Strong Motion User Guide

User guide

Part No. MAN-SMO-0001

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

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1 Introduction

The CMG-DM24mk3 digitiser is capable of performing several calculations useful for strong motion study. This document details the setup and operation of the strong motion mode.

The strong motion results are computed and transmitted in real-time, in parallel with waveform data.

IMPORTANT: Users of the CMG-DM24mk3 machine may be familiar with the Guralp Systems software package "*Scream*". This software is currently not compatible with strong motion mode. *Scream*'s configuration dialog must not be used to configure the digitiser once strong motion mode is enabled, and it cannot be used to view strong motion data. However, *Scream* can still be used to examine the raw data waveforms, and to open terminal mode on the digitiser.

To follow the instructions in this document, it will be useful to examine these documents as well:

- Information blocks (each digitiser and instrument pair must have an information block containing the calibration values, allowing the strong motion results to be calculated in ground units): http://www.guralp.com/articles/20060315-howto-information-blocks/support

- The DM24 manual (and in particular the section on commandline): http://www.guralp.com/products/DM24/

1.1 Firmware changes

v.103 build 68

This build causes unified status packets (enabled with +monitor) to revert to deprecated CD status packets. Unified status packets are required for operation with the CMG-DCM and must be re-enabled after the upgrade with the "uspmonitor" command.

v.103 build 70

This build causes the 20sps low latency data output to be turned off by default (it is still computed for the strong motion calculations, but not transmitted). To re-enable the data, issue the “LLstreams enable” command. The data may be turned off at any time with “LLstreams disable”.

This build also fixes several bugs connected with strong motion:

- Sometimes, only half of the low latency data was output (e.g. there would be data for 00:00:00, 00:00:02, 00:00:04 but not for 00:00:01, 00:00:03 etc.). This was triggered by a GPS sync occuring while the DM24 was creating such a block.

- Sometimes, there were 21 data samples transmitted in a low latency block. This was another manifestation of the GPS sync occuring while creating the block.

- The first SM packet was computed using incorrect values as the infoblock had not been interpreted yet.

2 Digitiser Configuration

Below is a set of commands, including sample output, that should be used to set up the DM24. Commands that should be typed are *emphasised*.

Bring up terminal mode on the digitiser. This can either be done with Scream or with the data-terminal command on a CMG-DCM or CMG-NAM. You should be presented with a message similar to the following. Hitting <enter> a couple of times will ensure the session is responsive.

```
LW A80800 CMG-3T Command Mode
0 blocks in buffer | 256 blocks free
Guralp Systems Ltd - DM+FW  v.103  mgs  17/10/07 (Build 60)
  ok_A808
```

2.1 Update firmware, upload infoblocks

Ensure that the firmware on the CMG-DM24 is up to date. At the time of writing, the latest versions are Bootloader 1030, DSP 1060, and system 1.03b70. Later versions will be backwards compatible. You can follow the instructions at:

http://www.guralp.com/articles/20060914-firmware-DM24mk3/support

Also upload an info block (or two blocks if you have a two-instrument digitiser). Instructions are at:

http://www.guralp.com/articles/20060315-howto-information-blocks/support

2.2 System identity

Now, set the system identity. This gives the System and Stream IDs of the generated GCF data.

```
resetlabels  ok_A808
set-id
System Identifier { LW } ? 5 characters : LW
Serial # { A80800 } ? 6 characters : A808
LW A80800 CMG-3T  ok_A808
```

If you have a 2-instrument CMG-DM24, you should enable a second serial number for the second instrument. This is required otherwise the 2nd info block will not be emitted by the digitiser. This is achieved with the "serial2" command.

```
serial2
Secondary Serial # { 0 } ? 6 characters : B808 B80800  ok_A808
```

GSL recommend that the system identifier is set to the digitiser serial number, and that the stream identifier is set to the last four digits of the sensor serial number.

2.3 Basic setup

These steps should be followed to ensure the digitiser behaves as expected:

```
6 sensor-type
Sensor type set to CMG-5TD ok_A808
adaptive
Adaptive Storage : Circular  ok_A808
erasefile
Are you SURE you want to delete ALL Flash Data? Y/Ny
Erasing ALL  65.5MB
\  49.1MB
  64MB Flash Memory Buffer : 0 Blocks Written  0 Unread   65,536
Free
Oldest data  [16] Blank
 Read point  [16] Blank
Latest data  [16] Blank
File Replay  [16] Blank  ok_A808
normal compression Optimum Compression ok_A808
0 1 bandpass 10.0->90.0HzBandPass ok_A808
3 highpass
HighPass at 1000 sec ok_A808
```

“6 sensor-type” tells the digitiser that it is connected to a CMG-5T. This does not alter data acquisition, or the behaviour of the system, but merely disables some commands, such as mass lock/unlock, which are not used with strong motion instruments. The sensor-type command applies only to Sensor A. Use the command “explain sensor-type” to get a list of additional sensors.

“adaptive” turns on adaptive mode, in which the digitiser's internal flash is used as a temporary buffer should data not be acquired by a connected system. Other digitiser modes such as FIFO or Direct are also compatible. Consult the DM24 manual to determine which mode is the most appropriate for you. When switching into this mode, the command “erasefile” is used to clean the flash memory, which may contain stale data.

The “compression” and “bandpass” commands are required for correct operation of lowlatency mode. The “highpass” command introduces a highpass filter at 1000s, which has the effect of removing DC offset from the sensor's output. This should improve the quality of strong motion results.

2.4 Enable strong motion mode

The CMG-DM24 has a flexible system of output taps which can be used to choose which sample rates are transmitted. Strong motion mode requires the first tap be set to 200 samples per second. The configuration below transmits 100sps continuous data, which you can alter as you please. It also transmits the 20sps low-latency data, which is filtered differently (see the section below on low latency data). The low-latency data is always at 20sps. The output taps must be configured as follows for correct operation:

```
200 100 20 10 samples/sec
200 100 20 10 samples/sec ok_A808
```

The steps below enable lowlatency mode, and turn on the 20sps low latency data. Change “$77 triggers” to simply “7 triggers” for a one-instrument system.

```
lowlatency
Tap0  200 s/s  Low Latency mode ( 20s/s ) ok_A808
$77 triggers
Tap0  200 s/s  Low Latency mode ( 20s/s )  ZC NC EC ZC NC EC
ok_A808
LLstreams enable
Low Latency Data Streams enabled  ok_5E63
```

Transmission of the low latency 20sps streams is controlled by the “LLstreams” command. In v.103 build 70, low latency is disabled by default, and must be explicity enabled with the above command. It can be disabled again with “LLstreams disable”.

Next, the continuous data transmission is configured. The first hex code below tells the DM24 to output continuous data from the second tap on both instruments. For a one-instrument digitiser setup, this should be changed to 00070000. The second hex code turns off the multiplexor channels, which are not used for strong motion instruments.

```
set-config
Hex code to select taps {00770000} 00770000
Hex code to select mux channels {0000} 0000
Tap0  200 s/s
Tap1  100 s/s Continuous: Z2 N2 E2 Z2 N2 E2
Tap2   20 s/s
Tap3   10 s/s  ok_A808
```

The first hex code could be 77000000 to enable 200sps data on both sensors (or 07000000 for Sensor A only), 00000077 to enable only 10sps data, or a combination of any of these codes. The CMG-DM24 manual can be consulted for further information.

Finally, enable the remaining strong motion features:

```
+simode  ok_A808
rtstatus enable  SQpatch disabled  ok_A808
ok-1
Forth Vocabulary now available
Guralp Systems Ltd - DM+FW  v.103  mgs  17/10/07 (Build 60)
SYSTEM  FORTH  ROOT
Current: FORTH
 ok_A808
+monitor  ok_A808
uspmonitor  ok_A808
```

2.5 Common scenarios

This section holds concise instructions for setting up three common scenarios. Ensure that you have read the previous sections and understand what each command does before issuing these instructions.

1x strong motion sensor

resetlabels
set-id
6 sensor-type (for CMG-5T)
adaptive (if desired)
erasefile
normal compression
0 1 bandpass
3 highpass
200 100 20 10 samples/sec
lowlatency
7 triggers
LLstreams enable
set-config (use e.g. 00070000, 0000)
+simode
rtstatus enable
ok-1
+monitor
uspmonitor
re-boot

2x strong motion sensor

resetlabels
set-id
serial2

6 sensor-type (for CMG-5T)
adaptive (if desired)
erasefile
normal compression
0 1 bandpass
3 highpass
200 100 20 10 samples/sec
lowlatency
$77 triggers
LLstreams enable
set-config (use e.g. 00770000, 0000)
+simode
rtstatus enable
ok-1
+monitor
uspmonitor
re-boot

1x weak motion + 1x strong motion sensor

When using a 2-sensor digitiser with both a weak motion and a strong motion instrument, the weak motion instrument must be connected as Sensor A and the strong motion instrument as Sensor B.

resetlabels
set-id
serial2
1 sensor-type (for CMG-40T)
adaptive (if desired)
erasefile
normal compression
0 1 bandpass
3 highpass
200 100 20 10 samples/sec
lowlatency
$70 triggers
LLstreams enable
set-config (use e.g. 70070000, FF00)
+simode
rtstatus enable
ok-1
+monitor
uspmonitor
re-boot

3 Viewing Results

Currently, the *Scream* software does not allow display of strong motion or unified status packets. This feature is scheduled to be implemented in the next version of *Scream*.

3.1 The Unified Status Packet

The unified status packet is a special, binary coded status message from the digitiser that is transmitted every second. It allows a connected system to determine the reliability of strong motion data, and is intended for realtime monitoring and alarm systems.

Some example packets are shown below. The first packet is from a system that does not have a GPS lock, and thus has no reliable time source.

```
00000000032A6C1F | LW-B808/ttyS2/rhod | 2008-03-12T12:42:43.000Z
| LW    -B80801 | unknown     | unified status |   19 words
        |  Clock  status:  locked=0,  differential=-2147483647us,
source=GPS receiver, last_locked=1989-11-17T00:00:00.000
    | Unable to interpret GPS receiver status.
    | Channel 'Z' (instrument 0) flags:
    | Channel 'N' (instrument 0) flags:
    | Channel 'E' (instrument 0) flags:
```

This packet is from a system with a reliable time source:

```
000000000024557C | LW-A830/Port A/loc | 2008-03-12T12:43:17.000Z
| LW    -A83001 | unknown     | unified status |   27 words
      |  Clock  status:  locked=1,  differential=-694us,  source=GPS
receiver, last_locked=2008-03-12T12:43:17.000
       |  GPS  receiver  status:  fix=3D,  latitude=+51.216703deg,
longitude=-001.098548deg, elevation=+000105.000m
    | Channel 'Z' (instrument 0) flags:
    | Channel 'N' (instrument 0) flags:
    | Channel 'E' (instrument 0) flags:
    | Channel 'X' (instrument 0) flags:
    | Channel 'Z' (instrument 1) flags:
    | Channel 'N' (instrument 1) flags:
    | Channel 'E' (instrument 1) flags:
```

Channel flags may occasionally be observed. These indicate that the data is not reliable for some reason. Typically these are observed immediately after a time step when the digitiser's clock is synchronised for the first time. This will correspond to a spike in the waveforms as the FIR filters charge.

3.2 The Strong Motion Packet

The strong motion packet contains calculated strong motion data in floating point format. The data is in ground units (gal, kine, etc.) and requires an accurate infoblock is uploaded to the digitiser (the infoblock stores the calibration values of the ADC and the analogue sensor components).

An example strong motion block:

```
0000000000245B5B | LW-A830/Port A/loc | 2008-03-12T12:47:58.000Z
| LW    -A830SM | unknown     | strong motion |   50 words
    | Windowed MMA | 0Z | -4.09785 -4.09660 -4.10911
    | Windowed MMA | 0N | -4.19176 -4.18925 -4.19427
    | Windowed MMA | 0E | -4.43434 -4.43434 -4.44563
    | Windowed MMA | 0h | 6.10199 6.10026 6.11192
    | Windowed MMA | 0a | 7.35028 7.34815 7.36480
    | PGA          | 0Z | 0.0125049
    | PGA          | 0N | 0.00502158
    | PGA          | 0E | 0.0112897
    | PGA          | 0h | 0.0123561
    | PGA          | 0a | 0.0175797
    | RMS          | 0Z | 0.0113237
    | RMS          | 0N | 0.00376618
    | RMS          | 0E | 0.0125441
    | RMS          | 0h | 0.0130973
    | RMS          | 0a | 0.0173137
    | SI           | 0Z | 0.615240
    | SI           | 0N | 0.628953
    | SI           | 0E | 0.663583
    | SI           | 0h | 0.914289
    | SI           | 0a | 1.10202
```

3.3 Viewing Packets

On a CMG-DCM or CMG-NAM unit that is connected to a strong motion data source, the packet contents may be viewed with the following terminal commands:

- `dumpstatus` – shows unified status blocks.
- `dumpsm` – shows strong motion blocks.
- `dumpdata` – shows a summary of all incoming data blocks, but not their contents.

Scream or a CMG-DCM or CMG-NAM will record all GCF blocks, including strong motion and unified status, to disk. See the page http://www.guralp.com/articles/20080313-howto-gcfreference/support for details on interpreting these blocks in your own programs.

3.4 CMG-STA-DISP Display Unit

As part of a seismic hazard monitoring system, a real-time display unit (the CMG-STA-DISP) has been developed. This displays the peak ground acceleration and spectral intensity values being recorded by an instrument.

Illustration 1: The CMG-STA-DISP.

The CMG-STA-DISP has several options for warning and alert levels, peak hold, etc. and is further described in the document MAN-SMD-0001.

4 Calculation Details

This section describes the concept of the strong motion calculations. The document SWA-RFC-STMN holds the details of the algorithms used and the packet format.

4.1 Low Latency Waveform Data

Using the setup given in section 2, the digitiser will transmit low latency data blocks. These are 20sps blocks that are emitted every second. They can be turned off with the command “0 triggers” and on with “$77 triggers” (or simply “7 triggers” for a 2-channel instrument).

Turning off the transmission of the blocks does not affect the strong motion calculations. The low latency streams are always computed, even if they are not transmitted or stored in flash, as they are used by the strong motion calculations to produce a strong motion data block.

The low latency data uses a different pre-decimation filter to the normal 20sps data. You will see a difference between the two if they are turned on simultaneously. There are two differences between the normal and the low latency filter:

- The low latency filter has a high pass effect, with a corner frequency at approximately 0.001Hz (1000s).

- The low latency filter is implemented as an IIR (Infinite Impulse Response) rather than an FIR (Finite Impulse Response) filter. This implementation was chosen because an FIR filter requires many taps to produce a good cut-off, but more taps introduce more latency. An IIR filter can be implemented with far fewer taps, allowing the data to be retrieved in much shorter order.

The low latency filter has a different phase and freqency response to the normal filter. Bode plots (filter response magnitude and phase plotted against frequency) for both types of filter are displayed below.

The Bode plots (see illustrations 2 and 3) show the magnitude and phase shift of the response of each set of filters to a range of frequencies. The normal pre-decimation filter (a cascaded divide by 2 and divide by 5 FIR filter) has a sharp cut-off point and rolls off very quickly. The low latency pre-decimation filter

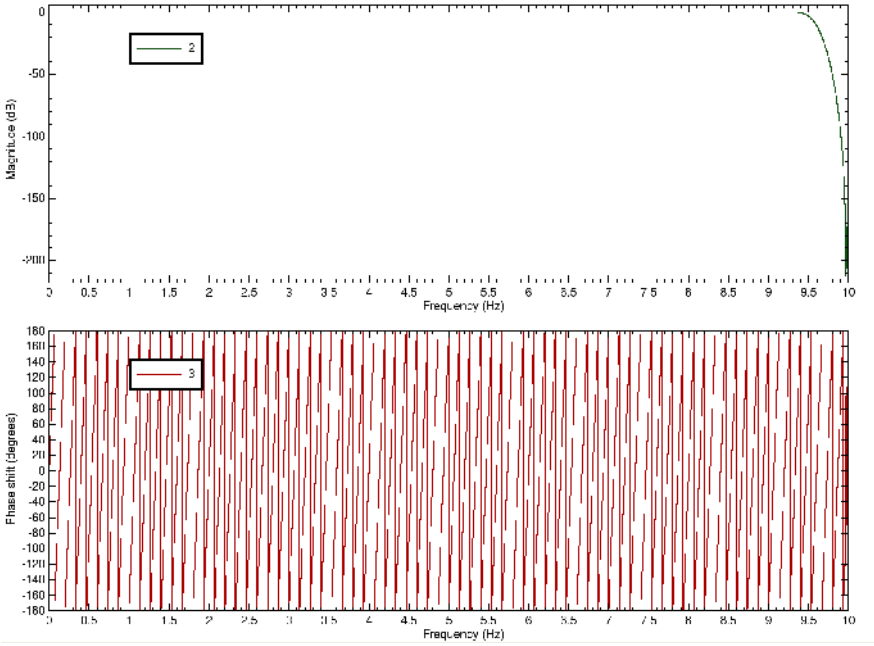

Illustration 2: Bode plot of normal 200Hz to 20Hz pre-decimation FIR filter.

is a set of four cascaded first-order IIR filters. Its roll off is comparitively more shallow and begins at a lower frequency.

The phase shift observed in illustration 2 is actually a linear phase shift introduced by a pure time delay. The FIR filter used has a completely flat phase response, but is acausal. A pure time delay must be used so that the filter can be realised. This simply means that the output sample y(t) does not correspond to the input sample u(t) but instead to the sample u(t-n).

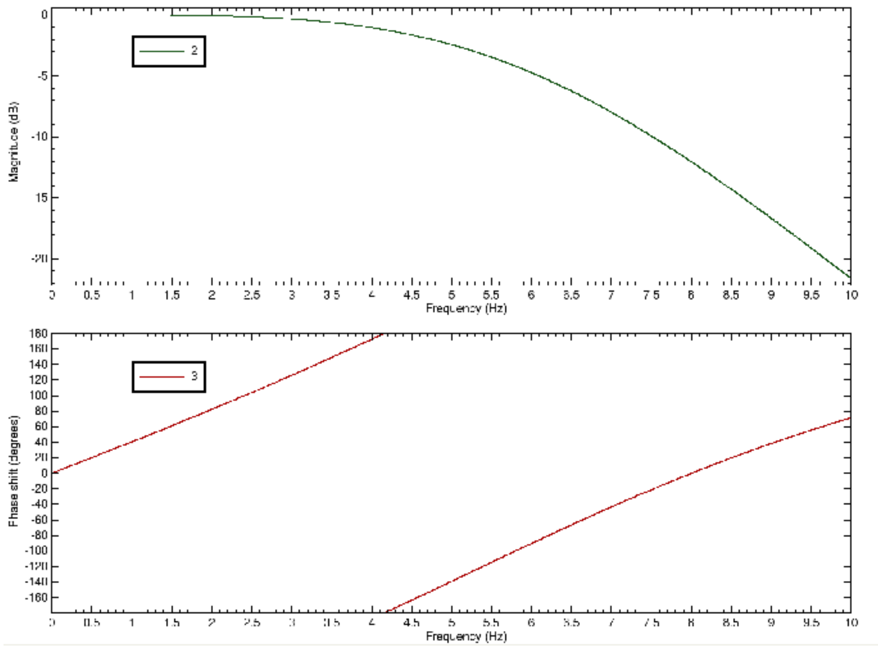

Illustration 3: Bode plot of low latency 200Hz to 20Hz pre-decimation IIR filter. The high pass effect is present but cannot be seen on this scale.

4.2 Types of Strong Motion Result

The following strong motion results are calculated every second, in real-time. They are transmitted in the SM GCF block.

Windowed MMA (minimum, maximum and average)

The most basic strong motion result type is the minimum, maximum and average (arithmetic mean). This is computed every second and uses a 10 second sliding window (so the result at y(t) is based on input data from u(t) to u(t-10)).

This calculation finds the minimum, maximum and average number of counts, and then converts these numbers (in digital counts) into ground units using the calibration info in the info block. The result is in *gal*.

PGA (peak ground acceleration)

The peak ground acceleration is computed every second, and is the magnitude of the largest acceleration recorded in a 1s interval. The acceleration is simply the difference between the raw sampled value of the input and the sliding average from the windowed MMA data. The result is in *gal*.

RMS (root mean square)

The RMS is computed every second and is the root mean square of the digital counts for a one-second period. The DC offset of the signal is removed by subtracting the average from the MMA calculation. The RMS is a measure of the energy imparted to the digitiser during a one-second period. The result is in *gal*.

SI (spectral intensity)

The spectral intensity is a measurement that attempts to determine the amount of energy absorbed by structures in the vicinity of the sensor during an event. The calculation uses a series of frequency-dependent filters to model structures and performs an integration calculation to compute the expected velocity (pseudo-velocity) of these structures.

The result, in *kine*, is thus an indication of how fast a structure was moving and thus how likely it is to be damaged. SI corresponds very closely to physical damage.

5 Revision history

2008-07-18	F	Add LLstreams enable command. Add section on firmware changes.
2008-06-06	E	Add uspmonitor command.
2008-03-18	D	Remove “0 triggers”, explain settings for mixed weak/strong motion instruments.
2008-03-17	C	Add further required setup commands. Add section on strong motion results.
2008-03-14	B	Tidy up. Add details of low latency 20sps streams.
2008-03-12	A	New document.