Enhanced LIGO TCS Review

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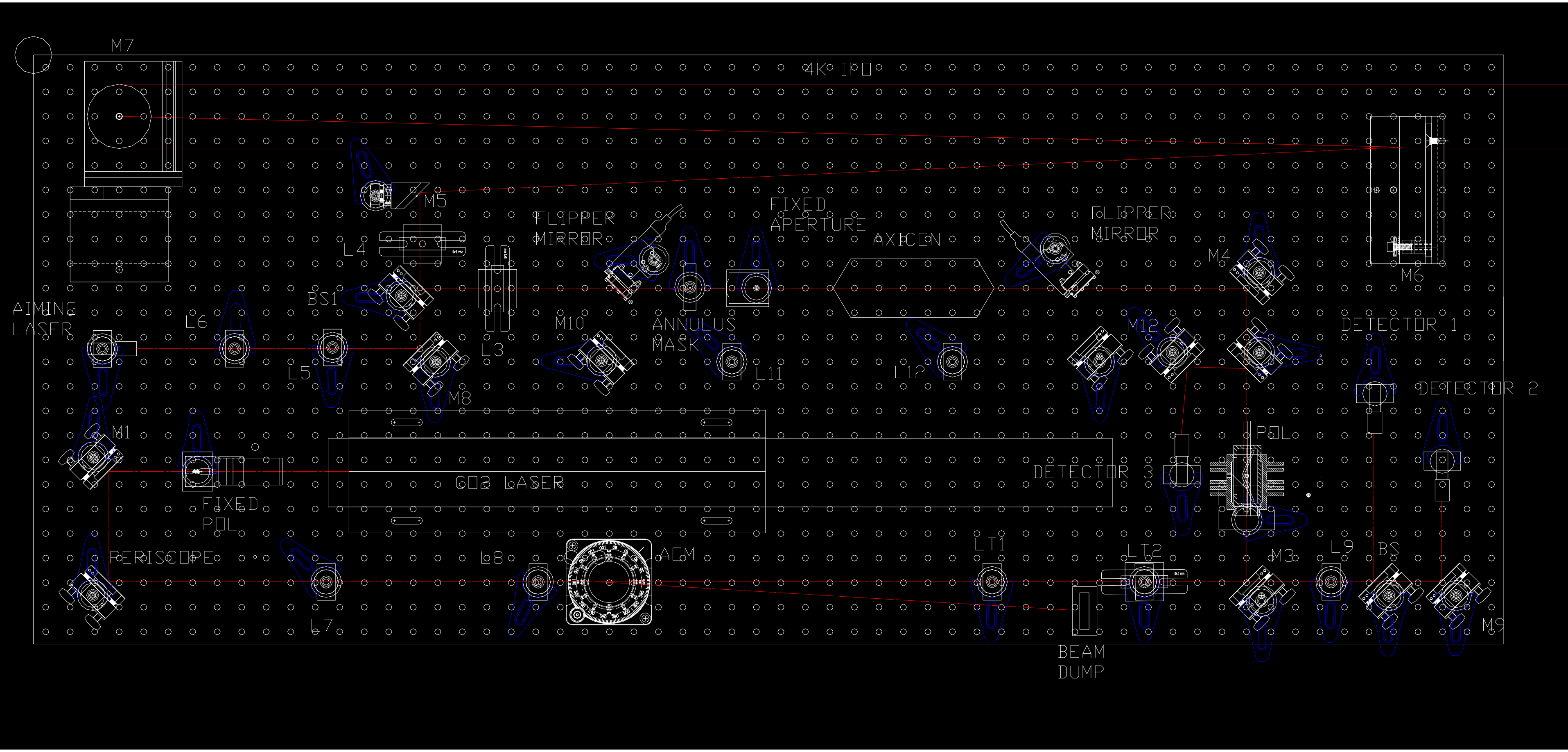
Elements of TCS Upgrade

- Higher heating power (pp. 4-8)
- More efficient optical power delivery (axicons) (p. 23-25)
  - » Modified table layout (p. 3)
- Power stabilization using AOMs (pp. 9-16)
- Power output level adjust using rotating polarizers
- Better, quieter chillers (p. 21-22)
- Modified differential mode control
  - » Initial LIGO AS_I error signal our starting point, but DC readout and output mode cleaner may call for different approach.

Enhanced LIGO TCS Layout



- Design recycles most of the existing TCS table hardware.
- Precise lens powers and locations and design of mask (if any) are still TBD.
- Optics for axicon alignment beam not shown, may be done off table.
- Flipper mirrors redirect beam around axicons for central heating.

ITM Absorption Will Likely Be High

- Values measured at end of S5:
  - » H1 ITMX: 6.8 ppm
  - » H1 ITMY: 5.4 ppm
  - » L1 ITMX: 2.3 ppm
  - » L1 ITMY: 3.4 ppm
- ITMs have been drag-wiped and should absorb less now, but Enhanced LIGO TCS design is not assuming this. Assuming 75 kW arm power, and 10x more annular power than absorbed power, Enhanced LIGO will need:
  - » H1 ITMX: 5.1 W
  - » H1 ITMY: 4.1 W
  - » L1 ITMX: 1.7 W
  - » L1 ITMY: 2.6 W

Higher Power Lasers Required

- Current Merit-S 8W lasers might be enough if the drag wipe worked well, but would have no power margin.
- We have chosen the Synrad 48-2
  - >25 W CW operation, ample power
  - Adequate mode profile
  - Water-cooled
  - $8,000
  - Well characterized
- Access Laser Co. recently introduced the LASY-20
  - 20 W CW operation
  - $16,000
  - Virgo has chosen this model for their TCS, their experience might inform AdLIGO design, but too late for Enhanced LIGO.
  - They have not taken delivery of this laser yet, so we know little about it.

Reviewers’ Laser Comments

- “If the laser is CW, does it make sense to operate it at a power level close to the operating point, so the polarizer may induce less power dependent deviation?”
  - » Yes. The laser operates CW only at full power, but the AOM can divert a large, unneeded fraction to a beam dump, sparing the downbeam optics. The pickoff mirror transmissivity to the ISS PD should then be chosen for optimal through power at this incident level.
- “Are the currently installed polarizers able to withstand higher powers?”
  - » The PHB-7 polarizer by OFR can handle 1 kW CW.
- “The old polarizer/beam dumps should go away- update to the LHO high power TCS design or similar: polarizer secured by a clamp, beam dump separate from rotator.”
  - » Will do.

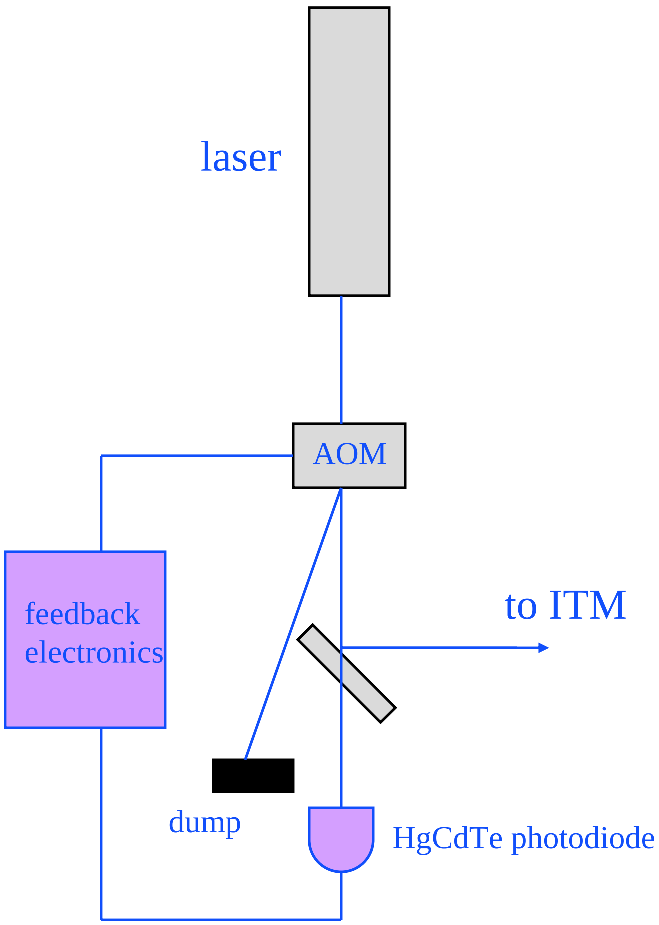
Reviewers' Laser Comments

- "What could be the expected power requirement for the Advanced LIGO TCS CO_2 laser?"
  - » From the AdLIGO TCS CDD, we expect nominally to deliver 6W to the compensation plate, but plan for 2x power margin. Given 89% throughput for axicons, ~80% for AOM, 99% per lens, etc, 25W is better than 20W (our Synrad delivers 35W).
- "Has the Synrad 48-2 been tested anywhere else?"
  - » Yes, at LHO.
  - » It converts DC to RF internally- ask Rob Schofield about PEM issues for this laser
  - » LHO used a Sorensen power supply, not the Synrad supply
  - » Plumbing lines had to be gently curved to minimize what looked like a turbulence-related noise problem (but see ISS slide to follow).
- The Access Laser may be the better option on account of prior experience in LIGO unless the Synrad has some desirable qualities that Access Laser does not have."
  - » Agreed. When we first looked for more powerful lasers the Access LASY-20 was not in production, so we bought a Synrad. Right now we have more experience with the Synrad than the LASY-20.

Reviewers' Laser Comments

- "What was the ratio of annular power to absorbed power in initial LIGO?"
  - » We don't know, really. The 10x assumption derives from Stefan's analysis that central heating is 9.6x more efficient per Watt in producing thermal lens (p. 53 of his thesis).
- "What is a reasonable estimate of TCS power required, as opposed to the overestimate used here?"
  - » Hard to say. Drag wiping H1 ITMY in the past reduced absorption to 3.5 mW/W on MC. This is about 1/3 what we have now. Will the optic stay clean this time?
- "Any experience/expectation with the real world level back scattering from polarizer/axicon/mask/whatever?"
  - » No backscattering problem seen so far with this laser, but our layout is simple.
- "In LHO quite often the lasing peak width is 0.1 C, which is a pain to maintain."
  - » With our laser and lab's Polyscience chiller, operation was stable within 1 C or so if chiller was kept full. We see some temperature sensitivity, but our lab temperature swings a lot (at least 6 C). This needs more study.

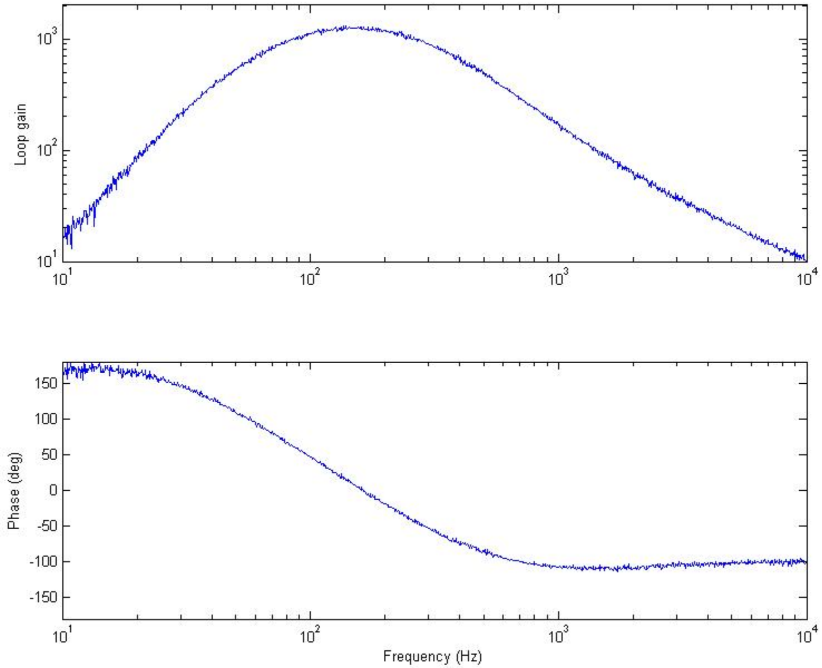
Intensity Stabilization

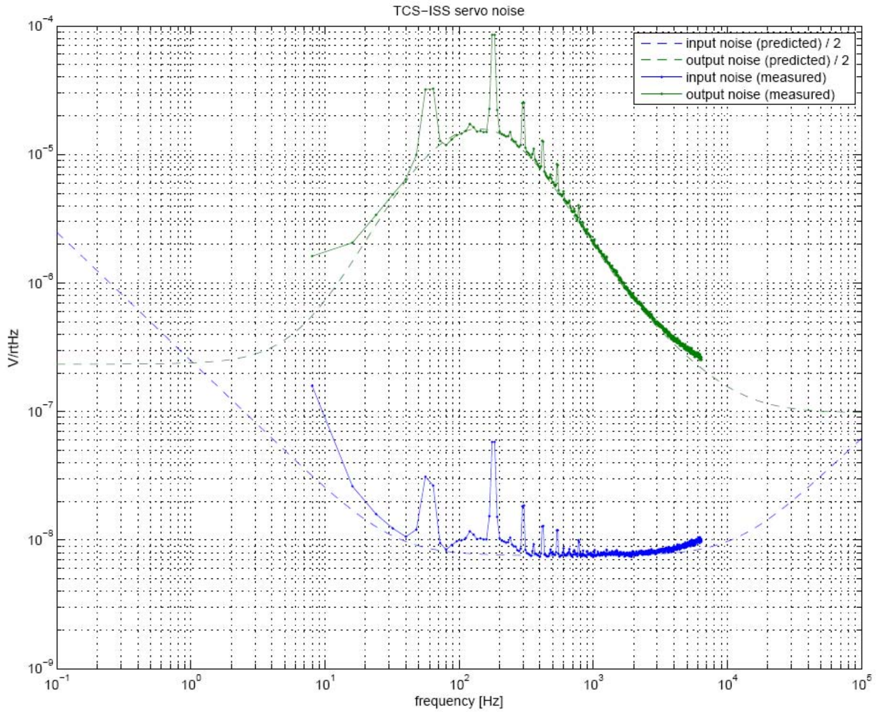


- Free running laser noise would inject too much noise at Enhanced LIGO power levels (see LIGO-T070224-01-D)
- Stabilization uses AOM to control undeflected beam power within LIGO band.
- Coarse power adjust to ITM then made using rotating polarizer
- Constant power through AOM allows easy optimization of ISS

Intensity Stabilization Servo

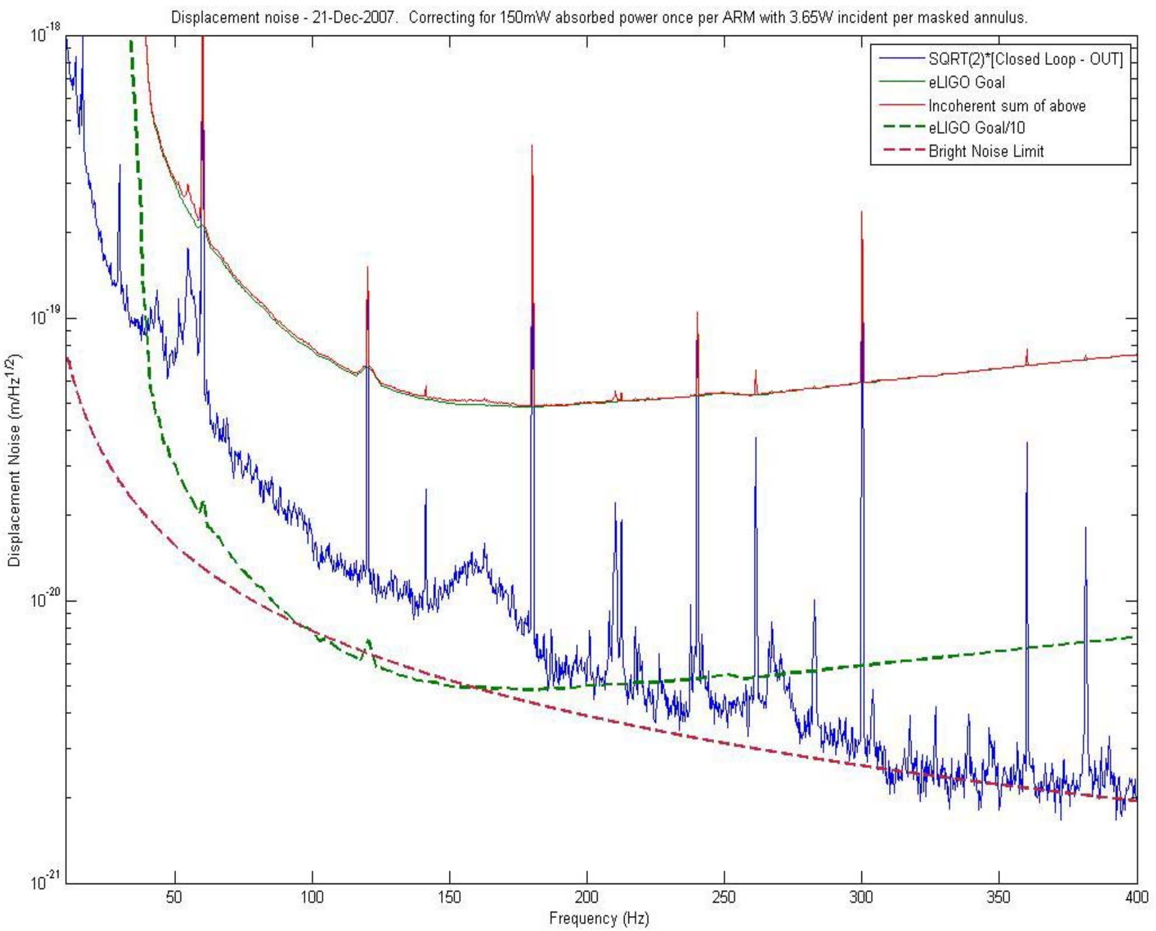
- The electronics are built and tested, but not tried in the loop
- The results that follow use SR560's and validate overall servo philosophy. (Note: SR560's used 50x gain, 3 kHz low-pass filter)
- Question: how much control over servo should operators have? This circuit allows electronic gain control, AOM deflection also accessible.





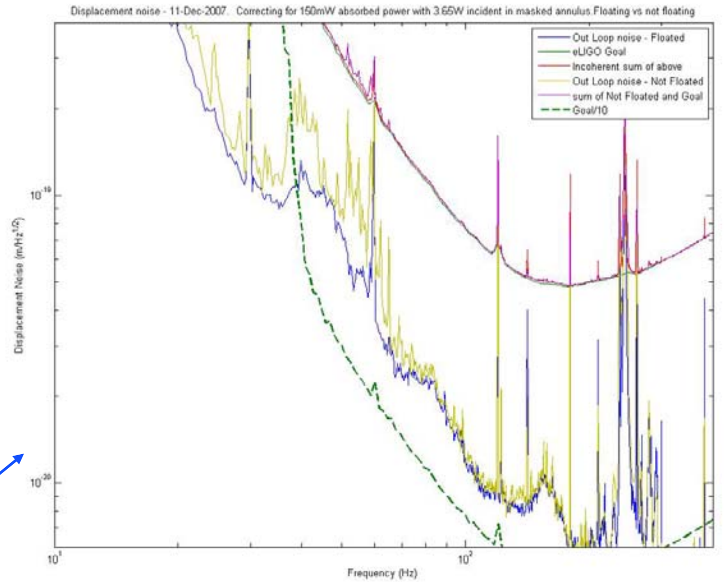
Intensity Stabilization Performance

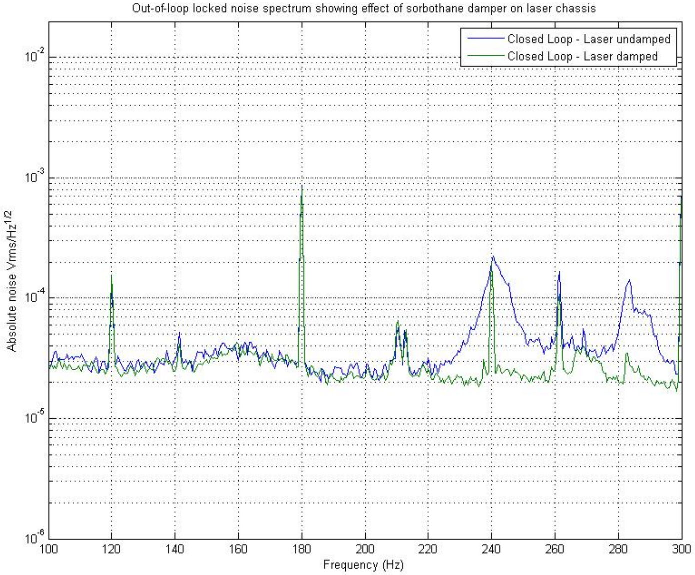
- Within LIGO band, TCS noise is approaching PD limits, except in narrow bands
- Servo is unconditionally stable
- PD noise level is elevated over dark level with high incident power (dark noise -> 'bright noise')

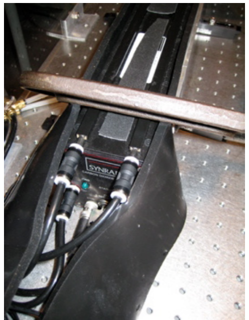


Noise Hunting Progress

- Noise hunting philosophy is to show good performance, find and fix any ‘show-stoppers’ but leave detailed noise hunting for during installation.
- Floating table reduced 10-80 Hz noise in shaky room, quieter LVEA floor should not need this
- Optic clipping minimized, 1” optics sufficient
- Laser sandwiched in sorbothane
- Chiller moved to remote location
- Table enclosed

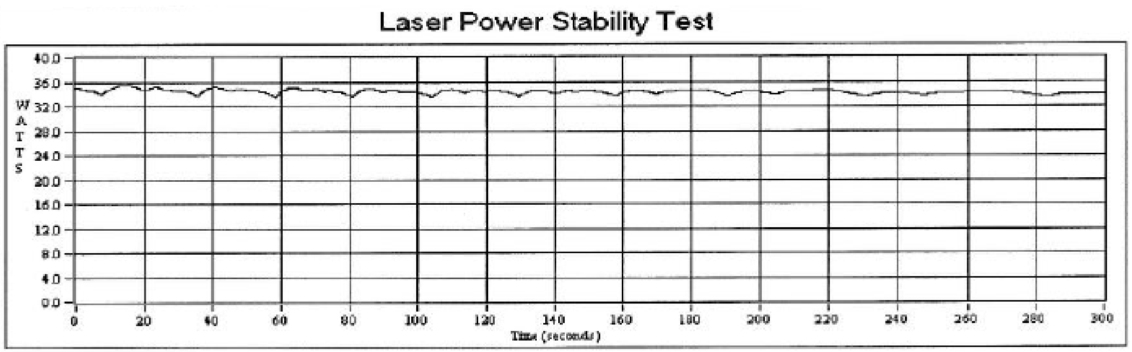






Remaining ISS Issues

- Noise hunting continues (e.g., jitter peaks in AOM could still use damping)
- Need to know temperature sensitivity
- Laser has long startup transient (~few hours), during which noise is elevated



Synrad Laser Startup Transients

- "How long after startup is noise good enough? How long until it's at the SRD/2 level? Will this be helped by the higher gain ISS servo? Could you put a PSD of the elevated noise?
  - » As laser warms up after ignition, the tube expands into a new thermal equilibrium length. During this time the output power shifts from one level to another, and during these transitions the noise is elevated. Thus the turn-on transient has non-stationary noise, for which we have not yet collected a spectrum. The transitions occur less frequently, the longer we wait. The transitions are generally gone after a few hours, but we have not made long-term tests. Noise is ~4-5x worse during transition.
- "More information about the graph would be helpful. What type of cooling was used? Has the laser been tested for more than 5 minutes?"
  - » This is test data supplied with the laser; the laser was water-cooled. We intend long-term testing after completing ISS tests, but during ISS tests spectrum is usually stable for hours before we shut down.

Reviewers' ISS Comments

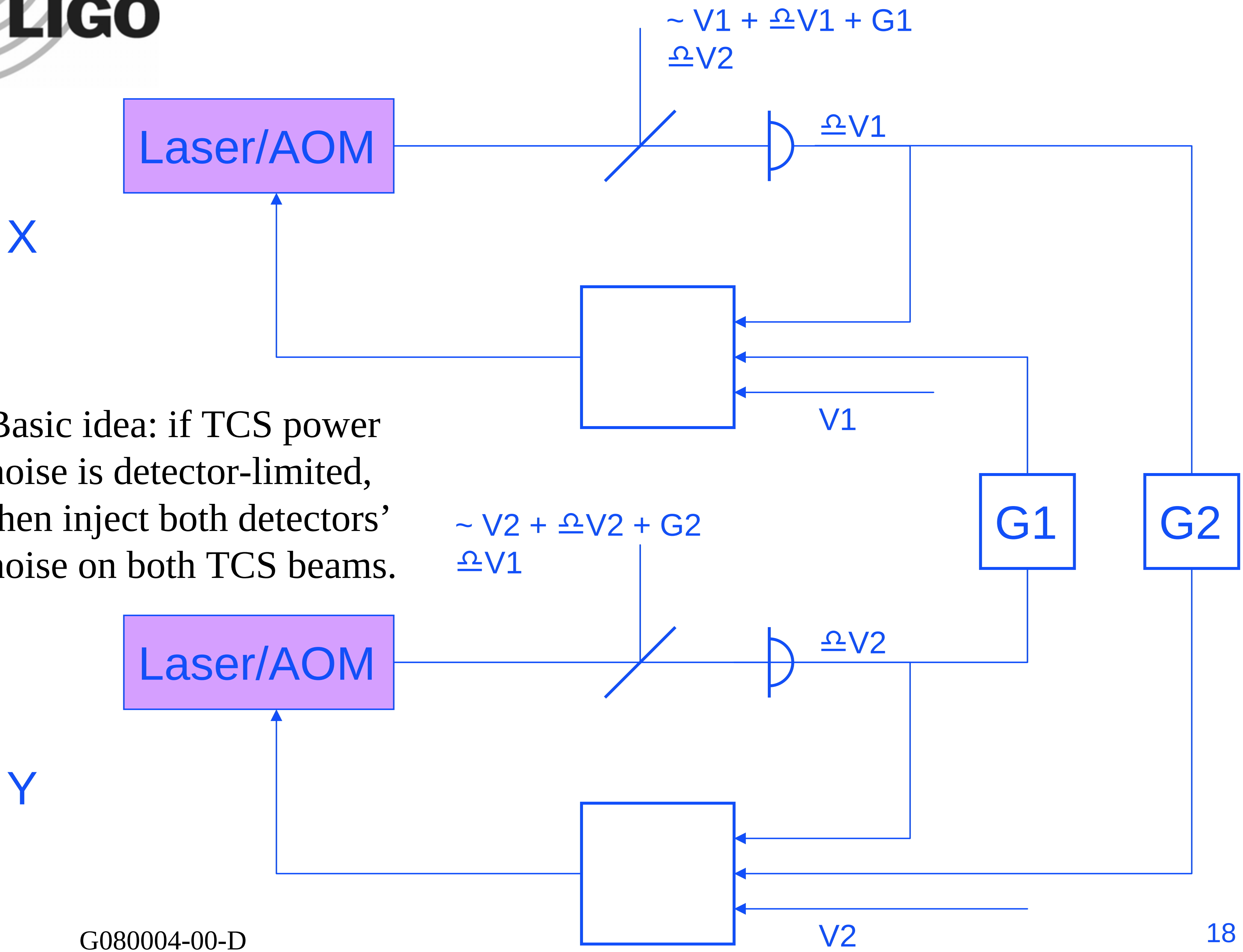
- "Is it possible to move the ISS detectors further down the chain so that they suppress any noise introduced in later sections?"
  - » They need to be before the rotating polarizer, or the RIN will vary with delivered power. It might be possible to put the polarizer after the axicon/central heating split and stabilize before the polarizer and after any masks, but this is an extensive redesign. Different spatial patterns would then be on the PDs for different heating patterns, which might be a complication.
- "Is it possible to move the in-loop and out-of-loop PD's closer together? The out-of-loop PD must be put after the AOM."
  - » Done and done. Sorry.
- "Can we monitor the output power of the projector?"
  - » Yes, a pickoff and PD are added. There may be a cleaner way to do this.
- "What's the DC performance of the electronics?"
  - » The PD preamps have 100x DC gain.

Reviewers' ISS Comments

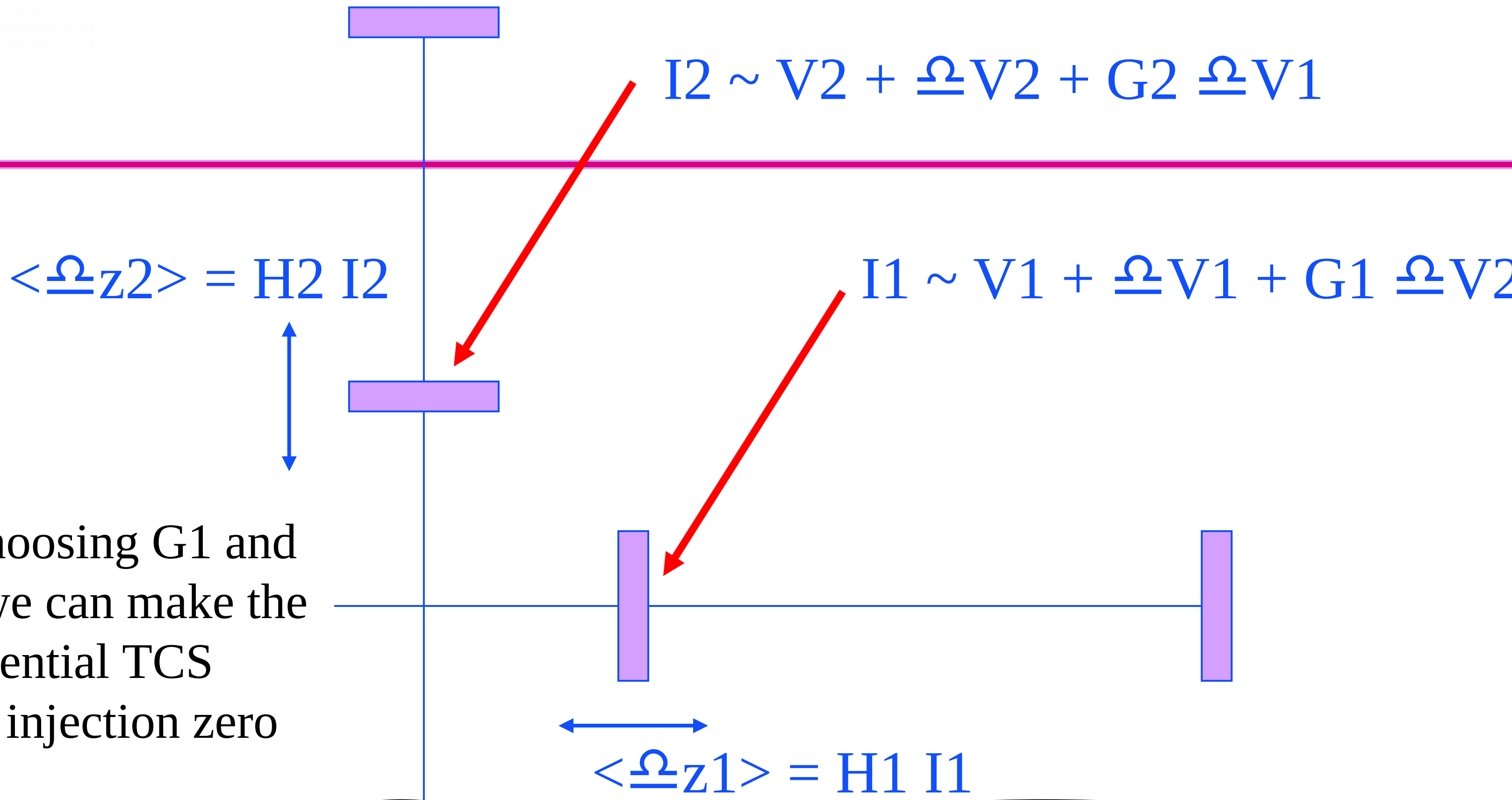
- "Any update on the uniformity of the Polish detector?"
  - » Sadly, no.
- "Is your estimation consistent with Dave Ottaway's measurement on H1, May 2005?
  - » Yes, almost. We see a slightly different noise spectrum than he did, though at the same rough level, and predict similar noise from an unstabilized laser. But our relative detector noise levels are much lower, so we expect more from our ISS.
- "The TCS ISS control room interface should be the same as the PSL ISS control room interface."
  - » Okay.
- "We can 'float' the TCS table on viton if the LVEA is too noisy."
  - » Good, let's.

Making TCS Noise Common Mode

- New stabilization strategy might improve noise coupling to strain by making all TCS noise injection *common mode.*
- This is not in the baseline but is being considered as a reserve later in commissioning.
- Requires only electronic connection between the TCS tables plus some servo filters- no new optical hardware or change in layout required. Easily disabled without penalty if strategy fails.



Basic idea: if TCS power noise is detector-limited, then inject both detectors' noise on both TCS beams.



By choosing G1 and G2, we can make the differential TCS noise injection zero

♎z2 - ♎z1 = H2 V2 – H1 V1 + H2 (♎V2 + G2 ♎V1) + H1 (♎V1 + G1 ♎V2)

static term

noise term

This technique requires only electronic feedback between the two TCS tables (no new optics) and can be held in reserve if we need better noise performance.

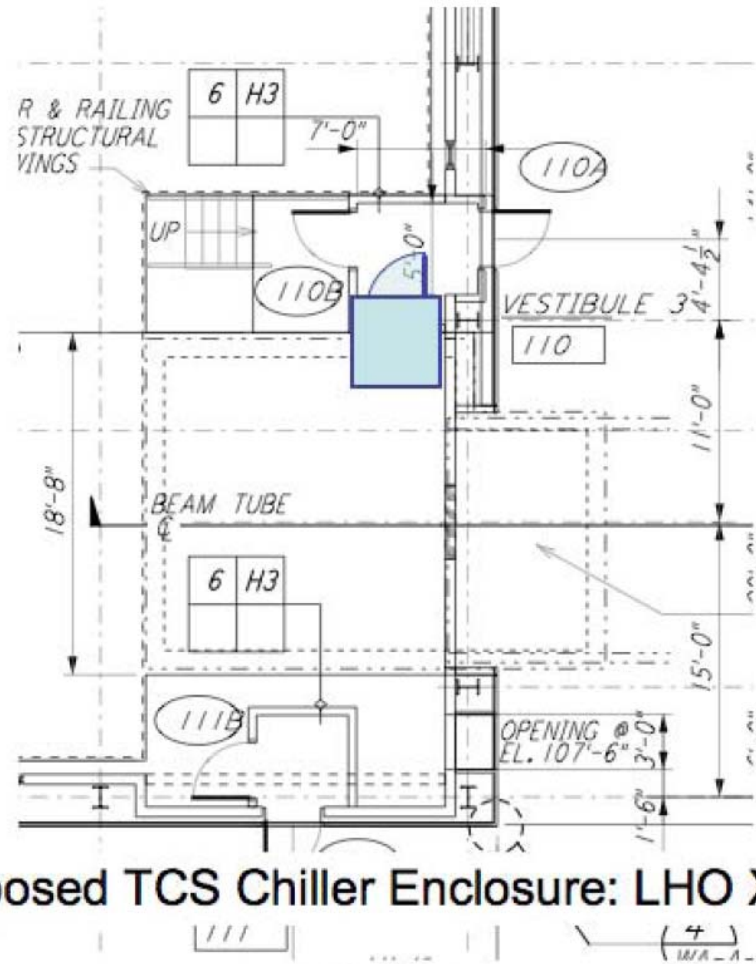
Reviewers' Comments

- "Don't you need to scale the servo mixing dynamically? The heating for X and Y certainly changes dynamically."
  - » Yes, the servo mixing would rescale with power. Heating might be fixed in detection mode, so scaling may not need to adjust on the fly.
- "How good does the matching between paths have to be for this to work? Since it increases the individual lasers' noises it seems like there would have to be a common mode cancellation which is as good as the servo action. 1%, 10%?"
  - » If noise is truly correlated from TCS tables, then any CMRR will help. For example, if one TCS table were utterly quiet, adding the noise of the other would help even if noise coupling were 50% off between arms. The question is how correlated the two tables can get.

New Chillers

- Laser requires 0.8 GPM
- AOM requires 0.125 GPM
- Laser power supply requires ??? (ours is air-cooled)
- AOM driver requires ???
- ThermoFlex 1400 provides 2.0 GPM
- No pulsed heater to broadcast EMI (Rob Schofield gives it a thumbs up! See Dec. 5 Hanford elog)
- Chiller closets are far from other LVEA electronics and acoustically isolated.

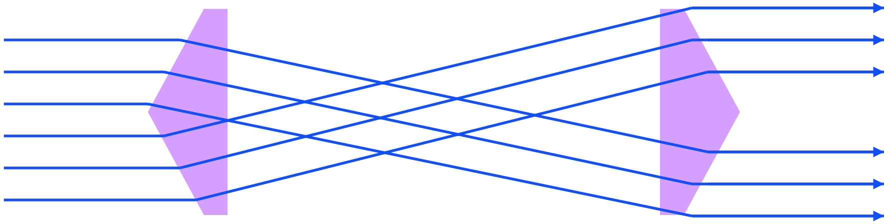
New Chiller Closets



Proposed TCS Chiller Enclosure: LHO X arm

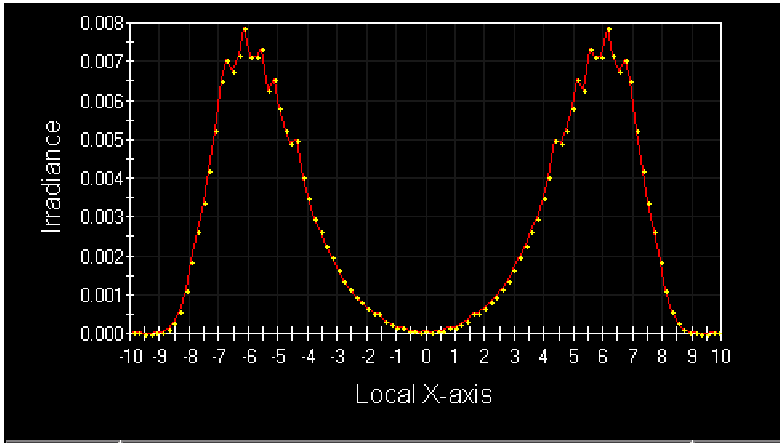
Chillers will be enclosed in closets far from the TCS table and optical lever piers- acoustic and electromagnetic interference should be minimized. Waste heat dumped into plenum air.

Axicons



ray trace of axicon pair

typical expected output intensity

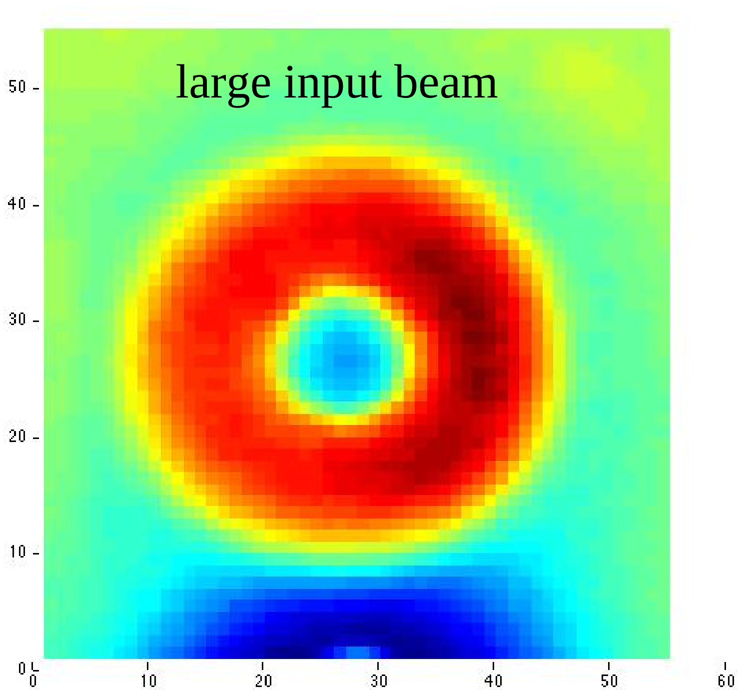


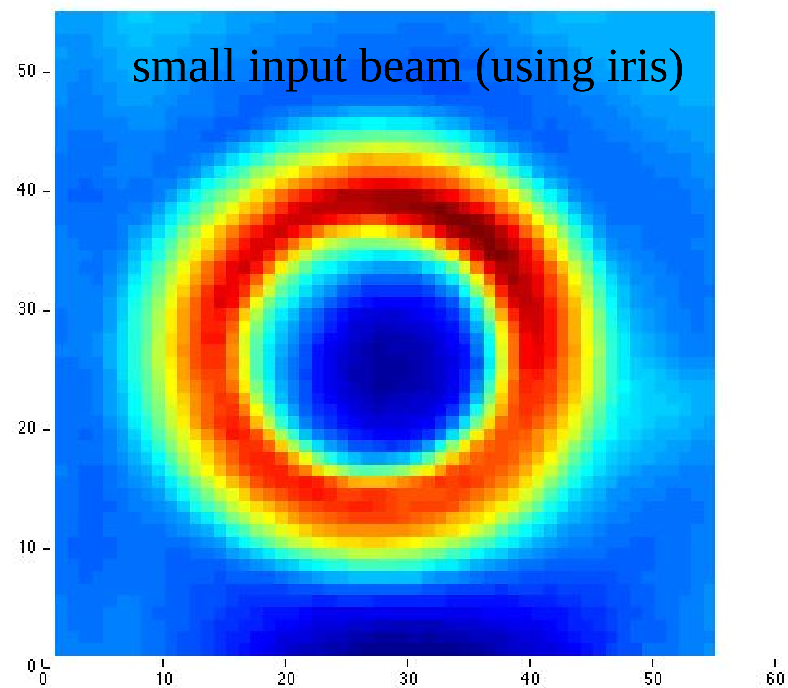
- Axicons are lenses or mirrors with <u>conical</u> rather than <u>spherical</u> surfaces. They naturally convert incident centralized beams into output annular patterns.

Axicons in the Lab

- Converts collimated gaussian to collimated annulus with measured 89% efficiency
- Annulus parameters adjustable with input beam size, axicon separation
- Alignment is tricky but manageable with collinear HeNe beam and thermal imaging camera

Measured axicon intensity profiles





Reviewers' Axicon Questions

- "What are the requirements on the uniformity and the centering of the annulus heating pattern?
  - » We have no solid requirements on uniformity. Centering requirements should be the same as in initial LIGO, within 10mm.
- "How hard is it going to be to change the size of the annulus pattern?
  - » Not too hard. The axicon separation can be changed to vary the pattern without defocusing the projector. Plus, we can still tweak the output profile with masks.
- "Have there been any stability tests?"
  - » Not so far. Estimates of required stability of axicon mounting seem well within optomechanical capabiliites. We may, however, want to move the rotating polarizer after the axicon.
- "Is the pattern projected by the axicon roughly the same as the old annular mask?"
  - » It is better. The old annular mask pattern is strongly peaked at the inner radius, while the axicon moves the power further out where we want it.
- "Is the back scattering from the axicon any smaller or larger than the old system?"
  - » The axicon itself should not contribute backscatter, if we point the conical surface toward the laser. The rest of the system should scatter about as before.
- "What would we gain by using the axicon instead of the annular mask?"
  - » Two things: a better spatial profile (see above), and much more efficient power delivery (89% compared to ~30% with the mask

Remaining Issues

- ISS done using SR560's- dedicated servo electronics just starting tests (too much gain).
- Ultimate ISS parameters could be tweaked for better performance (precise HdCdTe power setpoint, detector active area)
- Exact axicon separation and projector telescope lenses TBD, mask design TBD (but likely to be tweaked during commissioning)
- Details of axicon alignment and mounting are TBD.
- Synrad laser power supply is air-cooled and probably switchmode- best to substitute linear, water-cooled supply (or move it far away).
- Beam deviation by polarizer w.r.t. axicon needs study- elements may need to swap places.

Answers to Remaining Reviewers' Comments

- "Is there a plan of testing the table setup in Caltech (including everything like AOM and axicon)? If not, why?"
  - » There is no plan to test the full table setup in Caltech. Mostly, this is because the experience of building the first article at Hanford in initial LIGO worked pretty well. Also, because the new table is not very different from the old table. For this reason, we are only testing the really new stuff at Caltech: axicons and intensity stabilization.
- "What is the reproducibility of the central heating beam pointing"
  - » The flipper mounts have 50 microrad reproducibility, which then is divided by the 25x magnification of the final telescope. Over 30 m the error is <<1mm.

Answers to Remaining Reviewers' Comments

- "Is there enough time for the TBD's, and who is responsible?"
  - » Biggest TBD is purchase of major items- lasers, chillers, AOMs, detectors. Caltech responsibility (Phil): time is getting pretty tight for LLO.
  - » Next biggest TBD is precise layout of the optical table, especially finalizing first choice of heating profile. This affects purchases of smaller things like lenses and masks. Caltech responsibility (Aidan, Phil): plenty of time.
  - » Electronics fabrication. Caltech responsibility (Mohana, Tobin, Phil): plenty of time.
  - » Chiller plumbing. Sites responsibility: plenty of time, I hope.
  - » ISS tweaking and noise hunting. Caltech responsibility: to be done during installation and commissioning.