the digitiser to trigger if the STA/LTA ratio is above 4 for the Z component or above 10 for the remaining components.

6.4.6 PRE-TRIG

Syntax: *`time`* `PRE-TRIG`

Sets the pre-trigger recording time. The argument *`time`* is the number of seconds of data to output from before a trigger is declared.

6.4.7 POST-TRIG

Syntax: *`time`* `POST-TRIG`

Sets the post-trigger recording time. The argument *`time`* is the number of seconds of data to output after a trigger condition lapses. If an event persists for some time, all triggering components must fall below the threshold before the trigger condition will lapse; only then will the post-trigger period begin.

6.4.8 TRIGGERIN

Syntax: `TRIGGERIN ENABLE | TRIGGERIN DISABLE`

Enables or disables external trigger input, in instruments equipped with this option.

Enabling external trigger input allows you to trigger the digitiser from an external logic level supplied through its digital output port. This voltage can be between 5 and 10 V supplied between the Trigger In pin and signal ground. If the digitiser is triggered externally, it will behave exactly as if it had generated the trigger itself.

6.4.9 TRIGGEROUT

Syntax: `TRIGGEROUT ENABLE | TRIGGEROUT DISABLE`

Enables or disables external trigger output, in instruments equipped with this option.

Enabling external trigger output allows you to trigger other equipment through a relay contained within the digitiser whenever it triggers. The digitiser's digital output port contains two pins (Trigger out, common and Trigger out, normally-open) which are connected when it triggers. In particular, you can connect a second digitiser with `TRIGGERIN ENABLE` in effect, in which case triggered data from both instruments will be transmitted whenever the digitiser triggers.

If a digitiser has both `TRIGGERIN ENABLE` and `TRIGGEROUT ENABLE` in effect, only triggers which the digitiser itself has generated will be output. Triggers received through the Trigger in port will cause the digitiser to output triggered streams, but will not be passed on to other digitisers.

6.5 Calibration

These commands are all concerned with calibration.

6.5.1 SINEWAVE

Syntax: *`component freq-or-period unit`* `SINEWAVE`

Instructs the digitiser to inject a sine-wave calibration signal, starting on the zero crossing.

The argument *`component`* specifies which component is to be calibrated, one of Z, N/S, E/W, or X. Some sensors use only the Z calibration loop for all three components.

The arguments *`freq-or-period`* and *`unit`* together determine the frequency of the calibration signal. If unit is `HZ`, then *`freq-or-period`* is taken as a frequency, in Hz; if `SECOND`, then it is interpreted as a period, in seconds.

For example:

```
N/S 4 HZ SINEWAVE
```

The argument *freq-or-period* must be an integer; if you want to specify a period of, for example, 0.5 s, you should specify it as 2 HZ instead. T he calibration signal will be automatically disconnected after 2 minutes if you have not altered the setting using the `MINUTE` command, described below.

Whilst calibration is in progress, the fourth (auxiliary, or X) data channel is switched on to monitor the returning calibration signal.

6.5.2 SQUAREWAVE

Syntax: *component* `SQUAREWAVE`

Instructs the digitiser to inject a square-wave (step function) calibration signal, consisting of a positive step on the start of the next clock minute, followed by a negative step some minutes later (by default, 2). The calibration is disconnected the same number of minutes after the negative edge.

The argument *component* specifies which component is to be calibrated, one of Z, N/S, E/W, or X. Some sensors use only the Z calibration loop for all three components. You can alter the duration of each step using the `MINUTE` command, described below.

Whilst calibration is in progress, the fourth (auxiliary, or X) data channel is switched on to monitor the returning calibration signal.

6.5.3 RANDOMCAL

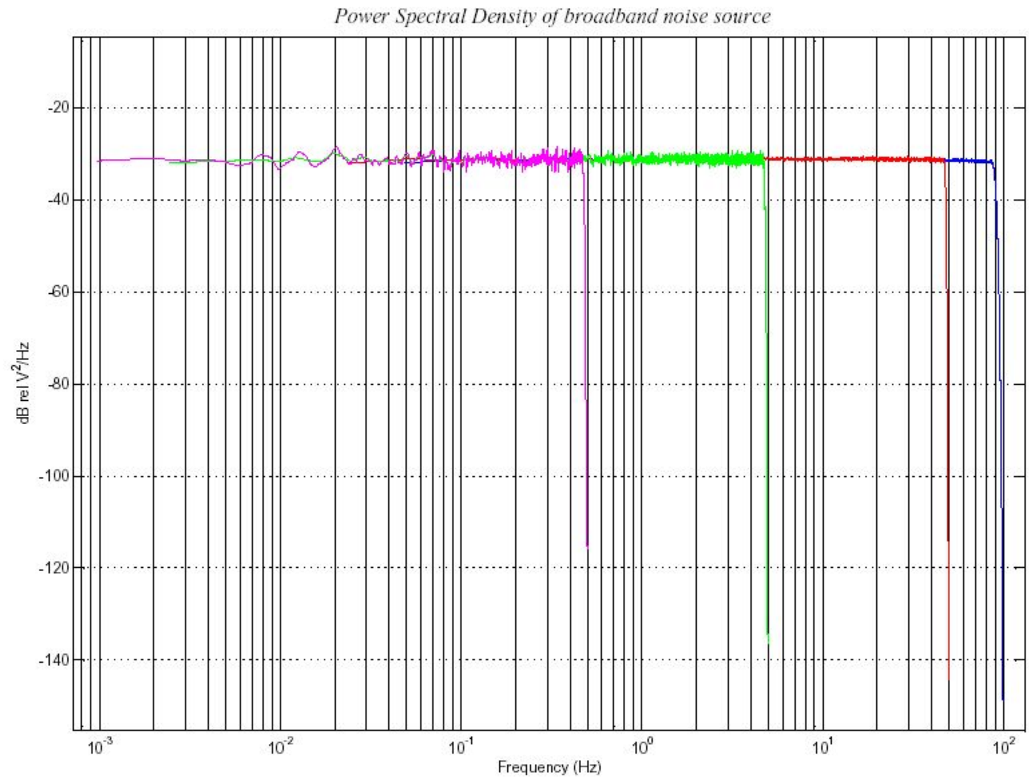
Syntax: *component* `RANDOMCAL`

Instructs the digitiser to inject a white-noise calibration signal generated by an on-board pseudo-random number generator.

The argument *component* specifies which component is to be calibrated, one of Z, N/S, E/W, or X. Some sensors use only the Z calibration loop for all three components.

The calibration signal will be automatically disconnected after 2 minutes if you have not altered the setting using the `MINUTE` command, described below.

Whilst calibration is in progress, the fourth (auxiliary, or X) data channel is switched on to monitor the returning calibration signal. The pseudo-random number generator produces true white noise over the entire passband, as shown in the power spectral density plot below:



The different coloured lines show the results of experiments which measure the power spectral density over several frequency bands. Together, the results show a flat noise level over the entire passband to within experimental error.

6.5.4 MINUTE

Syntax: *duration* MINUTE

Sets for how long the next SINEWAVE or RANDOMCAL calibration signal will be injected, or the period of the next SQUAREWAVE calibration signal.

The argument *duration* is the desired interval, in minutes. If you now issue a SINEWAVE or RANDOMCAL command, the calibration will last *duration* minutes; if the next calibration command is SQUAREWAVE, a positive step of duration minutes will be generated, followed by a negative step of a further duration minutes.

If you do not issue MINUTE, calibration signals will default to 2 minutes. This is to avoid the sensor and digitiser inadvertently being left in calibration mode. Issuing, e.g., 5 MINUTE will cause the next calibration signal to last 5 minutes, but later calibration signals will revert to a duration of 2 minutes. You will need to issue a MINUTE command before each injection.

Because of the way FORTH works, you can insert MINUTE commands into SQUAREWAVE, SINEWAVE or RANDOMCAL commands, for example:

```
N/S 4 HZ 5 MINUTE SINEWAVE E/W 10 MINUTE SQUAREWAVE
```

6.5.5 %AMPLITUDE

Syntax: `value %AMPLITUDE`

Sets the relative amplitude of the signal, as a percentage. For `SQUAREWAVE` and `RANDOMCAL` calibrations, the default of 100% is normally suitable. If you have a high-gain sensor, you may have to use a lower value. For `SINEWAVE` calibrations, you may have to adjust the `%AMPLITUDE` setting to suit the frequency of the calibration signal.

You can insert `%AMPLITUDE` commands into calibration commands as described above, e.g.:

```
Z 3 MINUTE 50 %AMPLITUDE RANDOMCAL
```

6.6 Actions

The commands in this section trigger specific actions, such as mass-locking.

6.6.1 LOCK

Syntax: `LOCK`

Locks the sensor mass of the instrument. Whilst this process is executing, the system displays the mass position for each component, measuring one position each second (i.e. one reading every 4 seconds for each component of a 4-component instrument). The process returns when locking is complete. The mass positions are measured to 16-bit accuracy, with full deflection corresponding to values around ±32000 counts.

6.6.2 UNLOCK

Syntax: `UNLOCK`

Unlocks the sensor mass, and returns when unlocking is complete. The system will display the mass positions as the process continues, as for `LOCK`, above.

6.6.3 CENTRE

Syntax: `CENTRE`

Centres the sensor mass, and returns when centring is complete. The system will display the mass positions as the process continues, as for `LOCK`, above. When the mass is correctly centred, the readings should be less than ±1000 counts.

6.6.4 RE-BOOT

Syntax: `RE-BOOT` (interactive)

Causes the digitiser to reset after a delay of 2 seconds.

```
RE-BOOT
Confirm with 'y' ? y
```

Responding to the confirmation message with anything other than `y` will abort the reset.

6.7 Data storage and recovery

These commands control how data are stored, transmitted and recovered from the internal flash storage.

6.7.1 SHOW-FLASH

Syntax: `SHOW-FLASH`

Reports status information about the Flash memory in the digitiser, if fitted. For example, the `SHOW-FLASH` output for a new system with 8 × 64Mb chips fitted might be

```
512MB Flash File buffer : 16 Blocks Written 0 unread 524,288
Free
Oldest data [16] Blank
 Read point [16] Blank
Latest data [16] Blank
File Replay [16] Blank
```

Similarly, SHOW-FLASH on a system in use with 1 × 64Mb chip fitted might display:

```
64MB Flash File buffer : 65,536 Blocks Written  65.532
Unread  4 Free
Oldest data [36,272]  GURALP TESTZ1 2004 12  3 20:20:41
 Read point [36,272]  GURALP TESTZ1 2004 12  3 20:20:41
Latest data [36,268]  GURALP TESTX2 2004 12  4 10:09:12
File Replay [36,272]  GURALP TESTZ1 2004 12  3 20:20:41
```

The first line displays general status information, namely the quantity of Flash memory available (`64MB Flash File buffer`), how many 1k GCF blocks have been written (`65,536 Blocks Written`), how many remain to be transmitted (`65,532 Unread`), and how much space (in 1k blocks) remains (`4 Free`).

The next lines show, in turn:

- the stream and time-stamp of the oldest data in memory,
- the current position of the read pointer,

- the stream and time-stamp of the latest data in memory, and
- the current position of the replay point.

The read pointer normally points to the oldest data in the file; however, if all the data up to the replay point have already been downloaded, the read pointer is set to the replay point and the number of blocks remaining unread is updated. Downloads where a time-period is not specified always start from the read pointer.

6.7.2 DIRECT

Syntax: `DIRECT`

Instructs the digitiser not to use Flash memory for storage. Instead, all data are transmitted directly to clients. A temporary RAM buffer allows clients to request blocks they fail to receive using the Block Recovery Protocol.

6.7.3 FILING

Syntax: `FILING`

Instructs the digitiser not to transmit blocks to clients, but to store all digitised data in the Flash memory. The memory is used in circular fashion, i.e. if it becomes full, incoming blocks begin overwriting the oldest in memory.

6.7.4 ADAPTIVE

Syntax: `ADAPTIVE`

Instructs the digitiser to transmit current blocks to clients if possible, but to store all unacknowledged blocks in the Flash memory and resend them when time allows. This differs from `DIRECT` in the following ways:

- the client does not have to keep track of which blocks it has not received, and
- the entire Flash memory can be used for blocks awaiting retransmission, rather than a temporary RAM buffer.

Adaptive mode is best suited for installations where the link between digitiser and client is intermittent or difficult of access.

6.7.5 FIFO

Syntax: `FIFO`

Instructs the digitiser to begin writing blocks to Flash memory as for FILING, but also to transmit data to clients. Data are transmitted in strict order, oldest first; the digitiser will only transmit the next block when it receives an acknowledgement of the previous block.

6.7.6 DOWNLOAD

Syntax: `DOWNLOAD`

Sets up a data transfer from the Flash memory over the serial connection. Which data are downloaded depends on various parameters you can set, which allow you to select a particular stream, streams of a specified sample rate, or streams within a certain time window. You can set parameters separately, or string the definitions before the `DOWNLOAD` command, e.g.

```
ALL-FLASH STREAM HPA0N1 DOWNLOAD

2004 12 01 00 00 FROM-TIME ALL-DATA DOWNLOAD

100 S/S ALL-TIMES DOWNLOAD
```

`DOWNLOAD` with no arguments starts another download with the same parameters as last time. See below for full details of the parameter commands.

The `DOWNLOAD` command returns immediately, so that you can issue more commands if required. To close the connection and begin downloading, issue the `GO` command. You can pause the download by entering terminal mode, and restart with another `GO` or abort with `END-DOWNLOAD`.

6.7.7 ALL-FLASH

Syntax: `ALL-FLASH`

Sets the read point to the oldest data held by the digitiser. This command does not alter which streams are to be transmitted; you should specify streams or use the `ALL-DATA` command in addition to this one.

6.7.8 ALL-DATA

Syntax: `ALL-DATA`

Instructs the digitiser to transmit all the data streams it holds next time a `DOWNLOAD` is issued. This command does not alter the read point or time period; you should specify a time period or use the `ALL-FLASH` command in addition to this one.

6.7.9 STREAM

Syntax: `STREAM` *`stream-id`* (n.b.)

Instructs the digitiser to transmit only the stream with ID *`stream-id`*. Stream IDs are normally a 4-character device code (e.g. HPA0) followed by a component letter (N) and a tap number (1). Unlike most FORTH commands, the *`stream-id`* parameter goes after the command.

6.7.10 STATUS-ONLY

Syntax: `STATUS-ONLY`

Instructs the digitiser to transmit only status streams (text streams, normally with stream IDs ending in 00.)

6.7.11 S/S

Syntax: *`rate`* `S/S`

Instructs the digitiser to transmit only streams with sample rates equal to *`rate`*. If *`rate`* is zero, only status streams are transmitted. Note that this command should not be confused with the `SAMPLES/SEC` command.

6.7.12 ALL-TIMES

Syntax: `ALL-TIMES`

Clears any time selection in force, allowing you to download all data held by the digitiser. This command does not alter which streams are to be transmitted; you should specify streams or use the `ALL-DATA` command in addition to this one.

6.7.13 FROM-TIME

Syntax: *`yyyy mm dd hh mm`* `FROM-TIME`

Instructs the digitiser to transmit only data more recent than *`yyyymm-dd hh:mm`*, where

- *`yyyy`* is a four-digit year (1989 – 2069);
- *`mm`* is the month number (1 – 12);
- *`dd`* is the day of the month (1 – 31);
- *`hh`* is the hour of the day (0 – 23); and
- *`mm`* is the minute of the hour (0 – 59).

6.7.14 TO-TIME

Syntax: *`yyyy mm dd hh mm`* `TO-TIME`

Instructs the digitiser to transmit only data more recent than *`yyyymm-dd hh:mm`*, where *`yyyy`*, *`mm`*, *`dd`*, *`hh`* and *`mm`* have the same meanings as in `FROM-TIME`, above.

6.7.15 GO

Syntax: GO

Closes terminal mode, and begins any download that you have set up. You can pause the download by re-entering terminal mode, and restart with another GO or abort with END-DOWNLOAD. Once the download has completed, the digitiser will carry on transmitting real-time data, if you have so configured it.

6.7.16 END-DOWNLOAD

Syntax: END-DOWNLOAD

Aborts any downloads which were in progress at the time you entered terminal mode.

6.7.17 DISKMENU

Syntax: DISKMENU (interactive)

Allows you to select various options for downloading data over the optional FireWire interface. When you issue this command you will see the message

```
Plug in FireWire cable
```

and the digitiser will wait for you to plug in a compatible disk. When it detects one, it will print out information about the disk:

```
FireWire Connection *BR
Node: FFC1 #Nodes 2
Reading Node FFC0 .
LaCie Group SA
1394-IDE Rev B2
LaCie DATA BANK drive LUN 0
Logging on @AgentCSR= 0010:00000
Capacity 39.0GB

Press a key for options else
7 seconds to automatic disk backup
```

At this point, pressing a key will cause the digitiser to bring up an options menu and pause. If you do not press a key within seven seconds, the disk will be automatically backed up.

```
Disk Options :-
 (A) save All data
 (N) save New data
 (S) save Selected time window
 (D) Directory – contents
 (R) Reset disk – overwrite
 (X) eXit
A/N/S/D/R/X ?
```

During the operation of any of these options, progress reports will occasionally be printed out and shown on the terminal, as well as on the on-board LCD screen, if fitted.

6.7.18 MBTRANSFER

Syntax: `size MBTRANSFER`

If a FireWire disk is plugged in to the digitiser outside the `DISKMENU` system, and there is enough new data in Flash memory, it will automatically transfer the new data to the disk. The `MBTRANSFER` command sets how much new data there needs to be, before the digitiser will power up the disk and transfer it. If the disk is left attached, the digitiser will then wait until it has collected the same amount of data again before starting another transfer.

The argument *size* is the amount of data to transfer, in megabytes; it must be greater than 10 and less than the total quantity of Flash memory in the device. Larger values will save power, because the disk needs to be accessed less often.

If you plug a FireWire disk into the digitiser when there is less than *size* Mb of data ready, no data will be transferred. If you need to transfer smaller amounts of data, you should use the DISKMENU system.

6.7.19 ERASEFILE

Syntax: `ERASEFILE` (interactive)

Removes all data from the Flash memory, and resets all pointers to the beginning. You will be asked for confirmation before you do this, as all data will be destroyed.

If you have been running the digitiser with a FireWire disk attached, remember that there will be some data still in Flash memory awaiting transfer, up to the amount you last set with `MBTRANSFER`. You should make sure these data are transferred with the `DISKMENU` command before you `ERASEFILE`.

7 Inside the 3ESPCD

7.1 Inside the 3ESPCD

7.1.1 The sensors

The horizontal and vertical sensors are similar in design. The inertial mass in both cases consists of a transducer coil and a leaf-spring suspended boom which swings on a frictionless hinge. A triangular spring supports the weight of the mass; in the vertical sensor this spring is pre-stressed, with a natural period around half a second, whilst the horizontal sensor has an unstressed flat spring with a natural period around 1 second. Güralp3ESPCD sensors have no spurious resonances below 140 Hz, and weigh around 180 g. The small boom size and stiff springs allow three independent instruments to be mounted within the casing, together with all the associated feedback electronics.

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

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

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

See section 3 on page 9 for detailed instructions on how to set up your 3ESPCD installation.

The signal voltages output by the 3ESPCD 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 3ESPCD also receives control signals, which are used to clamp and un-clamp 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.

7.1.2 The control system

The internal operations of the 3ESPCD are supervised by a control microprocessor, which drives the mass clamping and centring adjustment motors. It responds to commands sent on three input lines. To activate a line, it should be grounded to digital ground for seven seconds. The delay is to prevent accidental activation. The signals sent to the microprocessor are termed LOCK, UNLOCK, and CENTRE. Each command acts on the vertical, N/S and E/W masses in turn. The microprocessor prevents the system from attempting incompatible actions (e.g. centring when the masses are locked).

While a command is taking place, the 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 integrated instruments, such as the 3ESPCD, the lines are controlled by the digitiser.

7.1.2.1 LOCK

This command locks the vertical mass and clamps the horizontal sensors by tilting them up to their end stops. If LOCK is activated when the masses are already locked, the processor will unlock them and attempt to lock again. This is useful if you suspect that the locking procedure has failed.

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

In the three-stage process, the vertical mass is locked with a motorised micrometer, and the N/S and E/W sensor bases are tilted to their end stops. At some point during each tilting stage, the position of the relevant mass will flip to one or other side. With the horizontal bases tilted, gravity will keep the masses pressed against their end stops, effectively locking them in place.

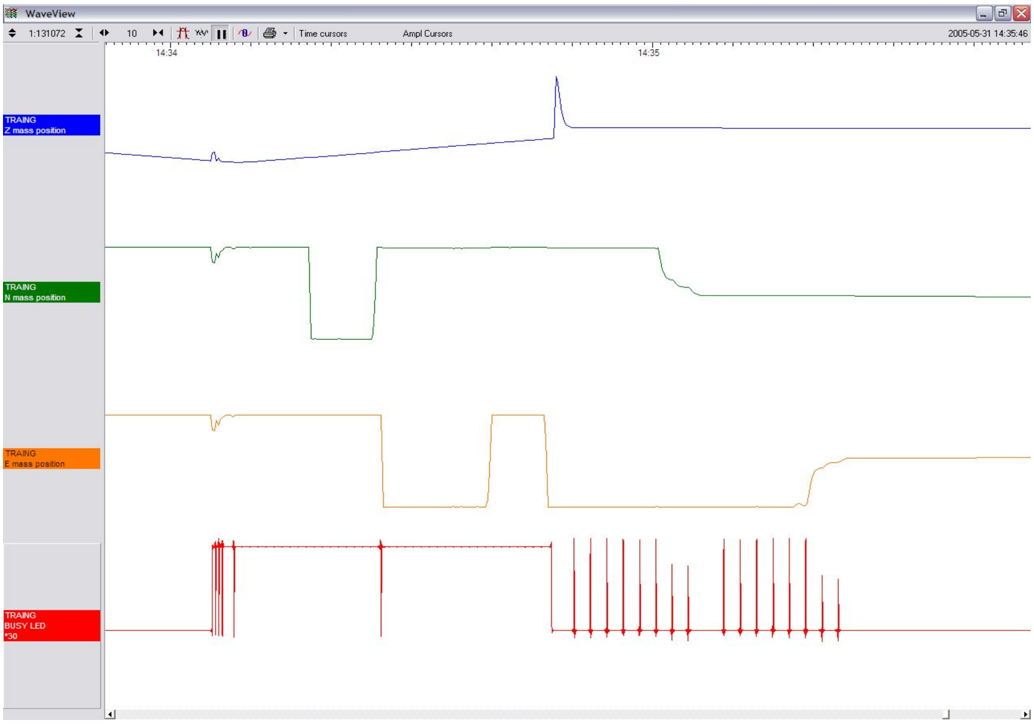
Because the 3ESPCD mass assembly is designed for a degree of robustness, no further locking is required.

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

7.1.2.2 UNLOCK

This command unlocks the sensor masses and prepares the instrument to begin operating. If `UNLOCK` is activated when the masses are already unlocked, the processor will lock them and attempt to unlock again. This is useful if you suspect that the locking procedure has failed.

During the `UNLOCK` procedure, the instrument automatically performs a round of centring for each component. Again, you can use the BUSY LED to monitor the progress of unlocking.



As shown, the process is:

1. The instrument checks to see whether the vertical mass is locked, and unlocks it if necessary.
2. The vertical 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.
3. The instrument checks the N/S sensor and base, and unlocks the sensor.
4. The N/S sensor base is tilted to its level position. This process takes rather longer. At some point during this stage, the mass may flip to the other side (as seen in the green trace.)

5. The N/S sensor mass is centred by applying pulses to the motor. This stage will take longer than stage 2, since it must move the mass all the way from its end stop. As the mass nears the centre, the control circuit spaces out the pulses.

6. The E/W component is checked and unlocked.

7. The E/W sensor base is tilted to its level position as in step 4.

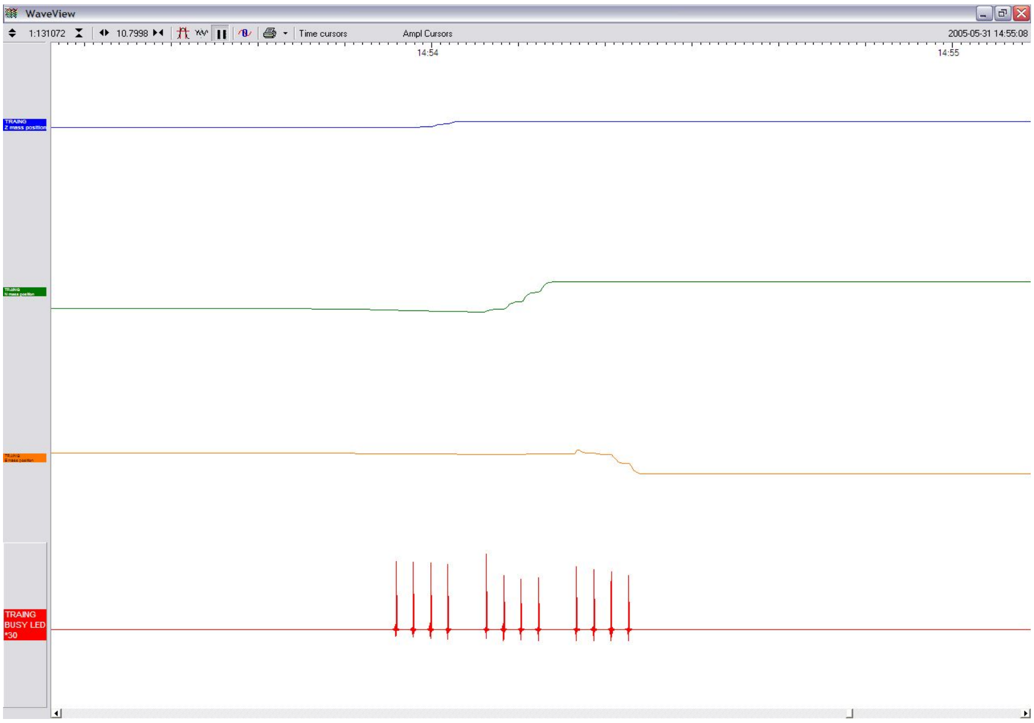
8. The E/W sensor mass is centred as in step 5. After unlocking, the instrument automatically performs a round of centring (see below).

7.1.2.3 CENTRE

This command re-centres the masses. If the masses are clamped, or if the sensor mass positions do not exceed ± 1.2 V, the `CENTRE` command does nothing. Otherwise, it attempts to zero the output of the vertical, N/S and E/W sensors in sequence by exerting small extra forces on the boom.

For the vertical sensor, a motor-driven adjuster presses a small spring lever against the boom until the mass position sensor indicates an offset close to zero. In the case of the horizontal sensors, the sensor frame is tilted on its base plate. Again, the controller monitors the mass position sensor and stops the centring process once it reaches its lowest offset.

This graph shows a typical centring process:



1. The BUSY LED pulses to indicate that it is centring the Z component. Each pulse corresponds to a small force on the mass. The pulses become briefer as this goes on, until a pulse is missed, signifying that no corrective impulse is needed.

2. The N/S component follows in the same way. If the true mass position is outside the range of the output, you may not see the output change for some time. If the pulses cause the mass to overshoot the central position, a second group of pulses in the opposite direction is applied to bring it into line.

3. The E/W component follows in the same way. All three masses are now centred and the process completes.

After the sensor unlocks the masses, the first round of centring has to move the N/S and E/W components all the way from their end stops, whilst the Z component is often closer to the proper position. Because of this, the first Z centring operation takes much less time than the others, and you may not notice it.

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

7.1.3 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 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 Güralp 3ESPCD are designed so that the field strength from the feedback transducer is constant over large deflections and current levels.

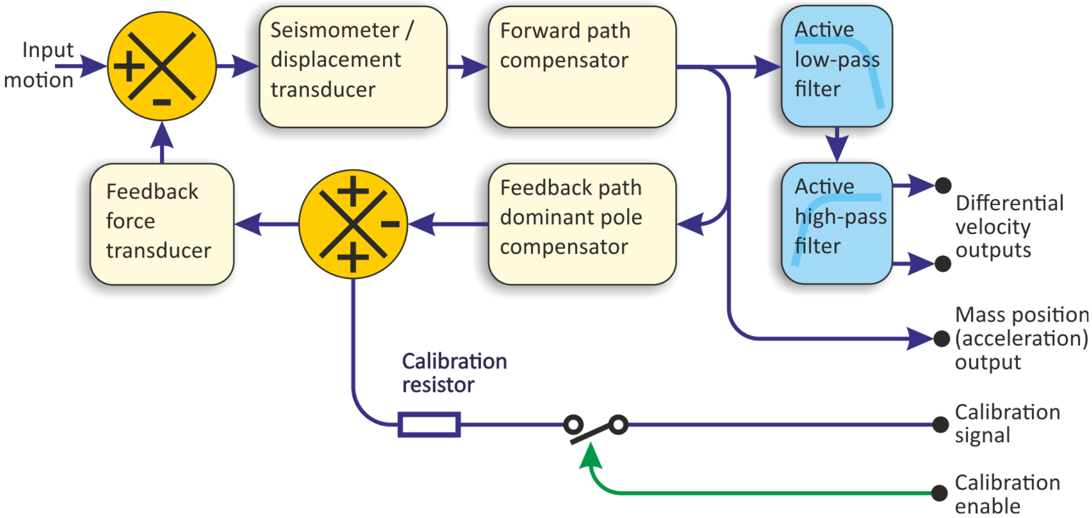
In a force-feedback seismometer, it is essential to monitor the acceleration output. This provides the position of the inertial mass. The sensor should always be operated with the mass centred, so that the response to input acceleration is linear.

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

7.1.3.1 Hybrid feedback

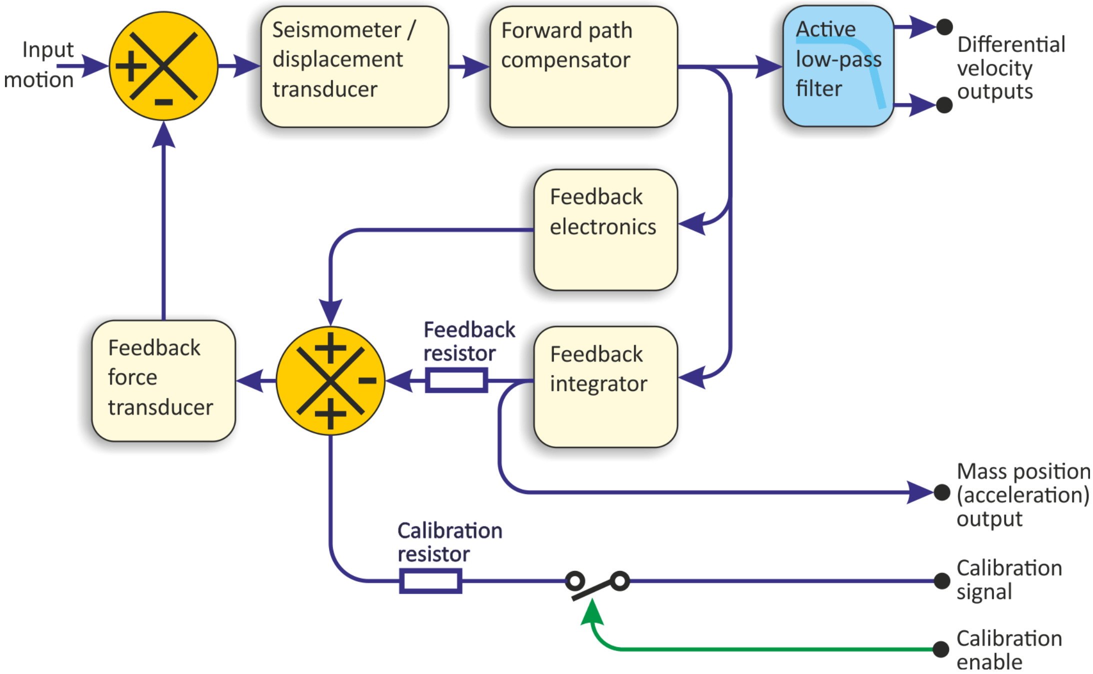
The hybrid feedback circuit contains a single capacitor in parallel with a resistor, resulting in a single dominant pole at 0.033 Hz (30 seconds). Below this frequency, the response of the seismometer is flat to ground acceleration; above it, the response is flat to velocity. (Other values for the acceleration-velocity 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 cut-off point at a frequency you specify. Without the filter, the velocity response is flat up to 100 Hz. Outside the feedback loop, there is an active high-pass filter with a corner frequency of 0.01 Hz (100 s) or 0.005 Hz (200 s), which serves to remove any DC offsets.



7.1.3.2 Conventional-response feedback

The conventional-response feedback system has an additional parallel feedback circuit, consisting of a non-inverting integrator in series with a resistor.

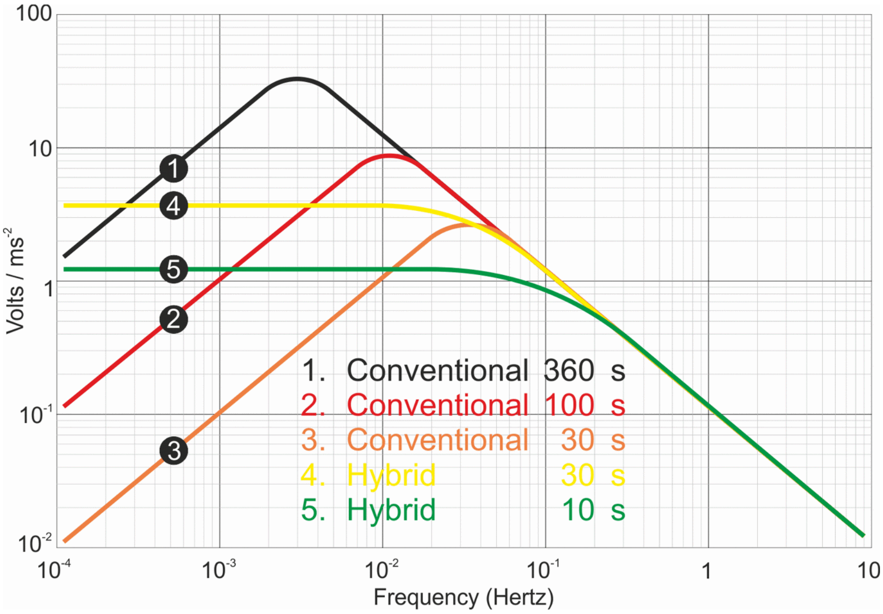


This arrangement results in two poles at specified frequencies. The velocity response of a conventional-response system is defined by a transfer function identical to that of a conventional long-period sensor with a damping constant ζ of 0.707 (1/√2).

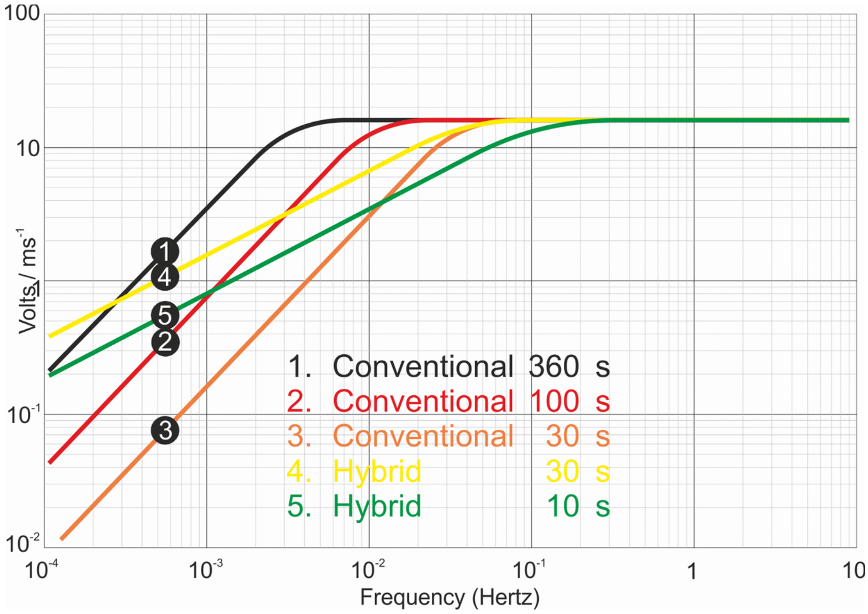
The seismometer can be supplied with an equivalent resonant frequency of 0.033 Hz (30 s), 0.01 Hz (100 s) or 0.0083 Hz (120 s) as required. An active low-pass filter provides a high-frequency cut-off point at a frequency you specify.

7.1.3.3 Comparisons

The figures below plot the comparative response of a conventional velocity output broadband sensor and a hybrid output broadband sensor.



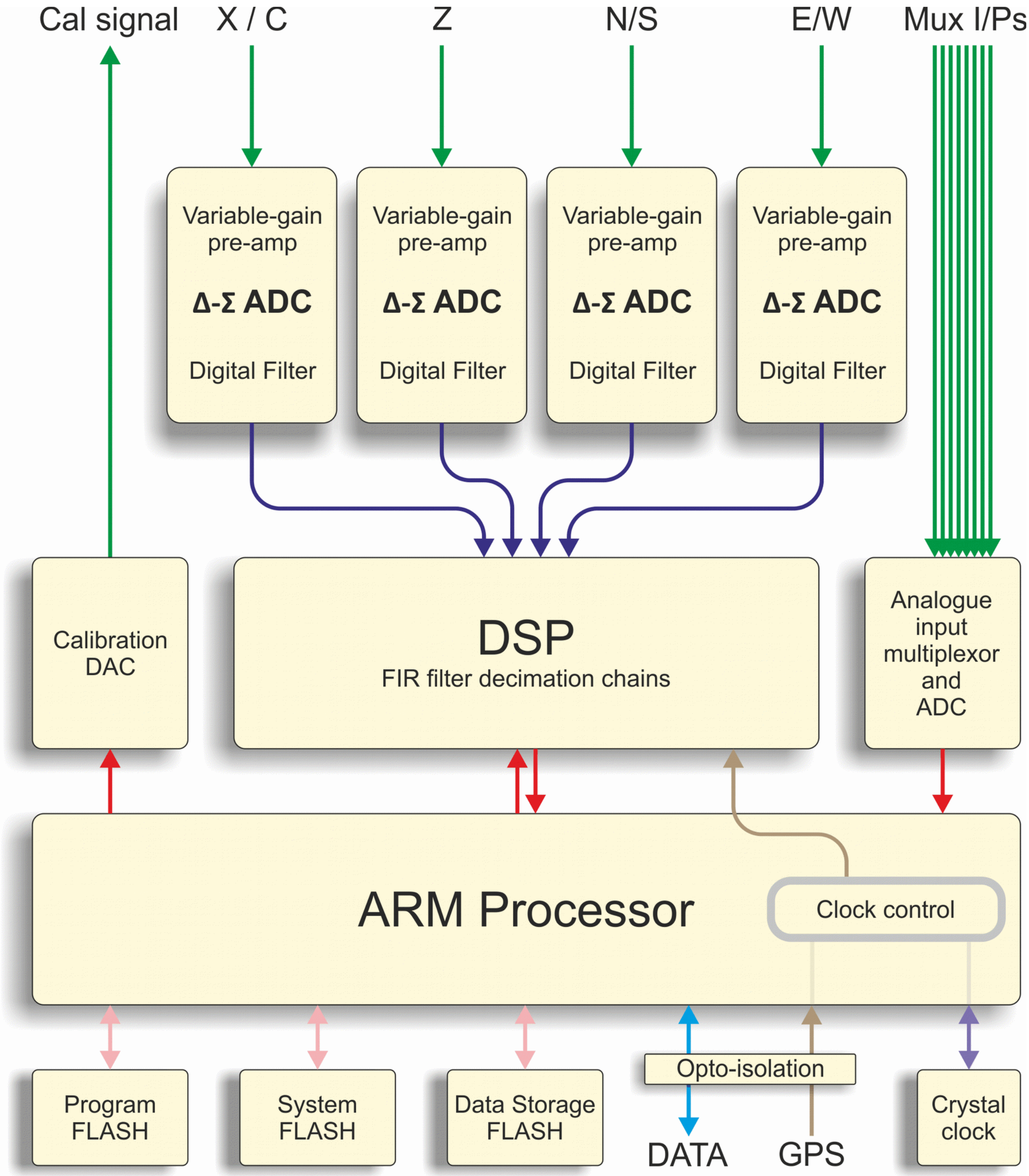
The graph above shows the response in terms of output against input acceleration in units of V/ms^{-2}, whilst the second graph is plotted in terms of output against input velocity, in V/ms^{-1}.



7.2 Inside the DM24

7.2.1 Architecture

Internally, DM24 digitisers are structured as shown in the following diagram.



The system is designed around a low power, high performance ARM microprocessor. This is a 32-bit processor with a large address space for data storage and manipulation. It also includes many integrated functions such as multiple timers and serial I/O ports. In addition, the system contains a Cirrus Logic CS5376 digital filtering chip-set and TMS320VC33 digital signal processor

(DSP). The CS5376 provides data to the DSP at 2,000 samples per second, triggered by timing signals from the ARM processor. The DSP can control all 5 ADCs and process the data in real time.

An important feature of the system design is its ability to synchronise the sampling of the analogue to digital converter to an external time reference. This way, data samples are accurately time stamped at source. To keep sampling accurately in step with UTC, you can synchronise the microprocessor's time-base to an external reference such as GPS or, in larger arrays, to a centrally-transmitted time reference. Transmitting a time reference avoids the cost and power consumption of multiple GPS receivers, and since it only involves sending 2 characters per second it can utilise a low band-width, even half-duplex link.

To achieve the high degree of timing precision required for a 24-bit digitiser system, the microprocessor time-base is run from a precision voltage controlled oscillator. On-board software keeps this oscillator tuned to the external reference so that its frequency is accurately set and maintained through changes in temperature or ageing. Once the system has stabilised, the control is sufficiently accurate to maintain precision sampling for several days without an external reference. The system also automatically compensates for the pure time delay introduced by the digital filtering/decimation processes in the DSP.

The DSP software consists of 6 cascaded programmable filter/decimation stages, which allow you to select multiple data output rates simultaneously. Each stage can be set individually for decimation factors of 2, 4, or 5. Data can be output at any or all of these rates according to constraints of storage and transmission bandwidth. For example, a system can be configured to provide data at 200, 50, and 10 samples/sec, covering the whole of the seismological broad band range. The configuration of the DSP is programmable in the field via the host ARM microprocessor.

The primary digital interface for the system is the serial port cards. One serial port is configured to send the data packets to a local EAM unit for storage, or via a modem or radio link to a central recording station. A second serial port is normally used with a local GPS receiver for time synchronization, or alternatively the first (data) port can be used for time synchronization from a central station (stream-sync mode).

Each of the serial ports on the digitiser can be configured for a wide range of standard baud rates (with different settings available for transmit and receive channels), allowing a wide range of data links to be used depending on the required data rates. The UARTs and serial port module are optically isolated to avoid any ground loops that could degrade the performance of the ADCs. The serial port module also includes 32k of RAM for data buffering and formatting by the transmission/reception process.

7.2.2 Updating firmware with an EAM

The simplest way to update the digitiser firmware is by use of a Güralp EAM. The Platinum firmware installed on EAMs contains copies of the most recent DM24 firmware so it is recommended to first update the EAM's firmware. Once this is done:

7.2.2.1 through the web interface

Navigate to Configuration→Instruments→Port A instrument.... and scroll to the bottom of the page. If the EAM has firmware more recent than that loaded on your 3ESPCD, a check-box is displayed which, when ticked, will cause the DM24 firmware on the 3ESPCD to be updated when the web form is submitted.

7.2.2.2 from the command line

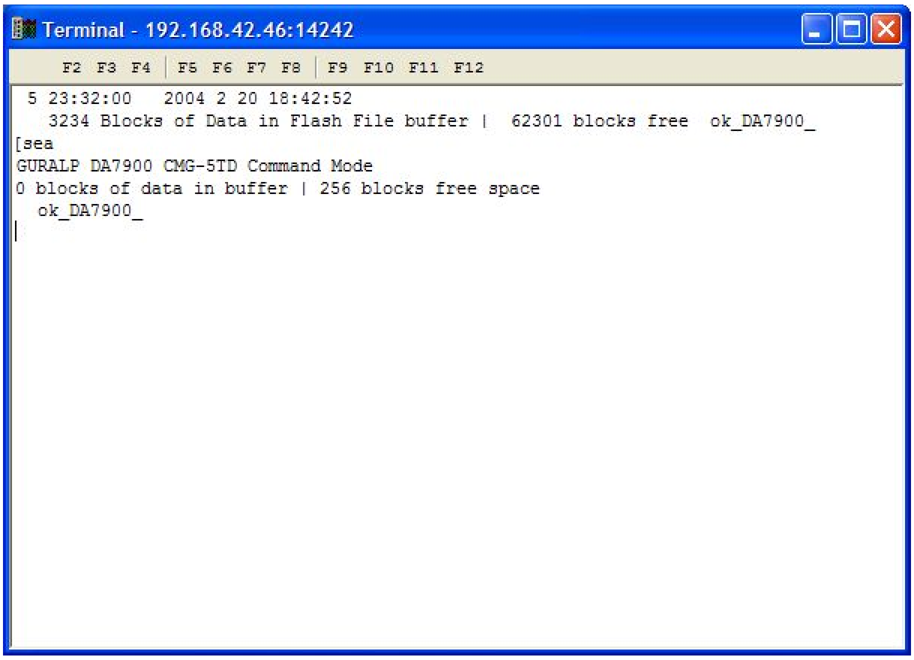
The DM24 firmware on the 3ESPCD can be updated from the EAM's command line using the command

```
dm24-upgrade PortA
```

Running the command with no arguments displays a description of the options available.

7.2.3 Updating firmware with Scream!

You can update the digitiser firmware using any terminal program which supports the Xmodem protocol, such as PuTTY or Scream!. If you are using Scream!, right-click on the digitiser’s icon in the main window and select Terminal from the pop-up menu:



Check that there is two-way communication with the digitiser by pressing Enter. The digitiser should reply with `ok` on a new line. Type `re-boot` to reinitialize the digitiser, and confirm with `y`. As it is restarting, the digitiser will report its status over the terminal connection, followed by a maintenance menu:

```
I/OPort =$42 :   RTModule no I2C ACK @ $78  MPE ARM ANS ROM
PowerForth v6.30
 ARM Serial BootStrap v1.100, 11 August 2003
 Copyright (c) 2002-3  GSL, EDSL & MicroProcessor Engineering Ltd.
```

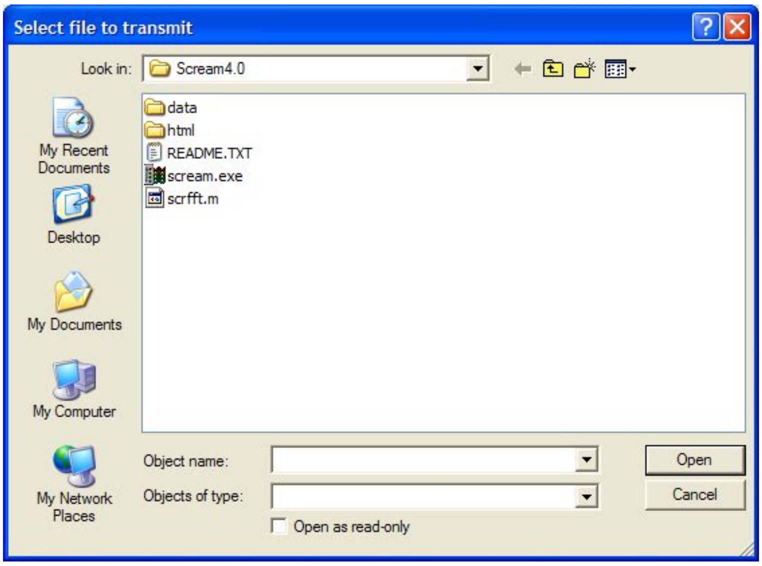
```
Port 0 38400 baud  Port 1 38400 baud  Port 2 38400 baud

Guralp Systems Ltd - ARM-BOOT v2.0 mgs  27/04/11 (Build 13)
 System Code versions loaded :-
 Current  0108:0000 Guralp Systems Ltd - DM+FW  v.106  mgs
05/03/12 (Build 57d)
 Previous 0110:0000 Guralp Systems Ltd - DM+FW  v.106  mgs
05/03/12 (Build 57d)
 Backup   0118:0000 Guralp Systems Ltd - DM+FW  v.106  mgs
05/03/12 (Build 57d)
 DSP Code :
 0106:0000  dsp1090.bin                    Default
 0107:0000  dsp1090.bin
 Command keys:
 C - set real time Clock (2013 11 13 17:17:55 )
 I - view/upload InfoBlock
 F - run the Forth monitor
 S - update System program
 O - select Other system program
 B - update Boot program
 D - update DSP code
 T - Toggle default DSP code
 Q - Quit maintenance system
  5 seconds to auto-start Enter command:
```

If you do not press a key in the next five seconds, the digitiser will start up normally. The digitiser has three firmware components, which can be updated separately: the system program, the DSP code and the boot loader.

7.2.3.1 Loading a new system program

To update the system firmware, press S at the maintenance menu. The digitiser will then request a transfer using the Xmodem protocol. If you are using Scream!, a file browser window will appear automatically.



Navigate through the directories on your computer and select the file to be uploaded, or type in its full path and file name and click Open.

Whilst the file is loading, a progress window will be displayed. Depending on the speed of the link, it may take up to 20 minutes to transfer the firmware. Once the file is fully transferred, the digitiser will return to the maintenance menu.

7.2.3.2 Loading new DSP code

Press D at the maintenance menu. The digitiser will reply with

```
Enter 0/1 to select DSP code to update
```

Select which of the two DSP code slots you want to overwrite, and press ENTER. The default is always 0.

```
Enter Filename/date – upto 31 characters
```

You can enter a descriptive string for the DSP code here. The digitiser will print this string at every boot-up, to remind you which version of the DSP code you are using. When you press ENTER, the digitiser will then request a transfer using the Xmodem protocol, as described above.

7.2.3.3 Loading a new boot loader

Press B at the maintenance menu to update the boot-loader. The digitiser will then request a transfer using the Xmodem protocol, as described above. When you are returned to the maintenance menu, press Q or wait 30 seconds for the system to restart.

8 Appendix A - Connector pin-outs

8.1 GPS port

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

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

Pin	Function
A	Power 0 V
B	Power + V
C	PPS signal
D	*not connected*
E	*not connected*
F	*not connected*
G	RS232 ground
H	*not connected*
J	*not connected*
K	RS232 receive from GPS

Wiring details for the compatible socket, ***-12-10S, as seen from the cable end (*i.e.* when assembling).

8.2 DATA OUT port

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

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

Pin	Function
A	Power 0V
B	Power +10 to +36 V DC
C	*not connected*
D	*not connected*
E	External trigger output
F	External trigger output
G	RS232 ground
H	External trigger input
J	RS232 receive
K	RS232 transmit

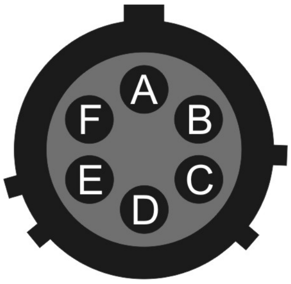
Wiring details for the compatible socket, ***-12-10S, as seen from the cable end (*i.e.* when assembling).

8.3 FIREWIRE port

This is a standard 6-pin "mil-spec" plug, conforming to MIL-DTL-26482 (formerly MIL-C-26482). A typical part-number is 02E-10-06P although the initial "02E" varies with manufacturer.

Suitable mating connectors have part-numbers like ***-10-06S and are available from Amphenol, ITT Cannon and other manufacturers.

Pin	Function
A	Power 0 V
B	TPA +ve
C	TPA -ve
D	TPB -ve
E	TPA +ve
F	Power + V



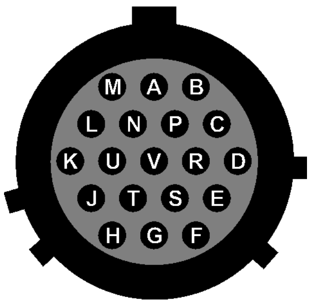
Wiring details for the compatible socket, ***-10-06S, as seen from the cable end (*i.e.* when assembling).

8.4 AUXILIARY port (optional)

This is a standard 19-pin “mil-spec” plug, conforming to MIL-DTL-26482 (formerly MIL-C-26482). A typical part-number is 02E-14-19P although the initial “02E” varies with manufacturer.

Suitable mating connectors have part-numbers like ***-14-19S and are available from Amphenol, ITT Cannon and other manufacturers.

Pin	Function	Pin	Function
A	*not connected*	L	*Signal ground*
B	*not connected*	M	*not connected*
C	*not connected*	N	Digital ground
D	*not connected*	P	User channel 1
E	*not connected*	R	User channel 2
F	*not connected*	S	User channel 3
G	*not connected*	T	User channel 4
H	*not connected*	U	User channel 5
J	Auxiliary / calibration channel +	V	User channel 6
K	Auxiliary / calibration channel -		



Wiring details for the compatible socket, ***-14-19S, as seen from the cable end (*i.e.* when assembling).

9 Appendix B - Sensor Specifications

Hybrid sensors	Velocity output bandwidth	0.1 – 50 Hz
	HPF output flat to acceleration	100 seconds - spec*
	HPF output flat to velocity	spec – 50 Hz*
	Mass position output	DC – 0.1 Hz
	Velocity sensitivity	1400 V/ms^{-1}
	Acceleration sensitivity	2000 V/ms^{-2}
Velocity sensors	Velocity output bandwidth	spec – 50 Hz*
	Mass position output	DC to spec Hz*
	Velocity sensitivity	2 × 750 V/ms^{-1}
	Mass position sensitivity	1000 V/ms^{-2}
Controls	Mass locking and unlocking	Remotely operated
	Mass centring	Manual and/or automatic
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
	Temperature range with masses locked	–35 to +75 °C
	Operational temperature range	–20 to +65 °C**
Power	Supply voltage	10 – 36 V
	Current at 12 V DC	75 mA†
	... during calibration	100 mA†
	... during centring (average)	330 mA†
	... during locking/unlocking	490 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.

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

† 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.

10 Appendix C - Digitiser specifications

Seismic channels	Number	4
	Format	32 bit
	Inputs	Differential with transient protection; ±10 V input range
	Input impedance	1 MΩ, 10 nF
	Common mode rejection	110 dB at 10 Hz
Mux channels	Number	8
	Format	24 bit
	Inputs	Single ended; ±10 V input range
GPS	Unit	External GPS (CMG-GPS2)
	Power	Via GPS connector
	Time format	NMEA
	Max. cable length	50 m
Sensor control	Functions available	Lock, unlock, and centre sensor; enable calibration
Sensor calibration	Types	Sine and square wave, adjustable amplitude and frequency; broadband noise, adjustable amplitude
Digital signal processing	Type	Texas TMS320CV33
	Hardware sampling rate	512 KHz
	Sample output rates	6 cascaded rates, each 2, 4, or 5 times lower than the previous rate
	Anti-aliasing filters	2 pole
	Low-pass filters	FIR
	Out-of-band rejection	140 dB
	In-band ripple	–140 dB
	Trigger modes	STA/LTA, level, external
Digitiser performance	Output format	32 bit
	Noise-free resolution (NPR)	22.5 bits at 20 samples/s 21.5 bits at 100 samples/s
	Absolute accuracy	0.5% standard (0.1% optional)
	Type	5th-order, single-bit low-pass noise shaper

	Analogue transducer outputs	3-C signals
Clock	Oscillator	8×10^{-7} standard (5×10^{-8} oven-controlled optional)
	External receiver interface	GPS RS232 and PPS
	External receiver synchronisation	<50 µs
Power	Supply	+10 – +36 V DC
	Current at 12 V DC	~0.12 A

11 Revision History

A	5 November 2005	Initial document
B	14 November, 2013	Major rewrite
C	21 November, 2013	Highlight the fact that this document describes the DM24 variant.
D	20 June, 2016	Clarify dead period for control lines