# **PRMI** Locking Procedure

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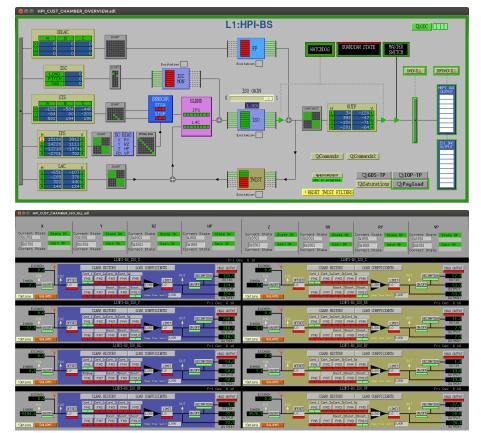
December 5, 2013

#### Seismic configuration

Contrary to IMC locking, at Livingston we found that the ambient ground motion was too large to lock the PRMI without the active seismic isolation systems running. The largest effect is excess angular motion, particularly of the HLTS optics (PR3 & SR3), which couple strongly to cavity misalignment.

HEPI:

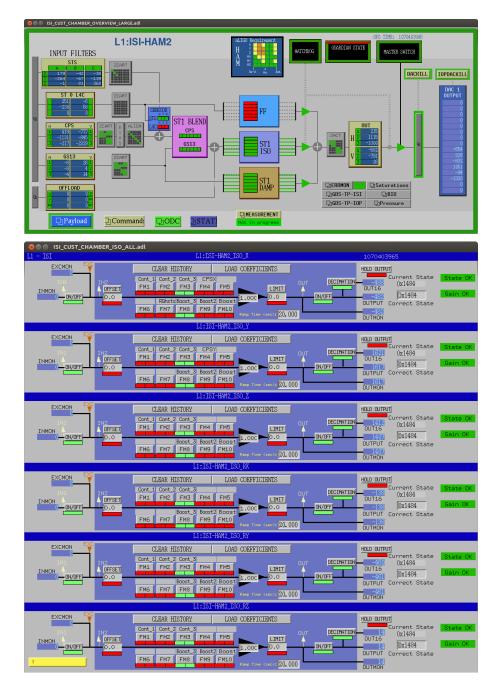
 $\bullet\,$  HAM HEPI systems can either be fastened in place with their hard stops or with position sensor loops (UGF  ${\sim}5~{\rm Hz})$ 



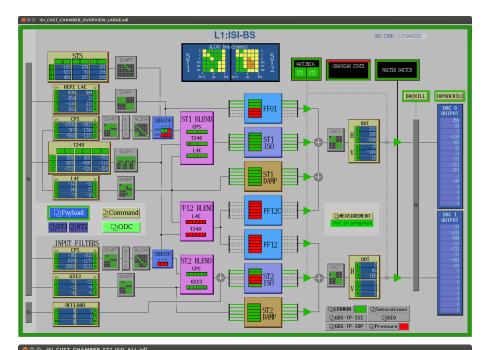
• BSC HEPI systems should be running position sensor loops (UGF  $\sim 5$  Hz)

ISI:

• HAM ISIs run feedback loops with ~30 Hz UGFs (*level 3*) and the ISI inertial sensors blended into the error point around 250 mHz in translation and around 400 mHz in rotation. Isolation at the microseism is achieved via feed-forward to the ISI error point, using an STS-2 seismometer on the LVEA slab located next to HAM2 (this is called STSA in the front ends and drawings).



- Stage 1 of the BSC ISIs run feedback loops with ~40 Hz UGFs in translation and ~30 Hz UGFs in rotation (*both are level 3*), except for RZ which only uses a *level 1* controller with ~10 Hz UGF. The stage 1 inertial sensors blended into the error point around 45 mHz in translation, providing isolation at the microseism, and around 250 mHz in rotation. Some sensor correction is also used, from STSB on the LVEA slab, to provide extra isolation around the main core optic suspension resonances, ~0.5 Hz. A feed-forward path from the HEPI L4Cs provides some isolation around 10 Hz, where the BSC's suffer from some amplification of ground motion due to structural resonances.
- Stage 2 of the BSC ISIs run feedback only in the translational DOFs, with  $\sim 10$  Hz UGFs (*level 1*) and the inertial sensors blended in around 250 mHz. This isolation is only effective above  $\sim 1$  Hz and is **not** required for lock acquisition.



8 CUST_CHAMBER_ST1_ISC	D_ALL.adl		
L1	L1ISI-BS_ST1_ISO_X	Fri Dec 6 16	
	CLEAR HISTORY         LOAD COEFFICIENTS           Cont_1 Cont_2aCont_20 40Hza 40Hzb         FM3         FM4         FM5           FM1         FM2         FM3         FM4         FM5         LIMIT           40Hzc 40Hzb         FM3         FM4         FM5         LIMIT         0.00         0.00           FM6         FM7         FM8         FM3         FM4         FM3         0.00	HLD OUTPUT CCCIPMTION 00115 00115 00115 00115 00116 00115 0014f8 0016 00 00 00 00 00 00 00 00 00 0	State OK Gain OK
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L1	L1ISI-BS_ST1_ISO_Z	Fri Dec 6 16	
	FN1         FN2         FN3         FN4         FM5         LINIT           40Hzc         ************************************	OUT DECIMITION	State OK Gain OK
L1	L1ISI-BS_ST1_ISO_RX	Fri Dec 6 16	
EXCMON 0.0 111 111 111 112 0.0 112 0.0 112 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.	CLEAR HISTORY         LOAD COEFFICIENTS           Cant, 2 Cant, 2a Cant, 2b 30Hza         30Hza           FH4         FH3         FH4           S0Hzc         Sector, 2b act, 2b act, 1           FM6         FH7         FH8           FH9         FH10         FH10	OUT OCCUMIENT OUTS Current State OUT COLLES CURRENT CALL OUTS CALL OUTS CALL OUTS CALL OUTS CORECT State OUTPUT CORECT State	State OK Gain OK
L1	L1ISI-BS_ST1_ISO_RY	Fri Dec 6 16	
	CLEAR HISTORY         LOAD COEFFICIENTS           Cont_20Acnt_20 30Hza 30Hzb         THUE           FM1         FN2         FN3         FM4         FM5           30Hzc         THMAHAM         Boot_2Poot_1         0.00         0.00           FM6         FM7         FM8         FM9         FM4         FM2         0.00           LINIT         FM8         FM9         FM10         THM         0.00         0.00	PLD OUTPUT OUT FECTIVATION OUT 12 OUT	State OK Gain OK
	CLEAR HISTORY LOAD COEFFICIENTS	HOLD OUTPUT	
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See ISI_CUST_CHAMBER_ST2_IS			
L1	L1ISI-BS_ST2_ISO_X	Fri Dec 6 16	
	CLEAR         HISTORY         LOAD         COEFFICIENTS           Cont_1         Cont_2aCont_2b	OV/OFF 95.4 OX1601 Gain	te OK n OK
L1	L1ISI-BS_ST2_ISO_Y	Fri Dec 6 16	
	CLEAR         HISTORY         LOAD         COEFFICIENTS           Cont, 1         Cont, 20         FM4         FM5         FM4         FM5           FM1         FM2         FM3         FM4         FM5         FM1         FM1         FM1           B000t, 2800t, 10         PM0	Correct State	te OK n OK
D1	L1ISI-BS_ST2_ISO_Z	Fri Dec 6 16	
	COLLEAR HISTORY         LOAD COEFFICIENTS           Cont_1 Cont_2a Cont_2b         FM4         FM5           FM4         FM2         FM3         FM4         FM5           FM4         FM2         FM3         FM4         FM5           FM6         FM7         FM8         FM9         MA0	OV/OFF OUTPUT Correct State Gair	te OK n BAD
L1	L1ISI-BS_ST2_ISO_RX	Fri Dec 6 16	
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## Suspension configuration

Damping:

• HAM triple suspensions use velocity damping with resonant gain for the length and pitch DOFs (*FM1, FM3, FM5, and FM10 engaged*), and plain velocity damping for the other DOFs, all with 50 Hz elliptical cutoffs (*FM1, FM5, and FM10* engaged). For a HSTS the damping gains in L,T,V,R,P,Y are [-4, -2, -2, -2, -2, -1].

SOB 0 SUS_CUST_HXTS_M1_DAMPadl			
LI	L1SUS-PRM_M1_DAMP	Fri Dec 6 15:50:09 2013	
	CLEAR HISTORY LOAD COEFFICIENTS	tLD CUTTOT UIT12 CUTTOT CUTTOT COTTOT COTTOT COTTOT COTTOT COTTOT COTTOT	
	CLEAR HISTORY LOAD COEFFICIENTS 0:30,30 FM1 FM2 FM3 FM4 FM5 FM5 FM7 FM8 FM9 FM10 FM6 FM7 FM8 FM9 FM10 Ramp Time (s)5,000	01.0 000000         Current State           01.00000000000000000000000000000000000	
	CLEAR HISTORY LOAD COEFFICIENTS 0:30,30 FM2 FM3 FM4 FM5 FM4 FM5 FM2 FM3 FM4 FM5 FM6 FM7 FM8 FM9 FM40 Ramp Time (s)5,000	DLD DUTPUT -0.523 DUT16 -0.749 -0.749 -0.77 -0.77 -0.77 Correct State	
	CLEAR HISTORY LOAD COEFFICIENTS 0:30,30 FM4 FM2 FM3 FM4 FM5 FM4 FM5 FM6 FM7 FM8 FM9 FM0 Ram Time (s6,000	LLD OUTPUT OUTON OUTON OUTON OUTON	
	CLEAR HISTORY LOAD COEFFICIENTS	ILD OUTFUT OUTOUT OUTOUT OUTFUT OU	
	CLEAR HISTORY         LOAD COEFFICIENTS           0:30,30         RG1.1         nonmY           FM1         FM2         FM3         FM4           FM4         FM5         -1.00         0.0           FM6         FM7         FM8         FM9           FM1         FM3         FM1         FM3	DU OUTPUT UTTUTUT UTU	

For a HLTS the damping	g gains in L,T,V,R,P,Y	are [-5,-15,-15,-0.2,-0.01,-0.2].
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8 SUS_CUST_HXTS_M1_DAMP		
L1	L1SUS-PR3_M1_DAMP	Fri Dac 6 15:50:47 2013
	CLEAR HISTORY         LOAD COEFFICIENTS           0115.15         448644         PASS         DOPML           FM1         FM3         FM4         FM5         DOPML           FM1         FM3         FM4         FM5         DOPML           FM4         FM3         FM4         FM5         DOPML           FM6         FM7         FM8         FM9         FM3           FM6         FM7         FM8         FM9         FM3	BLD OUTPUI           10         7,555           001145         0005000000000000000000000000000000000
	CLEAR HISTORY LOAD COEFFICIENTS 0:15,15 4488041 FML FM2 FM3 FM4 FM5 FM4 FM5 FM4 FM5 FM5 FM7 FM8 FM9 FM4 R05 FM6 FM7 FM8 FM4 FM5 FM6 FM7 FM8 FM7 FM8 FM7 FM7 FM8 FM8 FM7 FM8 FM7 FM8 FM8 FM7 FM7 FM8 FM8 FM8 FM8 FM8 FM7 FM8	ILD OUTPU IDUIS DUIS DUIS DUIS DUIS DUIS DUIS DUIS DUIS Current State MSSISIS State OK DUIS Correct State
	CLEAR HISTORY         LOAD COEFFICIENTS           0:15,15         ************************************	till outful 10 10 10 10 10 10 10 10 10 10
	CLEAR HISTORY         LOAD COEFFICIENTS           015,15         ************************************	ULD OUTPUT 00115 00122 00125 00125 00225 002606034 0.2 0.2 0.2 0.2 0.2 0.2 0.2 0.2
	CLEAR HISTORY         LOAD COEFFICIENTS           015,15         ************************************	BLD OUTPUT           10         103           00115         Current State           00170         Diffus           00170         Correct State
	CLEAR HISTORY         LOAD COEFFICIENTS           0115_15_1448044         DOPMY           FM1         FM2           FM4         FM3           FM4         FM3           FM4         FM3           FM4         FM3           FM4         FM3           FM4         FM4           FM3         FM4           FM4         FM3           FM4         FM3	DU 00791 10 00722 00135 00135 001450 001450 001450 001450 001450 001450 001450 001450 001450 001450 000000 000000 000000 000000

- The BS suspension damping loops use velocity damping with resonant gain in the length, transverse, and pitch DOFs (*FM5, FM6, FM8, FM9 engaged*), with plain velocity damping for the other DOFs, all with 50 Hz elliptical cutoffs (*FM5, FM6, FM9* engaged). The damping gains in L,T,V,R,P,Y are [-18,-0.5,-2,-0.5,-5,-0.6]. An optical lever servo is also used, feeding to the M2 stage actuators.
- The ITMs have resonant gain damping on all DOFs (*FM1, FM2, FM5, FM10* engaged), all damping gains are set to -1.

SUS_CUST_QUAD_M0_DAMP.adl	
LI LISUS-ITWX_MO_DAMP	Fri Dec 6 16:00:07 2013
EXCMON EXCMON	III COUPUT           II
INMON         OFFSET         FM1         FM2         FM3         FM4         FM5         LINIT           IMAGE         0.0	UNTIO UNTIO UNTIO UNTIO UNTON UNTON UNTON
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CLEAR HISTORY LOAD COEFFICIENTS	RLD OUTPUT IMATIO 20145 20145 00140 00140 00140 00140 00140 000000 0000000 00000000
INNON         OFFSET         FM1         FM2         FM3         FM4         FM5         LINIT           2558.805         INVOFF         0.0         INVOFF         0.0         INVOFF           FM6         FM7         FM8         FM9         FM2         Saup         Saup	DLD DUTPU UNITO UUTIE
EXCMON EXCMON CLEAR HISTORY LOAD ODEFFICIENTS CLEAR HISTORY INFORM INFOR	DATE OUTPUT DUTIS OUTPUT OUTPUT OUTPUT OUTPUT OUTPUT OUTPUT OUTPUT

BIO switches:

• All HSTS and BS stages are in state 2 (ACQ ON, LP OFF). The ITMs and PR3 are not used for length actuation, and can be in low noise mode.

#### BS suspension tuning

Balancing is done with the BS optical lever servo engaged.

- Balance the BS M2 coils by adjusting their gains while driving the M2 stage at high frequency (above the suspension resonances) in the pringle/butterfly degree of freedom and minimizing the peaks in pitch and yaw as measured by the optical lever. The coil gains are normalized to give a sum of the magnitudes equal to 4.
- Measure the transfer functions from the M2 L2P and P2P filters in the DRIVEALIGN matrix to the optical lever response (above 5 Hz the suspension model may be more accurate than the measurement).
- Fit the transfer functions, P2P and L2P, using the vectfit MATLAB routine. Be aware that this fit can produce RHP zeros.
- Make the synthetic data for the frequency response of the ratio of the filters L2P/P2P and fit it again with vecfit.
- Invert the filter from the previous step and install the inverted filter into the L2P filter of the DRIVEALIGN matrix.
- Repeat the above steps for yaw.

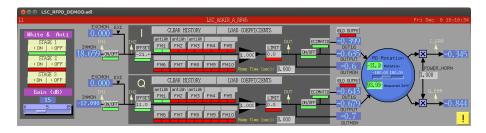
#### Initial alignment

• Align the input beam (adjusting IM3 or IM4) by centering the beam on the PR2 baffle.

- Align PR2/PR3. With the PRM misaligned find the leakage beam on the REFL port camera by moving PR2 and/or PR3. The PR2/PR3 alignment is degenerate in this configuration. The cavity alignment relative to the input beam is ~10x more sensitive to PR3's angle than to PR2's.
- Align the simple Michelson. With the PRM misaligned use the camera at the AS port (try using REFL if AS not available?) camera to overlap the beams returning from the ITMs.
- Align the PRM. Maximize the flashes on the AS camera or dips/spikes in the REFL/POP detectors.

### Simple Michelson locking

• The AS (REFL if AS not available?) port I/Q phases are first adjusted with the free swinging Michelson. At LLO the AS45\_AIR phase is -21.2°. The AS45\_AIR photodetector also has 15 dB of analog gain.



- The filters are:
  - f starting at 1 Hz with roll off at 50 Hz, 0.1:0.6 Hz boost (FM4 in L1:LSC-MICH)
  - bandstop for the BS bounce mode around 17 Hz (*FM6* in L1:LSC-MICH)
  - bandstop for the BS roll mode around 25 Hz (FM7 in L1:LSC-MICH)
  - $f^2$  starting at 1 Hz with roll off above 50 Hz (*FM6* in L1:SUS-BS\_M2\_LOCK\_L)
- two boosts are triggered, *FM2* and *FM8*
- the servo ugf is  $\sim 10$  Hz with a MICH gain of +/- 600 (dark/bright)

## PRX/Y locking

- The REFL port phases can be initially set/checked with free swinging PRX(Y)
- No analog gain is used for the REFL photodetectors

😣 🗇 🗉 LSC_RFPD_DEMOD.adl		
L1	LSC_REFL_A_RP9	
EXCMON EXC White & Anti STRE: ION IDFF STRE: S	FM6 FM7 FM8 FM9 FM10 Ramp Time (sec): 0.000 0.0 F17.	
CXCHON EXC Goin (dB) 0 0 0 0 0 0 0 0 0 0 0 0 0	CLEAR HISTORY LUAD ORREFICIENTS IN DIGITIZATION	7 Hessared 2117
Se LSC_RFPD_DEMOD.adl	LSC REFL A RF45	Fri Dec 6 16:21:49
Hhite & Anti STAGS 1 I ON   DEF STAGS 2 I ON   DEF	CLEAR HISTORY LAAD COEFFICIENTS CLEAR HISTORY INAL FIRS CFREET FIRE FIRS FIRS FIRS CFREET FIRE FIRS FIRS FIRS COULTED COULTE	Rotation
STAR 3 I DN 1 OFF Gain (dB) 0 0 15 -5.637 - DV/0FF	CLEAR HISTORY LOAD COEFFICIENTS	

- Once PRX(Y) is locked **on sideband** the phase is set by minimizing the response to PRM drive in the Q-quadrature.
- The phase difference between PRX and PRY is determined by the Schnupp assymetry and should be 22° for RF45 and 4.5° for RF9. For the PRMI locking REFL RF phases are set up as an average between PRX and PRY configurations.
- Other checks can be made in PRX(Y) configuration:
  - the BS optical lever loop shapes
  - the BS suspension transfer function
  - the PRM suspension transfer function
  - the PRM M2/M3 crossover transfer function

#### PRMI locking

- The servo gains in PRMI configuration can be obtained from the PRX(Y) servo gain and Optickle modeling. At LLO the PRX cavity is locked with a servo gain of +/-10000 (side-band/carrier) to give a UGF of ~100 Hz. To get the same UGF in the PRMI configuration the PRCL servo gain is set to 1/500 of the PRX gain (+/-20 in sideband/carrier). The simple Michelson is locked on AS 45Q with a MICH servo gain of +/- 600 (dark/bright) and a UGF of ~8 Hz. To get the same MICH UGF in PRMI the scaling is ~1/20 so the MICH gain is 30.
- The actuation used in the PRMI configuration is: MICH to BS M2, PRCL to PRM M3/M2 and PR2 M3 (PR2 is only needed during the lock acquision transient).
- During the lock transient the PRM M3/M2 crossover is set to 0.4 Hz to avoid a strong suspension transient. The PRCL and MICH filter outputs are triggered when the PRC build up is ~3. Once lock is acquired, integrators are triggered for the PRCL and MICH loops with a delay of 0.5 sec. The PRM M2 gain is icreased by a factor of 10 and an integrator is enabled in this bank as well.

#### Scripts

Some temporary setup and locking scripts were generated, and can be made available upon request, but is expected to be replaced by an ISC Guardian in the future.