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# Proposed changes for the Advanced LIGO Output Mode Cleaner

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# 1 Introduction

The Advanced LIGO Output Mode Cleaner enables DC readout of the differential arm error signal. DC readout was a central component of the Enhanced LIGO program, enabling extended prototyping and commissioning of low noise DC readout. Although the Enhanced LIGO Output Mode Cleaner performs as designed, there are a few points where design changes may improve performance and usability.

DC readout, also known as homodyne detection, uses carrier light at the anti-symmetric (AS) port as the local oscillator against which the signal sidebands interfere. In contrast to RF heterodyne detection for which the photodiode signals occur at RF frequencies, in DC homodyne detection the photodiode signals occur directly at the signal frequency. For Advanced LIGO, this requires shot noise limited detection of the carrier light from a differential arm offset across the entire signal frequency range from 10 Hz to 10 kHz. The OMC spatially and chromatically filters the AS port light so that only differential arm signals fall on the photodiode.

The OMC consists of a suspended, semi-monolithic four mirror bow tie cavity with round trip length of approximately 1 meter. Figure 1 shows the as-built optical layout for the H1 Enhanced LIGO OMC. The basic design will remain unchanged: two QPDs determine the input alignment, four mirrors define the filter cavity, two actuators (one fast PZT, one slow thermal transducer) match the cavity length to the carrier frequency, and two DC photodiodes detect the mode cleaner transmitted light.

The following section will enumerate the proposed changes.

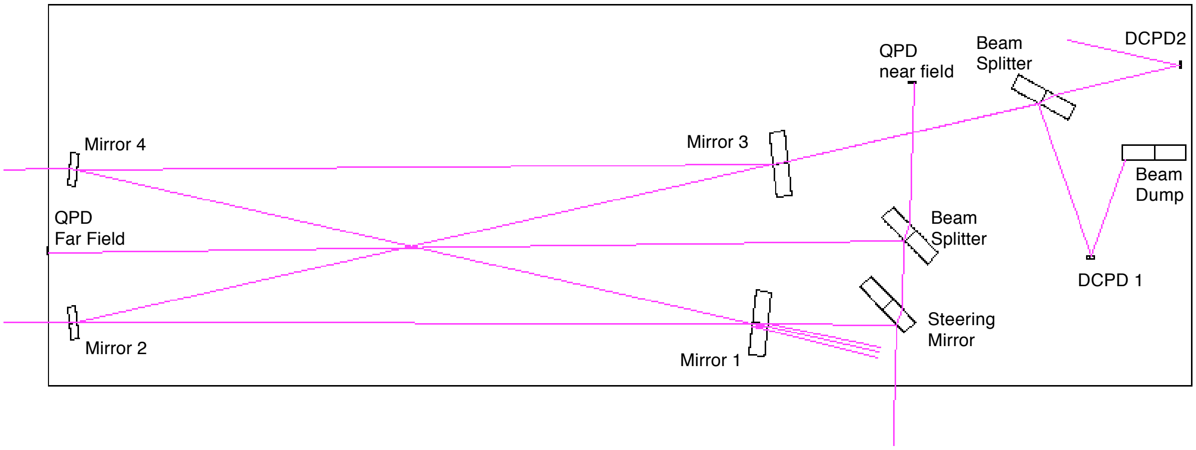

Figure 1: As built optical layout for the H1 output mode cleaner.

# 2 Proposed changes

## 2.1 Monolithic tombstones

The eLIGO OMC uses standard REO 1 inch optics bonded to custom designed fused silica "tombstones". The advantages of this scheme, parallel procurement and well understood tolerances, are outweighed by the disadvantages, difficult tombstone manufacturing, restricted access to optic surfaces, and tight spatial constraints. For the advLIGO OMC we will procure custom tombstones for all of the fixed optics consisting of optical quality fused silica prisms with coatings applied directly to the prism surfaces.

## 2.2 Fused silica breadboard

The eLIGO OMC optics base plate, also known as the breadboard, was constructed of Zerodur in order to minimize the effect of thermal drifts in HAM6 and from the heat of the electronics and thermal length actuator. In practice, thermal drifts have not been a problem and the manufacturing in Zerodur was more difficult than anticipated. Future breadboards will be manufactured out of fused silica (not optical quality) for which the thermal properties are practically equivalent and the manufacturing better understood.

## 2.3 Increase payload weight

Fully loaded, the eLIGO OMC weighs 6.9 kg (higher than the intended 6 kg). We consider 7 kg the baseline mass for the advLIGO OMC.

## 2.4 Improving the length actuation

The fast PZT and slow thermal actuator combined to provide an adequate dither error signal, high bandwidth control loops, and long actuation range. We will retain the two actuator design for advLIGO. However, both actuators were designed with the mirror high reflector surface as the bonded surface recessed behind a small aperture. This aperture caused two problems: it was the limiting aperture in the OMC, potentially causing clipping, and it made access to the mirror surface for cleaning difficult.

Consequently, for advLIGO we will bond the optics to their back surface with the high reflector as an unobstructed front surface. We will continue to extract the beams through the high reflectors for diagnostic purposes. For the PZT actuator, this design change is mainly an issue of tolerances: can the PZT mounted mirror be aligned in pitch taking into account the wedge in the substrate?

In addition to the small aperture, the eLIGO thermal actuator introduced a pointing into the OMC that should be eliminated. The actuator also had an inadequate temperature read back that a) introduced an additional time constant and b) was sensitive to pick up from the PZT drive signal. For advLIGO, a full redesign of the thermal actuator will be required.

### 2.5 AFWFS alignment

The Audio Frequency Wave Front Sensors (AFWFS) allow readout of the OMC cavity alignment without large angular dither lines. The AFWFS alignment scheme will be the baseline advLIGO alignment, allowing a reduction in the high frequency modulation requirements for the tip/tilt suspensions. However, we should retain the capability for low frequency dither alignments, and the co-located QPDs will definitely be maintained. Because of the alignment requirements of the AFWFS diodes, Pico motors will be included in the AFWFS path.

### 2.6 Analog mod / demod

The eLIGO OMC senses length offsets using a 10 to 12 kHz dither on the OMC PZT and demodulation of the DCPD signals. The high frequency dither was difficult to produce digitally and introduced noise via the digital-to-analog conversion process. The advLIGO OMC will use an analog sine-wave synthesizer and demodulator (a.k.a. lock-in amplifier) for the OMC length error signal. Note that this requires demodulators for the AFWFS as well.

### 2.7 16 kHz front end clock

The eLIGO front ends run at 32 kHz (30 microseconds). This high speed is motivated by the high frequency digital demodulation which will be deprecated for advLIGO. Furthermore, the 30 microsecond timing is restrictive. Consequently, we will run the advLIGO front ends at 16 kHz (60 microseconds).

### 2.8 Other electronics changes

The electronics changes are minor. The advLIGO OMC will incorporate independent switching of the DCPD whitening and trans-impedance. Pending a full noise analysis, the high frequency roll off of the DCPDs will be extended from 16 kHz to a 100 kHz (or higher) to allow high frequency modulations and observations of the test mass internal modes. Before advLIGO, the DCPDs will be tested at the required shot noise limited sensitivity in a bench top experiment.

### 2.9 Scattered Light Control

The eLIGO OMC doesn't include very many beam dumps and baffles. The advLIGO OMC design will include AR coated black glass beam dumps wherever appropriate, particularly in front of the DC photodiodes.

### 2.10 Construction Fixtures

Both the H1 and L1 eLIGO OMC builds were more dramatic than necessary. In both cases, the problems arose because of inadequate fixtures during the epoxy process. The advLIGO fixtures should positively position the tombstones with 3-axis control (x, z, and yaw). Ideally all tombstones will be fixtured. This will require some design since the clearances are tight. All four OMC mirrors should be held simultaneously during bonding.

### 2.11 Varying G-factor

The H1 eLIGO OMC changes the mode spacing as a function of the thermal actuator temperature. This is believed to be caused by a 7 mm radius of curvature change on the 2 m radius of curvature mirror bonded to the thermal actuator. This "bug" may be considered a "feature" – the temperature dependence was used to change the OMC g-factor *in situ* and minimize the noise. If this feature is incorporated into the advLIGO OMC , it should be explicitly modelled and deliberately designed. Otherwise the new thermal actuator design should take pains to leave the cavity g-factor unaffected.

### 2.12 DCPD path lengths

The eLIGO OMC has unequal path length between the two DCPDs. If possible, this situation will be avoided for advLIGO.

## 3 Conclusion

Although the list of changes in OMC design for advLIGO seems long, the OMC has been a successful part of the eLIGO program. The changes are, on the whole, modest and should be easy to implement.