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SUBJECT: Documentation of Two-hour Lock Milestone for L1

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Refer to: LIGO-L1400119-v1

The L1 interferometer first achieved full locking on May 27, 2014 (LLO alog 12762). There have now been several lock stretches lasting more than 2 hours. L1 has thus reached the Advanced LIGO Project integration milestone of achieving a 2+ hour lock, with a functional strain readout. This memo serves to document this milestone.

Lock start definition. We define the start of a lock stretch as the point when control of CARM (common mode arm cavity) is transitioned to the reflection port RF error signal (REFL9I), with zero offset. This corresponds to all length degrees-of-freedom being at their operating point. There are a few transitions that may (and typically do) occur after this juncture:

- DARM readout is transitioned from RF to DC (using the output mode cleaner)
- Additional angular control loops are closed
- Laser input power is increased

Lock stretches. The table below lists the times of the L1 locks that were at least 2 hours long.

Date	Start time – stop time (UTC)	Duration	Notes
2014-07-23	07:59:09—11:01:00	3 hr 2m	1h 50m on DC readout
2014-07-15	03:18:43—05:32:52	2 hr 14m	1 ½ hrs at 4.7 W input
2014-06-30	07:32:30—09:47:15	2 hr 15m	1h 20m at 2.4 W input

Length controls. The table below summarizes the state of the length controls during the long locks.

DOF	Error signal	Feedback	Bandwidth
DARM	AS45Q (RF) or DC	Differential ETMs	50 Hz
CARM	REFL9I (in-vac)	Laser frequency	10 kHz
MICH	POP45Q (in-vac)	Beamsplitter	10 Hz
PRCL	POP9I (in-vac)	PRM	100 Hz
SRCL	POP: 9I & 45I (in-vac)	SRM	50 Hz

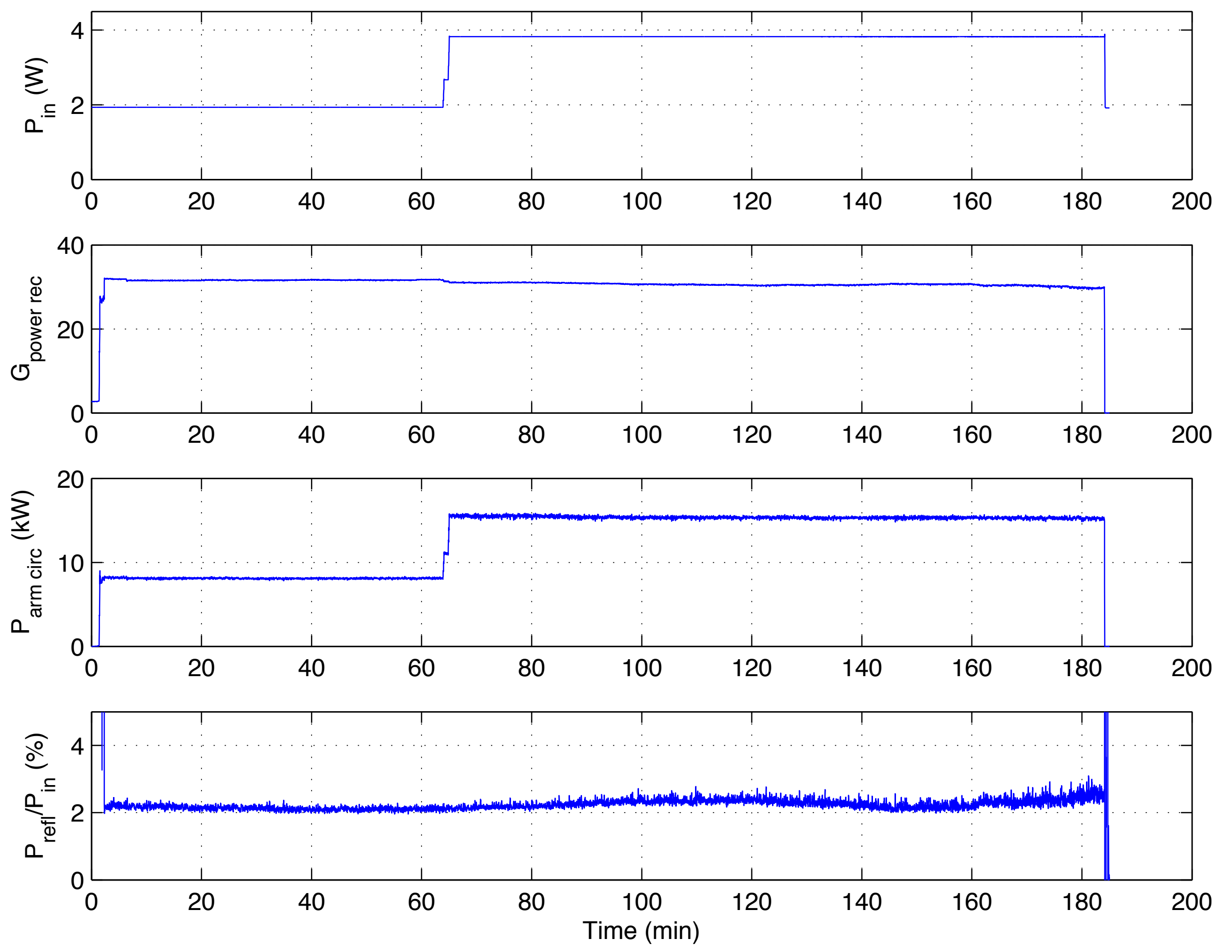

Figure 1 Power levels for the 3 hour lock on 23-July-2014. Top: input power to the input mode cleaner. Second: power recycling gain. Third: arm cavity power. Bottom: reflected power, as fraction of input power. The input power was intentionally increased at the 65 minute mark.

Alignment controls. The table below summarizes the state of the angular controls during the long locks.

DOF	Error signal (WFS)	Feedback	Bandwidth
Diff Hard	AS45Q	Differential ETMs	3 Hz
Common Hard	REFL_A_45I	Common ETMs	1 Hz
MICH	AS_B_36Q	Beamsplitter	1 Hz
PRC	REFL_A_9I	PRM	0.1 Hz
PRC	REFL: A_9I & B_9I	PR2	0.1 Hz
SRC	AS_B_36I	SRM	0.1 Hz

Strain readout. The strain readout can come from either the AS port RF detector (in-air, detecting a few percent of the AS port light), or the OMC output detectors (DC readout). The latter is of course more sensitive at frequencies where shot noise is dominant. The DARM feedback loop, and thus the strain readout, is run on the RF detector at the beginning of a lock stretch, and is typically transitioned to DC readout after several minutes.

For DC readout, the DARM offset is typically ~10 pm, giving a couple of milliamps of total OMC transmission photodiode current. The OMC length is dither locked, with a dither frequency of several kHz. The OMC alignment is also controlled with dither sensing, using the tip-tilt output mirrors.

The strain readout is calibrated by first measuring the electrostatic driver (ESD) response in the state where the arm cavities are controlled with the arm length stabilization (ALS) system. The calibrated voltage controlled oscillator in the differential ALS signal chain provides the reference for the ESD calibration. The calibrated DARM signal is obtained by combining in the time domain the DARM control signal and the DARM error signal. The former is calibrated using the ESD calibration; the error signal is corrected for the coupled cavity response, and scaled to match the control signal at the measured DARM open loop unity gain frequency. We estimate the calibration uncertainty is no better than 30%. The plot below (red curve) shows the DARM calibrated spectrum from the 2014-07-23 lock, from LLO alog entry 13708.