APPENDIX A

Sensitivity Study
for Optimum OBS Station Locations

Dr. Felix Waldhauser performed various sensitivity tests using synthetic earthquake locations to find the optimal OBS locations that also fit the permitting requirements. Waldhauser's analysis method and selected results are shown at the end of his email 'train".

He felt that synthetic tests Syn04.2 and Syn05.2 were considered good array designs that would meet our objectives. The Syn04 design would probably record and locate very small events on the shoreline fault right off-shore DC (Figure 1). The Syn05 design would be optimized to best constrain events towards the fault intersection, and produce better network criteria for events on the Hosgri fault (Figure 2). However, due to the constraints set by the permitting agencies, designs Syn04.2 and Syn05.2 had to be modified. The results labeled syn07.2_20km and syn07.2_55km are the preferred OBS locations (Figure 3). Figure 4 shows the final locations and corresponding errors from HYPOINVERSE for synthetic events recorded at stations within 20 km (top) and 55 km (bottom). These final results were used to write the request for proposal. Details of these tests are described in the emails below.

From: felixw@ldeo.columbia.edu
Subject: Re: synthetics setup
Date: September 15, 2010 5:56:42 PM EDT
To: MKM2@pge.com
Cc: felixw@ldeo.columbia.edu

Write-up:
Synthetic travel times (P and S) were computed using a grid of synthetic sources (open circles) and the McLaren and Savage model (M&S,2001) in order to get the network parameters for each source. Criteria are essentially thresholds of the parameters I determine, e.g. the number of stations within 10 km is a parameters, and the criteria as shown in the figures are 3 recording stations or more within 10 km. .

Red sources indicate all sources that have the following network criteria:
1) At least one station within 5 km (to constrain shallow events)
2) At least 3 stations within 10 km (to best constrain events down to seismogenic depth)
3) Max azimuthal gap < 180 deg (to constrain epicenter)

(*See Email date September 22, 2010 for the definition of yellow sources.)*

Network parameters are based on the four OBS and the permanent land stations. Maps are created for two sets of OBS configurations (syn01 and syn02), and for max station distances of 20 km and 55 km to simulate small and larger earthquakes. These maps indicate the area that is reliably covered by the given OBS configuration.

Also shown are the respective hypoinverse solutions and associated standard errors, derived after adding noise with a standard deviation of 0.05 s for P- and 0.1 s for S-waves to the perfect travel times at all stations.

I posted new figures w/ slightly different filenames:
station set up syn01 (the old one) showing network criteria and location error (z color coded) information:
http://www.ldeo.columbia.edu/~felixw/PGE/2010/syn01_20km_netwcrit.eps
http://www.ldeo.columbia.edu/~felixw/PGE/2010/syn01_20km_locerr.eps
http://www.ldeo.columbia.edu/~felixw/PGE/2010/syn01_55km_netwcrit.eps
http://www.ldeo.columbia.edu/~felixw/PGE/2010/syn01_55km_locerr.eps

station set up syn02 (per our phone conversation) showing network criteria and location error (z color coded) information:
http://www.ldeo.columbia.edu/~felixw/PGE/2010/syn02_20km_netwcrit.eps
http://www.ldeo.columbia.edu/~felixw/PGE/2010/syn02_20km_locerr.eps
http://www.ldeo.columbia.edu/~felixw/PGE/2010/syn02_55km_netwcrit.eps
http://www.ldeo.columbia.edu/~felixw/PGE/2010/syn02_55km_locerr.eps

From: felixw@ldeo.columbia.edu
Subject: Re: Best spots?
Date: September 22, 2010 6:09:05 PM EDT
To: MKM2@pge.com
Cc: felixw@ldeo.columbia.edu

I posted two new sets of OBS locations, syn04 and syn05, that I find give the best monitoring capabilities:
http://www.ldeo.columbia.edu/~felixw/PGE/2010/syn04.1_55km_netwcrit.eps
http://www.ldeo.columbia.edu/~felixw/PGE/2010/syn04.2_55km_netwcrit.eps
http://www.ldeo.columbia.edu/~felixw/PGE/2010/syn04.1_20km_netwcrit.eps
http://www.ldeo.columbia.edu/~felixw/PGE/2010/syn04.2_20km_netwcrit.eps
http://www.ldeo.columbia.edu/~felixw/PGE/2010/syn05.1_55km_netwcrit.eps
http://www.ldeo.columbia.edu/~felixw/PGE/2010/syn05.2_55km_netwcrit.eps
http://www.ldeo.columbia.edu/~felixw/PGE/2010/syn05.1_20km_netwcrit.eps
http://www.ldeo.columbia.edu/~felixw/PGE/2010/syn05.2_20km_netwcrit.eps

I computed the network criteria for both the original line sources along the Shoreline and Hosgri faults, and the 'carpet' sources that I used in the most recent figures. I also added, in yellow, a more stringent network criteria:
red (original):
    at least 3 stations within 10 km
    at least one station within 5 km
    max azimuthal station gap < 180
yellow (new):

at least 3 stations within 10 km
at least one station within 3 km
max azimuthal station gap < 110

Both station configurations monitor the area you indicated well (red dots). In the case of syn04 I optimized them to get the best network criteria for sources off-shore Diablo Canyon (yellow dots). With syn04 you are probably able to record and locate very small events on the shoreline fault right off-shore DC. Syn05 is optimized to best constrain events a bit more to the north towards the fault intersection, and produces better network criterias for events on the Hosgri fault.

Note that I increased the source density so the covered area is a bit easier to see. I avoided placing the OBSs on faults. Note that syn05 requires longer cables.

From: felixw@ldeo.columbia.edu
Subject: Re: Best spots? + need final SFZ analysisreport
Date: September 24, 2010 12:11:35 PM EDT
To: MKM2@pge.com
Cc: felixw@ldeo.columbia.edu

I uploaded syn06 and syn07.
http://www.ldeo.columbia.edu/~felixw/PGE/2010/syn06.1_20km_netwcrit.eps
http://www.ldeo.columbia.edu/~felixw/PGE/2010/syn06.2_20km_netwcrit.eps
http://www.ldeo.columbia.edu/~felixw/PGE/2010/syn06.1_55km_netwcrit.eps
http://www.ldeo.columbia.edu/~felixw/PGE/2010/syn06.2_55km_netwcrit.eps
http://www.ldeo.columbia.edu/~felixw/PGE/2010/syn07.1_20km_netwcrit.eps
http://www.ldeo.columbia.edu/~felixw/PGE/2010/syn07.2_20km_netwcrit.eps
http://www.ldeo.columbia.edu/~felixw/PGE/2010/syn07.1_55km_netwcrit.eps
http://www.ldeo.columbia.edu/~felixw/PGE/2010/syn07.2_55km_netwcrit.eps

syn06: moved O2 NE as you suggested, and O3 a bit south to improve coverage.
syn07: move O2 N. Builds a tight array near the fault intersection.

In both configuration control of events along the Hosgri fault in the SW corner is lost for small events.

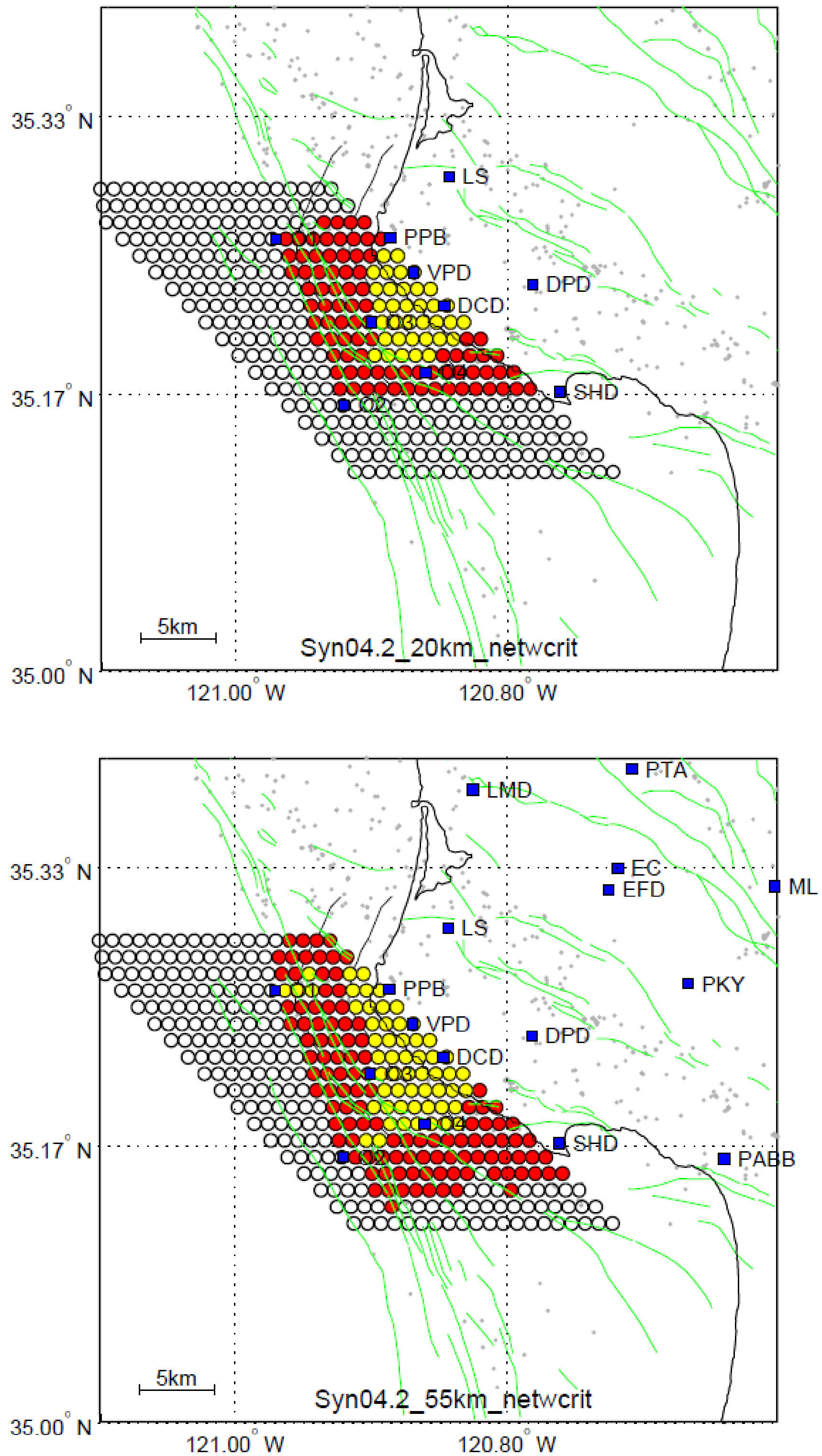


Figure 1. Synthetic test 04.2 showing network criteria needed for this design (red and yellow criteria described in emails above) for maximum stations distances of 20 km (top) and 55 km (bottom). Onshore OBS and onshore stations are represented by blue squares.

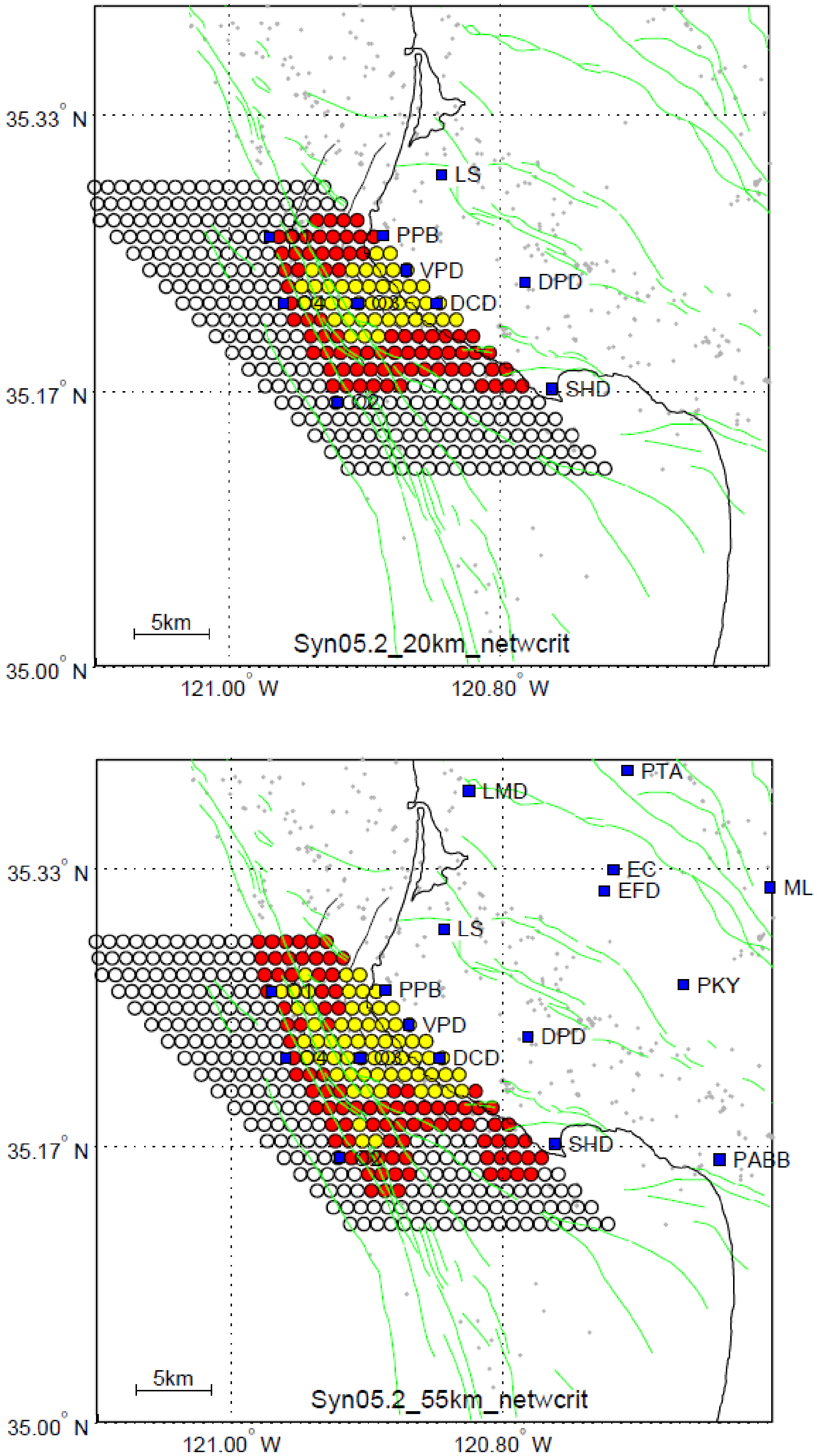
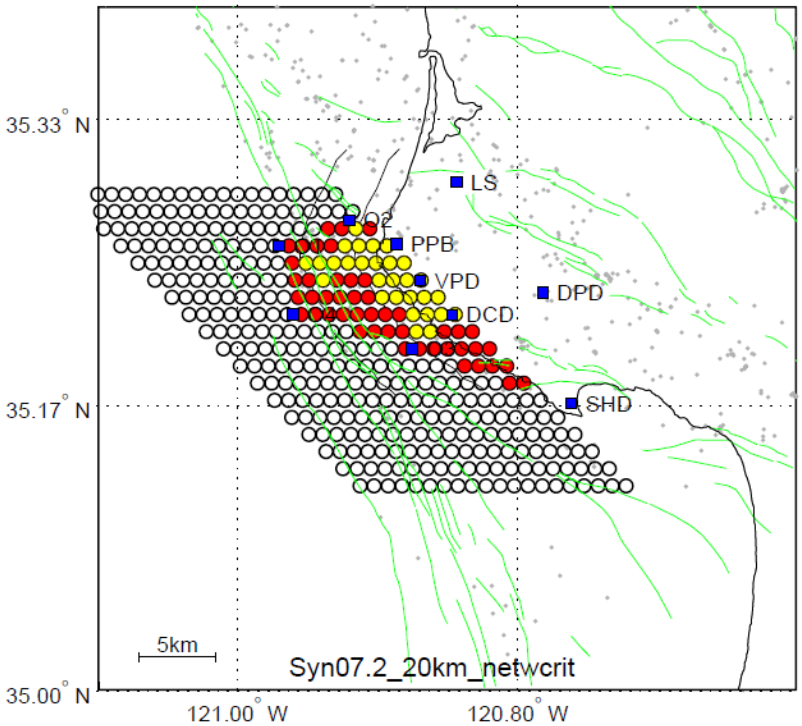


Figure 2. Synthetic test 05.2 showing network criteria needed for this design (red and yellow criteria described in emails above) for maximum stations distances of 20 km (top) and 55 km (bottom). Onshore OBS and onshore stations are represented by blue squares.



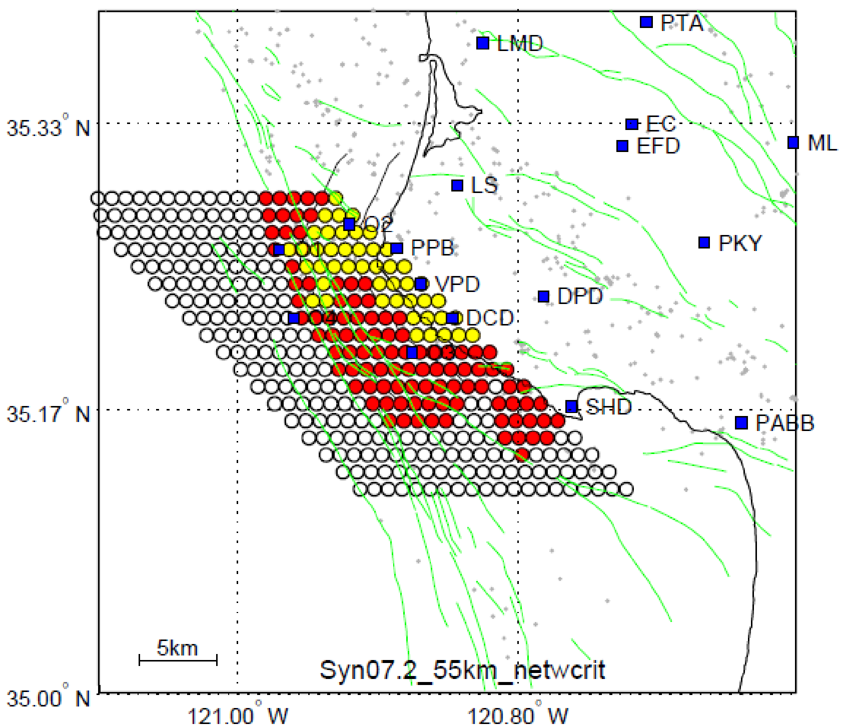


Figure 3. Preferred results. Synthetic test 07.2 showing network criteria needed for this design (red and yellow criteria described in emails above) for maximum stations distances of 20 km (top) and 55 km (bottom). Onshore OBS and onshore stations are represented by blue squares.

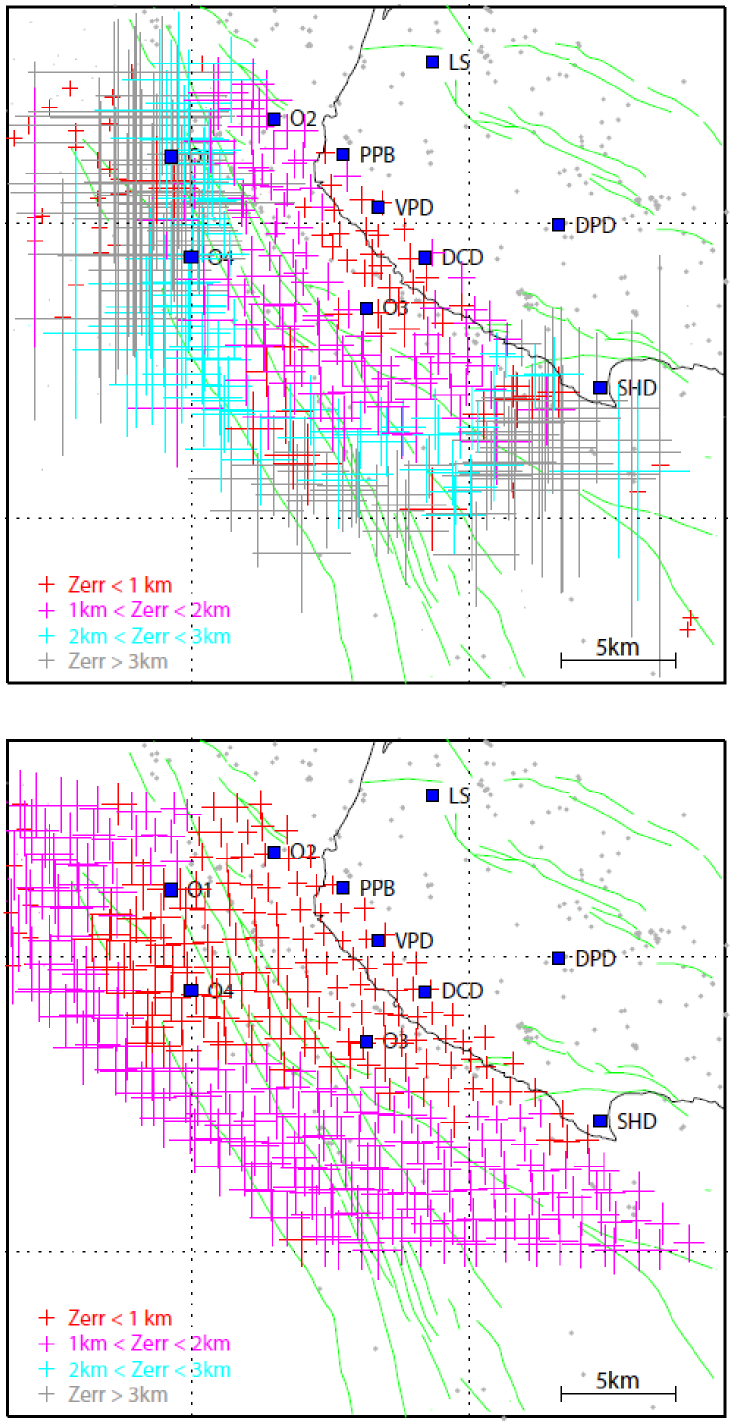


Figure 4. Locations and corresponding errors from HYPOINVERSE for synthetic events recorded at stations within 20 km (top) and 55 km (bottom). Size of '+' represents lateral errors; vertical errors are color coded. Onshore OBS and onshore stations are represented by blue squares.

APPENDIX B

Calibrations, Hydrostatic Test Report, and Technical Manual

GURALP SYSTEMS

TEST AND CALIBRATION DATA

Works Order 6411

Pacific Gas and Electric Company

OBS System

DESIGNED AND MANUFACTURED BY:

GÜRALP SYSTEMS LIMITED
3 MIDAS HOUSE
CALLEVA PARK
ALDERMASTON
READING
BERKS, RG7 8EA
ENGLAND

Telephone: +44 (0) 118 9819056 **Fax: +44 (0) 118 9819943**

1. WORKS ORDER NUMBER: The Works Order Number is the number used at Güralp Systems Limited to file sensor manufacture details.

2. SYSTEM ID: This number (can be alphanumeric) can be used by the customer to identify the name of a network. Normally it is set to be the Works Order Number. The customer can change the System ID (a 6 character space is available).

3. UNIT ID: Specified the name of the data stream. Unit ID is designed to be used as a station identifier within a network. It is normally set to be the serial number of the station. When the Unit ID is changed the last two characters are used by the DM to identify the component and the sample rate associated with that component. Only 4 characters are available to the user as the last two characters are overwritten by the DM.

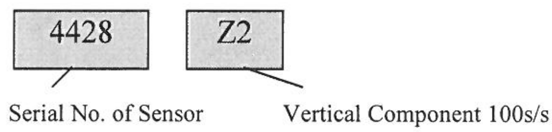
4. OUTPUT DATA FORMAT: GCF stands for Güralp Compressed Format.

5. BAUD RATE This is the baud rate set at the factory. The baud rate can be changed by the customer.

6. VELOCITY CHANNELS: The sensitivity of each digitizer channel in units of Volts/bit and combination of each sensor digitizer channel in units of m/s/bit is given. M/s/bit is not specified if the calibration data is specific to a stand-alone digitizer.

The calibration of each sensor velocity output is also given separately in the sensor calibration sheet in units of V/m/s.

The stream ID specifies the component and the tap used from the DSP which provides the sample rate. For example.



7. MASS POSITION CHANNELS: These mass position channels are only used to establish the status of the seismometer system. These outputs must be checked occasionally to establish the operating condition of the sensor.

The variation of the mass position outputs can be ± 15,000. As long as the sensor mass position outputs are within the given counts range the sensor operation will be satisfactory.

8. AUXILLIARY INPUTS:

The input sensitivity is given in V/Bit. The outputs of the equipment connected to these channels should have its signal ground connected as given in the documentation.

1. CALIBRATION SHEET

* The data provided in the calibration sheet are the measured velocity responsivities over the flat portion of the sensor frequency response. The velocity responses are given in units of Volts/metre/second (V/m/s). Please note that some instruments may also be only acceleration output instruments in this case the published units are Volts/metre/(second*second) $V/m/s^2$.

The sensor velocity outputs are differential (push-pull or balanced output) and it is required that a factor of * 2 must be used when the sensor outputs are interfaced to a recording system with a differential input. For example, in the calibration sheet, the velocity responsivity may be given as 2 * 1000 V/m/s which includes the factor * 2.

CAUTION

Do not ground any of the differential outputs. When interfaced to a single input recording system use the signal ground as the return line.

* The mass position output (also known as the acceleration output) is given in units of $V/m/s^2$. This is a single ended output referenced to the signal ground.

* The feedback coil constant given in Ampere/metre/second^2 ($A/m/s^2$) is an important parameter used when calibrating the sensor by injecting calibration signals into the sensor.

* Works Order Number is the number used at Güralp Systems Limited to file sensor manufacturing details.

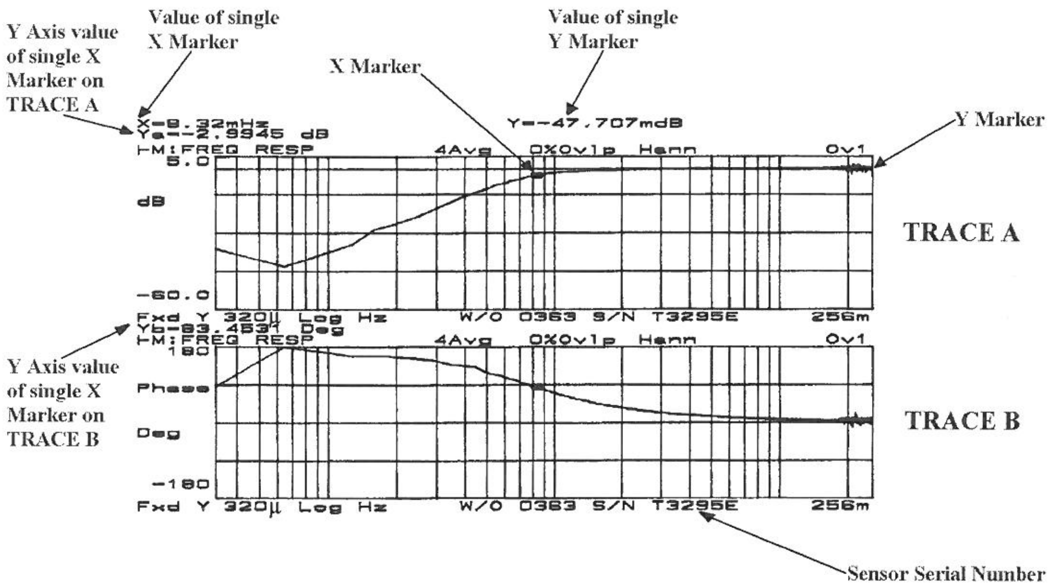
2. FREQUENCY RESPONSE

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

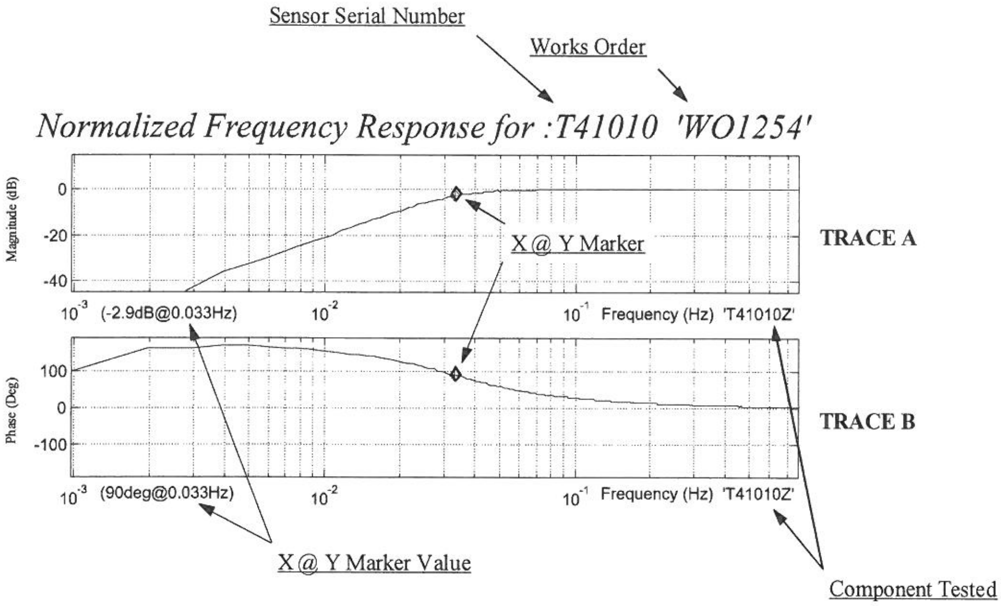
When testing the instrument, to confirm that it meets its design specification, it is most convenient in any one test to concentrate the range of frequencies over about 3 decades (i.e. 1000:1) of excitation frequencies, in the low and high end of the spectrum separately. Consequently the normalized frequency plots of each component are provided as low frequency and high frequency sections. In each plot, the low frequency cut-off value and the high frequency cut-off values (often quoted as -3dB or half power points) are marked. The frequency responses are normalized (unity gain) in order to show the corner frequencies.

Frequency response tests are always performed on every sensor produced at Güralp Systems Limited and records are archived for future reference.

There are two types of frequency plot representations. These are explained in the following frequency amplitude and phase plots.



Frequency response from 320µHz to 256 milliHz
TRACE A:- Y axis in dB.
TRACE B:- Y axis in degrees.



Normalized Frequency Response from 976.5 μHz to 781.25 mHz
TRACE A:- Y axis in dB
TRACE B:- Y axis in degrees.

3. SENSOR TRANSFER FUNCTION

It is convenient for most users of seismometers to consider the sensors as 'black-boxes'. Thus the details of the internal mechanics and electronics need not be known, but only the overall effect of the instrument in producing a usable output signal V from the desired input variable of x is required. The generic form of such a transfer function (in terms of Laplace variable s) is given as:

$$\frac{V}{x}(s) = G * A * H(s)$$

where:

G : is the velocity output sensitivity (gain constant) of the instrument relating to the actual output to the desired input over the flat portion of the frequency response. Output sensitivity is supplied in the calibration sheet. As well as the output sensitivity, a frequency response plot for each component incorporating the sensor gain is also shown. A straight line is drawn showing the sensor sensitivity value over a wide frequency range. (see overleaf for example)

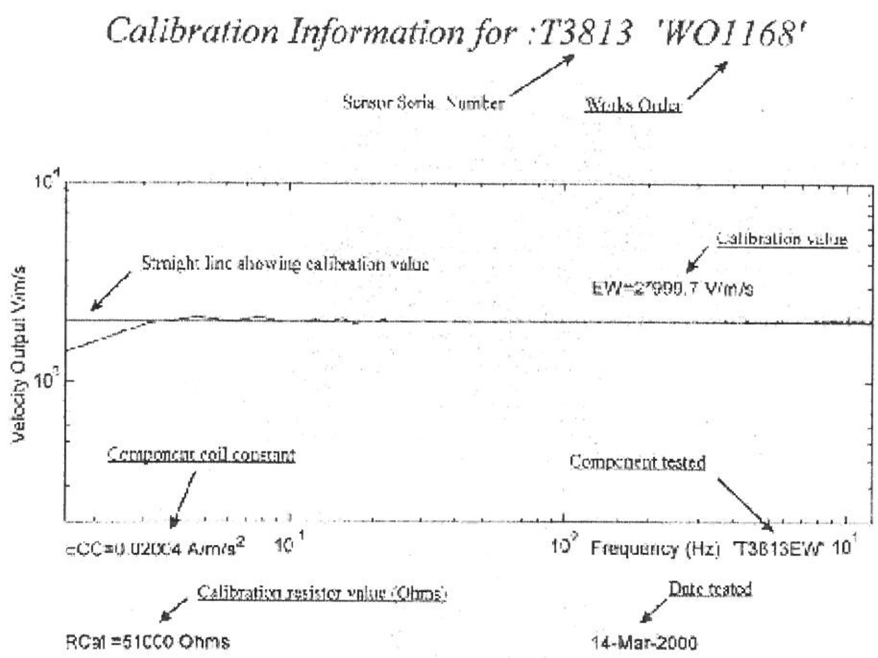
H(s) : the transfer function of the sensor can be expressed in factored form.

$$H(s) = \frac{\prod_{n=1}^{N} (s - z_n)}{\prod_{m=1}^{M} (s - p_m)}$$

—

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. See: poles and zero table.

A : is a constant which is evaluated to make the magnitude of A * H(s) unity, with no dimensions over the flat portion of the frequency response. In practice it is possible to design a system transfer function with a very wide range of flat frequency response. For convenience, the normalizing constant A is calculated at a normalizing frequency value fm = 1 Hz with s = j fm, j = $\sqrt{-1}$. The value of A is given in the poles and zeros table.



Output Sensistivity plot from 15.6 mHz to 12.5 Hz
Y axis in Volts / meter / second.

1. CALIBRATION SHEET

* The data provided in the calibration sheet are the measured acceleration responsivities over the flat portion of the sensor frequency response. The acceleration responses are given in units of Volts/metre/second * second ($V/m/s^2$).

The sensor acceleration outputs are differential (push-pull or balanced output) and it is required that a factor of * 2 must be used when the sensor outputs are interfaced to a recording system with a differential input. For example, in the calibration sheet, the acceleration responsivity may be given as 2 * 50 $V/m/s^2$ which includes the factor * 2.

CAUTION

Do not ground any of the differential outputs. When interfaced to a single input recording system use the signal ground as the return line.

* Works Order Number is the number used at Güralp Systems Limited to file sensor manufacturing details.

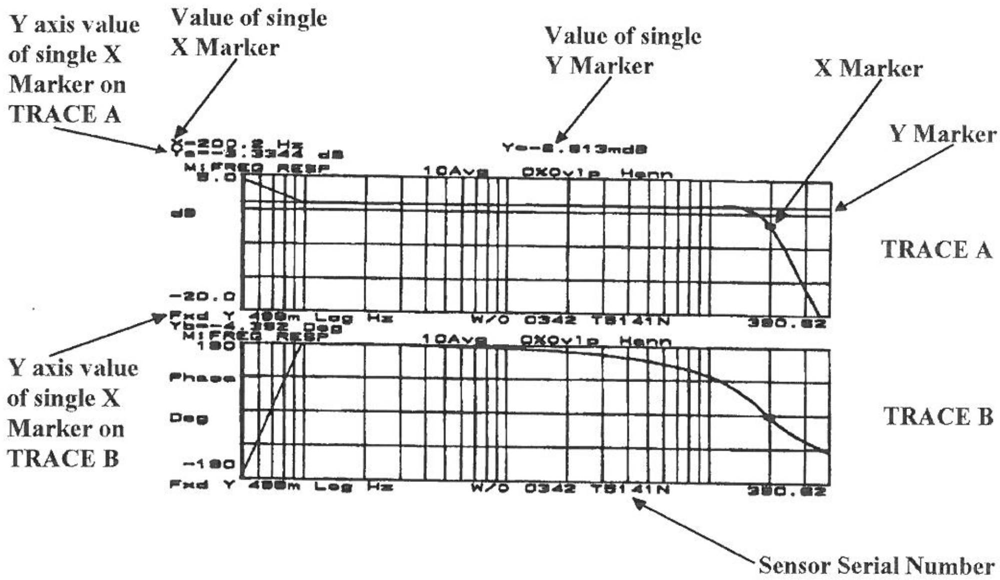
2. FREQUENCY RESPONSE

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

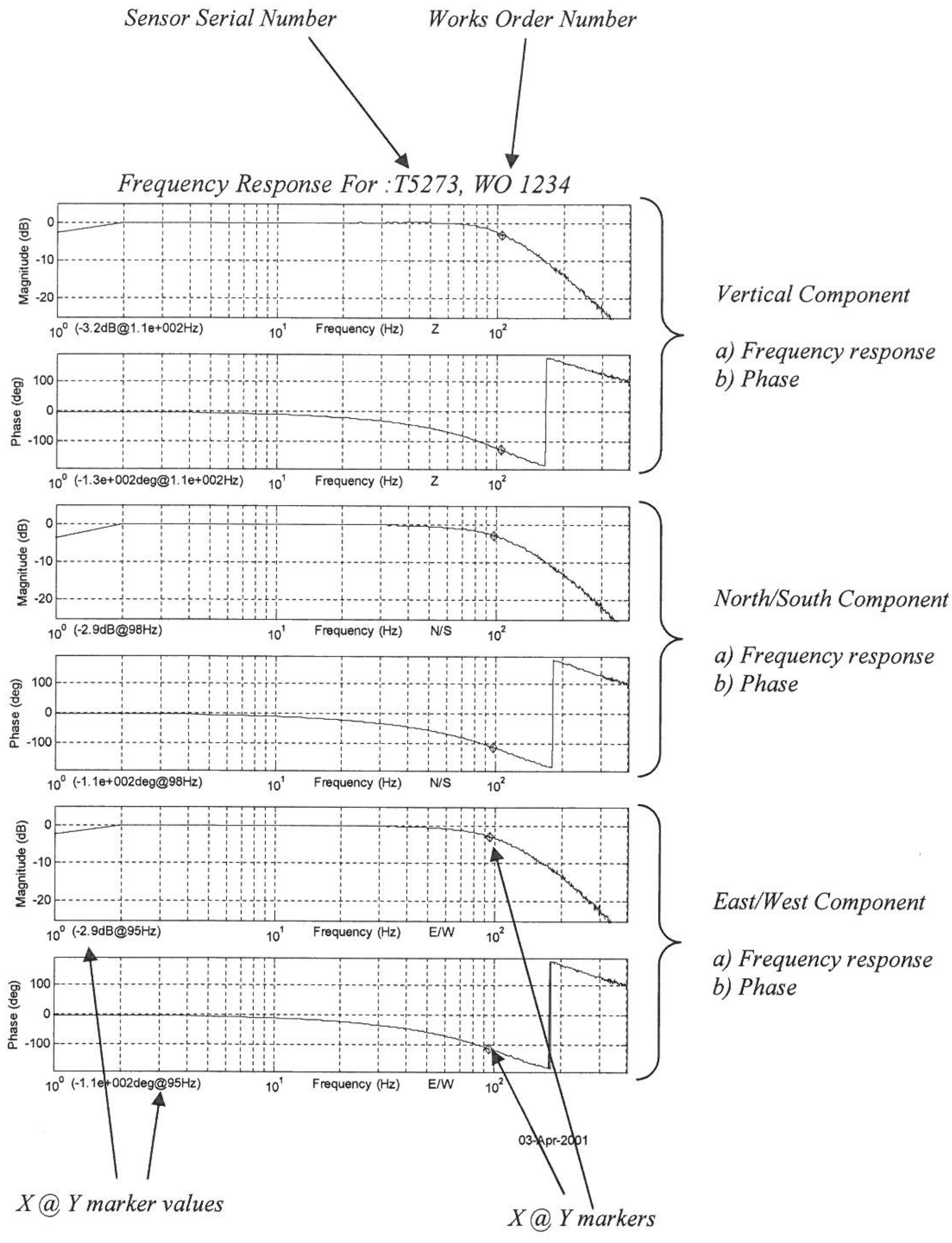
When testing the instrument, to confirm that it meets its design specification, it is most convenient in any one test to concentrate the range of frequencies over about 3 decades (i.e. 1000:1) of excitation frequencies. Consequently the normalized frequency plots of each component are provided. In each plot, the frequency cut-off value (often quoted as -3dB or halfpower points) are marked. The frequency responses are normalized (unity gain) in order to show the corner frequencies.

Frequency response tests are always performed on every sensor produced at Güralp Systems Limited and records are archived for future reference.

There are two types of frequency plot representations. These are explained in the following frequency amplitude and phase plots.



Frequency response from 488 milliHz to 390.62 Hz
TRACE A:- Y axis in dB.
TRACE B:- Y axis in degrees.



Frequency response from 1 second to 300Hz

3. SENSOR TRANSFER FUNCTION

It is convenient for most users of seismometers to consider the sensors as 'black-boxes'. Thus the details of the internal mechanics and electronics need not be known, but only the overall effect of the instrument in producing a usable output signal V from the desired input variable of x is required. The generic form of such a transfer function (in terms of Laplace variable, s) is given as:

where:

$$\frac{V}{x}(s) = G * A * H(s)$$

G: Is the acceleration output sensitivity (gain constant) of the instrument relating to the actual output to the desired input over the flat portion of the frequency response. Output sensitivity is supplied in the calibration sheet.

A: Is a constant which is evaluated to make the magnitude of A * H(s) unity, with no dimensions over the flat portion of the frequency response. In practice it is possible to design a system transfer function with a very wide range of flat frequency response. For convenience, the normalising constant A, is calculated at a normalising frequency value fm = 1 Hz, with s = j fm, where j = √-1. The value of A is given in the poles and zeros table.

H(s): The transfer function of the sensor can be expressed in factored form.

$$H(s) = \frac{\sum_{n=1}^{N}(s - z_n)}{\sum_{m=1}^{M}(s - p_m)}$$

z_n : are the roots of the numerator polynomial, giving the zeros of the transfer function,

p_m : are the roots of the denominator polynomial giving the poles of the transfer function. See: poles and zero table.

GURALP SYSTEMS

TEST AND CALIBRATION DATA

OBS System 1

EAM – 3899
DM24 – A3367
3T – T37829
5TC – T5X97

DESIGNED AND MANUFACTURED BY:

GÜRALP SYSTEMS LIMITED
3 MIDAS HOUSE
CALLEVA PARK
ALDERMASTON
READING
BERKS, RG7 8EA
ENGLAND

Telephone: +44 (0) 118 9819056 Fax: +44 (0) 118 9819943

DM24 CALIBRATION

WORKS ORDER: 12009 **DIGITISER SERIAL NUMBER:** A3367

SYSTEM ID:	12009	CPLD:	A0.E1
UNIT ID:	3367	BOOTLOADER:	MK3BOOT213.IMG
OUTPUT DATA FORMAT:	GCF	DSP SOFTWARE:	DSP1090.BIN
BAUD RATE:	38400	SYSTEM:	DMNET106b57d.IMG

VELOCITY CHANNELS

Channel:	3367Z2	Vertical	3.190 μV/Count
	3367N2	North/South	3.187 μV/Count
	3367E2	East/West	3.207 μV/Count
	3367Z3	Vertical	3.200 μV/Count
	3367N3	North/South	3.204 μV/Count
	3367E3	East/West	3.207 μV/Count

MASS POSITION CHANNELS

Sample Rate: 4 samples/sec (Default)

Channel:	3367M8	Vertical	286.073 μV/Count
	3367M9	North/South	286.500 μV/Count
	3367MA	East/West	287.142 μV/Count

Sample Rate: 1 samples/sec

Channel:	3367M8	Vertical	2.235 μV/Count
	3367M9	North/South	2.238 μV/Count
	3367MA	East/West	2.243 μV/Count

CAL SIGNAL MONITOR

3367X2/ C23367 3.201 μV/Count

GPS RECEIVER

PWM: 8000 Counts
At Temperature Reading: 23°C

POWER CONSUMPTION

Digitiser Power Consumption	80mA @ 12v
GPS Power Consumption	28mA @ 12v

AUXILIARY CHANNELS

Sample Rate: 4 samples/sec (Default)

Channel:	3367MB	287.207 μV/Count
	3367MC	285.669 μV/Count
	3367MD	285.626 μV/Count
	3367ME	288.263 μV/Count
	3367MF	286.778 μV/Count

Sample Rate: 1 samples/sec

Channel:	3367MB	2.244 μV/Count
	3367MC	2.232 μV/Count
	3367MD	2.231 μV/Count
	3367ME	2.252 μV/Count
	3367MF	2.240 μV/Count

CMG-3T CALIBRATION SHEET

WORKS ORDER:	6411	DATE:	12-Jun-2013
SERIAL NUMBER:	T37829	TESTED BY:	S. Goddard

	Velocity Output V/m/s (Differential)	Mass Position Output (Acceleration output) V/m/s^2	Feedback Coil Constant Amp/m/s^2
VERTICAL	2 x 747	797	0.02416
NORTH/SOUTH	2 x 759	723	0.01539
EAST/WEST	2 x 751	727	0.01546

Power Consumption: 60mA @ +12V input
Calibration Resistor: 51000

NOTE: A factor of 2 x must be used when the sensor outputs are used differentially (also known as push-pull or balanced output). Under no conditions should the negative outputs be connected to the signal ground. A separate signal ground pin is provided.

POLES AND ZEROS TABLE

WORKS ORDER NUMBER: 6411

SENSOR SERIAL NO: T37829

Velocity response output, Vertical Sensor:

POLES (HZ)	**ZEROS HZ**
$-23.65 \times 10^{-3} \pm j23.65 \times 10^{-3}$	0
-180	0
-160	
-80	

Normalizing factor at 1 Hz: A = 2304000

Sensor Sensitivity: See Calibration Sheet.

Velocity response output, Horizontal Sensors:

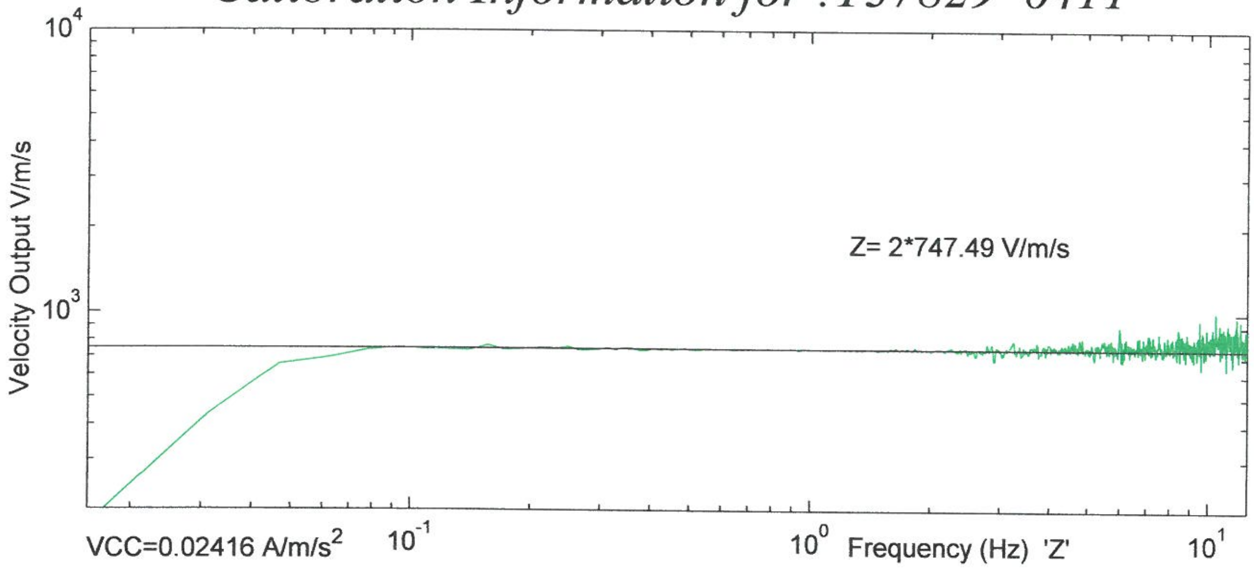
POLES (HZ)	**ZEROS (HZ)**
$-23.65 \times 10^{-3} \pm j23.65 \times 10^{-3}$	0
-180	0
-160	
-80	

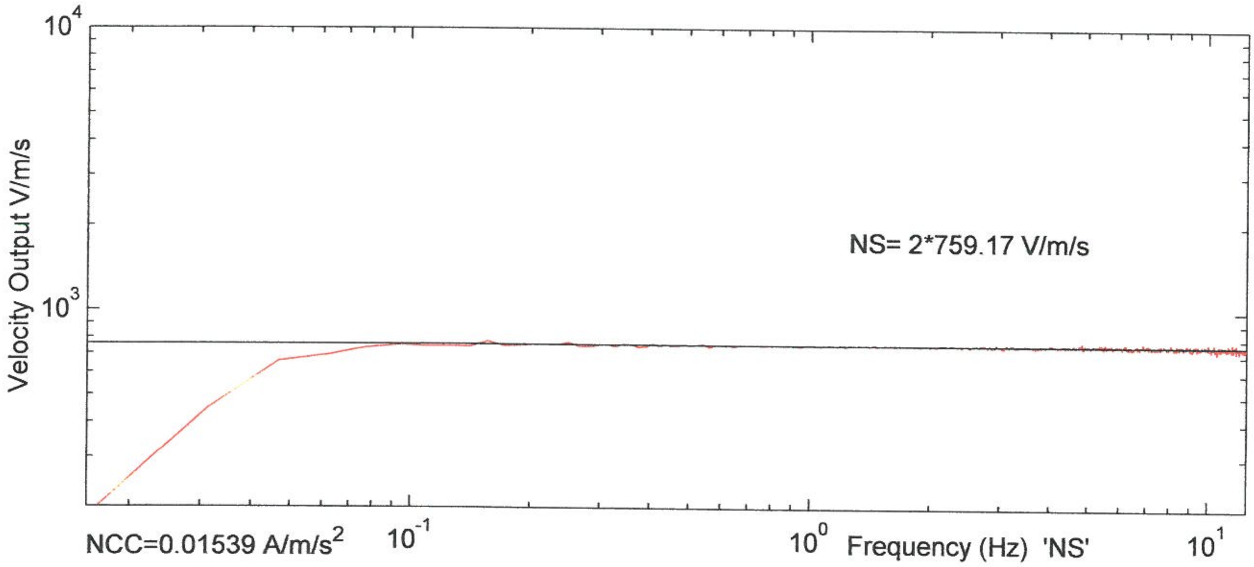
Normalizing factor at 1 Hz: A = 2304000

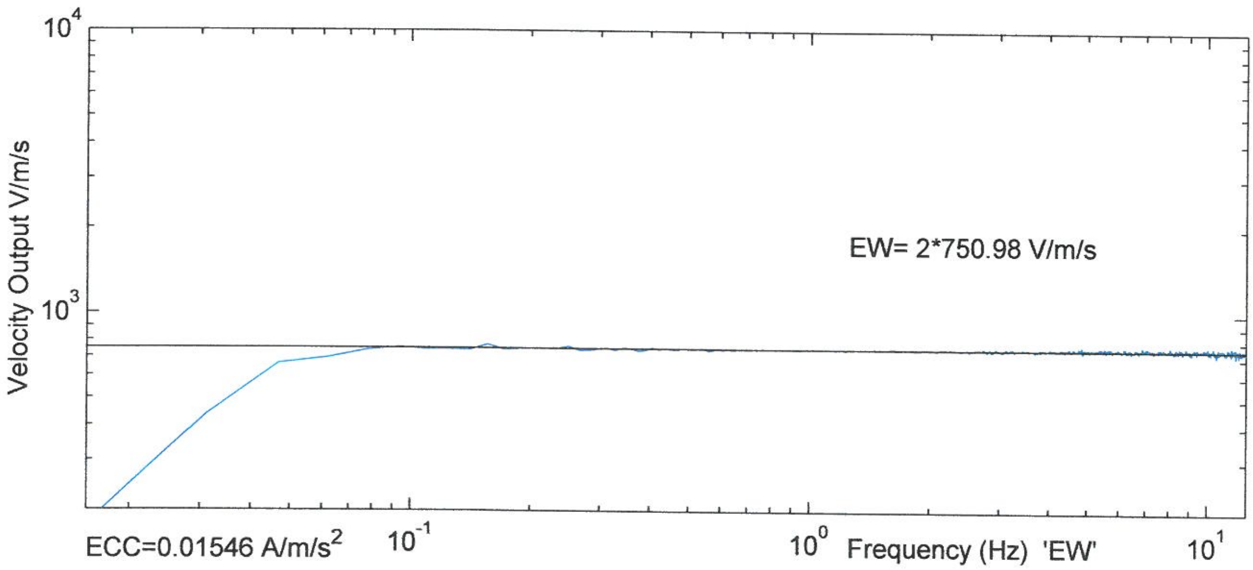
Sensor Sensitivity: See Calibration Sheet.

NOTE: The above poles and zeros apply to the vertical and the horizontal sensors and are given in units of Hz. To convert to Radian/sec multiply each pole or zero with 2π. The normalizing factor A should also be recalculated.

Calibration Information for :T37829 6411



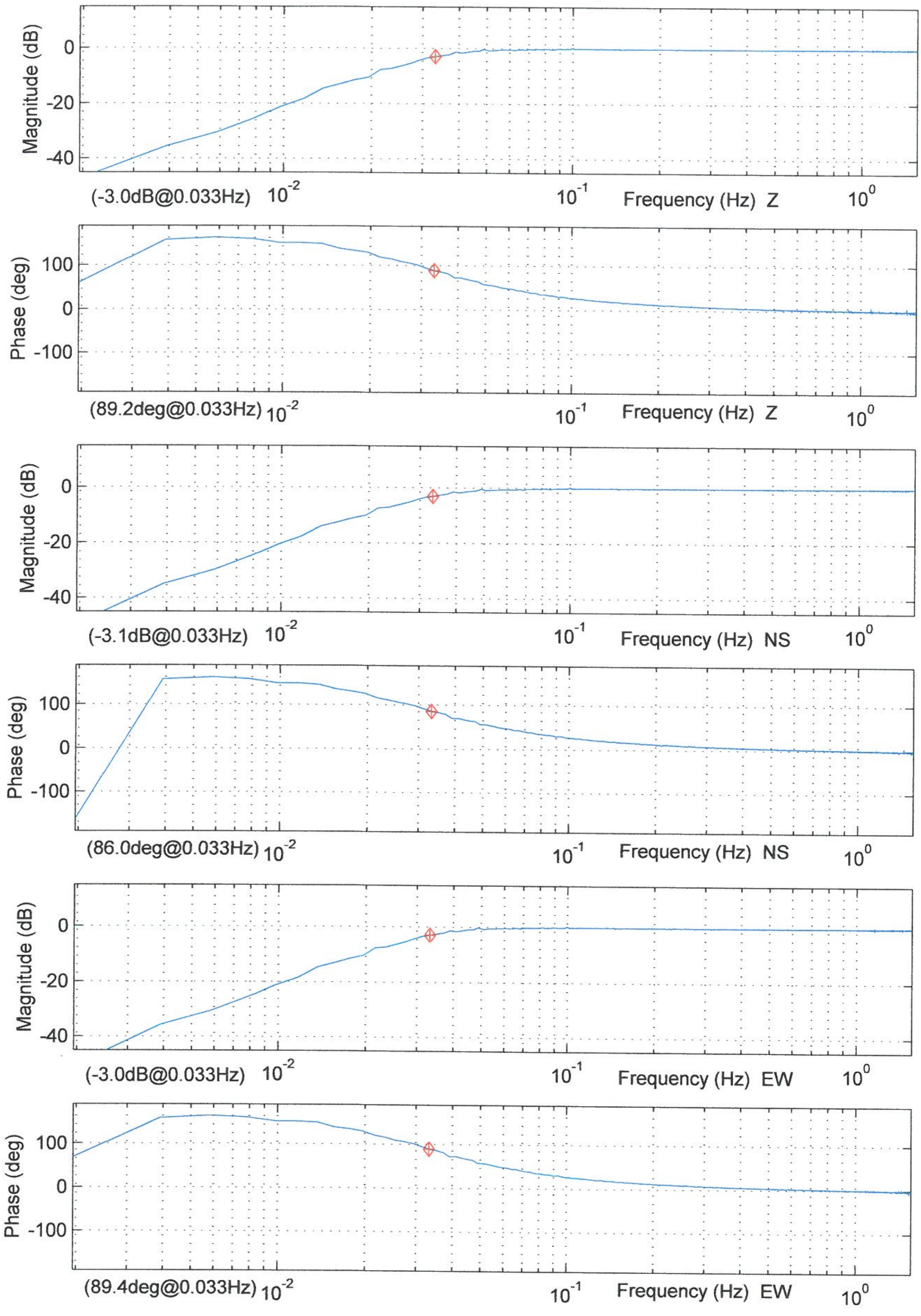




RCal =51000 Ohms

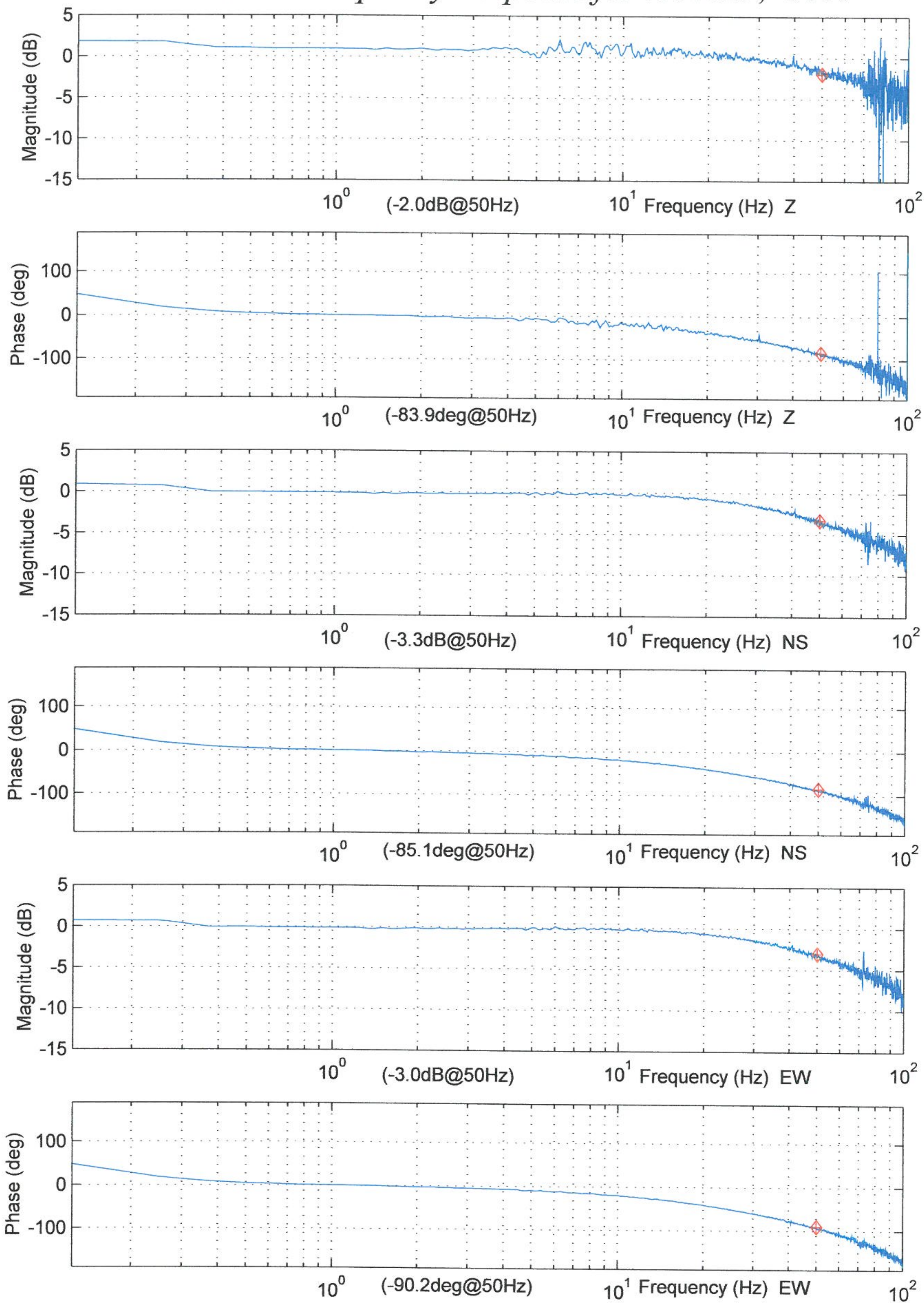
12-Jun-2013

Normalized Frequency Response for :T37829, 6411



12-Jun-2013

Normalized Frequency Response for :T37829, 6411



12-Jun-2013

CMG-5T ABSOLUTE CALIBRATION
(ACCELERATION OUTPUTS)

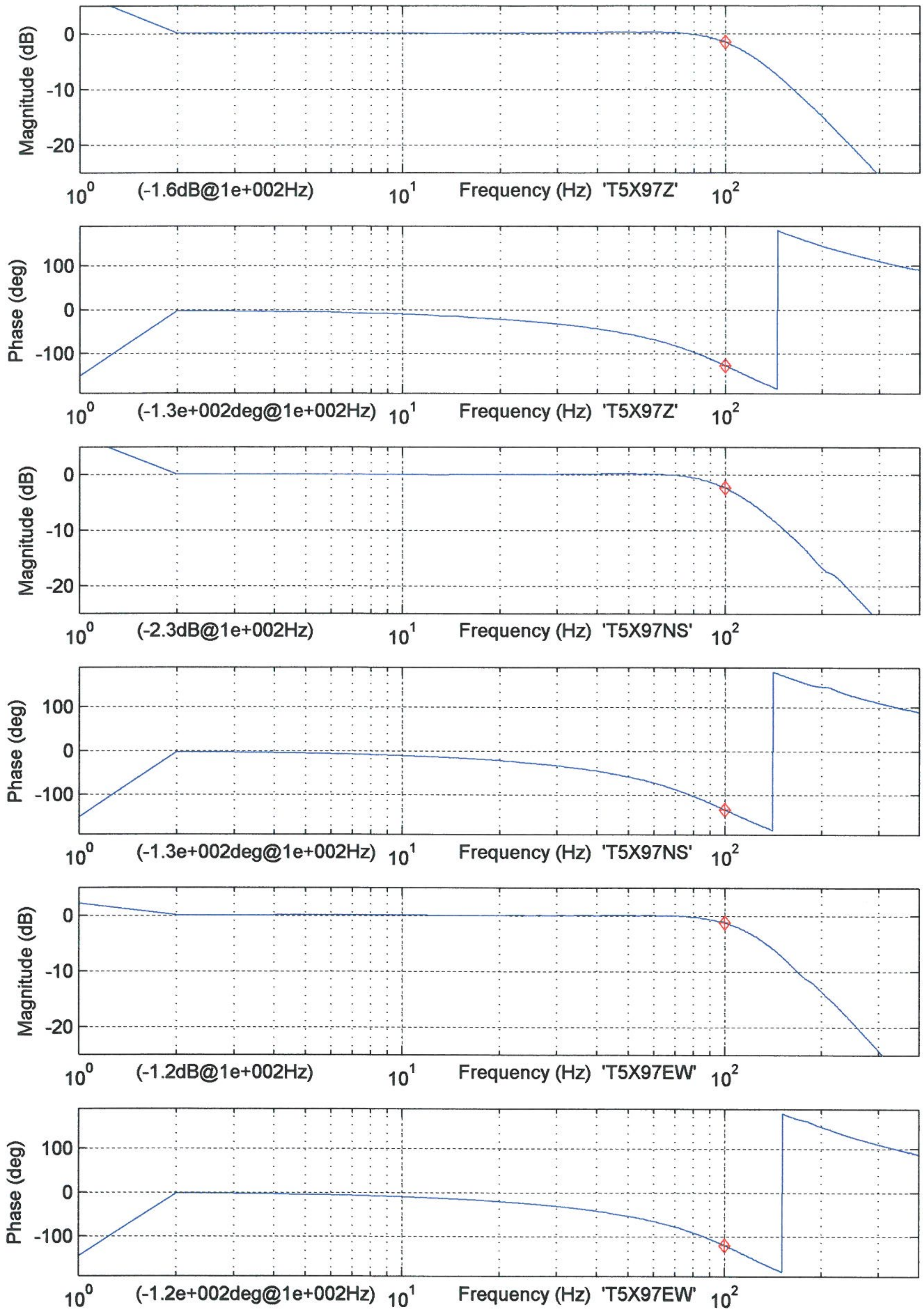
WORKS ORDER:	6411	DATE:	18/08/2011
SERIAL NUMBER:	T5X97	TESTED BY:	SH
		OUTPUT at 1g	5 volts

	Acceleration Response $V/m/s^2$
VERTICAL	2 x 0.508
NORTH/SOUTH	2 x 0.508
EAST/WEST	2 x 0.508

Vertical component equivalent acceleration from calibration signal of:	1 Volt = 0.984 m/s^2
North/South component equivalent acceleration from calibration signal of:	1 Volt = 0.984 m/s^2
East/West component equivalent acceleration from calibration signal of:	1 Volt = 0.984 m/s^2
Calibration enable signal polarity:	Active Low
Typical Current Consumption:	
This sensor operates from:	10 to 36 Volts

NOTE: A factor of 2 x must be used when the sensor outputs are used differentially (also known as push-pull or balanced output). Under no conditions should the negative outputs be connected to the signal ground. A separate signal ground pin is provided.

Frequency Response for :T5X97 'WO6411'



Low Gain Acceleration Output

18-Aug-2011

GURALP SYSTEMS

TEST AND CALIBRATION DATA

OBS System 2

EAM – 3901
DM24 – A3366
3T – T37831
5TC – T5AE5

DESIGNED AND MANUFACTURED BY:

GÜRALP SYSTEMS LIMITED
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ENGLAND

Telephone: +44 (0) 118 9819056 Fax: +44 (0) 118 9819943

DM24 CALIBRATION

WORKS ORDER: 12009 **DIGITISER SERIAL NUMBER:** A3366

SYSTEM ID:	12009	CPLD:	A0.E1
UNIT ID:	3366	BOOTLOADER:	MK3BOOT213.IMG
OUTPUT DATA FORMAT:	GCF	DSP SOFTWARE:	DSP1090.BIN
BAUD RATE:	38400	SYSTEM:	DMNET106b57d.IMG

VELOCITY CHANNELS

Channel:	3366Z2	Vertical	3.200 μV/Count
	3366N2	North/South	3.193 μV/Count
	3366E2	East/West	3.191 μV/Count
	3366Z3	Vertical	3.202 μV/Count
	3366N3	North/South	3.202 μV/Count
	3366E3	East/West	3.195 μV/Count

MASS POSITION CHANNELS

Sample Rate: 4 samples/sec (Default)

Channel:	3366M8	Vertical	288.123 μV/Count
	3366M9	North/South	286.768 μV/Count
	3366MA	East/West	287.821 μV/Count

Sample Rate: 1 samples/sec

Channel:	3366M8	Vertical	2.251 μV/Count
	3366M9	North/South	2.240 μV/Count
	3366MA	East/West	2.249 μV/Count

CAL SIGNAL MONITOR

3366X2/ C23366 3.192 μV/Count

GPS RECEIVER

PWM: 8000 Counts
At Temperature Reading: 23°C

POWER CONSUMPTION

Digitiser Power Consumption	80mA @ 12v
GPS Power Consumption	28mA @ 12v

AUXILIARY CHANNELS

Sample Rate: 4 samples/sec (Default)

Channel:	3366MB	288.275 μV/Count
	3366MC	289.535 μV/Count
	3366MD	289.273 μV/Count
	3366ME	288.947 μV/Count
	3366MF	290.082 μV/Count

Sample Rate: 1 samples/sec

Channel:	3366MB	2.252 μV/Count
	3366MC	2.262 μV/Count
	3366MD	2.260 μV/Count
	3366ME	2.257 μV/Count
	3366MF	2.266 μV/Count

CMG-3T CALIBRATION SHEET

WORKS ORDER:	6411	DATE:	12-Jun-2013
SERIAL NUMBER:	T37831	TESTED BY:	S. Goddard

	Velocity Output V/m/s (Differential)	Mass Position Output (Acceleration output) V/m/s^2	Feedback Coil Constant Amp/m/s^2
VERTICAL	2 x 749	794	0.02406
NORTH/SOUTH	2 x 748	699	0.01488
EAST/WEST	2 x 747	733	0.0156

Power Consumption: 60mA @ +12V input
Calibration Resistor: 51000

NOTE: A factor of 2 x must be used when the sensor outputs are used differentially (also known as push-pull or balanced output). Under no conditions should the negative outputs be connected to the signal ground. A separate signal ground pin is provided.

POLES AND ZEROS TABLE

WORKS ORDER NUMBER: 6411

SENSOR SERIAL NO: T37831

Velocity response output, Vertical Sensor:

POLES (HZ)	**ZEROS HZ**
$-23.65 \times 10^{-3} \pm j23.65 \times 10^{-3}$	0
-180	0
-160	
-80	

Normalizing factor at 1 Hz: A = 2304000

Sensor Sensitivity: See Calibration Sheet.

Velocity response output, Horizontal Sensors:

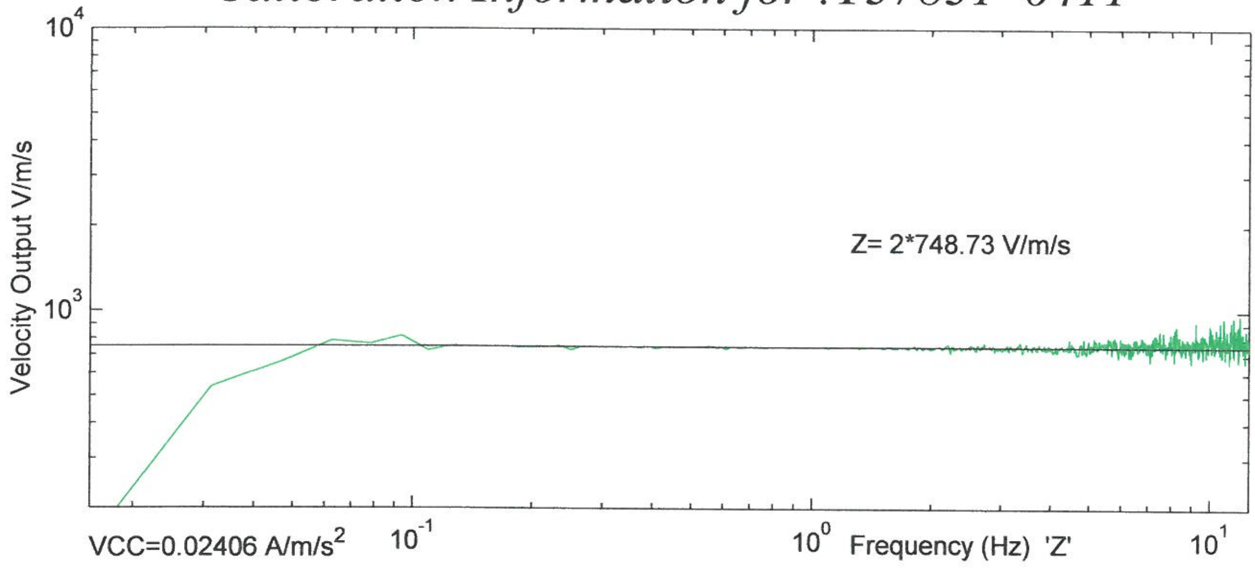
POLES (HZ)	**ZEROS (HZ)**
$-23.65 \times 10^{-3} \pm j23.65 \times 10^{-3}$	0
-180	0
-160	
-80	

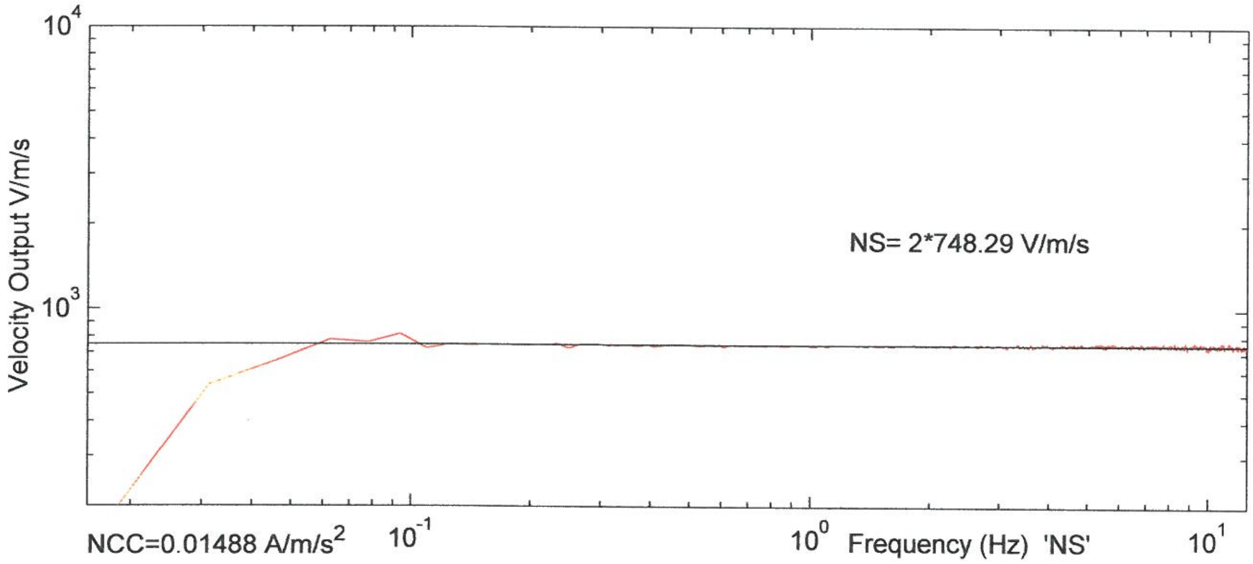
Normalizing factor at 1 Hz: A = 2304000

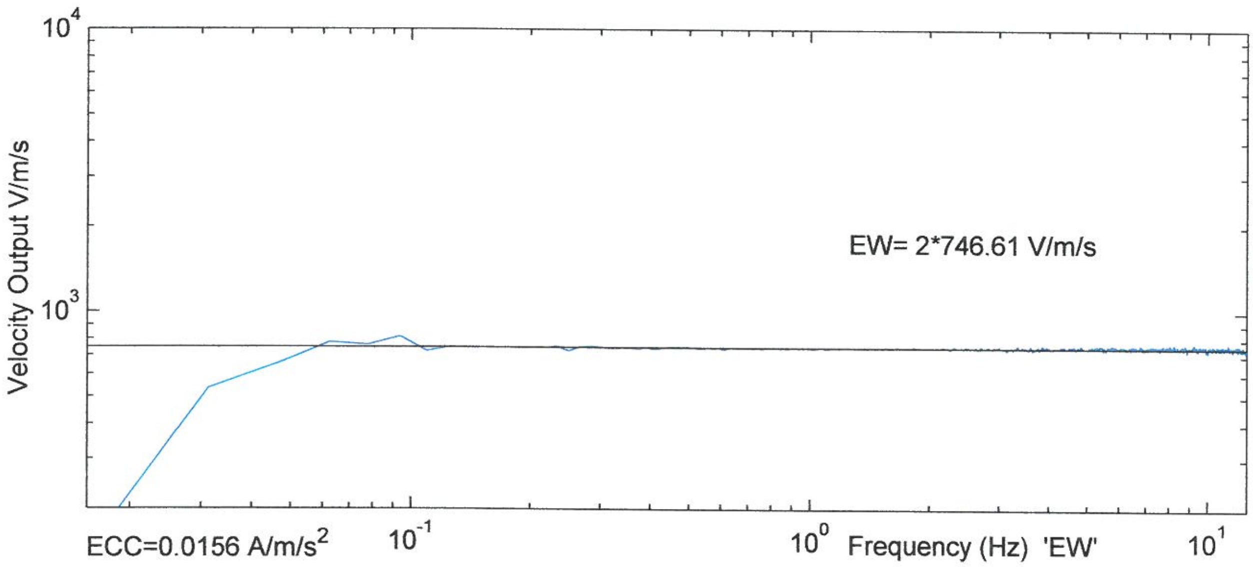
Sensor Sensitivity: See Calibration Sheet.

NOTE: The above poles and zeros apply to the vertical and the horizontal sensors and are given in units of Hz. To convert to Radian/sec multiply each pole or zero with 2π. The normalizing factor A should also be recalculated.

Calibration Information for :T37831 6411



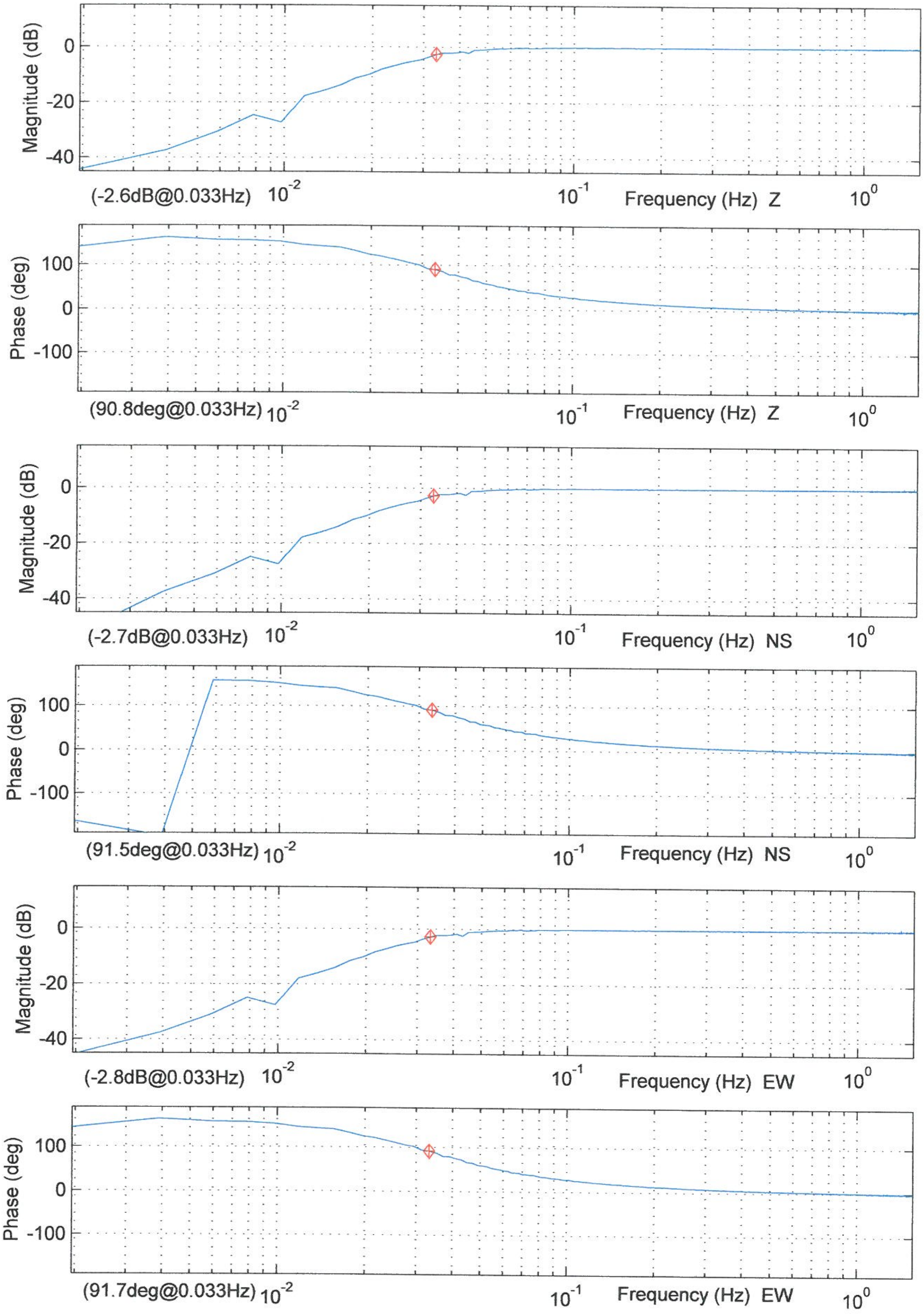




RCal =51000 Ohms

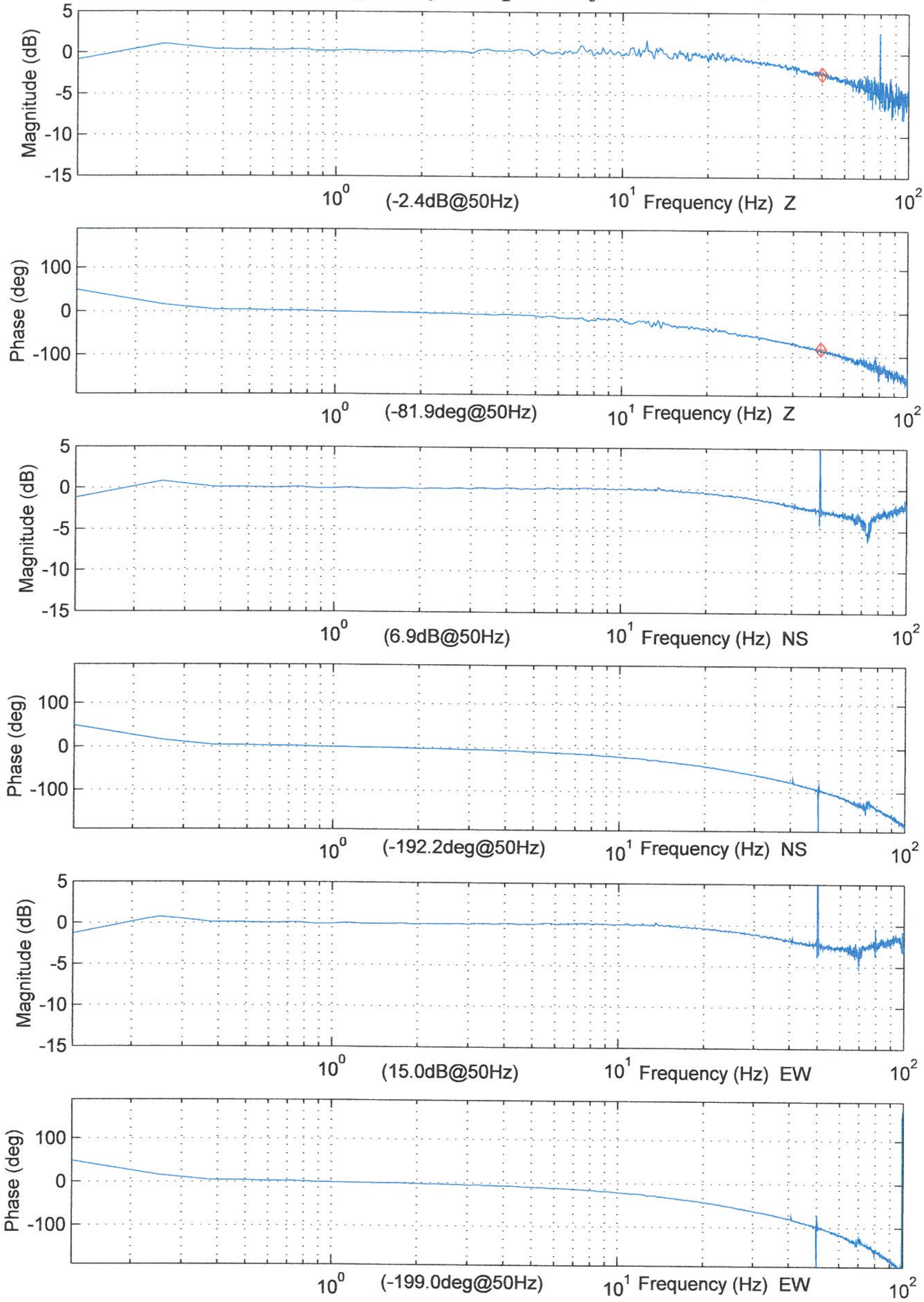
12-Jun-2013

Normalized Frequency Response for :T37831, 6411



12-Jun-2013

Normalized Frequency Response for :T37831, 6411



12-Jun-2013

CMG-5T ABSOLUTE CALIBRATION
(ACCELERATION OUTPUTS)

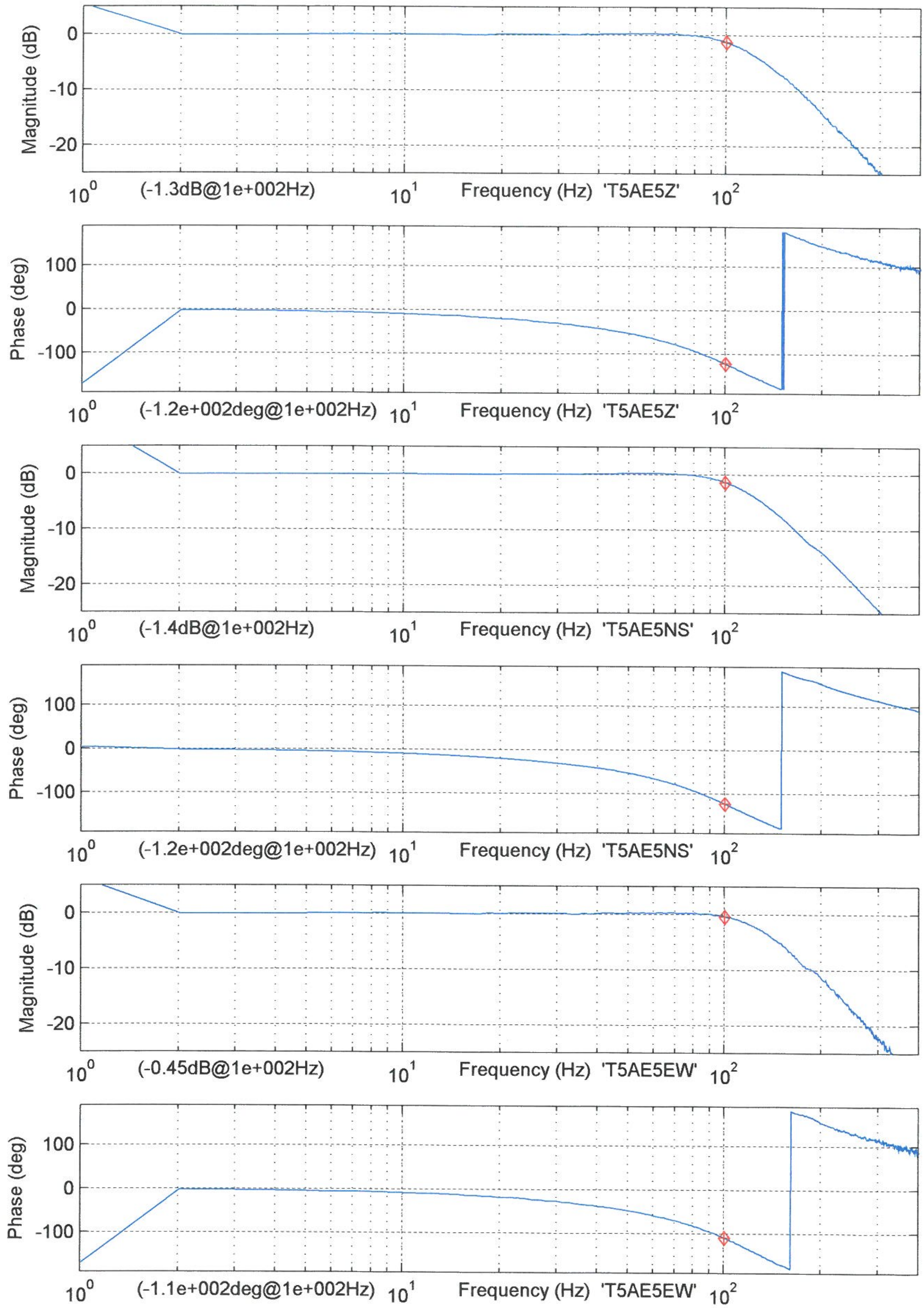
WORKS ORDER:	6411	DATE:	8/12/2011
SERIAL NUMBER:	T5AE5	TESTED BY:	SH
		OUTPUT at 1g	5 volts

	Acceleration Response $V/m/s^2$
VERTICAL	2 x 0.509
NORTH/SOUTH	2 x 0.511
EAST/WEST	2 x 0.509

Vertical component equivalent acceleration from calibration signal of:	1 Volt = $0.982 m/s^2$
North/South component equivalent acceleration from calibration signal of:	1 Volt = $0.978 m/s^2$
East/West component equivalent acceleration from calibration signal of:	1 Volt = $0.982 m/s^2$
Calibration enable signal polarity:	Active Low
Typical Current Consumption:	N/A
This sensor operates from:	10 to 36 Volts

NOTE: A factor of 2 x must be used when the sensor outputs are used differentially (also known as push-pull or balanced output). Under no conditions should the negative outputs be connected to the signal ground. A separate signal ground pin is provided.

Frequency Response for :T5AE5 'WO6411'



Low Gain Acceleration Output

12-Jun-2013

GURALP SYSTEMS

TEST AND CALIBRATION DATA

OBS System 3

EAM – 3902
DM24 – A3369
3T – T37832
5TC – T5Y00

DESIGNED AND MANUFACTURED BY:

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DM24 CALIBRATION

WORKS ORDER: 12009 **DIGITISER SERIAL NUMBER:** A3369

SYSTEM ID:	12009
UNIT ID:	3369
OUTPUT DATA FORMAT:	GCF
BAUD RATE:	38400
CPLD:	A0.E1
BOOTLOADER:	MK3BOOT213.IMG
DSP SOFTWARE:	DSP1090.BIN
SYSTEM:	DMNET106b57d.IMG

VELOCITY CHANNELS

Channel:	3369Z2	Vertical	3.202 μV/Count
	3369N2	North/South	3.208 μV/Count
	3369E2	East/West	3.195 μV/Count
	3369Z3	Vertical	3.190 μV/Count
	3369N3	North/South	3.201 μV/Count
	3369E3	East/West	3.196 μV/Count

MASS POSITION CHANNELS

Sample Rate: 4 samples/sec (Default)

Channel:	3369M8	Vertical	288.346 μV/Count
	3369M9	North/South	287.612 μV/Count
	3369MA	East/West	288.216 μV/Count

Sample Rate: 1 samples/sec

Channel:	3369M8	Vertical	2.253 μV/Count
	3369M9	North/South	2.247 μV/Count
	3369MA	East/West	2.252 μV/Count

CAL SIGNAL MONITOR

3369X2/ C23369 3.180 μV/Count

GPS RECEIVER

PWM: 8000 Counts
At Temperature Reading: 23°C

POWER CONSUMPTION

Digitiser Power Consumption	80mA @ 12v
GPS Power Consumption	28mA @ 12v

AUXILIARY CHANNELS

Sample Rate: 4 samples/sec (Default)

Channel:	3369MB	286.946 µV/Count
	3369MC	288.650 µV/Count
	3369MD	287.440 µV/Count
	3369ME	288.563 µV/Count
	3369MF	287.763 µV/Count

Sample Rate: 1 samples/sec

Channel:	3369MB	2.242 µV/Count
	3369MC	2.255 µV/Count
	3369MD	2.246 µV/Count
	3369ME	2.254 µV/Count
	3369MF	2.248 µV/Count

CMG-3T CALIBRATION SHEET

WORKS ORDER: 6411 DATE: 12-Jun-2013

SERIAL NUMBER: T37832 TESTED BY: S. Goddard

	Velocity Output V/m/s (Differential)	Mass Position Output (Acceleration output) $V/m/s^2$	Feedback Coil Constant $Amp/m/s^2$
VERTICAL	2 x 748	799	0.02422
NORTH/SOUTH	2 x 749	727	0.01546
EAST/WEST	2 x 750	768	0.01633

Power Consumption: 60mA @ +12V input
Calibration Resistor: 51000

NOTE: A factor of 2 x must be used when the sensor outputs are used differentially (also known as push-pull or balanced output). Under no conditions should the negative outputs be connected to the signal ground. A separate signal ground pin is provided.

POLES AND ZEROS TABLE

WORKS ORDER NUMBER: 6411

SENSOR SERIAL NO: T37832

Velocity response output, Vertical Sensor:

POLES (HZ)	ZEROS HZ
$-23.65 \times 10^{-3} \pm j23.65 \times 10^{-3}$	0
-180	0
-160	
-80	

Normalizing factor at 1 Hz: A = 2304000

Sensor Sensitivity: See Calibration Sheet.

Velocity response output, Horizontal Sensors:

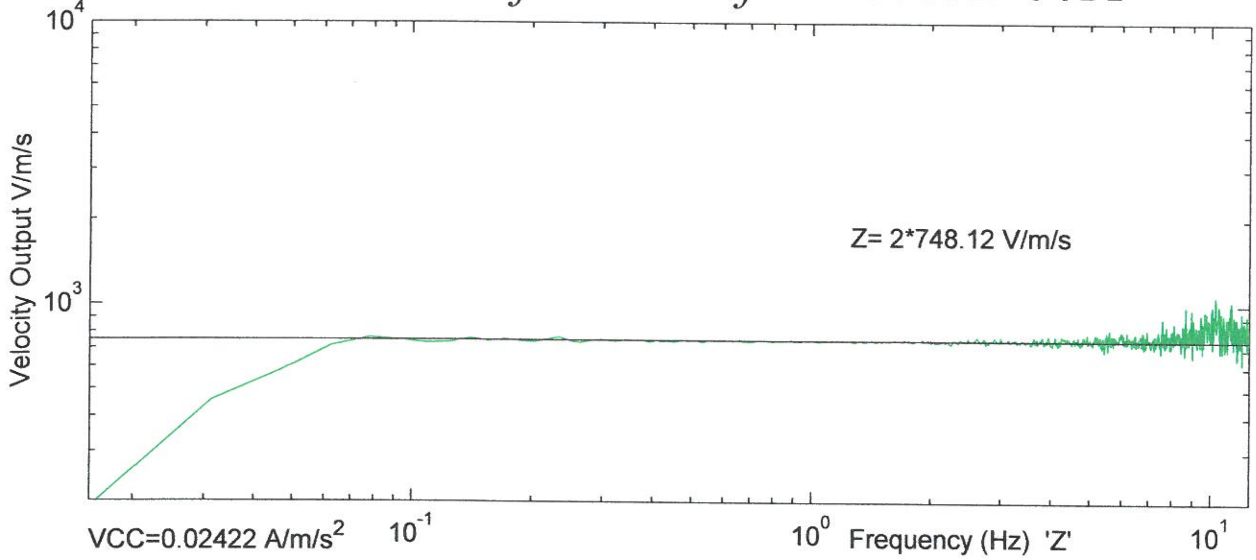
POLES (HZ)	ZEROS (HZ)
$-23.65 \times 10^{-3} \pm j23.65 \times 10^{-3}$	0
-180	0
-160	
-80	

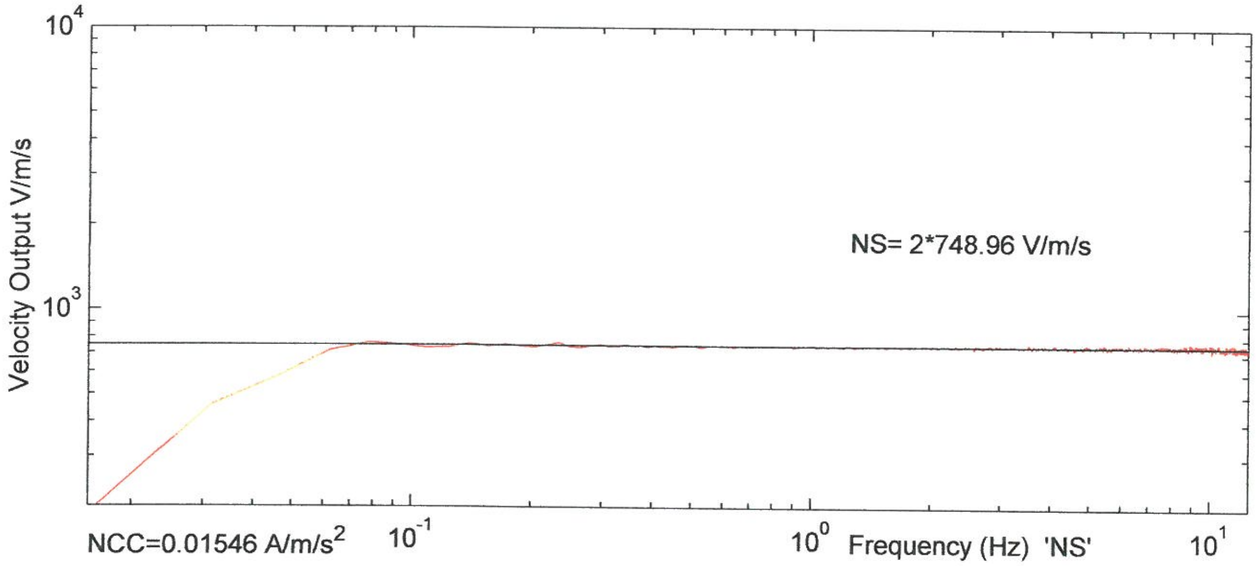
Normalizing factor at 1 Hz: A = 2304000

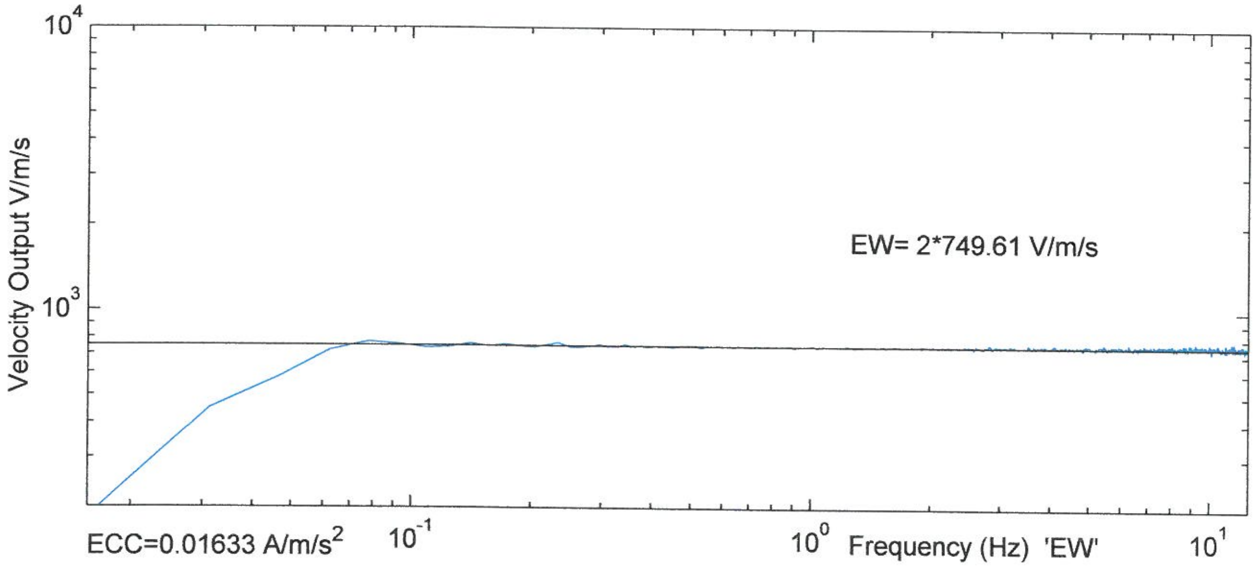
Sensor Sensitivity: See Calibration Sheet.

NOTE: The above poles and zeros apply to the vertical and the horizontal sensors and are given in units of Hz. To convert to Radian/sec multiply each pole or zero with 2π. The normalizing factor A should also be recalculated.

Calibration Information for :T37832 6411



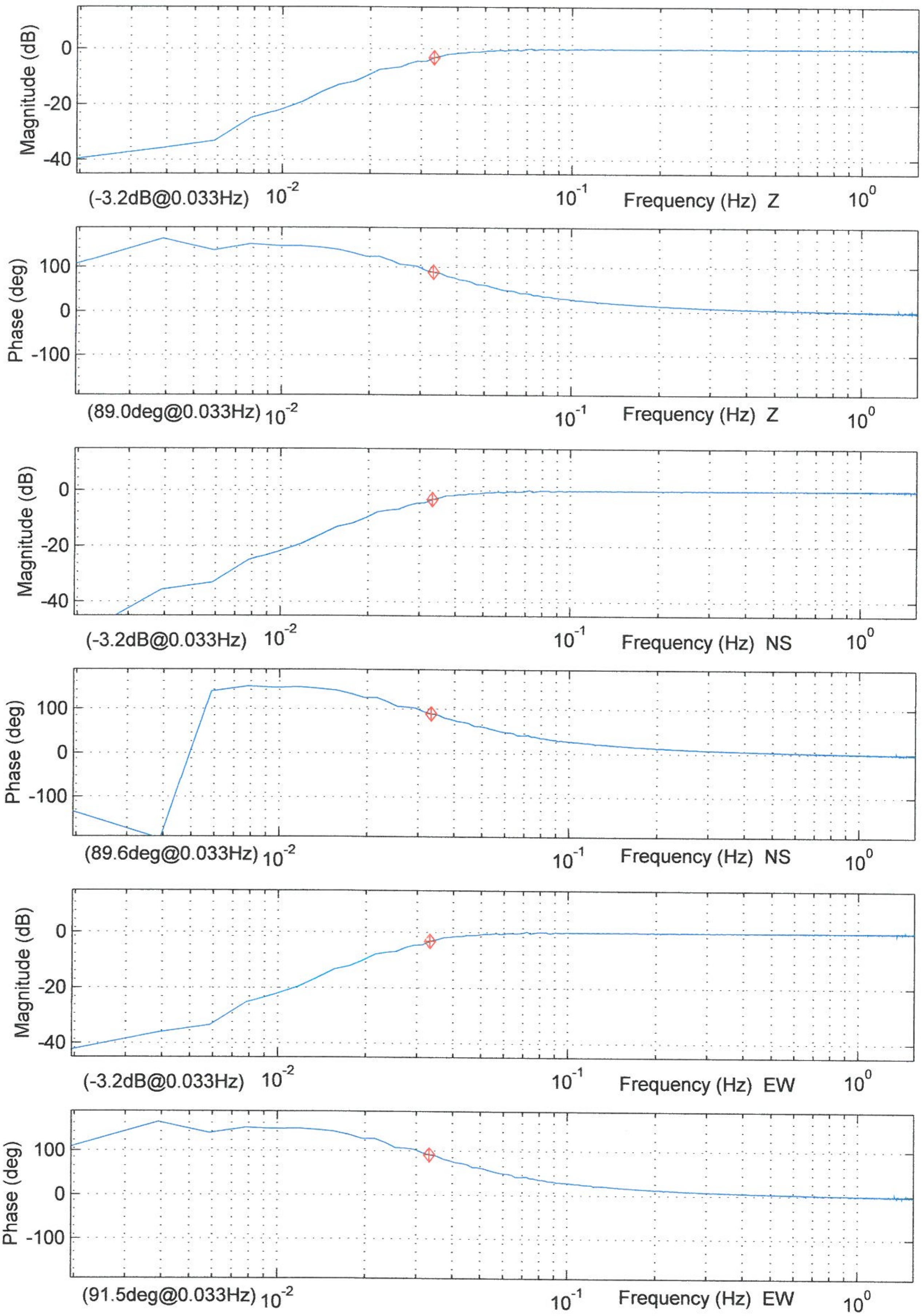




RCal =51000 Ohms

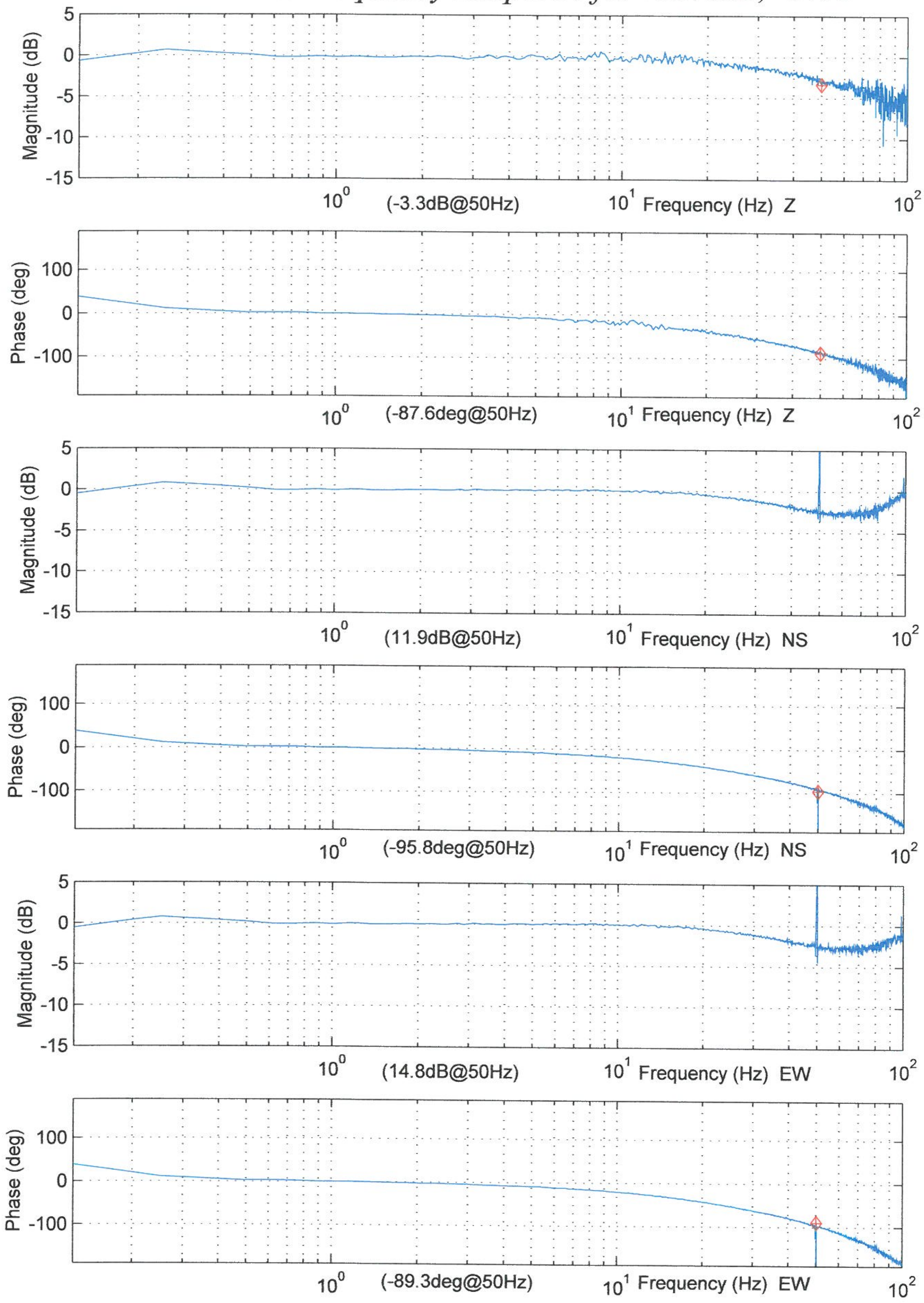
12-Jun-2013

Normalized Frequency Response for :T37832, 6411



12-Jun-2013

Normalized Frequency Response for :T37832, 6411



12-Jun-2013

CMG-5T ABSOLUTE CALIBRATION
(ACCELERATION OUTPUTS)

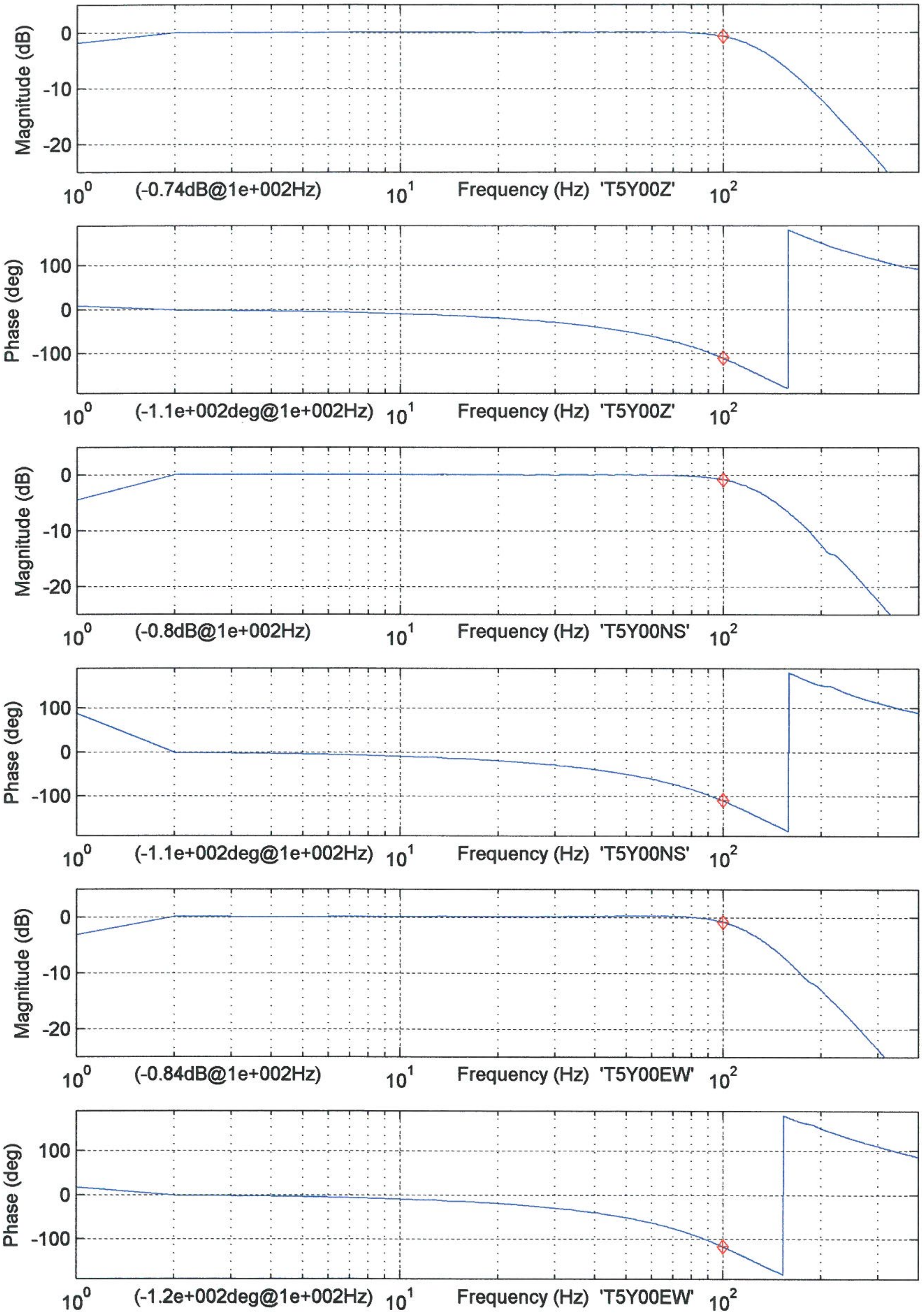
WORKS ORDER:	6411	DATE:	18/08/2011
SERIAL NUMBER:	T5Y00	TESTED BY:	SH
		OUTPUT at 1g	5 volts

	Acceleration Response $V/m/s^2$
VERTICAL	2 x 0.510
NORTH/SOUTH	2 x 0.509
EAST/WEST	2 x 0.509

Vertical component equivalent acceleration from calibration signal of:	1 Volt = 0.980 m/s^2
North/South component equivalent acceleration from calibration signal of:	1 Volt = 0.982 m/s^2
East/West component equivalent acceleration from calibration signal of:	1 Volt = 0.982 m/s^2
Calibration enable signal polarity:	Active Low
Typical Current Consumption:	
This sensor operates from:	10 to 36 Volts

NOTE: A factor of 2 x must be used when the sensor outputs are used differentially (also known as push-pull or balanced output). Under no conditions should the negative outputs be connected to the signal ground. A separate signal ground pin is provided.

Frequency Response for :T5Y00 'WO6411'



Low Gain Acceleration Output

18-Aug-2011

GURALP SYSTEMS

TEST AND CALIBRATION DATA

OBS System 4

EAM – 3900
DM24 – A3370
3T – T37830
5TC – T5X98
Differential Pressure Gauge - 9055

DESIGNED AND MANUFACTURED BY:

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DM24 CALIBRATION

WORKS ORDER: 12009 **DIGITISER SERIAL NUMBER:** A3370

SYSTEM ID:	12009	CPLD:	A0.E1
UNIT ID:	3370	BOOTLOADER:	MK3BOOT213.IMG
OUTPUT DATA FORMAT:	GCF	DSP SOFTWARE:	DSP1090.BIN
BAUD RATE:	38400	SYSTEM:	DMNET106b57d.IMG

VELOCITY CHANNELS

Channel:	3370Z2	Vertical	3.196 µV/Count
	3370N2	North/South	3.190 µV/Count
	3370E2	East/West	3.203 µV/Count
	3370Z3	Vertical	3.201 µV/Count
	3370N3	North/South	3.189 µV/Count
	3370E3	East/West	3.193 µV/Count

MASS POSITION CHANNELS

Sample Rate: 4 samples/sec (Default)

Channel:	3370M8	Vertical	287.818 µV/Count
	3370M9	North/South	289.358 µV/Count
	3370MA	East/West	288.185 µV/Count

Sample Rate: 1 samples/sec

Channel:	3370M8	Vertical	2.249 µV/Count
	3370M9	North/South	2.261 µV/Count
	3370MA	East/West	2.251 µV/Count

CAL SIGNAL MONITOR

3370X2/ C23370 3.192 µV/Count

GPS RECEIVER

PWM: 8000 Counts
At Temperature Reading: 23°C

POWER CONSUMPTION

Digitiser Power Consumption	80mA @ 12v
GPS Power Consumption	28mA @ 12v

AUXILIARY CHANNELS

Sample Rate: 4 samples/sec (Default)

Channel:	3370MB	288.618 μV/Count
	3370MC	290.123 μV/Count
	3370MD	288.922 μV/Count
	3370ME	289.162 μV/Count
	3370MF	287.301 μV/Count

Sample Rate: 1 samples/sec

Channel:	3370MB	2.255 μV/Count
	3370MC	2.267 μV/Count
	3370MD	2.257 μV/Count
	3370ME	2.259 μV/Count
	3370MF	2.245 μV/Count

CMG-3T CALIBRATION SHEET

WORKS ORDER: 6411 DATE: 12-Jun-2013

SERIAL NUMBER: T37830 TESTED BY: S. Goddard

	Velocity Output V/m/s (Differential)	Mass Position Output (Acceleration output) $V/m/s^2$	Feedback Coil Constant $Amp/m/s^2$
VERTICAL	2 x 748	816	0.02473
NORTH/SOUTH	2 x 751	725	0.01543
EAST/WEST	2 x 752	725	0.01543

Power Consumption: 60mA @ +12V input
Calibration Resistor: 51000

NOTE: A factor of 2 x must be used when the sensor outputs are used differentially (also known as push-pull or balanced output). Under no conditions should the negative outputs be connected to the signal ground. A separate signal ground pin is provided.

POLES AND ZEROS TABLE

WORKS ORDER NUMBER: 6411

SENSOR SERIAL NO: T37830

Velocity response output, Vertical Sensor:

POLES (HZ)	**ZEROS HZ**
$-23.65 \times 10^{-3} \pm j23.65 \times 10^{-3}$	0
-180	0
-160	
-80	

Normalizing factor at 1 Hz: A = 2304000

Sensor Sensitivity: See Calibration Sheet.

Velocity response output, Horizontal Sensors:

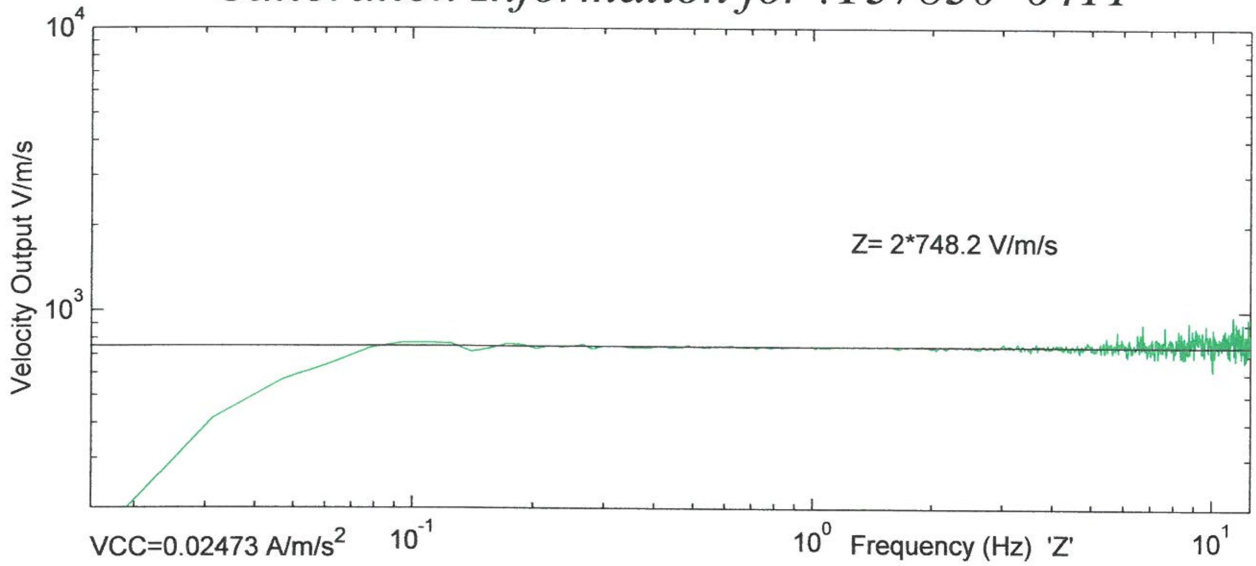
POLES (HZ)	**ZEROS (HZ)**
$-23.65 \times 10^{-3} \pm j23.65 \times 10^{-3}$	0
-180	0
-160	
-80	

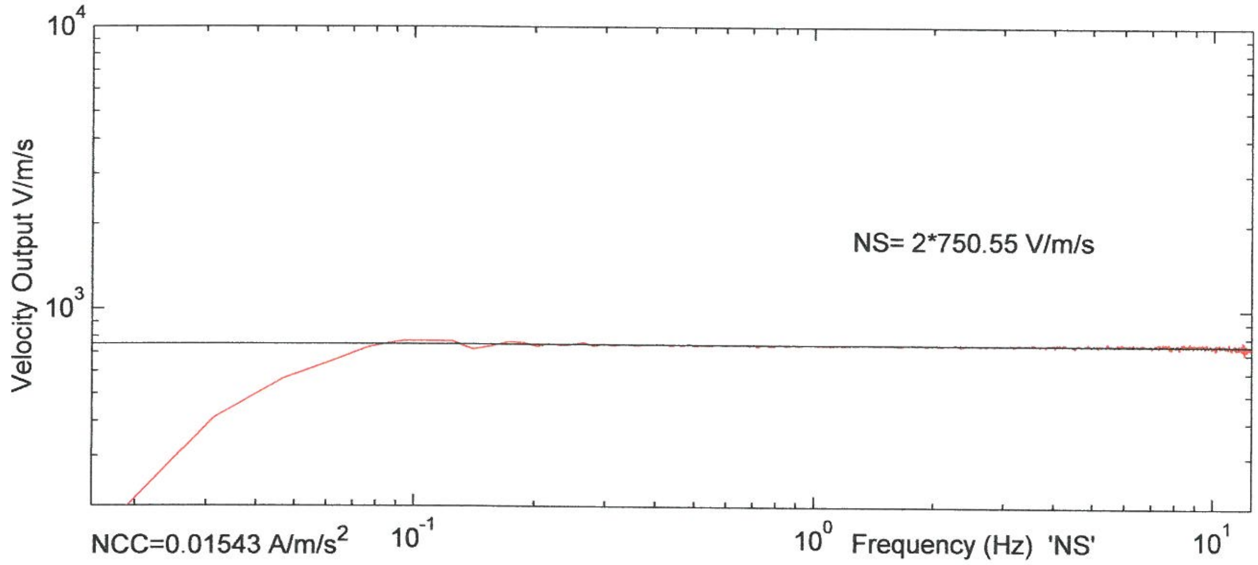
Normalizing factor at 1 Hz: A = 2304000

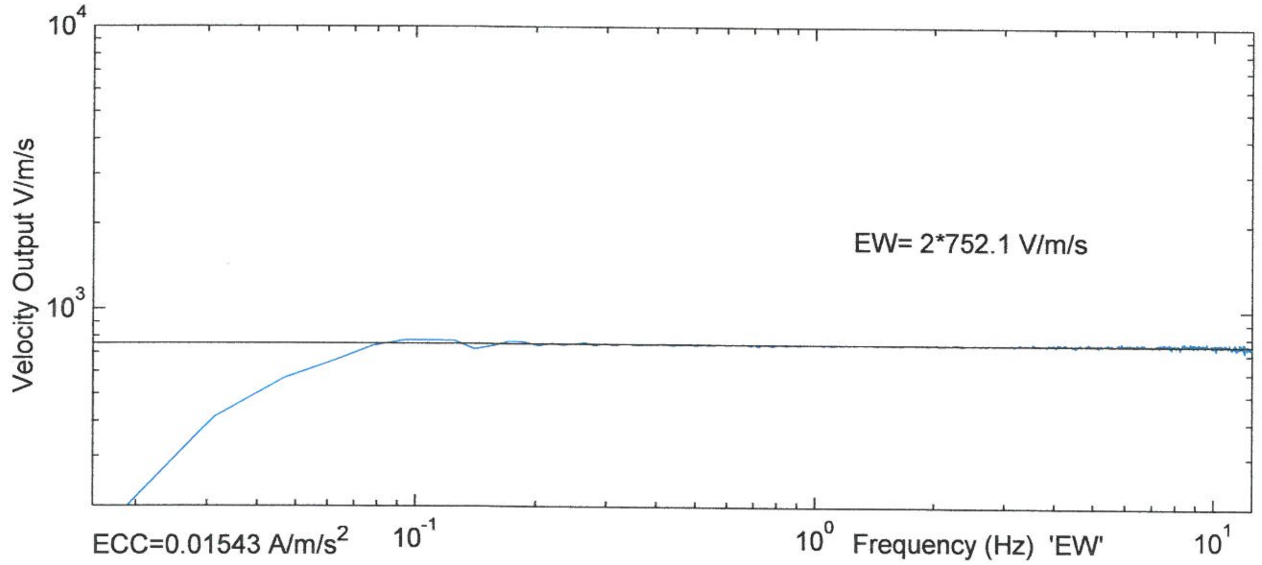
Sensor Sensitivity: See Calibration Sheet.

NOTE: The above poles and zeros apply to the vertical and the horizontal sensors and are given in units of Hz. To convert to Radian/sec multiply each pole or zero with 2π. The normalizing factor A should also be recalculated.

Calibration Information for :T37830 6411



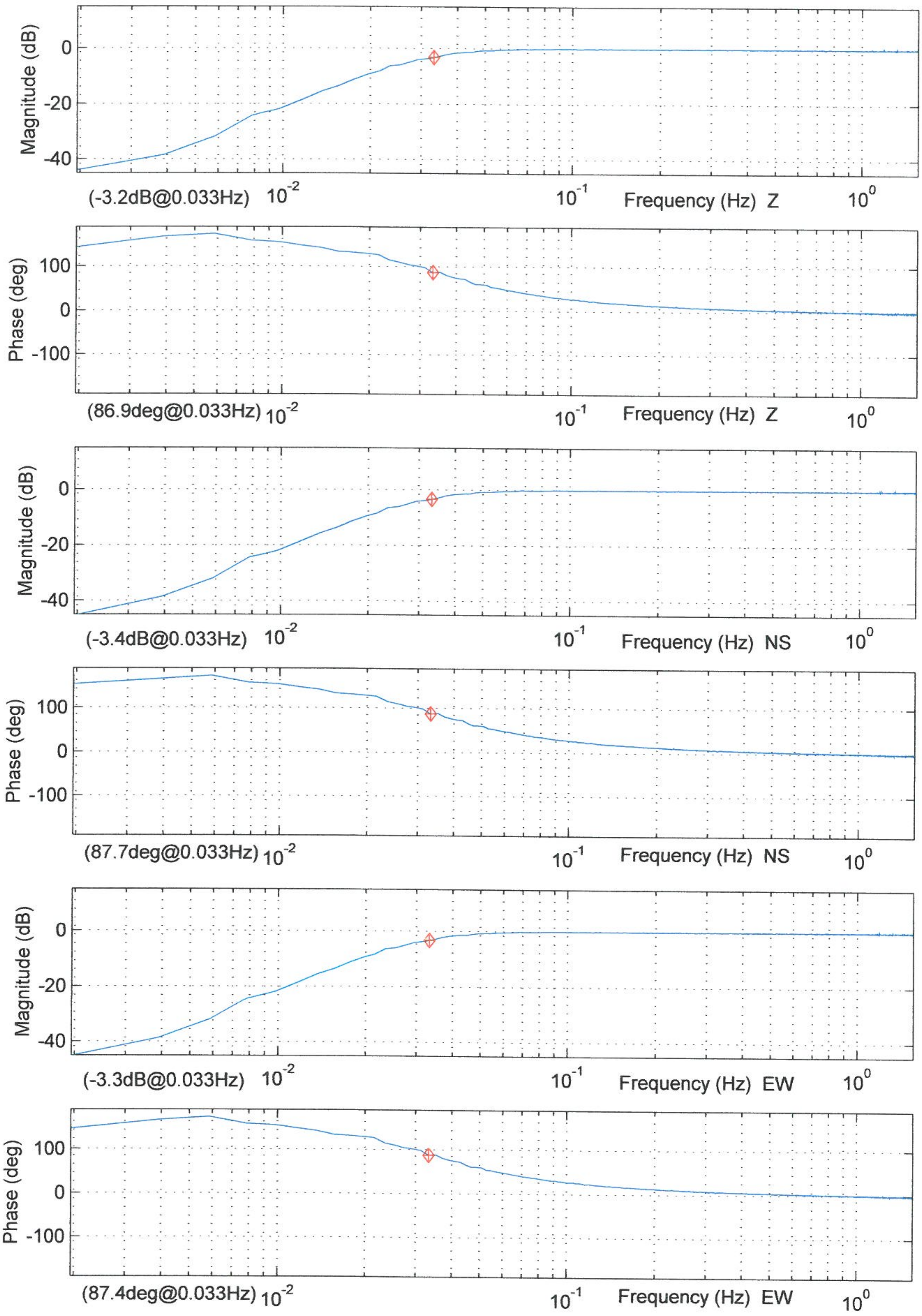




RCal =51000 Ohms

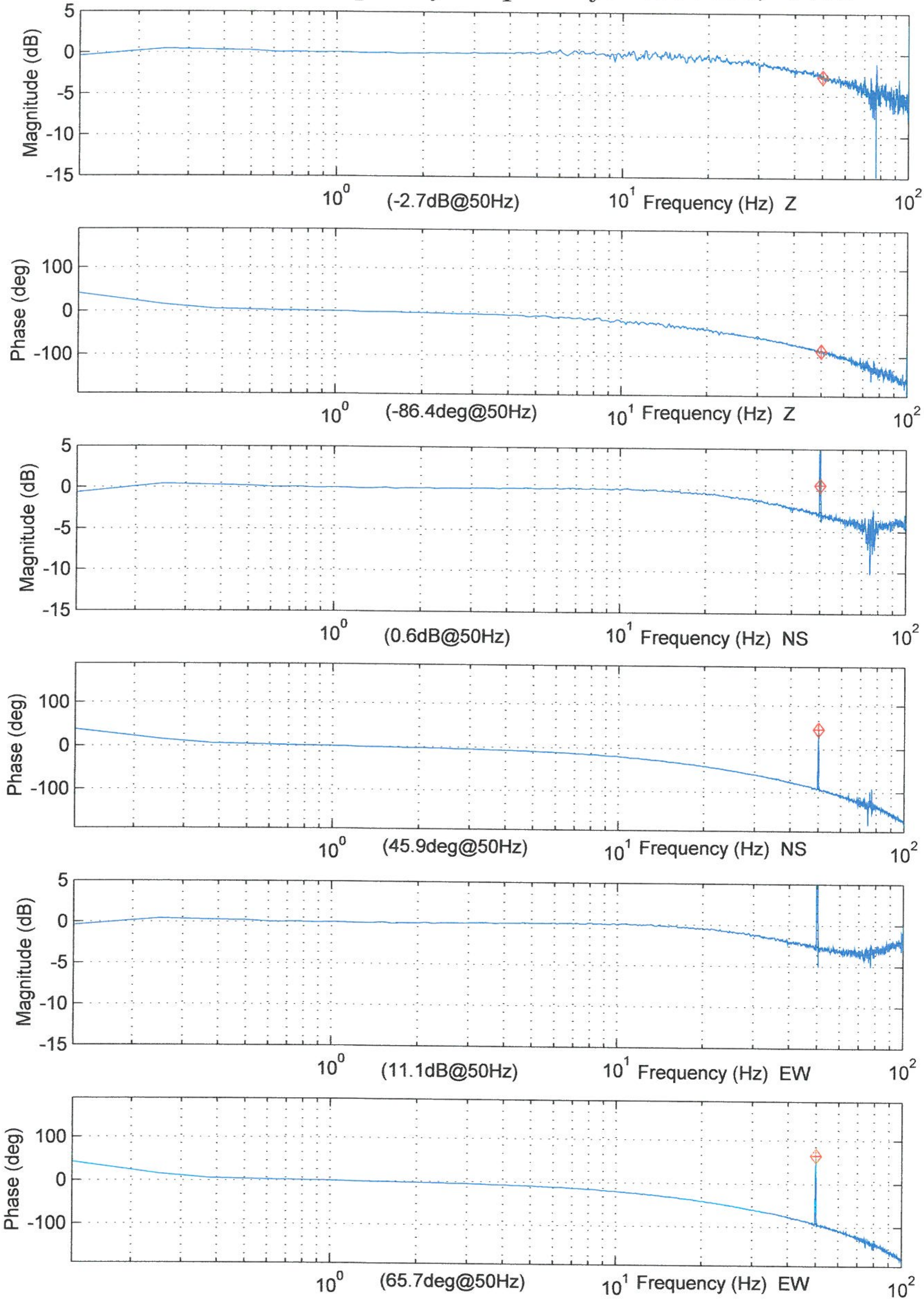
12-Jun-2013

Normalized Frequency Response for :T37830, 6411



12-Jun-2013

Normalized Frequency Response for :T37830, 6411



12-Jun-2013

CMG-5T ABSOLUTE CALIBRATION
(ACCELERATION OUTPUTS)

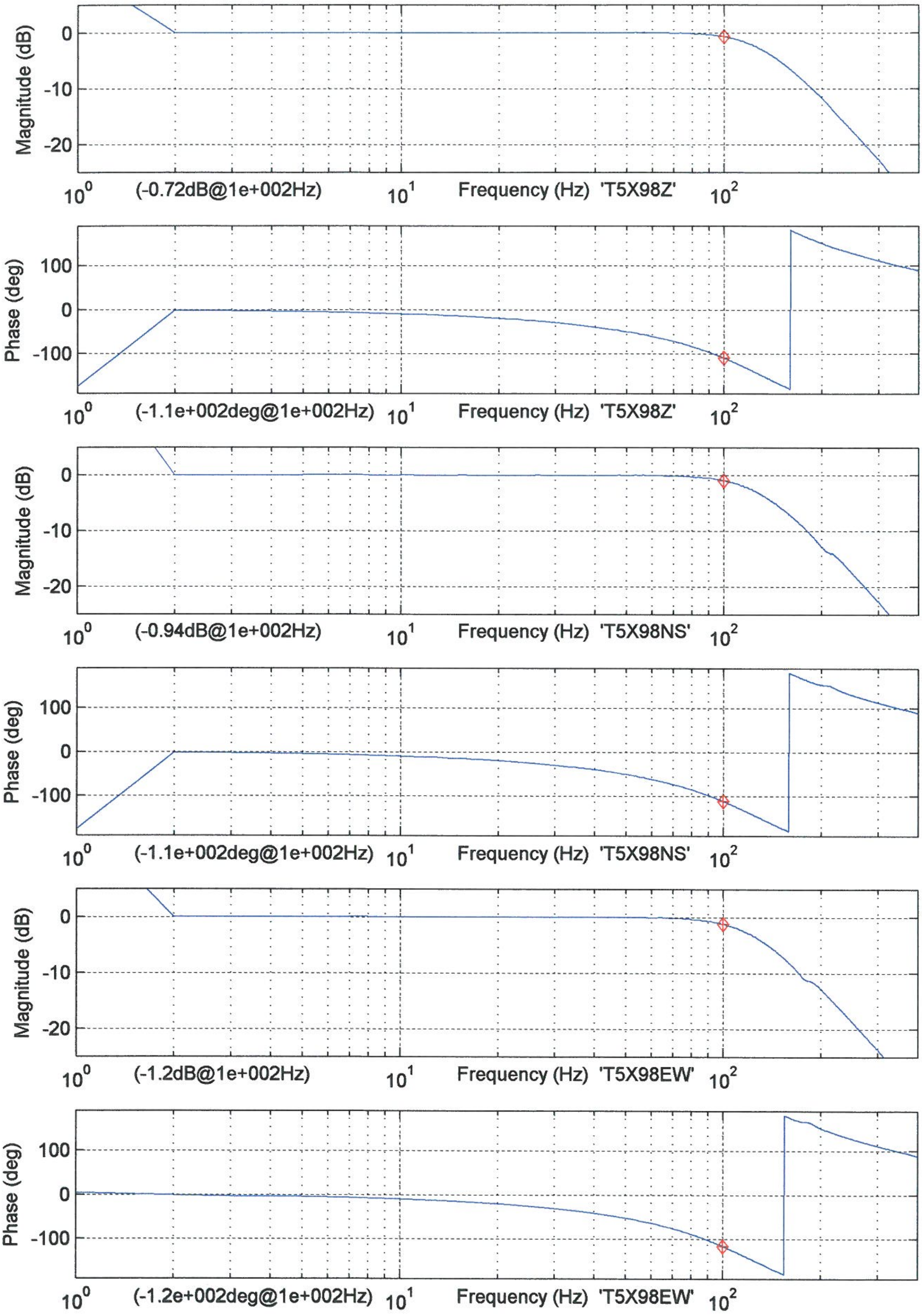
WORKS ORDER:	6411	DATE:	18/08/2011
SERIAL NUMBER:	T5X98	TESTED BY:	SH
		OUTPUT at 1g	5 volts

	Acceleration Response $V/m/s^2$
VERTICAL	2 x 0.509
NORTH/SOUTH	2 x 0.510
EAST/WEST	2 x 0.510

Vertical component equivalent acceleration from calibration signal of:	1 Volt = 0.982 m/s^2
North/South component equivalent acceleration from calibration signal of:	1 Volt = 0.980 m/s^2
East/West component equivalent acceleration from calibration signal of:	1 Volt = 0.980 m/s^2
Calibration enable signal polarity:	Active Low
Typical Current Consumption:	
This sensor operates from:	10 to 36 Volts

NOTE: A factor of 2 x must be used when the sensor outputs are used differentially (also known as push-pull or balanced output). Under no conditions should the negative outputs be connected to the signal ground. A separate signal ground pin is provided.

Frequency Response for :T5X98 'WO6411'



Low Gain Acceleration Output

18-Aug-2011

Differential Pressure Gauge Calibration Sheet

Works Order Number: 6411 **Serial Number:** 9055

Reference Volume = 31,184 cc

DPG Volume = 2859 cc

Effective Volume = 28325 cc

Difference in Pressure at each step $= \frac{1\ \text{cc}}{28325\ \text{cc}} \times 100{,}900\ \text{Pa}$

$= 3.56$ Pa

Step 1	+3.56 Pa	increased by	+3120 counts
Step 2	- 3.56 Pa	decreased by	- 2928 counts
Step 3	+3.56 Pa	increased by	+2928 counts
Step 4	- 3.56 Pa	decreased by	- 3056 counts

Mean Sensitivity = 844.9 counts / Pa

= 1.184 mPa / count

GURALP SYSTEMS

TEST AND CALIBRATION DATA

OBS System 5

EAM – 3903
DM24 – A3368
3T – T37833
5TC – T5Y01

DESIGNED AND MANUFACTURED BY:

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DM24 CALIBRATION

WORKS ORDER: 12009 **DIGITISER SERIAL NUMBER:** A3368

SYSTEM ID:	12009	CPLD:	A0.E1
UNIT ID:	3368	BOOTLOADER:	MK3BOOT213.IMG
OUTPUT DATA FORMAT:	GCF	DSP SOFTWARE:	DSP1090.BIN
BAUD RATE:	38400	SYSTEM:	DMNET106b57d.IMG

VELOCITY CHANNELS

Channel:	3368Z2	Vertical	3.190 µV/Count
	3368N2	North/South	3.187 µV/Count
	3368E2	East/West	3.199 µV/Count
	3368Z3	Vertical	3.182 µV/Count
	3368N3	North/South	3.193 µV/Count
	3368E3	East/West	3.192 µV/Count

MASS POSITION CHANNELS

Sample Rate: 4 samples/sec (Default)

Channel:	3368M8	Vertical	286.443 µV/Count
	3368M9	North/South	286.230 µV/Count
	3368MA	East/West	287.903 µV/Count

Sample Rate: 1 samples/sec

Channel:	3368M8	Vertical	2.238 µV/Count
	3368M9	North/South	2.236 µV/Count
	3368MA	East/West	2.249 µV/Count

CAL SIGNAL MONITOR

3368X2/ C23368 3.202 µV/Count

GPS RECEIVER

PWM: 8000 Counts
At Temperature Reading: 23°C

POWER CONSUMPTION

Digitiser Power Consumption	80mA @ 12v
GPS Power Consumption	28mA @ 12v

AUXILIARY CHANNELS

Sample Rate: 4 samples/sec (Default)

Channel:	3368MB	286.935 μV/Count
	3368MC	285.953 μV/Count
	3368MD	285.422 μV/Count
	3368ME	287.386 μV/Count
	3368MF	287.709 μV/Count

Sample Rate: 1 samples/sec

Channel:	3368MB	2.242 μV/Count
	3368MC	2.234 μV/Count
	3368MD	2.230 μV/Count
	3368ME	2.245 μV/Count
	3368MF	2.248 μV/Count

CMG-3T CALIBRATION SHEET

WORKS ORDER:	6411	DATE:	12-Jun-2013
SERIAL NUMBER:	T37833	TESTED BY:	S. Goddard

	Velocity Output V/m/s (Differential)	Mass Position Output (Acceleration output) $V/m/s^2$	Feedback Coil Constant $Amp/m/s^2$
VERTICAL	2 x 745	749	0.0227
NORTH/SOUTH	2 x 750	727	0.01547
EAST/WEST	2 x 752	726	0.01545

Power Consumption:	60mA @ +12V input
Calibration Resistor:	51000

NOTE: A factor of 2 x must be used when the sensor outputs are used differentially (also known as push-pull or balanced output). Under no conditions should the negative outputs be connected to the signal ground. A separate signal ground pin is provided.

POLES AND ZEROS TABLE

WORKS ORDER NUMBER: 6411

SENSOR SERIAL NO: T37833

Velocity response output, Vertical Sensor:

POLES (HZ)	**ZEROS HZ**
$-23.65 \times 10^{-3} \pm j23.65 \times 10^{-3}$	0
-180	0
-160	
-80	

Normalizing factor at 1 Hz: A = 2304000

Sensor Sensitivity: See Calibration Sheet.

Velocity response output, Horizontal Sensors:

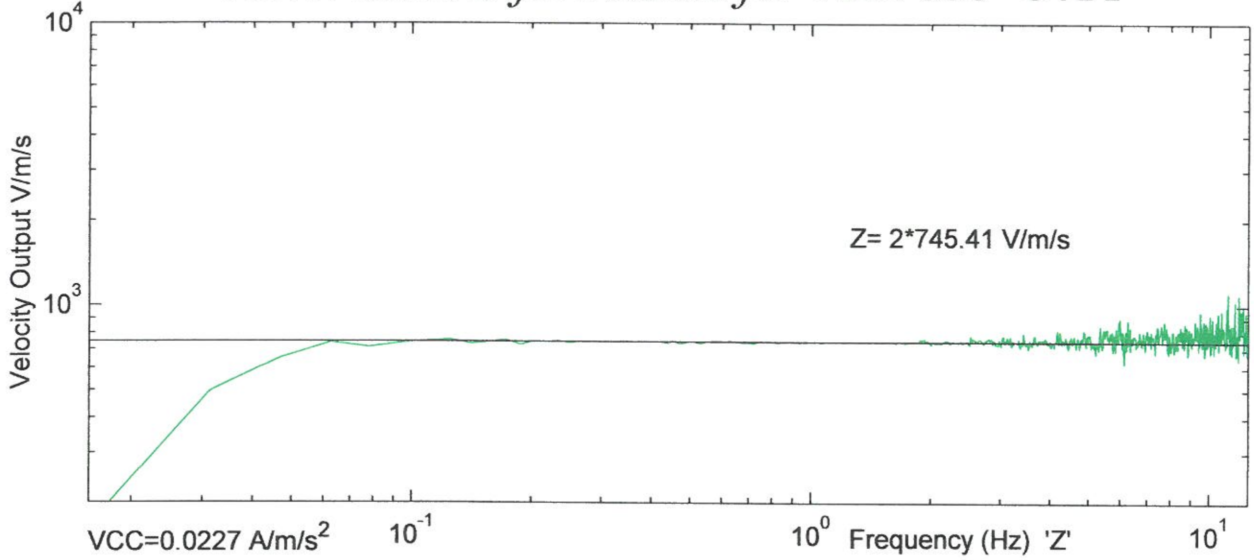
POLES (HZ)	**ZEROS (HZ)**
$-23.65 \times 10^{-3} \pm j23.65 \times 10^{-3}$	0
-180	0
-160	
-80	

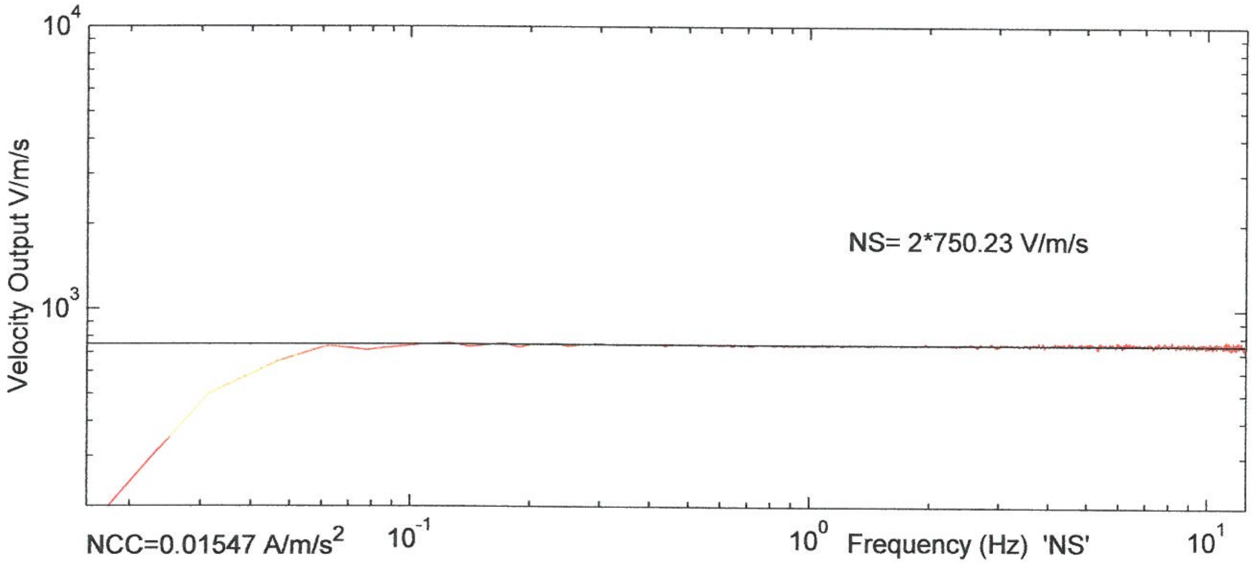
Normalizing factor at 1 Hz: A = 2304000

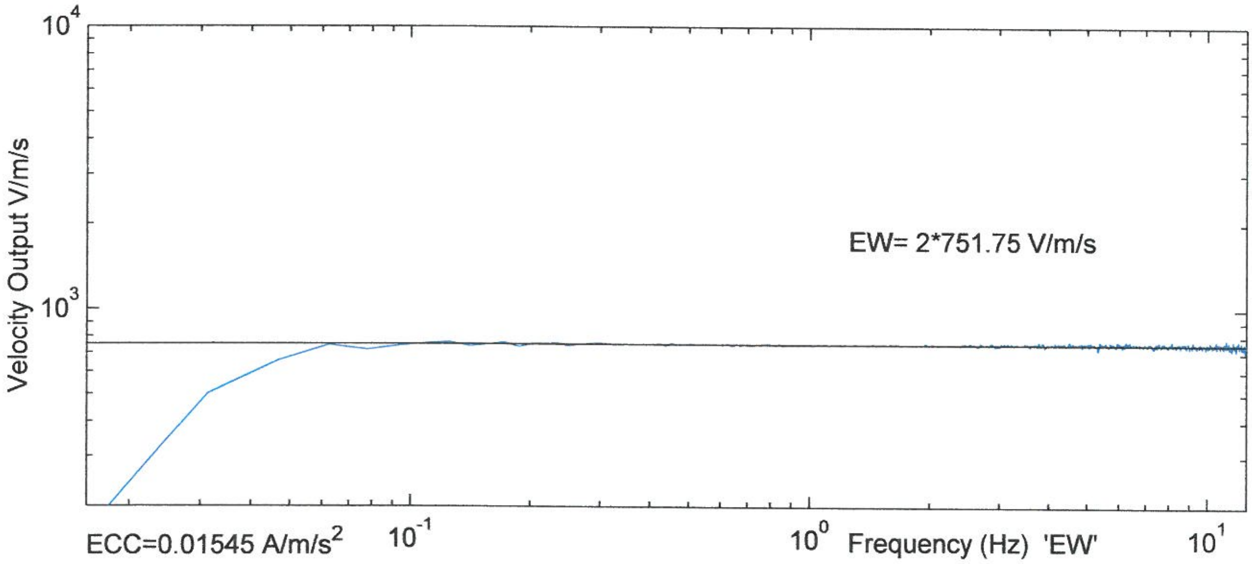
Sensor Sensitivity: See Calibration Sheet.

NOTE: The above poles and zeros apply to the vertical and the horizontal sensors and are given in units of Hz. To convert to Radian/sec multiply each pole or zero with 2π. The normalizing factor A should also be recalculated.

Calibration Information for :T37833 6411



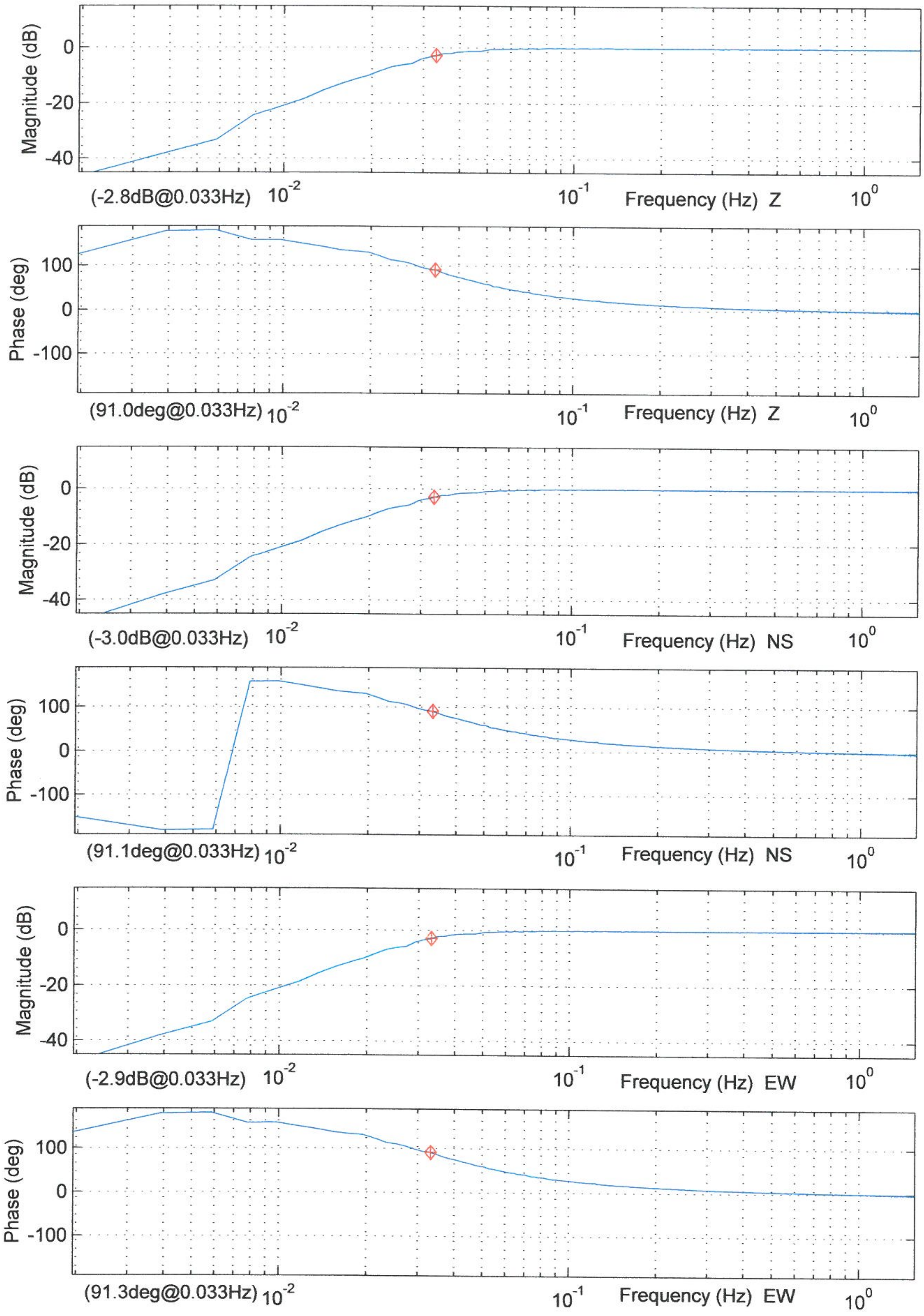




RCal =51000 Ohms

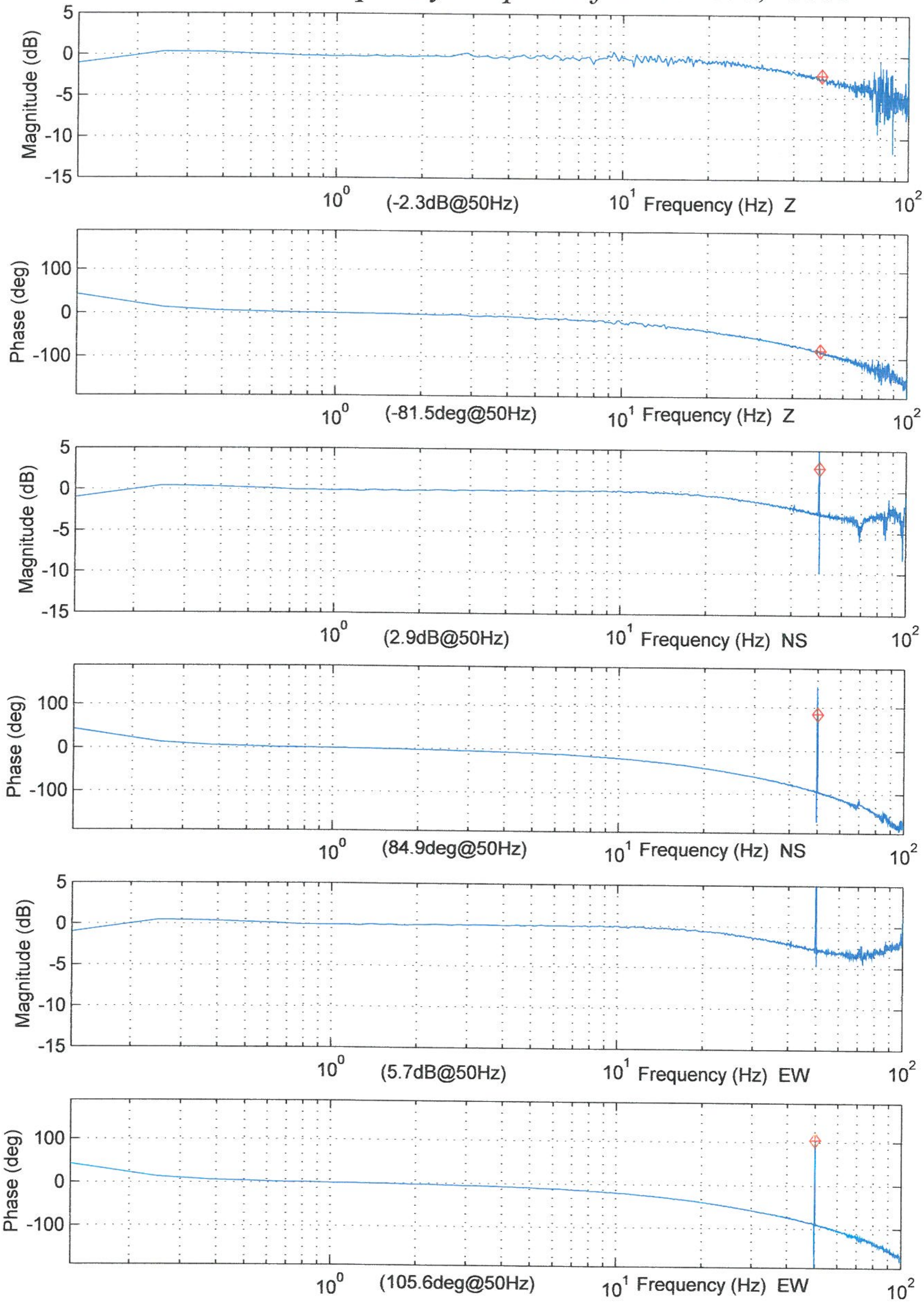
12-Jun-2013

Normalized Frequency Response for :T37833, 6411



12-Jun-2013

Normalized Frequency Response for :T37833, 6411



12-Jun-2013

CMG-5T ABSOLUTE CALIBRATION
(ACCELERATION OUTPUTS)

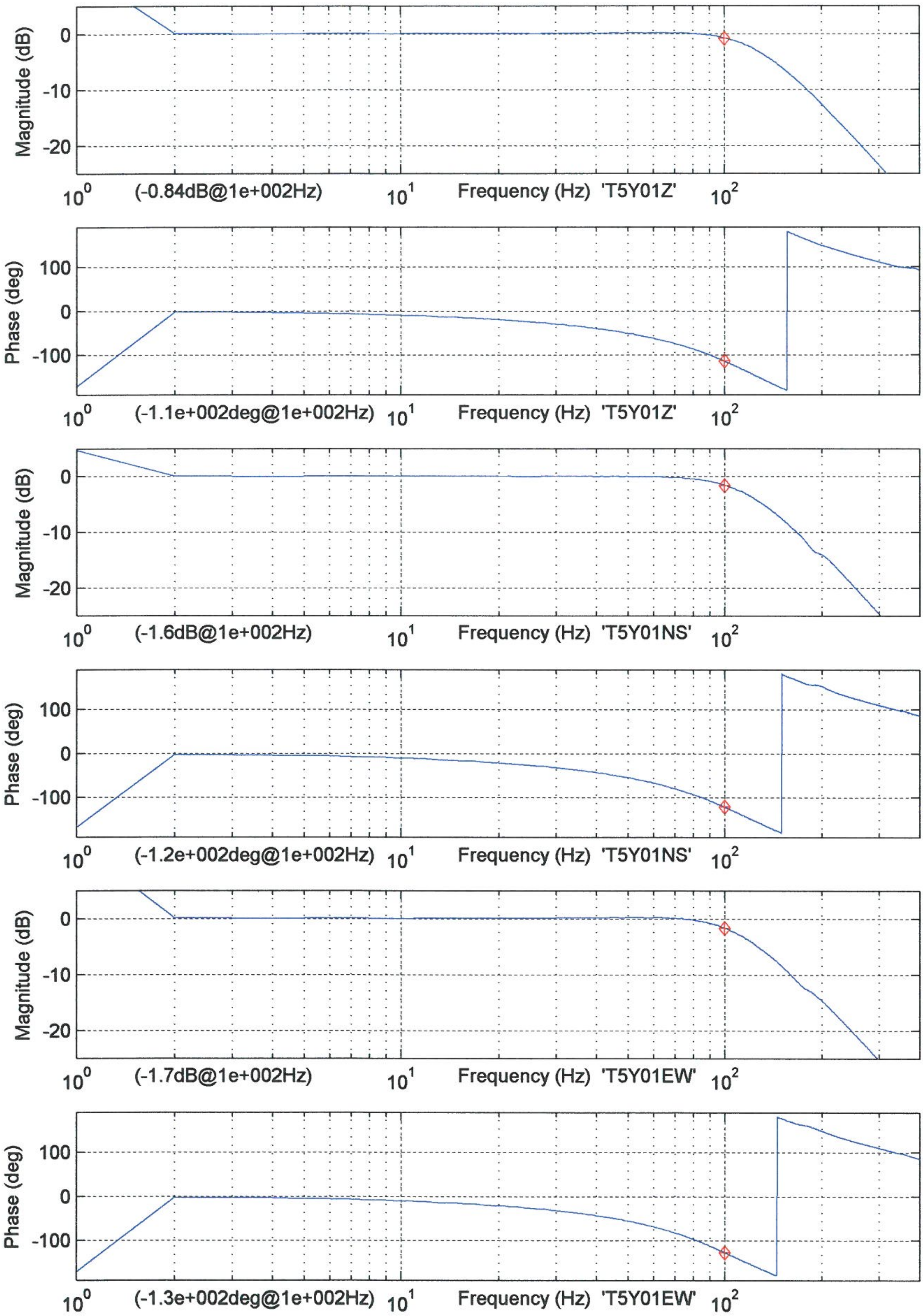
WORKS ORDER:	6411	DATE:	18/08/2011
SERIAL NUMBER:	T5Y01	TESTED BY:	SH
		OUTPUT at 1g	5 volts

	Acceleration Response $V/m/s^2$
VERTICAL	2 x 0.510
NORTH/SOUTH	2 x 0.510
EAST/WEST	2 x 0.510

Vertical component equivalent acceleration from calibration signal of:	1 Volt = 0.980 m/s^2
North/South component equivalent acceleration from calibration signal of:	1 Volt = 0.980 m/s^2
East/West component equivalent acceleration from calibration signal of:	1 Volt = 0.980 m/s^2
Calibration enable signal polarity:	Active Low
Typical Current Consumption:	
This sensor operates from:	10 to 36 Volts

NOTE: A factor of 2 x must be used when the sensor outputs are used differentially (also known as push-pull or balanced output). Under no conditions should the negative outputs be connected to the signal ground. A separate signal ground pin is provided.

Frequency Response for :T5Y01 'WO6411'



Low Gain Acceleration Output

18-Aug-2011

National Oceanography Centre
NATURAL ENVIRONMENT RESEARCH COUNCIL

National Oceanography Centre
University of Southampton Waterfront Campus
European Way, Southampton SO14 3ZH
United Kingdom

Pressure Test Lab +44 (0) 23 8059 6309
http://noc.ac.uk

Purchase Order; 28104

Date: 17/06/13

HYDROSTATIC TEST REPORT

Company: Guralp Systems Limited

Address: 3 Midas House
Calleva Park
Aldermaston
Reading
RG7 8EA

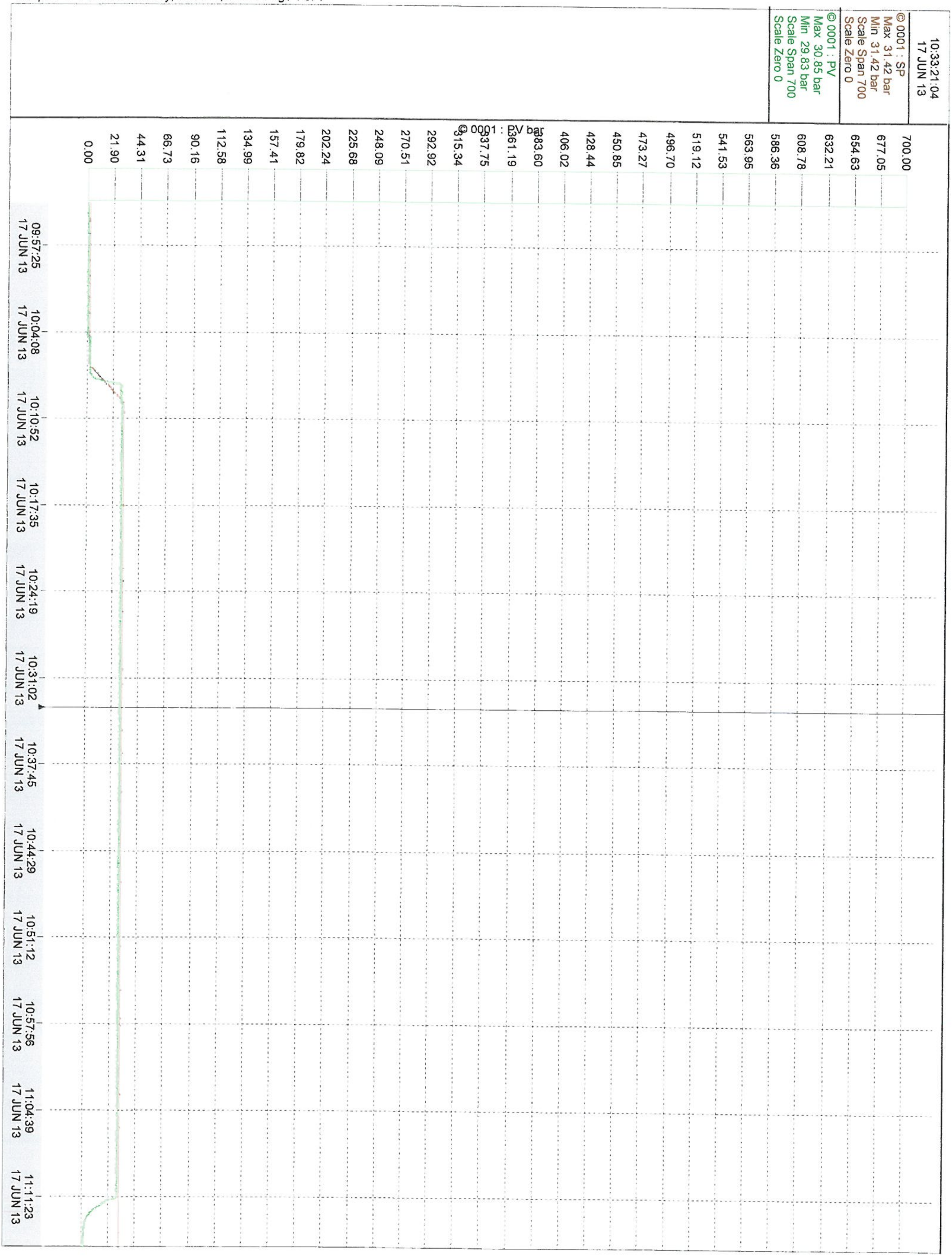
Equipment: 1 x PG & E Titanium sensor housing.
Serial No; 3900

Schedule: 300 metres for 1 hour

Comments: No visual signs of leaks or damage.

Andy Staszkiewicz
023 8059 6309

Graph 1 - 11:15AM Monday, June 17, 2013 - Page 1 of 1



GURALP SYSTEMS

Cabled OBS for PG&E

Technical Manual

Document No. MAN-BSP-0017

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

Issue A July 2013

Table of Contents

1 Preliminary Notes

1.1 Proprietary Notice

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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:

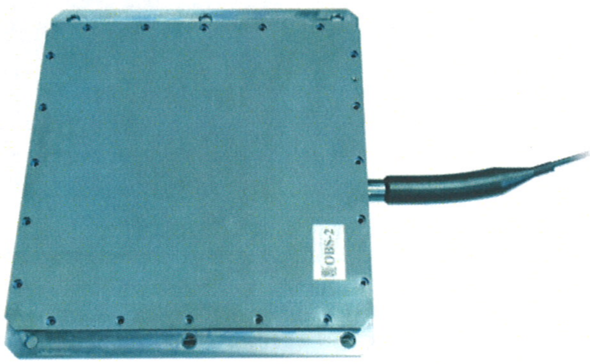
Warning: A black cross indicates a chance of injury or death if the warning is not heeded.

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

Güralp Systems Ltd have designed and built a cabled ocean-bottom seismometry system for Pacific Gas and Energy, consisting of four instrumentation units, mounted in concrete domes, four sub-sea junction boxes, a sub-sea splitter unit, five custom sub-sea cables and a data acquisition/power supply rack.

Most of the subsystems are existing GSL designs which have their own documentation. This document describes the way that the subsystems are interconnected and highlights any non-standard configurations and system-specific instructions. It should be read in conjunction with the supplied "Information Pack for WO6411".

3 System components

3.1 The sensor packages

Each sensor package consists of a custom grade 5 titanium housing containing:

- A CMG-5TC triaxial accelerometer – see MAN-050-0004 for specifications;
- A CMG-3V vertical seismometer – see MAN-030-0001 for specifications;
- Two CMG-3ESPCH horizontal seismometers arranged orthogonally – see MAN-C3E-0001 for specifications;
- A differential pressure gauge (DPG) (fourth unit only);
- A seven-channel CMG-DM24 digitiser – see MAN-D24-0001 for specifications; and
- A CMG-EAM data acquisition units – see MAN-EAM-0001 for specifications.
- A compass/magnetometer – see section 5.1 on page 11.
- An Ethernet-to-fibre media converter.

The CMG-EAM provides a web-based interface to the CMG-DM24 digitiser, from which the instruments can be controlled and the digitiser can be configured. It is not normally necessary to interact directly with the CMG-DM24 digitiser, although the CMG-EAM's web interface does provide direct command-line access to the digitiser for advanced functionality.

Caution: The three seismometers contain inertial masses suspended from extremely delicate pivots. To prevent damage, the masses ***must*** be locked before the unit is moved in any way and unlocked again before measurements can begin. These operations can be initiated using the Instrument Control page of the CMG-EAM's web interface.

3.2 The protection domes

Each sensor is protected by a cast concrete dome, which provides isolation from sea currents and limited protection from trawling activities.

3.3 The junction boxes

The junction boxes are situated on top of the protection domes and route power lines and fibre-optic data lines to each individual sensor. Each contains a 24 V DC power supply for its associated sensor. The junction boxes contain no configurable components. They are constructed in grade 5 titanium casings with 'O'-ring seals.

3.4 The cables

The system is designed such that the four sensor packages are connected in series using five custom-designed cables. The three cables closest to the shore are armoured and each carries eight separate power cores and eight separate fibre cores. The two most distant cables are not armoured; they have eight separate fibre cores but only four power cores.

3.5 The splitter box

The splitter box provides a "straight-through" connection for the power lines and fibre-optic data lines. It is situated between sensor packages three and four (the two closest to the shore) and contains no configurable components.

3.6 The shore rack

The shore rack consists of a nineteen-inch rack cabinet containing:

- a power conditioning and distribution unit;
- a CMG-NAM network acquisition module – see MAN-EAM-0001 for operating instructions;
- A sixteen-slot horizontal rack containing four fibre-optic media converters;
- A twenty-four-port smart gigabit Ethernet switch;
- A custom-designed power supply, monitoring and distribution system; and
- A project-specific OBS cable junction box.

Caution: The shore unit requires a 110 V AC input at 50 or 60 Hz. It must not be used with any other supply voltage.

4 Operating Notes

4.1 Power

4.1.1 Distribution

The shore unit requires a 110 V AC input at 50 or 60 Hz. The key-switch on the shore rack controls power to all components.

The shore rack provides individual switches for each OBS unit, along with voltage and current monitoring. An individual OBS unit can be power-cycled without disturbing the rest of the system by use of these switches.

Caution: Long cable runs present considerable resistance in the power cores. This causes a current-dependent voltage drop along the cable. The system has been designed to cater for this voltage drop but, if power is applied to any junction box without its associated sensor being connected, the current will be less so the voltage drop will be less and the increased voltage seen at the junction box may cause damage to the internal power supply. Never provide power to a junction box without first connecting the sensor and never disconnect a sensor without first turning off the associated power feed.

The shore rack provides factory-selectable power outputs of 220 V, 310 V, 330 V, 380 V or 415 V AC to each junction box. The outputs have been pre-configured for the cable runs as supplied.

Warning: The power distribution system in the rack, the cables and the junction boxes all contain components at lethal voltages. Never attempt to open or modify any of these components: serious injury or death may result.

The power is distributed as high-voltage AC along the sub-sea cables to the junction boxes. Each of the four sensors has its own power supply circuit. The three cables closest to the rack each have eight separate power cores. The two most distant cables only have four power cores.

Each junction box contains a power-supply unit which provides 24 V DC to the sensor. The junction box and sensor casings are electrically isolated from the power ground (0V input). The power ground is isolated from analogue ground and digital ground.

4.1.2 Sensor power

Each sensor can be run from a DC power supply providing between 9 V and 36 V. The junction box provides 24 V DC. The CMG-EAM in each sensor package provides individual power control and monitoring for the various subsystems. As shipped:

- The CMG-5TC accelerometer is powered up by default
- The CMG-3V vertical seismometer and the two CMG-3ESPCH horizontal seismometers are powered up by default. They can be powered down and up using the CMG-EAM's “Digital I/O” page, where they appear as “Sensor A power”;
- The CMG-DM24 digitiser is powered up by default. It can be powered down and up using the CMG-EAM's “Digital I/O” page, where it appears as “Port A power”;
- The magnetometer is powered down by default. It can be powered up using the CMG-EAM's “Digital I/O” page, where it appears as “External power switch 4”;
- The DPG in unit four is powered from the same circuit as the CMG-3V vertical seismometer and the two CMG-3ESPCH horizontal seismometers.

4.2 Data

Analogue signals from the various instruments are routed to the CMG-DM24 digitiser in each sensor package. The CMG-3V is connected to the 'Z' input and the two CMG-3ESPH instruments are connected to the 'N/S' and 'E/W' inputs of the digitiser's “SENSOR A” channel. The DPG in sensor package four is connected to the 'X' input of the digitiser's “SENSOR A” channel . Note that digitisation of the X input is interrupted during calibration operations.

The CMG-5TC accelerometer is connected to the digitiser's “SENSOR B” channel.

The CMG-DM24 has a serial output which is connected to “Port A” of the CMG-EAM embedded acquisition module.

The magnetometer is connected directly to a serial port of the CMG-EAM: see section 5.1 on page 11 for details.

The CMG-EAM has an Ethernet output which is fed to a fibre-optic media converter.

Each ocean-bottom cable has eight fibre cores, providing two (Tx and Rx) for each sensor package. The technology chosen supports maximum transmission distances of 30 km.

The shore rack contains four fibre-optic media converters with Ethernet outputs which feed a twenty-four-port smart gigabit Ethernet switch, to which customer equipment may be connected.

Data can be stored on the CMG-EAM or output in near-real-time in either GCF or miniSEED format.

4.3 Start-up

4.3.1 Accelerometer

The CMG-5TC will automatically centre itself, nulling any DC offsets on its outputs each time power is applied.

4.3.2 Seismometers

The CMG-3V and the two CMG-3ESPHs will all power up in a locked condition. When the system is physically stable, they should be unlocked using the web interface of the CMG-EAM.

Once unlocked, they should each have their masses centred. Although no DC offsets will appear, the system will operate with lower noise levels if the masses are properly centred. This operation can be carried out using the web interface of the CMG-EAM.

Frequent re-centring will be necessary until the system reaches physical and thermal equilibrium, which may take several days, depending on the nature of the sea-bed at the deployment location.

The seismometer components have been tested and found to centre correctly at up to 12° of tilt with respect to their nominal orientation.

4.3.3 Digitisers

The CMG-DM24 digitisers will start automatically when power is applied to the sensor packages.

4.3.4 CMG-EAMs

The CMG-EAM acquisition units will start automatically when power is applied to the sensor packages.

4.3.5 DPG

The DPG in unit four will start automatically when power is applied to the sensor packages.

4.3.6 Compass/Magnetometer

The magnetometer does not start automatically. It can be powered up using the appropriate CMG-EAM's "Digital I/O" page, where it appears as "External power switch 4".

4.4 Networking

The gigabit Ethernet switch in the rack has been partitioned into two separate switches, with no internal connection between them. Ports one through twelve are assigned to the instrument-side network; the other ports are assigned to the data-centre network.

The CMG-NAM has two Ethernet interfaces. Interface `eth0` is assigned to the data-centre network and interface `eth1` is assigned to the instrument-side network.

4.4.1 Instrument network

The instrument-side network is statically configured and each CMG-EAM has an `/etc/hosts` file reflecting this configuration, as does the CMG-NAM.

Port	Assignment	IP address
Port 1	CMG-NAM `eth1` interface	192.168.99.100
Port 2	OBS-1 via media converter	192.168.99.101
Port 3	OBS-2 via media converter	192.168.99.102
Port 4	OBS-3 via media converter	192.168.99.103
Port 5	OBS-4 via media converter	192.168.99.104
none	OBS-5 (spare)	192.168.99.105
any	Switch management address	192.168.99.99

The Ethernet switch can only be configured from the instrument-side network.

The network configuration for each CMG-EAM includes a default route via the CMG-NAM (192.168.99.100).

4.4.2 Data-centre network

Ports thirteen through twenty-four are assigned to the data-centre network (including two fibre connections). Port thirteen is connected to the `eth0` interface of the CMG-NAM.

The CMG-NAM is configured as a DHCP client on this network, with MAC address 00:18:7D:28:AF:E2.

5 Appendices

5.1 The compass/magnetometer

The compass/magnetometer in each sensor package provides a serial output, which is connected to Port D of the CMG-EAM. The CMG-EAM provides a serial-to-tcp conversion service, running in "simple server" mode, so that the data can be passed over the Ethernet links to the CMG-NAM and beyond, to the consumer.

The data can be read by connecting to TCP port 10,004 on the IP address of the appropriate CMG-EAM.

The magnetometer produces a sequence of ASCII sentences such as

```
$C10.0P-0.5R0.0T18.9*3C
```

which is parsed as

- **$** - prologue character
- **C10.0** – angle to the north, in (decimal) degrees
- **P-0.5** – pitch, in (decimal) degrees
- **R0.0** - roll, in (decimal) degrees
- **T18.9** – temperature in (decimal) degrees centigrade
- ***3C** – prologue character and hexadecimal checksum

Note that, due to the high levels of magnetic flux within the sensor packages, the angle to the north is not linear or consistent between units.

Note: Note that, due to the high levels of magnetic flux within the sensor packages, the angle to the north is neither linear nor consistent between units. If true north is to be determined, the sensor packages should first be aligned using other means and the magnetometer readings obtained and recorded. At deployment, the sensor package can then be rotated until the magnetometer displays the previously recorded value.

5.2 Timing

The system is configured to time-stamp recorded data using NTP timing from the CMG-NAM. The CMG-NAM requires on-site configuration to tell it which NTP servers to query for timing information.

Each CMG-EAM is configured to use the CMG-NAM as its timing source with polling every sixteen seconds. This requires non-standard options to be passed to ntpd (`minpoll 4 maxpoll 4`) via the NTP configuration page of the CMG-EAMs' web interfaces.

Port C of each CMG-EAM is configured for NMEA output at 4800 Baud. Internal switching routes the NMEA to the GPS input of theCMG-DM24 when this port function is selected.

> **Note:** NMEA output will only be enabled when NTP reports an offset of less than 1,000 μs. This parameter is adjustable via the CMG-EAMs' web interfaces (Configuration → Serial Ports → Port C → NMEA Output Settings). During periods when the reported NTP offset is greater than this value, the status stream of the associated CMG-DM24 will report "No Fix" and the data will be effectively unsynchronised.

6 Revision History

A 2013-07-05 Initial release

Serial Numbers for PG&E OBS-Network

System	OBS-1	OBS-2	OBS-3	OBS-4	OBS-5 (spare)
EAM	3899	3901	3902	3900	3903
DM24/S6	A3367	A3366	A3369	A3370	A3368
CMG-3ESP	T37829	T37831	T37832	T37830	T37833
CMG-5TC	T5X97	T5AE5	T5Y00	T5X98	T5Y01
DPG				9055	

APPENDIX C

Acceptance Test Plans and Sign-offs

FACTORY ACCEPTANCE TEST PLAN (FAT)
PACIFIC GAS AND ELECTRIC CO.
OCEAN BOTTOM SENSOR SYSTEM

From PG&E

Author: JHCE

REVISIONS

Version	Primary Author(s)	Description of Version	Date Completed
6	Jim Cullen	Updated	06/21/13

INTRODUCTION

This document outlines the methods and testing procedures for the Factory, Pre-Deployment and Site acceptance testing (FAT, PDT and SAT) for **Pacific Gas and Electric Co. (PG&E) Ocean Bottom Sensor System**. In order for acceptance testing to be completed successfully, **Guralp Systems Ltd.** must perform all tests to successful completion in the presence of a **PG&E** representative. Each test has two possible outcomes: pass or fail. Any failed test is reason for the entire test sequence to be failed. Any of the tests may be passed with deficiencies if approved by **PG&E**. Written copies of all deficiencies must be provided to **PG&E** prior to the signoff. All deficiencies from FAT or PDT must be rectified prior to SAT.

This document consists of two copies, one held by the PG&E witness, the other by **Guralp Systems Ltd.** This document is only valid when both copies are signed-off by the test personnel.

PROJECT DESCRIPTION

Deployment of a four-station Ocean-Bottom Seismometer (OBS) Network offshore from the Diablo Canyon Power Plant (DCPP), located along the south-central coast of California, 25 km west of San Luis Obispo. The seismic instrumentation for the four stations, associated equipment, data transmission to PG&E onshore, and installation of underwater and onshore equipment.

The primary objectives of the OBS network are to:

Provide full waveform data with accurate timing of local and near-regional earthquakes to be used to improve the accuracy of micro-earthquake locations and focal mechanisms primarily in the onshore-offshore area adjacent to the alignment of the Shoreline fault zone (SFZ), along the Hosgri fault zone, and at the possible intersection of the two fault zones.

The FAT includes a 5th OBS unit. It is identical to the four sensors to be deployed. It is being kept by **Guralp Systems Ltd.** as a spare for the duration of the project. This unit remains property of **Guralp Systems Ltd.**

TEST TEAM

PERSONNEL

The test team consists of one **Guralp Systems Ltd.** tester and one primary **Pacific Gas and Electric Co** witness who have the authority to sign off tests. Optionally, a small, agreed number of additional **Pacific Gas and Electric Co** observers can observe the tests and input their observations to the primary witnesses.

Name	Role	Company
Horst Rademacher	Project Manager	**Guralp Systems Ltd.**
Chris Pearcey	Chief Engineer	**Guralp Systems Ltd.**
Jim Cullen	Primary Witness	**Pacific Gas and Electric Co**

GLOSSARY

Term	Definition
ATP	Acceptance Test Plan
FAT	Factory Acceptance Test/s
PDT	Pre- Ocean Bottom Deployment Acceptance Tests
SAT	Site Acceptance Test/s

SIGN-OFF FOR ACCEPTANCE TEST PLAN

By signing this document, each party agrees to the terms and protocols in the Acceptance Test Plan.

	Guralp Systems Ltd.	Pacific Gas and Electric
Signature	H. Rademacher	Jim H. Cullen
Name	Horst Rademacher	Jim Cullen
Title	Project Manager	Primary Witness
Date	June 21, 2013	June 21, 2013

SYSTEM ACCEPTANCE TEST PLAN

STRUCTURE

There will be distinct stages of acceptance testing including Factory Acceptance Tests (FAT), Pre-Ocean Deployment Functionality Tests (POB/DAT) and Site Acceptance Tests (SAT) after full offshore deployment. Each test process involves **Guralp Systems Ltd.** personnel running the test procedures described in this document to the satisfaction of **Pacific Gas and Electric Co.**

PRE-FACTORY ACCEPTANCE REQUIREMENTS (PRE-FAT)

Pre-FAT will be conducted at **Guralp Systems Ltd.** facility. All available elements of the system will be tested.

1. Model numbers and serial numbers (s/n) of all components to be tested are listed and verified
2. Calibration sheets are present or available for all sensors and data loggers to be tested.
3. All major sub-systems of the PG&E'S ocean bottom sensor system are listed, connected and operational

FACTORY ACCEPTANCE TESTS (FAT)

FAT will be conducted at Guralp Systems Ltd. facility. All available elements of the system will be tested.

1. Guralp Performance Test (With All OBS Components And Cables)
    a. Recorded time series at two time scales have been produced and evaluated
    b. Recorded time series at two time scales meets Guralp specifications
    c. Power spectral density of recorded ground motion meets Guralp specifications

2. Guralp Functionality Test (With All OBS Components And Cables)
    a. Verify that all sensor data gets through all OBS system components and onto Laptop
    b. Verify that Command and Control functions can be performed from laptop
        i. Lock / unlock and re-center masses of all sensors
        ii. Verify all State Of Health (SOH) Logs are present
        iii. Compass data available
        iv. Tilt Data verified
3. Guralp Time Aligned Data Test (With All OBS Components And Cables)
    a. With all components operational utilize a drop test and verify sensor data is time aligned to Guralp Specifications

4. Guralp verify recorded waveform data is aligned with UTC Test (With All OBS Components And Cables)
    a. With all components operational input a one pulse per second GPS controlled signal; verify sensor data is time aligned to Guralp Specifications

PRE- OCEAN BOTTOM DEPLOYMENT ACCEPTANCE TESTS (PDT)

PDT Tests will be conducted at the project staging area on the **Dynegy LLC** property in Morro Bay, CA. prior to ocean bottom deployment installation, commissioning

1. FAT sign-off has been completed
2. Guralp Functionality Test (With All OBS Components And Cables)
    a. Verify that all sensor data gets through all OBS system components and onto Laptop
    b. Verify that Command and Control functions can be performed from laptop
        i. Lock / unlock and re-center masses of all sensors
        ii. Verify all State Of Health (SOH) Logs are present
        iii. Compass data available
        IV. Tilt Data Available

SITE ACCEPTANCE TESTS (SAT)

SAT will be conducted at the **Pacific Gas and Electric Co** site in San Luis Obispo, CA after installation and commissioning has been completed, and will include:

1. FAT sign-off has been completed
2. POB/DAT sign-off has been completed
3. Guralp Performance Test (With All OBS Components And Cables)
    a. Recorded time series at two time scales have been produced and evaluated
    b. Recorded time series at two time scales meets Guralp specifications
    c. Power spectral density of recorded ground motion meets Guralp specifications

4. Guralp Functionality Test (With All OBS Components And Cables)
    a. Verify that all sensor data gets through all OBS system components and onto Laptop
    b. Verify that Command and Control functions can be performed from laptop
        i. Lock / unlock and re-center masses of all sensors
        ii. Verify all State Of Health (SOH) Logs are present
        iii. Compass data available
        iv. Tilt Data Available

HARDWARE

The following hardware items are subejct to the test sequence described in this document and will be delivered to **Pacific Gas and Electric Co.** fully inspected and functional.

Quantity	Location	Model #	Description	Serial #	Pass/ Fail
1	OBS-1	CMG-3ESP	Triaxial Seismometer	T37829	Pass
1	OBS-1	CMG-5TC	Triaxial Accelerometer	T5X97	Pass
1	OBS-1	DM24/S6	Digitizer (6 channel)	A3367	Pass
1	OBS-1	CMG-EAM	Embedded Acquisition Module	3899	Pass
1	OBS-1	Enclosure	Titanium Enclosure	n/a	Pass
1	OBS-2	CMG-3ESP	Triaxial Seismometer	T37831	Pass
1	OBS-2	CMG-5TC	Triaxial Accelerometer	T5X99	Pass
1	OBS-2	DM24/S6	Digitizer (6 channel)	A3366	Pass
1	OBS-2	CMG-EAM	Embedded Acquisition Module	3901	Pass
1	OBS-2	Enclosure	Titanium Enclosure	n/a	Pass
1	OBS-3	CMG-3ESP	Triaxial Seismometer	T37832	Pass
1	OBS-3	CMG-5TC	Vertical Accelerometer Sensor	T5X100	Pass
1	OBS-3	DM24/S6	Digitizer (6 channel)	A3369	Pass
1	OBS-3	CMG-EAM	Embedded Acquisition Module	3902	Pass
1	OBS-3	Enclosure	Titanium Enclosure	n/a	Pass
1	OBS-4	CMG-3ESP	Triaxial Seismometer	T37830	Pass
1	OBS-4	CMG-5TC	Vertical Accelerometer Sensor	T5X98	Pass
1	OBS-4	DPG	Digital Pressure Gauge	9055	Pass
1	OBS-4	DM24/S6	Digitizer (6 channel)	A3370	Pass
1	OBS-4	CMG-EAM	Embedded Acquisition Module	3900	Pass
1	OBS-4	Enclosure	Titanium Enclosure	n/a	Pass
1	OBS-5	CMG-3ESP	Triaxial Seismometer	T37833	Pass
1	OBS-5	CMG-5TC	Vertical Accelerometer Sensor	T5X101	Pass
1	OBS-5	DM24/S6	Digitizer (6 channel)	A3368	Pass
1	OBS-5	CMG-EAM	Embedded Acquisition Module	3903	Pass
1	OBS-5	Enclosure	Titanium Enclosure	n/a	Pass
20060 m	n/a	n/a	Underwater cable	n/a	Pass

ORDER OF TESTS

The tests are listed in the same order as they should be performed during acceptance testing. This is to help give a logical flow of work on the system. The order of the tests is designed to minimize the use of the same elements of the system at the same time.

TESTING

UNIT TESTING

Each mechanical piece of hardware, 3rd party peripheral component must be tested to show basic unit performance as designed by Guralp Systems Ltd. or the 3rd party manufacturer. If any sub-system fails unit testing which prevents further testing from proceeding, then Guralp Systems Ltd. must rectify the solution before testing can continue. If a sub-system function fails and it has no direct impact on testing then it can be noted as a deficiency and rectified prior to SAT or sign-off.

SYSTEM TESTING

If any part of the system fails testing and prevents further testing from proceeding, then Guralp Systems Ltd. must rectify the solution before testing can continue. If a system function fails and it has no direct impact on testing then it can be noted as a deficiency and rectified prior to SAT or sign-off.

THROUGHPUT TESTING

The entire system as well as individual pieces of the system should be tested for throughput to show that they meet the expectations as described in the User Requirements Specifications.

SIGN-OFF

PRE-FAT

ALL ELEMENTS OF THE SYSTEM WERE FUNCTIONAL, TESTED AND PROVIDED WITH THEIR RESPECTIVE DOCUMENTATION.

DEFICIENCIES

ISSUES: *No Deficiencies Have Been Noted In Testing*

#	Test # / Sequence	Description	Comments
			No Deficiencies

ACTION PLAN

Deficiency	Action Plan
None	n/a

Final Judgement: ACCEPTED

Tested by:	Date:	Witnessed by:	Date:
Horst Rademacher H. Rademacher	6/21/13	Jim Cullen James H. Cullen	June 21, 2013
Guralp Systems Ltd.		**Pacific Gas and Electric Co**	

FAT

The System was tested as described in section FAT on page 4 of this document.

DEFICIENCIES

ISSUES: *No Deficiencies Have Been Noted In Testing*

#	Test # / Sequence	Description	Comments
			No Deficiencies

ACTION PLAN

Deficiency	Action Plan
None	n/a

Final Judgement: ACCEPTED

Tested by:	Date:	Witnessed by:	Date:
Horst Rademacher H. Rademacher	6/21/13	Jim Cullen James H. Cullen	June 6 2013
Guralp Systems Ltd.		**Pacific Gas and Electric Co**	

PDT

The System was tested as described in section "Pre-Deployment Testing" on page 5 of this document.

DEFICIENCIES

ISSUES:

#	Test # / Sequence	Description	Comments

ACTION PLAN

Deficiency	Action Plan
None	n/a

Final Judgement: Accepted JHC

Tested by:	Date:	Witnessed by:	Date:
Horst Rademacher H. Rademacher	7/10/13	Jim Cullen James H. Cullen	7/10/13
Guralp Systems Ltd.		**Pacific Gas and Electric Co**	

SAT

The System was tested after deployement as described in section SAT on page 5 of this document.

DEFICIENCIES

ISSUES:

#	Test # / Sequence	Description	Comments

ACTION PLAN

Deficiency	Action Plan
None	n/a

Final Judgement: Accepted JHC

Tested by:	Date:	Witnessed by:	Date:
~~Horst Rademacher~~ CHRIS PEARCEY [signature]	NOV 27 2013	Jim Cullen [signature]	NOV 27 2013
Guralp Systems Ltd.		**Pacific Gas and Electric Co**	

FAT

WO 6411 | Pacific Gas and Energy | 19/13/2013

Factory Acceptance Test Check Sheet.

SYSTEM	OBS-1	OBS-4	OBS-2	OBS-3	OBS-5
Serial numbers					
EAM	3899	3900	3901	3902	3903
DM	A3367	A3370	A3366	A3369	A3368
3T	T37829	T37830	T37831	T37832	T37833
5T	T5X97	T5X98	T5X99	T5X100	T5X101
DPG		9055			
3T cal docs present	Yes	Yes	Yes	Yes	Yes
3T response docs present	Yes	Yes	Yes	Yes	Yes
5T cal docs present	Yes	Yes	Yes	Yes	Yes
5T response docs present	Yes	Yes	Yes	Yes	Yes
Digitiser cal docs present	Yes	Yes	Yes	Yes	Yes
Digitiser Traveller present	Yes	Yes	Yes	Yes	Yes
Sensor Traveller present	Yes				
Junction box traveller present	Yes				
All cables checked for continuity, isolation between cores and fibre connection.	Yes				
Power interface rack traveller present	Yes				
EAM traveller present	Yes	Yes	Yes	Yes	Yes
NAM traveller present	Yes	Yes	Yes	Yes	Yes
Timing Checked	Yes	Yes	Yes	Yes	Yes
PSD's present	Yes	Yes	Yes	Yes	Yes
Time domain plots present	Yes	Yes	Yes	Yes	Yes
Final system check performed	Yes	Yes	Yes	Yes	Yes

SIGNED... DATE 21/6/13 sensor traveller

WO 6411 Pacific Gas and Energy 19/13/2013

Sensor Traveller

SYSTEM	OBS-1	OBS-4	OBS-2	OBS-3	OBS-5
EAM	3899	3900	3901	3902	3903
DM	A3367	A3370	A3366	A3369	A3368
3T	T37829	T37830	T37831	T37832	T37833
5T	T5X97	T5X98	T5X99	T5X100	T5X101
DPG		9055			
3T cal docs present	Yes	Yes	Yes	Yes	Yes
3T response docs present	Yes	Yes	Yes	Yes	Yes
5T cal docs present	Yes	Yes	Yes	Yes	Yes
5T response docs present	Yes	Yes	Yes	Yes	Yes
Digitiser cal docs present	Yes	Yes	Yes	Yes	Yes
Digitiser Traveller present	Yes	Yes	Yes	Yes	Yes
magnetometer checked	Yes	Yes	Yes	Yes	Yes
Back board screwed down	Yes	Yes	Yes	Yes	Yes
Sensors screwed down	Yes	Yes	Yes	Yes	Yes
DM /EAM checked	Yes	Yes	Yes	Yes	Yes
Media converter checked	Yes	Yes	Yes	Yes	Yes
Centred on 12 degrees tilt					
V	Yes	Yes	Yes	Yes	Yes
N/S	Yes	Yes	Yes	Yes	Yes
E/W	Yes	Yes	Yes	Yes	Yes
Blanking hole filled	Yes	Yes	Yes	Yes	Yes
Calibration done	Yes	Yes	Yes	Yes	Yes
Response done	Yes	Yes	Yes	Yes	Yes
LPNB done	Yes	Yes	Yes	Yes	Yes
DM calibration signal checked	Yes	Yes	Yes	Yes	Yes
Isolation checked between signal gnd and case (>20MΩ)	Yes	Yes	Yes	Yes	Yes
All o-rings greased and checked	Yes	Yes	Yes	Yes	Yes
Titanium screws all present	Yes	Yes	Yes	Yes	Yes

SIGNED.. DATE 21/6/13

Junction box

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Junction box traveller

	1	2	3	4	Splitter
Power Supply checked	Yes	Yes	Yes	Yes	N/A
All screws checked	Yes	Yes	Yes	Yes	Yes
Run as part of the system	Yes	Yes	Yes	Yes	Yes
O-rings present	Yes	Yes	Yes	Yes	Yes
screws present	Yes	Yes	Yes	Yes	Yes
Sensor cable installed	Yes	Yes	Yes	Yes	Yes
final inspection completed	Yes	Yes	Yes	Yes	Yes

SIGNED.. DATE 21/6/13

Power Interface Rack

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Power interface rack traveller

Output Voltage checked	Yes
ELCB Functional Check	Yes
Circuit breaker checked	Yes
System Safe switch Checked	Yes
Meter Calibration	Yes
Earth Checked	Yes
Operational Check.	Yes

SIGNED.. DATE 21/6/13

APPENDIX D

Site Acceptance Test Results

PG&E Site acceptance test. (SAT)

11/24/13

Present: Jim Cullen, Chris Pearcey

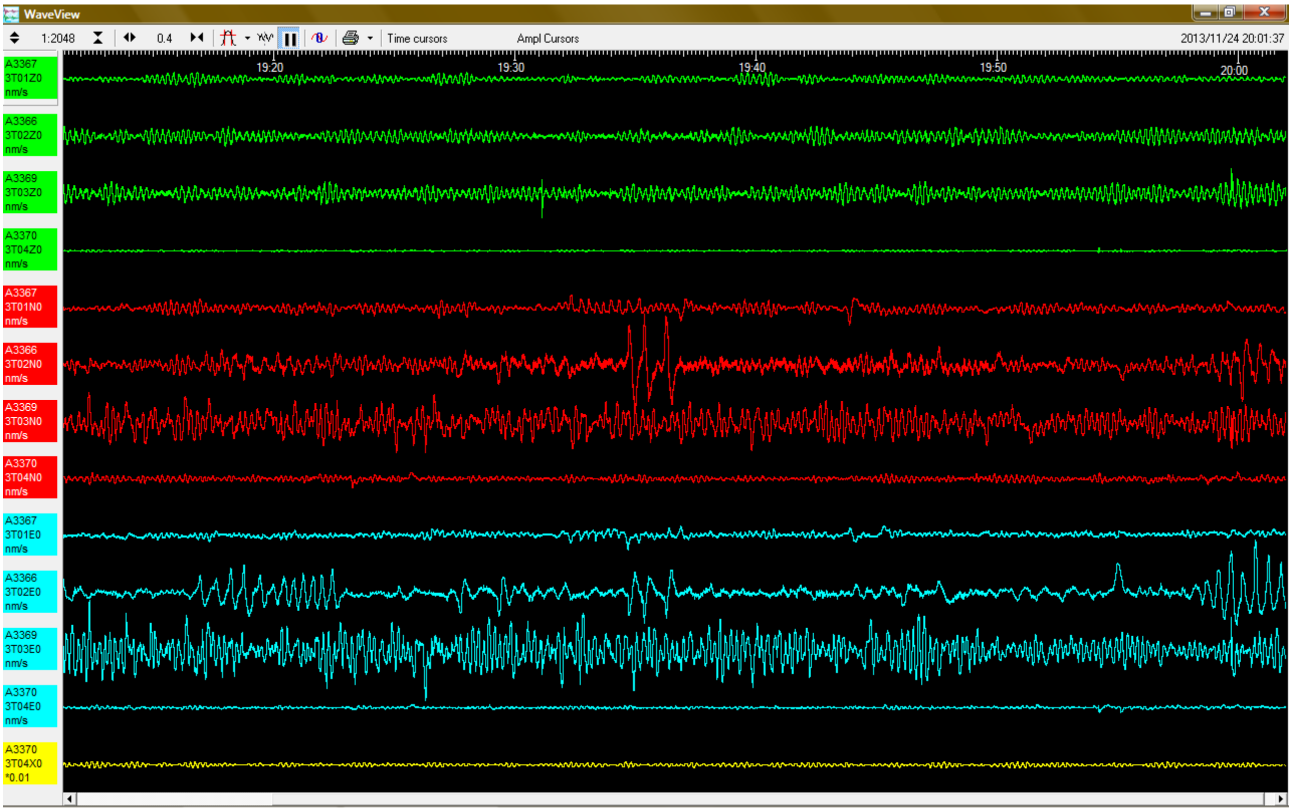
FAT complete OK

PDT complete OK

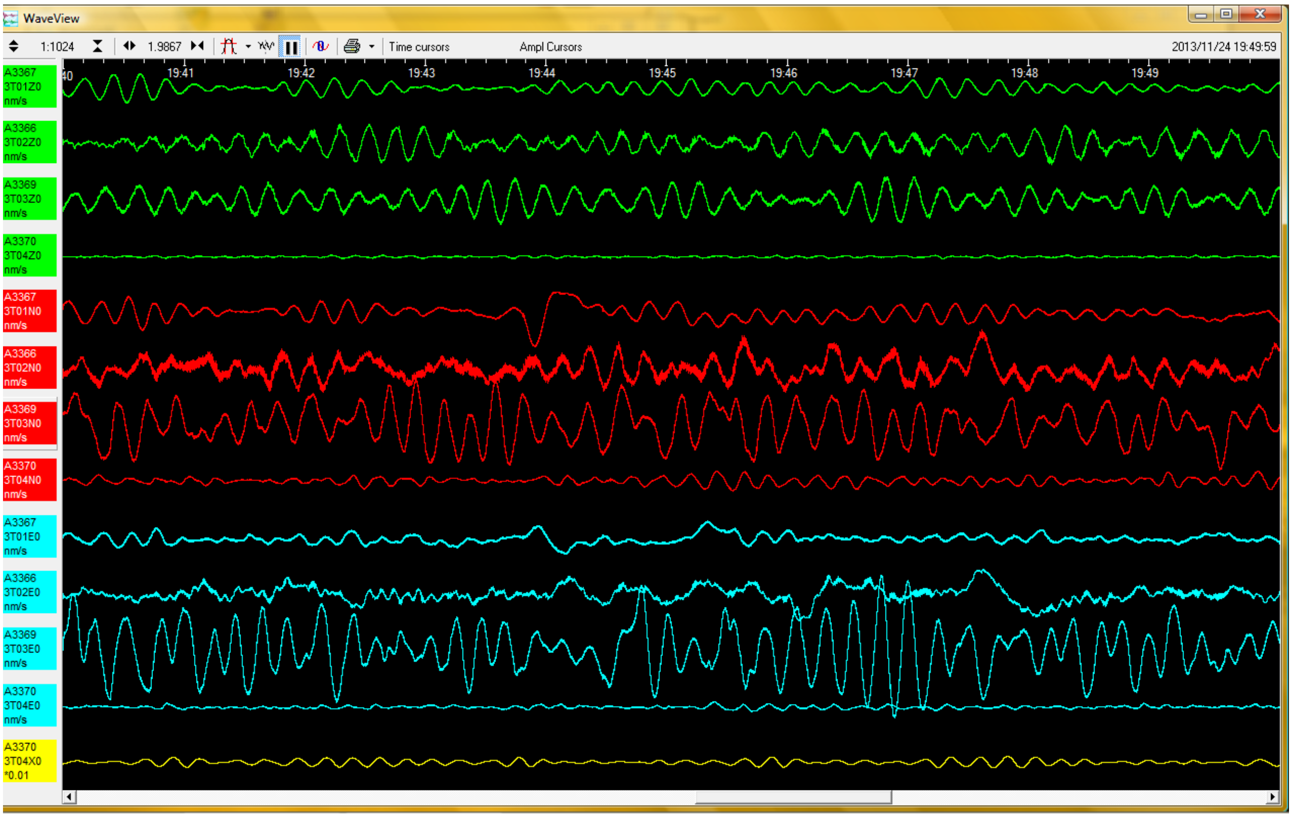
Guralp performance test.

Time series evaluation.

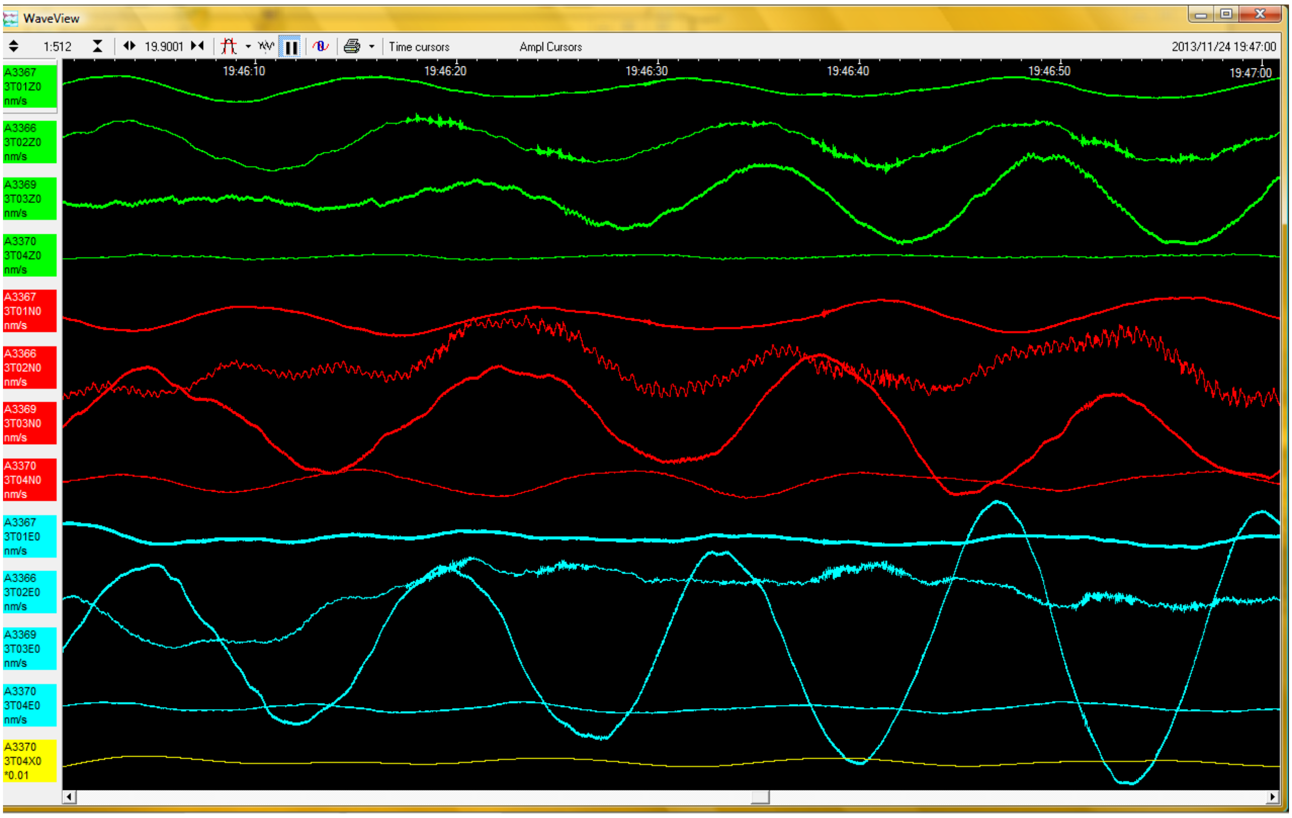
Time series period 1 hour for velocity sensors.



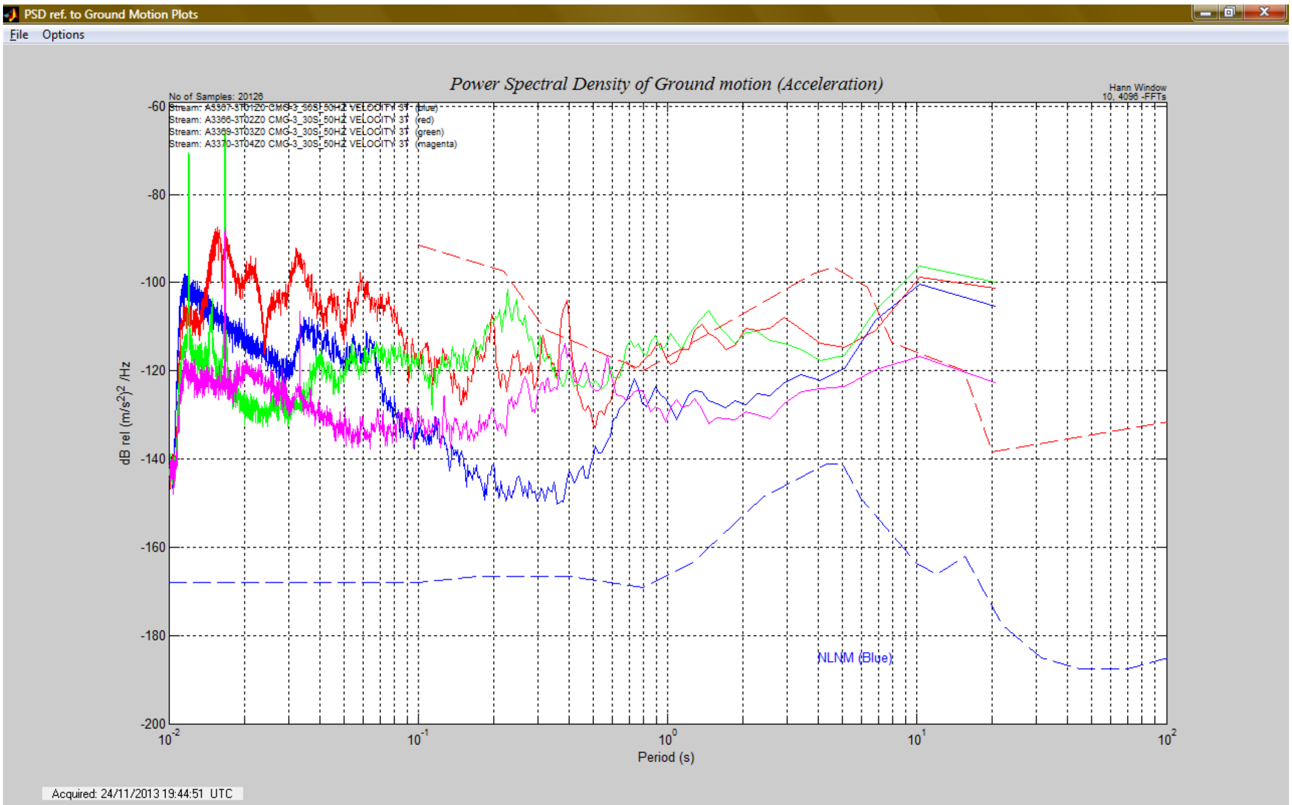
Time series period of 10 seconds for velocity sensors.



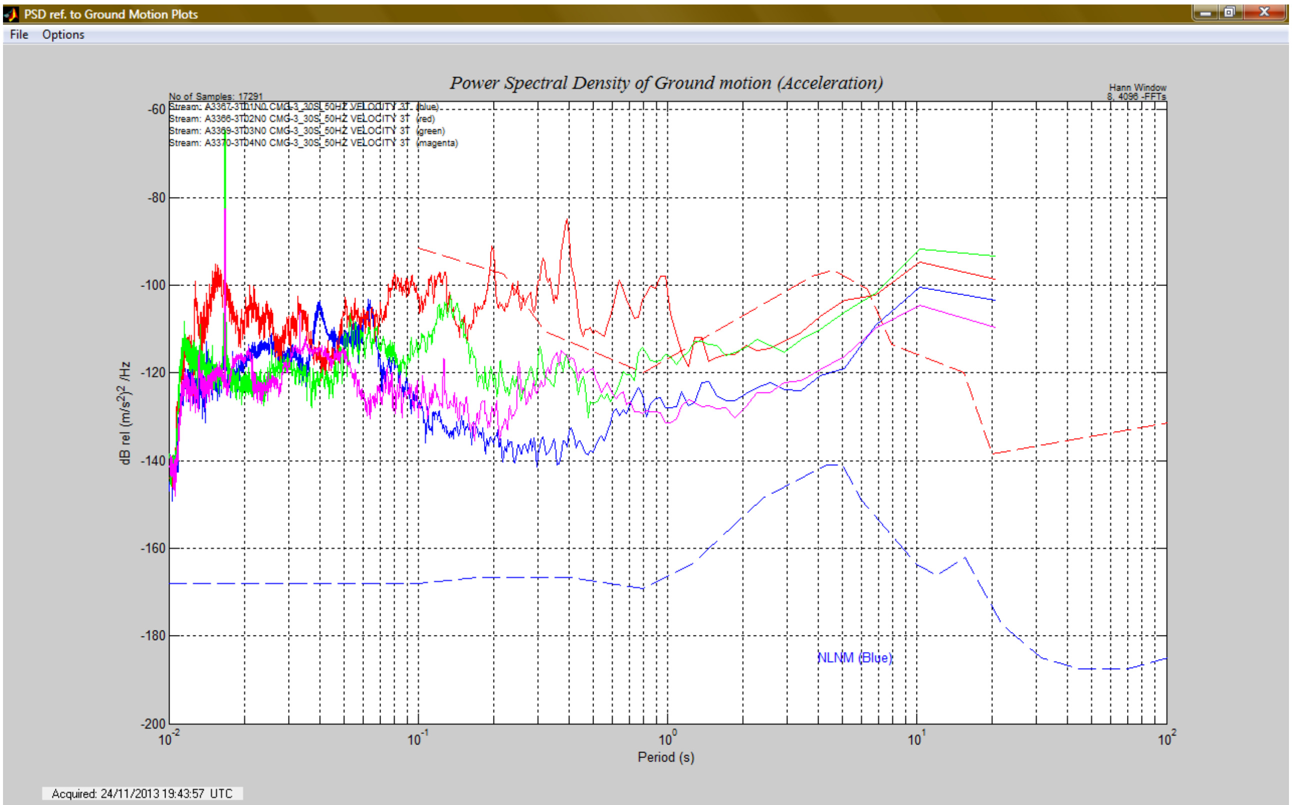
1 second section of data from velocity sensors.



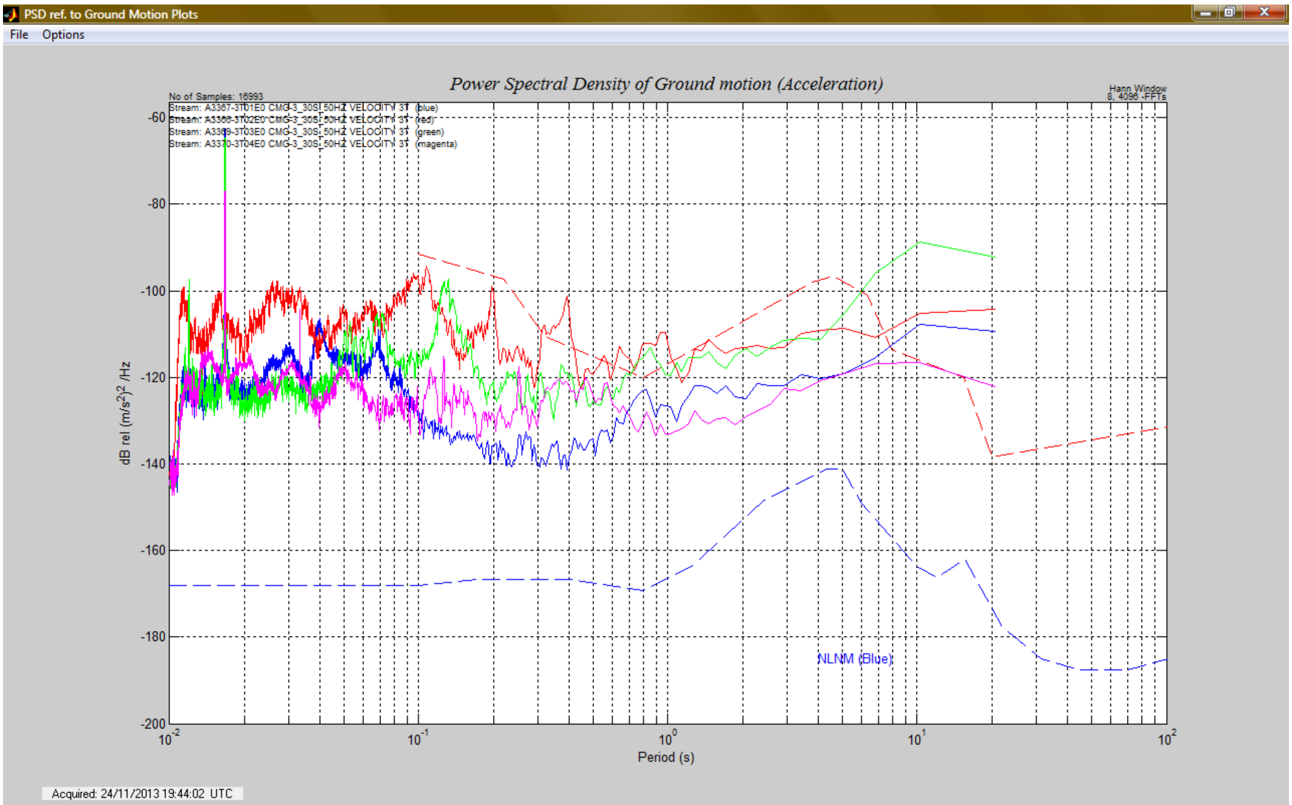
PSD for vertical velocity channels.



PSD for North South velocity channels.

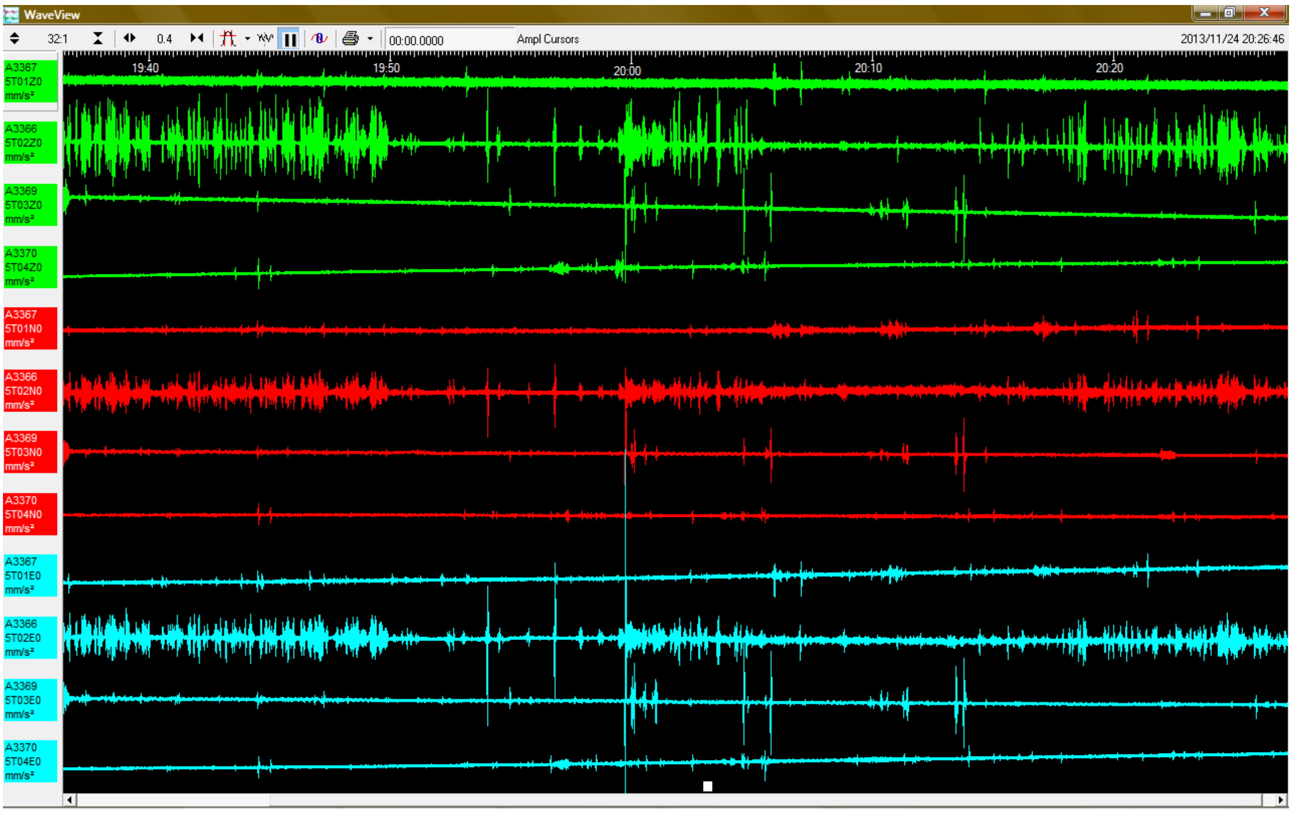


PSD for East West velocity channels

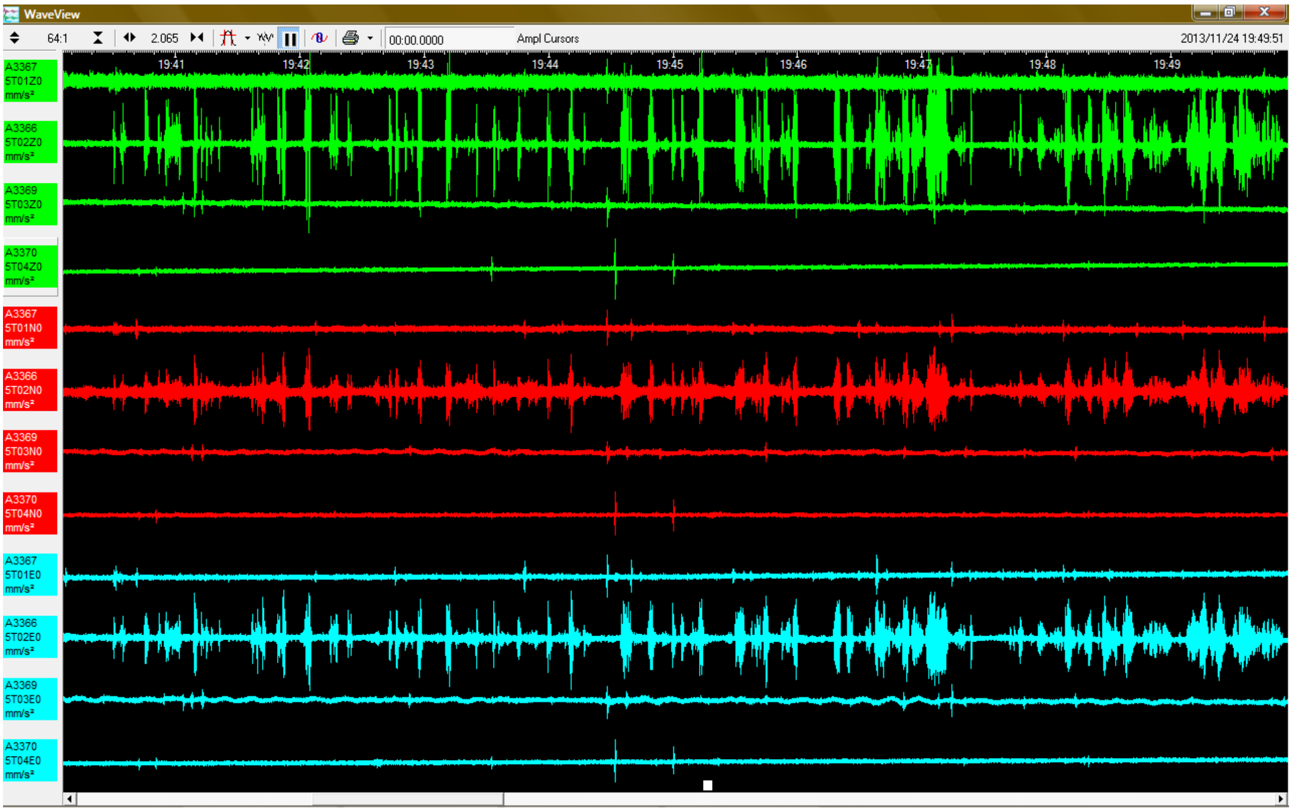


60 Hz signal observed. Physical coupling of AC/DC PSU to sensor system is the likely cause. The observed 60Hz signal is a result of the relocation of the junction box on to the sensor dome, which was a request made to allow permitting requirements to be met. This should not effect the primary objectives of this network.

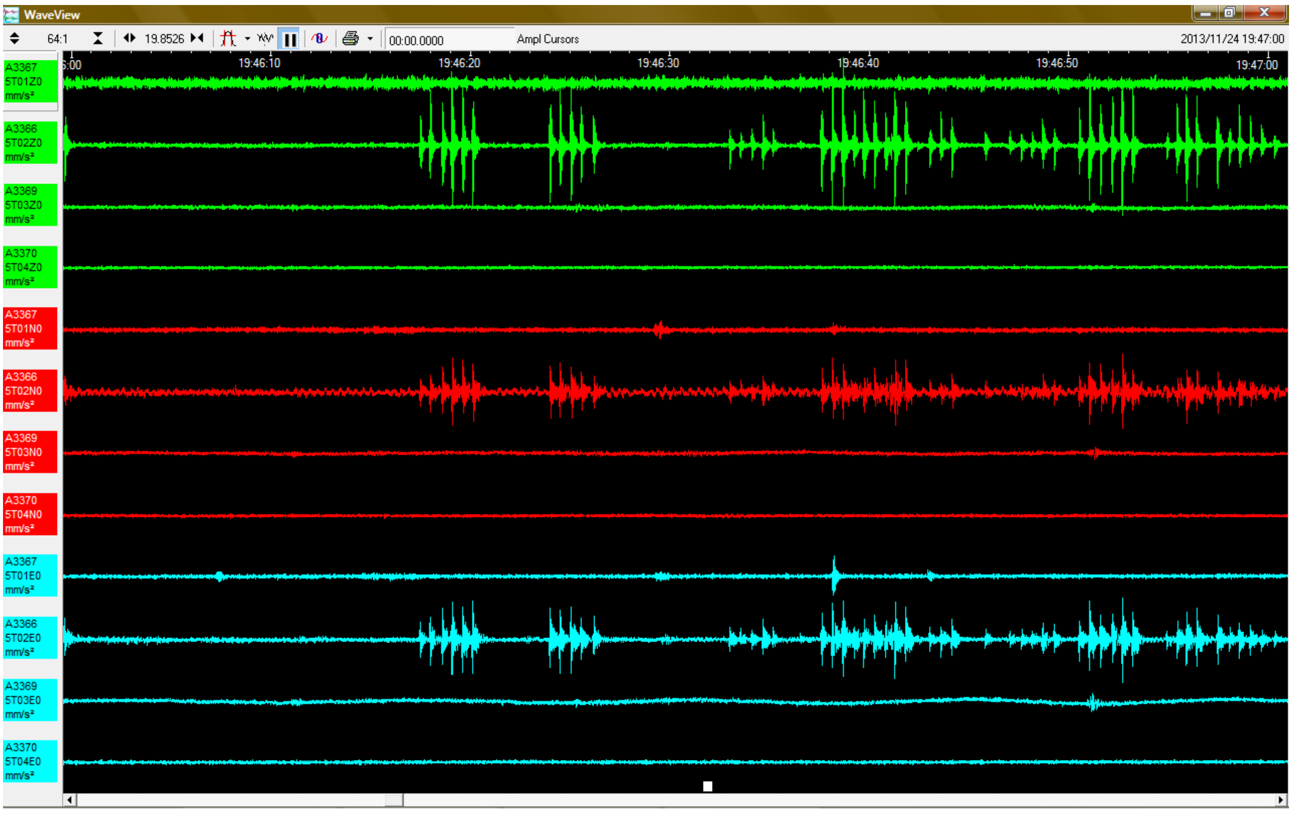
Time series period 1 hour for acceleration sensors.



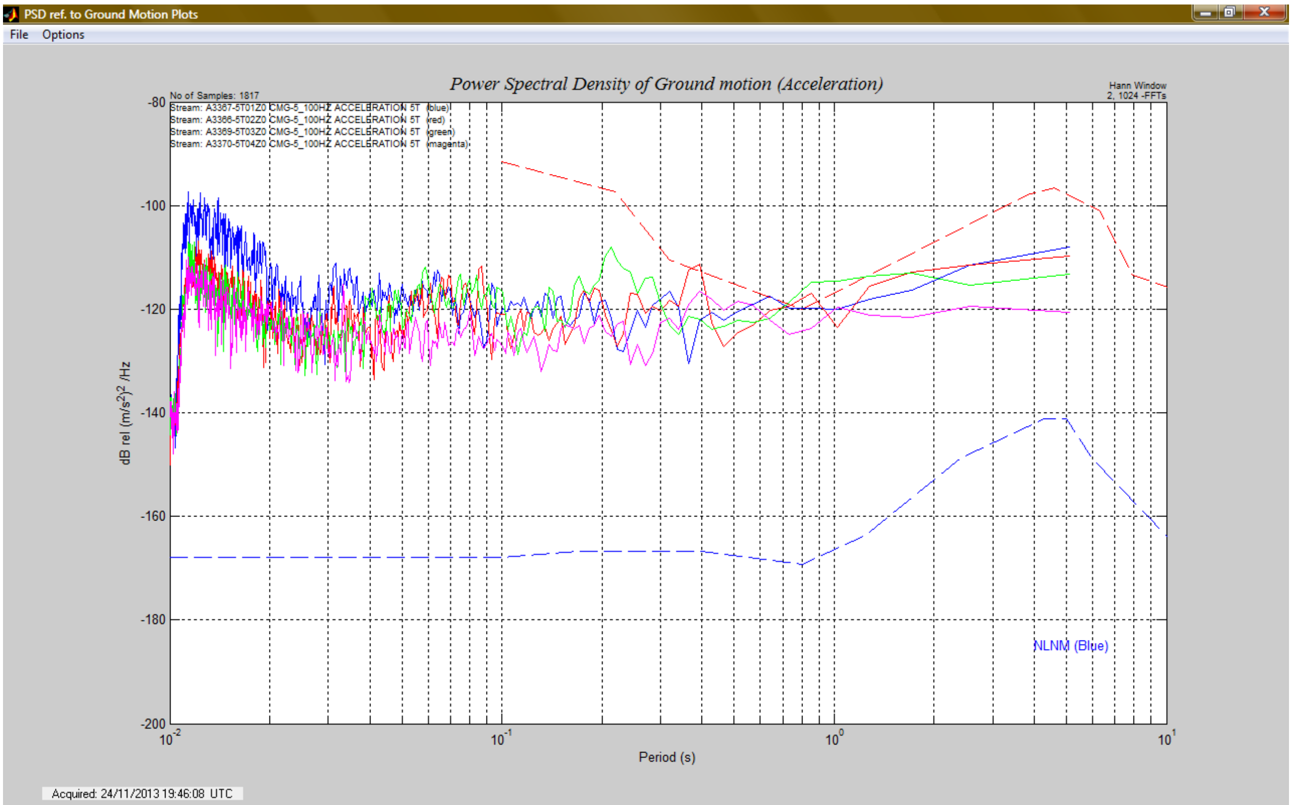
Time series period 10 seconds for acceleration sensors.



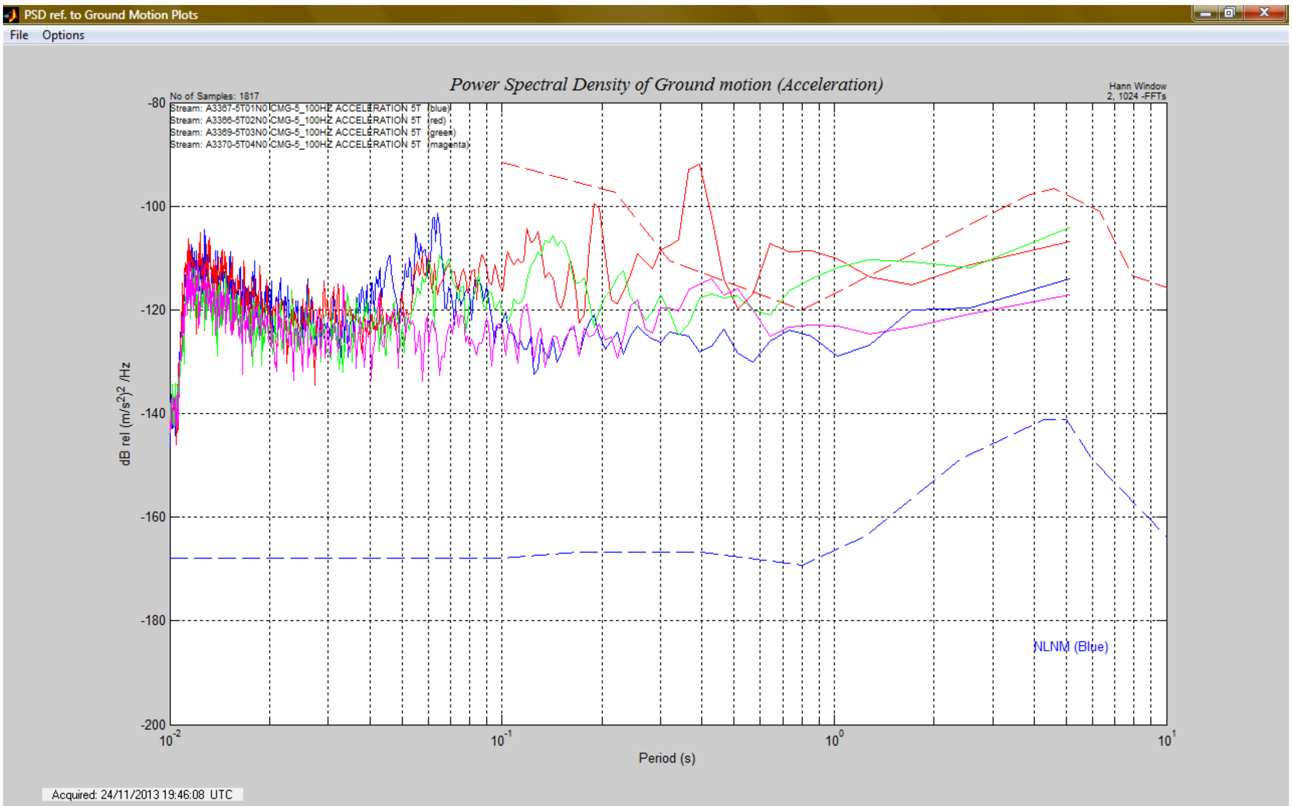
Time series period 1 second for acceleration sensors.



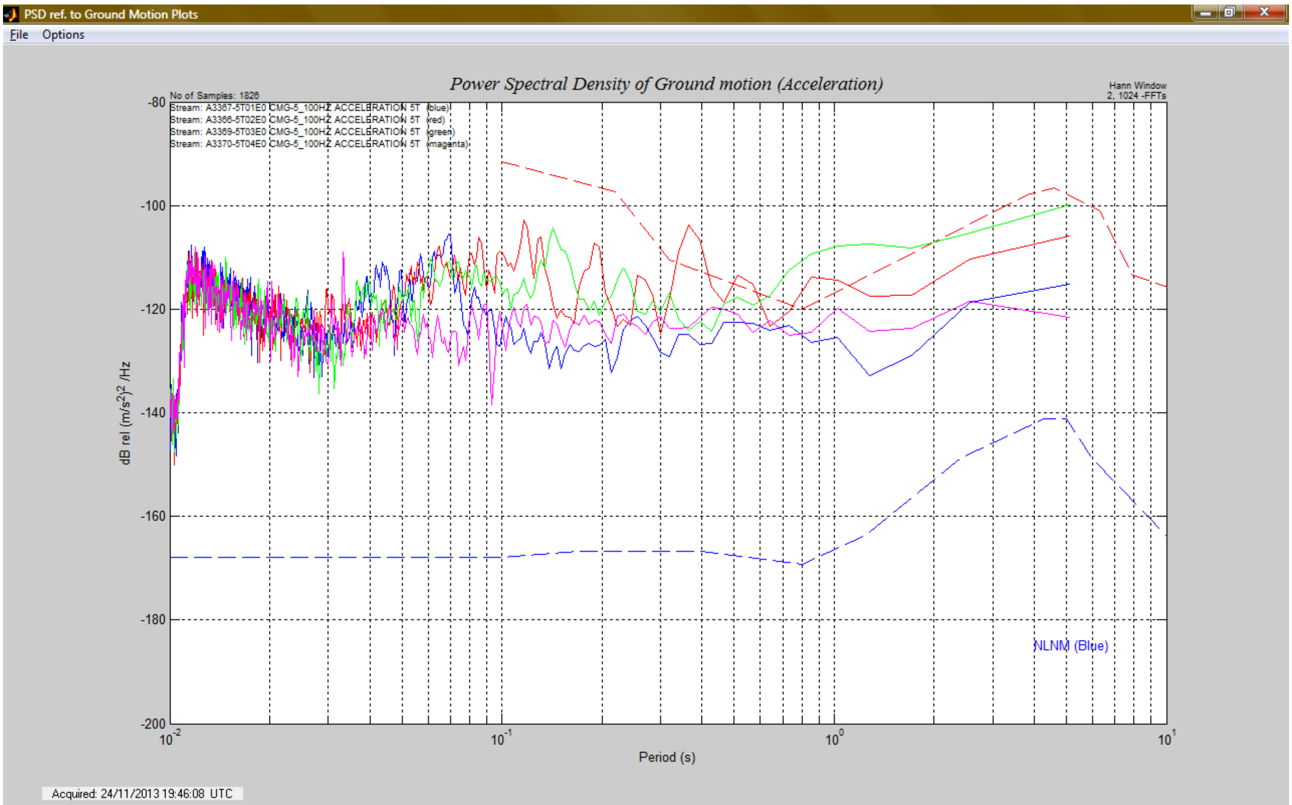
PSD of Vertical acceleration channels



PSD of North South acceleration channels

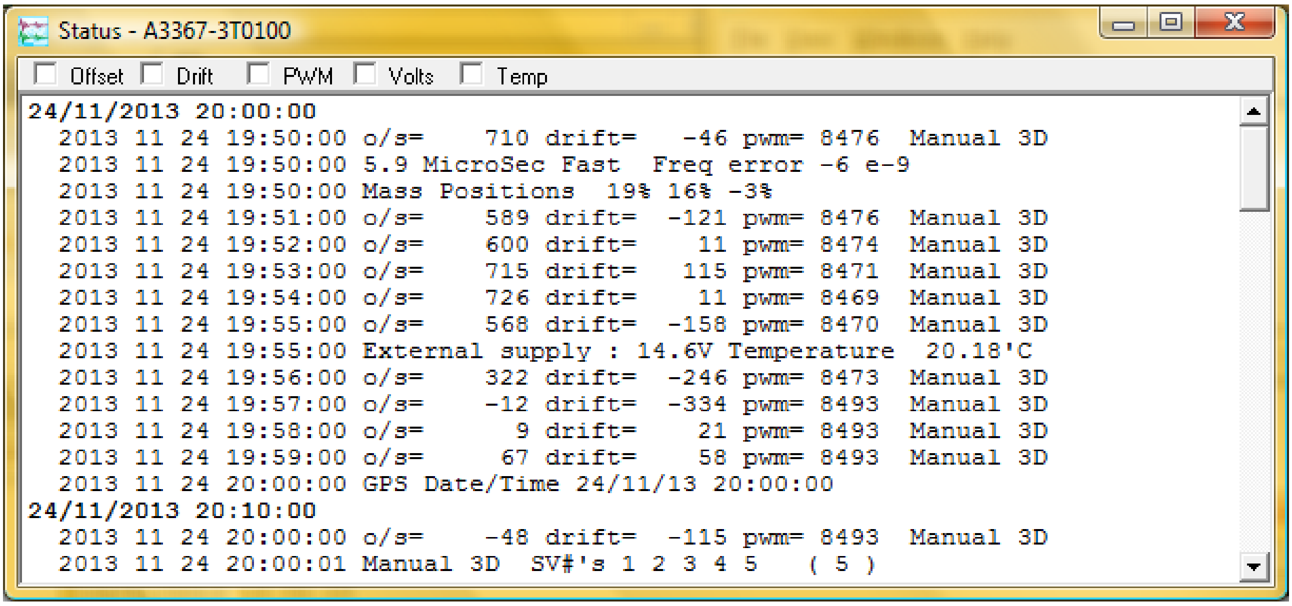


PSD of East West acceleration channels.

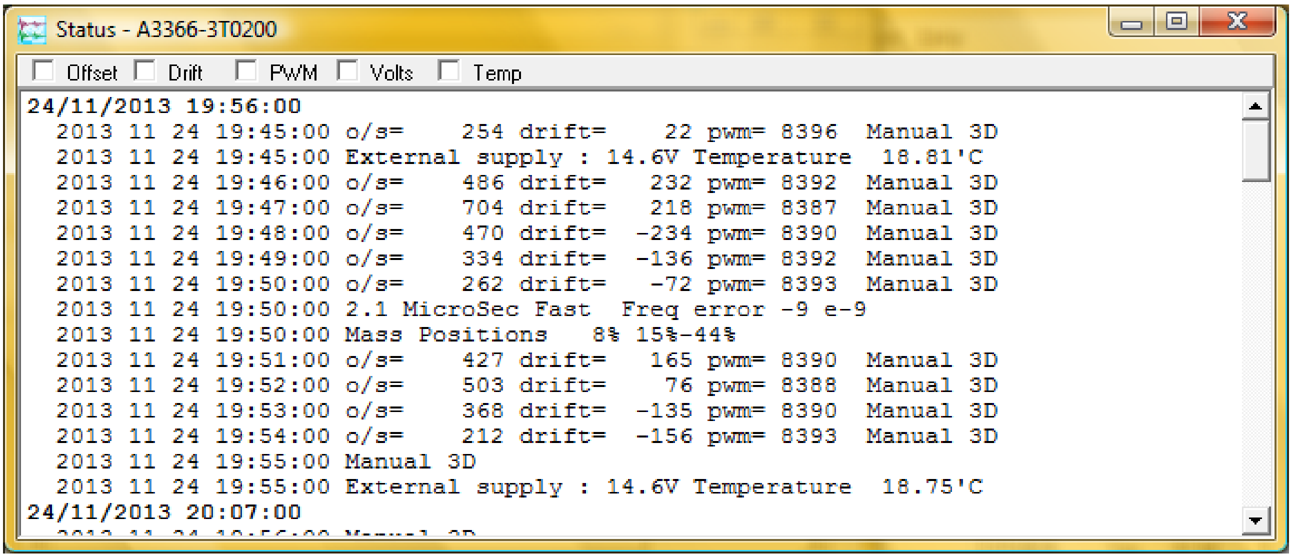


Status data of each sensor system.

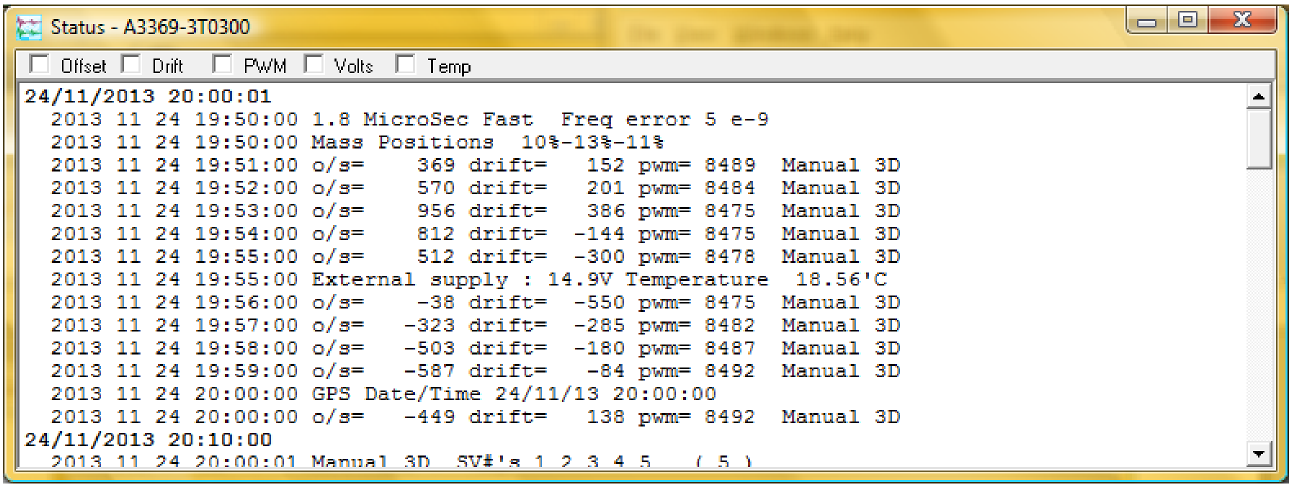
OBS-1



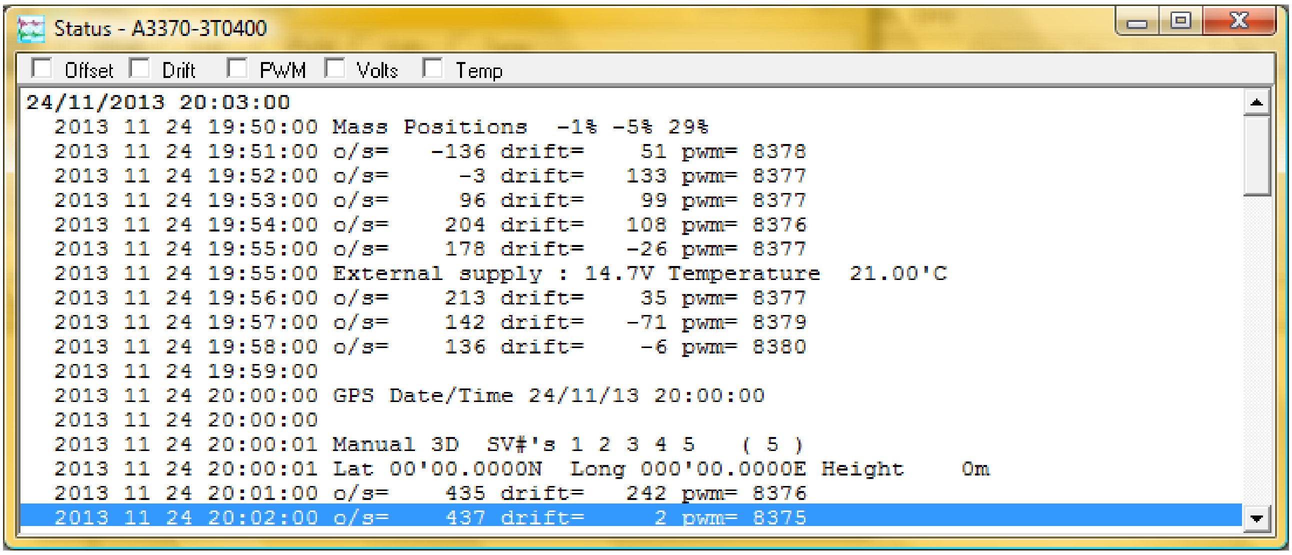
OBS-2



OBS-3



OBS-4



```
Status - A3370-3T0400
Offset  Drift  PWM  Volts  Temp
24/11/2013 20:03:00
  2013 11 24 19:50:00 Mass Positions  -1% -5% 29%
  2013 11 24 19:51:00 o/s=   -136 drift=    51 pwm= 8378
  2013 11 24 19:52:00 o/s=     -3 drift=   133 pwm= 8377
  2013 11 24 19:53:00 o/s=     96 drift=    99 pwm= 8377
  2013 11 24 19:54:00 o/s=    204 drift=   108 pwm= 8376
  2013 11 24 19:55:00 o/s=    178 drift=   -26 pwm= 8377
  2013 11 24 19:55:00 External supply : 14.7V Temperature  21.00'C
  2013 11 24 19:56:00 o/s=    213 drift=    35 pwm= 8377
  2013 11 24 19:57:00 o/s=    142 drift=   -71 pwm= 8379
  2013 11 24 19:58:00 o/s=    136 drift=    -6 pwm= 8380
  2013 11 24 19:59:00
  2013 11 24 20:00:00 GPS Date/Time 24/11/13 20:00:00
  2013 11 24 20:00:00
  2013 11 24 20:00:01 Manual 3D  SV#'s 1 2 3 4 5   ( 5 )
  2013 11 24 20:00:01 Lat 00'00.0000N  Long 000'00.0000E Height    0m
  2013 11 24 20:01:00 o/s=    435 drift=   242 pwm= 8376
  2013 11 24 20:02:00 o/s=    437 drift=     2 pwm= 8375
```

APPENDIX E

As-Laid ROV Survey

padre associates, inc.
ENGINEERS, GEOLOGISTS & ENVIRONMENTAL SCIENTISTS

January 31, 2014
Project No. 1102-0621

PG&E Geosciences Department
245 Market Street
San Francisco, California 94105

Attention: Ms. Marcia McLaren
Senior Seismologist

Subject: PG&E Point Buchon Ocean Bottom Seismometer Project, As-Laid ROV Survey Report

Dear Ms. McLaren:

In accordance with the California State Lands Commission (CSLC) issued lease, Padre Associates, Inc. (Padre) is pleased to submit this report for the subject Project for your submittal to CSLC. This report summarizes the results of the as-laid survey of the ocean bottom seismometer (OBS) system. Included in this report is Attachment A which contains figures of the OBS locations and cable route, and photographs from the ROV survey.

INTRODUCTION

As part of Pacific Gas & Electric Company's (PG&E) seismic safety assessment at the Diablo Canyon Power Plant (DCPP), an OBS system was installed in the nearshore waters off Pt. Buchon, San Luis Obispo County (Attachment A - Figures 1, 2 and 3). The system is comprised of four long-term OBS units, approximately 11.5 miles (mi) (18.5 kilometer [km]) of 2-inch (in) (5-centimeter [cm]) diameter cable that provides power to the OBSs and transmitted data to and from the shorebased facility within DCPP, and two temporary OBS units. The temporary OBS units were installed for seventeen weeks and removed in November 2013. The cable for the long-term OBS units enters the DCPP facility through a PVC conduit, which extends into the marine waters of the DCPP intake embayment adjacent to the power plant. Initial installation of those units and cable was completed from July 20 through July 27, 2013. Final adjustments to the system were made between November 6 and November 24, 2013. PG&E accepted the fully-adjusted system on November 24, 2013.

Regulatory requirements specified that following installation (including completion of all adjustments) of the OBS system, a post-installation (as-laid) visual survey of the entire cable route and OBS locations was to be completed by a qualified contractor. Tenera Environmental (Tenera) was retained by PG&E to complete a diver survey of the nearshore segment from the PVC conduit to the 80 foot (ft) (24 meter [m]) isobath. Padre was retained to complete the deeper water segments of the cable corridor, seaward of the 80 ft [24 m] isobath.

Lease conditions also specified that the results of the as-laid survey were to be presented in a technical report and on a series of maps (Figures 1, 2 and 3). The final alignment of the cable, final locations of the long-term OBS units, and an assessment of impacts to the seafloor habitat and associated biota were to be provided to various regulatory and resource agencies within the periods specified in the lease. The following discusses the results of Tenera's and Padre's surveys and provides the aforementioned assessment of impacts.

METHODS AND EQUIPMENT

The nearshore segment (between the offshore end of the conduit within the DCPP intake embayment and the 80 ft [24 m]) isobath was surveyed by Tenera divers using SCUBA. The dive survey was completed on October 16, 2013. Divers collected latitude/longitude coordinates of the as-laid nearshore cable alignment, and completed underwater videography to document habitats and species along the cable. The submerged cable was videotaped using a Sony Handycam Model HDR-CX550V digital video camera inside a Light and Motion Bluefin 550 waterproof housing. At the same time, divers towed a Garmin ETrex Legend GPS unit. The unit was attached to a surface float with the tether line held taught to keep the GPS unit directly above the divers. This provided a trackline of latitude/longitude coordinates for the nearshore cable segment. A technical report, a GIS shapefile with the coordinates of the cable alignment, and a video were provided to PG&E as separate deliverables.

The ROV survey was completed over a three-day period (December 6, 8, and 9, 2013). Offshore segments and locations of the two temporary OBS units were surveyed with a Phantom 2+2 ROV, owned and operated by Aqueos Corporation under subcontract to Padre. The ROV was equipped with a scanning sonar and video cameras. The 77 ft (24 m) workboat, MV *Danny C.*, owned and operated by Castagnola Tug Services, Santa Barbara, was the ROV support vessel, and ROV and vessel positioning was provided by Fugro Pelagos, Inc. The ROV survey was initiated at OBS-4 and progressed inshore to near the termination point of the Tenera dive survey. The deeper-water segments were surveyed sequentially from OBS-4 to OBS-1.

Video images from the Tenera and Padre surveys were reviewed by Mr. Ray de Wit, Padre Senior Marine Scientist and the discussion and impact assessment provided below are based upon that review.

NEARSHORE OBSERVATIONS

On October 16, 2013, the nearshore segment was surveyed by Tenera divers. The nearshore surveyed was approximately 1,800 ft- (560 m-) long, from the 80 ft (24 m) isobath to where the cable entered the PVC conduit along the shoreline of the DCPP intake embayment. Diver observations, as documented in video collected by Tenera divers, indicate that the seafloor habitat comprises both sedimentary and rocky substrates.

The sedimentary habitat consists of medium to coarse-grain sand, with more coarse material found immediately offshore of the DCPP embayment entrance, in water depths ranging from 59 to 78 ft (18 to 24 m). Finer-grain sediments are prevalent within the embayment. Substantial drift algae also covered the seafloor inside the embayment breakwaters. A tube-building worm (*Diopatra* sp.) is common within the sedimentary seafloor habitat along this segment; also present is the bat star (*Patiria miniata*). Sand waves within this segment range from 1 to approximately 3 in (3 to 8 cm) high. Cable tension was light to moderate within the sedimentary habitat areas, and approximately 50% of the 1,083 ft (330 m) of cable within the sedimentary habitat was buried; depth of natural burial ranged from 1 to 3 in (2.5 to 8 cm). No sediment-associated biota were buried or damaged by the installed cable; however, thick drift algae covered much of the inshore portion of the survey area, precluding direct observations of the cable on the sedimentary seafloor there.

Rock habitat, comprised of boulder/cobble beds and isolated reefs, supported several algae species, including the sea palm (*Pterogophora californica*), a brown strap kelp (*Laminaria setchellii*), and occasional giant kelp (*Macrocystis pyrifera*). Epifauna attached to rocky substrate included bat stars, unidentified solitary corals, at least two species of sea stars (*Pisaster giganteus* and *P. ochraceas*), and the strawberry anemone (*Corynactis californica*), which were most common on the rocky substrate offshore of the embayment entrance. Rocky substrata within the embayment had sediment cover and supported a less diverse epibiota community. Rockfish (*Sebastes* spp.) and the convict fish (*Oxylebius pictus*) were present to common around rock features.

The cable crossed over approximately 755 ft (230 m) of rock habitat, but due to the irregular topography of the substrate, actually contacted rock along approximately 131 ft (40 m). The cable was laid adjacent to several sea palm plants, but did not appear to have damaged any stipes or holdfasts. No other epibiota were observed to have been crushed or covered by the cable where it touched the rocky substrate.

OFFSHORE OBSERVATIONS

-80 FT ISOBATH TO OBS-4. Observations within this 1.3 mi (2.1m) -long segment were completed on December 6, 2013. The ROV initiated the survey at OBS-4 and followed the cable inshore to approximately the 80 ft (24 m) isobath, where Tenera had terminated the inshore diver observation survey in October 2013. Approximately 4.5 hours of video were recorded within this segment at a water depth range between 80 and 176 ft (24 and 54 m). Based on navigational post-plots, approximately 72 ft (22 m) of the cable was not observed by diver or ROV surveys. The 72 ft (22 m) segment was between the inshoremost point of the ROV survey and the offshore terminus of the Tenera diver survey. The segment was within sedimentary habitat, and no rock or other high-relief objects were observed on the scanning sonar image screen.

Seafloor habitats within this segment comprised both sedimentary (silty clay to sand) and rocky (boulder fields and isolated low to moderate relief reefs [1 to 8 ft- [0.3 to 2.4 m-]), with 1 to 6 in-(2.5 to 15 cm-) high north-south oriented sand waves present where sediment was coarse. Sand waves inshore of the 120 ft (37 m) isobath were smaller and “less organized” (no linear orientation) than those observed in deeper water. Sedimentary habitat was present along approximately 5,837 ft (1,779 m; 86%) of the segment and rock habitat was observed along 955 ft (291 m; 14 %). OBS-4 was located on a coarse sediment seafloor habitat with sand waves up to 6 in (15 cm) high present (Figure 4).

Within the 955 ft (291 m) of rock habitat crossed within this segment, the cable actually contacted rock substrate for only 92 ft (28 m). The cable was suspended over rock habitat along the remaining distance. While the suspension of the cable was generally less than 1 ft (0.3 m), in two locations the cable was suspended up to 5 ft (1.5 m) between rock features. The lower-relief rock habitat within this segment was covered with a thin veneer of sediment and was relatively depauperate of epibiota, though higher features did support the plumose anemone *Metridium giganteus.* Other rock-associated epibiota included solitary corals, gorgonian coral (i.e., *Muricea* sp.), and unidentified hydroids (Figure 5).

No attached macrophytic algae was observed on the rock features within this segment, and juvenile and adult rockfish were present, but not common, around rock features. Observed impacts to epibiota were limited to two *Muricea*, both of which were under the cable. Common biota observed within the sedimentary habitats included the bat star (*Patiria miniata*) and two species of seapen (*Stylatula elongata* and *Acanthoptilum* sp.). An unidentified burrowing anemone was also present within the sedimentary habitat, and a tube worm (*Diopatra ornata*) was present to common inshore of the 100 ft. (30 m) isobath. Unidentified octopi, the lingcod (*Ophiodon elongatus*), and Dungeness crabs (*Metacarcinus=Cancer magister*) were present within this habitat. No sediment-associated biota was observed to have been directly impacted by the cable, and crabs and lingcod were “hiding” under the cable where it was suspended between sand waves.

Cable tension within this segment varied from none to moderate; the cable was relatively taut where it was suspended between rock features. Burial depth of the cable within the sedimentary habitat varied from 0 (between the peaks of the higher sand waves) to an estimated 3 in (7.6 cm) (within the silty clay sediment areas). OBS-4 (Figure 4) was located on sedimentary seafloor habitat and appeared to have settled less than 1 ft (0.3 m) into the sandy sediments.

OBS-4 TO OBS-3. Observations within this 4.9 mi- (7.9 km) long segment were completed on December 8, 2013 (poor sea conditions precluded operations on December 7), with the ROV initiating the survey at OBS-4 and following the cable offshore to OBS-3. A portion of this cable within this segment was “loosely laid” in a loop with a circumference of approximately 1,290 ft. (393 m). Approximately 2.5 hours of video were recorded within this segment and the water depth range was from approximately 176 to 340 ft (54 m to 104 m).

Seafloor habitats within this segment were both sedimentary (silty clay) and rocky (low to moderate relief reefs with boulders, 1 to 8 ft [0.3 to 2.4 m] high,). Sedimentary habitat was present along approximately 24,074 ft (7,274 m) (97%) of the cable length within this segment and rock habitat was observed along 742 ft (226 m) (3%). No coarse sedimentary habitat or sand waves were observed within this segment. OBS-3 was located on silty/clay sedimentary seafloor habitat (Figure 6). In addition to the OBS unit, a junction box (also referred to as a “splitter box”), approximately 11.9 in length and 6.6 in diameter (302 millimeters [mm] by 168 mm), that connects the cable between OBS-4 and OBS-3 was observed within this segment (Figure 7).

Fifty- three ft. (17 m) of rock habitat is contacted by the cable between these two OBS units. Approximately 2.5 mi (4.0 km) northwest of OBS-4, the cable loop described above extends to the northeast and then to the southwest. Within this 1,290 ft-(393 m-) long loop, the cable crosses 551 ft (168 m) of rock habitat and actually contacts the rock for approximately 32 ft (10 m). The seafloor habitat within the remaining cable alignment between the two units is sedimentary with coarse grain material and sand waves present in water depths of 154 ft (47 m) or less and silty/clayey sediment throughout the remainder of the cable corridor.

Rock habitat supported an epibiota similar to that described above; however, rock substrata in water depths of 250 ft (76 m) or more supported the crinioid *Florometra* sp. Rockfish, including blue rockfish (*Sebastes mystinus*), were more abundant within this segment that inshore of OBS-4, but were not common. An aggregation of approximately 100 ratfish (*Hydrolagus colliei)* was observed near a rock feature at 244 ft (74 m) depth within this segment. Based on observations, four *Metridium* were impacted (cut or crossed) by the cable laid across rock habitat within this segment; no other impacts to the rock habitat or associated biota were recorded.

Characteristic sediment-associated macroepibiota included the two aforementioned sea pen species and the plumose sea pen (*Ptilosarcus gurneyi*). The multi-armed sunstar (*Solaster* sp.) and the grey tectrabranch (*Pleurobranchus* sp.) were present but not abundant. One sea pen (*Acanthoptilum* sp) was buried under the cable within this segment. No other impacts to the sediment-associated biota were observed within this segment.

The cable was approximately 20% buried within the sedimentary substrate. Depth of burial ranged from approximately 1 in (2.5 cm) through the peaks of sand waves to approximately 3 in (7.5 cm) in finer-grained sediments. In fine-sediment habitat, the cable was approximately 50% buried. Within coarse-grain habitat, burial was approximately 10% due to the topography of the sand waves within that habitat. With time, the cable is expected to be completely buried within the silty sediments, but is likely to remain exposed in the coarse-grain habitat where the sediment is subjected to stronger currents.

Tension on the cable ranged from zero (within finer grain sediment habitat) to moderate within the sand wave habitat and where it crossed higher elevation rock features.

OBS-3 TO OBS-2 AND TEMPORARY OBS-2. The cable route from OBS-3 to OBS-2 was also completed on December 8, 2013. Fine sediments characterize the seafloor habitat at the OBS-2 location (Figure 8) and along the 3.0 mi - (4.5 km-) long cable route between OBS-3 and OBS-2; no rock habitat was observed within this area. Similarly, the location where the Temporary OBS-2 was placed comprises fine sediments. Macroepibiota observed within this cable segment was similar to that discussed above, with sea pens (particularly *Acanthoptilum* sp. and *Stylatula elongata)* and unidentified octopi being most common. Fish observed on and around the sedimentary seafloor included both long and short-spine combfish (*Zaniolepis latipinnis* and *Z. frenata*, respectively), and unidentified flatfish.

Approximately halfway between OBS-3 and OBS-2, in approximately 346 ft (105 m) of water, the former location of Temporary OBS-2 was observed. An approximately 1 ft. (0.3 m) deep and 3 ft (1 m) long depression was recorded; no obvious loss of biota associated with the placement or removal of Temporary OBS-2 was observed.

The cable between the two long-term OBS units within this segment was approximately 15% buried and the cable was under no tension along this entire segment. No biota was observed to have been impacted by the cable within this segment.

OBS-2 TO OBS-1 AND TEMPORARY OBS-1. The cable route from OBS-2 to OBS-1 was completed on December 9, 2013. The seafloor at OBS-1 (Figure 9) and along 2.1 mi- (3.4 km-) long corridor between OBS-2 and OBS-1 is predominantly sedimentary, comprising fine-grain sediments; no coarse-grain sediments were observed within this segment. The epibiota associated with the sedimentary habitat was similar to that discussed above; however, Dungeness crab were more common here than in deeper water areas. No impacts on the sediment-associated biota related to the placement of the cable or the temporary and permanent OBS units within this segment were observed.

A single, low-relief (approximately 1 ft. [0.3 m] high) 39 ft.- (12 m-) long rock reef was observed approximately half-way between the two OBS units, at approximately 255 ft. (78 m) depth. Most of the rock was sediment-covered, but two *Metridium* were observed attached to the substrate. The cable contacted rock substrate for 5 ft. (2 m) of the rock feature, however no cable-associated impacts to the rock-associated epibiota were observed.

The former location of Temporary OBS-1 was observed, however no obvious depression or other seafloor scarring at or around that location was recorded. The seafloor habitat at the location of Temporary OBS-1 was fine-grain sediment, and no impacts to the sediment-associated biota at the site were observed.

Approximately 10% of the cable within this segment was buried in the silty sediment and no cable tension, including where it crossed the low-relief rock feature discussed above, was apparent.

ASSESSMENT OF IMPACTS

This project-specific environmental document indicates that an estimated 1.3 mi. (2.1 km) of cable was expected to cross rocky substrate, and that some undetermined number of organisms could be affected. Based on the review of video footage from the as-laid diver and ROV surveys, approximately 0.47 mi (0.76 km) of rocky substrate was crossed, and approximately 313 ft. (95 m) of cable was observed to be in contact with rocky substrate. As a result of that contact, two sea fans (*Muricea* sp.) and four anemones (*Metridium giganteum*) were impacted. No physical damage to the rocky substrate (i.e., breaking of rock) was recorded in the video from the two surveys. Although the cable is moderately taut across some of the rock features, the size and relative flexibility of the cable is not expected to result in future damage to the rocky substrate.

Within the sedimentary habitat areas, one sea pen (*Acanthoptilum* sp.) was crossed by the cable in the sedimentary habitat. It is likely that some additional macroepibiota were under the long-term OBS units when they were placed and have, therefore, been crushed. Based on the density of those organisms and the size of the OBS units, it is expected that between 10 and 20 seapens and/or anemones were affected. The cable did create a narrow, 2 in. (5 cm) depression in the finer, clayey sediments; that depression is expected to fill within one to two years. In the coarse-grained sediments, characteristic of areas where near-bottom currents are stronger, no habitat alteration was observed.

All long-term OBS units are on sedimentary habitat and the current cable alignment appears to have avoided rocky substrate to the greatest extent possible. Impacts to the seafloor appear to be minimal and less than was originally estimated in the environmental document.

If you should have any questions regarding the above information and/or require additional information, please contact me at (805) 683-1233, ext. 4, or spoulter@padreinc.com.

Sincerely,

PADRE ASSOCIATES, INC.

Simon A. Poulter

Manager, Environmental Sciences Group

Attachments: Attachment A - Figures

c: Kris Vardas (PG&E)

ATTACHMENT A
FIGURES

PG&E Geosciences Department
January 31, 2014 (1102-0621)

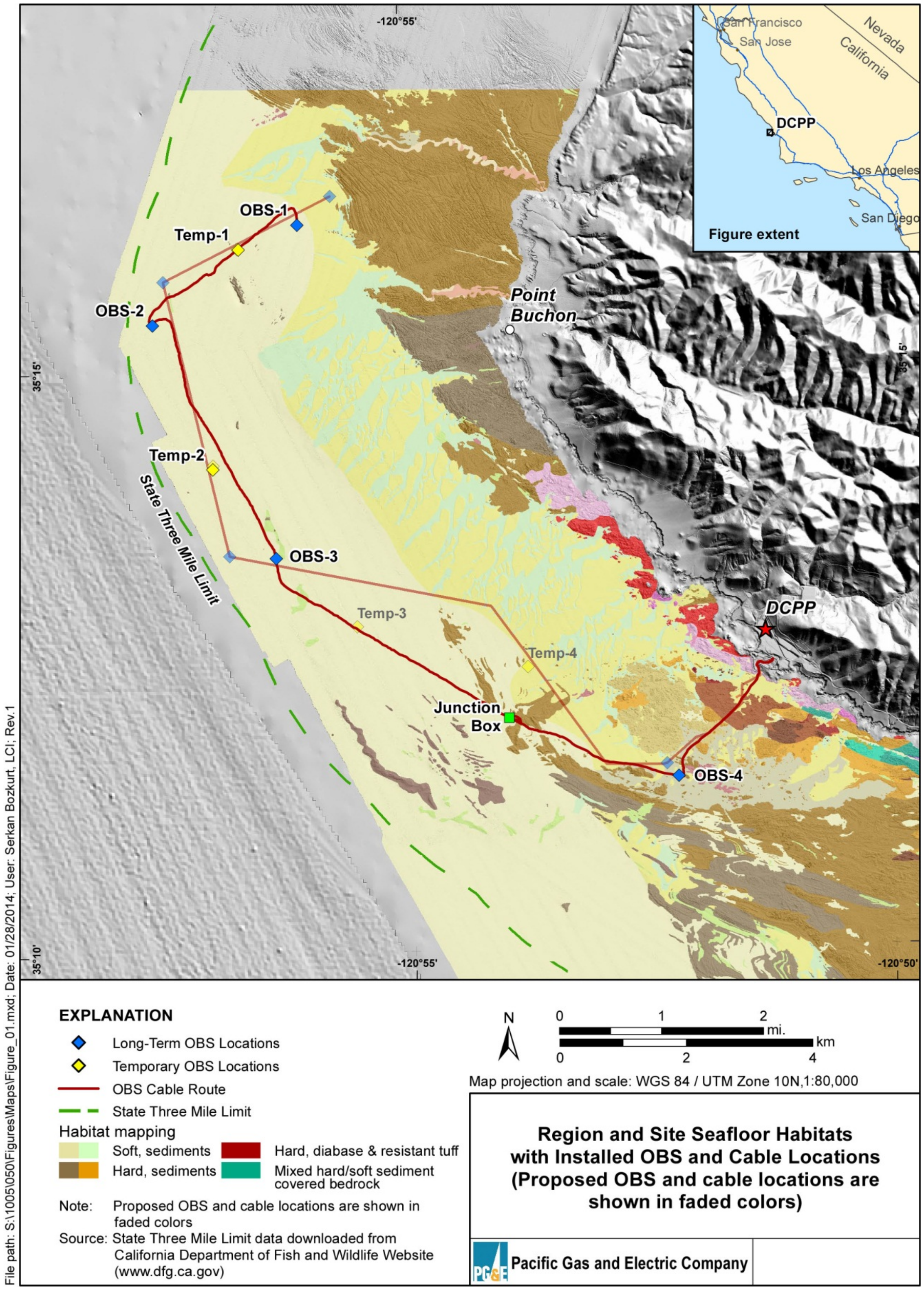


Figure 1. Region and Site Seafloor Habitats with Installed OBS and Cable Locations

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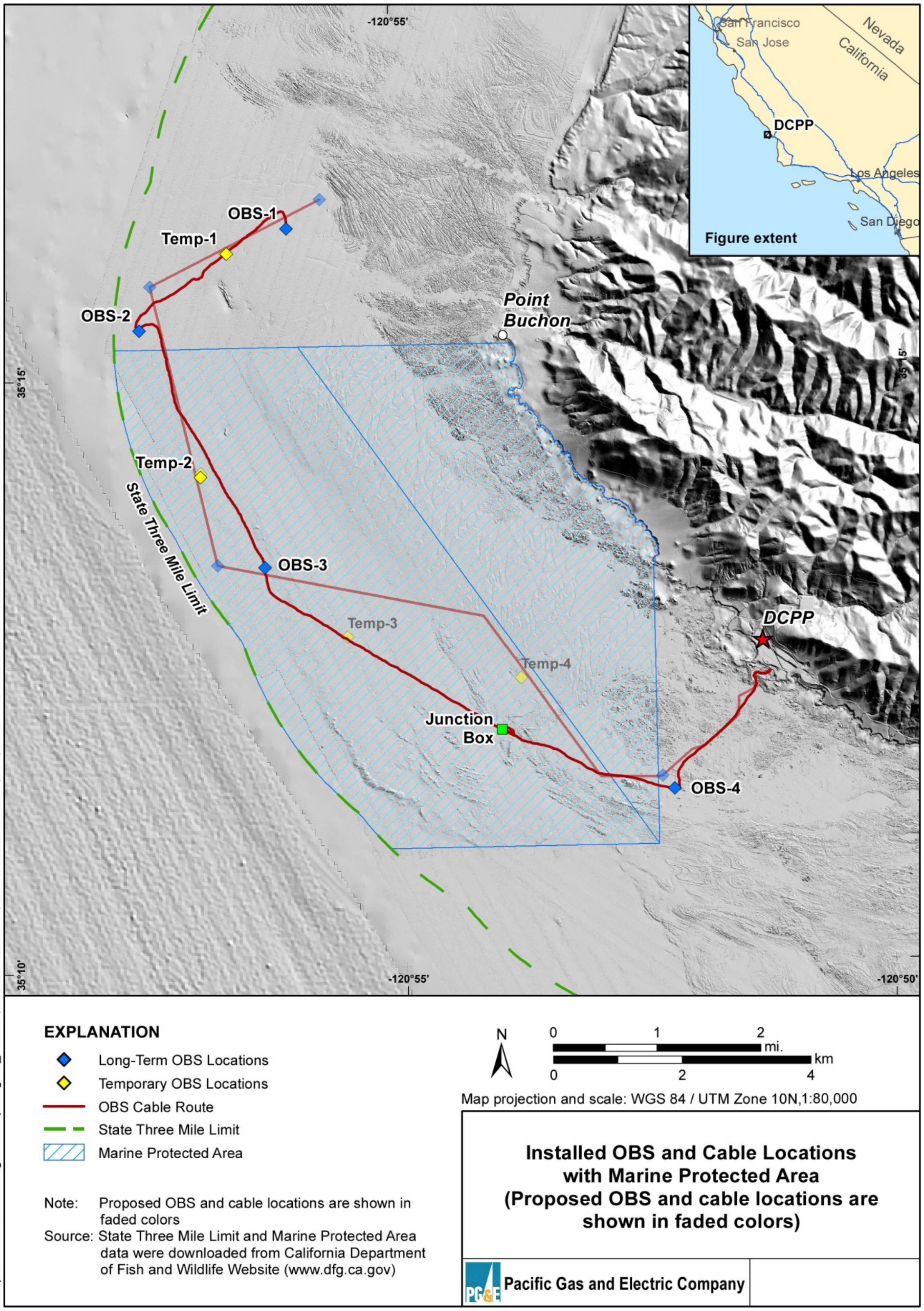

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Figure 2. Installed OBS and Cable Locations with Marine Protected Area

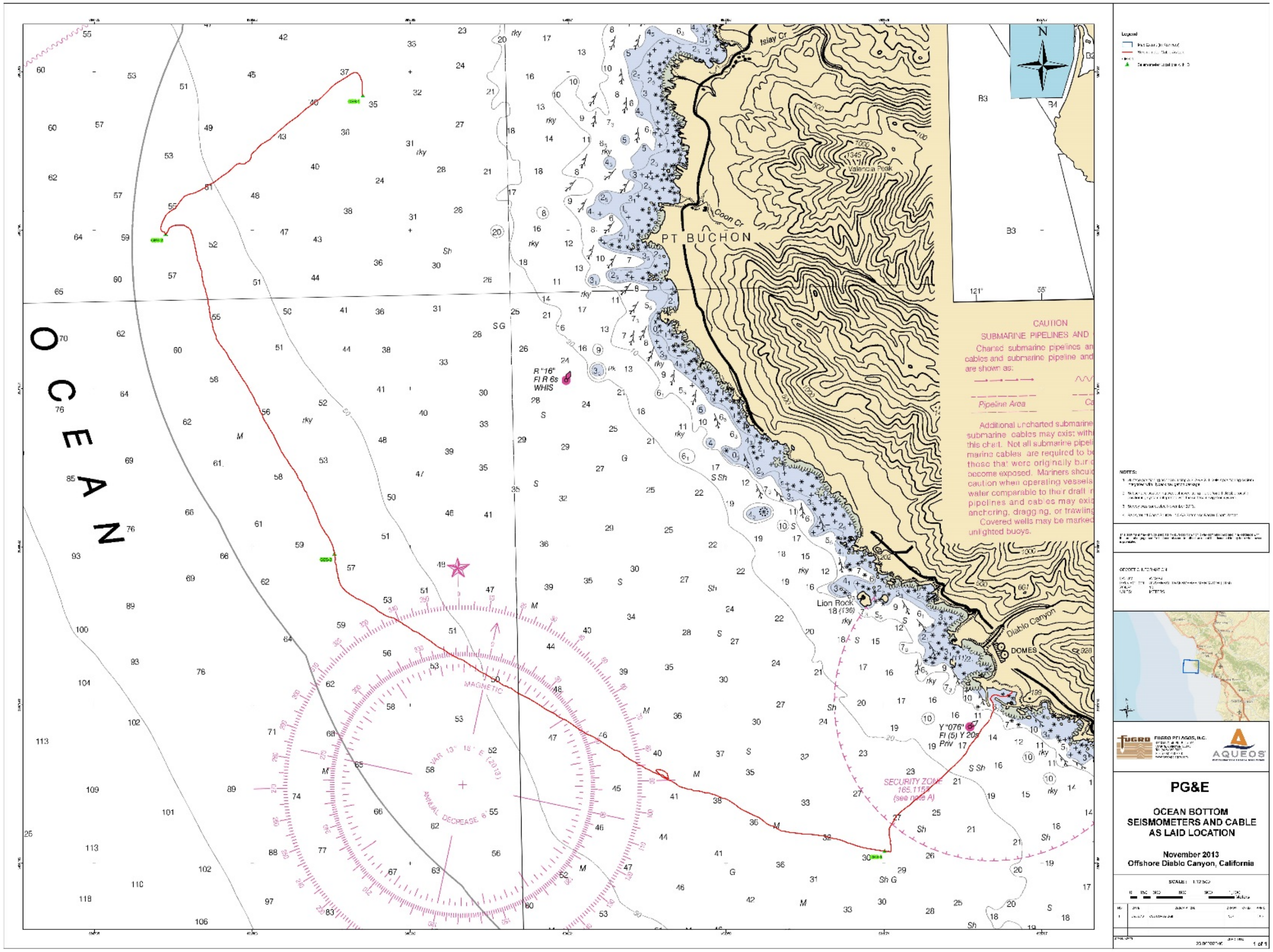

Figure 3. OBS and Cable As Laid Location with NOAA Nautical Chart

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Figure 4. Video-Still of OBS-4 with Deployment Bridle (Water Depth 174 ft. [53 m])

Figure 5. Video-Still of Cable Crossing Rock Feature and Suspended Between Rock Features (Water Depth 175 ft. [53 m])

Figure 6. Video-Still of OBS-3 and Installation Bridle (Water Depth 340 ft. [104 m])

Figure 7. Video-Still of Junction Box Between OBS Units 4 and 3 (Water Depth 252 ft. [77m])

Figure 8. Video-Still of OBS-2 and Installation Bridle (Water Depth 330 ft. [101 m])

Figure 9. Video-Still of OBS-1 and Installation Bridle (Water Depth 210 ft. [64 m])

APPENDIX F

Post-Deployment Nearshore Diver Survey

Diablo Canyon Power Plant
OBS Cable Post-Deployment Diver Survey

November 14, 2013

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Purpose

This report describes the post-deployment survey findings for the nearshore section of the Diablo Canyon Power Plant (DCPP) Ocean Bottom Seismometer (OBS) cable. The nearshore section of the cable starts at the -80 ft (-24 m) MLLW depth contour outside the DCPP intake cove and passes through the intake cove to where it rises up the intertidal revetment through a conduit on the northeast shore of the intake cove (**Figure 1**). From there the cable passes under a road and terminates inside the data processing lab.

The nearshore section was surveyed by divers using SCUBA because the shallow area cannot be surveyed by remote operated vehicles (ROVs), due to the presence of kelp and rock pinnacles that can tangle the ROV tether and cable. The divers collected latitude/longitude coordinates of the as-built nearshore cable alignment, and completed underwater videography to document the habitats and species along the cable. A GIS shapefile with the coordinates of the cable alignment and the video are provided as additional deliverables.

Prior to the cable deployment, the habitats and predominant benthic species along the planned cable route of the nearshore section were documented in surveys completed by Tenera divers on May 17-20, 2011.[1] The nearshore section of the OBS cable was subsequently deployed through the intake cove on July 26, 2013. Tenera divers assisted with deploying and positioning portions of the nearshore cable section to its final (as-built) alignment. The post-deployment survey of the nearshore cable section was then completed on October 16, 2013. The following sections of the present report describe the survey methods and findings.

[1] Tenera Environmental. 2011. Ocean Bottom Seismometer Cable Landing, Habitat Characterization Study, Diablo Canyon Power Plant, May 27, 2011.

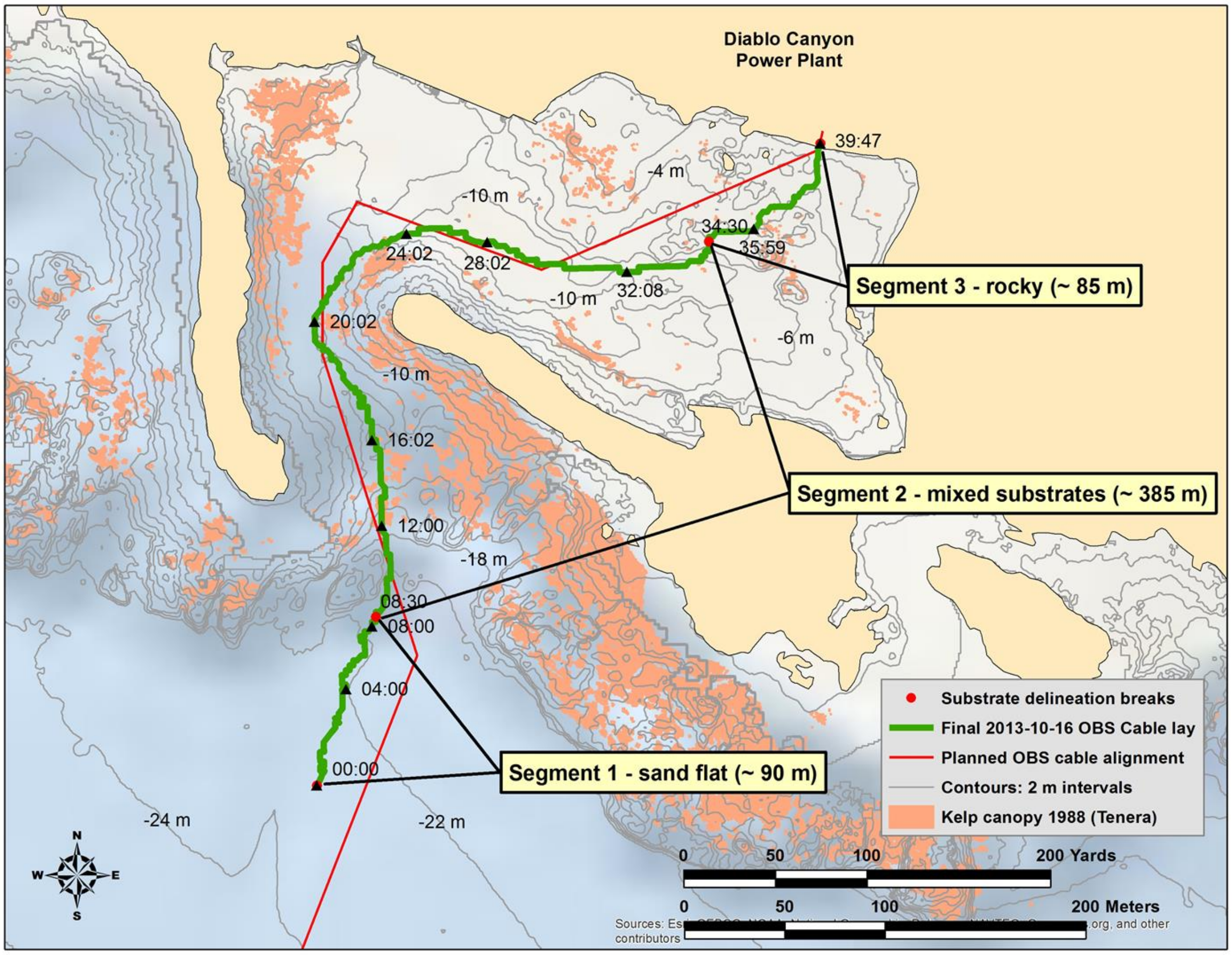


Figure 1. OBS cable nearshore section through the DCPP intake cove showing the as-built alignment (green) and planned alignment (red) and divided into three segments based on substrate habitats crossed. Running times of the video camera are shown for every 4-minutes.

Methods

The OBS cable post-deployment survey of the nearshore section was completed on October 16, 2013. Seas were calm with 1–2 ft (0.3–0.6 m) swell, and winds were light. Underwater horizontal visibility was approximately 20 ft (6 m).

The survey began at a starting depth of approximately -76 ft (-23 m) MLLW, which was approximately 230 ft (70 m) further offshore from the outermost location of the pre-deployment survey. From there the survey progressed inshore (**Figure 1**). The submerged cable was videotaped using a Sony Handycam Model HDR-CX550V digital video camera inside a Light and Motion Bluefin 550 waterproof housing. At the same time, the divers towed a Garmin ETrex Legend GPS unit attached to a surface float with the tether line held taught to keep the GPS unit directly above the divers. This provided a trackline of latitude/longitude coordinates for the nearshore cable section (**Figure 1**). The GPS unit was set to record at 3-second intervals. The GPS and camera times were synchronized by correcting for the time offset between the two units (by videotaping the time display of the GPS unit). This allowed the video images to be synced with their locations along the cable route.

Results and Discussion

The total cable distance surveyed from the -76 ft (23 m) MLLW depth outside the intake cove to the intertidal revetment at the shoreline was approximately 1,837 ft (560 m). The total run time of the underwater video was 39 minutes 46 seconds. The divers were able to survey this entire distance in a single dive, and thus the videotaping and position recordings ran continuously and were never interrupted.

The as-built OBS cable alignment of the nearshore section determined by towing a surface GPS unit over the cable appears in **Figure 1**. The actual alignment, however, is likely ‘smoother’ than the line shown in **Figure 1**, due to the GPS unit not being able to be kept directly above the video divers at all times. It was difficult to keep the GPS unit directly above the video divers when they were in deep water, in the intake cove entrance area where currents were strong, and where surface canopy kelp and drift kelp became tangled with the GPS tether line.

Overall, the as-built cable alignment of the nearshore section closely matches the planned alignment (**Figure 1**); the cable passes through the same general zones described in the pre-deployment survey that were differentiated based on habitat and species characteristics. The underwater video reveals the as-built cable laying across three types of substrate habitats: an expansive sand flat mainly outside the intake cove; areas of mixed substrates (bedrock, boulder, cobble, gravel, sand) inside the intake cove; and areas of mainly bedrock and boulders where the cable approaches the intertidal revetment and comes to shore (**Figure 1**, **Table 1**).

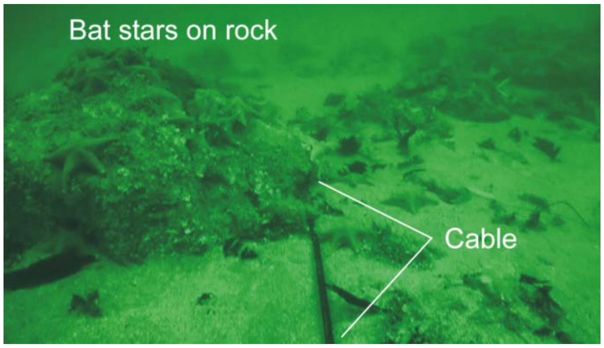
Table 1. Approximate lengths (m) of the nearshore OBS cable crossing over three types of substrates.

Segment	**Video Run Time** (minutes-seconds)	**Depth Range** (m MLLW)	**Sand Flat** (m)	**Mixed Substrates** (m)	**Rocky** (m)	**Comments**
1	00:00–08:30	21-23	90	-	-	Largely barren sand flat. Occasional low-relief rocks covered with bat stars (*Patiria miniata*).
2	08:30–34:30	6-21	-	385	-	Giant kelp (*Macrocystis pyrifera*), subcanopy kelps (*Pterygophora californica*, *Laminaria setchellii*), sea stars (*P. miniata*, *Pisaster* spp.), and ornate tube worms (*Diopatra ornate*) prevalent in general area. Red and green algal understory prevalent in shallower water.
3	34:30–39:46	0-6	-	-	85	Larger proportion of bedrock and boulders, relative to sand.

The cable lengths associated with the substrate habitats in **Table 1** are approximate, and would be expected to change seasonally due to sand accretion and attrition associated with natural sediment transport in the area.

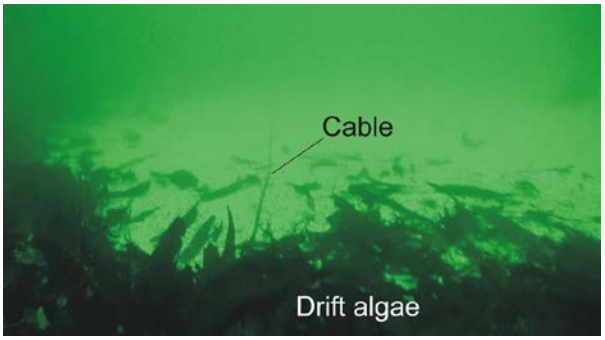
There were no indications of habitats or biota having been impacted from the cable installation. The cable was deployed very close to the planned route, and there were no observations of overturned rocks, damaged kelp, or injured or dislodged invertebrates, which would indicate potential impacts due to the deployment of the cable. Furthermore, the divers shifted the alignment of the cable in areas where movement may have resulted in impacts. The cable is small in diameter (approximately 0.5 in. [1.3 cm]), and was already settling and becoming buried under sand in many areas. It had been 73 days since the time the cable was deployed. Representative video images of the nearshore cable section follow.

Segment 1 at 00:00 run time. Diver is holding the tether of the GPS unit that is directly above.

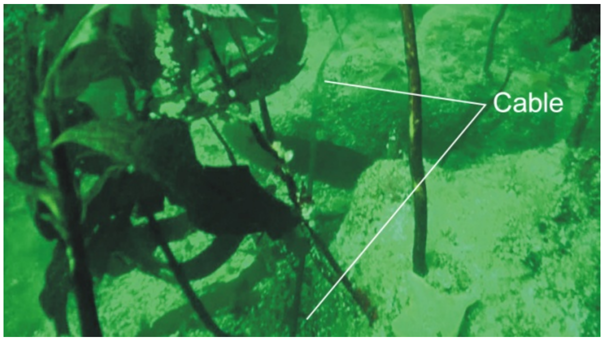


Segment 1 at 00:07 run time showing cable passing next to rock covered with bat stars.

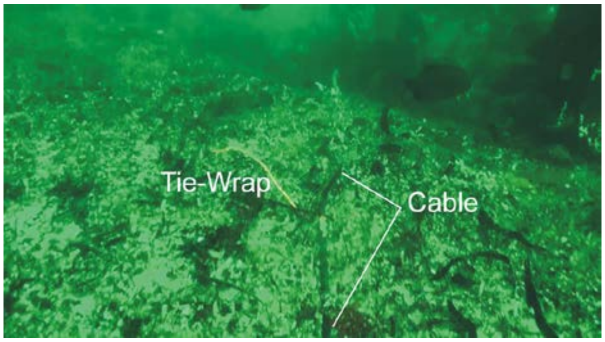
Segment 1 at 00:40 run time with cable buried under sand with tie-wrap protruding.



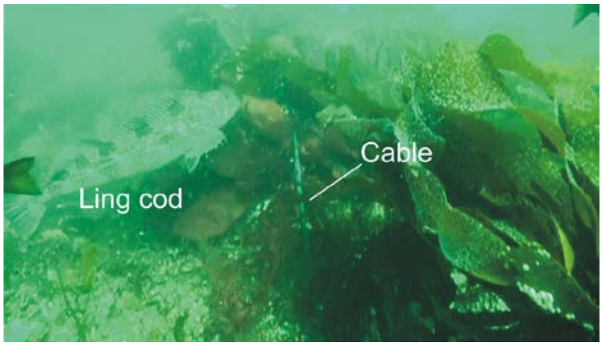
Segment 1 at 07:20 run time with cable over sand.



Segment 2 at 16:27 run time with subcanopy kelps attached to rocks next to cable.

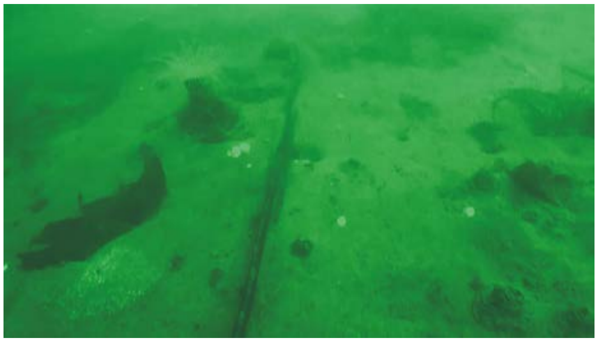


Segment 2 at 20:46 run time with cable settling between mats of ornate tube worms.

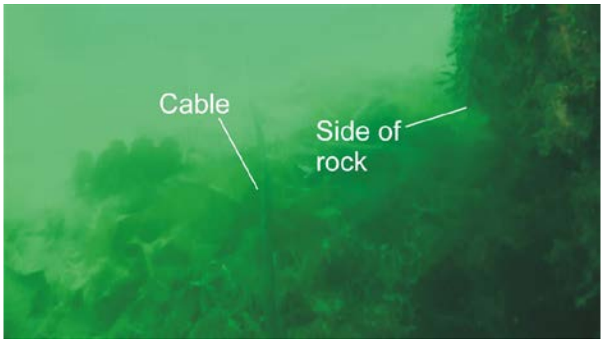


Segment 2 at 20:59 run time.

Segment 2 at 27:41 run time.

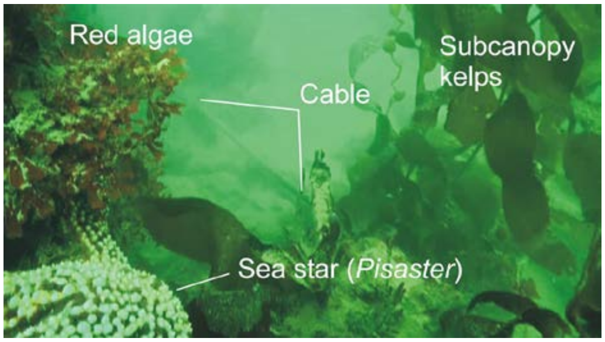


Segment 2 at 29:30 run time with cable crossing over a sand pocket area.

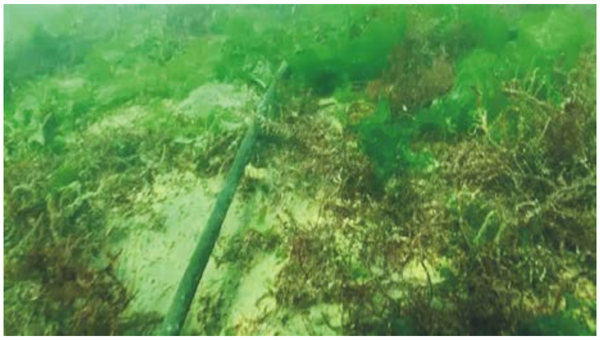


Segment 2 at 32:24 run time.

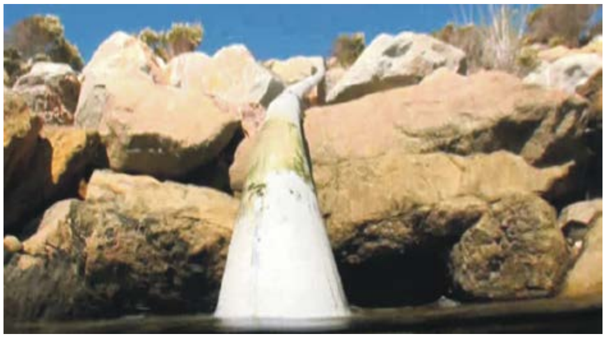
Segment 2 at 32:32 run time with cable on heavily silted boulder.



Segment 2 at 33:56 run time



Segment 3 at 38:50 run time.



Segment 3 at 39:38 run time with cable in conduit running up shore revetment.

APPENDIX G

Noise Survey

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Deployment of two Portable OBS off Point Buchon, CA

10 Feb 14
Version 2.1

Portable OBS

In the late summer and early fall of 2013 Guralp Systems Ltd. (GSL) deployed two autonomous portable Ocean Bottom Seismometers (P-OBS) near Point Buchon, CA. Their deployment was part of a wider OBS based system for monitoring two off-shore faults, the Hosgri- and the Shoreline-Fault in the waters off Central California. Initially we had planned to deploy each sensor for two weeks each at two different locations. However, for operational reasons, each sensor was left in its first location for more than three months and not deployed at a second location. In this report, we will give an initial description of the performance of the portable instruments and assess the data they collected. This report is meant as a survey and not as an exhaustive scientific analysis of the data gathered by the OBS.

1. The instruments

Fig. 1: The two instruments in their initial pre-deployment configuration. The glass spheres are covered with orange plastic protectors

Each instrument consists of a frame, two sealed glass spheres, the sensor package, the anchor weights and peripheral equipment (figure 1). The glass spheres contain the batteries, the digitizer and the data storage device. They also provide the buoyancy necessary for the recovery of the instruments. The peripheral equipment includes an acoustic transponder and various recovery aids, i.e. a strobe light, a GPS receiver and an FM transmitter.

The sensor package is mounted in the center underneath the frame (see figure 2). It contains a standard CMG-40T feedback seismometer with a flat frequency response between 60 sec and 80 Hz and a sensitivity of 2000 V/[m/sec]. The sensor is housed in a glass sphere which in turn is contained in a stainless steel frame.

Fig. 2: Sensor mounted in center underneath the frame

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Portable OBS

Figure 2 also shows two black cylinders at the bottom of the frame. These are the original anchor weights, which are made of ABS pipes filled with concrete. They can be released by an acoustic signal given to the transponder on top of the frame (black round canister in figure 1).

2. Deployment and Recovery

2.1 The Procedures

Because of restrictions set by the State of California during the permitting process for the wider OBS project, we were not able to deploy the two portable OBS in the usual manner. During a common type of deployment one heaves an instrument over board of the deployment vessel, unhooks it from the winch cable and lets it free fall to the sea floor under its own weight. The recovery is initiated by an acoustic signal given from the recovery vessel. Upon receiving this signal through its transponder, the instrument releases itself from the anchoring weights and floats to the sea surface under its own buoyancy. Once at the surface, it is recovered manually by the deck crew of the vessel. As a consequence, the anchor weight, usually an environmentally benign piece of heavy steel or concrete, is left on the sea floor. Because the State permit did not allow us to leave anything behind on the sea floor, we changed the deployment and recovery procedures for this project.

2.1.1 Deployment

Instead of letting the instruments sink to the ocean floor under their own weight, we lowered each of them by winch and wire rope from the deck of the ship. In addition each instrument was connected by a line to a clump weight. The length of this line was about twice the water depth at the deployment site. We attached a second line to the clump weight which had buoys and floaters at the other end. The floaters were needed to mark the location of the portable OBS for the recovery operation. In order to prevent the instruments from being dragged over the sea floor by ocean currents or maritime operations, we added a heavy anchor chain to the frame (see figure 3). The chain increased the weight of the instruments considerably and actually made the deployment more stable.

Fig. 3: One of the portable OBS shortly before deployment. Note the chains added to increase stability of the OBS.

2.1.2 Recovery

We recovered the instruments in early November 2013 after each had spent more than 100 days on the sea floor. One of the instruments (Temp-1) had the buoys and floaters still attached to the line connected to the clump weight. After recovering the floaters, we hooked this line to a winch and pulled the clump weight on deck. We then disconnected the line between the clump weight and the sensor frame from the clump weight, attached it to the winch and pulled the instrument up.

Portable OBS

The buoys and floaters orginally attached to Temp-2 had gotten lost during the deployment period. In order to recover this instrument, we used an ROV. With its help, we could attach a carabine hook and a line to the instrument's frame (see figure 4). The ROV brought the line to the sea surface and handed it over to the recovery vessel. Once this line was secured on the deck of the recovery vessel, we attached it to the winch and pulled up the instrument. In the last step, we recovered the clump weight, using the line between it and the sensor frame, thus satisfying the requirement to leave nothing behind on the sea floor.

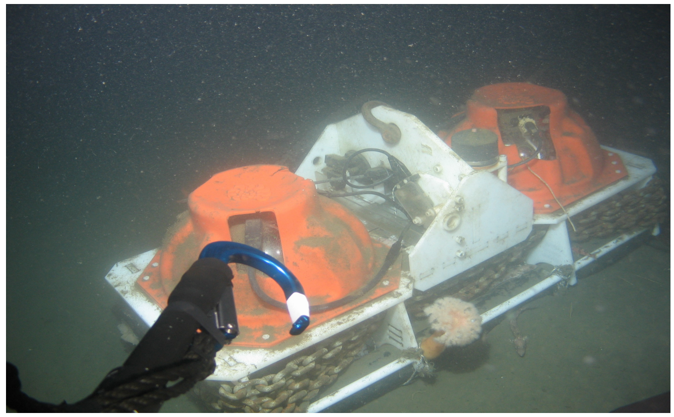


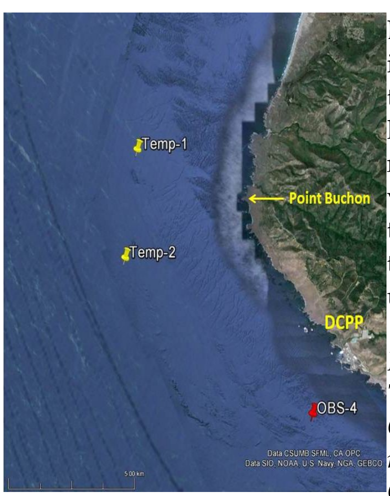
Fig. 4: Instrument Temp-2 on the sea floor shortly before recovery in a photo taken by the ROV. The blue hook in the foreground is attached to the manipulator arm of the ROV. It is used to hook into the shackle at the center of the frame.
Note the fish on the sea floor and sea anemone (Metridium farcimen), which had taken up residence at the bottom of the instrument during its 104 days on the sea floor.

2.2 Deployment Duration and Locations

Table 1 gives the data for the deployment duration and the locations of the instruments.

Name	GSL S/N	Date	Date	Days	Latitude	Longitude	Water depth
		deployed	recovered	deployed	decimal °N	decimal °W	[m]
		2013	2013		(drop point)	(drop point)	
Temp-1	GSL00-POBS	27 Jul	7 Nov	102	35.267477	120.945115	70
Temp-2	6217C-1616	25 Jul	7 Nov	104	35.236093	120.950308	106

Table 1



During the recovery process the ROV found each of the two instruments located on the ocean floor within a distance of less than 30 m from the drop points at the sea surface. The surface locations were measured upon deployment by GPS by the navigator on the deployment vessel. Because this difference is very small, we decided to use the drop point GPS coordinates as the actual locations of the instruments. The error introduced by this difference is minute compared to the other, larger uncertainties usually dealt with when interpreting seismic data.

Fig. 5: A Google Earth map of the locations of the two portable OBS Temp-1 and Temp-2 with respect to the shore station, labelled DCPP. OBS-4 is the location of the only other instrument of the wider OBS network operating during the time of the deployment of the portable OBS units.

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Portable OBS

3. The Data

In this chapter I will give an evaluation of the data collected by the two instruments. I will focus on various types of noise in different frequency bands and will show the recordings of several earthquakes. This evaluation is not meant to be, and does not replace, an exhaustive scientific analysis of the recordings.

In the time series shown in the some of following figures, the green line always represents the vertical, red the first horizontal component and blue the horizontal component perpendicular to the first. What I call in this chapter the first horizontal component would normally be referred to as the N/S component, with the other being the E/W component. However, because we do not know the orientation of the sensors on the sea floor, we cannot refer to the horizontal components by their common nomenclature. Unless otherwise noted, the data shown are always the unfiltered original broadband recordings. The traces in each figure are scalled to the same common factor. The time marks in UTC are always along the top of the figure with the data shown in the upper right hand corner.

The color scheme for the spectrograms shown in other figures in this chapter goes from blue (least intense) to red and even deep purple (most intense). The colours represent relative and not absolute intensities. Unless otherwise noted all figures showing data are generated using the program "Scream" which stands for "**S**eismometer **C**onfiguration, **RE**al time **A**cquisition and **M**onitoring". Scream is a Windows and Linux application developed by Guralp Systems Ltd. and distributed with its digitizers. It allows to monitor, configure and record data from an entire seismic network, including both local and remote sites.

3.1 Data Availability and Timing Drift

Because the duration of the actual deployment of the two senors was much longer than anticipated (see note in introductory paragraph), both systems filled up their respective memories towards the end of the deployment period and stopped recording afterwards. Table 2 shows the periods of data availability.

Name	**GSL S/N**	**Recording Start (UTC)**	**Recording End (UTC)**
Temp-1	GSL00-POBS	25 Jul 14, 23:25	29 Oct 14, 14:47
Temp-2	6217C-1616	27 Jul 14, 17:42	3 Nov 14, 06:30

Table 2

During the recording period as decribed in table 2, the collected data are complete without any gaps or component failures within the instruments. This corresponds to a **data availability of 100 percent**.The total amount of data collected during the deployment by these two instruments was more than 33 GByte in Guralp's own GCF Format. In addition both sensors, the digitizers and

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data loggers to which they were connected performed nominally over the whole deployment period. This lead to an excellent data quality without any anomalies.

As is typical for the deployment of portable OBS, these two units were not connected to a timing source during their deployment on the sea floor. We synchronized each digitizer's internal clock to GPS shortly before deployment and then again immediately after recovery. We found that the drift of the internal clocks was less than 300 msec in both cases. This corresponds to less than 3 msec a day assuming a linear drift. Because the sampling rate was set at 200 samples per second (sps) - one sample every 5 msec -, this clock drift corresponds to less than one digitisation interval per day. As the data evaluation presented here is only initial, I chose to ignore this very small clock drift.

However, depending on the depth and thoroughness of a future seismic analysis of the data collected by the two protable OBS, the overall drift of 300 msec during the whole deployment duration may have to be compensated by a linear drift correction of 3 msec/day.

3.2 Noise

Even during the discussion and planning phases for the deployment of the portable OBS, we expected to see a lot of noise in their recordings for several reasons, among others:

- The instruments were deployed in very shallow water of no more than 106 m water depth (see table 1). They were therefore under the strong influence of wave action at the sea surface. Typically OBS are deployed in much deeper waters.
- In contrast to the cabled OBS deployed in the wider network, the portable OBS described here were not covered by heavy concrete domes, hence they were much more exposed to waves and currents.
- As seen in figure 4, during their deployment the portable OBS became a habitat for sea life in the otherwise barren sand plains of the ocean bottom in the deployment area. Because each instrument's seismometer housing is exposed in the OBS frame, such sea life can easily touch the sensors and thereby generate noisy disturbances.

In the following, I will show and discuss examples of several kinds of noise. This discussion is by no means exhaustive as it only allows a glimpse into the large amounts of data gathered here.

3.2.1 Short Period Noise

The short period seismic noise during the deployment period was highly variable, both in time as well as in shape and amplitude. To show some typical features I have randomly chosen a three hour window on 15 Oct 13 between 00:00 and 03:00 UTC for analysis. In the following three figures (figure 6-8) I always show in the top section the same three hour long unfiltered time series of the vertical component of Temp-2 (green line). The bottom section of each of shows a spectrogram of this time series in various spectral bands. A spectrogram is a visual representation of the of frequencies contained in the time series. In contrast to a spectrum or a power spectgral density plot, the spectogram shows how the amplitudes of the various vary over time.

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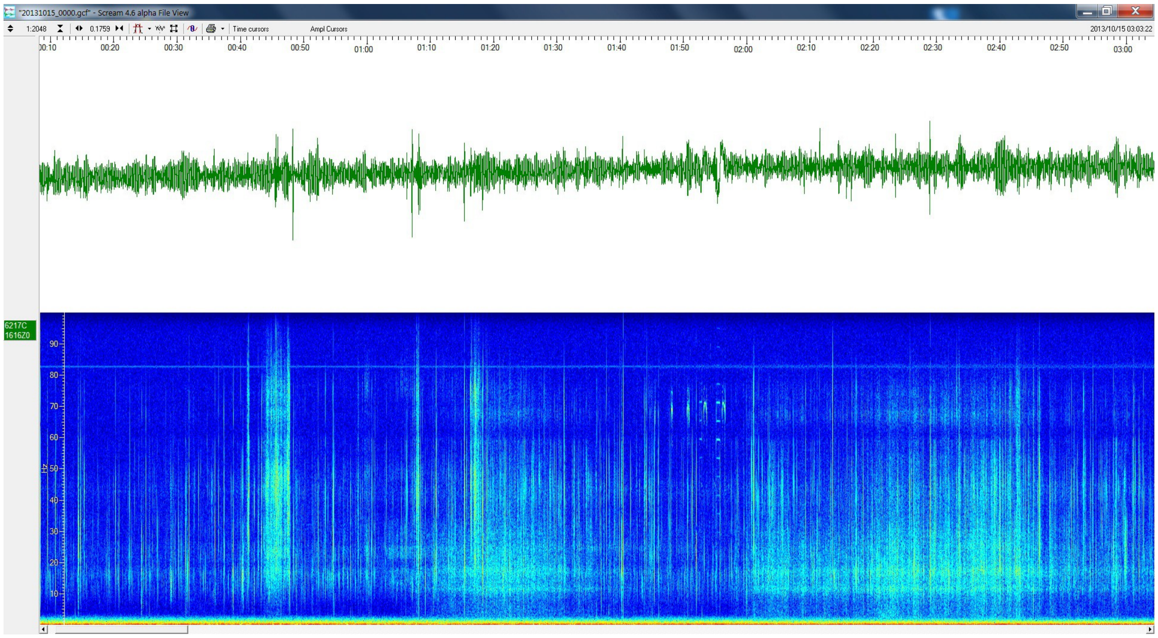

Fig. 6: Overview of the noise recorded by the vertical component of Temp-2 (green line)over three hours on 15 Oct 13. The spectrogram scale on the right shows shows the amplitudes in the frequency band up to 100 Hz, the Nyquist frequency determined by the sampling rate of 200 samples per second.

Among the notable feature in the spectrogram are
- a continuous hum with a frequency above 80 Hz and the
- waxing and waning bands of noise between 10 and 30 Hz.

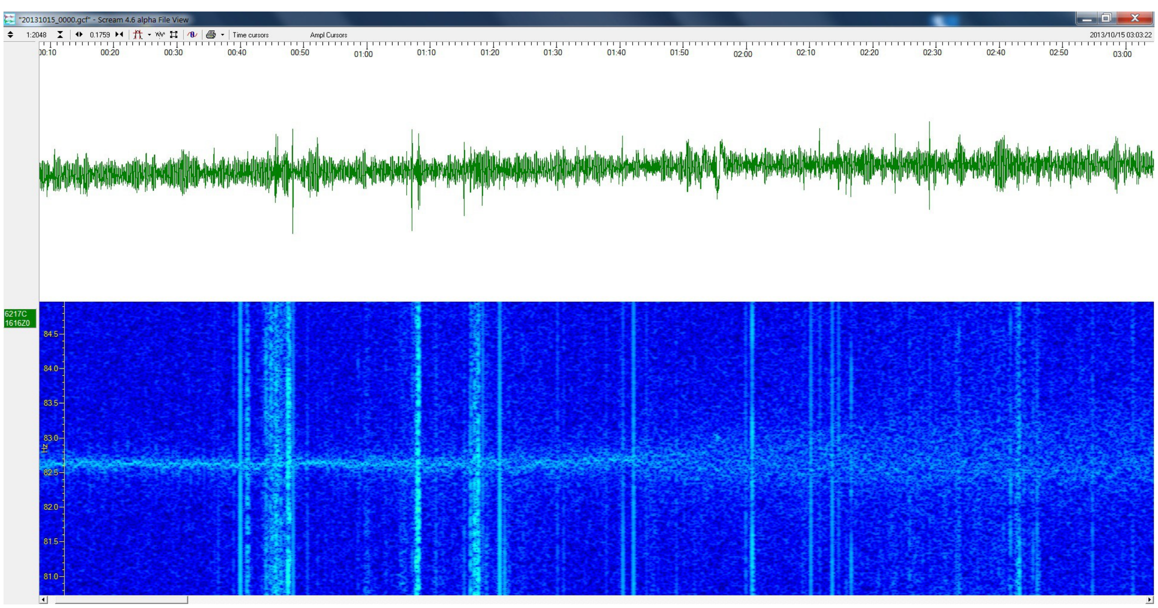

Fig. 7: The spectrogram of the high frequency hum in more detail. The time series on top is again the noise recorded by the vertical component of Temp-2 (green line)over three hours on 15 Oct 13. The spectrogram shows the frequency band between 80.5 and 85 Hz.

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As can be seen in figure 7, the hum has a frequency of about 82.6 Hz. It is rather intense until about 01:40 UTC and then becomes more diffuse. Such pattern of sharper lines waning into a more diffuse pattern at this frequency can be seen in the data almost every day. The same randomly oscillating pattern can be seen The spectrogram of the high frequency hum is shown in more detail in figure 7. It has a frequency of about 82.6 Hz. It is rather intense until about 01:40 UTC and then becomes more diffuse. Such pattern of sharper lines waning into a more diffuse pattern at this frequency can be seen in the data almost every day.

The same randomly oscillating pattern can be seen almost daily in the broader noise in the band between 10 and 30 Hz, as shown in detail in the spectrogram in figure 8. Note that the most intense noise is at 12, 16 and 24 Hz respectively.

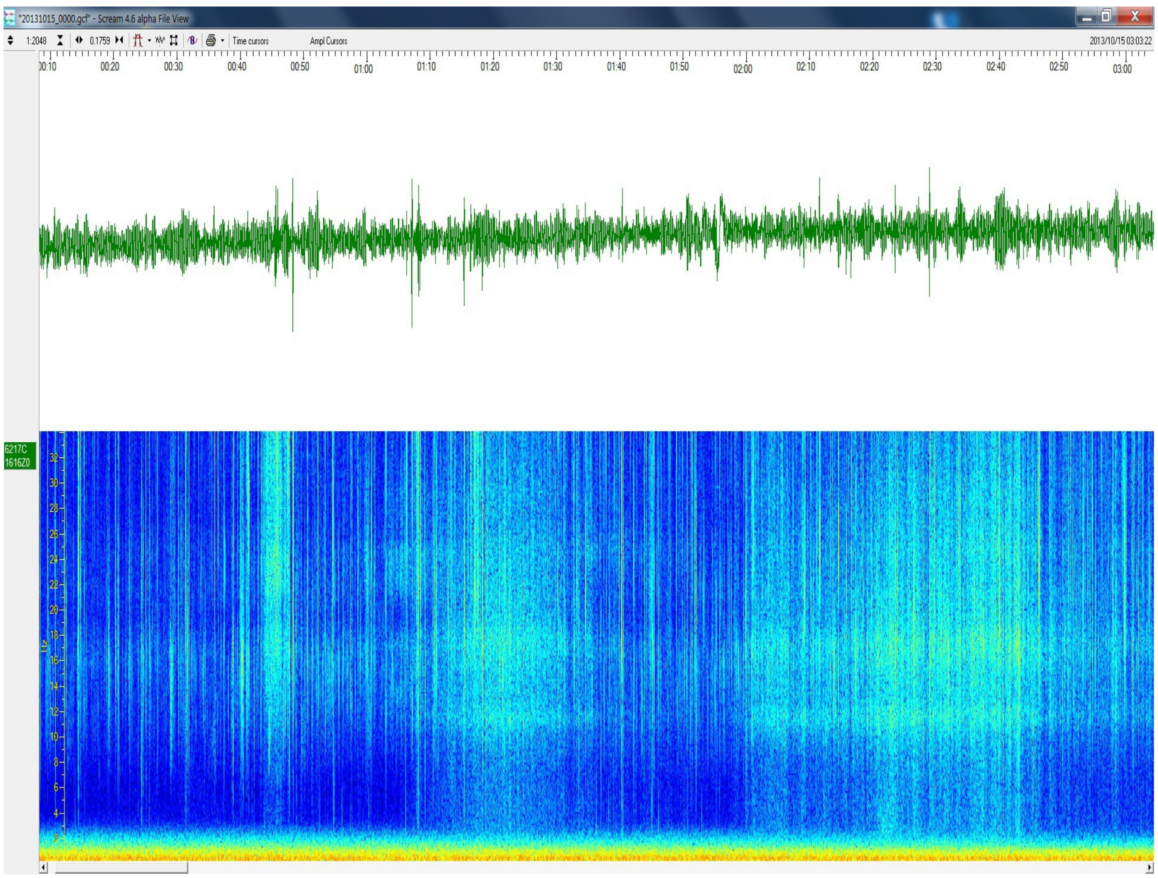

Fig. 8: Same three hour time window as in the previous two figures, with the spectrogram showing the frequencyy band up to 33 Hz. One can see diffuse noise waxing and waning at frequencies around 12, 16 and 24 Hz.

Given the fact that there are no known seismic sources with such characteristics in the deployment area, I assume that the two features shown above are sound waves from distant sources travelling through the water. They either cause the vibration of the instruments directly, or through coupling with the surrounding sea floor.

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3.2.2 Long Period Noise

While the short period noise seems to dominate in figure 6, the most intense noise recorded by the two portable OBS actually has much lower frequencies. In contrast to the short period noise, the noise at longer periods is not nearly as variable. For the analysis of the long period noise I again have randomly chosen a three hour time window between 15:00 and 18:00 UTC on 8 Aug 13.

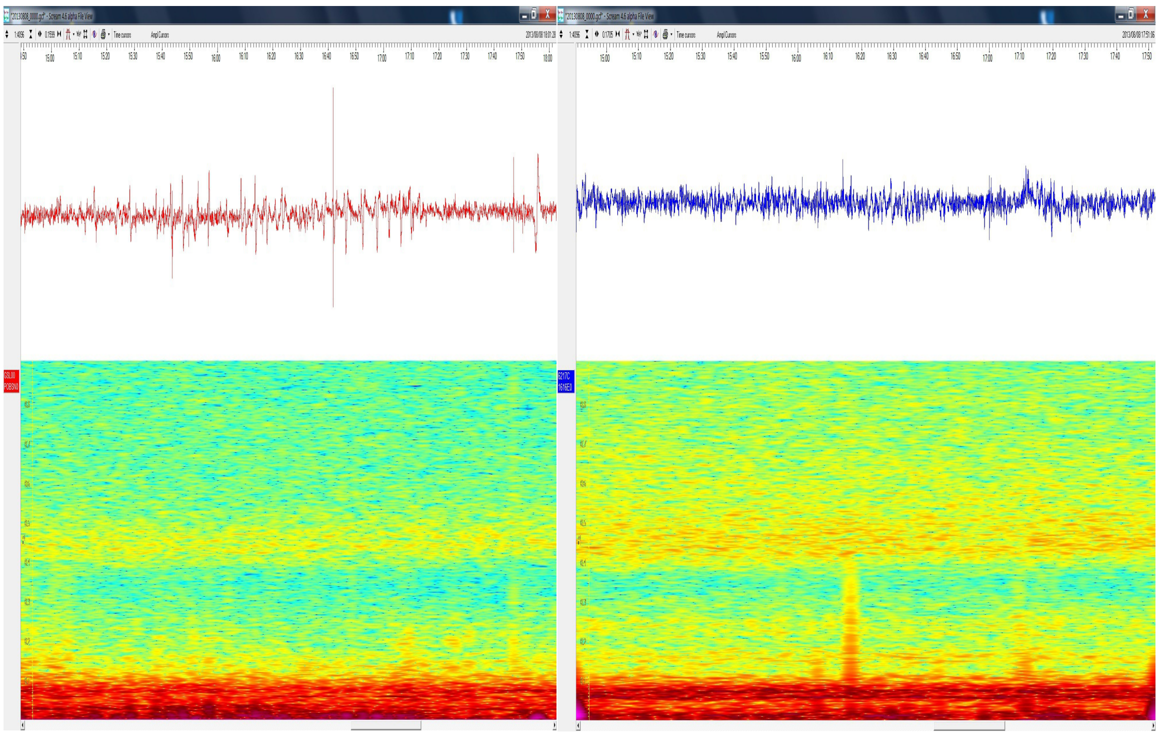

Fig. 9: The two panels show the same three hour time window recorded on 8 Aug 13 between 15 and 18 UTC on a horizontal component of Temp-1 (left panel) and Temp-2 (right). The red and blue lines are the respective time series. The bottom of each panel shows the spectrogram for each time series in the frequency band between 0.05 and 0.8 Hz (20 sec to 1.25 sec period).

While the diffuse band of yellow and red colours in figure 9 indicate some noise energy between 0.4 and 0.5 Hz (2.5 to 2 sec period), the dominant band has an even lower frequency of below 0.1 Hz (10 sec period).

The cause for this noise becomes clear when comparing the seismic noise data shown in figure 9 with the recordings of the differential pressure gauge (DPG) installed on OBS-4. As mentioned before, OBS-4 was the only station of the wider network operating during the deployment of the two portable instruments.

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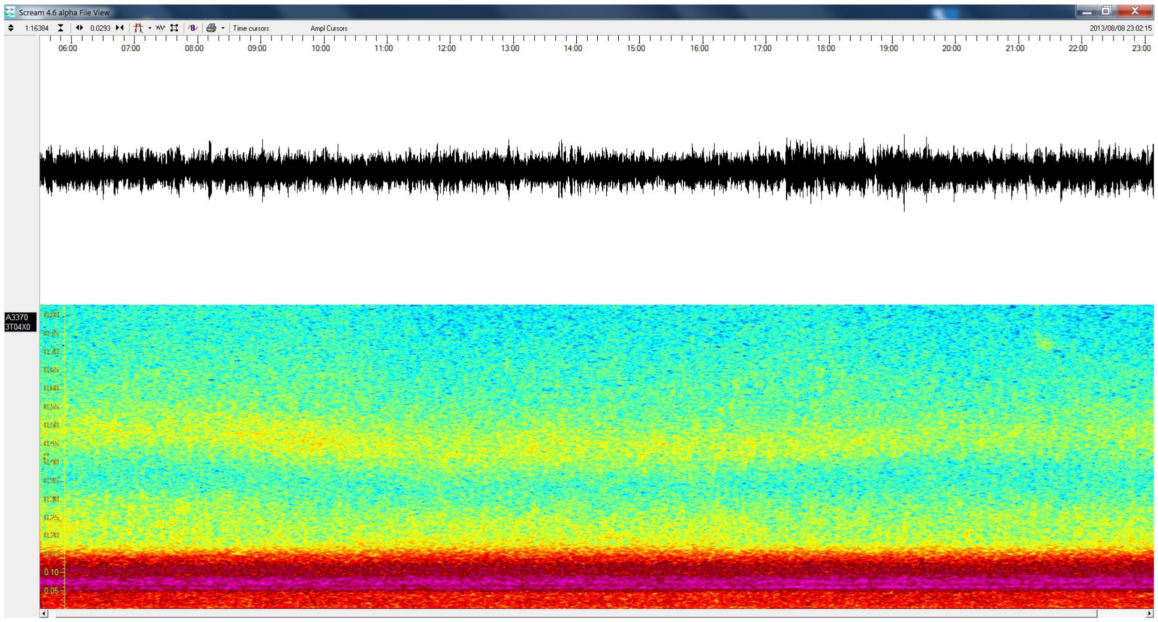

Fig. 10: The black line shows the time series of the DPG recordings on 8 Aug 13 between 05:30 and 23:00 UTC on 8 Aug 13. This includes the three hours (15:00 - 18:00) shown in figure 9. The spectrogram in the bottom panle shows the frequency band between 0.02 and 0.8 Hz (50 - 1.25 sec)

Similar to figure 9, we see in figure 10 a band of diffuse energy around 2 sec period and the dominant energy band (purple colour) at the bottom at about 14 sec period. The DPG records changes of water pressure acting on the OBS. The main cause for these changes in the shallow depth at which all instruments of this OBS network are deployed are changes in the hydrostatic pressure due to ocean waves travelling over the deployment area. The diffuse band at about 2 sec represents waves driven by local winds, while the more intense band at 14 sec is caused by the longer period ocean swell generated by distant storms.

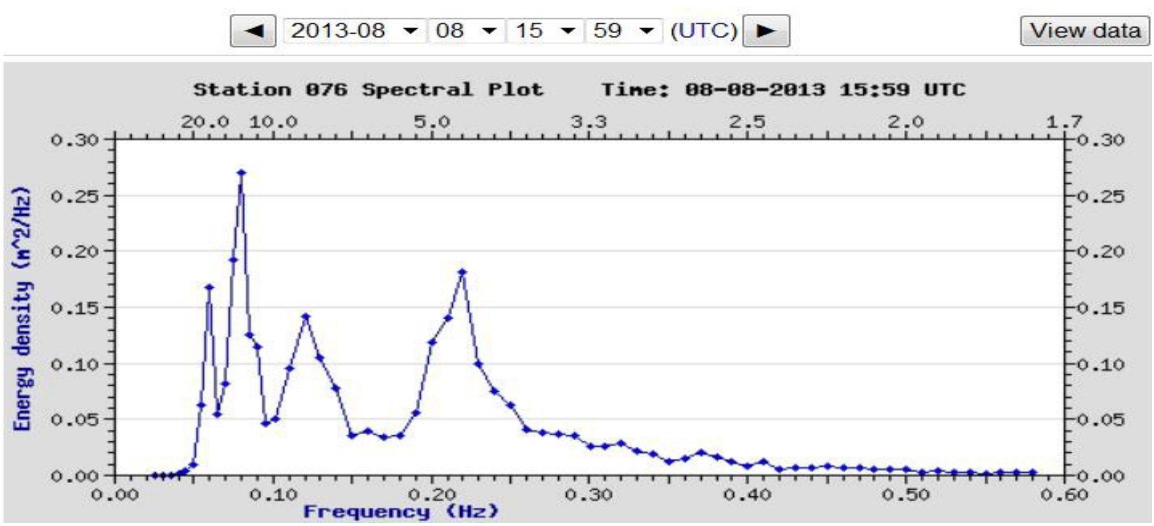

Fig. 11: Energy density spectrum of the ocean waves as measured by the waverider buoy 076 for 8 Aug 15 at around 16:00 UTC. The data were taken from this website: http://cdip.ucsd.edu/?nav=historic&stn=076&stream=p1&xitem=stn_home&sub=data

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This observation is corroborated by data from waverider buoy 076, a Datawell Mk3 directional buoy operated by PG&E, located in 22 m deep water betweeen OBS-4 and the inlet of DCPP. As can be seen in figure 11 the dominant wave period for 8 Aug 13 at around 16:00 UTC is at 14 sec, the same period which we observed in the seismic data (figure 9) and with the DPG (figure 10).

The change in hydrostatic pressure exerted by these two types of ocean waves causes the sea floor to tilt slightly, which is recorded by the horizontal sensors of the portable OBS. The long period noise shown in figure 9 is therefore a direct consequence of the wave action at the sea surface.

How strong the influence of the swell height on the long period recording is, can be judged when comparing periods of high ocean swell with phases of low ocean swell. Again, using data from waverider buoy 076, during the deployment window the highest swell with a maximum wave height of 5.5 m occured on 30 Sep 13 at around 15:30 UTC. The lowest swell with a maximum wave height of 1.1 m happend on 7 Aug 13 at around 5:20 UTC.

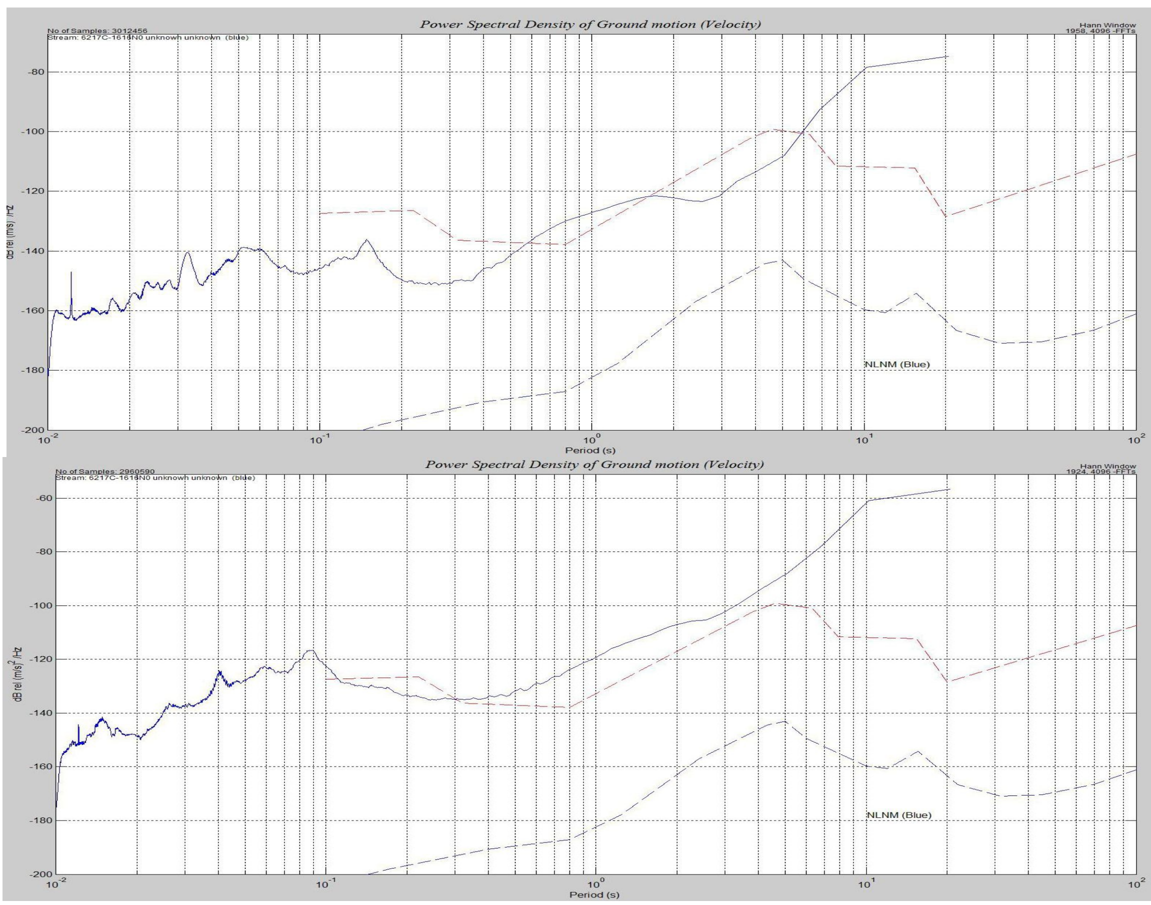

Fig. 12: Power spectral density plots for the same horizontal components of Temp-2. The top panel shows the noise spectrum (solid blue line) during the time of minimum swell (7 Aug 13) The bottom panel shows the noise during the time of maximum swell (30 Sep 13). Both panels are scaled to the same factor. In each of the panel, the dotted blue line represents to USGS low noise, the dotted red line the high noise model.

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As can be seen in figure 12 the seismic noise is between 5 and 25 dB higher during the period of highest swell (lower panel) compared to the day of lowest swell (upper panel).

This long period noise generated by the ocean swell is by far the most dominant noise in the data. How strong this noise is, became ultimately clear when the strongest teleseismic earthquake occured during the deployment period, the Mw=7.7 event in Pakistan on 24 Sep 13 at 11:29 UTC. In figure 13 I show the recordings for both portable OBS during the time when the arrivals of the different seismic waves are expected in the area. Despite the application of various filters, neither the P- nor the S-wave arrivals can be seen. Even the surface waves of this event, which are well recorded by other broadband stations in Central California, are masked by the swell noise.

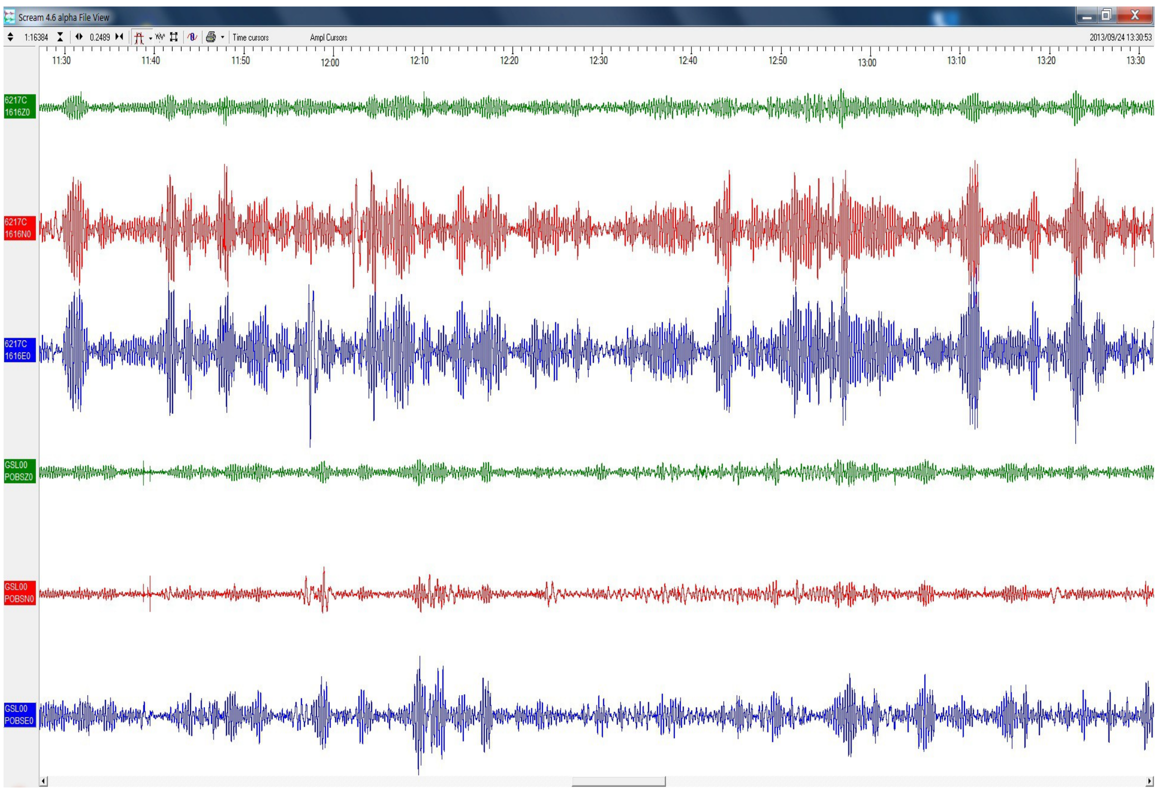

Fig. 13: The recordings of the three components of Temp-2 (upper three traces) and of Temp-1 (lower three traces) during the very two hour time window on 24 Sep 13, when the onsets of the Pakistan earthquake were expected.

While there is a strong correlation of recorded seismic noise with wave heights (see figure 12), we found no evidence in this survey, that changes in the ocean tides had any influence on the seismic noise. This is most likely due to the fact, that the lower frequency limit of the sensors is 60 sec, which is way above the typical tidal periods of 12 and 24 hours respectively.

3.2.3 Artifical Noise

The noise described in the previous sections can be seen with various intensities almost daily on both portable OBS simultaneously. This is an indication that its source is not in the immediate vicinity of one of the sensors but that the noise originates further away. There are however many noise recordings, which can only be seen on one of the instruments. One such example is shown in figure 14.

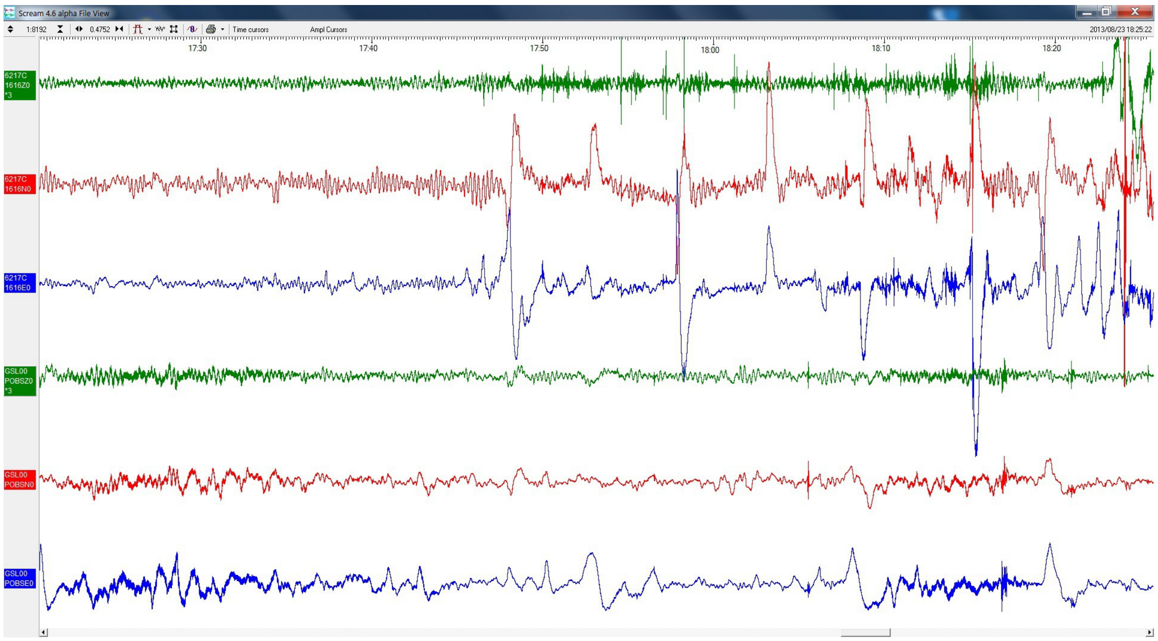

Fig. 14: A 70 min long time window on 23 Aug 13 from 17:20 to 18:30 UTC. The top three traces are the three components of Temp-2, the bottom three are the recordings of Temp-1.

During the first 30 min the data of Temp-2 show typical seismic noise dominated by the ocean swell. However, around 17:46 UTC this pattern changes abruptly. The later sections of the horizontal seismograms of Temp-2 are dominated by strong pings and peaks, which are clearly absent on the respective traces of Temp-1. I therefore conclude, that the change in pattern has a local source at or near Temp-2. It is very likely that it is caused by animals rumaging in the area as for example seen in figure 4. The crew of the ROV, which assisted us during the recovery of the portable OBS, reported numerous animal sightings, among them a large star fish crawling over the instruments.

3.3 Seismic Events Recorded by the Instruments

The main purpose for deploying the OBS network in this area is to monitor the microseismic activity on two faults offshore of Central California, the Hosgri- and the Shoreline-Fault. I will therefore refrain from showing the recordings of teleseismic events by the two instruments, particularly in light of the dominant effect of the swell generated noise in the longer period (see section 3.2.2). Instead I will concentrate on a few examples of local earthquakes.

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In order to find relevant local earthquakes in or near the deployment area I accessed the ANSS catalog through the Northern California Earthquake Data Center (NCEDC). Except for the seismic activity along the San Andreas Fault and in the aftershock area of the 2003 San Simeon earthquake further inland, there are in fact very few earthquakes within a 100 km radius around the deployment area. The are even fewer offshore quakes. The earthquakes used in this section are listed by date in table 3.

Event	Date	Time	Latitude	Longitude	Depth	Ml	Distance	Distance
	2013	(UTC)	decimal °N	decimal °W	(km)	or Md	to Temp-1	to Temp-2
1	17 Aug	10:01:02	35.19	120.9125	3.7	1.9	9.5	6.5
2	24 Aug	01:16:31	34.5667	120.9567	3.2	4.1	73.0	76.0
3	7 Sep	21:51:01	35.0753	120.9422	2.8	1.3	21.4	17.9

Table 3

3.3.1 Ml=4.1 off Pt. Arguello (Event 2 in table 3)

The strongest local earthquake during the deployment period occured offshore on 26 Aug 13 at 01:16:30 UTC about 30 km W of Point Arguello. It had a Ml of 4.1. The epicentral distances to Temp-1 and Temp-2 are 76 and 73 km respectively with the seismic waves arriving at the station almost directly from the S. Figure 15 shows the recordings of the two portable OBS (top six traces) compared to the recording of OBS-4 (bottom three traces). In figure 16 I have zoomed in on the P-onset of the same three stations, which are sorted by distance from the source.

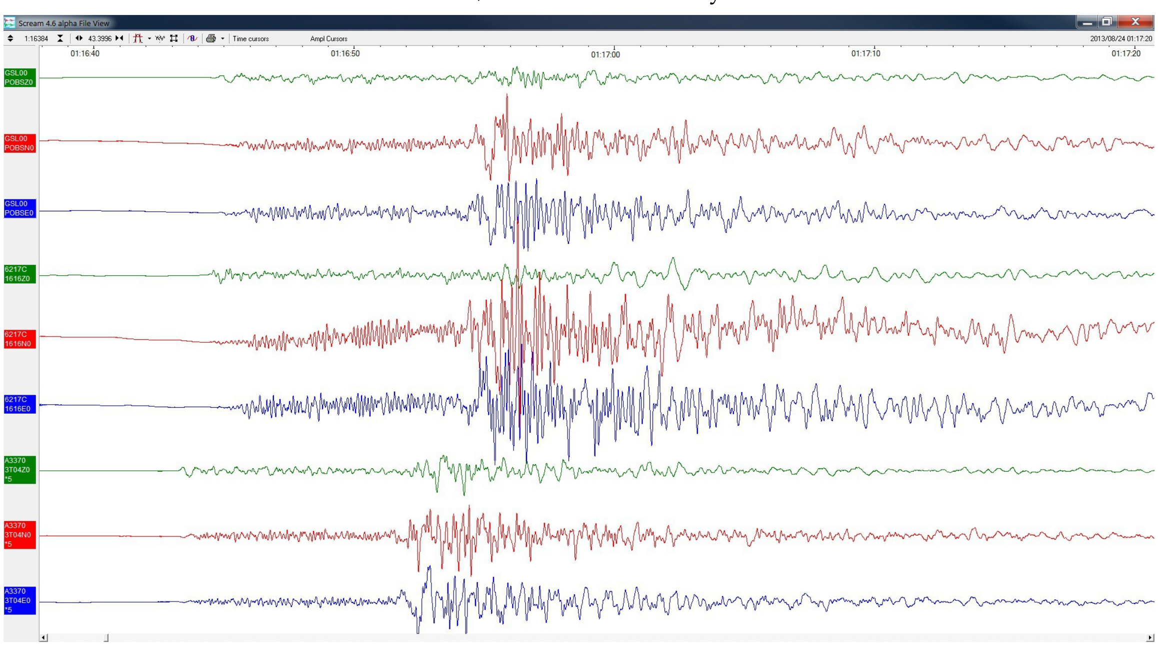

Fig. 15: Recordings of the Point Arguello earthquake on the respective three components of Temp-1 (top three traces), Temp-2 (middle) and OBS-4 (bottom). 40 sec of data shown.

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Fig 16: P-onsets of the Point Arguello earthquake shown on the vertical components of Temp-1 (top), temp-2 (middle) and OBS-4 (bottom). 15 sec of data shown

3.3.2 Md=1.9 on the Hosgri Fault (Event 1 in table 3)

The closest local earthquake during the deployment period occured on the Hosgri Fault WSW of DCPP on 17 Aug 13 at 10:01:02 UTC. It had a Md of 1.9 and a depth of 3.7 km. The epicentral distances to Temp-1 and Temp-2 are 9.5 and 6.5 km respectively. Figure 17 shows the recordings of the two portable OBS (bottom six traces) compared to OBS-4 (top three traces). Note that the P-onset is very clear on all three vertical components, while the S-onset is less clear on the horizontals of Temp-1, the most distant station.

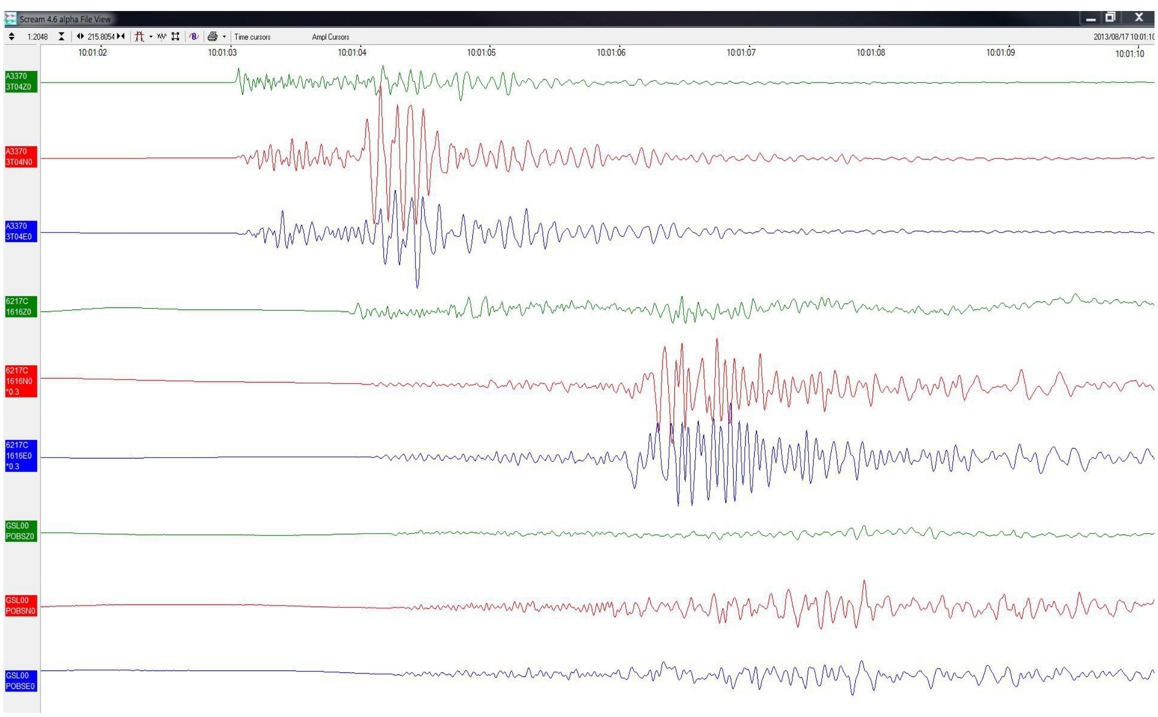

Fig. 17: Event on the Hosgri Fault as recorded by the three respective components of OBS-4 (top), Temp-2 (middle) and Temp-1 (bottom) 8 sec of data show.

3.3.3 Md=1.3 about 16 km WSW of DCPP (Event 3 in table 3)

This event occured on 7 Sep 13 at 21:51 UTC in the outer San Luis Bay about 16 km WSW of DCPP. It was about 18 and 22 km away from Temp-2 and Temp-1 respectively. Figure 18 shows the recordings of this event on both portable instruments (bottom six traces) as compared to OBS-4 (top three traces). While both OBS-4 and Temp-2 recorded both P- and S-waves clearly, the record of Temp-1 shows a different picture. There the onsets are masked by strong noise affecting only Temp-1 at this time. The only visible effect of this earthquake on Temp-1 are the Lg-waves arriving between 21:51:09 and 21:51:10 (black circle in figure 18). Under noisy conditions, an EQ with an Ml=1.3 in about 20 km distance seems to be the detection threshold of the portable OBS.

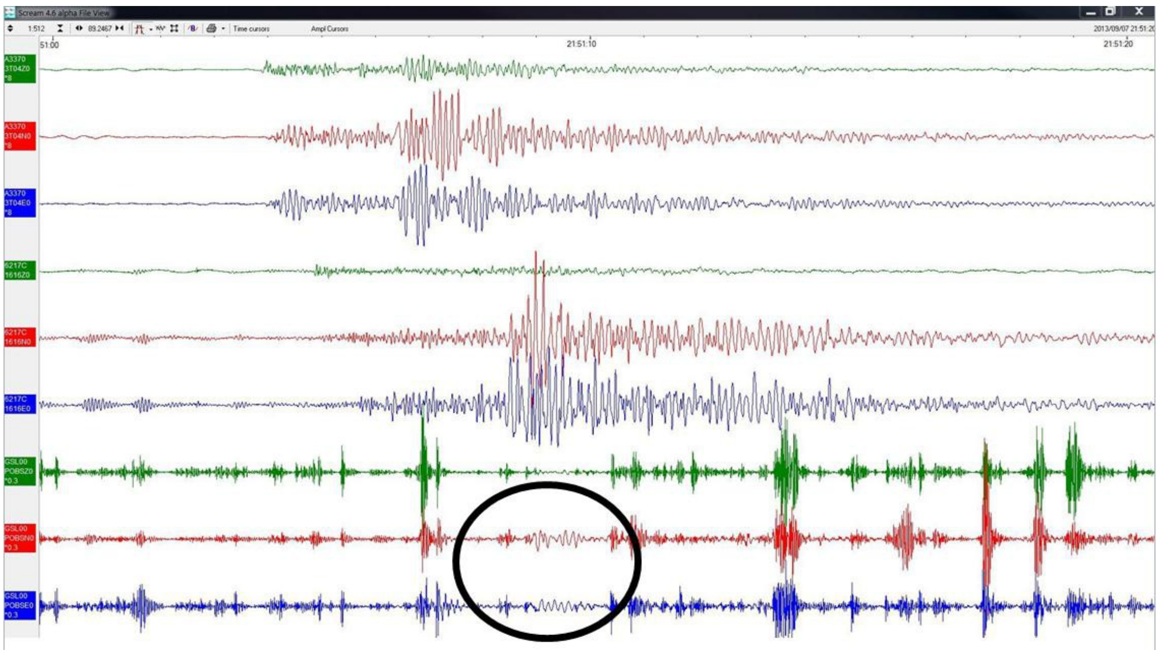

Fig. 18: Recordings of earthquake in Outer San Luis Bay with the three respective components of OBS-4 (top), temp-2 (middle) and Temp-1 (bottom). The 20 sec of data shown here are filtered by a highpass with a corner of 1 Hz.

4. Conclusions

While all compents of both instruments deployed for this project worked flawlessly and there are no data gaps, the data are very often dominated by noise from various sources and varying intensity. Some of the noise originates as natural or manmade acoustic emissions in the ocean, as swell and wave action on the sea surface, or from life on the sea floor. This noise, the absence of direct protection against waves and currents, and the suboptimal coupling of the sensors to the sea floor limit the detection capabilities of the two portable OBS. While the actual lower detection limit still needs to be defined in a more thorough analysis of the data, we find evidence in this initial investigation that such portable OBS in shallow waters are capable of recording events of magnitude just above 1 at a distance of about 25 km.

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Document history:

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Version 2.0	6 Feb 14	major re-write of chapter 3
Version 2.1	10 Feb 14	edited figure captions, layout