Fortis

Technical Manual

Document No. MAN-FOR-0001

Issue H, June 2018

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

Table of Contents

1 Preliminary Notes....................4
1.1 Proprietary Notice....................4
1.2 Warnings, Cautions and Notes....................4
1.3 Manuals and Software....................4

2 Introduction....................5

3 Fortis[PH] - the Post-hole Fortis....................7

4 Getting started....................9
4.1 Unpacking and packing....................9
4.2 Initial testing....................9
4.3 Setting the gain....................10
4.3.1 To adjust the gain using the switch....................10
4.3.2 To adjust the gain using a Güralp Minimus digitiser....................11
4.3.3 To adjust the gain using the control lines....................13
4.3.4 Gain interaction....................13
4.4 Output polarity....................14

5 Installation....................16
5.1 Permanent installations....................16
5.2 Temporary installations....................17
5.3 Installation in Hazardous environments....................18

6 Accessories....................19
6.1 The Break-out Box....................19
6.2 The hand-held control unit....................20

6.2.1 Signal meter....20
6.2.2 Calibration....21
6.2.3 Centring (offset-nulling)....21
6.2.4 Open-loop response....21
6.2.5 4 mm terminal posts (“banana” sockets)....22

7 Calibration....23

7.1 Absolute calibration....23
7.2 Relative calibration....23
7.3 Calibrating the Fortis....24
7.3.1 Broadband Noise calibration using Scream....24
7.3.2 Open-loop calibration....27
7.3.3 Calibration with third-party digitisers....27
7.4 The calibration pack....28
7.4.1 The calibration sheet....28
7.4.2 Frequency response....28
7.4.3 Obtaining copies of the calibration pack....28

8 Connector pin-outs....30

8.1 Fortis instrument connector....30
8.2 Fortis^{PH} instrument connector....31
8.3 Break-out box and HCU power connector....32

9 Revision History....33

1 Preliminary Notes

1.1 Proprietary Notice

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

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

1.2 Warnings, Cautions and Notes

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

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

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

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

1.3 Manuals and Software

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

2 Introduction

The Güralp Fortis is a three-axis, strong-motion, force-feedback accelerometer with an innovative, slim-line design for fast installation in any environment. The system has a flat response to ground acceleration from DC to 100 Hertz and a stable phase response within the passband.

Extremely low noise, a high dynamic range and switchable gain allow the instrument to perform optimally in a wide range of scenarios, providing versatility for all EEW (earthquake early warning) and structural health monitoring applications.

The hard-anodised aluminium casing protects the instrument from water, allowing it to be deployed in a range of environments. Installation is simple, using a single fixing bolt to attach the sensor to a hard surface. If required, you can also level the sensor using its adjustable levelling feet. An integrated bubble-level provides quick visual feedback.

Each accelerometer is delivered with a detailed calibration sheet showing its serial number, measured frequency response, sensor DC calibration levels and the transfer function in poles/zeroes notation.

Optionally, you can use a Güralp Hand-held Control Unit (HCU) and/or breakout box to distribute power and calibration signals to the sensor and to receive the signals it produces. The HCU is available in standard, rack-mounted and water-resistant portable formats.

A version designed for post-hole deployments, the Fortis^{PH}, is also available. See chapter 3 on page 7 for details.

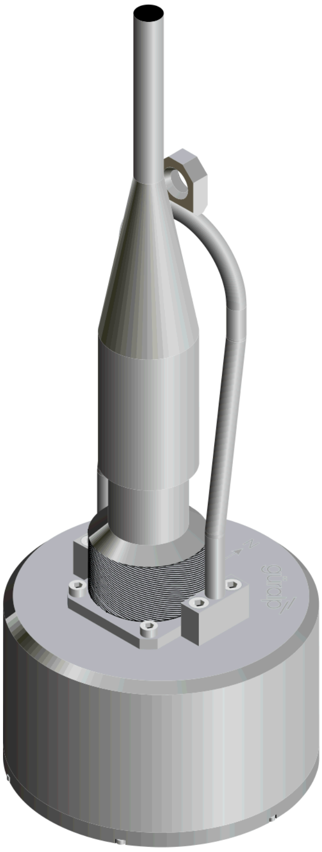
3 Fortis^{PH} - the Post-hole Fortis

The Fortis accelerometer is also available in borehole-specific packaging. This variant is called the Fortis Post-hole, or Fortis^{PH}. The components and electronics inside the sensor are identical to the surface module: the only difference is in the external casing and the connector, which is water-proof to 100 Bar (equivalent to 10 MPa or 1500 psi). See section 8.2 on page 31 for pin-out details.

Note: The Fortis^{PH} is not fitted with the bubble level, adjustable feet, engraved switch and pointers.

The Fortis^{PH} is 125 mm in diameter and 78 mm tall, excluding the connector. An engraved arrow on the top of the casing indicates direction in which the North/South component of the sensor should be oriented.

Four tapped holes in the lid, situated around the connector, allow the attachment of a lifting bail. The bail is cranked to allow easy access to the connector. When fitted, the top of the bail is around 290 mm above the bottom of the instrument.



Like the Fortis, the centring function allows installation of the accelerometer at up to around 10 degrees of inclination from the vertical axis. When the Fortis^{PH} is powered-up, a centring command is executed automatically in order to null any offset. The centring command can also sent via software from the Minimus' web-page, using the control in the Setup tab ("Centre Mass" button).

Analogue Sensors							
Selection							
MILSPEC 26W Connector	ANALOGUE 0 ▾						
Analogue to Digital Converter							
Input gain	x1.0 ▾	Input range	+/- 20.48 V	Input resolution	2.441 uV/count		
Identification							
Sensor type	Guralp Fortis ▾						
Response							
Fortis Range	-0.5g; +0.5g ▾	Fortis Loop	Open ▾				
Mass Centring							
Centre Mass		Mass Readout Z	-0.00375 V	Mass Readout N	-0.00312 V	Mass Readout E	-0.00375 V
Calibration							
DAC Source	Off ▾	DAC Level	100% ▾	Output Stream	Normal ▾	Calibration Signal	Disabled ▾

The physical switch used in the Fortis to set the gain is not accessible in the Fortis^{PH}. The gain is set at ±4 g by default but it is still possible to change the gain from the Minimus digitiser web page (see the Minimus manual, MAN-MIN-0001).

4 Getting started

4.1 Unpacking and packing

The Fortis is delivered in environmentally-friendly, flat-packable, suspension packaging. The packaging is specifically designed for the Fortis and should be re-used whenever you need to transport the sensor. Please note any damage to the packaging when you receive the equipment and unpack on a clean surface. The package should contain the accelerometer, the calibration pack and either a connection cable, if ordered, or a 19-pin line-socket, to which you can terminate your own cabling.

Caution: Although the Fortis is a strong motion instrument, it contains sensitive mechanical components which can be damaged by mishandling. If you are at all unsure about the handling or installation of the device, you should contact Güralp Systems for assistance.

- Do not bump or jolt any part of the sensor when handling or unpacking.
- Do not kink or walk on the data cable (especially on rough surfaces such as gravel), nor allow it to bear the weight of the sensor.
- Do not connect the instrument to power sources except where instructed.
- Never ground any of the output signal lines from the sensor.

4.2 Initial testing

Pre-installation testing is most easily accomplished with a Güralp Hand-held Control Unit (HCU) (see section 6.2 on page 20), which allows access to each individual output and input, but you can quickly assemble a test-rig using a spare connector and a screw-clamp connector block. You will need a DC power supply capable of providing over 100 mA at between 10 and 36 Volts and, if you are not using an HCU, a voltage meter which can measure in ± one-Volt and ± ten-Volt ranges.

1. Ensure the gain is set to ×2 (i.e. ±2 g full scale - see section 4.3 on page 10). This is the default configuration from the factory.
2. Place the Fortis on a flat, horizontal surface, connect the power supply, observing the correct polarity, and switch on.
3. Connect the voltmeter between pins B and A - the differential output of the vertical component – see Section 8 on page 30 for connection details. The steady output voltage should be about zero (± 10 mV).

4. Repeat the measurement for the N/S and E/W outputs.
5. Now turn the sensor on its side, propping it carefully to stop it rolling.
6. The vertical output should now read about –5 V, corresponding to –1 g
7. Rotate the Fortis until the “N” indication arrow points vertically upwards.
8. The North/South output should now read +5 V, corresponding to +1 g.
9. Rotate the Fortis until the “N” indication arrow points horizontally.
10. The East/West output should now read +5 V.

If the performance so far has been as expected, the instrument may be assumed to be in working order and you may proceed to install the unit for trial recording tests. In many cases, there will be a slight offset to the readings – this can be disregarded.

4.3 Setting the gain

The gain of the Fortis can be controlled by a rotary switch, recessed into the base of the instrument, by a configuration setting on the web page of a Güralp Minimus digitiser, or by selectively grounding none, one or both of two control lines, exposed on the main instrument connector.

Pin-out details for the connector are given in Section 8 on page 30.

Note: The Fortis is delivered from the factory with the gain-setting switch in position 2. This results in a full-scale output corresponding to ±2 g.

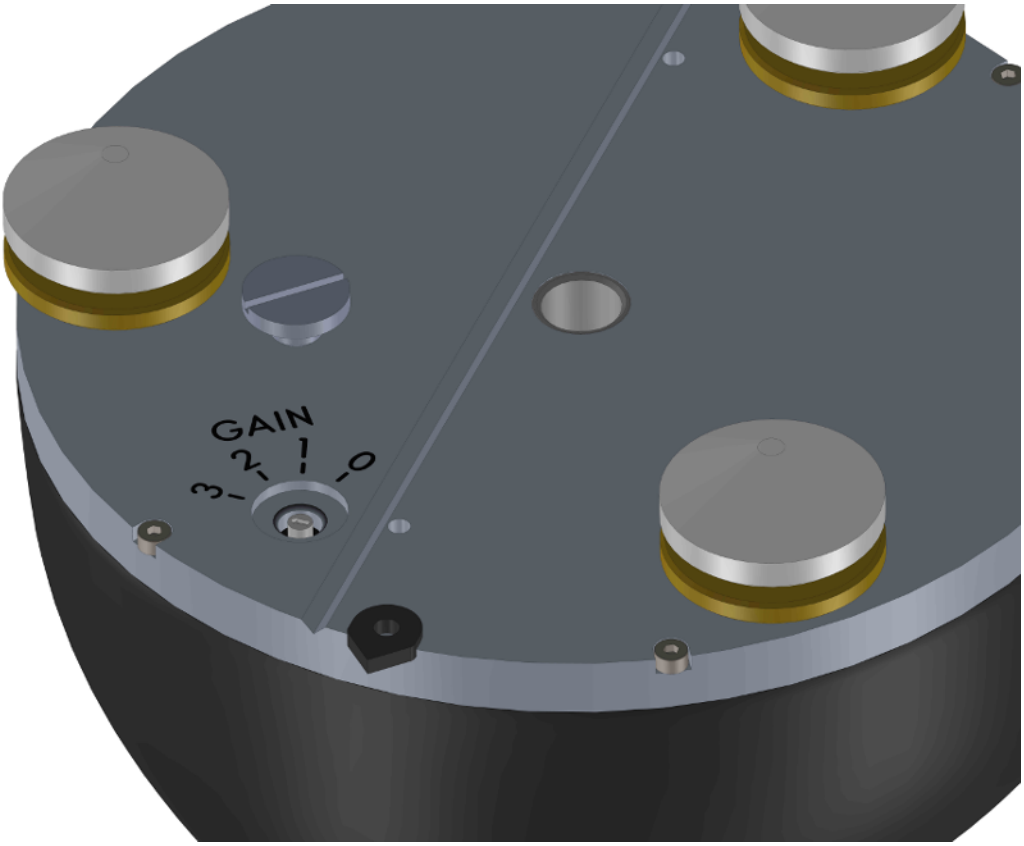
4.3.1 To adjust the gain using the switch

1. Remove the cover screw using a large, flat-bladed screwdriver.

Warning: Instruments are assembled at sea-level. If you are working at altitude, there may be a considerable pressure differential between the outside and the inside of the casing. Take care that the screw does not fly off, which may cause injury.

2. Using a small, flat-bladed screwdriver, turn the exposed switch to one of the four marked positions, as specified in the table below.

Switch position	Amplifier gain	Full-scale (g)
0	8	0.5
1	4	1
2	2	2
3	1	4



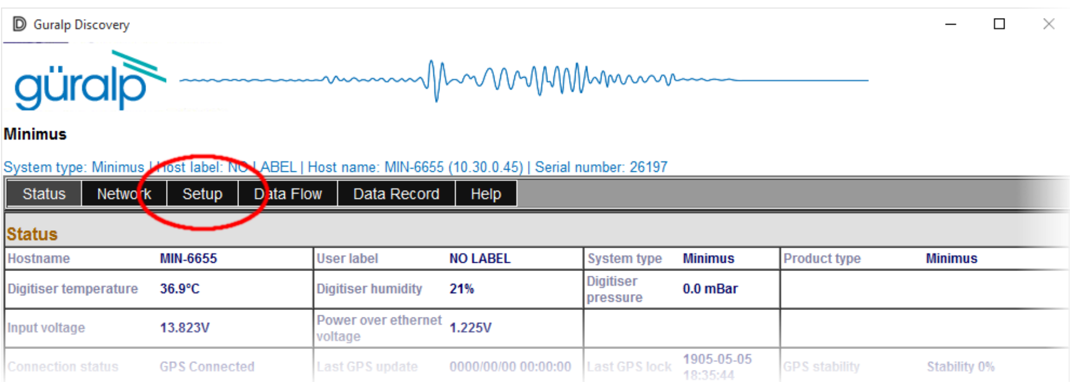
3. Check the cover screw, the 'O'-ring and the mating face on the base of the instrument for any dirt or contamination which may compromise the seal. Clean if necessary.

4. Replace the cover screw.

> **Caution:** Do not over-tighten the cover screw because this can damage the 'O'-ring seal.

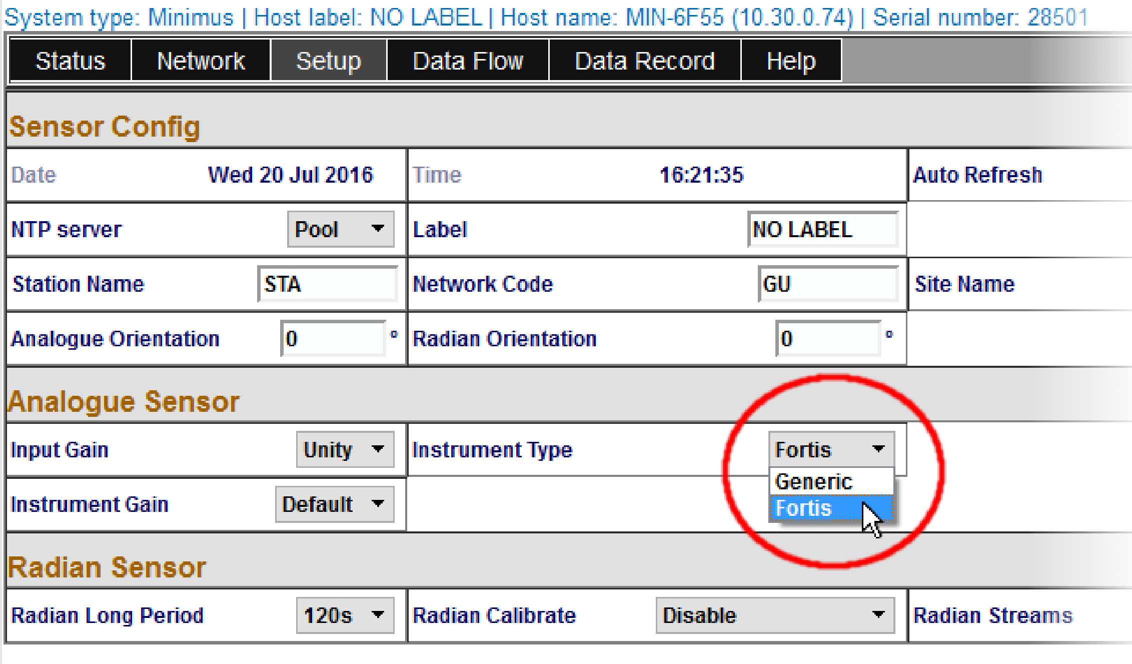
4.3.2 To adjust the gain using a Güralp Minimus digitiser

Ensure that the switch is set to position three and then open the web page of the Minimus. Click the Setup tab:

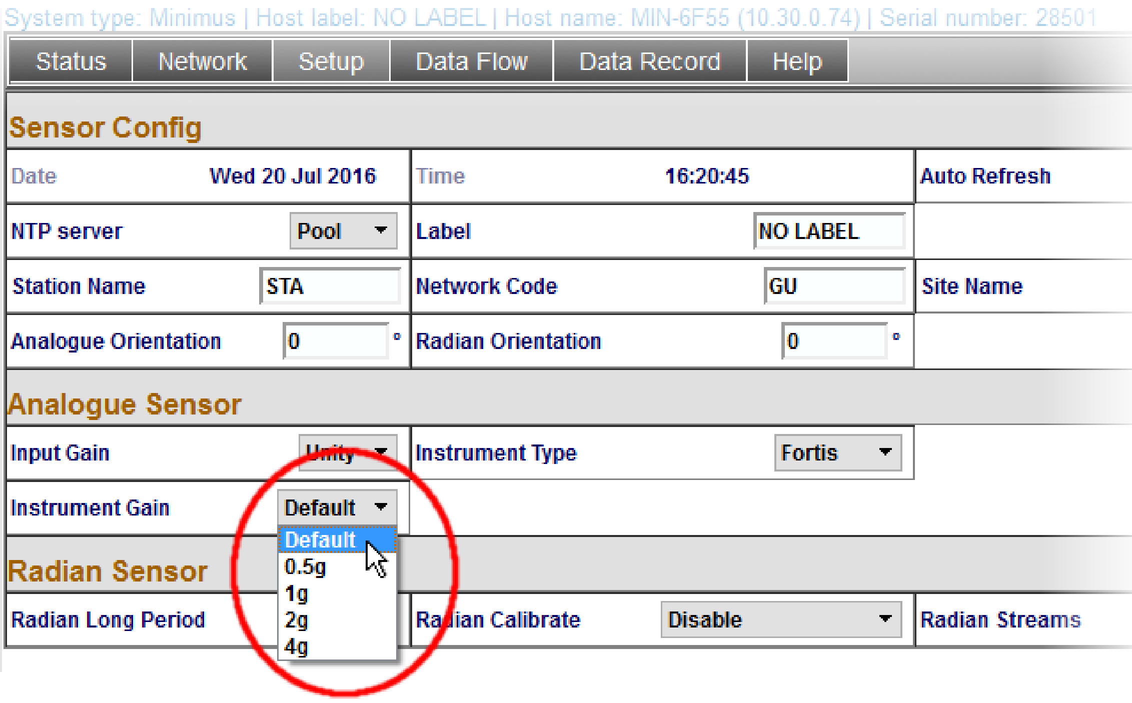


Ensure that the **Instrument Type** drop-down menu is set to Fortis…

Minimus



… then select the desired gain from the **Instrument Gain** drop-down menu:



The new setting takes effect immediately.

Note: This technique only works correctly if the physical gain-control switch on the instrument is set to position three (3).

4.3.3 To adjust the gain using the control lines

1. Ensure that the gain-selection switch is set to position '0', as described in the previous section;
2. Consult the table below to choose whether each of "Select 0" and "Select 1" should be "high" or "low".

Select 0	Select 1	Amplifier gain	Full-scale (g)	Equivalent switch position
low	**low**	8	0.5	0
low	**high**	4	1	1
high	**low**	2	2	2
high	**high**	1	4	3

3. Pins that are to be "high" should be left floating – i.e. not connected at all. An internal resistor pulls the corresponding line up to a positive voltage. Pins that are to be "low" should be grounded by connecting them to pin N.

Pin-out details are given in Section 8 on page 30.

4.3.4 Gain interaction

Güralp do not recommend attempting to use more than one gain control method simultaneously. The following information is provided for completeness only.

The gain control switch acts directly on the two gain control lines, "Select 0" and "Select 1", grounding neither, one or both as appropriate. The following table shows the effect of using both the physical switch on the instrument and the control lines at the same time.

Switch	Select 0	Select 1	Amplifier Gain	Full-scale (g)	?
3	**high**	**high**	1	4	✓
	high	**low**	2	2	✓
	low	**high**	4	1	✓
	low	**low**	8	0.5	✓
2	**high**	**ignored**	2	2	?
	low		8	0.5	?
1	**ignored**	**high**	4	1	?
		low	8	0.5	?
0	**ignored**	**ignored**	8	0.5	?

The following table shows the effect of using the physical switch on the instrument and the web page of a Güralp Minimus digitiser simultaneously:

Switch	Minimus (web) setting	Amplifier Gain	Full-scale (g)	?
0	**ignored**	8	0.5	?
1	**Unity**	4	1	✗
	×2	8	0.5	✗
	×4	4	1	✓
	×8	8	0.5	✓
2	**Unity**	2	2	✗
	×2	2	2	✓
	×4	8	0.5	✗
	×8	8	0.5	✓
3	**Unity**	1	4	✓
	×2	2	2	✓
	×4	4	1	✓
	×8	8	0.5	✓

4.4 Output polarity

The polarity of output from each component of the instrument is as follows:

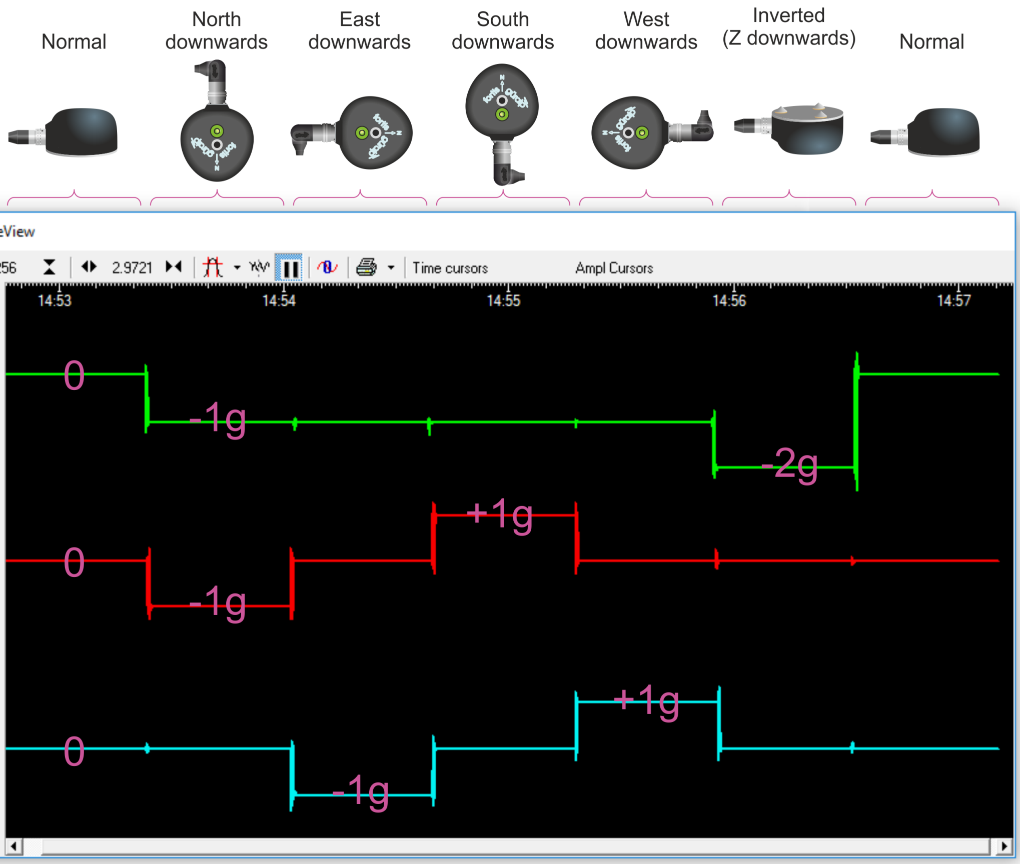
Direction of ground acceleration	Polarity of Z output	Polarity of N/S output	Polarity of E/W output
Upwards	**positive**	zero	zero
Downwards	**negative**	zero	zero
Northwards	zero	**positive**	zero
Southwards	zero	**negative**	zero
Eastwards	zero	zero	**positive**
Westwards	zero	zero	**negative**

If the ground accelerates northwards, this moves the casing of the instrument northwards and the N-axis inertial mass is left behind. From the instrument's frame of reference, the mass appears to have been deflected southwards. The feedback system then needs to provide a balancing force to accelerate it northwards and this, by design, will result in a positive output signal from the N/S component.

If the instrument is mounted with the 'N' arrow pointing downwards, gravity will try and pull the inertial mass in the direction of the instrument's N-axis. The feedback system then needs to provide a balancing force to accelerate it upwards which, from the instrument's frame of reference, is now southwards. This is the opposite of the situation described above, so the output from the N/S component will now be negative.

The converses are also true: if the ground accelerates southwards, the instrument will produce a negative output signal from the N/S component and if the instrument is orientated with it's 'N' arrow pointing upwards, it will produce a positive output signal from the N/S component

The polarity of the output signals with respect to acceleration can be demonstrated by selecting a sensitivity of 1 g, 2 g or 4 g and orientating the instrument as shown in the following diagram:



5 Installation

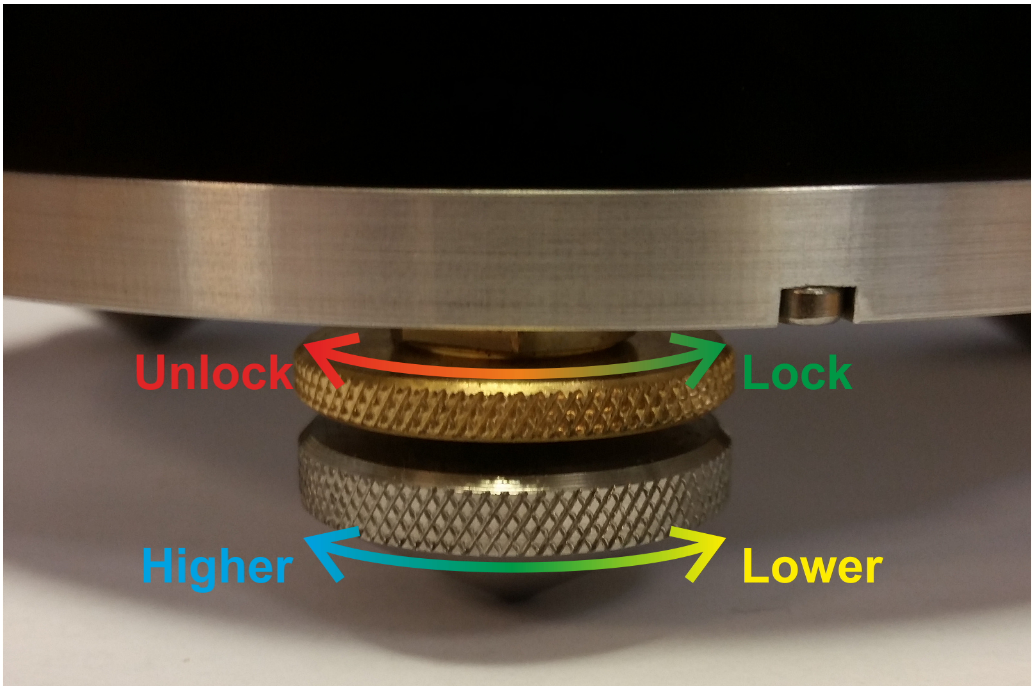
5.1 Permanent installations

You will need a hard, clean surface such as a concrete floor, to install the Fortis.

If you are in any doubt about how to install the sensor, you should contact Güralp Systems' Technical Support, via support@guralp.com.

1. Prepare the surface by scribing an accurate N/S orientation line and installing a grouted-in fixing bolt on the line, near the middle. A 6mm (0.25 inch) threaded stud is suitable, as is an expanding-nut rock bolt or anchor terminating in a threaded stud. The bolt should be about 120mm (5 inches) long.
2. Place the accelerometer over the fixing bolt and rotate to bring the orientation line and pointers accurately into registration with the scribed base-line.

   For more accurate alignment, a long, thin rod or a length of stiff wire can be aligned with a slot machined into the base of the instrument. It can be held in place by hand or, if preferred, by inserting two 3mm screws into the threaded holes provided.
3. Level the sensor, using its adjustable feet, until the bubble lies entirely within the inner circle of the level indicator.

   The feet are mounted on screw threads. To adjust the height of a foot, turn the brass locking nut clockwise to loosen it and rotate the entire foot so that it screws either in or out. When you are happy with the height, tighten the brass locking nut anti-clockwise to secure the foot.

4. Secure the instrument to the mounting stud using a nut and a spring washer.

   Caution: Do not over-tighten: the nut only needs to retain the instrument in place – not compress or deform it.

5. Connect a Güralp sensor cable between the instrument and your Güralp Affinity or other Güralp digitiser.

   Alternatively: connect a Güralp "pig-tail" cable between the instrument and your own recording equipment, using the pin-out details in Section 8 on page 30.

6. Power on the digitiser.

The instrument is now installed and transducing ground motion.

5.2 Temporary installations

The Fortis is ideal for monitoring vibrations at field sites, owing to its ruggedness, high sensitivity and ease of deployment. Temporary installations will usually be in hand-dug pits or machine-augered holes. Once a level base is made, the accelerometer can be sited there and covered with a box or bucket. One way to produce a level base is to use a hard-setting liquid:

1. Prepare a quick-setting cement/sand mixture and pour it into the hole.
2. "Puddle" the cement by vibrating it until it is fully liquefied, allowing its surface to level out.
3. Follow the cement manufacturer's instructions carefully. Depending on the temperature and type of cement used, the mixture will set over the next 2 to 12 hours.
4. Install the sensor as above, then cover and back-fill the emplacement with soil, sand, or polystyrene beads.
5. Cover the hole with a turf-capped board to exclude wind noise and to provide a stable thermal environment.

If you prefer, you can use quicker-setting plaster or polyester mixtures to provide a mounting surface. However, you must take care to prevent the liquid leaking away by "proofing" the hole beforehand. Dental plaster, or similar mixtures, may need reinforcing with sacking or muslin.

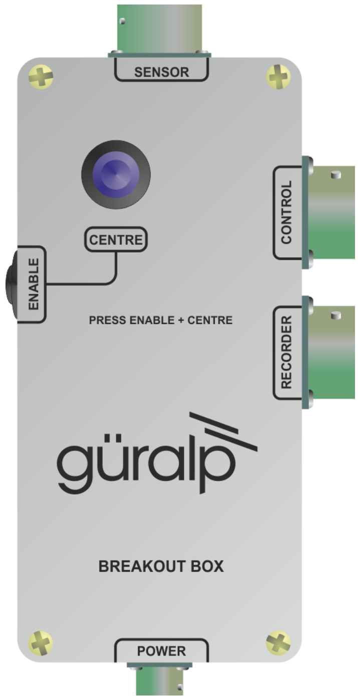
5.3 Installation in Hazardous environments

The fully enclosed, aluminium case design of the Fortis makes it suitable for use in hazardous environments where electrical discharges due to the build up of static charge could lead to the ignition of flammable gasses. To ensure safe operation in these conditions, the metal case of the instrument must be electrically bonded ('earthed') to the structure on which it is mounted, forming a path to safely discharge any static charge.

Where electrical bonding ('earthing') is required during the installation of a Fortis, the central mounting hole that extends through the instrument should be used as the connection point. This is electrically connected to all other parts of the sensor case. Connection can be made by either a cable from a local earthing point terminated in a 8mm ring tag or via the mounting bolt itself.

6 Accessories

6.1 The Break-out Box



The Fortis can be supplied with an optional Break-out Box (BoB). This is a small, passive device which simplifies the operation of the Fortis when used with third-party digitisers or when frequent local centring is required, as with some mobile structures.

The Fortis uses the same BoB as Güralp 5TC, 5TB and 40T instruments.

The Break-out Box has three 26-way bayonet connectors wired identically. These are labelled, SENSOR, CONTROL and RECORDER. A fourth connector, a 10-way bayonet labelled POWER, is wired in parallel with the power supply lines of the other connectors and can be used to provide power for the instrument in situations where the digitiser does not provide power.

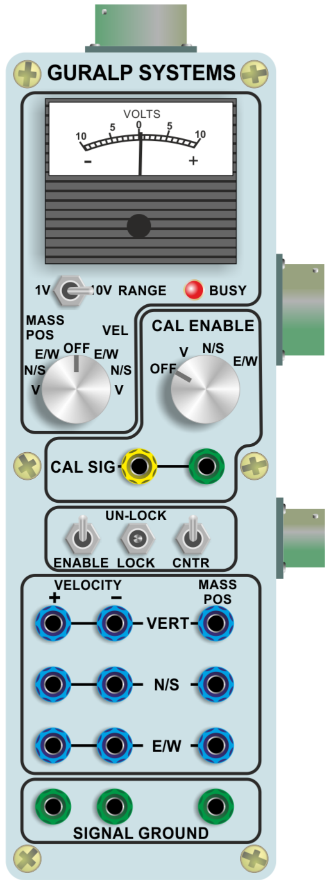
The Break-out Box is equipped with two buttons, marked ENABLE and CENTRE. Pressing both simultaneously for more than five seconds initiates the centring function (offset-nulling) in the instrument. They are wired in series so that the ENABLE button functions as a safety interlock to prevent accidental activation of the CENTRE button.

The Break-out Box can be permanently connected in-line between the Fortis (SENSOR connector) and the digitiser (RECORDER connector). This leaves the CONTROL connector free. A hand-held control unit (see section 6.2 on page 20) can be temporarily connected here in order to measure the instrument's outputs using the built-in analogue volt-meter, if required.

The pin-out for the SENSOR, CONTROL and RECORDER connectors is identical to that for the Fortis itself and is given in Section 8.1 on page 30.

The pin-out for the POWER connector is given in Section 8.3 on page 32.

6.2 The hand-held control unit



The Fortis can be supplied with an optional Hand-held Control Unit (HCU). This is a portable device which provides easy access to the accelerometer's outputs and calibration controls as well as displaying the output acceleration on an analogue meter. It can also be used as a convenient way to power the instrument when used with a digitiser which does not provide a suitable power supply.

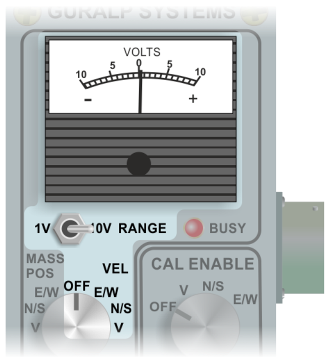
The Fortis utilises the same HCU as Güralp 3-series instruments but there are a few differences in the way the device is operated.

The output from the Fortis is acceleration, not velocity, and the instrument does not have mass position outputs. To view the acceleration output, put the main selection switch in one of the three 'VEL' positions.

Note: The Fortis does not have mass position outputs so the meter will not be active if the switch is in any of the 'MASS POS' positions.

Because the Fortis does not have mass-locks or mass position outputs, some parts of the HCU should be ignored.

6.2.1 Signal meter



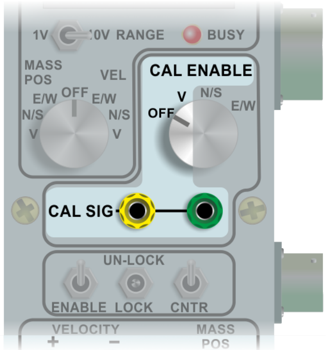
The upper section of the HCU contains a simple voltmeter for monitoring the signals from the instrument.

To monitor the outputs, the dial should be set to V, N/S or E/W in the VEL range.

You can set the range of the meter with the RANGE switch. When switched to 10 V, the meter ranges from –10 to + 10 V (as marked.) When switched to 1 V, the range is between –1 and +1 V.

Note: The V, N/S and E/W MASS POS settings are not applicable to the Fortis. The meter will not be active if any of these 'MASS POS' positions are selected.

6.2.2 Calibration



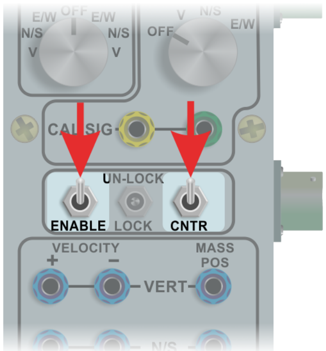
You can calibrate a Fortis through the HCU by connecting a signal generator across the yellow and green CAL SIG inputs and setting the CAL ENABLE switch to the "V" position. The sensor's response can now be monitored or recorded and calibration calculations carried out. See Section 7 on page 23 for more details.

Note: All three components will be calibrated simultaneously when the CAL ENABLE switch is in the "V" position.

Caution: Do not set the CAL ENABLE switch to either the N/S or the E/W positions. Depending on the setting of the gain switch (see section 4.3.1 on page 10), doing so may change the instrument's gain.

After calibrating, switch the CAL ENABLE switch back to the OFF position.

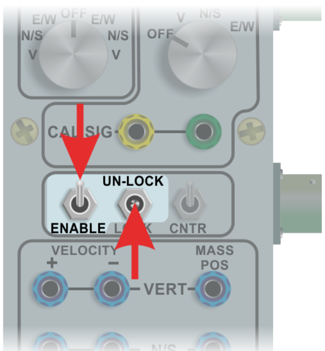
6.2.3 Centring (offset-nulling)



The next section of the HCU contains three toggle switches, marked ENABLE, UNLOCK/LOCK and CNTR. The Fortis has an automatic offset-nulling facility which can be operated by holding both the ENABLE switch and the CNTR switch down for five seconds. If the signal meter select switch is in any of the VEL positions and the RANGE switch is in the 1 V position, a series of centring pulses will be visible until the operation is complete complete.

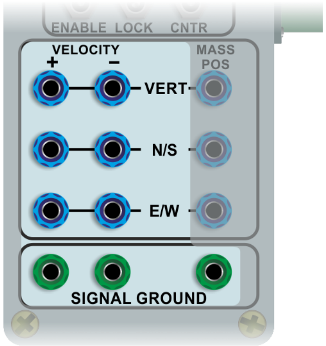
Note: The red LED marked BUSY (on the right, beneath the meter) is not used by the Fortis and should be ignored.

6.2.4 Open-loop response



The Fortis can be temporarily placed into open-loop mode by holding the ENABLE switch down while simultaneously holding the UNLOCK/LOCK switch in the UNLOCK position. Releasing either switch immediately returns the instrument to normal (feedback) mode. When in open-loop mode, the instrument will react much more quickly to changes in its orientation during, e.g., physical levelling.

6.2.5 4 mm terminal posts ("banana" sockets)



Beneath the switches are 4 mm terminal post connections, also known as "banana sockets" for each of the signal output lines from the instrument, for attaching to your own equipment as necessary.

Only the left-hand two columns of blue connectors, marked "VELOCITY", "+" and "-" and the green "SIGNAL GROUND" connectors are relevant to the Fortis. The connectors marked "VELOCITY", "+" and "-" are connected to the differential acceleration outputs. For single-ended use, use only the "+" connectors, together with a green SIGNAL GROUND connector, (all of which are equivalent).

7 Calibration

The Fortis is supplied with a comprehensive calibration document and it should not normally be necessary to calibrate it yourself. However, you may want to check that the response and output signal levels of the sensor are consistent with the values given in the calibration document.

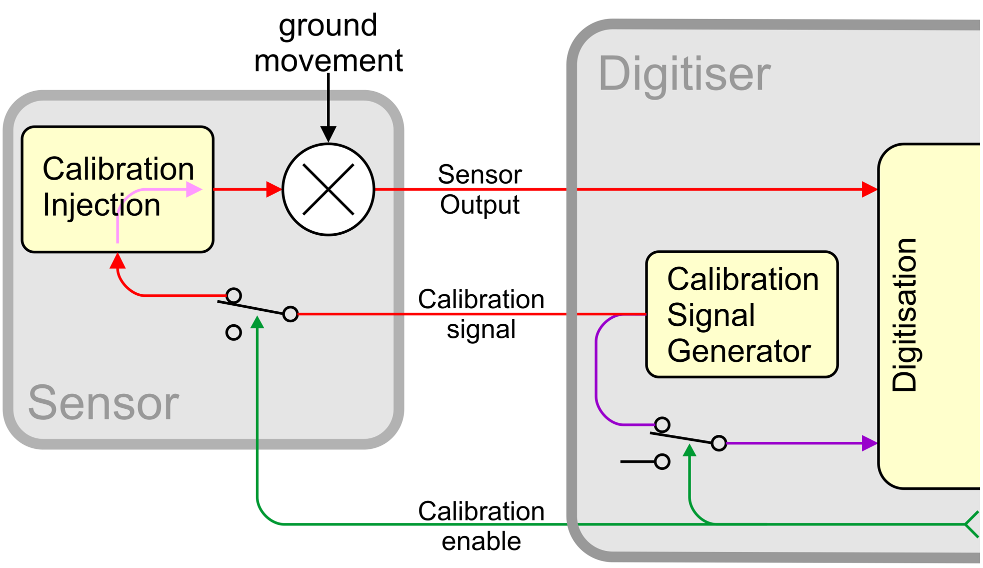
7.1 Absolute calibration

The sensor's response (in V/ms^{-2}) is measured at the production stage by tilting the sensor through 90 ° and measuring the acceleration due to gravity. In addition, sensors are subjected to the “wagon wheel” test, where they are slowly rotated about a horizontal axis. The output of the sensor traces out a sinusoid over time, which is calibrated at the factory to range smoothly from 1 g to –1 g without clipping.

7.2 Relative calibration

The response of the sensor, together with several other variables, is measured at the factory. The values obtained are documented on the sensor's calibration sheet. Using these, you can convert directly from voltage (or counts, as measured in Scream!) to acceleration values and back. You can check any of these values by performing calibration experiments.

Güralp sensors and digitisers are calibrated in the following way:



In this diagram, a Güralp digitiser is being used to inject a calibration signal into the sensor. This can be either a sine wave, a step function or broad-band noise, depending on your requirements. As well as going to the sensor, the calibration signal is returned to the digitiser.

The signal injected into the sensor gives rise to an equivalent acceleration, which is added to the measured acceleration to provide the sensor output. Because the injection circuitry can be a source of noise, a “Calibration enable” line from the digitiser is provided, which disconnects the calibration circuit when it is not required. The Calibration Enable line must normally be allowed to float high. To enable calibration, the Calibration Enable line should be connected to ground.

Note: Instruments can be supplied where this logic is reversed. This is known as “active-high” logic. For active-high instruments, the Calibration Enable line should normally be grounded and only allowed to float high during calibrations.

Fortis instruments are tuned at the factory to produce -1 V of output for +1 V input on the calibration channel. For example, a Fortis with gain set to unity (4 g full-scale) has an acceleration response of 0.25 V/ms^{-2} so it should produce -1 V output given a 1 V calibration signal (i.e. polarity-reversed), corresponding to 1/0.25 = 4 ms^{-2} = 0.408 g of equivalent acceleration.

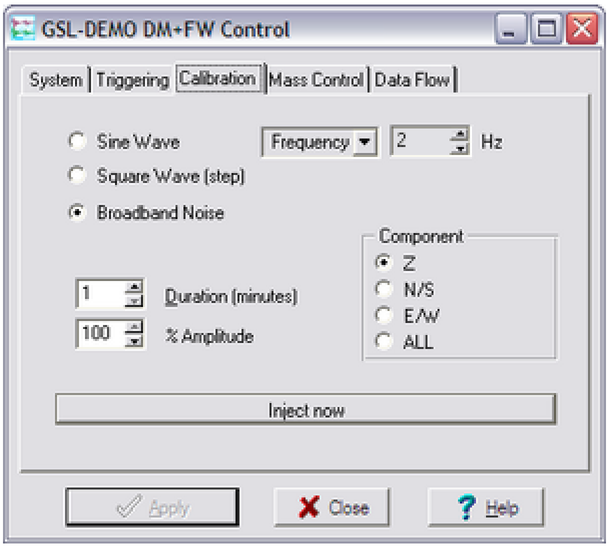
7.3 Calibrating the Fortis

Both the DM24 digitiser and Scream! software allow direct configuration and control of any attached Güralp instruments. For full information on how to use a DM24 series digitiser, please see its own documentation.

7.3.1 Broadband Noise calibration using Scream

To calibrate using Scream! and a Güralp digitiser:

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



2. Select “Broadband Noise” as the calibration type and, under Component, select “Z”. This will calibrate all three components simultaneously.

> **Note:** The Fortis has a single Calibration Line for all three components. Choices other than 'Z' will have undesired results.

3. Make any other choices you require and click Inject now. A new data stream, ending C*n* (where *n* is an integer in the range 0 – 7) or MB, should appear in Scream!'s main window. This contains the returned calibration signal.

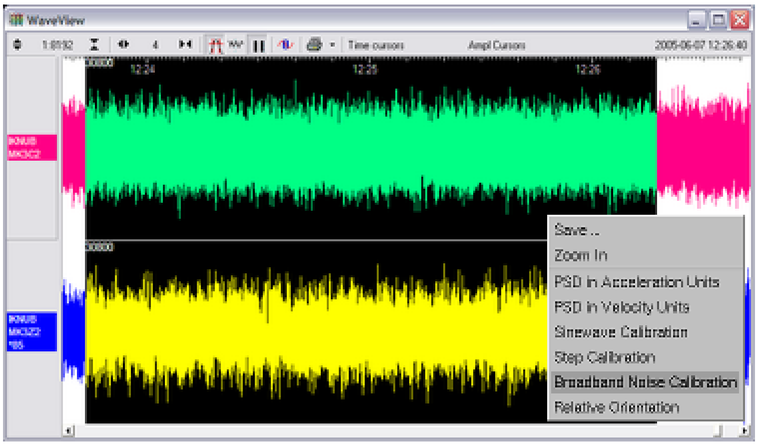
4. Open a WaveView window on the calibration signal and the returned streams by selecting them and double-clicking. The streams should display the calibration signal combined with the sensors’ own measurements. If you cannot see the calibration signal, zoom into the WaveView using the scaling icons at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

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

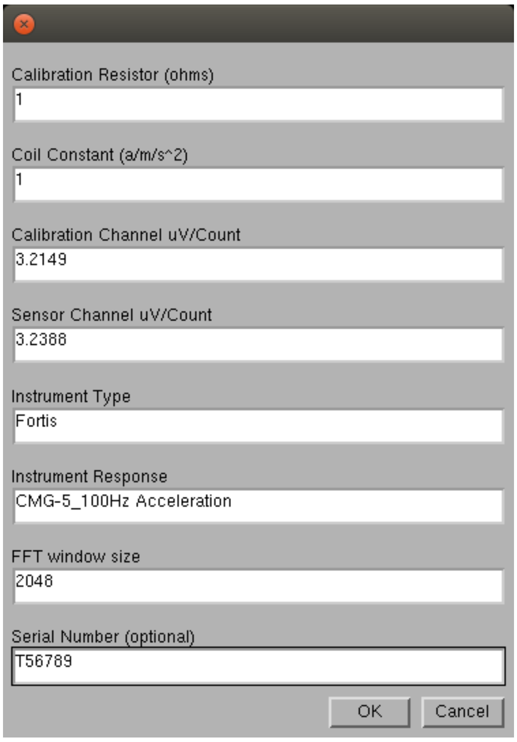
6. If you need to scale one, but not another, of the traces, right-click on the trace and select Scale…. You can then type in a suitable scale factor for that trace.

7. Pause the WaveView window by clicking on the icon.

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



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



10. Fill in the form as follows:
    1. "Calibration Resistor" should be set to 1
    2. "Coil Constant" should be set to 1
    3. The "Calibration Channel" sensitivity can be found on the calibration sheet for your digitiser.
    4. The "Sensor Channel" sensitivity for the appropriate axis can be found on the calibration sheet for your digitiser.
    5. "Instrument Type" should be set to "Fortis".
    6. "Instrument response" should be set to `CMG-5_100Hz Acceleration`
    7. The Number of FFTs is calculated automatically and need not normally be overwritten.
    8. The serial number can be filled in if desired: it is printed on the resulting graph.
11. Click OK. The script will return with a graph showing the response of the sensor in terms of amplitude and phase plots for each component. The accuracy of the results depends on the amount of data you have selected, and its sample rate. To obtain good-quality results at low frequency, it will save computation time to use data collected at a lower sample rate; although the

same information is present in higher-rate streams, they also include a large amount of high-frequency data which may not be relevant to your purposes.

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

The duration should be long enough to capture many periods of the lowest-frequency signal of interest. As a guide, allow one minute for each second of the lowest frequency for which you want accurate results. If, for instance, you are analysing signals with a period of 30 seconds, calibrate for at least half an hour.

If you prefer, you can inject your own signals into the system at any point (together with a Calibration enable signal, if required) to provide independent measurements and to check that the voltages around the calibration loop are consistent. For reference, a DM24-series digitiser will generate a calibration signal of around 16,000 counts (4V) when set to 100% (sine-wave or step) and around 10,000 counts (2.5V) when set to 50%.

7.3.2 Open-loop calibration

The Fortis exposes a logic level control line on the signal connector which switches the instrument into open-loop mode whilst it is activated. In this mode, force feedback to the masses is disabled, leaving each one free to oscillate at the fundamental resonance frequency of its spring. Voltages representing the acceleration of the masses can be measured on the normal channels.

On the Hand-held Control Unit (see section 6.2.4 on page 21), the logic line is connected to the UNLOCK switch. Hold this switch in the UNLOCK position whilst simultaneously holding the ENABLE switch to enable open-loop mode. You can carry out calibration experiments whilst in this mode. Release the switches to restore normal operation.

Opening the feedback loop merely enables the masses to move freely. If the masses are already near their equilibrium positions, switching to open-loop mode will not have a large effect.

7.3.3 Calibration with third-party digitisers

The sensor transmits the signal differentially, over two separate lines. This improves the signal-to-noise ratio by increasing common-mode rejection. If you are not using a Güralp digitiser, the voltage between the output pins should be halved before converting to acceleration.

If you are using a third-party digitiser, you can still calibrate the instrument as long as you activate the Calibration Enable line correctly and supply the correct voltages.

7.4 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.

7.4.1 The calibration sheet

The calibration sheet provides the measured acceleration output over the flat portion of the sensor frequency response in units of volts per metre per second squared (V/ms-2). Because the sensor produces outputs in differential form (also known as push-pull or balanced output), the signal received from the instrument by a recording system with a differential input will be twice the true value. For example, the calibration sheet may give the acceleration response as "2 x 0.50 V/ms-2", indicating that this factor of 2 was not included in the value given.

Caution: Never ground any of the differential outputs. If you are connecting to a single-input recording system, you should use the signal ground line as the return line and ignore the inverting output.

7.4.2 Frequency response

The poles and zeroes table describes the frequency response of the sensor. If required, you can use the poles and zeroes to derive the true ground motion mathematically from the signal received at the sensor. The Fortis is designed to provide a flat response (to within 3dB) over its passband.

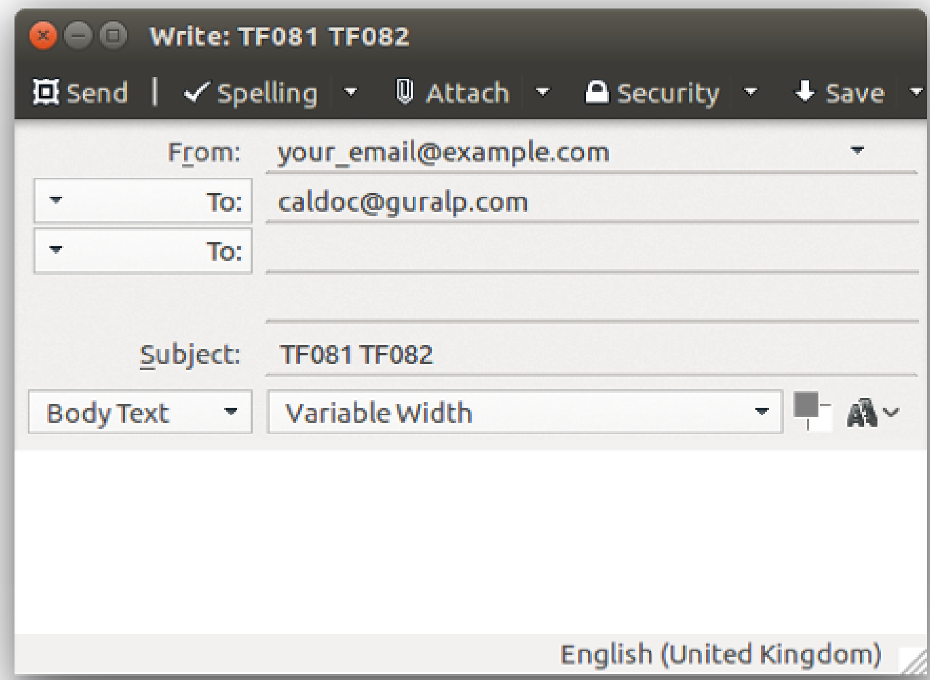
Güralp Systems performs frequency response tests on every sensor at the time of manufacture. All records are archived for future reference. The results of these tests are provided with the sensor.

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 "half-power" point).

7.4.3 Obtaining copies of the calibration pack

We keep a copy 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 email service. Simply email caldoc@guralp.com with the serial number of the instrument in the subject line.

For example:



The server will reply with the calibration documentation in Word format. The body of your email will be ignored. If you need multiple documents, enter all the serial numbers in the subject line, separated with spaces and/or commas.

8 Connector pin-outs

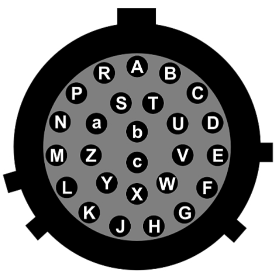
8.1 Fortis instrument connector

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

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

Pin	Function	Pin	Function
A	Vertical output: non-inverting	**P**	Calibration signal input
B	Vertical output: inverting	**R**	Calibration enable
C	N/S output: non-inverting	**S**	Sensitivity select 0 *
D	N/S output: inverting	**T**	Sensitivity select 1 *
E	E/W output: non-inverting	**U**	Centre
F	E/W output: inverting	V	*not connected*
G	*not connected*	**W**	Open loop
H	*not connected*	X	*not connected*
J	*not connected*	Y	*not connected*
K	*not connected*	Z	*not connected*
L	*not connected*	a	*not connected*
M	-V in (optional split power-supply)	**b**	0V in
N	Ground and casing	**c**	+V in

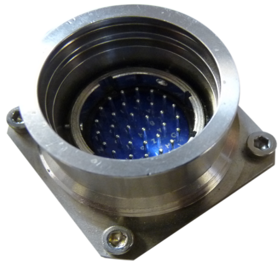
* see section 4.3 on page 10.



Wiring details for the compatible socket, ***-16-26S, as seen from the cable end (*i.e.* when assembling).

8.2 Fortis^{PH} instrument connector

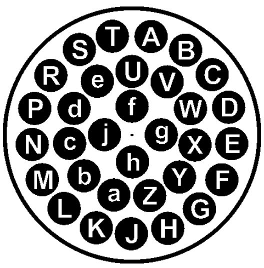
This is a custom 32-pin plug with pin spacing and layout conforming to MIL-DTL-26482 (formerly MIL-C-26482). The GSL part number is ELM-32P-18FX+MEC-GEN-1002-32W.



Suitable mating connectors are only available from GSL as part of cable assemblies.

Pin	Function	Pin	Function
A	Vertical output: non-inverting	**T**	Sensitivity select 1 *
B	Vertical output: inverting	**U**	Centre
C	N/S output: non-inverting	V	*not connected*
D	N/S output: inverting	**W**	Open loop
E	E/W output: non-inverting	X	*not connected*
F	E/W output: inverting	**Y**	Digital ground
G	*not connected*	Z	*not connected*
H	*not connected*	a	*not connected*
J	*not connected*	**b**	0V in
K	*not connected*	**c**	+V in
L	*not connected*	d	*not connected*
M	-V in (optional split power-supply)	e	*not connected*
N	Signal ground	f	*not connected*
P	Calibration signal	g	*not connected*
R	Calibration enable	h	*not connected*
S	Sensitivity select 0 *	j	*not connected*

* see section 4.3 on page 10.

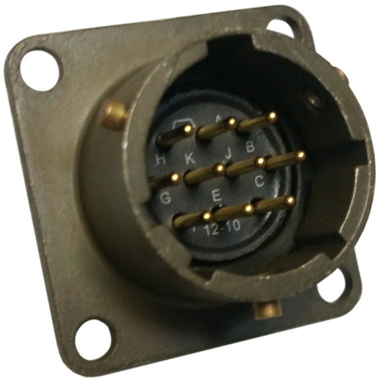


Wiring details for the compatible socket, MEC-GEN-2002-32W, as seen from the cable end (*i.e.* when assembling).

8.3 Break-out box and HCU power connector

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

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



Pin	Function
A	Power ground
B	Power +V
C	*not connected*
D	*not connected*
E	*not connected*
F	*not connected*
G	*not connected*
H	*not connected*
J	*not connected*
K	*not connected*

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

9 Revision History

H	2018-06-25	Renamed Phortis to Fortis^{PH} and replaced images.
G	2018-06-20	Added polarity section, Phortis dimensions and missing cross-reference
F	2018-06-06	Added Phortis chapter and connector pin-out
E	2018-04-21	Removed spurious pin-out diagram
D	2016-08-08	Modified Gain tables
C	2016-05-31	Added gain interaction table
B	2016-02-16	Expanded and corrected HCU section
A	2016-01-25	Initial release