LASER INTERFEROMETER GRAVITATIONAL WAVE OBSERVATORY

LIGO Laboratory / LIGO Scientific Collaboration

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LASTI Prototype Suspension Controller Operation Manual

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authors

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1 Introduction

1.1 Purpose and Scope

This document explains how to set up and operate the OSEMs and the dSpace controller for the LASTI prototype. It describes the Caltech version of the hardware for controlling two triple suspensions, with the software mcfulldiaglivedual20040212.

1.2 Documents

http://www.ligo.caltech.edu/%7Ebabbott/glas_wiring.PDF - GEO Controls Wiring

http://www.ligo.caltech.edu/%7Ejay/drawings/LIGO_receiver_mv1d.pdf - GEO LED/PD Receiver

http://www.ligo.caltech.edu/%7Ejay/drawings/LIGO_Idrivemv3c.pdf - GEO Coil Driver

D010072-A - LASTI SOS Controls Wiring

D961289 (Rev 01) – Satellite Module

D980181 (Rev 01) – SOS Controller

2 Triple

2.1 Geometry Conventions

2.1.1 Definition of “front”, “back”, “left” and “right”

The side of the suspension structure on which the HR side of the optic hangs is defined as the front. Conversely, the back is the side with the AR coating. “Left” and “right” are as viewed by a person standing at the back of the structure.

2.1.2 Definition of x, y and z coordinates.

The +x direction is horizontal and from back to front. The +y direction is horizontal and from right to left. The +z direction is up (so as to make a right-handed coordinate system). The software aims to follow this sign convention consistently, so that if a signal labelled x increases, it can be counted on to correspond to a physical movement towards the front.

2.1.3 Definition of yaw pitch and roll.

Yaw, pitch and roll are defined as right-handed rotations around the +z, +y and +x axes respectively. That is, for positive yaw, the front of the optic moves left, for positive pitch the front of the optic moves down, and for positive roll, the left side of the optic moves up. As for x, y and z, the software aims to follow this sign convention consistently.

2.2 OSEM Conventions

2.2.1 Sensors

The ideal sensor is taken to be a shadow sensor with a negative open light voltage. That is, the output from the electronics and the sampled values from the DAC are negative while the flag is far from the sensor, and increase towards zero as the flag engages. Correction factors are provided in the software to restore this convention immediately after the block representing the DAC for any channels that may be inverted in the electronics (such as and in particular, any channels that have a odd number of whitening filter stages enabled).

2.2.2 Actuators

The ideal actuator is taken to be a voice coil which pulls the magnet toward it for positive values of actuator input voltage. Correction factors are supplied in the software just before the block representing the ADC to make allowances for any channels that may be inverted (such as and in particular, any channels that have reverse-wound coils or reverse-mounted magnets).

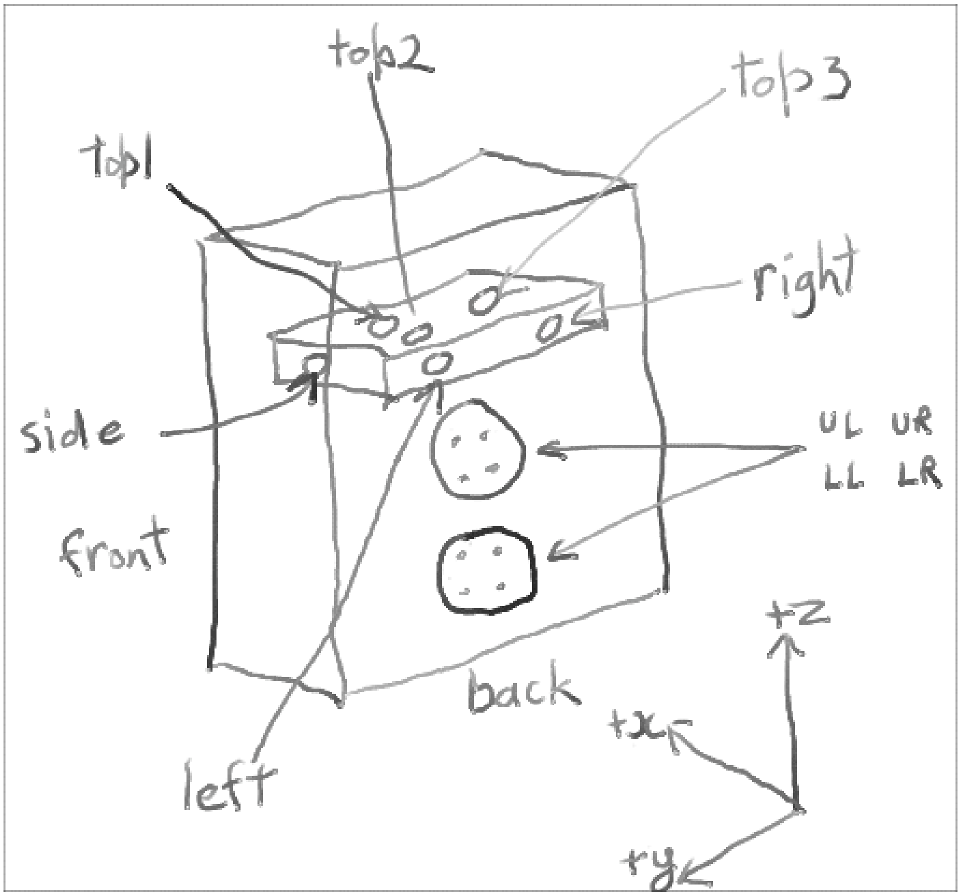


Figure 1: Geometry and sensor nomenclature

2.2.3 OSEM Internal Electronics

The OSEMs for the lower masses are standard LIGO I design. The ones for the top mass are physically larger but electrically identical. Each OSEM has a voice coil, an LED and a photodiode, for a total of 6 connections. The connections are exposed at the back of the OSEM, as in Figure 2.

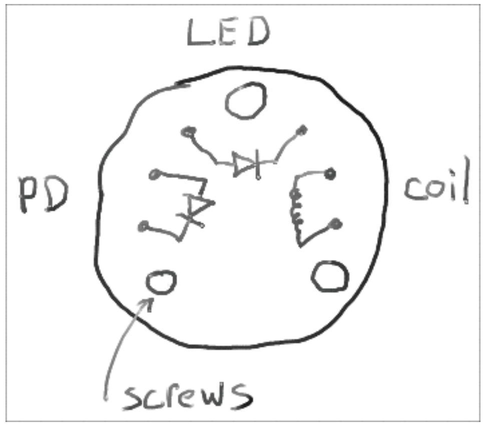


Figure 2: Back view of OSEM with functions of pins

The connections are brought out via a pigtail terminating in a 6 pin connector. The pinout of the connector is given in Figure 3.

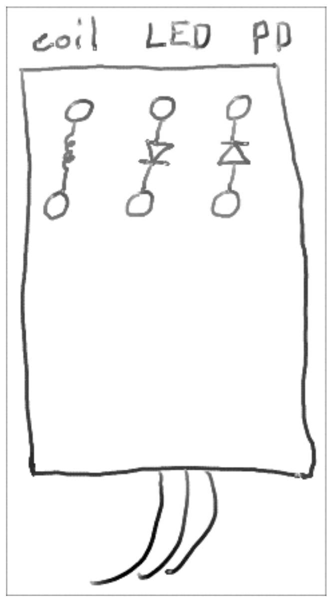


Figure 3: Back view of OSEM connector with functions of pins.

A OSEM can be tested for health with a multimeter. Use the resistance range to check that the resistance of the coil is around 12 ohms at the back of the OSEM or around 18 ohms at the end of the pigtail. Use the diode check range to confirm that the LED has a forward voltage of around 1.1 V and that the PD has a forward voltage of around 0.6 V. (Note that the LED is connected with opposite polarity to the PD.)

2.2.4 OSEM External Connections

The OSEM connectors plug into one of five DB25 female connectors mounted in two brackets. The first bracket has two DB25s for the top mass ("m1") OSEMs. The OSEM connectors are inserted with the pigtail leads down, starting from the extreme left, in the order shown in Figure 4. The GEO Receiver/LED Driver box has status lights that indicate whether the OSEMs are plugged in correctly (or more specifically, whether the OSEM LED is accepting drive current). The numbering of the positions is 1 through 6, counting right to left and top to bottom.

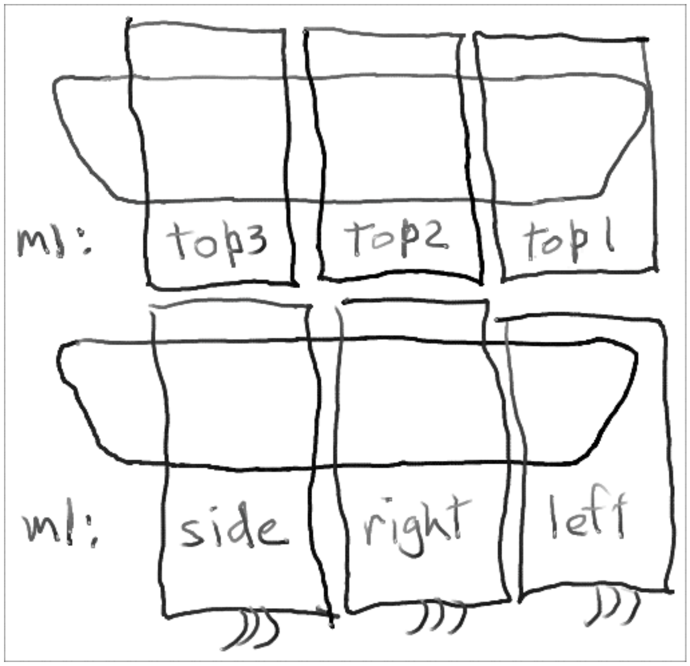


Figure 4: Connection of OSEMs for top mass ("m1").

The second bracket has three DB25s for the intermediate mass ("m2") and lower mass ("m3") OSEMs. The OSEM connectors are inserted with the pigtail leads down, starting from the extreme left, in the order shown in Figure 5.

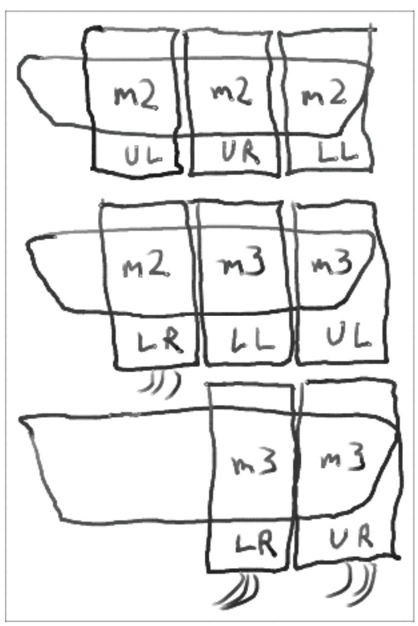


Figure 5: Connection of OSEMs for intermediate mass ("m2") and optic ("m3")

2.3 Signal Paths

The electronics has provision for two independent suspensions labelled SUS 1 and SUS 2. We describe the signal paths for the first suspension. The second is similar except where noted.

2.3.1 Inputs

2.3.1.1 Top mass (m1)

The two DB25s that accept the OSEM connections for the top mass are connected via two 25-conductor ribbon cables (called B1 and B2) to the back of a GEO-supplied Receiver/LED Driver box. A 15-wire ribbon cable leads from the "Outputs to filters" DB15 connector on the front panel of the box to a DB15 on Whitening Filter G (for GEO). See the next section but one for the rest of the input path description.

2.3.1.2 Intermediate mass (m2) and optic (m3)

The three DB25s that accept the OSEM connections for the intermediate mass and optic are connected via three 25-conductor ribbon cables to two LIGO-I satellite modules, lablelled SM A and SM B. SM A takes only one cable – the second input is unused. Each satellite module has one long connector for inputs, outputs and power supply. A piggy-back splitter card separates the three groups of signals. The sensor signal outputs emerge at the DB15 connector nearest the side of the satellite module with the OSEM cables. The outputs from each satellite module are brought via a 15-conductor ribbon cable to a whitening filter card. SM A connects to Whitening Filter A and SM B connects to Whitening Filter B. See the next section for the rest of the input path description.

2.3.1.3

Each whitening filter card has internal wire-wrapped connections to put the whitened signals onto the following channels of the card cage backplane:

	SUS 1	SUS 2	Signals
Whitening Filter G	1-6	15-20	m1top1, m1top2, m1top3, m1left, m1right, m1side
Whitening Filter A	7-9	21-23	m2UL, m2LL, m2UR
Whitening Filter B	10-14	24-28	m2LR, m3UL, m3LL, m3UR, m3LR

The Backplane Signal Collector Board gathers all these signals into a DB50 on its front. A 50-conductor ribbon cable transfers the signals to the equal-numbered input channels of the DS2003 DAC card in the dSpace controller.

2.3.2 Outputs

The control signals for the system are generated by five 6-output DS2102 cards in the dSpace controller. The channel assignment is:

Card Number	1	2	3	4	5
Hex Address	09H	0AH	0BH	0CH	0DH
Ch 1	SUS1 m1top1	SUS1 m2UL	SUS1 m3UR	SUS2 m2UL	SUS2 m1top1

Ch 2	SUS1 m1top2	SUS1 m2LL	SUS1 m3LR	SUS2 m2LL	SUS2 m1top2
Ch 3	SUS1 m1top3	SUS1 m2UR	N/C	SUS2 m2UR	SUS2 m1top3
Ch 4	SUS1 m1left	SUS1 m2LR	N/C	SUS2 m2LR	SUS2 m1left
Ch 5	SUS1 m1right	SUS1 m3UL	SUS2 m3UR	SUS2 m3UL	SUS2 m1right
Ch 6	SUS1 m1side	SUS1 m3LL	SUS2 m3LL	SUS2 m3LL	SUS2 m1side
Associated Anti-Aliasing Filter	SUS1 G	SUS1	SUS 1/2	SUS 2	SUS2 G

Each DAC card is connected to a standard 8-channel LIGO-I antialiasing filter (850 Hz LP) via a 25-conductor ribbon cable. The label of the filter card corresponding to each DAC card is given in the table. Channels 7 and 8 of each card are not used. From the filters, the signals for the top masses got to GEO hardware, whereas the signals for the intermediate mass and optics go to LIGO-I hardware as explained in the next two sections.

2.3.2.1 Top mass (m1)

The signals for the top mass appear at LEMO jacks on the front panel of the SUS 1 G filter card and are transferred to the GEO Coil Driver box with an octopus cable.

2.3.2.2 Intermediate mass (m2) and optic (m3)

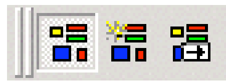
The signals for the intermediate mass and optic appear at the LEMO jacks on the SUS 1, SUS 2 and SUS 1/2 filter cards and are transferred to LIGO-I SOS coil driver cards by individual LEMO cables. Channels 1-3 on filter SUS 1, are connected to the first three channels on SUS 1 Driver A. Channels 4-6 on filter SUS 1 and Channels 1-2 on filter SUS 1/2 are connected to SUS 1 Driver B. Channels 1-3 on filter SUS 2, are connected to the first three channels on SUS 2 Driver A. Channels 4-6 on filter SUS 2 and Channels 5-6 on filter SUS 1/2 are connected to SUS 2 Driver B.

3 Software

3.1 General Overview

The software described here is as found in the archive `mcfulldiaglivedual20040212.zip`. The archive unpacks to a directory `mcfulldiaglivedual`. Here “mc” reflects the fact that the software is for a mode-cleaner triple suspension, “full” that it contains a detailed modelling of the sensors and actuators, “diag” that it includes a diagonalizing controller, “live” that it controls a physical suspension via real ADC/DAC electronics (as opposed to a simulation) and “dual” that it has duplicated code to allow for two suspensions.

The directory includes both the Matlab/Simulink source and the dSpace ControlDesk GUI. To view the source, start Matlab, set the working directory to `mcfulldiaglivedual` and type `generate_simulink`. This loads parameters of the electronics and suspension from `protoparam.m` and the Simulink model file `mcfulldiaglivedual.mdl`. If any changes need to be made, refer to the dSpace documentation for instructions on how to recompile the model.

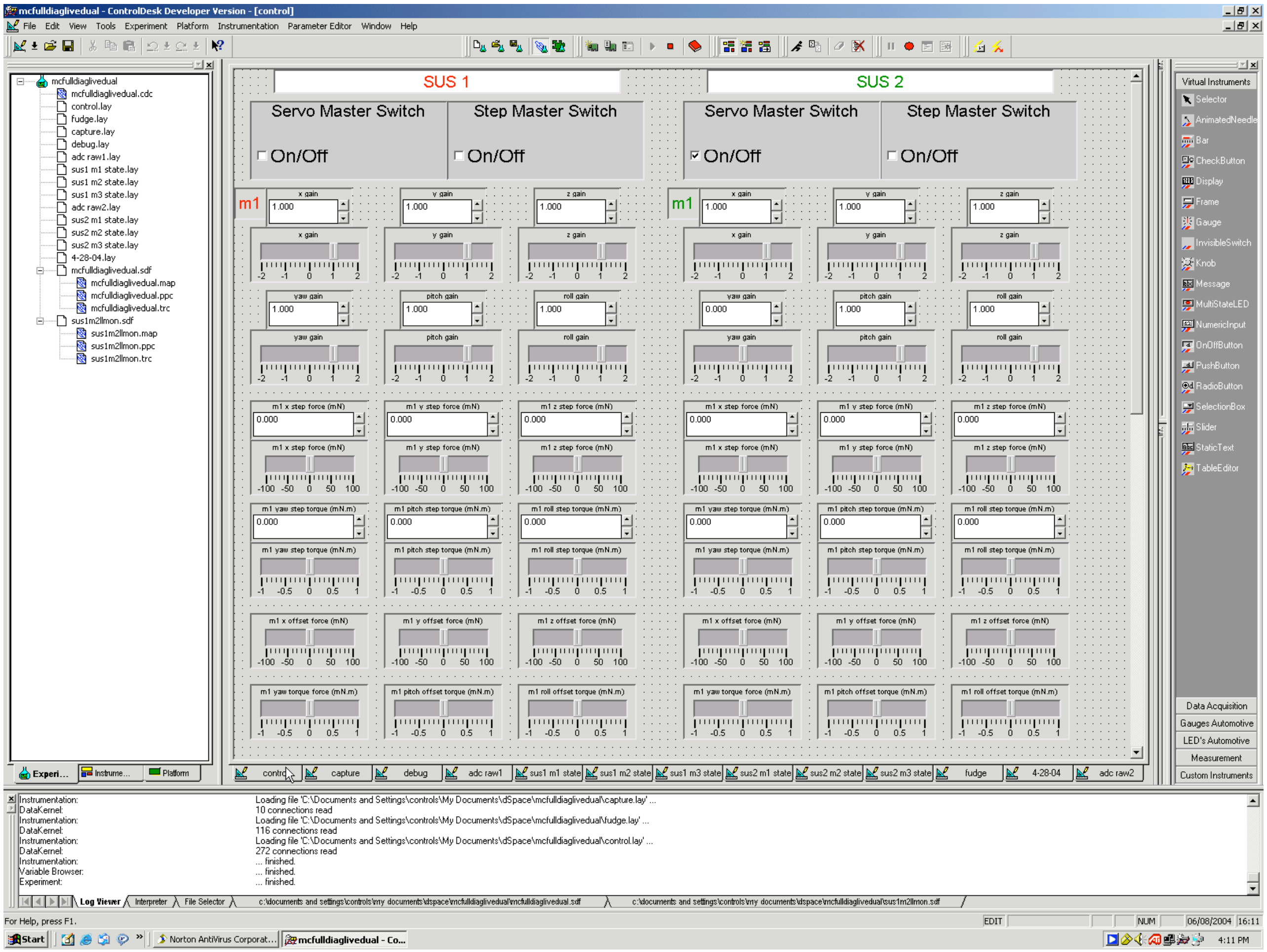
To use the controller, start dSpace ControlDesk, and open the experiment file `mcfulldiaglivedual.cdx`. This loads the user interface under ControlDesk on the PC, and also loads the cross-compiled controller program onto the dSpace process. The program on the dSpace starts runnng immediately but the user interface starts off in Edit mode. To interact with the program on the dSpace, ControlDesk must then be set to Animate mode (the right-most of the group of three toolbar icons looking like this: ).

3.2 Control Layout Overview

The controls for the pendulum control software are laid out in a number of tabbed panes ("layouts" in dSpace terminology) in the large central part of the window. For convenience, some commonly used controls such as the servo master switches are duplicated, and appear on more than one layout.

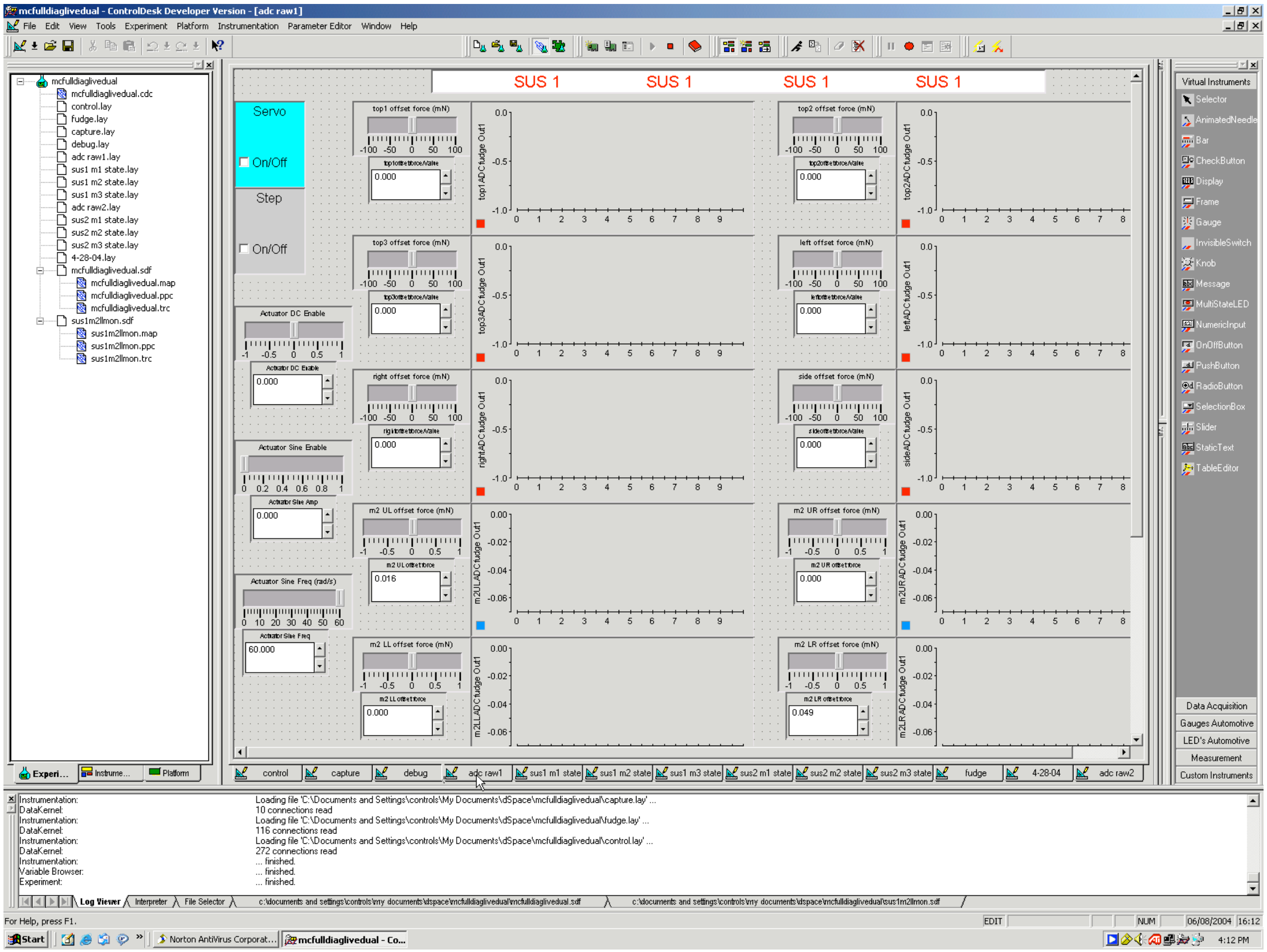
3.2.1 control

Controls for everyday running of both suspensions, including the master servo switches, gain controls for the x, y, z, yaw, pitch and roll DOFs, and provision for providing a calibrated step force input to specified DOFs.



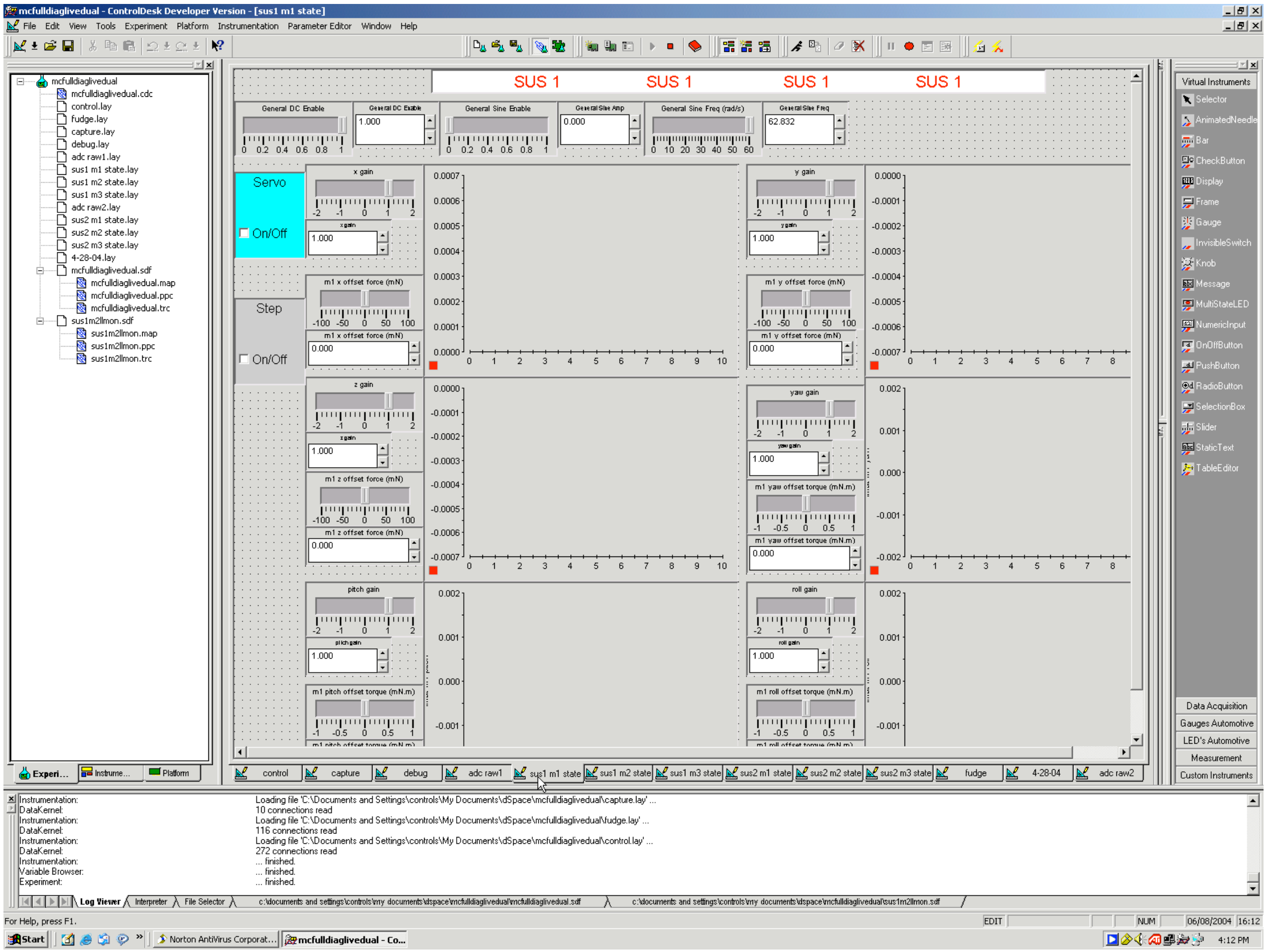
3.2.2 adcraw1 and adcraw2

For Suspensions 1 and 2 respectively: controls and plots of sensor signals just after the ADC (after correction for sign but before diagonalization) and actuator signals just before the DAC (before correction for sign but after de-diagonalization. There is provision for applying a DC offset or a sine wave excitation to any of the actuators.



3.2.3 sus1 m1 state and sus2 m1 state

For Suspensions 1 and 2 respectively: controls and plots for the diagonalized sensor signals for the top masses. There are servo gain controls for each DOF, and provision for applying a DC offset or a sine wave excitation to any of the DOFs.



3.2.4 sus1 m2 state and sus2 m2 state

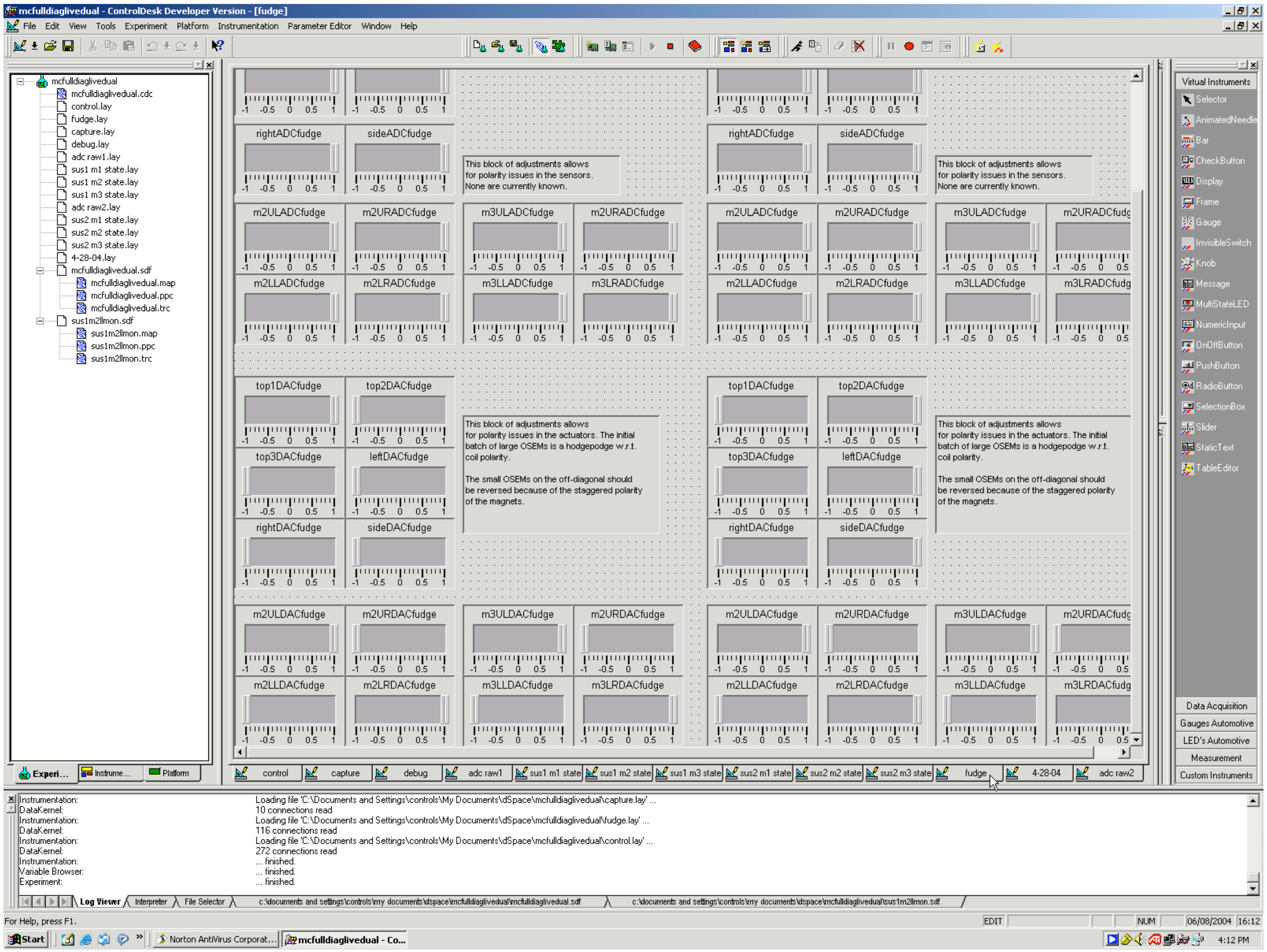
For Suspensions 1 and 2 respectively: controls and plots for the diagonalized sensor signals for the intermediate masses.

3.2.5 sus1 m3 state and sus2 m3 state

For Suspensions 1 and 2 respectively: controls and plots for the diagonalized sensor signals for the bottom masses.

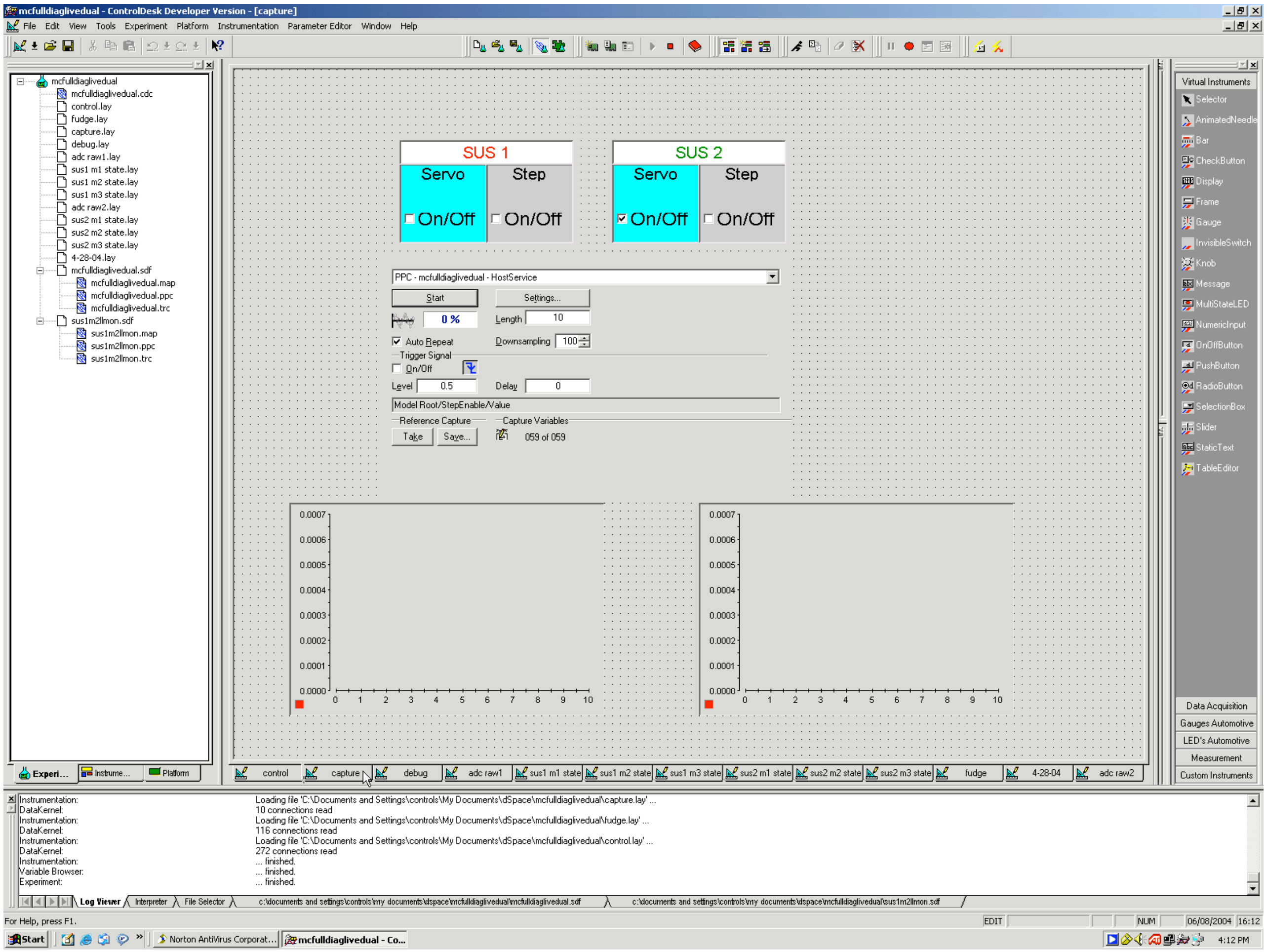
3.2.6 fudge

Controls for sign correction of individual sensor and actuator channels, to allow for mis-wound coils, reversed magnets and the like.



3.2.7 capture

Controls for the data capture from the dSpace to the PC, including the buffer length, the downsampling factor, and the file name and other parameters for saving selected data to disk.



3.2.8 debug

Reserved for adding temporary controls and plots for use in debugging.

3.3 Initial Setup of a Suspension

Before the servo is first engaged for a newly assembled suspension, the OSEMs need to be adjusted to the middle of the sensor range, and the polarities of the sensors and actuators need to be checked. Otherwise there is a risk of positive feedback and possible damage to the suspension.

3.3.1 Installation of Top Mass OSEMs

First check that there are magnets fitted to all the attachment points on the top mass where sensors are to be installed according to the diagram in Section 2.2.2, and that the pendulum is hanging so that the flags on the ends of the magnets are centred in the roughly circular holes in the "tablecloth" as near as possible by eye (about 1 mm).

Check that all outputs from the dSpace are disabled:

- Uncheck the Servo On/Off switch for the suspension (present on most layouts, e.g. `control`).

- Uncheck the Step On/Off switch for the suspension (present on most layouts, e.g. `control`).
- Set the Actuator DC Enable and Actuator Sine Enable sliders for the suspension to zero (on the `adcraw1` or `adcraw2` layouts).
- Set the General DC Enable and General Sine Enable sliders for the suspension to zero (on the `sus1 m1 state` or `sus2 m1 state` layouts).

Then repeat the following procedure for each sensor position:

- Connect the OSEM connector to the first connector bracket according to the chart in Section 2.2.4.
- Check that there is a negative signal being reported on the corresponding plot on the `adcraw1` or `adcraw2` layout. Record the magnitude of the signal. This is the "open light voltage", typically around 0.8 for the GEO electronics. (Actually the reported value is 1/10 of the physical voltage, but only relative values are important.)
- Place the OSEM against the surface of the tablecloth next to but not at the attachment position and use the adjustment screws on the OSEM so that the end of the coil former is the same distance from the outside surface of the tablecloth as the outside end of the magnet (not including the aluminum flag). This ensures adequate clearance in the next step.
- Next pull the OSEM back from the tablecloth and move it sideways so that it central cavity lines up with the magnet. Check that the OSEM is correctly oriented so that it will not foul on the suspension wire (especially top3) and that any earthquake stop screw align with the through-holes in the OSEM body (especially top1 and top2). For the left, right and side OSEMs the gap between the circuit boards in the central cavity should be horizontal to minimize cross-coupling to vertical.
- Move the OSEM in until it contacts the tablecloth and adjust its lateral position until the magnet is centred in the gap between the circuit boards. Attach it firmly in this position using a non-magnetic hex key.
- Using the four adjustment screws, set the position of the central section of the OSEM such that the signal at the dSpace is at 60% of the open light voltage.

On the `adcraw1` or `adcraw2` layout, set the Actuator DC Enable slider to 1.0. For each actuator, check that moving the corresponding slider towards positive values causes the trace from the corresponding sensor to move upwards (toward zero). If the motion is reversed, go to the `fudge` layout and toggle the corresponding sign-correction slider, which will have a name like xxxDACfudge, where xxx is one of top1, top2, etc. Set the Actuator DC Enable slider back to zero.

Bring up the `sus1 m1 state` or `sus2 m1 state` layout. Press gently on the top mass near the various OSEMs in turn and check that each sensor contributes to the diagonalized x/y/z/yaw/pitch/roll signals according to the sign convention given in Section 2.1. (If the OSEMs are in the positions indicated in Figure 1, this should be correct, but otherwise adjustments may have to be made to the imat-m1 block in the Simulink diagram.)

Set the General DC Enable slider to 1.0 and check that moving any of the individual x/y/z/yaw/pitch/roll offset sliders towards positive values produces a displacement of the corresponding diagonalized signal in the positive direction, with little motion in the other DOFs. (If there are any errors, make adjustments to the omat-m1 block in the Simulink.

Finally, set all the gain sliders to 1.0 and set the Servo On/Off switch to checked. **Monitor the diagonalized signals for any signs of positive feedback and switch the servo off immediately if there is any oscillation.**

3.4 Installation of Intermediate and Lower Mass OSEMs

For each OSEM position:

- Make sure that the correct size of LIGO-I OSEM holder ("tombstone") is fitted. Note that there are three different sizes and that two of them (D030017 and D020417) have part numbers that are easy to confuse. Make sure there are three washers of staggered sizes or the screws are likely to pull through when tightened.
- Plug the OSEM connector into the second connector bracket according to the chart in Figure 5.
- Note the open light voltage as reported on the `adcraw1` or `adcraw2` layout. Typical values are around 0.05 (0.5 V physical).
- Insert the OSEM into the tombstone with the circuit boards horizontal, leaving a 1-2 mm gap between the end of the coil former and the end of the magnet. Gently tighten the retaining screw just enough to ensure the OSEM is seated firmly on the locating rails (this is particularly important for the tombstones that hang down and have the screw at the bottom).
- Sight through the central cavity of the OSEM and adjust the position of the tombstone until the magnet is centred horizontally and vertically between the circuit boards, as near as possible by eye.
- Loosen the retaining screw just enough that the OSEM can be moved with some friction. Move the OSEM in until the signal is reduced to 60% of the open light voltage. Tighten the screw firmly and double check that the signal is still at 60%.

Once the OSEMS are inserted, check that all the coils work and have the correct sign by applying a DC offset to each actuator in turn at the `adcraw1` or `adcraw2` layout, as for the top OSEMs. Because the magnets are smaller than for the hybrid OSEMS it can be hard to see an effect. To increase the motion, it is possible to type a number larger than 1.0 (say 10.0) in the Actuator DC Enable text box.

4 Data Capture

4.1 General Notes

The data that is logged is selected using the CaptureSettings control on the `capture` layout. A few key settings are made on the front panel of the instrument, but most are accessed by clicking on the Settings button, which brings up the dSpace CaptureSettings Control Properties window.

The Acquisition Mode is set on the Acquisition tab of the Properties window. Most of the time it should be set to Continuous, which continuously downloads data from the dSpace to the PC and updates the plots, but does not save anything to disk. Most of the plots have been set to Extended mode for the time axis, which means that the range is set automatically to the Length parameter on front panel of the Capture instrument or on the Capture tab of the Properties window.

For most data-taking operations, the appropriate mode will be Autosave, which requires a filename to be entered and saves data to that file. Each time the Start button is pressed or the Auto Repeat or Trigger features activate, a new set of data is logged and written over any previous data in the file. The file is in Matlab `.mat` format and can be accessed with Matlab commands like the following:

```
load filename;
t = filename.X.Data;
x = filename.Y(n).Data;
figure(1);
plot(t,x,'r-');
```

The signals that are written include all the ones corresponding to plots plus any that have been added using the CaptureVariables tab of the Properties window. The appropriate value for *n* in the code example to select the desired signal can be determined by inspecting the signal names: `filename.Y(n).Name`.

4.2 Procedure for a Step-Function Response

To measure the response to a force step-function, proceed as follows:

On the `controls` layout, set the Servo Master Switch and the Step Master Switch for the suspension to checked.

Using the various step force and step torque sliders, select a combination of forces and torques.

Allow approximately one minute for the servo to damp out any excitations that this may have caused.

On the `adcraw1` or `adcraw2` layout, check that all sensors are still in range.

On the `capture` layout, set the Length to an appropriate value, taking into account the expected ringdown time (which depends on whether the servo will be on or off for the test).

Set the Auto Repeat to Off, the Trigger to On, the Slope to Down, the level to 0.5, and the Trigger Variable to "Model Root/StepEnable/Value".

On the Acquisition tab of the Properties window, set the Acquisition mode to Autosave and specify a filename.

If data is still being read from the old capture settings, click Stop and then Start.

If this is to be a run with the servo off, set the Servo switch to Off.

Set the Step switch to Off. The Trigger feature should activate and data should start being logged. Wait until progress is 100%, then set Acquisition Mode back to Continuous to avoid accidentally overwriting data.

Set the Servo switch back to On, the Trigger back to Off and Auto Repeat back to On.