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SUBJECT: Documentation of Two-hour Lock Milestone for H1

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Refer to: LIGO-L1500028-v1

The H1 interferometer first achieved full locking on February 7, 2015 (LHO alog 16544). There have now been several lock stretches lasting more than 2 hours. H1 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 H1 locks that were at least 2 hours long.

Date	Start time – stop time (UTC)	Duration	Notes
2015-02-09	12:25:00—14:50:00	2 hr 25m	DARM on RF
2015-02-11	00:00:00—03:05:00	3 hr5m	1 hr on DC readout
2015-02-12	05:10:00—07:48:00	2 hr 38m	2h 15m on DC readout
2015-02-13	06:10:00—09:25:00	3 hr 15m	2 hrs at 8W 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	ETMX	20-30 Hz
CARM	REFL9I (in-air)	Laser frequency	10 kHz
MICH	POP45Q (in-vac)	Beamsplitter	10 Hz
PRCL	POP9I (in-vac)	PRM	80 Hz
SRCL	POP: 9I & 45I (in-vac)	SRM	35 Hz

Power levels. Here are the typical power levels in the interferometer.

Input power to IMC	2.8 W typ.; has been operated at 8 W
Recycling gain	33-35
Reflected power	< 2% of input power
Arm buildup, relative to single arm	1000-1100x
Contrast defect	150 ppm

Alignment controls. For the long locks listed above, minimal alignment controls were in use. An AS port WFS (45 MHz, Q signal) fed back differentially to the ETMs, with a bandwidth of 150 mHz. Another AS port WFS (36 MHz, Q signal) was used at times to control the BS, but further work is needed to make this robust. Recently the common ETM alignment has been controlled using REFL WFS signals, with low bandwidth (tens of mHz).

Update: There was additional progress on alignment controls just at the end of February:

- Differential ETM control for pitch increased to a 3 Hz bandwidth
- IM4 (input beam) controlled with low bandwidth using REFL WFS
- PR2 pitch controlled with low bandwidth using REFL WFS
- SRM pitch controlled with low bandwidth using AS36I WFS
- BS pitch and yaw controlled with >1 Hz bandwidth using AS36Q WFS

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 tens 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.

Calibration of the strain readout is still in progress. The free-swinging Michelson and the photon calibrator have both been used for calibration, and differences between them are being investigated. We estimate the calibration uncertainty is no better than 40%. The plot below shows the DARM calibrated spectrum from the 2015-02-26 lock, from LHO alog entry 16982.