CMG-3T/5TB

Operator's guide

Part MAN-BSP-0002

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

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1 Introduction

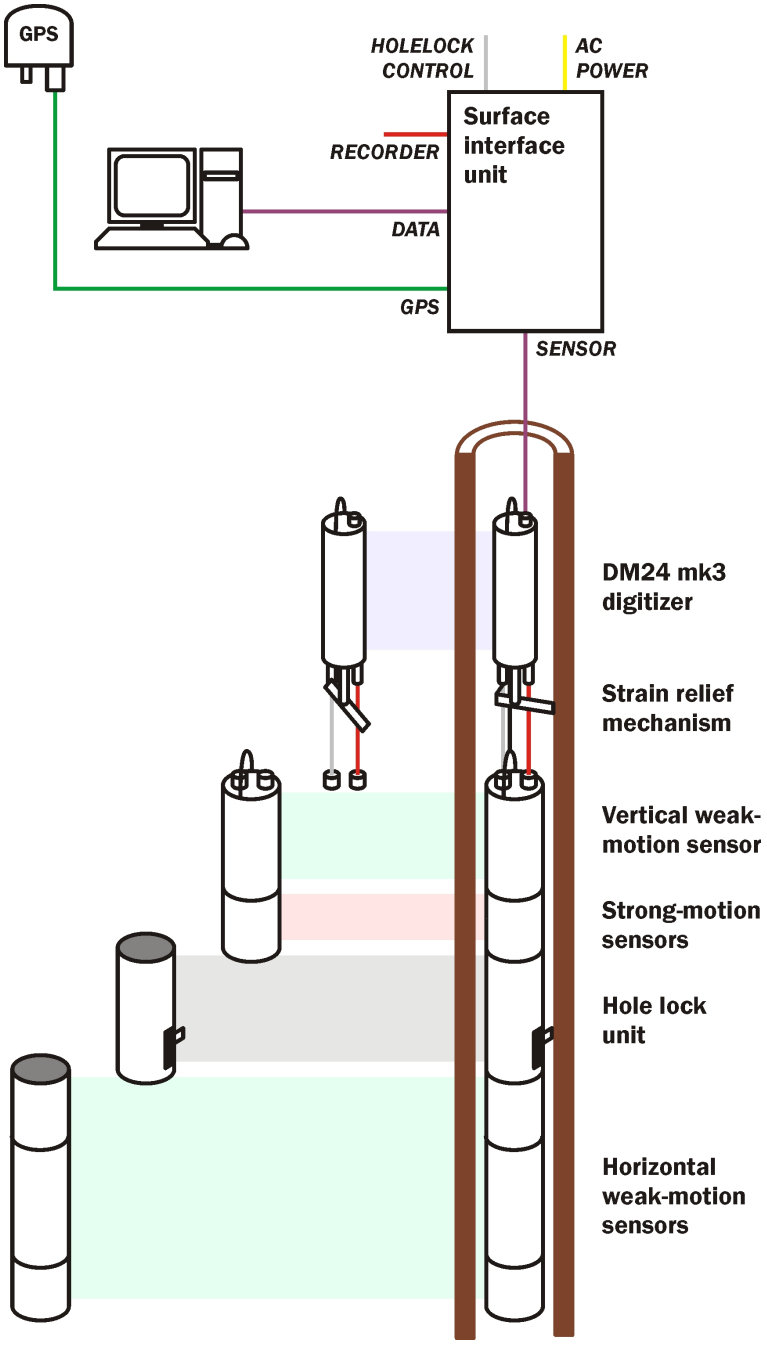
The CMG-3T/5T is a borehole package containing a complete set of seismic instrumentation, including both weak and strong motion triaxial sensors. It is designed for use in a cased borehole with diameter 7” / 178 mm.

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

The 3T/5T's weak-motion sensors are sensitive to ground vibrations in the frequency range 0.0027 – 50 Hz, whilst the strong-motion components are sensitive to acceleration from 0 to 100 Hz. These signals are output on balanced differential lines to the digitizer, as well as being passed through for connecting to your own recording equipment as necessary. The system is delivered with a detailed calibration sheet showing serial numbers for all components, measured frequency response in across the whole seismic spectrum, sensor DC calibration levels, and transfer functions in poles/zeros notation.

1.1 System configuration

The 3T/5T is shipped in several parts. When assembled and installed, the system has the following layout:



We recommend that you use a downhole DM24 digitizer to produce high-quality digital data at source. This has several advantages over a traditional borehole setup:

- Digital signals are not subject to attenuation as they travel up to

the surface, so signals received are stronger and more reliable.

- The low-noise environment of the sensor is also ideal for the digitizer's sensitive analogue-to-digital converters.

- Control signals returning to the sensor are reliable and stable.

The downhole digitizer includes a strain relief arm which ensures that the analogue signal cable is not stretched. All functions can be accessed remotely through the digitizer and the *DATA* port on the surface interface unit.

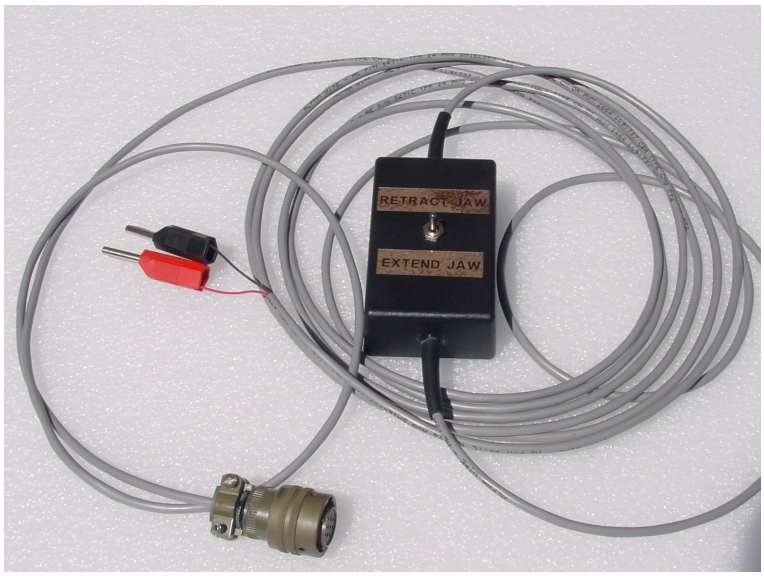
If you prefer to install a stand-alone digitizer at the surface, it should be connected to the 19-pin *RECORDER* socket of the surface interface unit. However, you must still install the downhole digitizer, since it provides the required connections to the sensor system. This digitizer can then be used to issue mass control and levelling commands.

1.2 The hole lock module

The hole lock unit in the 3T/5T system provides a stable platform for the sensor modules mounted above and below it. It is designed to maintain a positive pressure on the borehole casing over a prolonged period of time without attention, and to fix the sonde in place whilst avoiding transmitting any stresses. Güralp Systems hole locks are constructed to order from accurate measurements of your borehole at the depth you wish to install the instrument.

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

The motor's power supply is separate from that of the sensor, and can be controlled from the surface using a hole lock control unit, connected to the *HOLELOCK CONTROL* socket of the surface interface box.



Once the sonde is installed, the hole lock control unit may be removed. Without power, the hole lock will not be able to retract, and the sensor will be secured.

2 Assembly and installation

2.1 Unpacking and packing

The 3T/5T seismometer is delivered with the sensor components and hole lock mechanism packed separately. The packaging is specifically designed for the 3T/5T and should be reused if you need to transport the sensor. Please note any damage to the packaging when you receive the equipment, and unpack in a clean environment.

The system is delivered in seven parts:

- a sonde section for the horizontal weak-motion sensors;
- a sonde section for the hole lock;
- a sonde section for the vertical weak motion sensor and the strong-motion components;
- a separate borehole digitizer unit, including strain relief mechanism;
- a surface interface unit;

- a Güralp GPS receiver;
- a hole lock control unit; and
- a power supply.

The three sonde sections each consist of a number of parts separated by metal bulkheads. You should not need to disassemble the sections any further.

2.2 Handling notes

The 3T/5T is a sensitive instrument, and is easily damaged if mishandled. It should not be operated until it has been securely installed in a borehole casing. If you are at all unsure about the handling or installation of the device, you should contact Güralp Systems for assistance.

- Do not bump or jolt any part of the sensor when handling or unpacking.
- The sonde sections are heavy (over 25 kg each.) Do not attempt to move or lift them on your own.
- Ensure that you have suitable lifting and transportation equipment available before assembling.
- Keep the sonde sections vertical wherever possible.
- Never drag or roll the sonde.
- Never lay the sonde horizontally whilst the weak-motion sensors are unlocked. If the sensor system falls over, it will be permanently damaged.
- Keep all the parts of the sensor system protected and clean so that they can be joined together securely. Store in the original packaging if possible.
- Do not kink or walk on the data cable (especially on rough surfaces such as gravel), nor allow it to bear the weight of the sensor.
- Do not connect the instrument to power sources except where instructed.

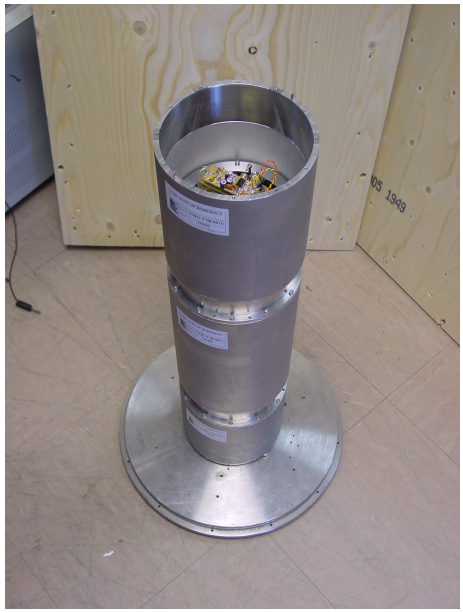
2.3 Assembling the 3T/5T

The 3T/5T is delivered in separate sections, which need to be assembled before the instrument can be installed in a borehole. You will need the help of at least one other person to perform these steps, and a suitable winch or other lifting equipment.

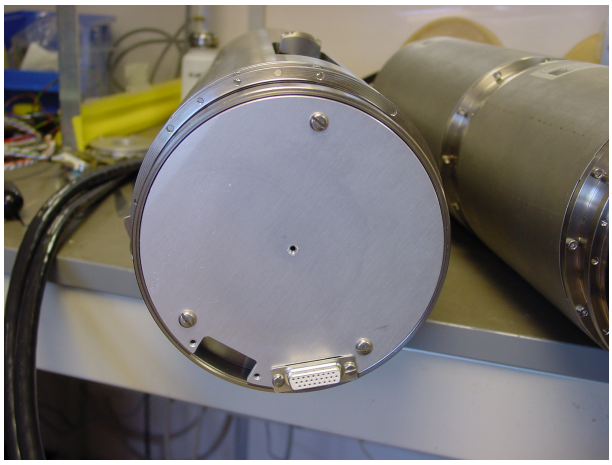
Important: Make sure your environment is clean and dust free before assembling the unit. Stray fibres or particles cause damage to the "O"-ring seals between the components and may render the sensor unusable. Do not remove the protective caps on the ends of each unit until you are ready.

Because the 3T/5T is heavy (82.5 kg), we recommend that you assemble it as close to the head of the borehole as possible. To provide a reasonably clean working environment at the borehole head, it may be desirable to erect a tripod and winch, and then cover the whole over with waterproof material.

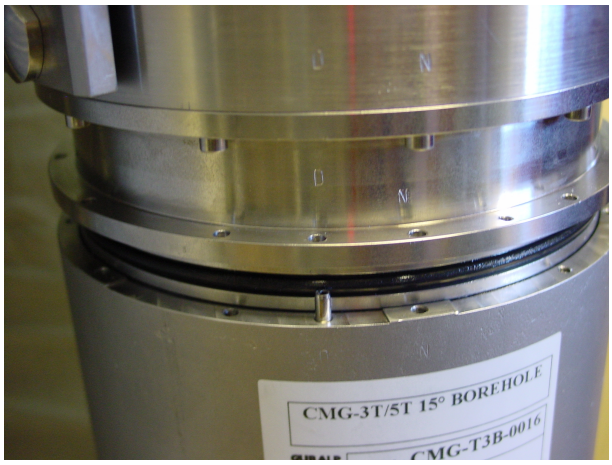
1. Stand the horizontal weak-motion sensor section on the ground, with the packing cap at the top. Remove the cap, and clean and grease the "O"-ring seal beneath.



2. Lift up the hole lock section, and remove the packing cap from the bottom. Clean and grease the "O"-ring seal. Note the internal connectors:



3. Position the hole lock section directly above the horizontal weak-motion sensor section, with the labels and *NORTH* indicators on the two sections lined up. Two short rods marked *D* on the horizontal sensor section should line up with holes in the hole lock section also marked *D*:



4. Carefully lower the hole lock section onto the horizontal weak-motion sensor section. The connectors inside should mate satisfactorily under the weight of the upper section.

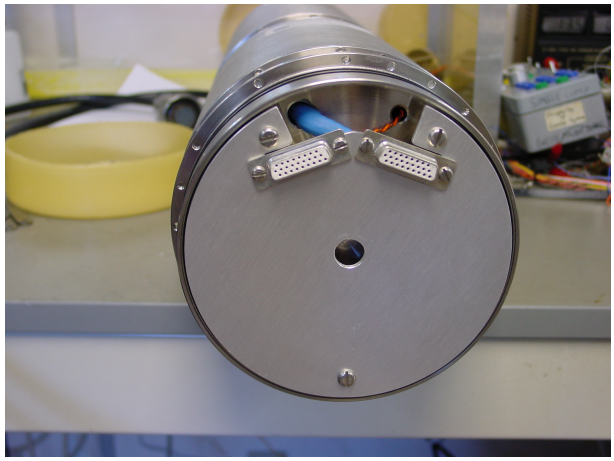
5. Fit twelve M3 × 10 cap head screws into the holes in the joint flange.

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

7. If possible, strap the lower sections to a secure fixture so the system cannot fall over.

8. Remove the packing cap at the top of the hole lock section. Clean and grease the “O”-ring seal.

9. Lift up the third sensor section (containing the strong-motion and vertical weak-motion components), and remove the packing cap from the bottom. Clean and grease the “O”-ring seal.



10. Position this section directly above the hole lock section. Line up the labels, *NORTH* indicators and *D* rods, and lower it onto the hole lock section. Again, the connectors inside should mate securely.

11. Fit twelve M3 × 10 cap head screws into the holes in the joint flange, and tighten as above.

12. Screw the skids provided onto the hole lock unit using the fastenings provided. There are two fixings for each skid, about 140 ° around from the hole lock arm in each direction.

2.4 Disassembling the instrument

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

- Make sure you only undo the screws that are necessary to disassemble the instrument, and not the ones which hold each module together. Each joint has several sets of screws holding it together. Only one set from each joint needs to be undone—the set which was added during assembly. Do not dismantle the joints between the horizontal weak-motion sensors below the hole lock, or the joint between the weak and strong motion sensors above it.

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

2.5 Installing the system

1. Two 26-way signal wires emerge from the bottom of the borehole digitizer, ending in waterproof connectors stamped *A* and *D*. Connect these to the two plugs on the top of the sensor system, also stamped *A* and *D*, so that the *A* connectors are joined to each other, and likewise the *D* connectors.

2. Fix the main lifting cable to the shackle on top of the digitizer, and connect the main signal cable. Do not allow the signal cable to bear any of the sensor's weight.

3. Attach the sensor lifting loop to the bottom of the strain relief mechanism using a doubled length of 3 mm stainless steel wire rope (provided.)

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

5. Fix the signal cable to the main lifting cable about 1 m above the strain relief mechanism using a metal clamp. Leave a little slack in the signal cable between the clamp and the strain relief mechanism.

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

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

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

9. Test the hole lock mechanism using the control unit supplied. For safety reasons, the hole lock is normally supplied with the arm extended. If the arm fails to retract, contact Güralp Systems. Extend the arm once more. The current drawn should dip slightly as the arm touches the casing, then drop to zero when it is fully extended. (The mouth of the borehole may be too wide for you to see this.)

10. Connect the digitizer to the *SENSOR* port of the surface interface unit, and power up the system.

11. Connect a serial cable to the *DATA* port of the surface interface unit, and access the digitizer's console.

12. Issue `LEVEL`, `UNLOCK`, and `CENTRE` commands to the sensor (see "The control system" in Section 4.1) so that it can be tested.

13. Check that the sensor is functioning correctly by connecting a PC running Scream! to the digitizer, or using your own recording equipment. If the sensor fails to register ground movements, contact Güralp Systems.

14. Lock the sensor masses once more with `LOCK` commands, tension the load bearing cable and retract the hole lock arm.

15. Gently lower the sensor to the required depth. At approximately 20 m intervals, fix the signal cable to the load bearing cable using metal clamps. This will ensure that the signal cable does

not become kinked or trapped within the borehole. Leave a little slack on the signal cable each time, so that it does not bear any weight. Too much slack, however, will cause the cable to scrape against the borehole casing.

16. Fix the sensor system into the borehole using the hole lock arm.

    The weight of the sensor will stretch the load bearing cable slightly. Remember to allow for this when raising or lowering the cable in the following steps.

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

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

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

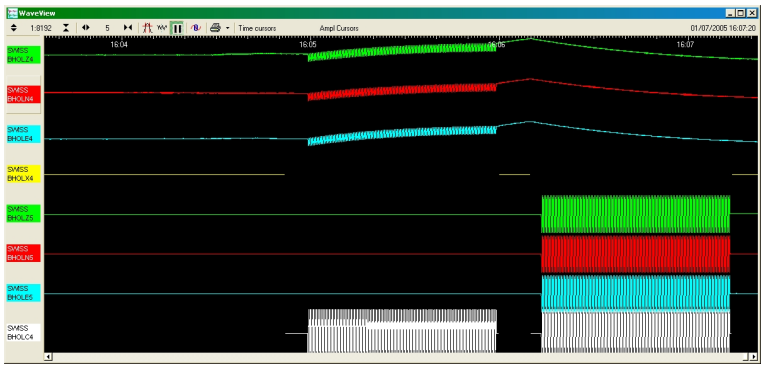
20. Tie the lifting and signal cables together above the strain relief mechanism using tie wraps.

21. The sensor can now be levelled and unlocked once more, and readied for use.

3 Calibrating the system

3.1 Overview

The velocity and acceleration components of the 3T/5T may be calibrated separately. To calibrate components in Scream!, you need to enable one or other set in the digitizer. When calibration is in progress, the fourth digitizer channel is interrupted and used instead to digitize the outgoing calibration signal.



This picture shows the result of a calibration being performed on the velocity (centre) and acceleration (right) components in turn. The strength of the returning signal (red, green and blue streams) can be compared in each case with the calibration signal (white stream) as detailed below.

Note also that the yellow stream, `BHOLX4`, is *replaced* with the calibration stream `BHOLC4` for the duration of the calibration.

3.2 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 velocity component at 1 Hz, in volts per m/s. Because the 3T/5T 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.

Acceleration Output (Differential) : The response of each accelerometer component, in V/m/s^2. This is measured at the production stage by tilting the sensor through 90 ° and measuring the acceleration due to gravity. Local *g* at the Güralp Systems production facility is known to an accuracy of 5 digits.

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

Feedback Coil Constant : A constant describing the characteristics of the feedback system. You will need this constant if you want to perform your own calibration calculations. Each component has separate feedback electronics, and has its own coil constant.

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

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

Poles and zeroes

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

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

In this equation

- G is the acceleration output sensitivity (gain constant) of the instrument. This relates the actual output to the desired input over the flat portion of the frequency response.

- A is a constant which is evaluated so that $A \times H(s)$ is dimensionless and has a value of 1 over the flat portion of the frequency response. In practice, it is possible to design a system transfer function with a very wide-range flat frequency response.

  The normalising constant A is calculated at a normalising frequency value fm = 1 Hz, with $s = j f$m, where $j = \sqrt{-1}$.

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

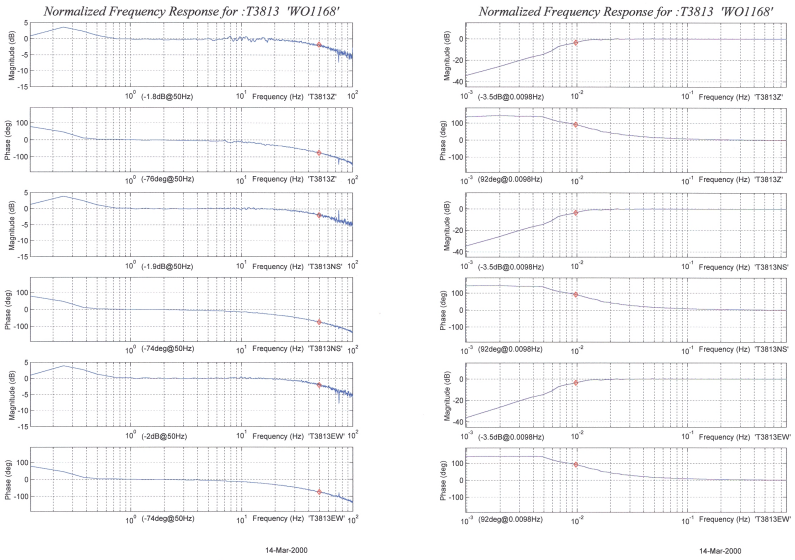
$$H(s) = N \frac{\prod_{i=1,n} s - Z_i}{\prod_{j=1,m} s - P_j}$$

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

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

Frequency response curves

The frequency response of each velocity component of the 3T/5T is described in the normalised amplitude and phase plots provided. The response is measured at low and high frequencies in two separate experiments. Each plot marks the low-frequency and high-frequency cutoff values (also known as –3 dB or half-power points).



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

Obtaining copies of the calibration pack

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

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

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

3.3 Calibrating velocity components

The velocity components of the 3T/5T system are not sensitive to constant DC levels, either as a result of their design or because of an interposed high-pass filter. Instead, three common calibration techniques are used.

- Injecting a step current allows the system response to be determined in the time domain. The amplitude and phase response can then be calculated using a Fourier transform.

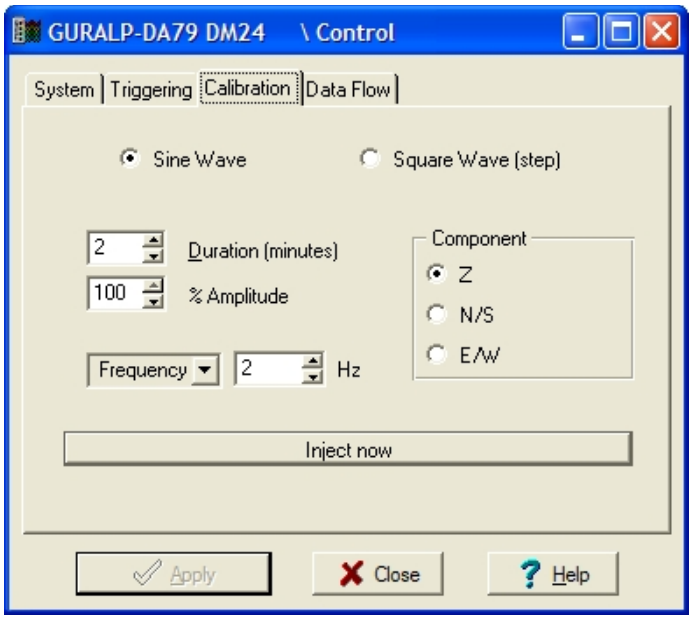
Because the input signal has predominantly low-frequency components, this method generally gives poor results. However, it is simple enough to be performed daily.

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

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

The Güralp DM24 digitizer provides calibration signal generators to help you set up your sensors. Calibration is most easily done through a PC running Güralp's Scream! software. In this section, sine-wave calibration will be used to determine the sensor response at a single frequncy of interest. Other calibration methods are detailed on the Güralp Systems website.

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

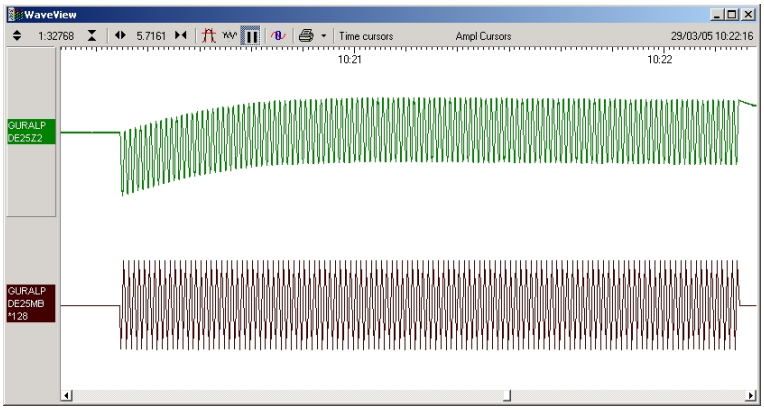


2. Select **Sine wave**, with a suitable frequency.

3. Under *Component*, select **Z**. This is done because the internal

electronics use the **Z** calibration loop to calibrate all of the weak-motion components, and the **N/S** loop for the strong-motion components.

4. Click **Inject now**. A new data stream, ending `C`*n* (*n* = 0 – 7) or `MB`, should appear in Scream!'s main window containing the returned calibration signal.



5. 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.

6. 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.

7. Click on **Ampl Cursors** in the top right hand corner of the window. A white square will appear inside the Waveview at the top left. This is in fact two superimposed cursors.

8. Drag one cursor down to be level with the lowest point of the signal trace.

9. Drag the other down to be level with the highest point.

10. The **Ampl Cursors** button will now be displaying a value, which is the strength of the returning signal in counts. Measure the other two signal strengths in this manner.

    If you have used the **Scale...** option, you will need to take the scale factor into account to produce the correct number of counts.

11. Convert to volts using the $\mu V/Bit$ value given on the digitizer's calibration sheet for the input port.

12. A calibration resistor is installed within the calibration loop, allowing you to convert this value to a *calibration acceleration*, which is analogous to the ground acceleration under normal working conditions. The value of this resistor is given on the calibration sheet.

    For example, a 1 V peak-to-peak sinusoidal signal, passed through a 20 KΩ calibration resistor, will drive a current of 1 / 20000 A = 50 μ A. Combining this value with the feedback coil constant, *K*, also given on the calibration sheet, gives the calibration acceleration:

    $a = V / RK = 1 / 20000\ K$

13. The sinusoidal acceleration function can now be converted to a velocity function by dividing by the angular frequency of the calibration signal:

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

    This voltage is the *equivalent input velocity*.

14. Compare the equivalent input velocity with the measured output voltage from step 7. The value you obtain is the velocity sensitivity *at the frequency of the calibration signal*. The measured sensitivity for a 1 Hz calibration signal is given on the sensor's calibration sheet. Since the instrument has a flat velocity response over the passband, measurements at other frequencies should give the same result.

The coil constant

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

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

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

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

3. Repeat this measurement for several tilt angles.

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

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

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

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

3.4 Calibrating acceleration components

The accelerometer components may be calibrated with the sine wave generator in a similar fashion to the velocity components. Here, the signal injected into the sensor gives rise to an *equivalent acceleration* which is added to the measured acceleration to provide the sensor output.

The equivalent acceleration corresponding to 1 V of signal at the calibration input is measured at the factory, and can be found on the sensor calibration sheet. The calibration sheet for the digitizer documents the number of counts corresponding to 1 V of signal at each input port. The sensor transmits the signal differentially, over two separate lines, and the digitizer subtracts one from the other to improve the signal-to-noise ratio by increasing common mode rejection. As a result of this, the sensor output should be halved to give the true acceleration.

All sensors are tuned at the factory to produce 1 V of output for 1 V input on the calibration channel. For example, a sensor with an acceleration response of 0.25 V/m/s^2 should produce 1 V output given a 1 V calibration signal, corresponding to 1/0.25 = 4 m/s^2 = 0.408 g of equivalent acceleration.

The remainder of this section describes how to calibrate the accelerometer components from Scream! *via* a DM24 digitizer.

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

2. Select the **N/S** component. This is done because the internal electronics use the **N/S** calibration loop to calibrate all of the strong-motion components.

3. Make any other choices you require and click **Inject now**. A Mux stream ending `MB` should appear in Scream!'s main window containing the returned calibration signal.

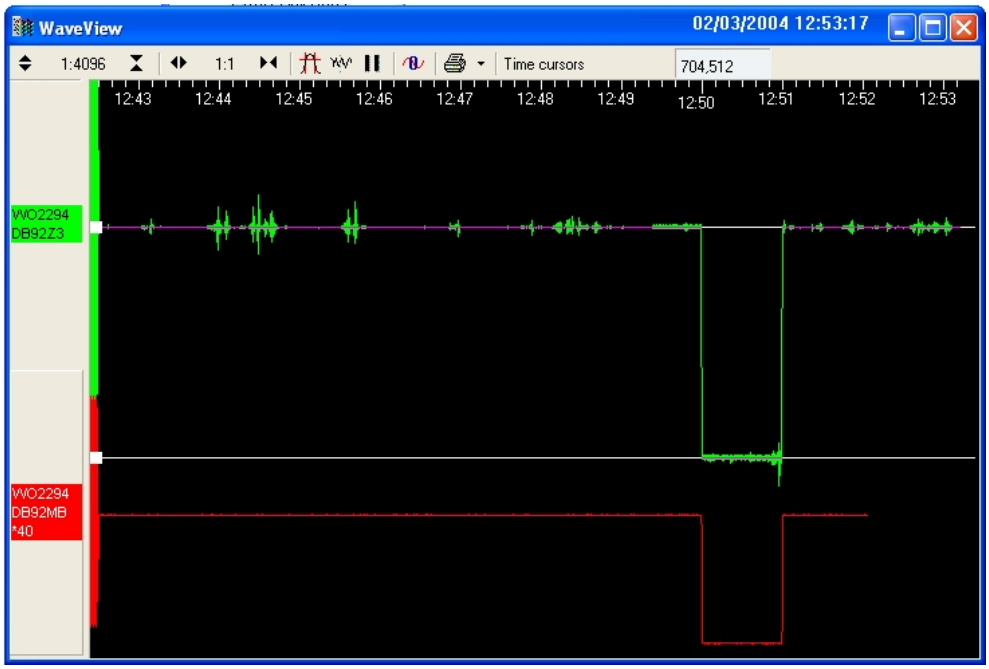
4. Open a WaveView window on the calibration signal and the returned streams by selecting them and double-clicking. The streams should display the calibration signal combined with the sensors' own measurements. If you cannot see the calibration signal, zoom into the WaveView using the scaling icons at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

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. Click on **Ampl Cursors** in the top right hand corner of the window. A white square will appear inside the WaveView at the top left. This is in fact two superimposed cursors.

7. Drag one cursor down to be level with the lowest point of the signal trace.

8. Drag the other down to be level with the highest point. In the following example, a step function of 1 minute duration has been applied to the `Z3` stream. Note that ground movements continue to be observed, superimposed on the returning calibration signal.



The **Ampl Cursors** button will now be displaying a value, which is the strength of the returning signal in counts (doubled, if using a sine wave). Measure the other two signal strengths in this manner.

Note that if you have used the **Scale...** option described above, you will need to take the scale factor into account to produce the correct number of counts. In the example, the MB (calibration input) signal has been scaled by a factor of 40, so the signal strength as measured by the **Ampl Cursors** must be *divided* by 40 to yield the correct value.

9. Convert to volts using the *μV/Bit* values given on the digitizer's calibration sheet for the various input ports, and compare the returned signal with the input calibration signal (MB).

10. In the example, the following data are now known:

Input calibration signal strength (MB)	9856 counts
Returning signal strength (Z3)	704512 counts

The calibration sheets provide us with the remaining values needed to calibrate the sensor:

Sensor acceleration response	0.254 V/m/s^2
Equivalent accel. from 1V calibration	1.968 m/s^2

Digitizer input port sensitivity	3.507212 μV/Bit
Mux channel sensitivity	255.9253 μV/Bit

From these we know that the calibration signal is producing $9856 \times 247 = 2434432$ μV (2.434 V). This corresponds to an equivalent input acceleration of $2.434 \times 1.968 = 4.791$ m/s^2.

The sensor's acceleration response is given as 0.254 V/m/s^2, so that an acceleration of 4.791 m/s^2 will produce an output of $0.254 \times 4.791 = 1.217$ V (1216904 μV), which corresponds to a count number at the digitizer's input port of 1216904 / 3.5 = 347687 counts.

Because the signal is transmitted differentially, the count number observed at the digitizer should be double this: 695373 counts. The actual signal at the digitizer of 704512 counts is within 1.5% of this value, indicating that the sensor is adequately calibrated.

11. If you know the local value of *g*, you can also perform absolute calibration by tilting the sensor by 90 ° and varying the calibration signal until it precisely compensates for the signal generated due to gravity.

12. Calibrate any other sensors connected to the digitizer in the same way. You must wait for the previous calibration to finish before doing this: clicking **Inject now** has no effect whilst the *Calibration enable* relay is open.

4 Inside the system

4.1 CMG-3 weak motion components

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 0.5 s, whilst the horizontal sensor has an unstressed flat spring with a natural period around 1 s. CMG-3T/5T 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.

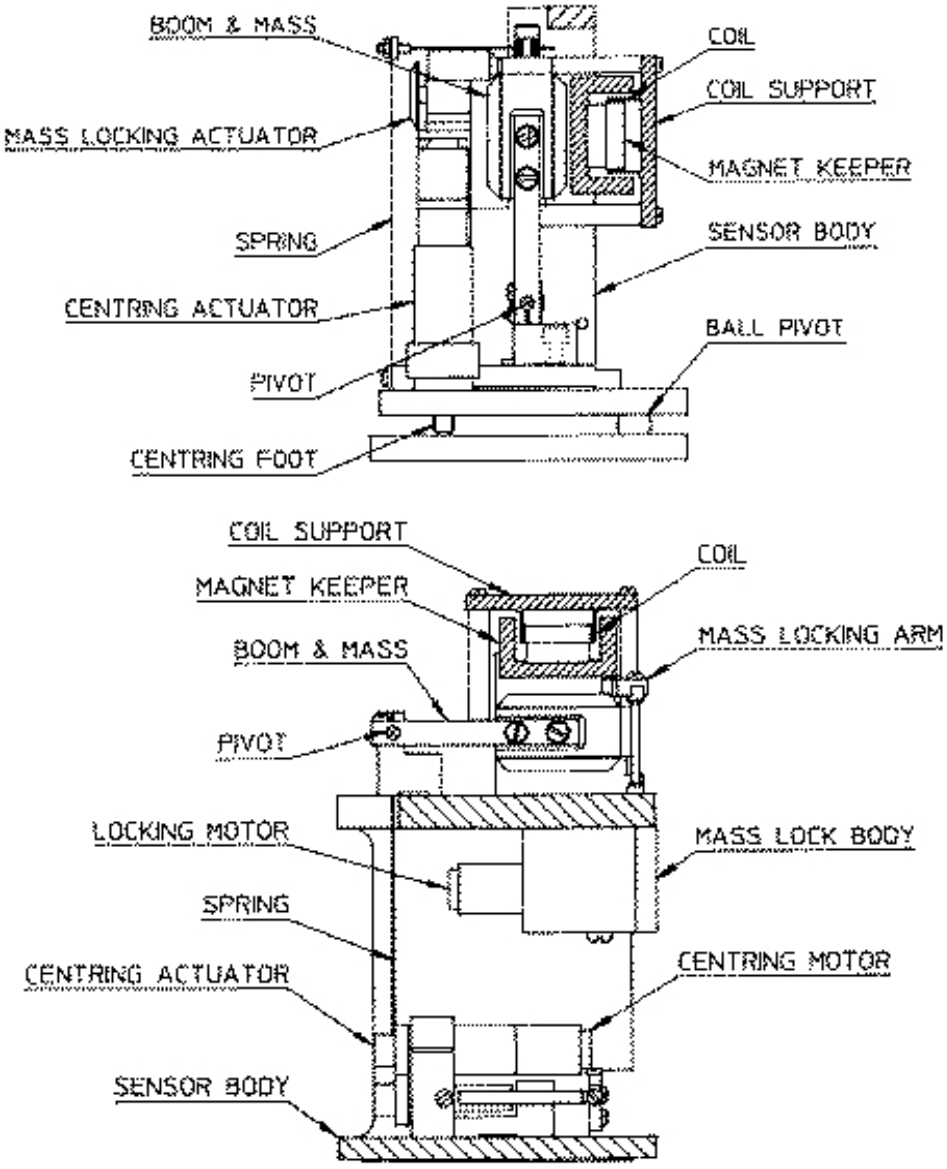
The sensor and hole lock units are stacked one on top of the other with a set of accurately-machined stacking tubes, which also form part of the sensor's pressure housing. Fixing holes provided on each end face allow for simple and accurate assembly. The base of each unit includes a double “O” ring to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

The 3T/5T 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 2.5, “Installing the system” for detailed instructions on how to set up your 3T/5T installation.

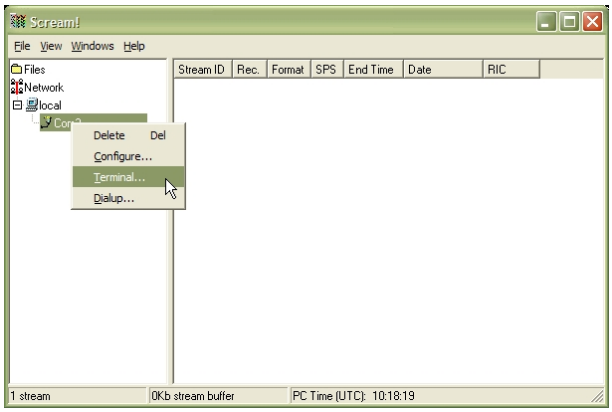


The signal voltages output by the 3T/5T are proportional to ground velocity, and are transmitted from the instrument on balanced differential lines. In addition, mass position signals are sent as single-ended circuits referred to analogue ground on the output plug. The 3T/5T also receives control signals, which are used to clamp and unclamp the masses, and to run the motors which level and centre the instrument once in position. Finally, a line is provided for you to apply a calibrating voltage to the force transducers, thereby measuring the deflection sensitivity.

The control system

The internal operations of the 3T/5T are supervised by a the downhole digitizer, which drives the mass clamping and centring adjustment motors in response to the commands *LEVEL*, *LOCK*, *UNLOCK* and *CENTRE*. Each command acts on a single component which you specify, either `Z`, `N/S` or `E/W`. The digitizer prevents the system from attempting incompatible actions (*e.g.* centring when the masses are clamped.)

To issue a command from Scream!, open the digitizer's terminal by right-clicking on its icon and selecting *Terminal...*.



After a short wait, a window should open with a prompt, indicating that the digitizer is ready to receive commands.

For a full description of the commands accepted by the digitizer, see Chapter 5, “The DM24mk3 digitizer module”.

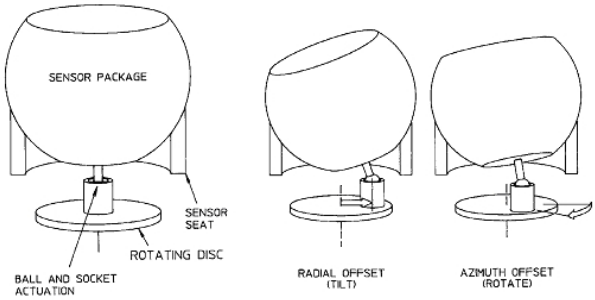
LEVEL

Before you unlock the components for the first time, you will need to level each one so that the mass lies in the right attitude to measure vertical or horizontal ground motion. The *LEVEL* command levels a component within the instrument.

E.g. `E/W LEVEL`

Each component is housed within a metal bowl which can rotate within the sonde.

The bowl is attached to an arm which passes through a slot in a disk below. The arm and disk can each be moved around using motors controlled by the digitizer.



The digitizer electronics monitor the state of an internal electronic bubble level to determine how to operate the motors. When the bubble level indicates that the component is adequately levelled, the command stops and the sensor returns to normal operation. The digitizer also outputs diagnostic information to the console:

```
z level
Z Mass Locking..
 179  499
Success
 161
138  1 1 0 1 1 1 1 1 TiltNull set 153
|  Tilt |Rotate|   X  |   Y  |
      0     -1    -28    -19 << Bowl Datum < Bowl Level
|  Tilt |Rotate|   X  |   Y  |
     -1      0    -29    -19 ok_BHOL00
```

You can now *UNLOCK* the sensor.

For safety, the *LEVEL* command automatically locks the component before it attempts to level it. You will *always* need to *UNLOCK* the component after issuing a *LEVEL* instruction, even if the component was unlocked beforehand.

The strong-motion parts of the 3T/5T do not need accurate levelling. You can adjust the DC offsets of the strong motion components, if necessary, using the digitizer command `5TNULL`.

LOCK

This command locks a mass, and for the horizontal sensors, clamps it by tilting it to its end stop.

E.g. `E/W LOCK`

Since locking will interrupt the flow of data, the digitizer prompts you before starting the lock. During the procedure, mass position information is output to the digitizer console.

```
e/w lock
Locking ONLY needed if instrument is to be moved !
Continue with operation y/n
? y
E/W Mass Locking..
  62  249
Success
E/W Base Locking..
 143 29993624314 2226 48 2021
  48 18991214078 1202
Success
East/West Mass_Locked Base_Locked Turned
Mass Position -2048  ok_BHOL00
```

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

UNLOCK

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

E.g. `N/S UNLOCK`

Note: To avoid damage to the sensor components, you should *LEVEL* the sensor (see below) before *UNLOCK*ing for the first time.

If *UNLOCK* is activated when the masses are already unlocked, the digitizer will stop with an error:

```
n/s unlock Already Unlocked!
North/South Mass_Unlocked Base_Unlocked Failure Turned
Mass Position -2048  ok_BHOL00
```

If the unlocking procedure fails, the digitizer may still regard the sensor as being unlocked, and will not allow you to attempt unlocking again. If this happens, use the LOCK command to lock the component and restore the system to a known state.

CENTRE

This command re-centres a component.

E.g. Z CENTRE

If the mass is clamped, or if the sensor mass position does not exceed ± 1.2 V, the CENTRE command does nothing. Otherwise, it attempts to zero the output of the sensor by exerting small extra forces on the boom. 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.

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.

During centring, the digitizer reports the mass positions on its console:

```
z centre
Z Mass Centring..
-2048   59  128 -1
Success
```

The second number (59 in the example) is a time-out, in seconds. If this number reaches zero, the procedure will abort the centring process. If this happens, you may be able to centre it by retrying the CENTRE command; otherwise, you may have to lock the component, level and unlock it.

The feedback system

The output from a modern broadband seismometer does not depend on the natural characteristics of the instrument. Instead, the period and damping of the sensor is completely determined by a feedback loop

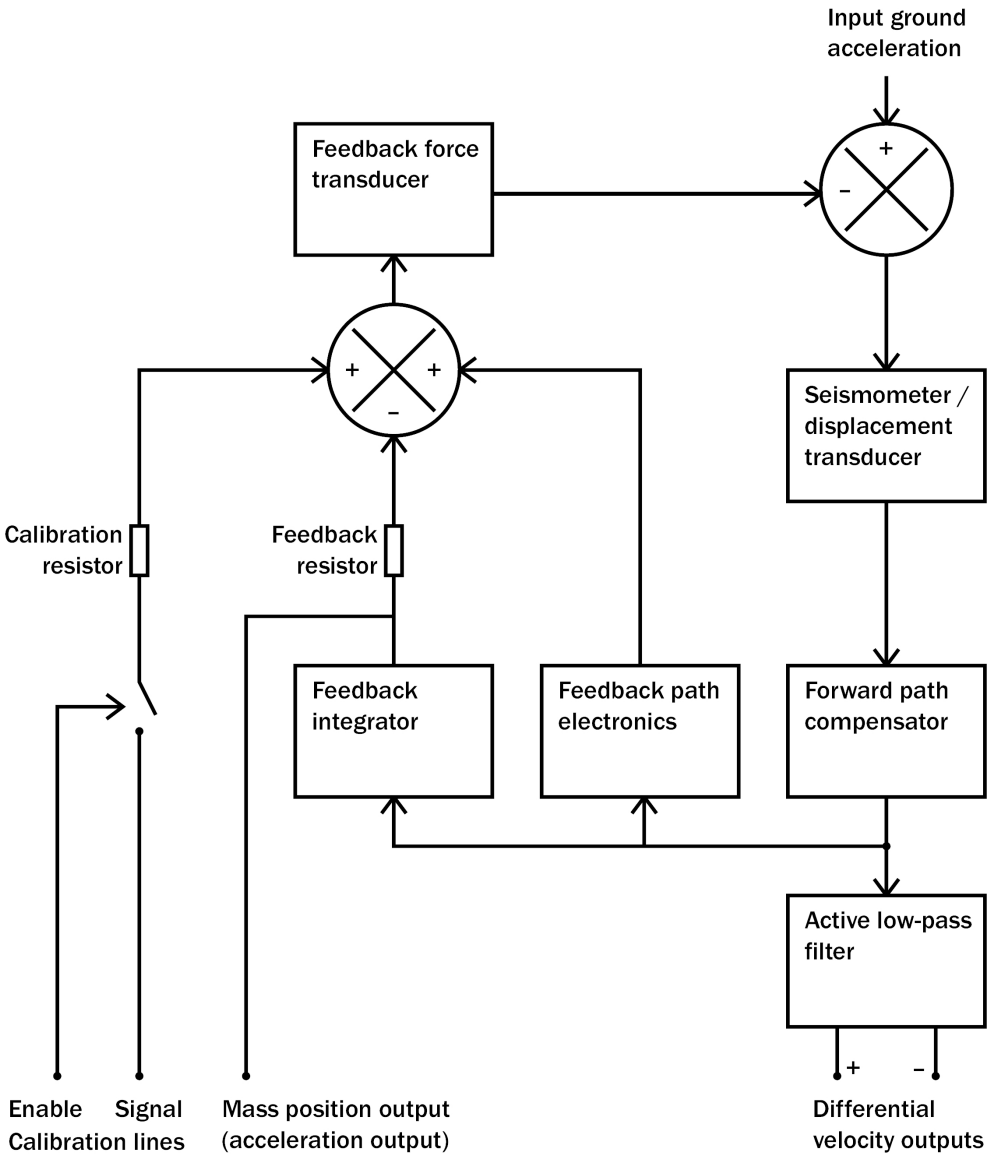
which applies a force to the sensor mass opposing any motion. The force required to *restrain* the movement of the mass can then be used to measure the inertial force which it exerts as a result of ground motion.

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

Force feedback seismometers of this type rely on the assumption that the force transducer produces a field of constant strength. The magnetic circuit and magnet/pole assembly in the 3T/5T are designed so that the field strength from the feedback transducer is constant over large deflections and current levels. Tests have shown that the mechanical suspension system and electronics of a 3T/5T instrument are linear to better than 107 dB (source: measurements made at ASL during evaluation for the USGS National Network.)

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

Feedback electronics



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

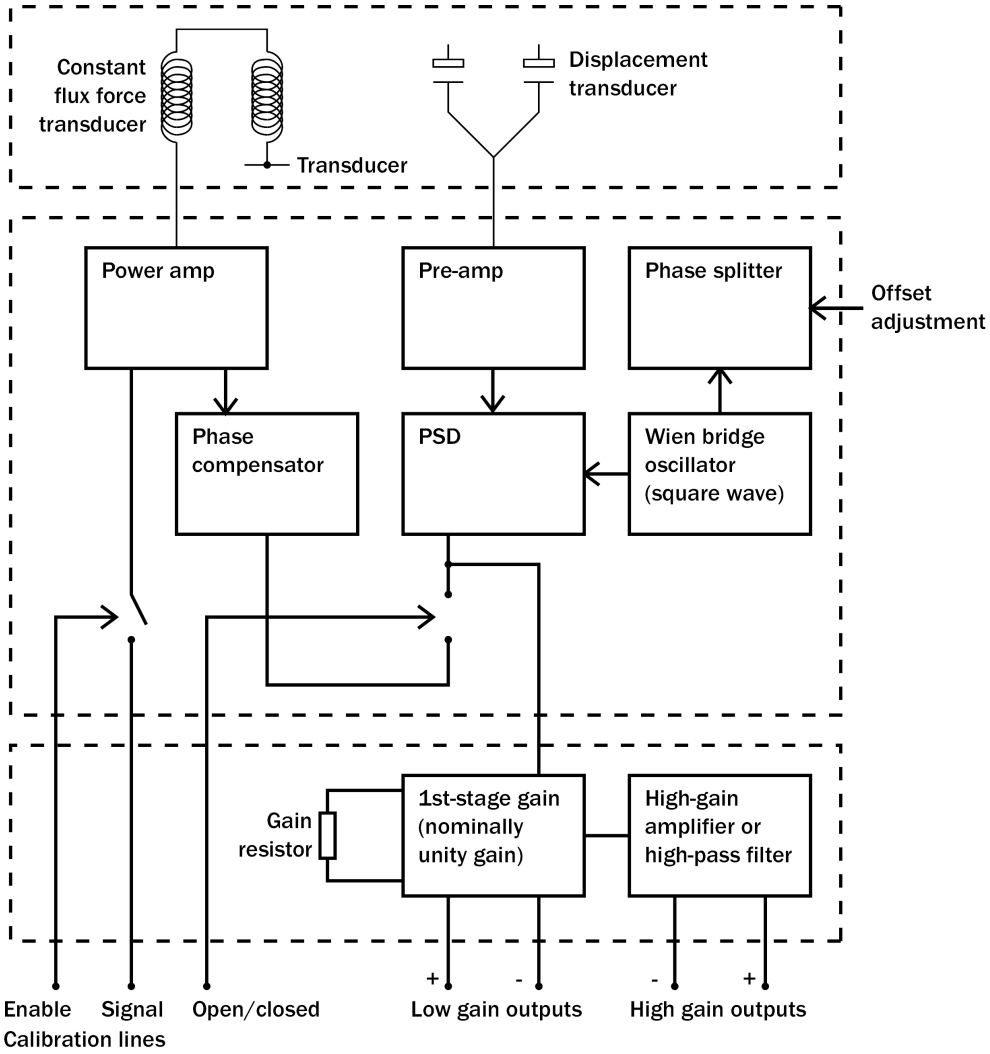
4.2 CMG-5 strong motion components

The mass of the vertical and horizontal strong-motion components is attached to the rigid frame with parallel leaf springs. The geometry of the spring spacing, together with the symmetrical design, ensures large

cross-axis rejection. The sensor mass is centred between two capacitor plates, and moves in a true straight line, with no swinging motion. Feedback coils are attached either side of the sensor mass, forming a constant-flux force feedback transducer.

The vertical and horizontal sensors are identical in mechanical construction; the vertical sensor's mass spring system is adjusted to compensate for gravity. They are mounted directly onto the base, with the sensor electronics fixed onto the rigid sensor frame. A single-row, 12-way surface mount R/A Molex connector joins each sensor to the main power supply circuit board.

The signal and feedback circuits inside the 3T/5T accelerometer are arranged according to the following diagram:



The mass and the capacitor plates are energised by a two-phase transformer driver, forming a differential capacitor. This acts as a capacitive transducer, whose signal is then demodulated with a phase-

sensitive detector. The accelerometer feedback loop is completed with a feedback loop compensator and a feedback force transducer power amp.

The differential output amplifier scales the output sensor sensitivity and a second stage amplifier can be configured (at the factory) either as a further cascaded gain stage or as a high-pass filter with unity gain.

The force transducer

The CMG-3T/5T is a force feedback strong-motion accelerometer which uses a coil and magnet system to generate the restoring feedback force. Such accelerometers inherently depend on the production of a constant-strength field in the magnet gap. Although the high quality magnets used in the 3T/5T accelerometer are exceedingly stable under normal conditions, if the sensor is sited in an area where the background seismic noise is much higher than that of vaults built in seismically stable locations, the flux density may be affected by the external magnetic field generated by the feedback transducer coil.

In order to minimise non-linearities in the feedback force transducer, the 3T/5T uses a symmetrical system of two magnets and two force coils. Any increase in flux in one coil is cancelled by a corresponding decrease in flux in the other, thus eliminating any non-linearity due to lack of symmetry.

Frequency response

The frequency response of each component is provided as amplitude and phase plots.

When testing the instrument to confirm that it meets its design specification, the range of frequencies used are concentrated over about 3 decades (*i.e.* 1000 : 1) of excitation frequencies. Consequently, the frequency plots of each component are provided in normalised form. Each plot marks the frequency cut-off value (often quoted as "–3dB" or "halfpower" point).

Güralp Systems performs frequency response tests on every sensor at the time of manufacture. All records are archived for future reference.

5 The DM24mk3 digitizer module

5.1 Introduction

The DM24 is a low-noise 24-bit digitizer in a borehole sonde form, with strain relief attachment.

Features

- A built-in Digital Signal Processor (DSP), which can provide simultaneous multiple sample rate data streams at user selectable rates. Up to 6 streams of data for each component are available at sample rates from 1 to 1000 samples/s.
- A precision microprocessor-controlled time base synchronizes Analogue to Digital Converters, and DSP, and time-stamps data blocks.
- Time synchronization to an attached GPS receiver or from a remote time source.
- An ARM microprocessor, which formats and buffers data in an on-board 256k RAM ring buffer.
- Efficient data storage and transmission using the Güralp Compressed Format.
- RS232 serial data output at user selectable baud rates.
- Built-in microprocessor system configuration and sensor control, including locking and unlocking, centring and calibration.
- Low system power consumption.
- Flash EEPROM for program code and filter coefficients.
- High-impedance, low-noise, differential input pre-amplifier modules with adjustable gain.
- Optional Flash memory storage.
- An optional Firewire interface, allowing you to download GCF data directly onto a compatible disk by simply plugging the disk

into the Firewire connector inside the casing, and monitoring progress on the built-in LCD screen.

5.2 Using Scream!

The DM24 can accept signals from up to 2 connected analogue sensors, and output digitized data to a computer running Scream! attached to its *DATA OUT* port. Scream! is a versatile seismic data visualisation program for Güralp instruments, and is available for download from Güralp Systems, or may have been supplied with your digitizer.

Configuring digitizers

Scream! 4 distinguishes between *configuration* and *control* of digitizers. The most important difference is that a digitizer 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 digitizer:

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

2. Right-click on the digitizer's entry (*not* the icon for the server or any **Com*xx*** icon). Digitizers are shown with icons depicting a coloured cylinder.

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

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

To control a digitizer whilst it is running, either right-click on the digitizer's entry in the list and click **Control...**, or double-click the entry. In either case Scream! will contact the digitizer 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 5.2),
- the length of pre-trigger and post-trigger periods,
- calibration signal options, and
- mass control functions.

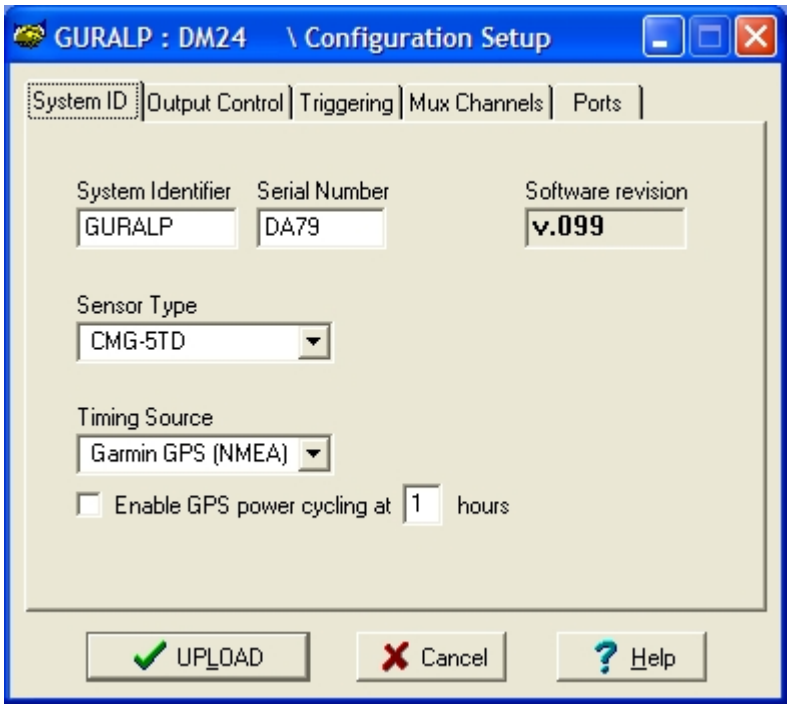
Some of these options can also be altered in the *Configuration setup* window. For more information on the *Control* window, see "Controlling digitizers" in Section 5.2.

If you need a more powerful interface to the DM24, you can also issue commands to it directly using Scream!'s terminal mode. A terminal window is opened by right-clicking on the digitizer's entry in the list and selecting **Terminal...**. The digitizer will stop collecting data while you have a terminal window open. For more details on the DM24's terminal mode commands, please see its technical documentation (available from Güralp Systems.)

The remaining sections of this chapter describe in detail the configuration options available for the DM24. Many of these options will also be available for other Güralp digitizers

System ID

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



System Identifier and *Serial Number* : The digitizer type is identified by its system identifier and serial number. Every data and status block generated by the digitizer 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 digitizer'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.

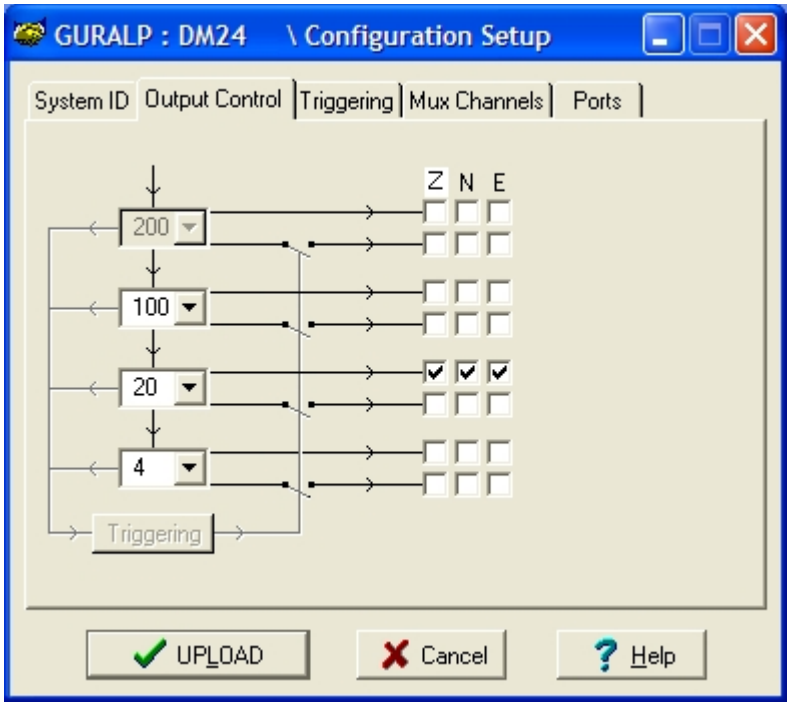
Sensor Type : If the sensor attached to the digitizer is a Güralp velocity sensor, useful seismometer functions (such as sensor locking, centring, and calibration) may be controlled through the digitizer. The *Sensor Type* you set here determines which functions will be available through the Scream! digitizer configuration set-up interface or through interactive commands.

GPS Type : The digitizer 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 digitizer 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.

Output control

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



Güralp digitizers initially sample incoming data at a high rate (*e.g.* 2000 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.

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

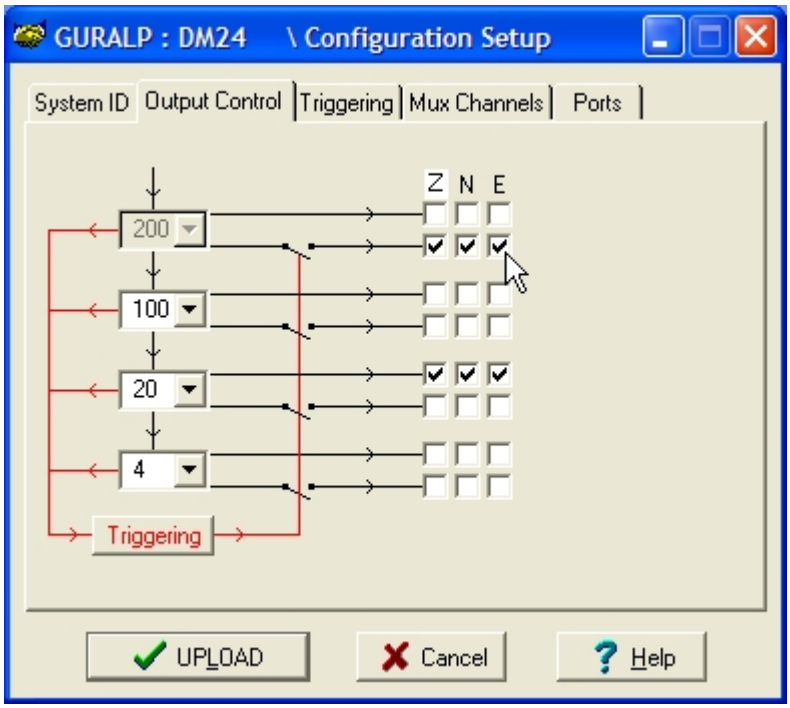
is 5.

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 screenshot above shows a possible configuration for a triaxial instrument. Every channel of the digitizer may be output at any tap; currently, all three axes are being output at Tap 2 (20Hz). The DM24 mkIII has a fourth channel for external input and calibration, which can also be output at any tap.

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 digitizer 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 unchecked to save communications capacity. You cannot check both continuous and triggered output for the same channel and tap.

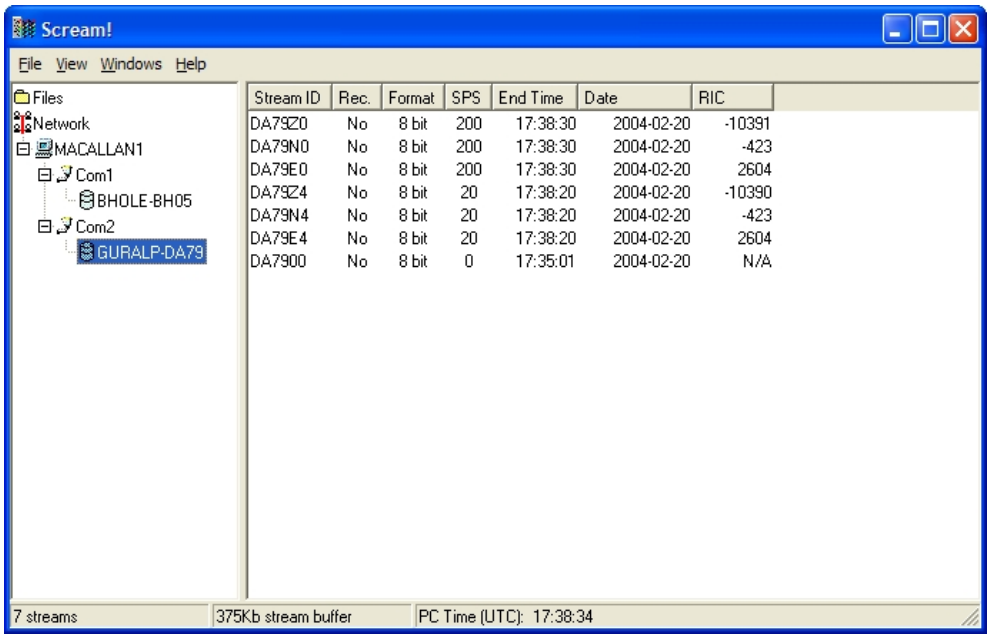
When you enable a triggered stream, the digitizer will output data in that stream only when a particular set of trigger criteria are met. This is shown diagrammatically as data passing through a switch. In the example above, we might want the high-rate data from Tap 0 to be generated only when an event 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 checked box in this window will give rise to a data stream coming from the digitizer, 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 digitizer, and the last two characters identify the individual stream. The first four characters are set by default to the serial number of the digitizer; you can change this on the *System ID* pane (see "System ID" in Section 5.2) or from the digitizer'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 digitizer.
- `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 digitizer 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 digitizer in the example has only one triaxial instrument connected to it, so Z/N/E1, 3, 5 and 7 are unused.

  Scream! can replace these designations with more helpful names if you wish: see the Scream! manual or online help for more details.
- `00` is the digitizer 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 5.2).
- `X0`–`X7`: the auxiliary analogue input channel, digitized using the same tap settings as `Z`, `N` and `E`.

- C0–C7: the same input channel, when it is digitizing an input calibration signal.
- Z, N, EG–N : the channels Z, N, E0–7, when they output triggered data.
- ME: another Mux channel, normally used for reporting the digitizer's internal temperature.
- CD, BP, IB: digitizer streams for specialised use.

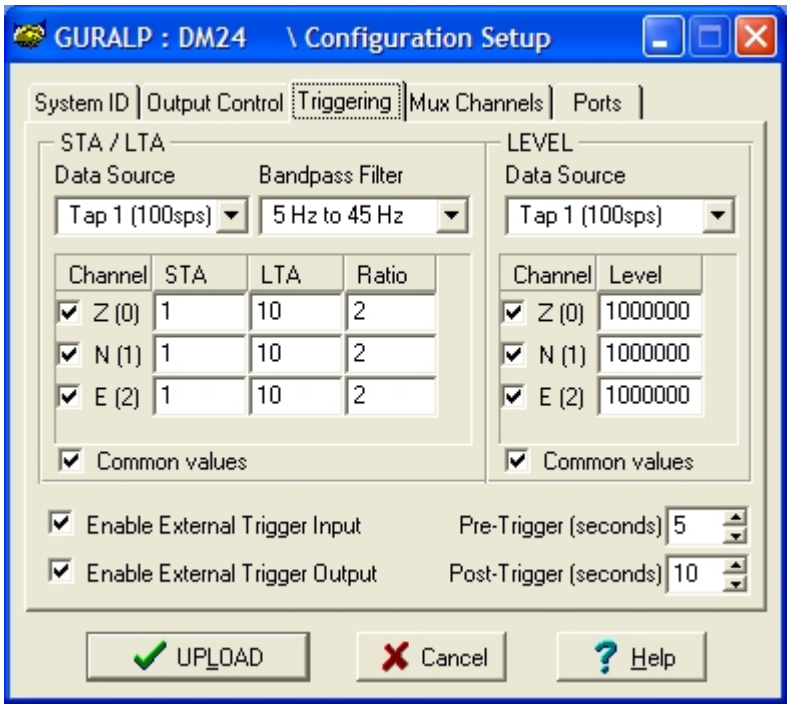
Triggering

In its standard configuration, the DM24 outputs continuous data at a sample rate you specify. In addition to this, Güralp digitizers 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 DM24 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! 4 also allows you to configure each digitizer to receive triggers from other digitizers.

To create a new stream with a trigger, open Scream!'s *Digitizer configuration* window for the relevant digitizer, 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 digitizers can use. However, not all models can use both methods. Scream! will find out from the digitizer whether its on-board software supports each method.

In addition, some digitizers support external and software triggering.

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.

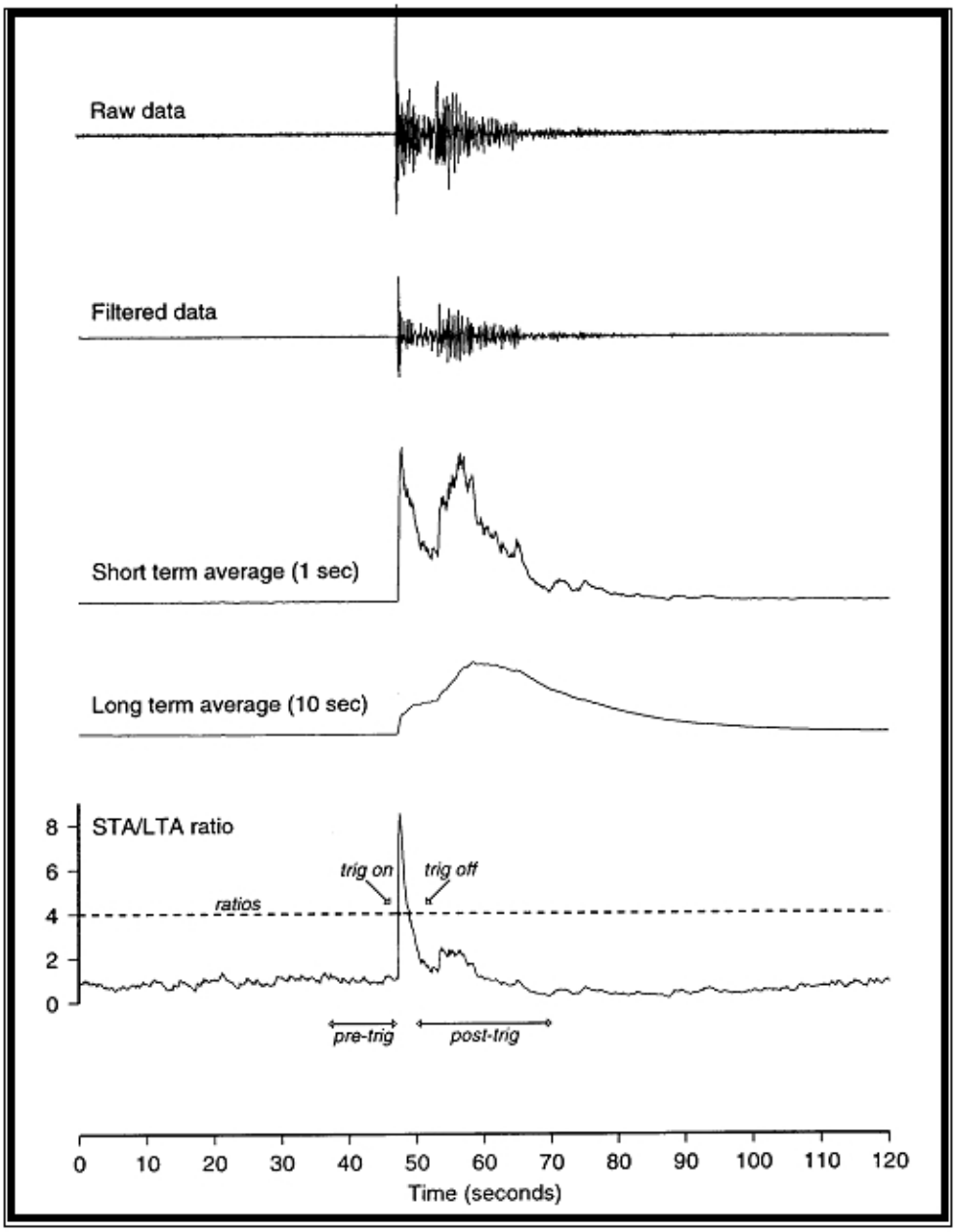
You can select which tap is tested for the trigger from the **Data source** drop-down menu. The tap does not have to output data to Scream! for you to be able to use it here.

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 checking the boxes in the **Channel** column of the table. If *any* of the checked channels passes the trigger condition, the trigger will activate, and will not detrigger until *all* of the checked 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 checked 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 uncheck **Common values** 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 digitizer (see "Controlling digitizers" in Section 5.2.)

Since it is not generally advisable to trigger from broadband data, the

digitizer 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.

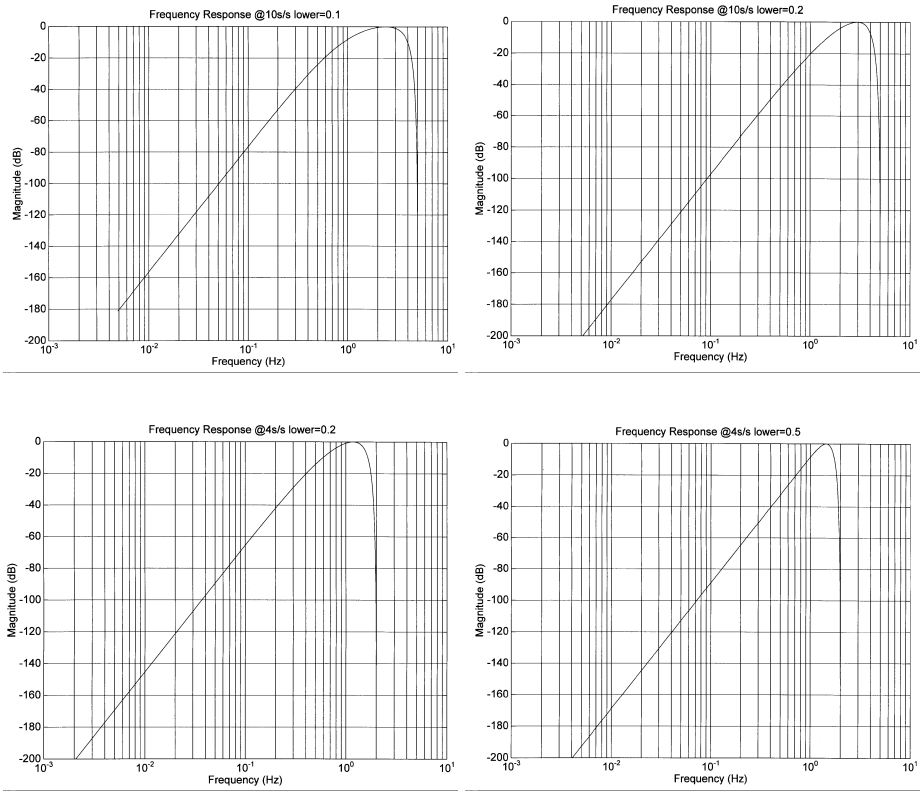
The possible filter configurations are shown in the following table:

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.



Level

Using the *Level* triggering method, a trigger is generated whenever one of the checked 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 checked channels. If you want to use different values for some channels, you should uncheck **Common values** 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 digitizer (see "Controlling digitizers" in Section 5.2.)

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 digitizers have an internal buffer of some seconds which allows this data to be added to the triggered stream. Pre-trigger data is 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 detriggers.

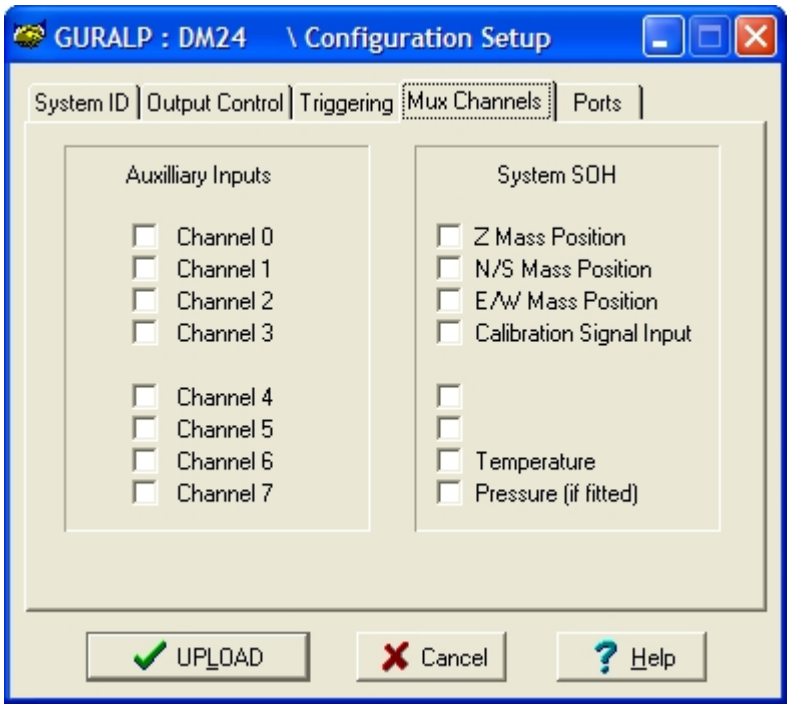
The two boxes at bottom right of the *Triggering* pane allow the user to set the pre-trigger and post-trigger data intervals, in seconds. These values determine the *minimum* length of time during which data will be saved before the trigger condition occurs, and after it has lapsed. Regardless of the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

Mux Channels

The DM24 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 stand-alone configuration, three of these are used to report the sensor mass position, and a fourth for measuring the internal temperature of the digitizer. There are a further four channels available at the time of manufacture for user-specified optional features, such as pressure monitoring, borehole orientation, etc., making eight factory-set Mux channels in all.

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

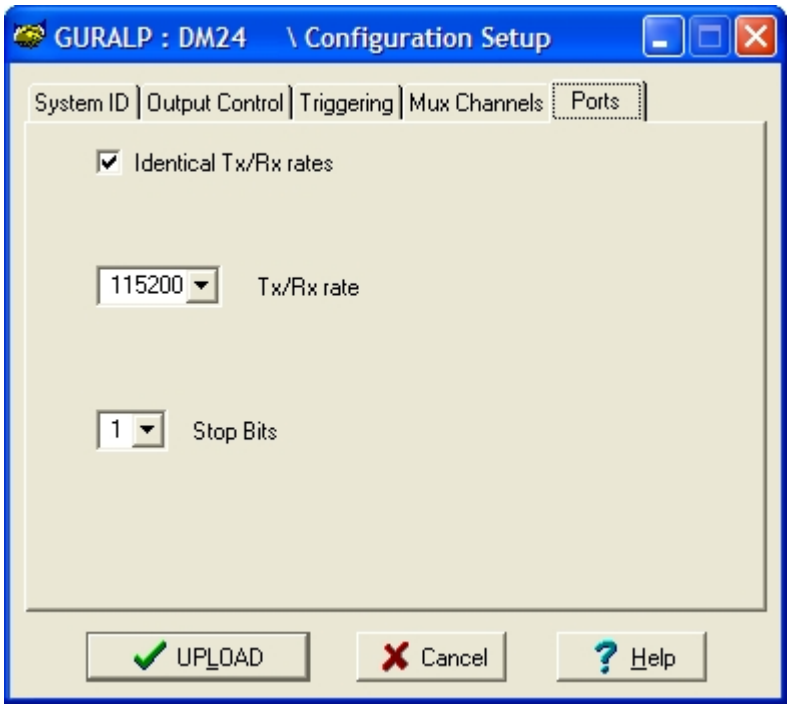


If a tick is placed in the box next to a channel, its data will be collected and transmitted as a data stream in GCF format, just as with the normal data channels. To indicate that the data comes from a Mux channel, the Stream ID will take the form `****Mx`, where `M` stands for Mux and `x` is a hexadecimal 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 DM24 also monitors its internal temperature, which is reported on channel `ME`.

The DM24 mk3 returns input calibration signals on the fourth full-rate data channel, so the *Calibration Signal Input* Mux channel is unused.

Ports

The *Baud Rates* pane of the *Configuration setup* window allows you to program the baud rate and stop bits for the DM24'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 digitizer at the sampling rates you have chosen. For three streams of data at 100 Hz, for example, 9600 baud will usually be sufficient. If you wish to transmit 200 Hz data, however, the baud rate must be at least 19200.

- 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 check in the 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 SAM/DCM 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 digitizer) and selecting **Configure...** from the pop-up menu: for more details, consult the online 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.

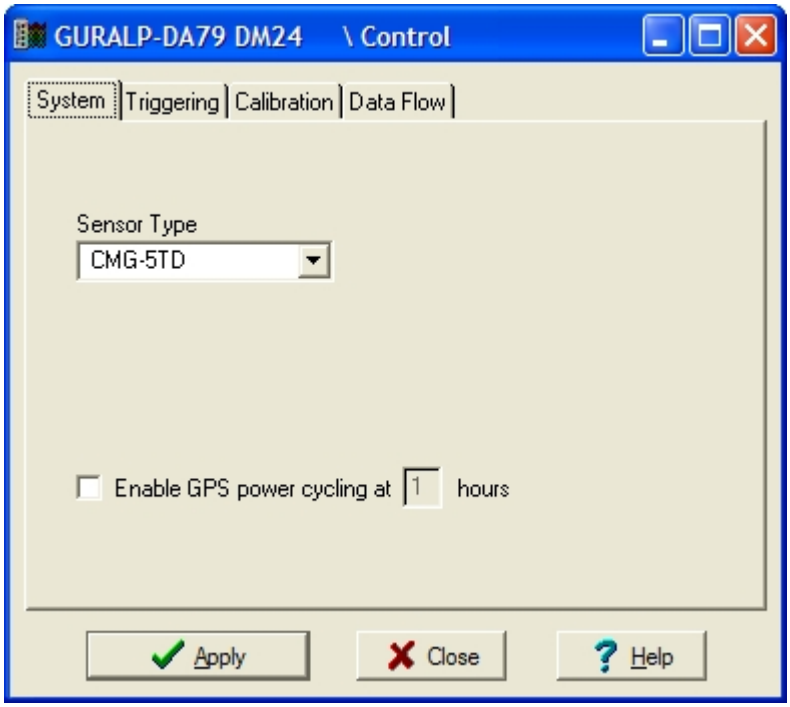
Controlling digitizers

To control a digitizer whilst it is running, either right-click on the digitizer'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 digitizer 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 **Apply** to send them to the digitizer, where they will take effect immediately.

This chapter describes the control options available to you for the DM24. Many of these options will also be available for other Güralp digitizers. For the most accurate information, you should consult the Operator's Guide for the digitizer or sensor you connect.

System

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



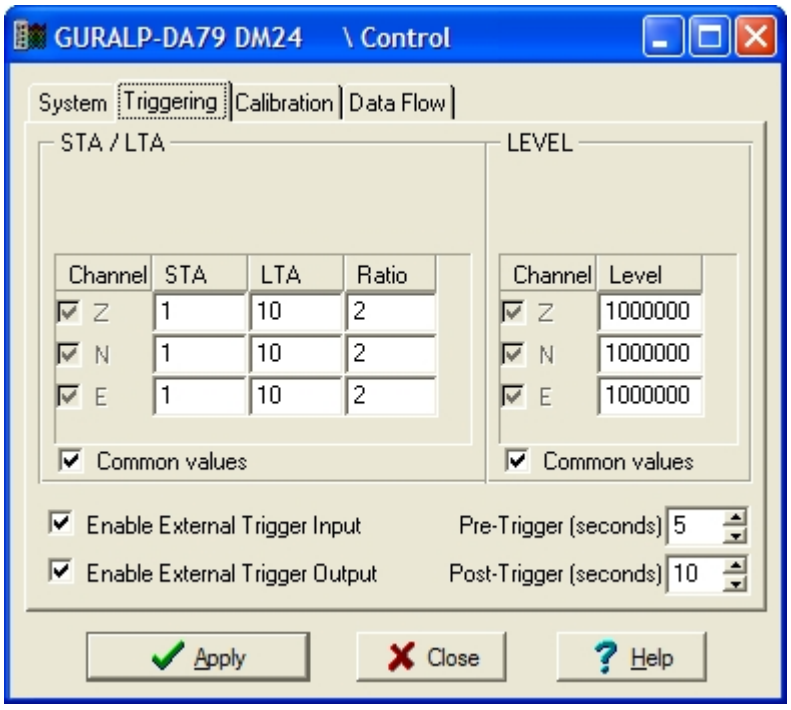
Sensor Type: If the sensor attached to the digitizer is a Güralp velocity sensor, you can send control commands to it from the *Mass Control* tab

(see below.) Which functions are available on this tab depends on the *Sensor Type* you have set here.

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.

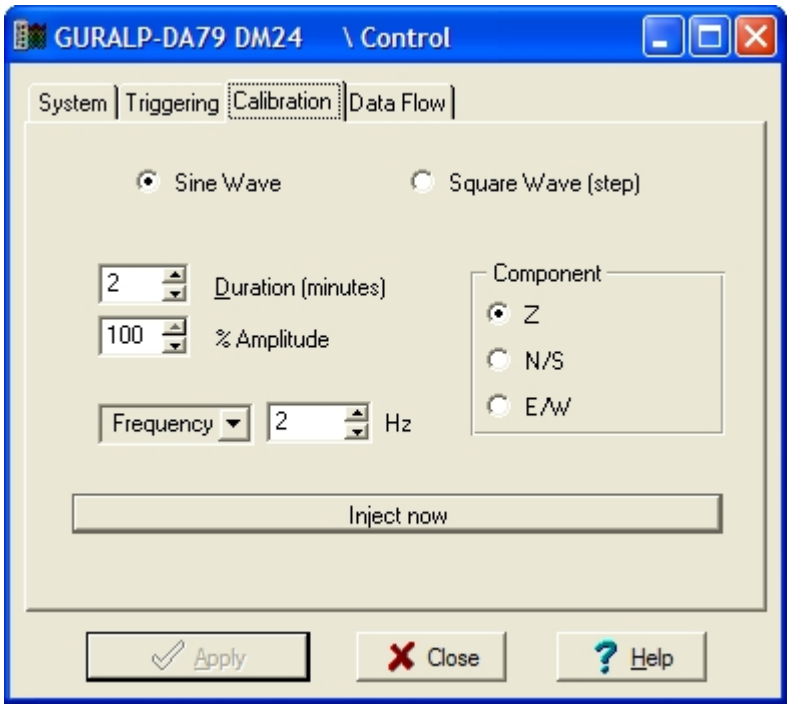
Triggering



The *Triggering* pane is very similar to the corresponding pane of the *Configuration setup* window, although not all options are available since some require rebooting the digitizer. See "Triggering" in Section 5.2 for more details.

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.



Selecting the **Z** channel will calibrate the weak-motion components only. To calibrate the strong-motion components, use the **N/S** channel. The **E/W** calibration loop is unused.

The calibration signal is digitized at the same rate as the *highest-rate* data stream you have selected for either continuous or triggered output. It is returned on a channel ending C*n* (*n* = 0 – 7.) The auxiliary analogue channel is interrupted whilst calibration is active.

The **Duration** box tells the digitizer how long to provide the calibration signal before disconnecting. This avoids the system being inadvertently left in calibration mode. The default is 2 minutes. If you change this setting, it will revert to the default value after one calibration stage.

The DM24 can produce either sine-wave or square-wave (step) calibration signals. The **Sine wave** calibration signal always starts and stops on the zero crossing. The frequency or period given by the boxes at bottom left. Only integers between 1 and 10 may be specified for either frequency or period, so to generate a 0.5 Hz signal you should select **Period** and set the time to 2 (seconds). Likewise, if you require a 0.25 second period you should select **Frequency** and set the rate to 4 (Hz). In this manner, you can select frequencies ranging from 0.1 to 10 Hz (10 to 0.1 s periods).

Alternatively, you can specify step calibration by selecting the **Square wave** button. The square wave consists of a positive step at the start of

the next minute of the digitizer's internal clock, followed by a negative step after a specified number of minutes. After a further delay of the same number of minutes, the calibration signal is disconnected. The default is 2 minutes.

Mass Control

Many Güralp instruments respond to control signals to centre, unlock, and lock the sensor masses. These signals are generated by the digitizer. You can tell the digitizer to send a signal using the **Centre**, **Lock** and **Unlock** buttons on the *Mass Control* tab.

Depending on which *Sensor Type* you have chosen in the *System* tab (see above), not all the control signals will be available. For example, a CMG-3ESP can be centred from Scream, but must be locked and unlocked manually, whilst a 3T has remote lock and unlock commands. Conversely, CMG-5T strong-motion instruments must be centred manually, and do not need locking or unlocking. If you have set the **Sensor Type** to *CMG-5T* or *CMG-5TD*, the *Mass Control* tab will not be available.

Data flow

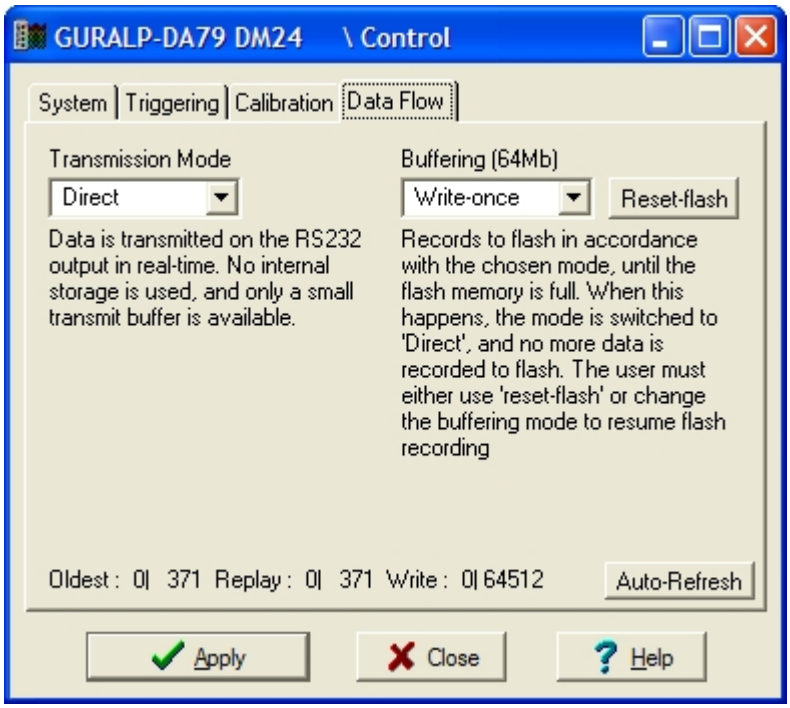
The DM24 operates in one of several *filing modes*. These modes relate to how the unit uses its Flash memory:

- 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, or
- stop writing and switch the DM24 into *DIRECT* mode.

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



Clicking **Apply** in this window immediately activates the filing mode you have selected—there is no need to reboot.

If you prefer, you can use the DM24 terminal to switch between filing modes. The commands to use, which take effect immediately, are given below.

DIRECT

Syntax: `DIRECT`

Instructs the DM24 not to use Flash memory for storage. Instead, all data is 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

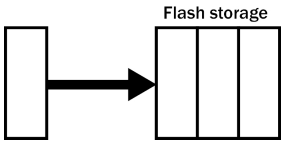
- *ADAPTIVE* mode, if you want data to stay as near to real time as

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.)

FILING

Syntax: `FILING`



Instructs the DM24 not to transmit blocks to clients automatically, but to store all digitized 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).

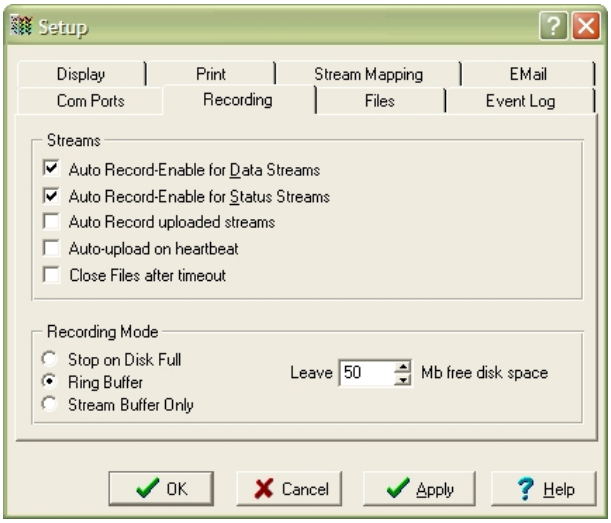
Heartbeat messages

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.



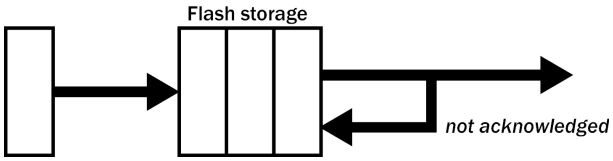
2. Check **Auto-upload on heartbeat**.

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

FIFO (First In First Out)

Syntax: `FIFO`



Instructs the DM24 to begin writing blocks to Flash memory as for *FILING* mode, but also to transmit data to clients. Data is transmitted in strict order, oldest first; the DM24 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.

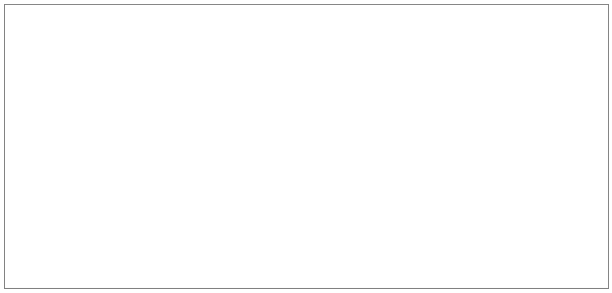
FIFO mode will consider a data block successfully transmitted once it has received an acknowledgement from the next device in the chain. If there are several devices between you and the instrument, you will need to set up the filing mode for each device (if applicable) to ensure

that data flow works the way you expect.

Like all the filing 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 it is overwritten (in the *RECYCLE* buffering mode, see below) or if you delete it manually.

ADAPTIVE

Syntax: `ADAPTIVE`



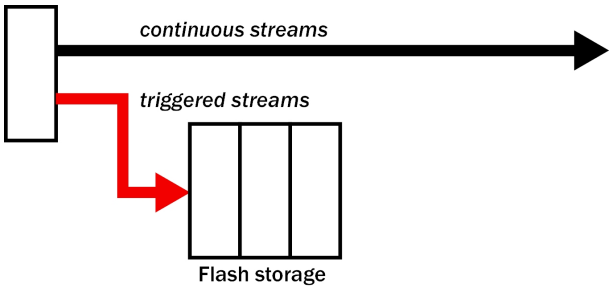
Instructs the DM24 to transmit current blocks to clients if possible, but to store all unacknowledged blocks in the Flash memory and re-send them, oldest first, when time allows. *ADAPTIVE* mode is best suited for "real-time" installations where the link between digitizer and client is intermittent or difficult of 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.

DUAL

Syntax: `FILING DUAL` (*n.b.*)



Instructs the DM24 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.

RE-USE / RECYCLE

Syntax: `RE-USE`

Instructs the DM24 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! and on the DCM.

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.

WRITE-ONCE

Syntax: `WRITE-ONCE`

Instructs the DM24 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.

5.3 Command line interface

Introduction

You can connect to the internal software of the DM24 over its output serial port and communicate with it.

To enter command mode from Scream!, right-click on the digitizer's icon and select **Terminal...** from the menu that pops up. A window will open, and once the digitizer 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 `hypertrm` on Microsoft Windows) to connect to the DM24.

Whilst you are in terminal mode, data transfer will be interrupted; the digitizer 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 DCM and AM modules also allow you to send commands direct to the digitizer using the command-line tool `gcli`. For more information, please see the manual for your data module.

If you have problems connecting to the digitizer'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 DM24 expects connections at 19200 baud, with 8 data bits, no parity bit and 1 stop bit. No flow control is used.

FORTH

The DM24 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 CMG-3T sensor.)

If a command completes with nothing remaining on the stack, the digitizer will show the prompt ok. Otherwise, the prompt will remind you that the digitizer 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, where information you enter is given in medium and messages returning from the DM24 are given in **bold**.

General configuration

SET-ID

Syntax: SET-ID (interactive)

Sets the system identifier and serial number of the DM24 to values you supply.

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

The system identifier you supply may contain up to 6 alphanumeric (0-9A-Z) characters, and must have a comma after it. 6-character strings later than ZIK0ZJ are not permitted.

The serial number you supply must contain exactly 6 alphanumeric (0-9A-Z) characters, and must have a comma after the fourth character.

SENSOR-TYPE

Syntax: *type* SENSOR-TYPE

Tells the DM24 which kind of sensor is attached to it. This affects whether or not the digitizer exposes commands such as locking and

centring.

type can be one of

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

GPS-TYPE

Syntax: *type* GPS-TYPE

Tells the DM24 which kind of GPS is attached to it.

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.)

BAUD

Syntax: *port* *baud-rate* BAUD

Sets the baud rate for one of the serial ports on the DM24, in bytes per second. 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 DM24 to its default configuration.

The allowable values for *baud-rate* are 4800, 7200, 9600, 14400, 19200, 38400, 57600 and 115200. GPS inputs should remain set at 4800 baud.

AZIMUTH

Syntax: *instrument* *angle* AZIMUTH

Some borehole digitizers can rotate incoming signals algorithmically as they are digitized. 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 digitizer and issue an AZIMUTH command, giving the angle you have measured.

instrument tells the digitizer which instrument to apply the rotation to; 0 for a 4-channel digitizer.

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 your sensor or for Scream!.

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

CROSS

Syntax: *channel* CROSS

Alters the DSP's transformation matrix to invert one of the digitizer channels. *channel* is one of 0 (vertical), 1 (N/S), 2 (E/W) and 3 (auxiliary).

The CROSS command only alters the digitizer's CMOS settings. You will need to re-boot the digitizer 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.

Output configuration

SAMPLES/SEC

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

The DSP software on the DM24 supports up to 7 cascaded

filter/decimation stages. At each stage, the sample rate can be decimated by a factor of 2, 4 or 5. The ADC within the unit outputs data at 2000 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 DM24 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.

For example:

```
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
```

Currently the DM software does not support the new GCF format for higher sample rates. It also does not properly support 250 samples/s, nor rates below 1 sample/s.

CONTINUOUS

Syntax: *tap components* CONTINUOUS

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

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.

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.

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.

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
```

- 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.

Triggering

TRIGGERS

Syntax: *components* `TRIGGERS`

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

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.

TRIGGERED

Syntax: *tap components* `TRIGGERED`

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

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.

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`.)

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.

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 s of the *Z* and *N* components, and 2 s of the *E* and auxiliary components.

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.

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 s of the *Z* component, and 20 s of the *N*, *E* and auxiliary components.

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.

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 DM24 to trigger if the STA/LTA ratio is above 4 for the *Z* component, *or* above 10 for the remaining components.

PRE-TRIG

Syntax: *time* PRE-TRIG

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

POST-TRIG

Syntax: *time* POST-TRIG

Sets the post-trigger recording time. *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.

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 DM24 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 DM24 is triggered externally, it will behave exactly as if it had generated the trigger itself.

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 DM24 whenever it triggers. The DM24'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 digitizer with `TRIGGERIN ENABLE` in effect, in which case triggered data from both instruments will be transmitted whenever the DM24 triggers.

If a DM24 has both `TRIGGERIN ENABLE` and `TRIGGEROUT ENABLE` in effect, *only* triggers which the DM24 itself has generated will be output. Triggers received through the *Trigger in* port will cause the DM24 to output triggered streams, but will *not* be passed on to other digitizers.

Calibration

SINEWAVE

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

Instructs the DM24 to inject a sine-wave calibration signal, starting on the zero crossing.

component specifies which component is to be calibrated, one of `Z`, `N/S`, `E/W`, or `X`. In the 3T/5TB the Z calibration loop is used for all three components of the weak-motion sensor, and the N/S loop for all three components of the strong-motion sensor.

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 s. For

example:

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

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.

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 to monitor the returning calibration signal.

SQUAREWAVE

Syntax: *component* `SQUAREWAVE`

Instructs the DM24 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.

component specifies which component is to be calibrated, one of `Z`, `N/S`, `E/W`, or `X`. In the 3T/5TB the Z calibration loop is used for all three components of the weak-motion sensor, and the N/S loop for all three components of the strong-motion sensor.

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 to monitor the returning calibration signal.

RANDOMCAL

Syntax: *component* `RANDOMCAL`

Instructs the DM24 to inject a white-noise calibration signal generated by an onboard pseudo-random number generator.

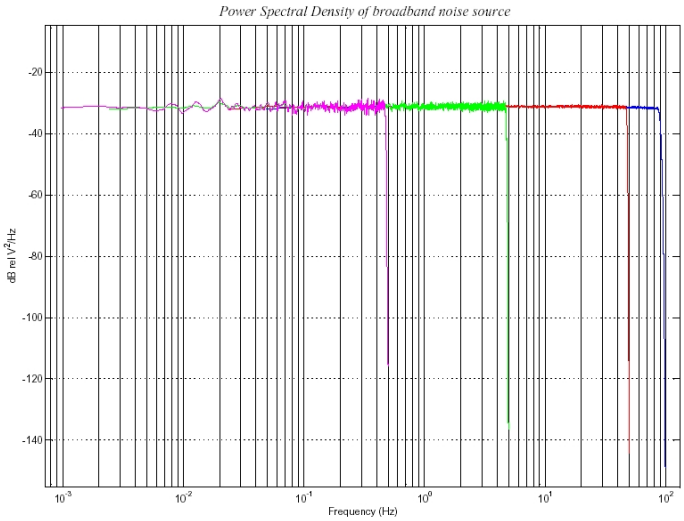
component specifies which component is to be calibrated, one of `Z`, `N/S`, `E/W`, or `X`. In the 3T/5TB the Z calibration loop is used for all three components of the weak-motion sensor, and the N/S loop for all three components of the strong-motion sensor.

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 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.

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.

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 digitizer 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
```

%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
```

Actions

LOCK

Syntax: *`component`* `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.

UNLOCK

Syntax: *`component`* `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.

CENTRE

Syntax: *component* 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.

LEVEL

Syntax: *component* LEVEL

Level a component of the sensor, returning when the built-in electronic bubble level indicates that the component is level.

You should level each component before unlocking, to ensure no damage is done to the components.

5TNULL

Syntax: 5TNULL

Remove any DC offsets in the strong-motion components by automatically adjusting potentiometer levels. This is the equivalent of *LEVEL* for the strong-motion portion of the system.

RE-BOOT

Syntax: RE-BOOT (interactive)

Causes the DM24 to reset after a delay of 2 s.

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

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

Filing

SHOW-FLASH

Syntax: SHOW-FLASH

Reports status information about the Flash memory in the DM24, if fitted. For example:

SHOW-FLASH for a new system with 8 × 64Mb chips fitted:

```
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
```

SHOW-FLASH for a system in use with 1 × 64Mb chip fitted:

```
64MB Flash File buffer : 65,536 Blocks Written  65,532 Unread  4
Free
Oldest data  [36,272]  GURALP TESTZ1 2003 12 3 20:20:41
 Read point  [36,272]  GURALP TESTZ1 2003 12 3 20:20:41
Latest data  [36,268]  GURALP TESTX2 2003 12 4 10:09:12
File Replay  [36,272]  GURALP TESTZ1 2003 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 timestamp of the oldest data in memory,
- the current position of the read pointer,
- the stream and timestamp 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 has 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.

All functions are fully implemented as before using the same commands except *write-once, re-use* and *dual* (as triggering is not available yet).

DIRECT

Syntax: DIRECT

Instructs the DM24 not to use Flash memory for storage. Instead, all data is transmitted directly to clients. A temporary RAM buffer allows clients to request blocks they fail to receive using the Block Recovery Protocol.

FILING

Syntax: `FILING`

Instructs the DM24 not to transmit blocks to clients, but to store all digitized 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.

ADAPTIVE

Syntax: `ADAPTIVE`

Instructs the DM24 to transmit current blocks to clients if possible, but to store all unacknowledged blocks in the Flash memory and re-send 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 digitizer and client is intermittent or difficult of access.

FIFO

Syntax: `FIFO`

Instructs the DM24 to begin writing blocks to Flash memory as for `FILING`, but also to transmit data to clients. Data is transmitted in strict order, oldest first; the DM24 will only transmit the next block when it receives an acknowledgement of the previous block.

DOWNLOAD

Syntax: `DOWNLOAD`

Sets up a data transfer from the Flash memory over the serial connection. Which data is 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 HPA0N1 STREAM DOWNLOAD
```

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

100 S/S ALL-TIMES DOWNLOAD
```

`DOWNLOAD` (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`.

ALL-FLASH

Syntax: `ALL-FLASH`

Sets the read point to the oldest data held by the DM24. 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.

ALL-DATA

Syntax: `ALL-DATA`

Instructs the DM24 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.

STREAM

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

Instructs the DM24 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.

STATUS-ONLY

Syntax: `STATUS-ONLY`

Instructs the DM24 to transmit only status streams (text streams, normally with stream IDs ending in 00.)

S/S

Syntax: *rate* S/S

Instructs the DM24 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.

ALL-TIMES

Syntax: ALL-TIMES

Clears any time selection in force, allowing you to download all data held by the DM24. 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.

FROM-TIME

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

Instructs the DM24 to transmit only data more recent than *yyyy*-*mm*-*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).

TO-TIME

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

Instructs the DM24 to transmit only data more recent than *yyyy*-*mm*-*dd hh:mm*, where *yyyy*, *mm*, *dd*, *hh* and *mm* have the same meanings as in FROM-TIME, above.

GO

Syntax: `GO`

Closes terminal mode, and begins the download 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 DM24 will carry on transmitting real-time data, if you have so configured it.

END-DOWNLOAD

Syntax: `END-DOWNLOAD`

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

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 DM24 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 DM24 to bring up an options menu and pause. If you do not press a key in 7 seconds, the disk will be automatically backed up.

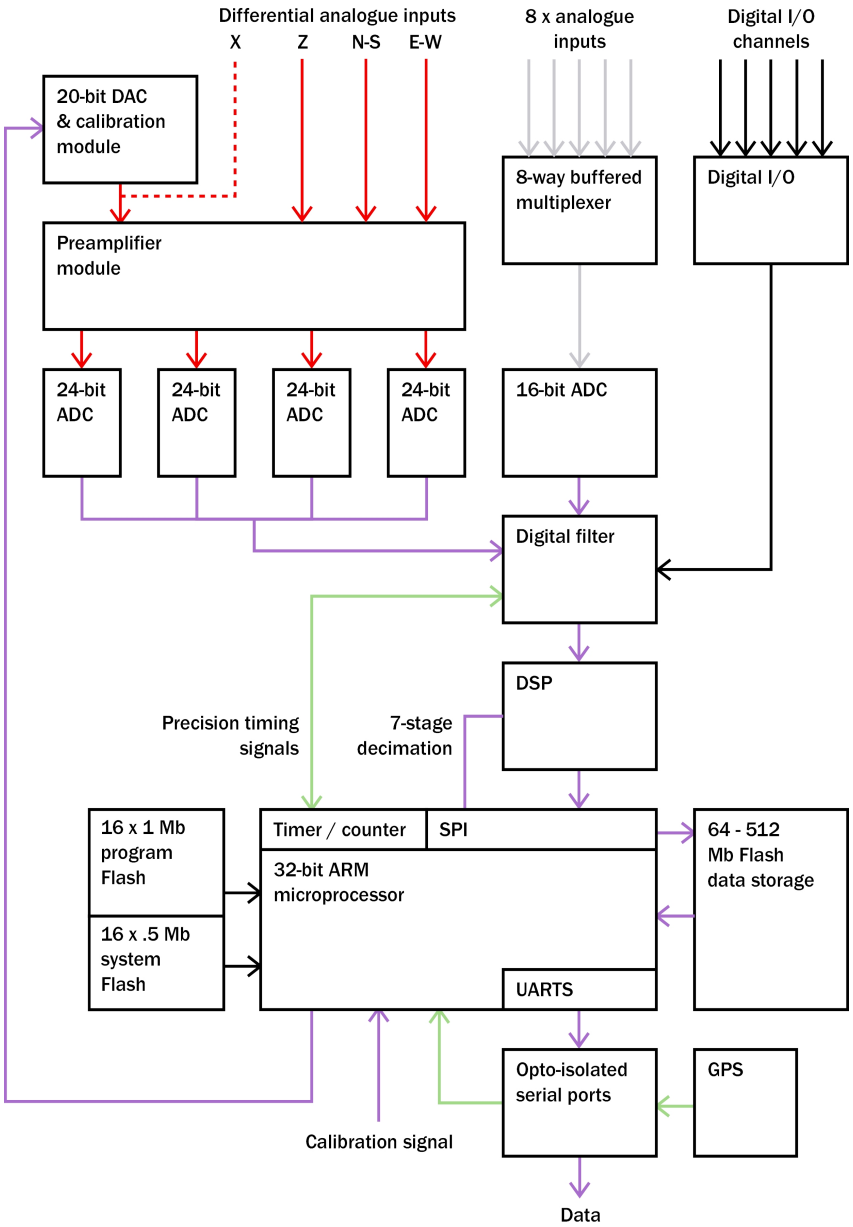
```
Disk Options :-
 (A) save All data
 (N) save New data
 (S) save Selected time window
 (D) Directory - contents
 (R) Reset disk - overwrite
```

```
(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.

5.4 Inside the DM24

Internally, DM24 digitizers are structured as shown in the following diagram, where each box represents a separate printed circuit board within the module.



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 chipset 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 digitizer 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 systems is the multiple serial port card, which allows the DM unit to support up to 8 serial ports using the ARM's on-board UARTs (Universal Asynchronous Receiver/Transmitters). On a DM unit with analogue inputs one serial port is usually configured to send the data packets to a local SAM or DCM unit for storage, or via a modem or radio link to a central

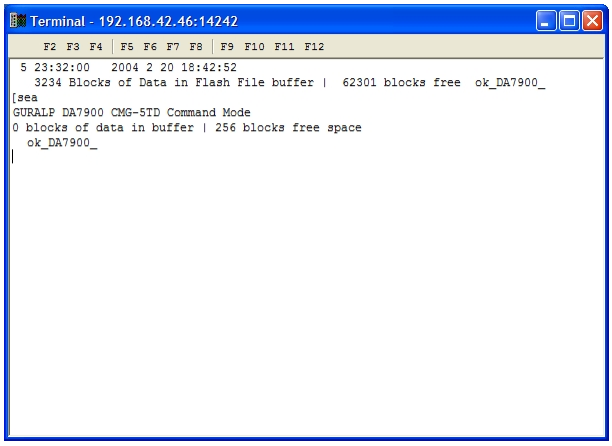
recording station. A second serial port is often used with a local GPS receiver for time synchronization, or alternatively the first (data) port can be used for time synchronization from a central station.

Each of the serial ports on the digitizer 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 ADC's. The serial port module also includes 32k of RAM for data buffering and formatting by the transmission/reception process.

Updating firmware with Scream!

You can update the digitizer firmware using any terminal program which supports the Xmodem protocol, such as `hypertrm` or newer versions of Scream!. If you are using Scream!, right-click on the digitizer's icon in the main window and select **Terminal** from the pop-up menu:



Check that there is two-way communication with the digitizer by pressing Enter. The digitizer should reply with ok on a new line.

Type `re-boot` to reinitialize the digitizer, and confirm with `y`. As it is restarting, the digitizer will report its status over the terminal connection, followed by a maintenance menu:

```
MPE ARM ANS ROM PowerForth v6.20
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 v01.0 mgs 29/07/04 [b 015]
System Code versions loaded :-
0103:0000 Guralp Systems Ltd  DMARM  v01.0 mgs 09/07/04 [Build
017]
0106:0000 Guralp Systems Ltd - DM+FW  v01.1  mgs  22/07/04 [Build
007i]
0109:0000 Guralp Systems Ltd - DM+FW  v01.1  mgs  11/08/04 [Build
007]    Default
010C:0000 Blank
DSP Code :
0101:0000  ARMT16D16-050304.BIN
0102:0000  dsprot037.bin 04/08/04          Default
Command keys:
C - set real time Clock (2004 8 13 09:29:48 )
F - run the Forth monitor
R - Run an application
E - Erase an application
S - update System program
B - update Boot program
D - update DSP code
N - set the default application Number (3)
Q - Quit maintenance system
3  seconds to auto-start
Enter command:
```

If you do not press a key in the next 5 seconds, the DM24 will start up normally.

The DM24 has three firmware components, which can be updated separately: the system program, the DSP code and the boot loader.

Loading a new system program

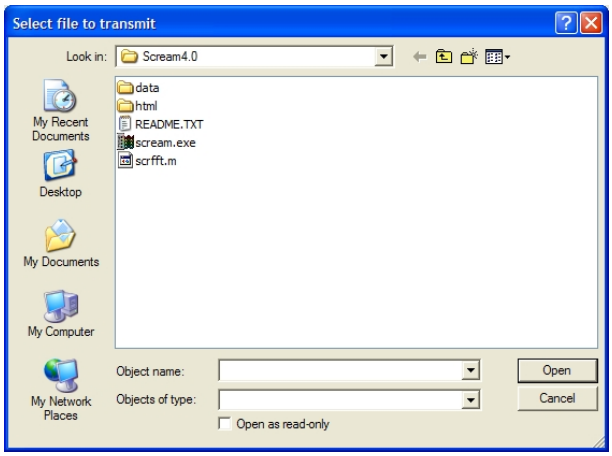
To update the system firmware, press `S` at the maintenance menu. The digitizer will display

```
Update System program
Enter Application number 1..4 :
```

There are four slots available for system application code. Enter the number of the slot you want to use. In the example above, there are three `System code versions loaded`, of which the one in slot 3 (`0109:0000` in memory) is currently the `Default`. It is recommended that you choose a different slot from the current `Default`, so that you can revert to the old firmware in case of a problem.

The digitizer 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. 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 DM24 will return to the maintenance menu. Press `N` to set the default application number.

```
Set default Application Number
Enter Application number 1..4:
```

Type the number of the slot you have used for the new code, followed by `ENTER`, and wait whilst the system reboots.

Alternatively, you can test the new system code by pressing `R` at the maintenance menu, followed by the slot number of the new code. This will run the DM24 with the new firmware for one session only. When it is rebooted, tha DM24 will revert to the `Default` application.

Loading new DSP code

Press `D` at the maintenance menu. The digitizer 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 DM24 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 digitizer will then request a transfer using

the Xmodem protocol, as described above.

Loading a new boot loader

There is only one slot available for the boot loader. Press `B` at the maintenance menu to update it.

The digitizer 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.

Appendix A Güralp Compressed Format

Güralp Systems sensors and data modules use Güralp Compressed Format (GCF) to share seismic data. The format can be used for data storage or transmission over a serial link or TCP/UDP network.

This section describes the specification of GCF format.

Appendix A.1 GCF blocks

A GCF file or stream consists of a sequence of *blocks*, which can be up to 1024 bytes long. Each block consists of a 16-byte header followed by either

- a series of data records, containing initial and final sample values and a sequence of first differences between intervening sample values, or
- status information in ASCII text format.

The format of the block's body is determined by information in the header.

The GCF header

The header is 16 bytes long, split into four 4-byte fields:

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
System ID				Stream ID				Date code				Data format			

System ID : A label identifying the originating system, encoded as a base 36 number. The base 36 digit in each position corresponds to a single character (0 – "0" ... 9 – "9" , 10 – "A" ... 35 – "Z"), with the least significant digit placed at the right-hand end of the string.

If the most significant base 36 digits are zero, they are omitted from the string; hence the encoding 1 corresponds to the string `1`, not `000001`.

For example, the string `HPA1` would be encoded as the number (17 × 36 × 36 × 36) + (25 × 36 × 36) + (10 × 36) + 1 = 825913.

The field is a signed, positive integer, allowing System IDs up to 2147483647 = `ZIK0ZJ`.

Stream ID : a unique 6-character label identifying the device, component and sample rate:

1	2	3	4	5	6
Device serial number				Component	Output tap

The 6-character label is encoded in 4 bytes as a base 36 number, in the same manner as the *System ID*, above.

Date code : The date and time when the data in the block begins, expressed as a 32-bit number where

- the bottom 17 bits are the time in seconds since midnight, normally between 0 and 86399 but possibly 86400 or 86401 in years with 'leap seconds'; and
- the top 15 bits are the Güralp day number, with day zero on 17 November 1989. The day number increments when the seconds number rolls over at midnight.

Data format : The final header element contains 4 bytes defining the format of the data in the block:

1	2	3	4
reserved	Sample rate	Compression code	Number of data records

Sample rate : The sample rate of the data records, an integer number of samples per second. If this field is zero, the block body contains status information in ASCII text format.

Compression code : A code for the compression format used for all the data in the block. Currently accepted values are

1	Data records contain one 32-bit difference
2	Data records contain two 16-bit differences
4	Data records contain four 8-bit difference

Other values are reserved for future expansion.

Number of data records : The number of 32-bit data records in the block. Combining this with the compression code enables you to find

out the total number of sample points in the block; dividing by the sample rate allows the time duration of the block to be determined. You should check for status blocks (which have *Sample rate* = 0) before performing this calculation. For status blocks, the number of characters is *Number of data records* × 4.

The block duration is always a whole number of seconds, and always starts on a whole second boundary. A data block has a maximum size of 1024 bytes. If the compression algorithm changes the compression format, blocks may appear which are not filled to the maximum capacity.

The rest of the block contains the data fields.

The GCF body

The body of a GCF block contains

- the absolute value of the first sample, a 32-bit signed integer referred to as the Forward Integrating Constant or FIC (this is not a data record, and is not counted in the *Number of data records*);

- a series of differences between following samples—32-bit, 16-bit or 8-bit signed integers according to the *Compression code*;

- the absolute value of the last sample, a 32-bit signed integer, referred to as the Reverse Integrating Constant or RIC. The RIC can be used as a checksum, as it should match the last decompressed sample value. It is not a sample in itself.

Because the value of the first sample is used as the FIC, the data record immediately after it is always zero.

Note: When data from a 24-bit digitizer is compressed into GCF blocks *and* the digitizer selects compression code 1 (32-bit data records) *and* the block is being transmitted over a serial link, the digitizer *may* truncate the 32 bit differences to 24 bits by omitting the top byte of each difference. This does not apply to true 32-bit data, even for blocks where the differences would fit into 24 bits.

This optimization is made purely to use the serial link more efficiently, and is not part of the GCF file format. When such data is stored on a disk or transmitted over a network using TCP or UDP, it must be expanded back to the full 32 bits.

Because 24-bit values have a range of 16 million (±8 million),

differences between them must be able to indicate ±16 million, which is 25 bits. However, the serial compression code discards the 25th bit. When decompressing the data, you will need to reconstitute this bit.

You can check that you have correctly reconstituted the sign bits by comparing the value you obtain at the end of the GCF block with the RIC.

Appendix A.2 Sending GCF streams over a network

GCF blocks can be embedded in TCP or UDP packets for transmission over a network to other Güralp instruments or computers running GCF-compatible software such as Scream!.

A GCF server is expected to understand control messages, and to respond with data as appropriate. This allows clients to start and stop data transfer and to request that any missing blocks be re-transmitted.

Initiating a connection

The default behaviour of a GCF server is to listen for UDP packets containing GCF commands. A client sends a command as a null-terminated string in a single UDP packet. The commands a client can issue are

GCFPING : acknowledge this packet;

GCFSEND:B : start sending data in big-endian ("network") byte order;

GCFSEND:L : start sending data in little-endian ("Intel") byte order;

GCFSEND : start sending data, in default byte order (Scream! interprets this as *GCFSEND:B*).

The server responds to any of these with a packet containing the string *GCFACKN*, again null-terminated.

A clients should continue issuing *GCFSEND* packets periodically while it still wants to be sent data. If a client does not issue a *GCFSEND* packet for a long period, the server will stop sending data to it.

If the server has active clients when it shuts down, it sends a packet containing the string *GCFNOSV* to all of the clients.

Data packets

Once the client has sent a *GCFSEND* packet, the server will start

sending it GCF blocks, each in a single UDP packet. There are two formats used, “Version 31” and “Version 40”.

Version 31 data packets

1024 octets – The GCF block as described above.

1 octet – The version number (decimal 31)

1 octet – The length of the following string, in octets

32 octets – A string describing the source of the data, padded to length 32 with zeros. The string takes the form STREAM-ID/COMxx/HOSTNAME where COMxx is the name of the serial port (COM1, etc.) and STREAM-ID is as in the GCF block (see above)

2 octets – The sequence number, in the byte order specified below (same as for data)

1 octet – A code for the byte order, 1 = big-endian (default), 2 = little-endian

Version 40 data packets

1024 octets – The GCF block.

1 octet – The version number (decimal 40)

1 octet – A code for the byte order as above

2 octets – The sequence number, in the byte order specified

1 octet – The length of the following string, in octets

48 octets – A string describing the data source, as above but padded to length 48 with zeros.

Recovering missing data

Because the UDP packets have sequence numbers, the client can detect when a packet has been lost. To recover this data, it initiates a TCP connection to the server, on the same port number. If the server accepts, the client sends a single-byte command to the server. The commands available are:

0xf9 (249) : Requests the server to use TCP only when communicating with this client. Subsequent GCF data packets will be sent over the active TCP connection, with the same format as the normal UDP

packets.

This feature is supported by the server in Scream! 4.0 and above.

0xfc (252) : Requests a version string, returned in PASCAL format (*i.e.* first octet = length, remainder = null-terminated string)

0xfe (254) : Requests the oldest sequence number held by the server. The sequence number is returned as 2 octets in big-endian byte order

0xff (255) sequence-number : Requests a block by sequence number. The block is returned on the TCP connection in one of the above formats. If the block is not available, the server returns `0xff 0xff 0xff 0xff`. The sequence number is 2 octets long, with big-endian byte order.

When the client has all the blocks it needs, it is free to close the connection.

Appendix A.3 Sending GCF streams over a serial link

Before it can be sent over a serial link, each GCF data block must be packaged in a 'transport layer', which consists of a 4-byte transmission header and a 2-byte checksum tail.

The transport layer

The transmission header consists of 4 bytes:

1	2	3	4
ASCII `G` (`0x47`)	Block sequence number	Block size (MSB)	Block size (LSB)

Block sequence number : An unsigned integer, which increments by 1 after each block, wrapping round to 0 from 255.

Block size : The size of the block in bytes, excluding the transmission header and checksum tail, but including the GCF block header.

After the transmission header, the GCF block is sent (with a length equal to the number of bytes specified in *Block Size*), followed by a two-byte checksum. This value is the sum of all bytes in the block header and body, modulo 65536, and is presented in big-endian byte

order.

To optimise the use of available transmitter bandwidth the transmitted data block is truncated to the actual data length. This reduction is only applied to the difference records - the first and last absolute values are still transmitted as 32 bit values.

ACK and NACK signals

After transmission of the block is complete, the transmitter waits a nominal 150 ms for either a *NACK* or *ACK* signal before starting to transmit the next block.

If it receives an *ACK*, transmission of the next block commences immediately. If *NACK* is received, the block is re-transmitted.

The receiver should read the block, calculate the data checksum, and compare that with the value sent in the transmission header. If the two values match, the receiver should send an *ACK* signal, otherwise a *NACK*.

ACK and *NACK* signals can be in two formats: (older) 2-byte and 6-byte. The 2-byte signal is simply the first 2 bytes of the 6 byte signal. When both the transmitter and receiver use the 6 byte version, the link is said to be operating BRP (Block Recovery Protocol), which allows recovery of lost data (from up to 255 blocks ago) as well as error correction on a per-block basis.

The format of an *ACK* or *NACK* message is

Byte	1	2	3	4	5	6
ACK	`0x01`	Stream ID LSB	`^S` (`0x13`) or `0`	Stream ID	Stream ID	Stream ID MSB
NACK	`0x02`	Stream ID LSB	Block number	Stream ID	Stream ID	Stream ID MSB

Stream ID should match the 4-byte stream ID of the last received block. Each system is able to identify its own *ACK* or *NACK* by matching this ID. 2-byte systems only match the least significant byte and ignore the rest.

For a *NACK* message, *Block number* specifies which block number to rewind to.

For an *ACK* message, the third byte is either unused (0), or `0x13` (Ctrl-

S) to switch to command mode.

DM24 digitiser units transmit data as complete blocks become available, without any flow control apart from *ACK* and *NACK*.

Appendix B Connector pinouts

This section details the pin assignments for each port on the surface interface unit. The *SENSOR* port has the same pin assignments as the output port of the downhole digitizer.

Appendix B.1 SENSOR port

This is a 32-way mil-spec plug (02E-19-32P).

Pin	Function
A	Weak-motion velocity +ve, vertical channel
B	Weak-motion velocity –ve, vertical channel
C	Weak-motion velocity +ve, N/S channel
D	Weak-motion velocity –ve, N/S channel
E	Weak-motion velocity +ve, E/W channel
F	Weak-motion velocity –ve, E/W channel
G	Strong-motion acceleration –ve, E/W channel
H	Strong-motion acceleration +ve, E/W channel
J	Strong-motion acceleration +ve, N/S channel
K	Strong-motion acceleration +ve, vertical channel
L	RS422 transmit +ve
M	RS422 receive +ve
N	RS422 1pps signal +ve
P	RS422 GPS signal +ve
R	RS422 GPS signal –ve
T	Hole lock motor
U	Hole lock motor return
V	Mass position, vertical channel
W	Mass position, N/S channel
X	Mass position, E/W channel
Y	Signal ground
Z	Strong-motion acceleration –ve, N/S channel
a	Strong-motion acceleration –ve, vertical channel
b	RS422 transmit –ve

c	RS422 receive –ve
d	RS422 1pps signal –ve
e	Digital ground
f	+48 V power
g	+48 V power
h	0 V power
j	0 V power

Appendix B.2 GPS port

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

Pin	Function
A	Power 0 V
B	Power +12 V
C	PPS
G	RS232 ground
J	RS232 transmit to GPS
K	RS232 receive from GPS

Appendix B.3 *DATA* port

This is a standard 6-pin mil-spec plug (02E-10-06P).

Pin	Function
A	RS232 transmit
B	RS232 receive
F	RS232 ground

Appendix B.4 RECORDER port

This is a 26-way mil-spec plug (02E-16-26P).

Pin	Function
A	Weak-motion velocity +ve, vertical channel
B	Weak-motion velocity –ve, vertical channel
C	Weak-motion velocity +ve, N/S channel
D	Weak-motion velocity –ve, N/S channel
E	Weak-motion velocity +ve, E/W channel
F	Weak-motion velocity –ve, E/W channel
G	Mass position, vertical channel
J	Mass position, N/S channel
L	Mass position, E/W channel
N	Signal ground
T	Strong-motion acceleration +ve, vertical channel
U	Strong-motion acceleration –ve, vertical channel
V	Strong-motion acceleration +ve, N/S channel
W	Strong-motion acceleration –ve, N/S channel
X	Strong-motion acceleration +ve, E/W channel
Y	Strong-motion acceleration –ve, E/W channel

Appendix B.5 HOLELOCK port

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

Pin	Function
F	Hole lock motor
K	Hole lock motor return

Applying a positive voltage to pin F will retract the jaw; applying a positive voltage to pin K will extend it. Retracting the jaw requires 0.4 – 0.5 A of current, whilst extending it consumes 0.25 – 0.3 A.

Through the hole lock switch supplied, you can connect the positive and negative pins of your power supply to the *HOLELOCK* port. You may need up to 50 V of power to drive the hole lock motor through 1 km of cable.

Appendix C Specifications

Appendix C.1 Velocity components

Sensors	Velocity output bandwidth	*spec* – 50 Hz*
	Mass position output	DC – *spec* Hz*
	Velocity sensitivity	2 × 1000 V/m/s**
	Mass position sensitivity	1000 V/m/s^2
Controls	Mass locking and unlocking	remotely operated
	Mass centring	automatic, microprocessor controlled
Mechanics and electronics	Sensors	3 orthogonal sensors in levelling gimbals
	Lowest spurious resonance	above 140 Hz
	Sensor transducer type	capacitive displacement
	Feedback transducer type	magnet/coil

Appendix C.2 Acceleration components

Outputs and response	Output response	2 *g*
	Dynamic range at 2 *g*	standard
	Dynamic range, 0.005 – 0.05 Hz	< 140 dB
	Dynamic range, 3 – 30 Hz	< 127 dB
	Standard frequency band	DC – 100 Hz (–3dB point)
	Linearity	0.1 % of full scale
	Cross-axis rejection	0.001*g* / *g*

Appendix C.3 Combined system

Power	Supply requirements	11 – 36 V DC
Physical	Connectors	pressure tight, waterproof
	Temperature range with masses locked	–20 to +75 °C
	Operational temperature range	–10 to +65 °C

Appendix C.4 Digitizer 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	supplied through *GPS* connector
	Time format	NMEA
	Max. cable length	50 m
Sensor control	Functions available	Lock, unlock, and centre sensor (active low CMOS); enable calibration
Sensor calibration	Types	Sine and square wave; adjustable amplitude and frequency

Digital signal processing	Type	Texas TMS320CV33
	Hardware sampling rate	2 KHz
	Sample output rates	6 cascaded rates, each 2, 4, or 5 times lower than the previous rate (even integers only)
	Anti-aliasing filters	2 pole
	Low-pass filters	FIR
	Out-of-band rejection	140 dB
	In-band ripple	–140 dB
	Trigger modes	STA/LTA, threshold, external trigger
Digitizer 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	5^{th}-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	$<50\ \mu s$
Power	Supply	+10 – +36 V DC or 110 – 230 V AC
	Current at 12 V DC	~0.12 A