



40 Meter Lab program for AdvLIGO R&D

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AdvLIGO R&D Technical Review, 10/8/02
LIGO-G020429-00-R



Primary objective: full engineering prototype of optics control scheme for a **dual recycling suspended mass IFO**, as close as possible to the Advanced LIGO optical configuration and control system



Advanced LIGO technical innovations tested at 40m

- **a seventh mirror for signal recycling**
 - » length control goes from 4x4 to 5x5 MIMO
- **detuned signal cavity (carrier off resonance)**
- **pair of phase-modulated RF sidebands**
 - » frequencies made as low and as high as is practically possible
 - » unbalanced: only one sideband in a pair is used
 - » double demodulation to produce error signals
- **short output mode cleaner**
 - » filter out all RF sidebands and higher-order transverse modes
- **offset-locked arms**
 - » controlled amount of arm-filtered carrier light exits asym. port of BS
- **DC readout of the gravitational wave signal**

Much effort to ensure high fidelity between 40m and Adv.LIGO!



Differences between AdvLIGO and 40m prototype

- **Initially, LIGO-I single pendulum suspensions will be used**
 - » No room for full scale AdvLIGO multiple pendulums – to be tested at LASTI
 - » Scaled-down versions to test controls hierarchy in 2004?
- **Only commercial active seismic isolation**
 - » STACIS isolators in use on all test chambers, providing ~30 dB of isolation from 1-100 Hz
 - » No room for anything like full AdvLIGO design – to be tested at LASTI
- **LIGO-I 10-watt laser, negligible thermal effects**
 - » Other facilities will test high-power laser (LASTI, Gingin)
 - » Thermal compensation also tested elsewhere
- **Small (5 mm) beam spot at TM's; stable arm cavities**
 - » AdvLIGO will have 6 cm beam spots, using less stable cavities
 - » 40m can move to less stable arm cavities if deemed useful
- **Arm cavity finesse at 40m chosen to be = to AdvLIGO**
 - » Storage time is x100 shorter
 - » significant differences in lock acquisition dynamics, in predictable ways
- **Control RF sidebands are 33/166 MHz instead of 9/180 MHz**
 - » Due to shorter PRC length
 - » Less contrast between PRC and SRC signals



Milestones achieved so far

- Laboratory infrastructure complete
 - » Building, control room, vacuum controls & pumps, vacuum envelope, seismic stacks, in-vac cables, electrical power, racks, cable trays, optical tables, enclosures, computers & networking
- STACIS, PEM, DAQ commissioned
- PSL commissioned
- Conceptual Design Review completed October 2001
- Digital suspension controllers for MC1,MC2,MC3
- 13-meter suspended-mass MC commissioned
- Detailed optical layout and ISC design for core IFO
- 3 of 7 core optics suspended



Next 9 months

- Install **digital ASC (WFS)** on 13m mode cleaner.
- Fully characterize 13m **mode cleaner performance**.
- The **digital suspension controllers** for all 10 suspended optics should be complete by the end of calendar 2002.
- Assemble, hang, and install the **remaining core suspended optics** (BS, ITM_x, ITM_y, done; ETM_x, ETM_y, PRM, SRM next) by the end of calendar 2002, and have them damped by the controller system.
- Fabricate and install all **remaining optical sensing beamline equipment** on the existing enclosed optical tables, by 2Q 2003 (SP, AP, POB, POI, TR_x, T_{ry}).



Next 9 months, continued

- Fabricate and install auxiliary optics systems: **scattered light control, initial alignment system, optical levers, video monitoring.**
- Fabricate and install the **length sensing and control system.**
- Fabricate and install the **alignment sensing and control system.**
- Data handling: fiber link to CACR? (Currently, we only save all trend frames, backed-up to AIT occasionally).
- There may be some necessary augmentation of the **DAQS, computing, networking, and environmental monitoring systems.**



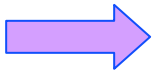
Longer term

- All systems installed, commissioning begun by summer 2003.
 - » First experiments in dual recycled configuration response, lock acquisition, and control are expected to take at least a year.
 - » We expect that LSC members, as well as students, will participate in this most interesting phase of the project.
- Elements not designed in detail will be delayed until FY04:
 - » Output mode cleaner
 - » DC demodulation scheme
 - » Multiple suspensions?
- The only impediments to this schedule that we foresee are:
 - » Availability of sufficient funding
 - » Sufficient communication and support to/from the LSC/AIC group on the top-level design



Milestones revisited

- **2Q 2002:**
 - » All in-vacuum cables, feedthroughs, viewports, seismic stacks installed.
 - » 12m input MC optics and suspensions, and suspension controllers.
- **3Q 2002:**
 - » Begin commissioning of 12m input mode cleaner.
 - » Acquisition of most of CDS, ISC, LSC, ASC.
- **4Q 2002:**
 - » Core optics (early) and suspensions ready. Ten Suspension controllers. Some ISC.
 - » Glasgow 10m experiment informs 40m program
 - » Control system finalized
- **2Q 2003:**
 - » Core optics (late) and suspensions ready.
 - » auxiliary optics, IFO sensing and control systems assembled.
- **3Q 2003: Core subsystems commissioned, begin experiments**
 - » Lock acquisition with all 5 length dof's, 2x6 angular dof's
 - » measure transfer functions, noise
 - » Inform CDS of required modifications
- **3Q 2004: Next round of experiments.**
 - » DC readout. Multiple pendulum suspensions?
 - » Final report to LIGO Lab.





(Some) outstanding issues and action items (40m, AdvLIGO)

- **Any significant changes in people's thinking** re: optical configuration, controls, CDS architecture??
- **180 MHz PD's for WFS, LSC. Double demodulation(180 Å 36 MHz).**
- **Develop ASC/WFS model.**
- **Design servo filters for LSC, ASC!**
- **Detailed noise model (RSENOISE, Jim Mason)**
- **Lock acquisition studies with E2E/DRLIGO.**
- **Develop lock acquisition algorithms, software.**
- **Triple-check thermal effects (Melody) – negligible?**
- **Output mode cleaner – will PSL-PMC-like device be adequate? (For 40m, for AdvLIGO). Suspended?**
- **Offset-lock arms - algorithms, software.**
- **DC GW PD – in vacuum? Suspended?**



40m Team

Live and breathe 40m, ~100%

- Alan Weinstein
- Dennis Ugolini
- Osamu Miyakawa
- Steve Vass
- Ben Abbott
- Bob Taylor
- Mike Smith

Contributing LIGO engineers:

- Larry Jones
- Jay Heefner
- Janeen Romie
- GariLynn Billingsley
- Helena Armandula
- Betsy Bland
- CDS folks (Bork, Ivanov, ...)
- PSL folks (King, Cardenas...)
- Lots of help from many others!

Also: Typically 5 SURF students, visiting students & physicists, etc.

The 40m team is minimal, but they're first-rate, with a very appropriate mix of skills. Our size is, I believe, adequate for the task (well, at least until commissioning begins in earnest), provided that LIGO engineering technical support remains available. From now on, we will primarily need continued CDS support – or, more meaningfully, CDS will need the 40m lab more, as we develop AdvLIGO CDS...



Cost baseline and issues

- **FY03 budget aims to complete construction of the DR IFO, and begin commissioning / experiments.**
- **Budget consists of salaries, misc. equipment and supplies, and... **equipment to complete DR IFO.****
- **Of course, you can't build an IFO of this complexity without an adequate equipment budget, and you're likely to regret cutting corners on instrumentation...**

The 8/17/02 revised budget (essentially, split into NOW and LATER):					
Misc equipment for computers, bake oven lab, potential NPRO replacement/repair, etc			100,000		ALREADY budgeted
Five penteks to complete DSC for vertex-area suspensions:			45000		Current request
ISC optics for everything except output mode cleaner and some oplevs:			300000		Current request
LIGO electro-optics and electronics for Michelson control			55000		Current request
These above 3 items were in a request for \$400K, approved by the CCB on 9/23/02					
CDS LSC and ASC (from Jay Heefner) + 20% contingency			416,460		Future request...
Auxilliary: remaining oplevs, baffling/scattered light control, monitoring, PEM, improved DAQS, etc.			?		Future request...
These last 2 items require a more careful scrubbing of the budget, which will likely go up!					



Additional slides with more detail

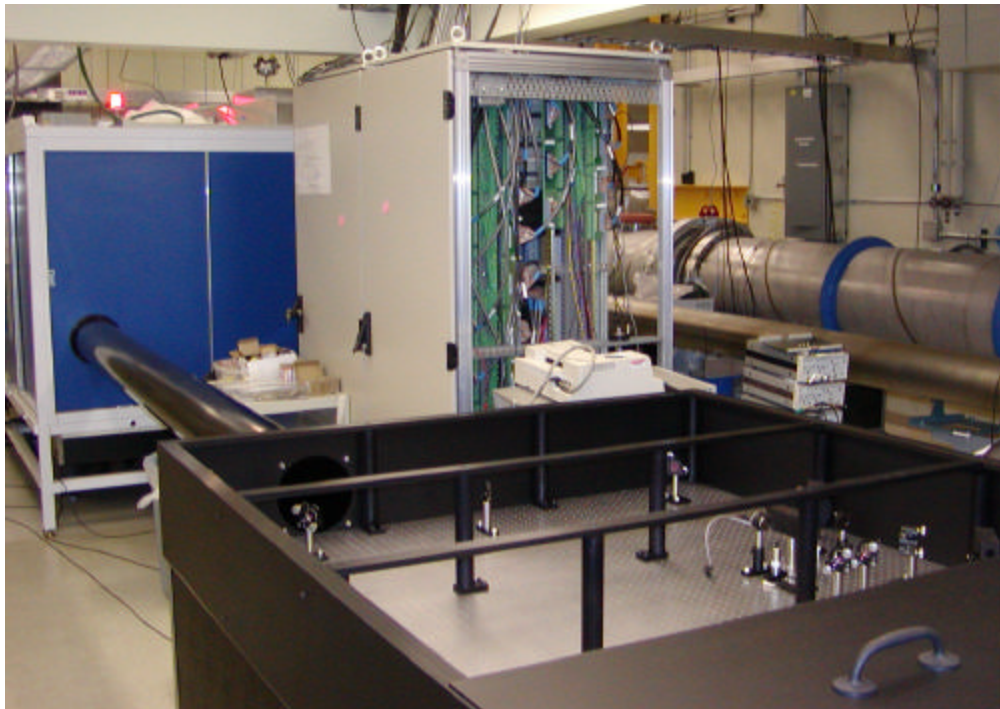
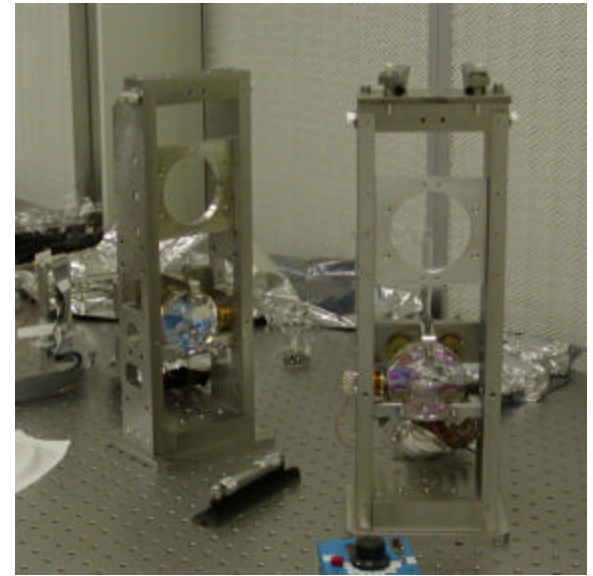


Milestones Achieved as of March LSC Meeting

- **Building renovation:** Control room added; electronics racks, power conditioners, cable trays, computers & networking infrastructure installed
- **Vacuum revision:** 13m MC and OOC added to envelope; pumps, controls updated
- **Active seismic isolation (STACIS)** installed at all test mass chambers
- **Initial LIGO PSL** commissioned and characterized; NPRO replaced and realigned
- **DAQ** installed and logging frames; trends saved since July 2001
- **PEM** installed and running (dust, seismometer, weather, STACIS readback)
- **Conceptual Design Review** completed in Oct 2001
- **Optical layouts complete** for in- and out-of-vacuum; parts lists assembled
- **Procurement** of CDS, ISC, etc. begun
- **More cleaner optics and suspensions** in hand, specs for core optics completed

Further Infrastructure

- Final optical table, beam tubes, table covers installed
- IR-coated viewports, cameras installed
- MC reflected and transmitted optical paths assembled

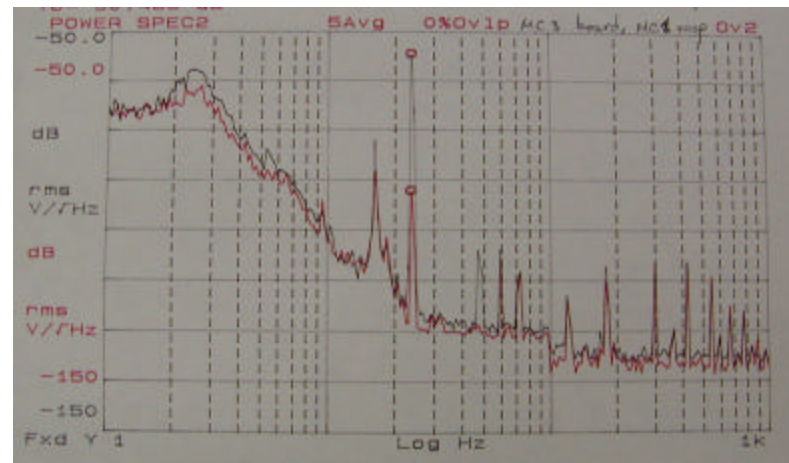
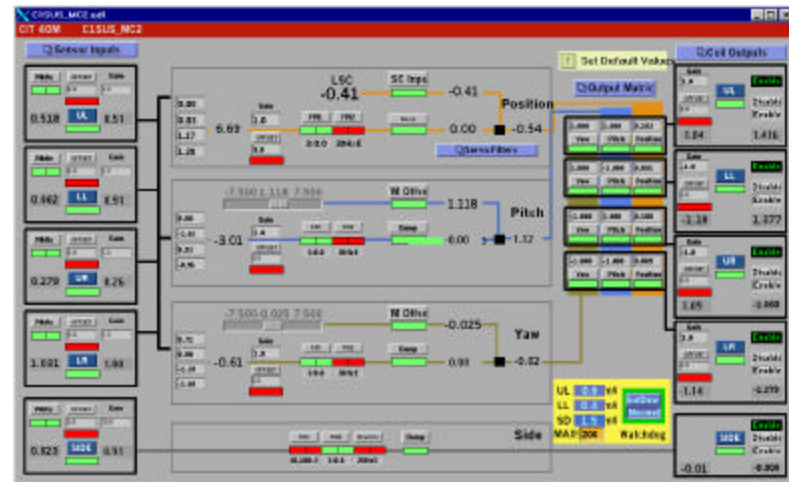


- MC, OOC seismic stacks installed and cabled
- MC optics hung, balanced, installed in April



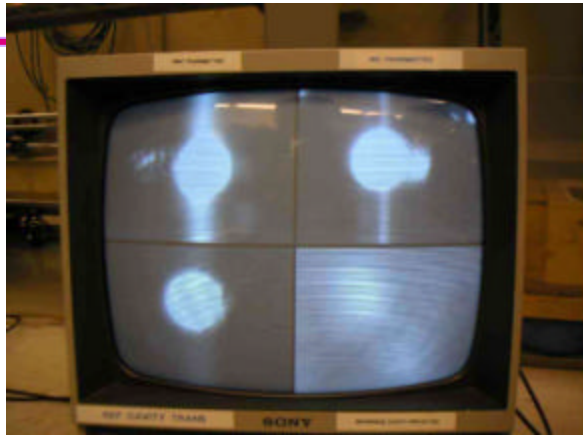
Digital Suspensions

- Digital suspensions for the mode cleaner optics were installed in May; full control system for all 10 core optics expected by end of 2002
- Digital notch filter added at 23.7 Hz to eliminate anomalous “roll mode” in MC1; may be due to lateral misalignment of OSEMs
- GDS/DTT/AWG installed; used Mark Barton’s code to diagonalize input, output matrices of MC2, MC3





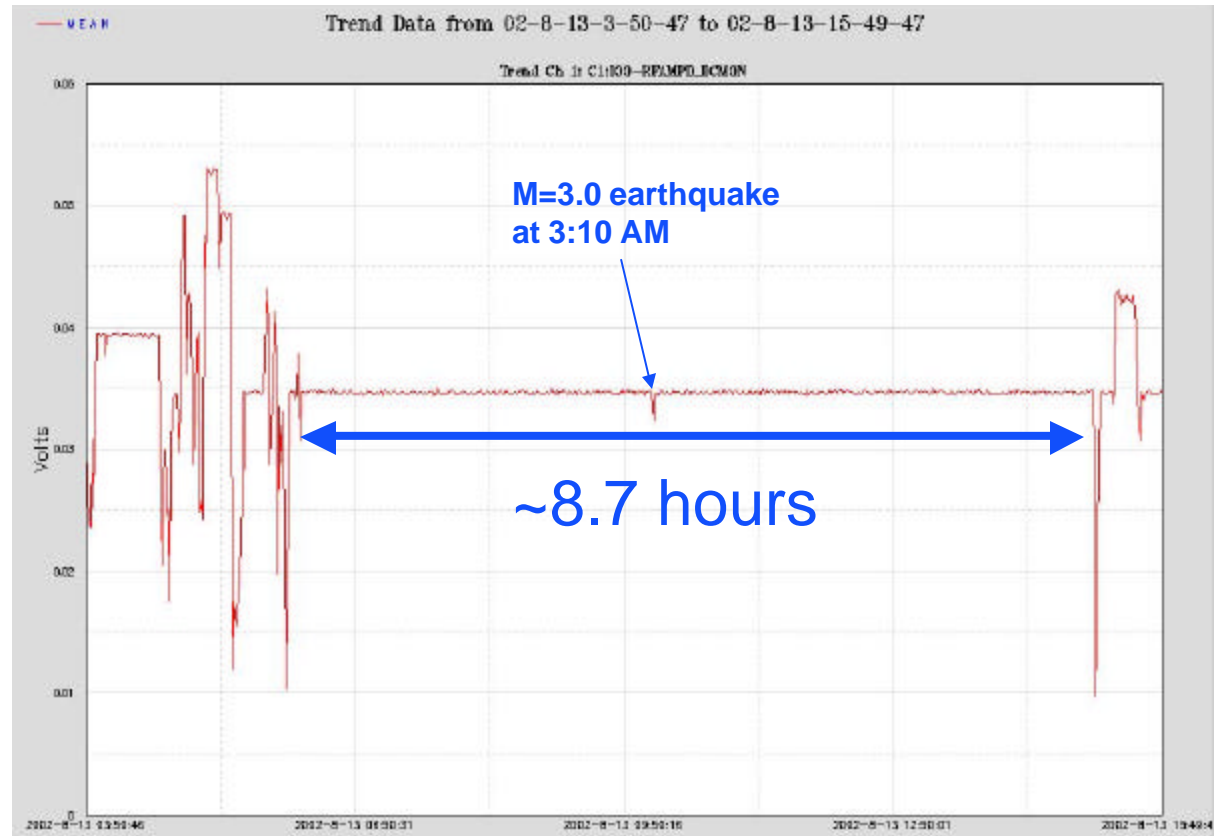
13-meter Mode Cleaner Lock



After considerable work diagnosing problems, and differences between documents and as-built systems at sites:

Lock is quickly and robustly achieved, and maintained (in detection mode), using the MC servo. **Much valuable experience gained by Ugolini, Miyakawa, Abbott**

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Core Suspended Optics

- The **core optics** for the main dual recycled interferometer were produced, polished, and coated as of Aug 2002. Completed pieces have been delivered and are have been measured by LIGO optical engineers (Armandula, Billingsley).
- The mechanical suspensions for the remaining 7 optics, for the main dual recycled interferometer, have been designed, fabricated, cleaned and baked.
- BS (SOS), ITM_x & ITM_y (“MOS”) **suspended in September 2002** (Bland, Armandula, Vass, Ugolini, Taylor).
- We plan to **hang the remaining 4 optics** (ETM_x, ETM_y, PRM, SRM), and install them in the vacuum envelope **this winter**.