Garner Valley Automated Velocity Measurement : Equipment Installation

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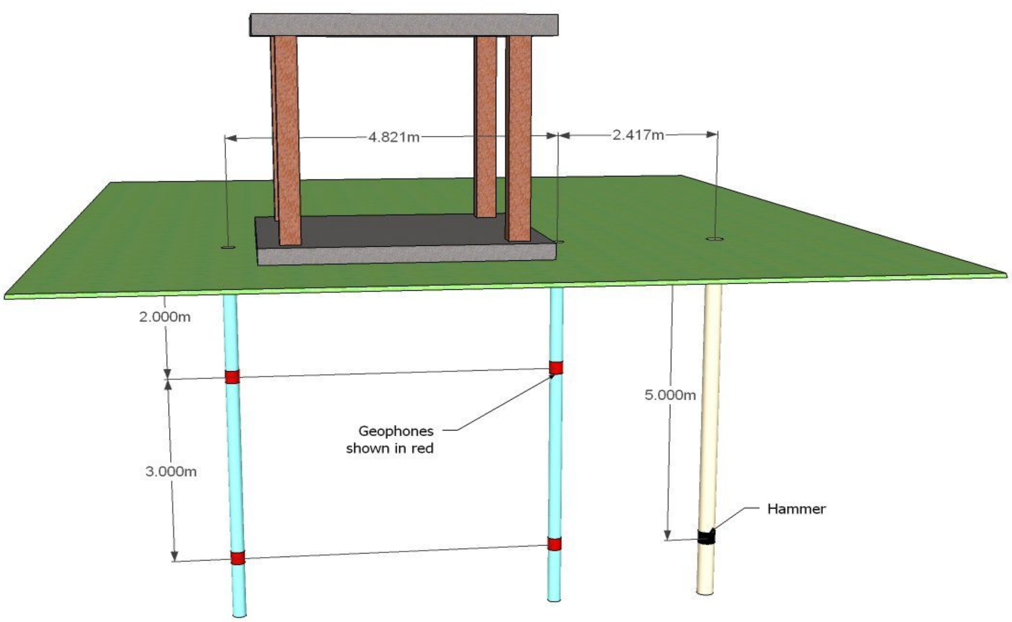
Overview

This document describes the installation and data-acquisition of a permanently installed ground-wave velocity measurement system at the NEES Garner Valley field site.

A controllable solenoid-activated 'hammer' with a striking 'anvil' is installed in a borehole at 5m depth. In separate boreholes some meters away sets of geophones are installed and connected to a data-acquisition system.
Once daily, and in a timed sequence following locally detected significant ground motion, the hammer is swung (or 'pinged') and the geophone motion is recorded.

Physical Setup

The equipment setup is part of the NEES permanently instrumented field site at Lake Hemet in the Garner Valley. The current installation uses three borehole which were drilled during the initial build-out of the site in 2004. These boreholes straggle the instrumented SFSI structure at the site.
The diagram below shows the basic layout



(this is a pseudo-cross-section as viewed from the door of the instrumentation hut)

Refer to the available site characterization data for details of the soil composition in the top several meters of the site.

The three boreholes are in a line that bisects the center of the SFSI foundation slab in a nominally NW-SE direction (from hammer-source to geophones, approx true heading of 146º).

The cabling from the 'hammer' and the geophones is brought from the top of the boreholes to the metal junction box at the front-right corner of SFSI structure and from there into the instrumentation-hut via underground conduit entering the hut through the stainless steel trough-box on the side of the building. Inside the hut the cables connect to the hammer-controller circuit board and to the Kinemetrics Granite Data-Acquisition system.

The geophone signals are carried in a single bundle (6-pair Belkin cable):

Name	Location	Depth	Cable pair	Granite Chan#	SEED Channel Name
EW2(a)	Near hole	5m	Brown/black	21	sfsi_HHZ_22
EW2(b)	Near hole	2m	Yellow/black	22	sfsi_HHZ_21
EW4(a)	Far hole	5m	Green/black	23	sfsi_HHZ_42
EW4(b)	Far hole	2m	Blue/Black	20	sfsi_HHZ_41

The hammer assembly has a separate cable bundle for signals and controls as well as a 14-awg pair for supplying 12V power.

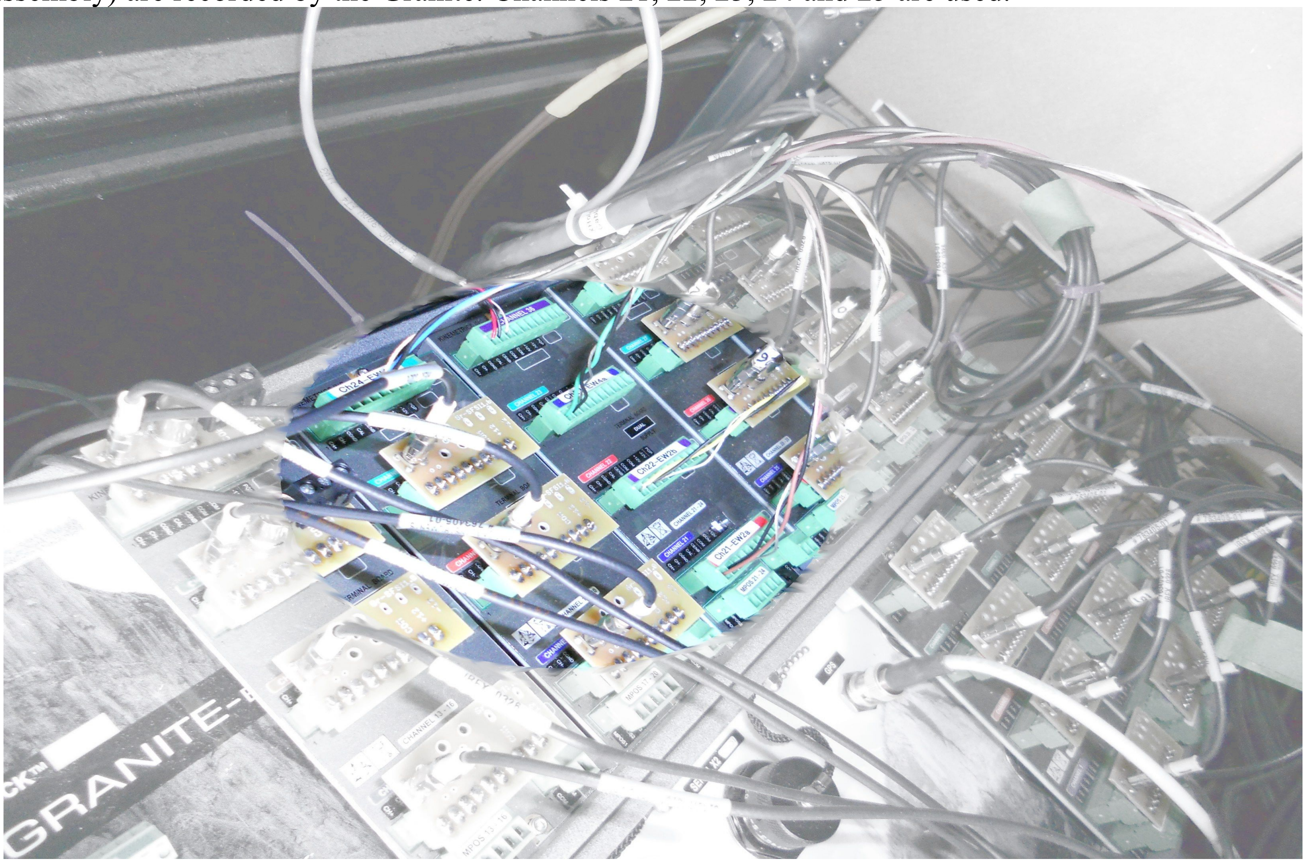
Function	Cable pair	Notes
Main charging/solenoid power	Separate 14-AWG cable	
Control for solid-state charging relay	Brown/Black	
Up-swing control signal	Green/Black	
Down-swing control signal	Blue/Black	
Accelerometer 12V power	Red/Black	
Accelerometer signal	Yellow/Black	

The accelerometer is hooked-up to Granite channel #24 and is SEED named sfsi_HNZ_11.

(SEED channels listed above as Hxy_ab (200sps) will be Exy_ab when recorded at 2ksps)

Granite Hook-up

The five sensor channels (the four geophones and the anvil-plate accelerometer in the hammer assembly) are recorded by the Granite. Channels 21, 22, 23, 24 and 25 are used.

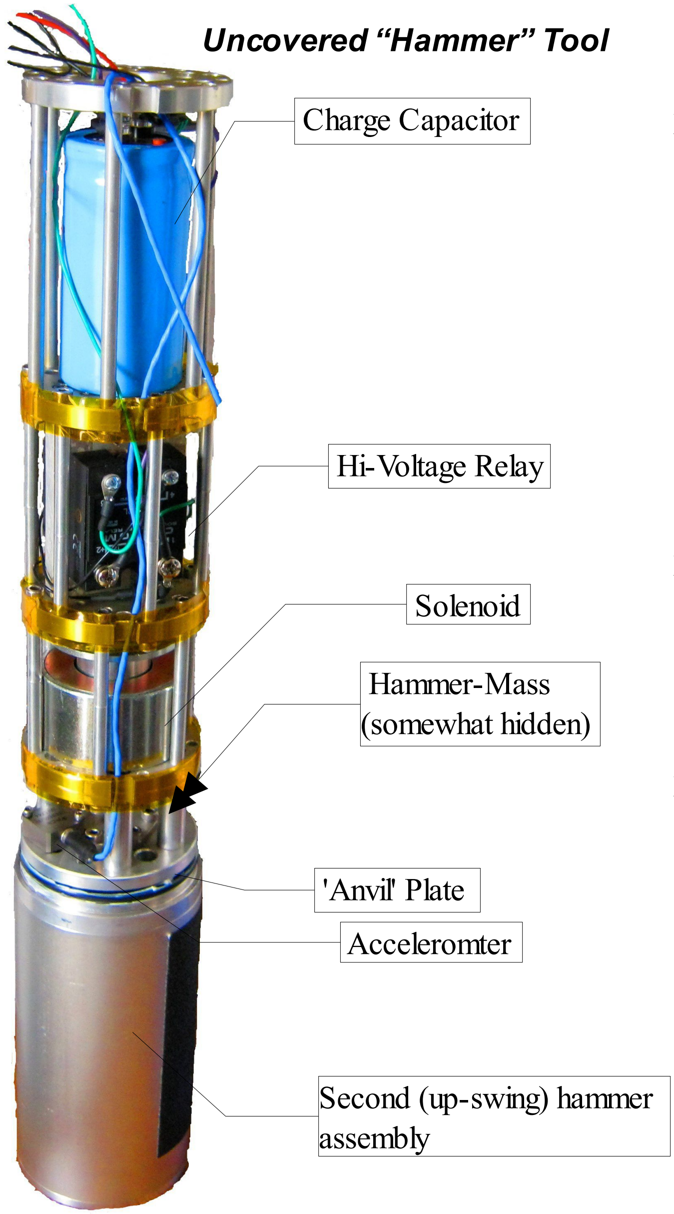


The Granite is configure with 40 virtual channels made up of the 36 physical channels sampled continuously at 200sps and four of the Velocity measurement channels (21-24) additionally sampled at 2ksps on an sta/lta triggered even basis.

Details of the Granite configuration is captured in an Appendix.

The Hammer hardware and the Controller

The downhole source or 'hammer' is based on two solenoid-driven masses (one which strikes upward and one that strikes down) and a center mass-plate or anvil.



Working from a 12V supply, a high-voltage up-converter DC-DC converter (at the wellhead, not part of the downhole tool) charges the Capacitor.

Once charged, one of two hi-voltage solid-state relays (one is visible in the photo, the other is around the back) is turned on to dump the energy into the solenoid coil which accelerates the center mass actuator towards the strike-plate 'anvil'.

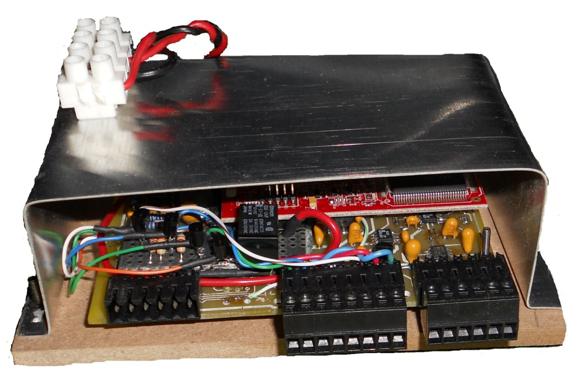
The tool shown when installed is encased in a sealed cylindrical metal casing and held firmly against the boreholes pvc casing with a pressurized bladder system.

The cabling from the downhole tool to the surface junction box contains the high-voltage charging voltage to the capacitor, the up-swing and down-swing relay control circuits and the power and signal-out of the anvil-plate accelerometer.

In the surface junction-box the accelerometer cabling and up/down relay controls are spliced on to the instrumentation hut. This junction-box contains the 12Vin (relay controlled on/off) → high-voltage out DC/DC converter, with the 12V and the control of the charge-up relay coming from the instrumentation hut (see the wiring table in an earlier section).

The operation of the hammer is executed by a configurable uProcessor based controller. This controller is ethernet connected and operation and configuration is accessed by a simple menu-driven telnet interface.

This system controls the three basic relays (charge-up, up-swing, down-swing) and an overall power-supply relay which allows the 12V to the tool (both charging circuit and accelerometer) to be turned on and off remotely.



Telnet to the controller for the menu interface:

```
     __________________________________
     Velocity Controller X1.3 (9/29/10)

Aux-power is ON
(state#1) Initial Power-up time: 30000mS
(state#2) Wait fixed 0.5s
(state#3) Up-swing time        : 60mS
(state#4) Post-swing wait time : 10000mS
(state#5) ReCharge time        : 10000mS
(state#6) Wait fixed 0.5s
(state#7) Down-swing time      : 60mS
(state#8) Post-swing wait time : 10000mS

Loop-iteration count set to 1

1. Run test sequence
2. Turn-on aux power
3. Turn-off aux power
4. System Configuration

  Enter selection:
```

Shows whether the main 12V to the tool is ON or OFF

The current sequence timing parameters, these parameters are adjusted by use of menu item #4

This is the settable number of hammer sequences to be done for each "run test" execution

The four menu options

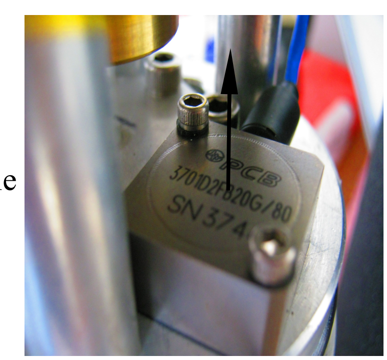
<u>The Sesnors</u>

The Geophones are passive velocity sensors.
The sensors used are Geospace GS-20DX 14 hz, They are set for 70% damping.

They are installed in the preinstalled ~2" inclinometer casings some 2.5m and 4.8m from the source tool borehole.
Each casing has two geophones, one at 2m and one at 5m depth.

The sensors are tightly coupled to the casing by a heavy 'spring-loop' attached to the body with a stainless hose clamp as can be seen opposite.

The hammer-tool accelerometer is a single-axis capacitive type, series 3701, from PCB Piezotronics. The sensitivity is 100mV/g with a full scale of +/-20g and a nominally flat response DC to beyond 100Hz.



Appendix I : Sensor Datasheets

GS-20DX

CLASSIC DIGITAL GRADE GEOPHONE

Specifications at 25°C.
Maintains all specifications at vertical to 15° tilt (8 Hz model); 20° tilt (10 Hz & 14 Hz models)

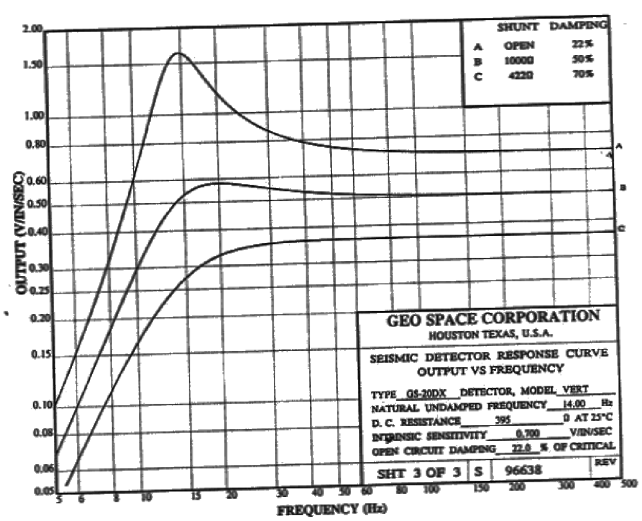
	8 Hz	10 Hz	14 Hz
Frequency			
Natural Frequency (Fn):	8 Hz ± .5 Hz	10 Hz ± .5 Hz	14 Hz ± .7 Hz
Typical Spurious Frequency:	>200 Hz	>250 Hz	>300 Hz
Resistance			
Standard Coil Resistance	395 ohms ± 5%	395 ohms ± 5%	395 ohms ± 5%
Distortion			
Harmonic Distortion with coil to case velocity of 0.7 in/s (1.8 cm/s)	<0.20% at 12 Hz	<0.20% at 12 Hz	<0.20% 14 Hz

Sensitivity
Intrinsic Voltage Sensitivity (G): .700 V/in/s, (.276 V/cm/s) ± 10%
Sensitivity @ 70% Damping .502 V/in/s, (.198 V/cm/s)

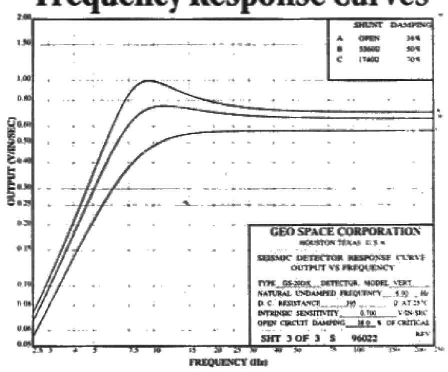
Normalized Transduction Constant: .0352 $\sqrt{DCR}$ V/in/s (.0139 $\sqrt{DCR}$ V/cm/s)

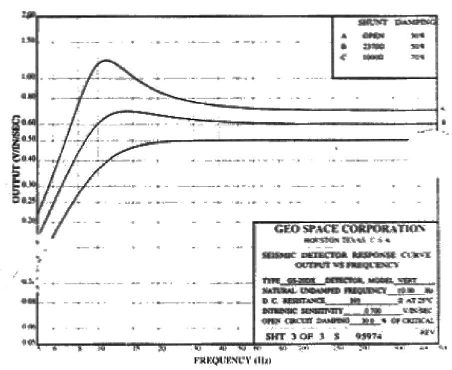
	8 Hz	10 Hz	14 Hz
Damping			
Open Circuit Damping (Bo)	.38 ± 10%	.30 ± 10%	.22 ± 10%
Shunt Resistance for Damping Calibration for 395 ohm coil:			
60% damping	2740 ohms	1430 ohms	634 ohms
70% damping	1740 ohms	1000 ohms	422 ohms
Damping Constant (B_cR_t)	688	550	393

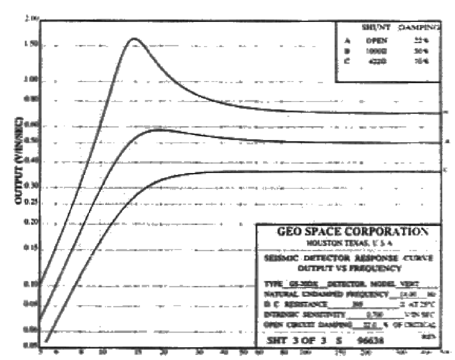
Physical Specifications
Moving Mass (M): .388 oz. (11.0g) ± 5%
Case to Coil Motion p-p: .06 in (.15 cm)
Operating & Storage Temperature: -45° C to +100° C
Dimensions (less terminals*)
Height 1.30 in (3.30 cm)
Diameter 1.00 in (2.54 cm)
Weight 3.08 oz (87.3g)



Frequency Response Curves







Specifications

Visit www.pcb.com for detailed specifications and drawings for specific models

Series 3701 and 3703 Precision Capacitive Accelerometers - Performance Specifications

Voltage Sensitivity (± 5%) [1] English	Voltage Sensitivity (± 5%) [1] SI	Measurement Range English	Measurement Range SI	Frequency Range (± 5%) English	Frequency Range (± 10%) SI	Damped Resonant Frequency	Broadband rms Resolution [2] English	Broadband rms Resolution [2] SI
10 mV/g	1.02 mV/m/s²	200 g	1961 m/s²	0 to 800 Hz	0 to 1000 Hz	≥ 2500 Hz	600 μg	5880 μm/s²
60 mV/g [3]	6.12 mV/m/s²	50 g	490 m/s²	0 to 450 Hz	0 to 600 Hz	≥ 1500 Hz	120 μg	1176 μm/s²
100 mV/g	10.2 mV/m/s²	20 g	196 m/s²	0 to 300 Hz	0 to 500 Hz	≥ 900 Hz	80 μg	785 μm/s²
1000 mV/g [4]	102.0 mV/m/s²	3 g	29.4 m/s²	0 to 100 Hz	0 to 150 Hz	≥ 400 Hz	30 μg	294 μm/s²

Series 3801 Low-cost Capacitive Accelerometers - Performance Specifications

Voltage Sensitivity (± 10%) [1] English	Voltage Sensitivity (± 10%) [1] SI	Measurement Range English	Measurement Range SI	Frequency Range (± 5%)	Frequency Range (± 10%)	Damped Resonant Frequency	Broadband rms Resolution [2] English	Broadband rms Resolution [2] SI
10 mV/g	1.02 mV/m/s²	200 g	1961 m/s²	0 to 600 Hz	0 to 800 Hz	≥ 2200 Hz	600 μg	5880 μm/s²
60 mV/g [3]	6.12 mV/m/s²	50 g	490 m/s²	0 to 350 Hz	0 to 500 Hz	≥ 1200 Hz	180 μg	1764 μm/s²
100 mV/g	10.2 mV/m/s²	20 g	196 m/s²	0 to 200 Hz	0 to 400 Hz	≥ 800 Hz	120 μg	1177 μm/s²
1000 mV/g [4]	102.0 mV/m/s²	3 g	29.4 m/s²	0 to 80 Hz	0 to 100 Hz	≥ 350 Hz	60 μg	588 μm/s²

Series	3701 Precision, Single Axis		3703 Precision Triaxial		3801 Low-cost, Single Axis	
Performance	**English**	**SI**	**English**	**SI**	**English**	**SI**
Non Linearity	≤ 1%	≤ 1%	≤ 1%	≤ 1%	≤ 2%	≤ 2%
Transverse Sensitivity	≤ 3%	≤ 3%	≤ 3%	≤ 3%	≤ 5%	≤ 5%
Environmental						
Overload Limit (shock)	± 3000 g pk	± 29,400 m/s² pk	± 2000 g pk	± 19,600 m/s² pk	± 3000 g pk	± 29,400 m/s² pk
Temperature Range (operating)	-40 to +185 °F	-40 to +85 °C	-40 to +185 °F	-40 to +85 °C	-40 to +185 °F	-40 to +85 °C
Temperature Range (storage)	-85 to +250 °F	-65 to +121 °C	-85 to +250 °F	-65 to +121 °C	-85 to +250 °F	-65 to +121 °C
Base Strain Sensitivity	0.0001 g/με	0.001 (m/s²)/με	0.0001 g/με	0.001 (m/s²)/με	0.0001 g/με	0.001 (m/s²)/με
Electrical						
Excitation Voltage (for best resolution) [2]	16 to 30 VDC	16 to 30 VDC	16 to 30 VDC	16 to 30 VDC	16 to 30 VDC	16 to 30 VDC
Excitation Voltage (optional) [3]	10 to 30 VDC	10 to 30 VDC	10 to 30 VDC	10 to 30 VDC	N/A	N/A
Excitation Voltage (optional) [3] [5]	5 to 30 VDC	5 to 30 VDC	5 to 30 VDC	5 to 30 VDC	5 to 30 VDC	5 to 30 VDC
Current Consumption	< 10 mA	< 10 mA	< 30 mA	< 30 mA	< 10 mA	< 10 mA
Output Impedance	50 ohms	50 ohms	50 ohms	50 ohms	50 ohms	50 ohms
Electrical Isolation	$>10^8$ ohms	$>10^8$ ohms	$>10^8$ ohms	$>10^8$ ohms	$>10^8$ ohms	$>10^8$ ohms
Physical						
Housing Material	Titanium	Titanium	Titanium	Titanium	Polymer	Polymer
Sealing	Hermetic	Hermetic	Hermetic	Hermetic	Epoxy	Epoxy
Size (l × w × h)	0.85 × 0.85 × 0.45 in	21.6 × 21.6 × 11.4 mm	1.1 x 1.1 x 1.1 in	28 x 28 x 28 mm	0.85 × 0.85 × 0.5 in	21.6 × 21.6 × 12.7 mm
Weight	0.62 oz [6]	17.5 gm [6]	2.7 oz [7]	78 gm [7]	1.1 oz	30 gm
Electrical Connector	4-pin or integral cable	4-pin or integral cable	9-pin or integral cable	9-pin or integral cable	Integral cable	Integral cable
Options - Specify using letter prefix to Model Number						

HT - High Temperature option, permits operation to +250 °F (+121 °C)

Notes

[1] Tighter tolerances available upon request

[2] Broadband rms resolution is measured from 0.5 to 100 Hz. This noise floor increases by approximately 1.5 × and 2× for the optional 10 to 30 VDC and 5 to 30 VDC Excitation Voltage configurations, respectively.

[3] 40 mV/g (4.1 mV/m/s²) for sensors specified with 5 to 30 VDC Excitation Power option.

[4] 700 mV/g (71.4 mV/m/s²) for sensors specified with 5 to 30 VDC Excitation Power option.

[5] When ordering ± 3 g or ± 50 g range sensors requiring 5 to 30 VDC excitation voltages, full-scale output code "D" (± 2 volt) must be specified. The sensitivity for these sensors will be set at 700 mV/g and 40 mV/g, respectively.

[6] 2.74 oz (77.8 gm) with 10 ft. integral cable

[7] 5.9 oz (169 gm) with 10 ft. integral cable

CE These products conform to applicable European Directives for CE marking.

Appendix II : Granite Configuration

The 36-channel Granite is configured (using the Layout Wizard) as a 40 virtual-channel, 36 physical-channel simple event recorder with a Text-format Data Archiver.

This gives the number of virtual channels required to have all 36 real channels sampled continuously at 200sps and four additional channels to be assigned the four major velocity measurement sensors at 2ksps.

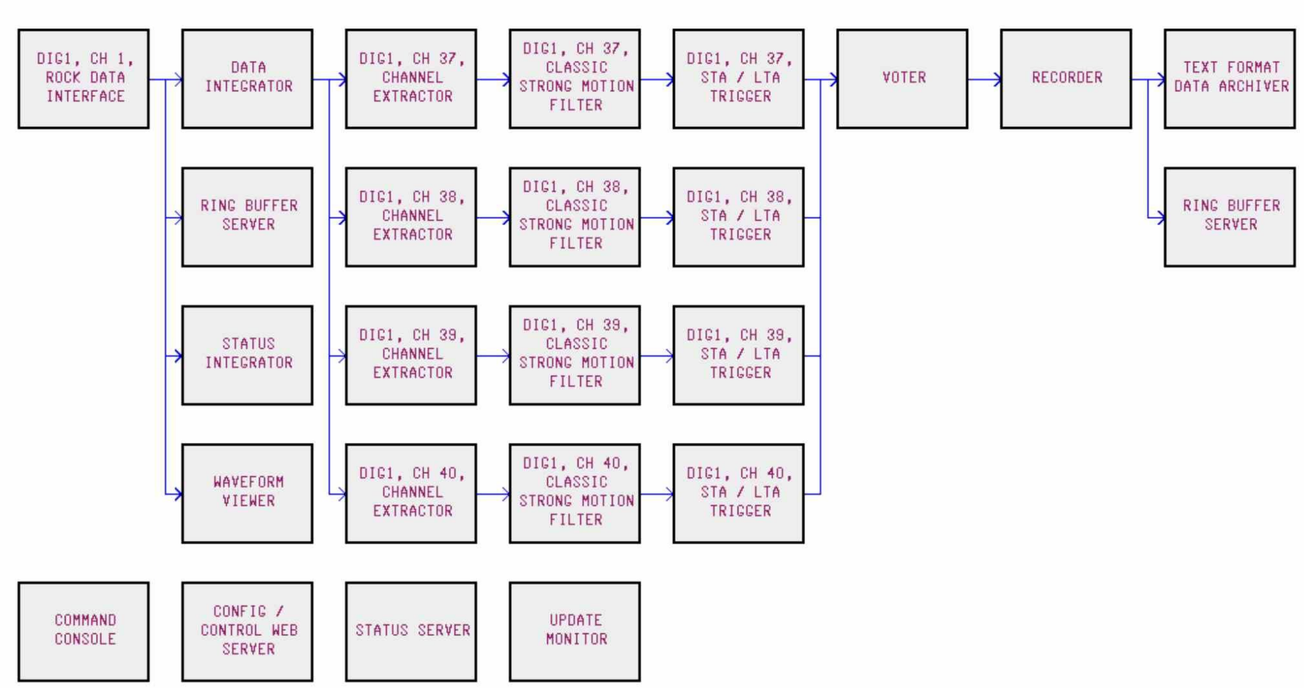
The 'System Operation' web form can then be used to assign the physical channels and sample-rates to the 40 virtual channels.

dig1, Ch 1, Rock Data Interface					
Number of channels	?	40			
Physical channels	?	36			
Channel mapping VCh1	?	ch1 200sps All	Channel mapping VCh21	?	ch21 200sps All
Channel mapping VCh2	?	ch2 200sps All	Channel mapping VCh22	?	ch22 200sps All
Channel mapping VCh3	?	ch3 200sps All	Channel mapping VCh23	?	ch23 200sps All
Channel mapping VCh4	?	ch4 200sps All	Channel mapping VCh24	?	ch24 200sps All
Channel mapping VCh5	?	ch5 200sps All	Channel mapping VCh25	?	ch25 200sps All
Channel mapping VCh6	?	ch6 200sps All	Channel mapping VCh26	?	ch26 200sps All
Channel mapping VCh7	?	ch7 200sps All	Channel mapping VCh27	?	ch27 200sps All
Channel mapping VCh8	?	ch8 200sps All	Channel mapping VCh28	?	ch28 200sps All
Channel mapping VCh9	?	ch9 200sps All	Channel mapping VCh29	?	ch29 200sps All
Channel mapping VCh10	?	ch10 200sps All	Channel mapping VCh30	?	ch30 200sps All
Channel mapping VCh11	?	ch11 200sps All	Channel mapping VCh31	?	ch31 200sps All
Channel mapping VCh12	?	ch12 200sps All	Channel mapping VCh32	?	ch32 200sps All
Channel mapping VCh13	?	ch13 200sps All	Channel mapping VCh33	?	ch33 200sps All
Channel mapping VCh14	?	ch14 200sps All	Channel mapping VCh34	?	ch34 200sps All
Channel mapping VCh15	?	ch15 200sps All	Channel mapping VCh35	?	ch35 200sps All
Channel mapping VCh16	?	ch16 200sps All	Channel mapping VCh36	?	ch36 200sps All
Channel mapping VCh17	?	ch17 200sps All	Channel mapping VCh37	?	ch21 2000sps All
Channel mapping VCh18	?	ch18 200sps All	Channel mapping VCh38	?	ch22 2000sps All
Channel mapping VCh19	?	ch19 200sps All	Channel mapping VCh39	?	ch23 2000sps All
Channel mapping VCh20	?	ch20 200sps All	Channel mapping VCh40	?	ch24 2000sps All

The basic Layout Wizard 'Simple Event Recorder' template is not, however, the system operation required. This template will have 40x trigger detections feeding a voter to an event only recorder.

What is required is a continuous recorder of all 36-physical channels at 200sps and an event only recording of the 4x 2000sps channels based on a trigger from the hammer-accelerometer. In addition for the GVDA setup the primary data-recording blocks should be Ring-Buffer-Servers.

The Layout pictured below is the desired final configuration.



To achieve this a number of edits to the generic layout/config generated by the Layout Wizard are required.

1. The filters/triggers into the voter from all virtual-channels 1-36 must be removed leaving only four channel-extractors, filters and trigger blocks. (this can be done by editing the layout.cfg file)
2. A Ring-Buffer-Server module is added and connected to the "dig1" source which is all available channels. In the RB Server configuration form select only 200sps for recording
3. A second Ring-Buffer-Server module is added and connected to the voter output. The config of the RB Server needs to specify a unique ring-buffer directory and port number and 2000sps channels only should be selected for recording.

Ring Buffer Server		
Ring Buffer Size	?	10000
Ring Buffer directory	?	\data\rb\
Clients	?	4
TCP Port Number	?	9500
Remote Writes	?	false
Status Interval	?	30
Status style	?	Antelope
Store only	?	200sps
ORB SOH Latency	?	0
ORB Data Latency	?	0

Ring Buffer Server		
Ring Buffer Size	?	10000
Ring Buffer directory	?	\data\rbEvt\
Clients	?	4
TCP Port Number	?	9501
Remote Writes	?	false
Status Interval	?	30
Status style	?	Antelope
Store only	?	2000sps
ORB SOH Latency	?	0
ORB Data Latency	?	0

Appendix III : Initial Results

Based on a number of individual hammer 'pings' and a simple cross-correlation to find the time displacement of the signals between the sensors, the following preliminary baseline results are presented:

```
Near_5m to Near_2m is  0.004500 seconds
Near_5m to Far_5m  is  0.022000 seconds
Near_2m to Far_5m  is  0.017000 seconds
Far_5m  to Near_2m is -0.017000 seconds
Hammer  to Near_5m is  0.010000 seconds
Hammer  to Near_2m is  0.014500 seconds
Hammer  to Far_5m  is  0.032000 seconds
```

(One important and potentially significant condition to remember when looking at these early results is that the 'Hammer' sensor is acceleration while the 'Near' and 'Far' transducers are velocity measurements. Additional work is required to produce a velocity record from hammer sensors, any phase change in the waveform introduced by this operation will affect the times (and so calculated propagation velocities) relative to the 'hammer').