*LIGO Laboratory / LIGO Scientific Collaboration*

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# Commissioning Advanced LIGO's HIFO-Y

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# 1 Introduction

The third major commissioning phase at the LIGO Hanford Observatory is the integration of a single arm cavity with the ALS system in the corner. This is a logical step after first commissioning a single arm cavity by injecting a green laser from the end stations, see T1100080, and after secondly commissioning the PSL and input mode cleaner. Integration testing of HIFO-Y (half interferometer Y-arm) is scheduled to start in April 2013. This document describes the ingredients, testing plans, and goals of this testing phase.

# 2 Motivation & Context

An interferometer must acquire lock reliably and robustly before serious strain sensitivity investigations can begin. The Advanced LIGO lock acquisition strategy is significantly different than in initial LIGO, and it was designed to improve upon the reliability and robustness of the earlier scheme. This acquisition strategy is described in T1000294, *Lock acquisition study for Advanced LIGO.* A new feature that is a significant part of this strategy is the Arm Length Stabilization (ALS) system, which is described in T0900144. The ALS is designed to provide independent control of each arm cavity length. Given that it is a new system in Advanced LIGO and that it is critical to achieving full lock, it is highly desirable to implement and test the ALS as early as possible. The ALS commissioning has been split into three phases: H2OAT (completed), HIFO-Y (current phase), and HIFO-X (next phase).

There are two main objectives of the HIFO-Y integration phase:

1. Attaining and verifying the performance of the ALS corner recombination using a single arm cavity, at the level required to support full interferometer lock acquisition.
2. Achieve full automation of the process.

These, and other secondary objectives, are discussed later in Section 4.

# 3 Components of the arm cavity integration phase

The HIFO-Y integration phase uses the same H2 end station equipment installed for OAT. In the corner we are using H1 hardware including an ITMY isolation system which has been moved from H2 to H1. The other equipment in the corner station required for this phase is:

1. The PSL
2. The input mode cleaner
3. The suspended beam path from the input mode cleaner to the ITMY, including the 3 power recycling mirrors and the BS, and the associated optical levers
4. The POP/ALS beam path from HAM3 to HAM1, POP
5. Optionally, the in-air REFL beam path
6. The ALS optics on the PSL table including the beam path to ISCT1
7. The SHG (second harmonic generator) and green locking photodiodes on ISCT1
8. The ISC electronics associated with the corner ALS.

# 4 HIFO-Y Objectives

As noted earlier, there are two main objectives of the HIFO-Y integration phase:

1. Attaining and verifying the performance of the ALS corner recombination using a single arm cavity, at the level required to support full interferometer lock acquisition.
2. Achieve full automation of the process.

These objectives, as well as various secondary objectives, are further discussed below. First we present noise estimates for the arm cavity.

## 4.1 ALS test objectives

The full ALS system has four main control loops:

1. Lock of ALS laser 532 nm beam to Arm Cavity (at each end)
2. Phase/frequency lock of ALS laser to PSL light (at each end)
3. Arm differential mode suppression: feedback to the arm cavity length differential mode, based on vertex heterodyning of X- and Y-arm ALS beams
4. Common mode feedback: feedback to the PSL frequency via the common mode servo, based on vertex heterodyning of X-arm (or Y) and PSL beams

The H2OAT has fully tested (1) and (2). The HIFO-Y is testing (4), whereas the HIFO-X will test (3). For HIFO-Y we have the following specific design issues that the testing should inform:

- Is our SHG fully functional, and does it operate stably and robustly?
- Does the interference between the green beams from the end station and PSL yield an adequate error signal which can be used to offset lock the laser frequency to the arm cavity?
- Are the red and green cavity locking points sufficiently stable relative to each other?
- How do we calibrate the frequency offset between the red and green locking points, and how stable is this offset?
- Comparison of alignment fluctuation data obtained in HIFO-Y using the TransMon IR QPDs, and the data obtained in OAT using 532 nm wave front sensors.
- What's the effect of pointing fluctuations on the offset locking?
- Do we have adequate information available in the slow controls system to fully automate the locking procedure?
- For SEI+SUS the OAT data resulted in a discrepancy between the cavity motion as measured by the cavity control signal, and the predicted cavity motion using the ISI data and the Quad SUS model—like a factor of 4 difference at the lowest Quad mode (0.45 Hz), where they really should match up pretty well (not dominated by frequency noise).

## 4.2 End Station Improvements

The H2 OAT test concluded with a couple of recommendations which are listed in T1200261. The one most relevant to HIFO-Y is improvements in automation, see E1200908. Part of the HIFO-Y commissioning phase will be to test and evaluate these improvements. In particular, we are interested in

- Quantifying the stability improvements of the light launched by the fiber from the PSL
- Implementing a robust automation scheme for the green laser locking.

# 5 Intermediate and Quantitative Test Goals

The table below lists some intermediate and quantitative goals that will be used to gauge progress and guide how the objectives mentioned above are evaluated.

| **Category/Subsystems** | **Goal** |
|---|---|
| SHG | Long term stability of the emitted green light at the 5% level |
| Cavity locking/ISC | Fully automated cavity locking using the improved hardware in the end |
| Controls/ALS | Locking the PSL laser frequency to the arm cavity and achieve 10 Hz relative stability over 10 minutes |
| TransMon/ISC | Calibration of IR QPDs for the cavity alignment at 10% level |
| TransMon/ISC | Use red Trans QPD to characterize the red cavity power and show resolution of 1% of full cavity power |
| ALS | Ability to control frequency offset between 1064 nm and 532 nm resonances at the 10 Hz level |
| ALS | Relative stability of the 1064 nm and 532 nm resonances at the 10 Hz level for frequencies below 0.5 Hz |
| Cavity alignment fluctuations / SEI/SUS | Characterize the effect of pointing fluctuations onto the locking offset and demonstrate less than 10 Hz rms over 10 minutes |
| Cavity length fluctuations /SEI/SUS | Agreement between modeled and measured length fluctuations, around the lowest quad suspension modes, to better than a factor of 2 |
| Controls / ISC | Fully automated ALS locking sequence; long term robustness |
| Optical levers | Optical lever long term drift below 1 µrad |