LIGO Laboratory

☑ California Institute of Technology
MC 18-34, 1200 E. California Blvd.
Pasadena CA 91125 USA
TEL: 617.395.2129
FAX: 617.304.9834
www.ligo.caltech.edu

☐ LIGO Livingston Observatory
P.O. Box 940
Livingston LA 70754 USA
TEL: 225.686.3100
FAX: 225.686.7189
www.ligo-la.caltech.edu

☐ LIGO Hanford Observatory
P.O. Box 159
Richland WA 99352 USA
TEL: 509.372.8106
FAX: 509.372.8137
www.ligo-wa.caltech.edu

☑ Massachusetts Institute of Technology
MIT NW22 – 295, 185 Albany St.
Cambridge MA 02139 USA
TEL: 617.235.4824
FAX: 617.253.7014
www.ligo.mit.edu

Date:	14 May 2008	Refer to:	L080055-00
Subject:	Systems Plans for the Final Design Phase		
To:	Systems PDR Review Committee		
From:	Peter Fritschel, Dennis Coyne		

This memorandum defines plans for the final design phase of the Systems efforts for Advanced LIGO in response to a request from the Systems Preliminary Design Review (PDR) committee[1]. The basic plan for each of the major issues is discussed first. Then the labor resources are defined and finally a schedule is presented which has milestones matched to key points in the project schedule, including those from effected subsystems.

Plans for Arm Length Stabilization.

The three proposed schemes for pre-lock acquisition stabilization of the arm lengths are briefly described in the response document to this committee, L080051-01. More technical descriptions and details can be found in the Advanced LIGO wiki.[2] Here we discuss the Systems plan for choosing which scheme to pursue, and the interfaces of the different schemes with other subsystems.

Systems will form a Technical Review Board to assess the three schemes, and to recommend a course of action by approximately the end of June 2008. The board will include people directly familiar with the different schemes, and also one or two 'outsiders' who have not been involved in any of the schemes (Coyne will also be on the board, and Fritschel will chair it). The board will consider technical pros and cons, integration with the rest of the interferometer, and cost estimates. We anticipate there will be sufficient technical information available for the board to recommend which scheme to adopt, but there is the possibility that it will recommend further study before a choice is made.

Interfaces:

i. SPI (end station injection). This scheme requires mounting three OSEMs on the quad suspension cage. An additional strut would be needed on the cage; the suspension

[1] See also the following documents in response to Systems PDR committee questions, some of which pertain to plans in the final design phase:
a) "Responses to the committee questions on the Systems Design (T010075-01)", L080051-01
b) "Responses to the committee questions on the Optical Layout (T010076-01) and Generic Requirements (E010613-02)", L080047-01

[2] http://ilog.ligo-wa.caltech.edu:7285/advligo/Seismic_Platform_Interferometer (look for the latest document in the 'Discussion paper' section of this page)

design team is aware of this and holes are being included to accommodate this. Holes in the arm cavity baffles would be needed for the SPI beam, and an injection platform similar to the ETM transmission monitor would be needed in the ETM chambers.

ii. Digital interferometry. This scheme requires a modification to the output Faraday isolator so that the probe beam can be injected through its input polarizer. The ETM transmission monitor design would need to provide for separation of the probe beam from the main beam.

iii. PDH locking with a shifted wavelength. With this scheme there would be some additional specifications on the reflectivity of the test masses at the probe wavelength. The ETM transmission monitor would need to provide for injection and detection of the probe wavelength.

With a choice of scheme in summer 2008, there is enough time to accommodate any of these interfaces. A later selection may be acceptable as well, but the TRB will evaluate that more carefully.

Plans for managing the parametric instability threat.

The plans for investigation of the phenomenon involve both modeling work and experimental tests.

Modeling:

- *Increase LIGO Lab modeling efforts*, beginning by redoing the single arm cavity FFT simulations (Bantilan's calculations) for the new arm parameters. The model for acoustic mode Qs will also be refined. Contrary to earlier statements, it's premature to say we expect R factors to be reduced by the cavity finesse reduction. This depends on how close a given mode is to its optical eigenfrequency; one mode that is shown in more detail in the Bantilan report is probably not close enough to the optical resonance to experience a gain reduction. Hans Bantilan will work with Bill Kells on this effort.
- *Increase our understanding of the UWA analysis*. The UWA group has apparently redone their parametric gain analysis for the new arm cavity parameters. In the past, many of the details of these calculations have not been evident (although their results are similar to Bantilan & Kells); we need to increase our interaction with them so we can understand the details to be able to compare results.
- *Calculations for damping techniques.*
    - Calculate effectiveness of ESD actuators in damping test mass modes (all modes below 90 kHz). I.e., how much force is needed to damp each mode to a given Q, with thermal excitation? Can also look at breaking up ESD pattern to increase effectiveness. This is being done now by a visiting student at MIT (Jonathan Soto); results in the next month or two.
    - Look at other mechanical damping techniques. For example, a new idea is to make a piezo-based damper, on the back face of the TM (equivalent to velocity damping, or faster with frequency).

Measurements:

- Measure modal Q's of the LASTI test mass, once it is installed in the quad suspension. This installation is scheduled for July 2008, and these measurements are one of the top priorities for testing, and should start by late summer 2008. These measurements

are important because the parametric gain calculations so far assume very high acoustic mode Q's – around 30 million in the 20-30 kHz region, e.g. – based on a model of silica bulk loss and coating loss. Any Q reduction due to losses not accounted for in this model would directly reduce the parametric gain estimates.

- Investigate ESD damping of internal modes at LASTI.
- Tests of any other mechanical damping techniques that look promising.
- Gingin has an experiment planned to create a parametric instability in a specially designed optical configuration. This will be useful to compare experiment with models, and to gain experience with PI. They expect to demonstrate parametric instability before the end of 2008. In 2009 they will explore techniques for PI suppression including ring dampers, gold barrel coating, detuning of parametric instability by thermal actuation in a stable power recycling cavity and possibly ESD active damping. Phil Willems and Guido Muller are partner investigators on this effort.

We also need to keep in mind the implications of potential mitigation techniques on the Advanced LIGO schedule:

Technique	*Subsystems affected*	*Technical & Schedule impact*
Barrel gold coating	COC	The technical case for and feasibility of a test mass barrel gold coating will be evaluated by a TRB in May-June 2008.
ESD damping	SUS (US)	This refers to any ESD pattern design changes made to increase its overlap with acoustic modes. The ESD pattern design needs to be finalized around the end of 2008.
Acoustic mode damper	COC	This refers to any damping mechanism that is add/attached to the test mass after they have been polished and coated (e.g., mechanical ring damper, or piezo-damper); they would have to be compatible with the current test mass design, but could be incorporated as late as late 2010.

Labor Resources

The Systems effort in the final design phase has been defined in the NSF proposal as a project effort. The baseline cost book has funding for a total of 4.8 Full Time Equivalent (FTE) staff in Systems, and specifically the individuals defined in Table 1 with Funding Source of AdL Sys. However, the Systems endeavor in AdL is a distributed effort among the subsystems so that detailed bottom-up design and analysis can inform top-down trade-off studies and because the implementation effort most often falls to the subsystems. The principal staff working on significant tasks for the Systems final design phase is also given in Table 1. The fraction of time that these individuals work on their assigned Systems tasks is approximate/guessed. (If the individual is a significant contributor, but the fraction of time that they contribute is small or not well known/guessed, then they are listed but without an estimate of time. All FTE fractions are normalized by the one year duration of the Systems final design phase, i.e. 100% contribution for 1 quarter is listed as 25% FTE.) Time from individuals who only contribute on Technical Review Boards (TRB) are not included. The total staff engaged in the principal Systems activities is approximately 8 FTE. The primary point of this table is not detailed time management or allocation for individuals but to convey the fact that many are contributing to resolution of the open system issues/tasks.

Individual	FTE	Funding Source	Primary Task(s)
Lisa Barsotti	0.25	AdL Sys	Lock acquisition modeling Angular Stability Studies (using optickle)
Dennis Coyne	1.0	AdL Sys	Systems engineering (interfaces, layout, subsystem oversight/review, etc.)
Engineer@CIT – modeling	0.50	AdL Sys	TBD; currently Hiro spends more time
Matt Evans	0.50	AdL Sys	Modeling Q measurement & ESD damping of acoustic modes
Peter Fritschel	0.25	AdL Sys	Systems science/engineering (performance, requirements, subsystem oversight/review, etc.)
Graduate student@CIT - modeling	0.50	AdL Sys	TBD; might pay for Hans Bantilan for summer work on PI
Mike Smith	0.30	AdL Sys	Optical layout (using Zemax)
Calum Torrie	1.0	AdL Sys	Systems engineering (interfaces, mass budget, generic requirements, subsystem oversight/review, etc.)
Hiro Yamamoto	0.50	AdL Sys	Simulation
Eric Gustafson	0.05	R&D	Optimized coating TRB
Greg Ogden	0.15	R&D	Optimized coating TRB
Eric Black	0.05	R&D	Optimized coating TRB
Bram Slagmolen	0.8	ANU	Arm Length Stabilization design
Glenn de Vine	0	ANU	Arm Length Stabilization design
David Rabeling	0	ANU	Arm Length Stabilization design

Kirk McKenzie	0	ANU	Arm Length Stabilization design
David McClelland	0	ANU	Arm Length Stabilization design
Bill Kells	0.10	COC	Oversight of revised FFT simulations for new optical configuration
Jonathan Soto	0.30	ISC	Analysis of ESD controllability of TM acoustic modes
Richard Mittleman et. al.	0.20	LASTI	Q measurement & ESD damping of acoustic modes
David Blair et. al.	0	UWA	GinGin measurement of PI & analysis updates as needed
GariLynn Billingsley	0.05	COC	Gold Barrel & Dielectric coating implementation issues and costs (input to TRB)
Helena Armandula	0.05	COC	Gold Barrel & Dielectric coating implementation issues and costs (input to TRB)
Luke Williams	0.50	AOS & IO	Optomechanical layout work in SolidWorks
Gregg Harry	0.25	AOS	Electro-static R&D planning, oversight, research
Ke-Xun Sun et. al.	0.25	Stanford	Electro-static approach trade-off studies
Mike Zucker	0.25	FMP	Particulate cleanliness requirements & conceptual design
Rolf Bork et. al.	0.10	DAQ	Electronics & Software input to the generic requirements document
Linda Turner	0.25	AdL PM	Configuration control, procedures documentation, web-based hierarchical indices to documentation, etc.
David Tanner	0	IO	Optomechanical layout checks
Muzamil Arain	0.20	IO	Cavity length checks, optical simulation checks
Total approx. FTEs	8.35		

Schedule/Plan

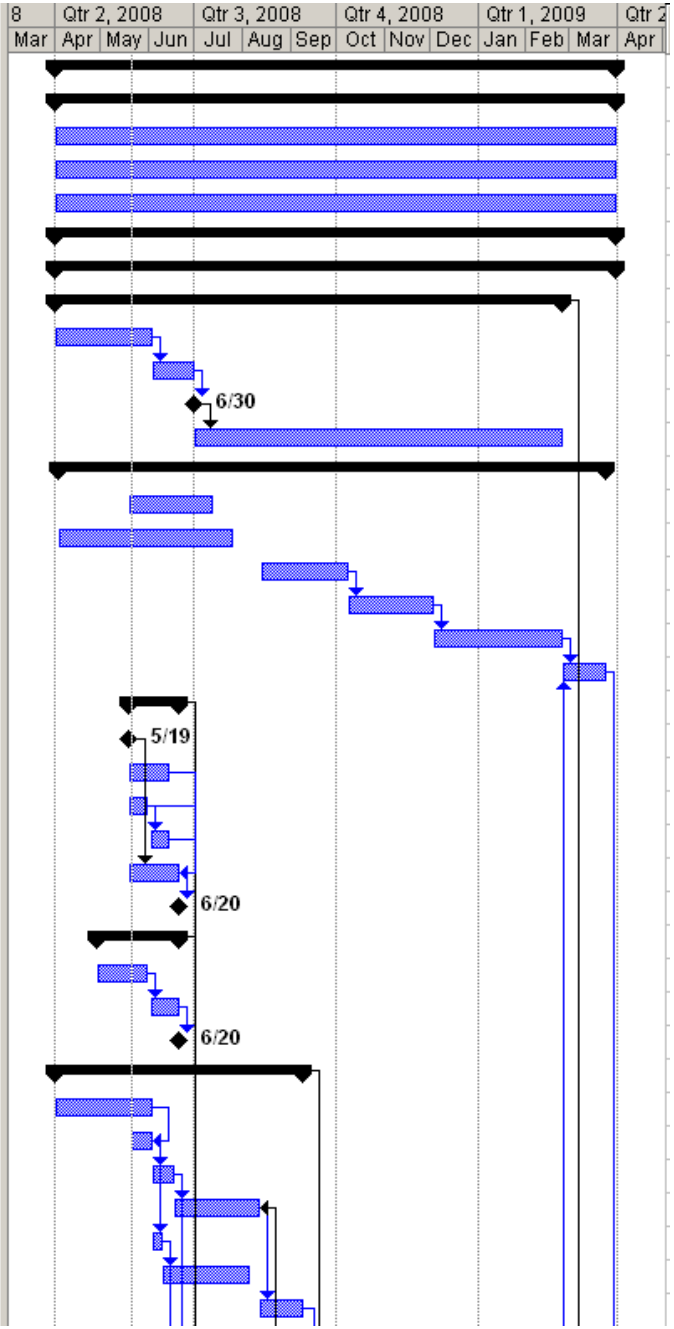
Below is a MS Project schedule showing the Systems final design phase planned activities/tasks and the relevant linked milestones or constraint dates from the master Primavera Project Planner schedule. TBW …

Some comments:

1) Only the duration of tasks within the final design phase are shown in the schedule. For example, the Arm Length Stabilization trade study has been underway for about one year, led by the ANU group, with guidance from Peter Fritschel. There have been several presentations and discussions (see the wiki pages). Only the balance of the estimated trade study completion leading to the imminent review is shown in the schedule.
2) Milestones from the master Primavera Project Planner schedule which are relevant targets dates for Systems tasks in the final design phase are indicated at the bottom of the schedule and are linked to the relevant tasks above. Also shown at the bottom of the schedule is the rough timeline for the GinGin PI studies in this timeframe.
3) Arm Length Stabilization: The arm length stabilization trade studies result in a TRB recommendation and AdL management decision by late June 2008. Which subsystem(s) work on the final design depends upon the chosen approach (Systems may only have peripheral involvement in the final design.). This work is intended to be a Australian contribution but there will be LIGO Lab effort as well.
4) Gold Barrel: The gold barrel test mass TRB review and decision is scheduled to support the COC FDR in late June or early July. The TRB has been formed. Much of the analysis has been completed.
5) Dielectric Coating Design: The decision, jointly with COC, to employ optimized thickness (non-quarter wave) dielectric coating design should also be made by the time of the COC FDR. (Although it is possible to delay this decision until early 2009 when coating RFs go out for bid with sufficient reason.) The recent thermal noise formulation correction by Matt Evans is presently undergoing review by a small group.
6) Optomechanical Layout: The primary emphasis for the optomechanical layout in the near term is finalizing the wedge angles to support the COC FDR. We will have a team review in the next week or two to finalize the new small wedge angle layout. Once this is concluded tolerances on the wedge angles will be set while simultaneously finalizing (vetting) the vacuum equipment layout parameters to support VE detail design and fabrication RFQs planned for immediately after the FMP VE PDR on June 9th (although float exists in this schedule). The balance of the layout efforts are principally in support of AOS stray light control and optical lever design efforts.
7) Electro-static Charge Mitigation: Gregg Harry and the LSC electro-static charge working group are formulating/revising a research plan which should be ready this summer. Note that most charging scenarios are not problematic for AdL. Nonetheless we will evaluate the interface implications of some of the practical charge mitigation approaches in order to make provisions to accommodate one or more of these approaches in the event that they are shown to be necessary.
8) Particulate Cleanliness: Mike Zucker has a good start on setting requirements and defining a practical design approach for processes, environment and equipment. The time frames are a rough estimate. We'll need a review of the requirements and concept (or perhaps preliminary design) before deciding which subsystems are tasked

with what work (e.g. revised handling or storage procedures or equipment). Most of the effort for implementing any special requirements (e.g. improved clean room systems) will likely fall to the FMP group, hence the linkage to the FMP FDR start on Sep 16th.

Task Name	Duration	Start	Finish
L.3.14.5 System Engineering	**260 days**	**Tue 4/1/08**	**Mon 3/30/09**
L.3.14.5.1 Modeling & Simulation Development	**260 days**	**Tue 4/1/08**	**Mon 3/30/09**
E2E development (LOE)	52 wks	Tue 4/1/08	Mon 3/30/09
FFT development (LOE)	52 wks	Tue 4/1/08	Mon 3/30/09
Optickle development (LOE)	52 wks	Tue 4/1/08	Mon 3/30/09
L.3.14.5.3 System Final Design	**260 days**	**Tue 4/1/08**	**Mon 3/30/09**
L.3.14.5.3.1 System Definition/Design	**260 days**	**Tue 4/1/08**	**Mon 3/30/09**
Arm Length Stabilization (ALS)	**235 days**	**Tue 4/1/08**	**Mon 2/23/09**
feasibility/trade study	9 wks	Tue 4/1/08	Mon 6/2/08
TRB	4 wks	Tue 6/3/08	Mon 6/30/08
decision on approach	0 wks	Mon 6/30/08	Mon 6/30/08
final design	34 wks	Tue 7/1/08	Mon 2/23/09
Parametric Instability (PI)	**253 days**	**Fri 4/4/08**	**Tue 3/24/09**
revised analysis -- current FP configuration	8 wks	Mon 5/19/08	Fri 7/11/08
ESD controlability & passive damping technique analysi	16 wks	Fri 4/4/08	Thu 7/24/08
measure Qs of LASTI TM	8 wks	Wed 8/13/08	Tue 10/7/08
Investigate ESD damping of LASTI TM acoustic modes	8 wks	Wed 10/8/08	Tue 12/2/08
Experiments on passive damping techniques @LASTI	12 wks	Wed 12/3/08	Tue 2/24/09
TRB Review/Recommendations	4 wks	Wed 2/25/09	Tue 3/24/09
Gold Barrel Decision	**25 days**	**Mon 5/19/08**	**Fri 6/20/08**
initiate TRB	0 days	Mon 5/19/08	Mon 5/19/08
COC implementation plan	4 wks	Mon 5/19/08	Fri 6/13/08
check passive damping analysis	2 wks	Mon 5/19/08	Fri 5/30/08
check thermal analysis	2 wks	Mon 6/2/08	Fri 6/13/08
TRB review	5 wks	Mon 5/19/08	Fri 6/20/08
TRB report/decision	0 days	Fri 6/20/08	Fri 6/20/08
Dielectric Coating Design	**40 days**	**Mon 4/28/08**	**Fri 6/20/08**
vet M. Evans's coating thermal noise model	5 wks	Mon 4/28/08	Fri 5/30/08
examine implications of dichroic requirements	3 wks	Mon 6/2/08	Fri 6/20/08
decide if coating is optimized (non-quarter wave)	0 days	Fri 6/20/08	Fri 6/20/08
Finalize Basic Optomechanical Layout	**115 days**	**Tue 4/1/08**	**Mon 9/8/08**
choose COC wedge angles (zemax)	9 wks	Tue 4/1/08	Mon 6/2/08
independently confirm wedge angles (optica, SW)	2 wks	Tue 5/20/08	Mon 6/2/08
define acceptable wedge angle tolerances (zemax)	2 wks	Tue 6/3/08	Mon 6/16/08
define ancilliary beams & equipment (zemax)	8 wks	Tue 6/17/08	Mon 8/11/08
VE infrastructure layout definition (zemax & SW)	1 wk	Tue 6/3/08	Mon 6/9/08
generate drawings from SolidWorks model	8 wks	Tue 6/10/08	Mon 8/4/08
decision/guidance on which optics require optical levers	4 wks	Tue 8/12/08	Mon 9/8/08



Task Name	Duration	Start	Finish
Electro-static Charge Mitigation	**220 days**	**Tue 4/1/08**	**Mon 2/2/09**
formulate/update plan	3 mons	Tue 4/1/08	Mon 6/23/08
evaluate interface implications	4 mons	Tue 6/24/08	Mon 10/13/08
R&D leading to selection of approach(es)	8 mons	Tue 6/24/08	Mon 2/2/09
Handoff to implementation by appropraite subsystem	0 days	Mon 2/2/09	Mon 2/2/09
Particulate Cleanliness	**120 days**	**Tue 4/1/08**	**Mon 9/15/08**
establish requirements & conceptual design	18 wks	Tue 4/1/08	Mon 8/4/08
CDR	6 wks	Tue 8/5/08	Mon 9/15/08
Optomechanical Layout (FD update)	2 wks	Tue 9/9/08	Mon 9/22/08
System Design Doc. (FD update)	4 wks	Tue 1/27/09	Mon 2/23/09
Generic Requirements Doc. (FD update)	8 wks	Tue 12/30/08	Mon 2/23/09
FD Review	5 wks	Tue 2/24/09	Mon 3/30/09
FD Review completed	0 days	Mon 3/30/09	Mon 3/30/09
L.3.14.5.3.2 System Simulation	**210 days**	**Tue 4/1/08**	**Mon 1/19/09**
E2E lock acquisition studies (high power, single arm with ar	42 wks	Tue 4/1/08	Mon 1/19/09
angular stability studies (Opticle)	42 wks	Tue 4/1/08	Mon 1/19/09
FFT optical & TCS imperfection tolerance studies (3 mirror, (	42 wks	Tue 4/1/08	Mon 1/19/09
L.3.14.5.3.5 Interface Mgmt	**260 days**	**Tue 4/1/08**	**Mon 3/30/09**
ICD development (LOE)	52 wks	Tue 4/1/08	Mon 3/30/09
L.3.14.5.3.6 Subsystem Readiness Reviews	**260 days**	**Tue 4/1/08**	**Mon 3/30/09**
LOE assistance to subsys	52 wks	Tue 4/1/08	Mon 3/30/09
L.3.14.5.3.7 System Test & Evaluation	**260 days**	**Tue 4/1/08**	**Mon 3/30/09**
overview/approval of subsystem plans (LOE)	52 wks	Tue 4/1/08	Mon 3/30/09
UHV qualification of materials & processes (LOE)	52 wks	Tue 4/1/08	Mon 3/30/09
Integrated System Test & Development Plan	12 wks	Tue 12/2/08	Mon 2/23/09
Relevant/Linked Non-SYS milestones	**74 days**	**Mon 6/9/08**	**Mon 9/22/08**
COC FDR start	0 days	Thu 6/26/08	Thu 6/26/08
FMP VE PDR	0 days	Mon 6/9/08	Mon 6/9/08
AOS CDR	0 days	Mon 9/22/08	Mon 9/22/08
AOS/TCS PDR	0 days	Fri 8/8/08	Fri 8/8/08
FMP FDR start	0 days	Tue 9/16/08	Tue 9/16/08
GinGin Parametric Instability Experiment	**420 days**	**Tue 4/1/08**	**Mon 11/9/09**
Observation of Parametric Instability	9 mons	Tue 4/1/08	Mon 12/8/08
Investigation of Suppression Techniques	12 mons	Tue 12/9/08	Mon 11/9/09