



LIGO Laboratory / LIGO Scientific Collaboration

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Advanced LIGO / A+

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**Review Report
Preliminary ISC Design
for the A+ Filter Cavity**

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1 Executive Summary

The committee finds the preliminary design for the inclusion of a filter cavity in Advanced LIGO adequate and sufficiently complete to start the procurement of optical and electronics components. This excludes the in-air optics tables, since we believe they require a final review. A number of caveats are listed the following sections.

Verifying the active mode matching solution and checking beam propagation parameters has been addressed by Aidan in [M1900177](#).

1.1 Findings

All major concerns from the design requirement review have been addressed to the satisfaction of the committee, see also [G1902267](#).

The filter cavity sensing requires the sensing noise to be low enough not to add back scatter noise. A test with a higher power CLF has been performed during the October 2019 commissioning break. This revealed additional noise that isn't related to intensity noise. This has been identifies as one of the major risk in the A+ ISC design. We consider it only partially retired.

1.2 Actions

1.2.1 Specifications of Filter Cavity Mirror Coatings

Bring up the filter cavity mirror coatings for review in a timely manner, so the manufacturing of the FC mirrors can proceed.

1.2.2 Faraday Isolation

Add another polarizer in between the two Faraday isolators on the OPO platform to maintain the isolation ratio.

1.2.3 In Vacuum QPDs in Transmission of the Filter Cavity

Move these QPDs to the in-air table.

1.2.4 Length sensing of Filter Cavity

Add a dedicated length sensor in parallel to the two existing QPDs. This will greatly reduce the requirement on the QPDs.

1.3 Recommendations

Additional questions and comments can be found at the end of the document.

1.3.1 Transmission Optical Table

Try to avoid optical tables at beam height, since they will require extra work safety. Try to use an optic table of either 8'x4' or 5'x3', since it simplifies the design and the procurement of the enclosure.

1.3.2 Inspection Beam

Work out the details of the inspection beam. Relying on the misalignment of ZM1 might be tight and a beam diverter may prove superior.

1.3.3 Filter Cavity Sensing

The green sensing of the filter cavity suffers from potential differences between the IR and green resonance condition as well as from fiber noise that is added independently between the green pump light of the OPO and the green beam used for sensing the filter cavity length. Consider a way to interfere samples of these two beams, so fiber noise could be suppressed. This would add more flexibility in designing the final sensing scheme in case that the current one runs into problems.

2 Technical Scope

2.1 Scope

The scope of this report is to review the preliminary ISC design of the A+ filter cavity, described in in [T1900416](#) and supporting documents.

Supporting documents are located in [E1900221](#):

- Preliminary ISC design: [T1900416](#)
- In air & vacuum complete optical layout: [D1900281](#)
- Controls block diagram: [E1900201](#)

The full scope of A+ ISC also includes additional sub-subsystems for adaptive wavefront compensation (AWC), low-loss Faraday isolators (FI), and the balanced homodyne readout (BHD) as well as the integrated electronic controls infrastructure (ISC CDS). These elements will be reviewed separately in future.

2.2 Charge to the Review Committee

1) Please refer to the check list of general LIGO review criteria in section 11.3 of [LIGO-M1500263](#); additional guidance specific to A+ Project design reviews can be found in [LIGO-M1800239](#).

2) Evaluate the PRD [T1900416](#) to insure that it captures all relevant criteria for success. These should include such factors as:

- Clarity of presentation and operating context
- Compatibility with the planned A+ optical and mechanical configuration
- How the action items of the DRD review were addressed
- Compatibility with existing Advanced LIGO infrastructure
- Provisions for installation, testing, commissioning and future maintenance

3) Please investigate and comment on the degree to which requirements for the filter cavity and relay optics may depend on uncertain or optional features of these related components. Identify what provisions, if any, may be required to insure that the designs can proceed independently without risk of incompatibility.

4) Summarize comments and recommendations in a report addressed to Dennis Coyne (LIGO Chief Engineer) and Michael Zucker (A+ Project Lead). Any panel requests for action should be clearly categorized as follows:

- Required change: Panel approval is conditional on implementation.
- Recommendation: Panel advises but does not require adoption.
- Comment/Suggestion: Panel requests the design team investigate and consider, e.g., a potential improvement, or wishes to convey other helpful information.

3 Review Comments and Questions

Here is a collection of questions and answers which were investigated during the review process.

1. **DS:** The main uncertainty is still the sensing scheme and its phase noise requirements. A higher power CLF test has been performed as part of the commissioning break in O3, but did not succeed. Even with intensity stabilization of both the green pump and the CLF beam, we have seen excess noise in the OMC DCPD, which limited the amount of squeezing available. We also saw temporary range drops which were due to the high power CLF. Do we need to plan for an extra Faraday isolator? Where in the beam path could this be installed?
2. **DS:** Well, let's not repeat the BSC numbering debacle, and name the optics tables catching beams from HAM7 and HAM8 SQZT7 and SQZT8, respectively. The 3rd table can be called SQZT0 or whatever.
3. **DS:** We have two QPDs sampling the beam reflected from the filter cavity. The sum can be used for length sensing. We should consider adding a proper length sensor, so we are not sensitive to jitter or differences in the segments. This will also reduce the requirements for the QPDs.
4. **DS:** As discussed, the HAM8 TransMon do not need to be in vacuum. There are 2 QPDs shown in near and far field, however, only the beam position on the FC end mirror is probably required. The beam angle may not be needed.
5. **DS:** Two cameras are shown looking at the face of the filter cavity mirror. As shown, the camera angle is rather steep (assuming we use the top window?) and may not see the beam on the mirror, since it is obscured by the baffle?
6. **DS:** SQZT8 is labeled as 2'x3'. Is there a space and size restriction near HAM8? If not, using an existing design like 3'x5' seems simpler. In fact, we have extra 4'x8' tables from H2, which we could use. Since SQZT7 also seems on the small side for what's on it, why not use an existing 4'x8' table as SQZT7 (beams coming in from the side, and use the now available 3'x5' table as SQZT8)?
7. **DS:** Having an optics table at beam height will require a working platform around it for access. This seems more complicated than just using periscopes.
8. **DS:** The sketch of SQZT7 seems to indicate that there are 2 beams going down the same periscope mirrors. Is this really necessary? Can we use the double periscopes instead?
9. **DS:** At least one of the drawings shows an SQZ inspection/insertion beam. Others don't. This beam is only available when ZM1 is misaligned. It measured the light from the interferometer after 3 Faraday isolators + the squeezed beam going towards the filter cavity.
 - A. It isn't clear where this beam goes on SQZT7?

- B. The listed deflection angle seems to be 3.5 mrad which gives about 10mm position change at the ZM2. This seems too small? Would a beam diverter be more useful?
- C. The steering optics in HAM7 for this beam seems to use 1” optics. We should use 2” optics at least down streams of the first pick-off mirror. If the lens can be changed to 600mm, there may be iLIGO stock available.

10. DS: I was trying to figure out the spec for the TFP in the squeezer Faradays. In the proposed design there is only one TFP between SFI2 and SFI1. Doesn't this mean the extinction ratio needs to be better than the combined isolation ratio of both Faradays? Isn't this (nearly) impossible?

Light coming from the ifo towards SFI2 will be in s-polarization. It will also be mostly in s-polarization, when it leaves the Faraday. This means A:SFI1TFP (in T1900649) is responsible to dump it all in reflection. Any remaining p-polarization will go through the TFP and will be further rejected by SFI1. However, any s-pol light, which isn't rejected by the TFP and passes through it, will be in the same polarization as the squeezer light and will pass through SFI1 with >99%.

I could only find C1900349 which projects 50dB for the better of the two designs. The extinction ratio for the ones we use for the PSL power adjustment are only 40dB.
 LM: Yes, I think you are right about this. That single TFP coupling arose during the VOPO platform design to simplify it and attempt to reduce loss. I must not have been considering the extinction ratio properly.

In this case, it should be fixed if an additional wedge or TFP polarizer is included between SFI2 and SFI1TFP? My understanding is that the wedges have quite good extinction (better than the TFPs at least). It's another adjustment potentially in the SFI2 mechanics, but relatively minor for the optical layout.

11. DS: The fourth port of B:BS1 is blocked by a beam dump. Adding a photodiode there would allow us to measure the power of the beam coming from the ifo and in effect extinction ratio of the OFI.

The fourth port of A:SFITFP (or a similar polarizer, if another one is added) catches the beam from the AS port when lock is lost. We have seen black glass damage in the AS_C path, so one might consider a beam block here that is not black glass.

12. DS: The beam path for the sample beam to lock and align the filter cavity seems to use 1” steering optics? What are we saving here? Why not just use 2” optics, at least for the turning mirrors?

13. DS: The HAM8 drawings seems to indicate the use of 1” optics in vacuum!?! This seems like a bad idea. We should use 2” minimum.

14. DS: The initial alignment seems to start at step 2. How are FC1 and FC2 placed and oriented in the first place? Also, there is no mention of ZM4-6?

15. VF: The ZM6 AOI appears to be >45deg – how much can the beam spot on ZM6 move (in yaw) before clipping on the suspension frame?

16. VF: There are two fixed steering mirrors in the OFI SQZ path in D1900281 – Why two mirrors are needed? Shouldn't ZM6 + one fixed mirror (turned towards ZM6 opposite to what is shown) be sufficient?
17. VF: For the initial alignment of the input beam to FC the beam can be propagated in LVEA in air over some tens of meters, with a section of the FC vacuum tube removed, to center within a few mm on the tube aperture to provide a few cm centering on FC2.
18. VF: The requirement for the IFO to OMC mode matching for A+ is >96% the same as OPO to FC and FC to IFO. The A+ design requirement T1800480 calls for two SAMs for (each) OMC. How will IFO->OMC mode matching be achieved for O4 without SAMs?
19. KA: (RLF generation) I believe AOM2/3 are used in single-path configuration. Is the effect of the different deflection angles for CLF and RLF minimal and negligible? Are the modes cleaned by the fiber? Don't we want to swap AOM2 and AOM3 to minimize spurious effects?
20. SD: In Figure 8+9 of T1900649, I'm having trouble understanding the legend or matching that with the text description. I'm cc'ing the rest of the review committee in case they run into the same confusion. I think the solid blue line shows the beam parameters for the lens at the center of the translation stage as the ROC of ZM2 changes. After that I'm not sure about the blue +s, the blue x might be the nominal beam, and I'm not seeing the dashed blue line or the dots.

LM: I agree those plots are confusing but I haven't figured out a better scheme yet. For fig 8, yes the solid blue line is the ZM2 actuation while A:L2 is centered in the stage. The thick side is adding diopters (making lens concave) and thin is removing (pushing lens convex). The dashed line is hidden amongst the center "+" symbols, but is sitting along the line where the thick and thin solid lines touch (the zero point of ZM2 AWC).

The "x" is in this plot the nominal beam for the FC parameter on the HR surface of FC1, and the "+" are propagating to it through the adjustable elements.

The dots are only present in the right LG1 plots giving the relative mismatch. The LG1 space is coordinate invariant, and so is preferable for relating the AWC degeneracy and strength to the Gouy phase and beam sizes between the actuators. In that space, the parameters can be related to the matching in other places along the beam path. For instance, making this plot along ZM2->ZM3 path, where one might use a profiler in-chamber, will change the left plots, but the right plots will show where a beam parameter measurement lands w.r.t the actuators or variations from many of these plots.

Since the lens stage is a bit of an unusual actuator, Figs 12-14 are perhaps more relatable to Aidan's AWC requirements document. For that beam path, you can also directly see his calculations in [M1900177](#) which may be more relatable than my plots. In any case, that RODA indicates that the layout is reasonably low-risk from an AWC design perspective.