

LASER INTERFEROMETER GRAVITATIONAL WAVE OBSERVATORY  
- LIGO -  
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<b>BS and RCM Suspension Electronics Operator's Manual</b>
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# 1 INTRODUCTION

## 1.1. Scope

This document covers the operation and control of the beam splitter and recycling mirror suspension control electronics installed on the 40 meter interferometer. Detailed descriptions of each electronics module are not covered by this document.

## 1.2. Purpose

The purpose of this document is to provide a general overview of the beam splitter and recycling mirror suspension control electronics. This general overview should be sufficient for operators to use in normal day to day operation of the systems. The document includes general troubleshooting guidelines and tips that the operators can use to detect and possibly correct system problems.

## 1.3. Document Organization

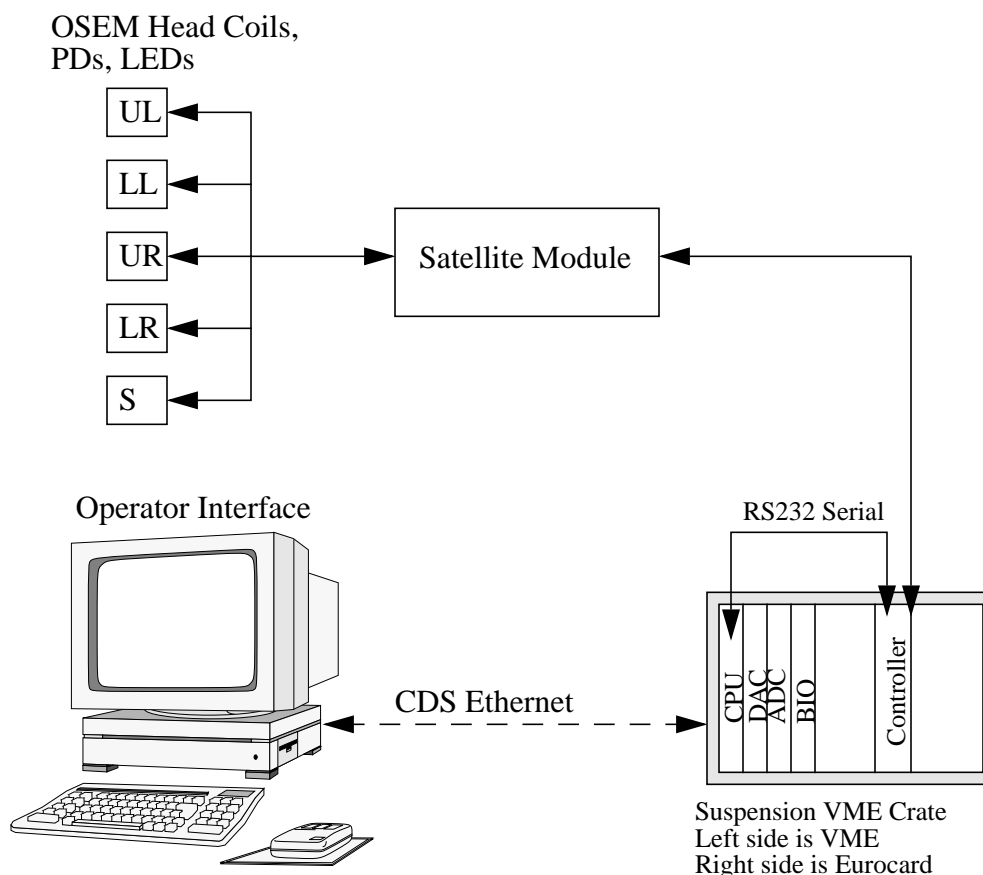
The document is organized into the following sections:

- Operator interfaces- descriptions of each operator interface including the location of the MEDM files.
- Electronics- block diagram level descriptions of each module.
- Software- file names of the databases and state notation programs and a brief description of their function.
- Troubleshooting- Troubleshooting guidelines and tips for the system.
- Schematics- detailed schematics for the systems and each module.

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## 1.4. Suspension System Block Diagram

The figure below is a block diagram of a typical suspension control system.



**Figure 1: Suspension Control System Block Diagram**

The OSEM heads shown in the figure include the LEDs and photodiodes used for local orientation sensing and the coils used to control the orientation of the optic under control. The coils, LEDs and PDs are connected to the suspension satellite module using a combination of multiconductor cables and connectors external to the vacuum system and cables and connectors internal to the vacuum system.

The satellite module provides the following functions:

- local amplification of the current signal from each photodiode
- bias for each LED
- connection of coil drive signals from controller coil drive circuitry to orientation coils.

The suspension controller is the heart of the suspension control system and provides the functionality described in section 3.2 of this document.

The suspension VME crate contains the VME CPU, ADCs, DACs and BIO modules that are used to control the system. The CPU is a Motorola MVME162-333 processor running VxWorks OS and the EPICS control software. Detailed descriptions of EPICS and VxWorks are outside the scope of this document and can be obtained from various sources. The filenames for the EPICS databases and state notation programs used by the BS and RCM suspension control systems are listed in section 4.0 of this document.

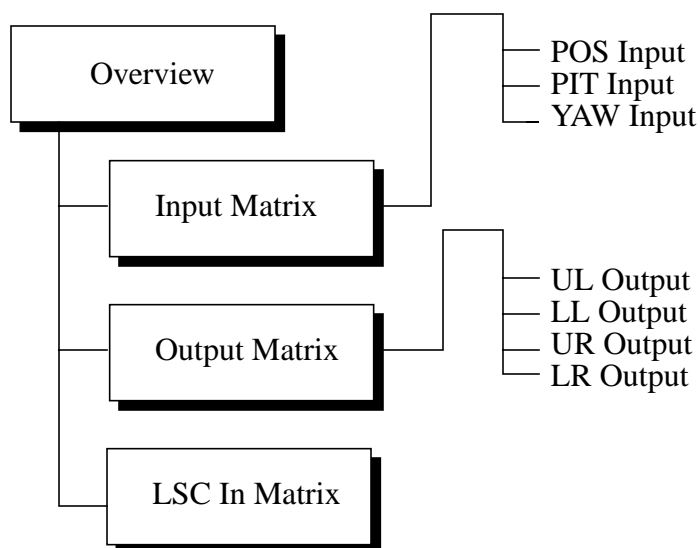
The operator interface is any CDS operator station that has been setup to run the EPICS operator interface software (MEDM). Detailed descriptions of the operation of MEDM is outside the scope of this document and can be obtained from various sources. The filenames for the BS and RCM suspension operator screens and a brief description of each is covered in section 2.0 of this document.

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## 2 OPERATOR INTERFACES

### 2.1. Screen Organization and File Names

The operator interfaces for the suspension controls are hierarchially organized. This hierarchy is shown in the figure below. All operator screens are located in the directory /opt/CDS/d/epics/apple/Caltech/suspension/opi/medm.



**Figure 2: Suspension Controls Operator Screen Organization**

**Table 1: BS and RCM Suspension Operator Interfaces**

<i>Operator Screen</i>	<i>Description</i>	<i>Filename</i>
BS_Overview	Beam Splitter overview screen	BS_Overview.adl
BS_POS_IN	BS Position input matrix	BS_POS_IN.adl
BS_PIT_IN	BS Pitch input matrix	BS_PIT_IN.adl
BS_YAW_IN	BS Yaw input matrix	BS_YAW_IN.adl
BS_UL_OUT	BS UL output matrix	BS_UL_OUT.adl
BS_LL_OUT	BS LL output matrix	BS_LL_OUT.adl
BS_UR_OUT	BS UR output matrix	BS_UR_OUT.adl
BS_LR_OUT	BS LR output matrix	BS_LR_OUT.adl

**Table 1: BS and RCM Suspension Operator Interfaces**

<i>Operator Screen</i>	<i>Description</i>	<i>Filename</i>
BS_LSC_IN	BS LSC input balance	BS_LSC_IN.adl
RCM_Overview	RCM overview screen	RCM_Overview.adl
RCM_POS_IN	RCM Position input matrix	RCM_POS_IN.adl
RCM_PIT_IN	RCM Pitch input matrix	RCM_PIT_IN.adl
RCM_YAW_IN	RCM Yaw input matrix	RCM_YAW_IN.adl
RCM_UL_OUT	RCM UL output matrix	RCM_UL_OUT.adl
RCM_LL_OUT	RCM LL output matrix	RCM_LL_OUT.adl
RCM_UR_OUT	RCM UR output matrix	RCM_UR_OUT.adl
RCM_LR_OUT	RCM LR output matrix	RCM_LR_OUT.adl
RCM_LSC_IN	RCM LSC input balance	RCM_LSC_IN.adl

## 2.2. Overview Screen

A copy of an overview screen is shown in Appendix 2. The overview operator screen allows the operator to adjust/control the following:

### 1. Gain for each controller signal path

- position,
- local pitch,
- global AC pitch,
- global DC pitch,
- local yaw
- global AC yaw
- global DC yaw
- side

Note that all gain adjustments are in percentage gain 0 to 100%.

### 2. Pitch and Yaw mode of operation

- local AC gain
- global AC gain
- global DC gain

### 3. Channel polarity

### 4. LSC Run/Acquire Mode

### 5. Test input enable for:

- position
- pitch
- yaw

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- side

## 6. Coil test enable for each coil

It should be noted that the overview operator screen has been designed and laid out to be a block diagram representation of the controller similar to the block diagram shown in Appendix 3.

## 2.3. Input Matrix Screen

There are three operator screens associated with the input matrix for each of the suspension systems. These screens allow the operator to adjust the input balance for position, pitch and yaw. The adjustment is in percentage gain from 0 to 100% in 256 discrete steps. The gain setting can be adjusted by dragging the sliders on the operator screen, using the arrow keys while the pointer is inside the slider area or by right mouse clicking on the slider and entering the desired gain setting. The software will then set the slider to the closest gain step. The screens can be displayed using one of two methods:

1. Open the screen using the MEDM screen manager. Shown in the figure below.



**Figure 3: MEDM Screen Manager Window**

2. Pushing the appropriate popup menu button on the controller overview screen.

## 2.4. Output Matrix Screen

There are four operator screens associated with the output matrix for each of the suspension systems. These screens allow the operator to adjust the output balance for each of the four coil drivers (UL, LL, UR, LR). The adjustment is in percentage gain from 0 to 100% in 256 discrete steps. The gain setting can be adjusted by dragging the sliders on the operator screen or by right mouse clicking on the slider and entering the desired gain setting. The software will then set the slider to the closest gain step. The screens can be displayed using one of two methods:

1. Open the screen using the MEDM screen manager.
2. Pushing the appropriate popup menu button on the controller overview screen.

## 2.5. LSC In Matrix

The LSC Input matrix screen can be accessed by using the MEDM screen manager. The names and location of the screens for the BS and RCM as listed in Table 1. These screens allow the operator to adjust the LSC input balance for each of the four coil drivers (UL, LL, UR, LR). The adjustment is in percentage gain from 0 to 100% in 256 discrete steps. The gain setting can be adjusted by dragging the sliders on the operator screen or by right mouse clicking on the slider and entering the desired gain setting. The software will then set the slider to the closest gain step.

# 3 ELECTRONICS

## 3.1. Satellite Module

The satellite module electronics are located in a field box close to the 40 meter vacuum chamber. The satellite module provides the following functions:

1. Bias of each of the 5 LEDs used for local orientation sensing. The bias current to each LED is 10 mA.
2. Reverse bias (10 volts) each of the 5 photodiodes used for local orientation sensing.
3. Amplify the current signal from each photodiode. The gain of each channel is 20 V/mA (20 Kohm transimpedance amplifier).
4. Pass the coil drive signals from the suspension controller to each of the 5 coils used to control orientation.

The schematic for the satellite module is shown in Appendix 1.

## 3.2. Suspension Controller

A block diagram of the suspension controller is shown in Appendix 3.

### 3.2.1. Functional Description

#### 3.2.1.1 Servo Filtering Function

The transfer function of the “main” servo filter for each channel of the suspension controller is a 10 pole, 35 Hz, 1 dB ripple chebychev low pass filter. In the AC gain modes (velocity damping) a zero at DC has been added to this response. In the DC gain mode a pole at 0.01 Hz and zeros at 0.1 and 1.0 Hz have been added to this response. A complete description of the response can be found in T970TBD, “Beam Splitter and Recycling Mirror Suspension Controller Design Requirements”.

#### 3.2.1.2 Input Matrix

The function of the input matrix is two fold:

1. transform the signals from photodiodes into position, pitch, yaw and side orientation signals, and
2. allow the operator to trim these signals to account for gain differences, etc. in the system.



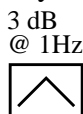
The input matrix is represented by the 12 adjustable gain stages on the left hand side of the block diagram. These gain stages are also referred to as pots 0 through 11.

### 3.2.1.3 Global Inputs

The suspension controller has global inputs for pitch and yaw. Global input signals can then be used in the global AC gain or the global DC gain modes described below. The input impedance of the global inputs is 1 Kohm.

### 3.2.1.4 Initial AC Filtering

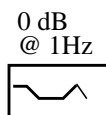
The initial AC filtering function is represented by



in the block diagram. The transfer function of this block has a zero at DC and the two most real poles of the overall 10 pole, 35 Hz chebychev low pass servo filtering function. Note that due to practical considerations in implementing the circuit a additional zero at DC and a pole at 0.1 Hz have been added to the AC response. The additional pole and zero do not affect the stability or the performance of the loop and can be ignored in most cases.

### 3.2.1.5 Initial DC Filtering

The initial DC filtering function is represented by



in the block diagram. The transfer function of this block has a pole at 0.01Hz, zeros at 0.1 and 1.0 Hz and the two most real poles of the overall 10 pole, 35 Hz chebychev low pass servo filtering function.

### 3.2.1.6 Output Matrix

The function of the output matrix is two fold:

1. transform the signals from position, pitch, yaw and side orientation signals, and
  2. allow the operator to trim these signals to account for gain differences, etc. in the system.
- The output matrix is represented by the 12 adjustable gain stages on the right hand side of the block diagram. These gain stages are also referred to as pots 12 through 23.

### 3.2.1.7 Final Filtering

The final filtering is represented by



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in the block diagram. The transfer function of this block is the remaining 8 poles of the nominal 10 pole chebychev response. Note that these poles can be bypassed by the operator on a coil by coil basis.

### 3.2.1.8 Coil Drivers

The coil driver is formed by placing the coil in the feedback loop of the output op amp/buffer stage for each output channel. In the run mode of operation a 4.99 Kohm resistor is placed in series with the coil. In the acquire mode of operation this resistance is changed to 499 ohms. Note that this change in resistance only affects the maximum current that can be applied to coil from the LSC input.

### 3.2.1.9 LSC Input

The LSC input is shown on page 2 of the block diagram. The adjustable gain stages, pots 24 through 27, are used to trim the LSC input response to provide a longitudinal push of the optic with no coupling to pitch or yaw.

The input impedance of the LSC input is 1 Kohm.

### 3.2.1.10 Test Inputs

Test inputs are provided for position, pitch, yaw, side and each of the coils. The input impedance of the position, pitch, yaw and side test inputs is 1 Kohm. The input impedance of each coil test input is 5Kohms when the coil test is enabled and an open circuit when the coil test is disabled. Note that when the coil test is enabled, the drive signal from the servo amplifier is disconnected and the coil test signal is connected to the coil driver circuitry.

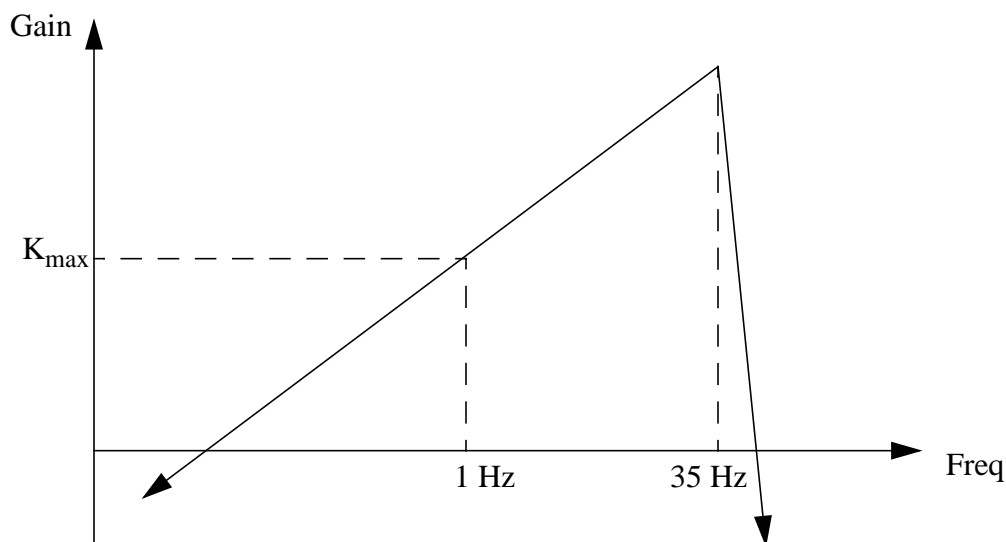
## 3.2.2. Modes of Operation

### 3.2.2.1 Local AC Gain Mode

The local AC gain mode of operation is provided for pitch and yaw. This mode of operation is enabled by performing the following steps.

1. Push the local side of the control button on the overview operator screen. Check that the read-back now shows "LOCAL".
2. Set the gain to the desired value using pot 30 for pitch and/or pot 32 for yaw. Verify that the read back value matches the slider requested value.
3. Enable AC mode of operation by pushing the AC enable/disable button on the operator screen. Disable the DC mode by pushing the DC enable/disable button on the operator screen. Check that the readbacks for each button match the desired state.
4. Disable the coil test for each coil driver output. Check that the readbacks for each button show "disabled".

The transfer function for the local AC gain mode of operation is shown in the figure below. Note that the maximum gain at 1 Hz shown in the figure is obtained by setting all sliders (including the input and output matrix) in the signal path to 100%.



$K_{max} = 69.5$  dB POS  
 $K_{max} = 52$  dB PIT  
 $K_{max} = 52$  dB YAW  
 $K_{max} = 76$  dB Side

**Figure 4: Local AC Mode Transfer Function**

### 3.2.2.2 Global AC Gain Mode

The global AC gain mode of operation is provided for pitch and yaw. This mode of operation is enabled by performing the following steps.

1. Push the global side of the control button on the overview operator screen. Check that the readback now shows “GLOBAL”.
2. Set the gain to the desired value using pot 30 for pitch and/or pot 32 for yaw. Verify that the read back value matches the slider requested value.
3. Enable AC mode of operation by pushing the AC enable/disable button on the operator screen. Disable the DC mode by pushing the DC enable/disable button on the operator screen. Check that the readbacks for each button match the desired state.
4. Disable the coil test for each coil driver output. Check that the readbacks for each button show “disabled”.

The transfer function for the Global AC mode is the same shape as that shown in Figure 4. The maximum gain at 1 Hz for pitch and yaw is 26 dB.

### 3.2.2.3 Global DC Gain Mode

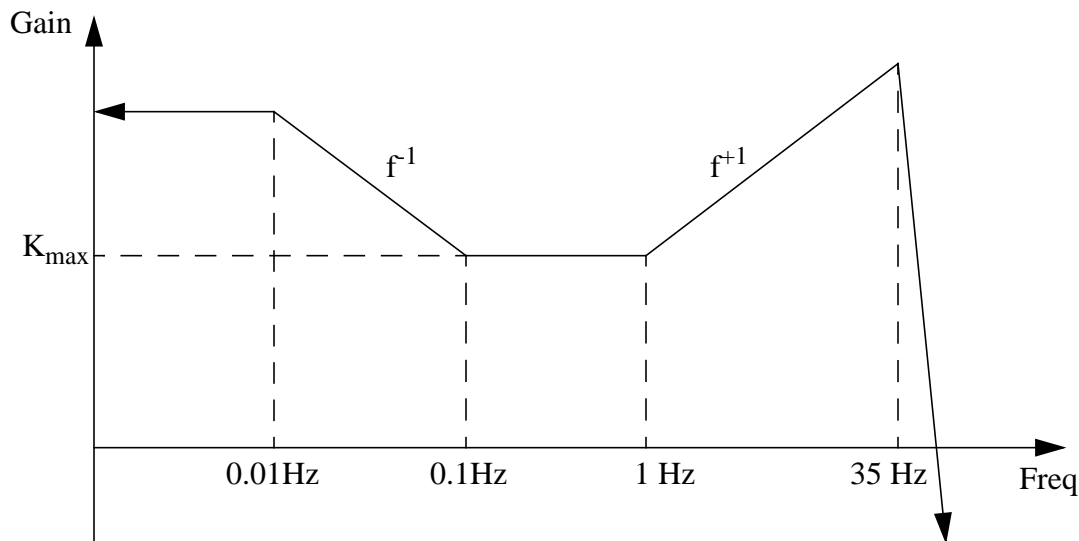
The global AC gain mode of operation is provided for pitch and yaw. This mode of operation is enabled by performing the following steps.

1. Set the gain to the desired value using pot 31 for pitch and/or pot 33 for yaw. Verify that the

read back value matches the slider requested value.

2. Enable DC mode of operation by pushing the DC enable/disable button on the operator screen. Disable the AC mode by pushing the AC enable/disable button on the operator screen. Check that the readbacks for each button match the desired state.
3. Disable the coil test for each coil driver output. Check that the readbacks for each button show “disabled”.

The transfer function for the global DC gain mode of operation is shown in the figure below. Note that the maximum gain at 1 Hz shown in the figure is obtained by setting all sliders (including the output matrix) in the signal path to 100%.



$$K_{\max} = 23 \text{ dB PIT}$$

$$K_{\max} = 23 \text{ dB YAW}$$

**Figure 5: Global DC Mode Transfer Function**

### 3.2.2.4 LSC Run/Acquire Mode

LSC run and acquire modes of operation are provided for each coil driver output. The mode of operation is set by pushing the appropriate side of the control button located inside each coil driver icon on the right hand side of the overview operator screen. Check to see that the readbacks for each button match the desired setting.

### 3.2.2.5 Coil Test Mode

Coil test mode is provided for each coil driver and is enabled by pushing the appropriate button or buttons on the overview operator screen. Note that if a coil test is enabled the output drive from the suspension controller for that particular coil driver is disconnected.

### 3.2.2.6 LSC Input Enable/Disable

The LSC input can be enabled or disabled by pushing the enable/disable button on the LSC input operator screen.

## 4 SOFTWARE

The following table is a list of the EPICS databases and state notation programs that are used for control and monitoring of the BS and RCM suspension systems.

**Table 2: BS and RCM**

<i>Database/Program</i>	<i>Description</i>	<i>Location</i>
RCM_Controller.db	RCM Suspension database	/opt/CDS/d/epics/apple/ Caltech/RCM_SUS/ scipe5/dev/database
RCM_pots.st	RCM Suspension SNL program	/opt/CDS/d/epics/apple/ Caltech/RCM_SUS/ scipe5/dev/src
BS_Controller.db	BS Suspension database	/opt/CDS/d/epics/apple/ Caltech/RCM_SUS/ scipe5/dev/database
BS_pots.st	BS Suspension SNL pro- gram	/opt/CDS/d/epics/apple/ Caltech/RCM_SUS/ scipe5/dev/src

## 5 TROUBLESHOOTING

The following table can be used as a troubleshooting guide. It not intended to be an exhaustive troubleshooting list, but is geared to help the system operator eliminate easily correctable prob-

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lems at the system level.

**Table 3: Suspension System Troubleshooting Guide**

<i>Symptom</i>	<i>Possible Cause</i>
Slider request does not match readback	<ul style="list-style-type: none"> <li>• Serial cable disconnected</li> <li>• Power to controller off</li> <li>• SNL program has stopped or has locked up</li> </ul>
Button readback does not match request	<ul style="list-style-type: none"> <li>• VME power off</li> <li>• VME CPU stopped</li> <li>• VME or operator console ethernet disconnected or malfunctioning</li> </ul>
Operator screen is not updating	<ul style="list-style-type: none"> <li>• VME power off</li> <li>• VME or operator console ethernet disconnected or malfunctioning</li> </ul>
Suspended optic does not damp	<ul style="list-style-type: none"> <li>• Cable to satellite module disconnected</li> <li>• Cable from satellite module to OSEM heads disconnected</li> <li>• Coil test is enabled for one or more channels</li> <li>• Power is off to controller and/or satellite module</li> <li>• Channels gains are too low or channels are disabled</li> <li>• Global AC or DC mode is enabled with no global input</li> <li>• Input and/or output gain matrix not adjusted properly</li> <li>• Pitch or Yaw bias adjustment has saturated the channel</li> <li>• Polarity for one or more channels is incorrect</li> </ul>

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**Table 3: Suspension System Troubleshooting Guide**

<i>Symptom</i>	<i>Possible Cause</i>
Suspended optic does not damp properly or oscillates improperly when channels polarity is inverted	<ul style="list-style-type: none"> <li>• Coil test is enabled for one or more channels</li> <li>• Coil wires for one or more OSEM heads not connected</li> <li>• Input and/or output gain matrix not adjusted properly</li> <li>• Pitch or Yaw bias adjustment has saturated the channel</li> <li>• Output filtering bypassed for one or more channels</li> </ul>
MEDM will not start on operator console	<ul style="list-style-type: none"> <li>• EPICS has not been setup properly</li> </ul>
Screen updates and/or system response to operator requests is slow	<ul style="list-style-type: none"> <li>• CDS ethernet is busy</li> <li>• Operator console is overloaded</li> <li>• Too many channel access connections to the VME CPU</li> </ul>

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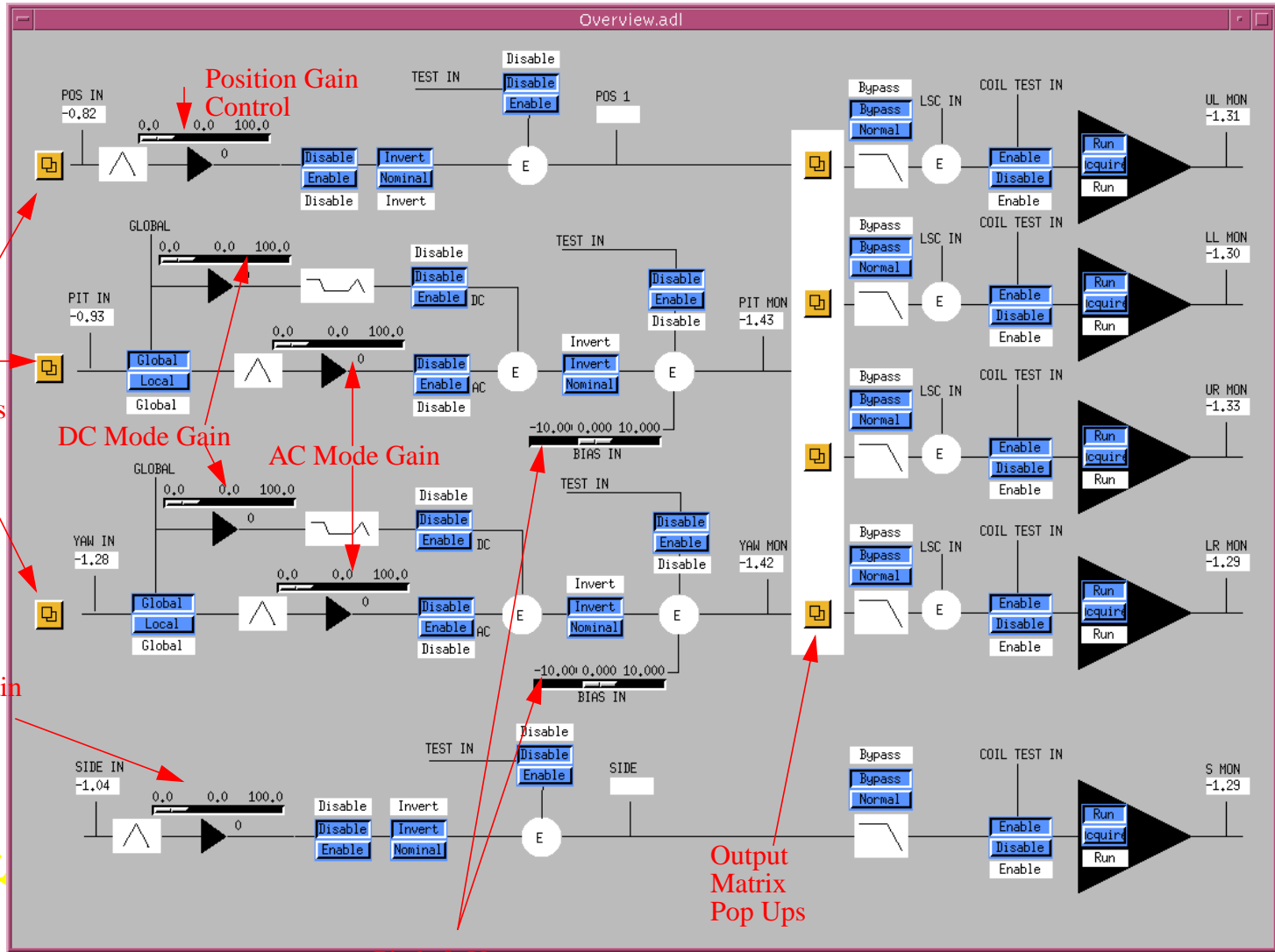
# APPENDIX 1      SCHEMATICS

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# APPENDIX 2 BS AND RCM SUSPENSION CONTROL OVERVIEW SCREEN

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Position Gain Control

Input Matrix Pop Ups

DC Mode Gain

AC Mode Gain

Side Gain Control

Output Matrix Pop Ups

Pitch & Yaw Bias Adjust

**APPENDIX 3      SUSPENSION CONTROLLER BLOCK  
DIAGRAM**

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