



LASER INTERFEROMETER GRAVITATIONAL WAVE OBSERVATORY

LIGO Laboratory / LIGO Scientific Collaboration

LIGO- E1300903-v4

Advanced LIGO

12/17/2013

ISC End Station User's Manual

Daniel Sigg, Keita Kawabe, Sheila Dwyer, Kiwamu Izumi, Stefan Ballmer and Alexa Staley

Distribution of this document:
LIGO Scientific Collaboration

This is an internal working note
of the LIGO Laboratory.

California Institute of Technology
LIGO Project – MS 18-34
1200 E. California Blvd.
Pasadena, CA 91125
Phone (626) 395-2129
Fax (626) 304-9834
E-mail: info@ligo.caltech.edu

Massachusetts Institute of Technology
LIGO Project – NW22-295
185 Albany St
Cambridge, MA 02139
Phone (617) 253-4824
Fax (617) 253-7014
E-mail: info@ligo.mit.edu

LIGO Hanford Observatory
P.O. Box 159
Richland WA 99352
Phone 509-372-8106
Fax 509-372-8137

LIGO Livingston Observatory
P.O. Box 940
Livingston, LA 70754
Phone 225-686-3100
Fax 225-686-7189

<http://www.ligo.caltech.edu/>

Table of Contents

1	<i>Introduction</i>	4
1.1	Block Diagram	4
1.2	Naming	4
1.3	Operations screens	4
1.4	Applicable Documents	5
2	<i>Transmission Monitor</i>	5
2.1	Controls Configuration	5
2.1.1	TMS Beam Centering Servo	6
2.1.2	TMS Suspension	6
2.1.3	IR Transmission Monitor	7
2.2	Standard Operating Parameters	7
2.2.1	QPD Whitening/Anti-whitening.....	7
2.2.2	Green QPD sum	8
2.2.3	TMS Suspension	8
3	<i>ISC End Station Optics Table</i>	9
3.1	Fiber Beam Setup	9
3.1.1	Corner Station Setup	9
3.1.2	Polarization Correction.....	9
3.2	Prometheus Laser Setup	9
3.2.1	Power Adjust.....	9
3.2.2	Frequency Setup	9
3.2.3	SHG Temperature Adjust.....	10
3.3	Nominal Laser Power Levels	10
3.3.1	Fiber Path	10
3.3.2	IR Laser Path.....	11
3.3.3	Green Laser Path	11
3.4	Beam Alignment	11
3.5	Input Steering Mirrors	11
3.5.1	Setup	11
3.5.2	Controls Parameters.....	12
4	<i>Laser Locking</i>	12
4.1	Controls Configuration	12
4.2	Standard Operating Parameters	13
4.2.1	Conditions.....	13
4.2.2	Filter and Gain Settings	13
4.2.3	Performance Checks	13
4.3	Failure Modes	13

- 5 Cavity Locking 13**
 - 5.1 Controls Configuration..... 13**
 - 5.2 Standard Operating Parameters 13**
 - 5.2.1 Conditions..... 13
 - 5.2.2 Filter and Gain Settings 13
 - 5.2.3 Performance Checks 13
 - 5.3 Failure Modes..... 13**

1 Introduction

This manual covers the setup and operations of the interferometer sensing and control equipment located in the end station.

1.1 Block Diagram

1.2 Naming

1.3 Operations screens

Under the “ALS” button on the site map (*Figure 1: MEDM Site Map. ALS button and end station SUS buttons are highlighted here. There should be two buttons named “End X Overview” and “End Y Overview”, which are linked to the ALS overview screen of corresponding end stations (Figure 2).*



Figure 1: MEDM Site Map. ALS button and end station SUS buttons are highlighted here.

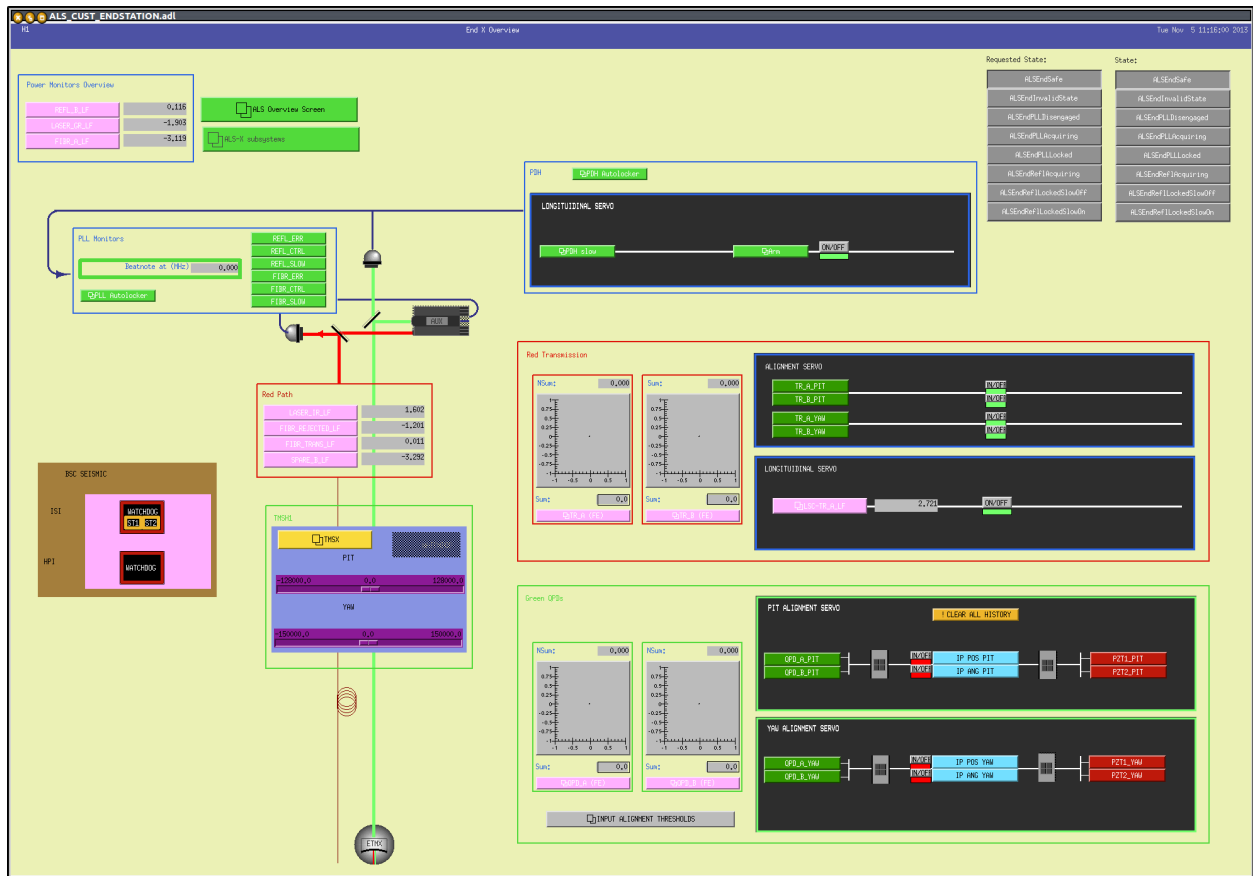


Figure 2: ALS X overview screen.

1.4 Applicable Documents

2 Transmission Monitor

The Transmission Monitor comprises a beam reduction/expansion telescope, an IR QPD “sled” to monitor the transmission of 1064 nm beam from the arm cavity, a green QPD “sled” to monitor 532 nm beam injected from the end station ISCT to the BSC. The entire structure is suspended by the Transmission Monitor Suspension (TMS). The transmission monitor system as a whole is sometimes also referred to as TMS.

2.1 Controls Configuration

The ALS End station overview MEDM screen (*Figure 2*) provides convenient links to most of important TMS functionality.

Two PZT mirrors on the in-air ISC table (ISCTEX and ISCTEY) will change the green beam pointing into the chamber, and the green QPD sled is used as the sensor to monitor the alignment of the green beam into the TMS telescope. Together they are used for a beam centering servo to automatically align the green beam to the TMS.

Once the green beam is “fixed” to the TMS via the servo, the TMS suspension biases change the pointing of the green beam leaving the telescope without affecting the beam path on the telescope.

When the IR light resonates inside the arm cavity, an IR QPD sled will work as an ASC sensor for the interferometer. A fraction of the IR beam is also directed towards the ISC table where a high gain photodiode is used to measure light levels during lock acquisition. Once the interferometer control transitions to science mode, a beam diverter will guide the IR beam leaving the vacuum towards an in-vacuum beam dump.

2.1.1 TMS Beam Centering Servo

On the bottom right of the ALS End station overview (Figure 2), the graphics inside a green rectangle are for the green QPD sled (represented by two X-Y monitors), and the beam centering servo (some buttons and matrices in black rectangle). The input of the servo is the QPD error signal, and the output is connected to the PZT mirrors.

To turn the servo on or off, click the ON/OFF button of four servo filters. This toggles the on/off indicator of each filter between green (ON) and red (OFF). In Figure 2 all filters are off.

The servo filters have an integrator, so disabling the servo means that the output of the filters are held constant until the servo is turned on again. This is convenient as turning them on/off doesn't suddenly throw the alignment off. When desired, you can reset the servo filters by “Clear all history” button.

The PZT control voltage is unipolar (0V to 10V) and is biased to mid range (5V) for a nominal zero.

2.1.2 TMS Suspension

The TMS suspension is used to change the angle of the TMS telescope, which in turn changes the green beam pointing towards the ETM (and thus ITM). From the ALS End station overview you can directly adjust the bias sliders to the TMS suspension.

If there is a problem with the TMS suspension, you should open the TMS suspension MEDM screen (Figure 3) to further diagnose the problem.

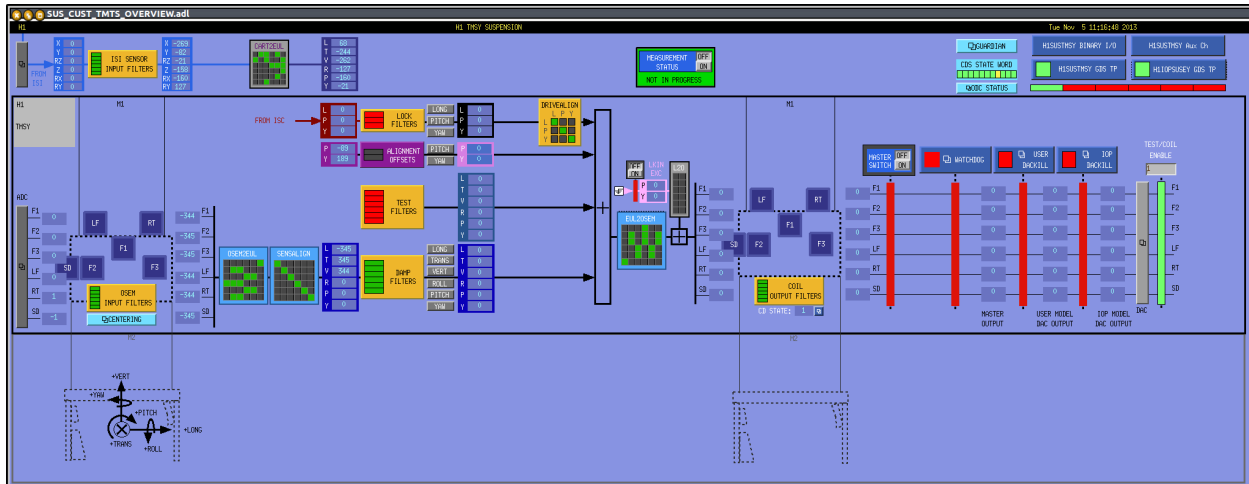


Figure 3: TMS Suspension screen. In this example the master ON/OFF switch is off (the first of the four red vertical bars next to the right most green bar) and the watchdog/DACKILL are also tripped (three red bars next to the master switch) so nothing should be working.

2.1.3 IR Transmission Monitor

IR QPD sled output and associated ASC and LSC servo boxes are in a red rectangle above the green QPD centering servo box (Figure 2).

2.2 Standard Operating Parameters

Parameter	Value
Whitening gain for IR QPDs	
Number of whitening/anti-whitening stages for IR QPDs	
Whitening gain for green QPDs	
Number of whitening/anti-whitening stages for green QPDs	
Minimum light level on the green QPDs (normalized sum field)	>0.7
Nominal unity gain frequency of the green beam steering servos	

Table 1: Standard Operating Parameters for the Transmission Monitor.

2.2.1 QPD Whitening/Anti-whitening

Pressing buttons like “TR A (FE)” (for transmission monitor A) or “QPD B (FE)” (for green injection monitor B) in the ALS End station overview will open the QPD overview for a corresponding QPD. Press “whiten” button, and read the numbers in the whitening gain slider.

There are three stages of switchable analog whitening and digital anti-whitening for all four quadrants of each of QPDs. The state of these can be monitored by the same screen as the whitening gain slider. It is extremely important that whitening and anti-whitening stages are

enabled/disabled as a pair. If not (e.g. whitening stage 2 is on but anti-whitening stage 2 is off), check the nominal status by trending H1:ALS-Y_QPD_A_WHITEN_FILTER_2 and H1:ALS-Y_QPD_A_AWHITEN_SET2, etc., and determine if they are enabled or disabled.

There is a non-switchable analog whitening stage, and a corresponding anti-whitening stage in FM4 of the input filter for each quadrant. You should not disable these, but if you suspect that they are disabled, open each of the filters (e.g. from the aforementioned QPD overview by pressing buttons labeled as “SEG1” “SEG2” etc.).

2.2.2 Green QPD sum

Check if the light level on the green QPDs is nominal (see Table 1). If the sum is significantly lower, first check if anything is coming in to the digital system. Check the whitening settings (see the previous section), move the whitening gain slider up and down and see if you’re getting any signal. Don’t forget to restore the slider back to normal after this. If you’re not getting anything you need to call a CDS or ISC expert.

If the readbacks are alive, the problem might be that the output of the QPD centering servo railed because of some unusual circumstance (e.g. somebody blocked the beam for a short period). To verify this, first turn off the beam centering servo for all four filters, then reset the integrators of the servo by pressing “Clear All History” button. If you are getting some light in both of the QPDs, turn on the servo again. If not, check if the offsets in the PZT output filters are lost. Open the PZT output filter screen by pressing buttons labeled “PZT1_PIT” etc., check the offset in the filter (it should be enabled and non-zero). If the offsets are off, enable them. If the offsets are zero, but restore them as necessary. If the offsets for all four filters are non-zero and enabled, trend these offsets and see if the current numbers are significantly different from a known good time. Set them back to the known good values.

If that doesn’t recover the sum, check if the TMS suspension bias is on, and if there is a large offset. Trend H1:SUS-TMSY_M1_OPTICALIGN_P_OUTPUT etc. and compare the current numbers with the known working numbers.

If the green QPD sums are still too low, call an ISC expert.

2.2.3 TMS Suspension

Usually, the TMS suspension should be damped with an alignment bias. These are handled in the same way as quad suspensions.

3 ISC End Station Optics Table

3.1 Fiber Beam Setup

3.1.1 Corner Station Setup

On the PSL table a portion of the reference cavity transmission is coupled into the fiber for ALS. We start with 9 mW in the path towards the fiber, and get 70% coupling into the fiber. This fiber goes to the Fiber Distribution Box (document tree [E1200121](#)). It has a 160 MHz AOM, when this AOM is driven the outputs for each end station contain just under 10% of the input power. There are PDs controlled by the slow controls system that monitor the power into the fiber, the power received in the fiber distribution box. They have medm screens which are accessible under DCPDs under LSC on the sitemap. These should be calibrated (by setting the responsivity) and the nominal powers set. The end station PLL autolocker will generate an error message if the power is low on these PDs.

3.1.2 Polarization Correction

The outputs from the fiber distribution box goes to a polarization controller (located in the MSR), MPC1, the manual is available at [T1200496](#). From here it is launched into the fiber to the end station, arriving at the end station with about 50%-75% loss. We need at a minimum 40 μ W coming out of the fiber at the end station, again there are DC PDs monitoring this power, and the polarization of the output. These PDs need to be calibrated, and limits and nominal values set. The PLL autolocker also checks the values of these PDs and will generate error messages when the polarization drifts or the power drops. The polarization needs to be adjusted manually using MPC1 when it drifts far enough.

3.2 Prometheus Laser Setup

The Prometheus manual can be found in [LIGO-T1000643](#). The Prometheus has a noise eater for intensity stabilization which should be disabled. The noise eater can oscillate making it impossible to lock the PLL until someone resets it. There is a noise eater monitor available on the laser head which is available in the laser MEDM screen, but this does not work and sometimes indicates that there is no oscillation when there is in reality an oscillation.

3.2.1 Power Adjust

Adjust the laser diode current near its nominal settings as indicated by the data sheet belonging to the specific laser. Sometimes the factory setting indicates that the current should be set to the maximum, in this case set it slightly below the maximum.

3.2.2 Frequency Setup

3.2.2.1 Nominal Frequency

Nominal frequencies are listed in [LIGO-T1300883](#). The X-end stations are using a down-shifted laser frequency, whereas the Y-end stations are using an up-shifted laser frequency. The X-end

stations are using a down-shifted laser frequency, whereas the Y-end stations are using an up-shifted laser frequency. The PLL autolocker screen is available from the small grey box that says “X (or Y) Arm PLL” in the corner of the ALS overview screen. On this screen you can choose Above PSL or below PSL to set the polarity of the locking.

3.2.2.2 Temperature Adjust

The coarse adjustment of the laser frequency needs to be done with the crystal temperature. A higher temperature corresponds to a lower frequency. However, mode hops will occur every $\sim 2^\circ\text{C}$ and reset the frequency back by some amount.

Use an RF spectrum analyzer with at least 500 MHz bandwidth to look for the beat note on the broadband LSC detector, FIBR_A. The initial frequency can be off by GHz which might be too far off to be detected by the photodetector. Scan the temperature until the beat note appears. Then, adjust it approximately to the desired frequency.

There is an interaction between the laser diode current adjust and the crystal temperature. We use this to make sure we are in the middle of a mode hopping region. First, move the temperature up and down and watch for the mode hope. If the desired frequency is close to a mode hope region, adjust the diode current by 0.1 A, and try again. Repeat this procedure until the desired frequency is near the approximately centered between two mode hope regions.

3.2.3 SHG Temperature Adjust

Monitor the green laser power and make sure that the temperature of the SHG is adjusted to deliver maximum green power.

3.3 Nominal Laser Power Levels

3.3.1 Fiber Path

The nominal power levels in the fiber path are as follows:

Parameter	Nominal	Minimum
Reference cavity transmission	10 mW	
Coupled into fiber	7 mW	4 mW
Receive in MSR	300 μW	100 μW
Send to end station	300 μW	100 μW
Receive at end station	150 μW	50 μW
On ISC table	150 μW	40 μW
On monitor photodiode (FIBR_TRANS)	9 μW	2.5 μW
On fiber locking photodiode (FIBR_A)	75 μW	40 μW

3.3.2 IR Laser Path

The nominal power levels for the IR path of the Prometheus laser are as follows:

Parameter	Nominal	Minimum
Laser output	1.1 W	100 mW
After attenuation	50 mW	25 mW
On monitor photodiode (LASER_IR)	350 μ W	100 μ W
On fiber locking photodiode (FIBR_A)	25 mW	600 μ W

3.3.3 Green Laser Path

The nominal power levels for the green path of the Prometheus laser are as follows:

Parameter	Nominal	Minimum
Laser output	20 mW	10 mW
After first Faraday isolator	17 mW	8 mW
On monitor photodiode (LASER_GR)	800 μ W	400 μ W
After second Faraday isolator	14 mW	6 mW
At periscope into vacuum chamber	12 mW	5 mW
Return from ETM on reflection photodiode (REFL_A)	12 mW	3 mW
Return from ETM on reflection photodiode (REFL_A)	12 mW	
Received at ISCT1 (X arm)		<5 mW
Received at ISCT1 (Y arm)		<5 mW

3.4 Beam Alignment

3.5 Input Steering Mirrors

3.5.1 Setup

The manual for the PZTs and controllers are available at [E1300870](#). The controllers should be operated in the low bandwidth mode. To do this you need to move a jumper in the controller, instructions are in the manual. The input steering PZTs have two axes, Y rotates yaw and X rotates

Pitch. They operate with inputs from 0-10V, so the initial alignment should be done with 5V input to the controllers. Before the initial alignment the sensor offset should also be adjusted according to the manual. Once the initial alignment is done and the TMS offsets set so that the retroreflection returns to the PD, the alignment of optics near the PZTs should be adjusted so that the beam is centered on the TMS QPDs when they are operated at the middle of their range.

3.5.2 Controls Parameters

4 Laser Locking

4.1 Controls Configuration

The autolocker for locking the PLL is in the Twin CAT library, a state diagram is available at [T1300891](#). The autolocker screen is available by clicking on the small grey box labeled X ARM PLL (or Y arm) in the ALS overview screens at each end station. The autolocker checks several locking conditions, if any of these are not met an error message will appear at the bottom of the screen and the locking conditions text will have a red background. To clear all of these each of the relevant DC PDs will need to be calibrated, and some of them will need to have limits set.

4.2 Standard Operating Parameters

4.2.1 Conditions

4.2.2 Filter and Gain Settings

4.2.3 Performance Checks

4.3 Failure Modes

5 Cavity Locking

5.1 Controls Configuration

5.2 Standard Operating Parameters

5.2.1 Conditions

5.2.2 Filter and Gain Settings

5.2.3 Performance Checks

5.3 Failure Modes