LIGO-T000147-00-D

Date: Thu, 25 May 2000 15:36:49 -0700
From: Dennis Coyne <coyne@ligo.caltech.edu>
X-Mailer: Mozilla 4.7 [en] (Win98; I)
X-Accept-Language: en
To: Fred Asiri <fba@ligo.caltech.edu>
Subject: LIGO-II Proposal Input for SEI

Attached is a draft proposal outline from Gary Sanders.

Also attached is:

1) my stab at a schedule & assignments for the SUS as an example -- we need to make one for the SEI subsystem.

2) an example WBS dictionary -- this needs to be fleshed out for SEI

Additional information is available at:

1) The LIGO-II site:
http://www.ligo.caltech.edu/~ligo2/

2) The WBS file is at

\\Pictor\p3win\Data\wbs_v6.xls

For Unix, the \ are /

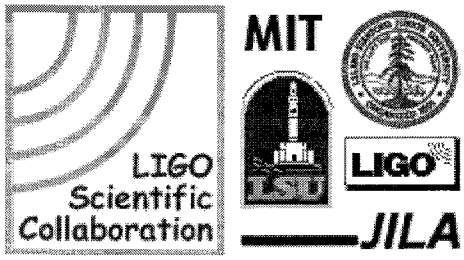
3) The SEI documents you alreafy have I think.

Dennis


proposal_outline_v1.PDF (#1)


wbs_dictionary_v1.PDF (#2)


proposal_v1_SUS.gif (#1)



A Proposed LIGO-II Seismic Isolation System by LSC members at Stanford, JILA, MIT, and LSU.

Some computer renderings and recent photos of our designs and prototype tests.

Documents requested by Technical Advisory Group:

Please note that most of these were made with Acrobat version 4, so cannot be read with version 3 readers. The Acrobat reader version 4 is now available for most all platforms at the Adobe site.

1. A Prototype Test Program Plan. Current version: 1.0, Feb 14, 2000. (LIGO-T000015-00) (#3)
2. Simulation Plan. Current version: 1.0.1, Feb 14, 2000. (LIGO-T000016-01)) (#3)
3. Baseline LIGO-II Implementation Design Description. (LIGO-T000024-00-U) (#5)

Additional Documents:

- 4/27/2000 Brief report of the latest single-stage prototype performance at Stanford. (#6)
- Slides presented at the March 2000 LSC Meeting, presenting the reference design.
- The most recent (I hope!) LIGO-II Seismic Isolation Design Requirements Document. (#4)
- Scanned spec sheets of a key low-noise seismometer in our design, the Streckeisen STS-2. (#7)
- The RSI paper from the JILA Group, describing their two-stage, 12-DOF active seismic isolation platform
- An interesting paper from the Univ. of Washington, describing a 6-DOF active isolation system.
- A huge file with complete transparencies from the Glasgow meeting, at which we tried to set interface requirements between the Seismic isolation and Suspension systems.
- "How to Construct a Mechanical Model of a Mass-Spring System," by Wensheng Hua.
- "LIGO-II Suspension: Reference Designs," by the Univ. of Glasgow GEO group, 31-Jan-00.
- "Quiet Hydraulics for Ultraprecision Actuation," by S. Peirce, H. Tran, M. Wiedemann ,and D. DeBra, (1994).

Server and web pages maintained by Joe Giaime

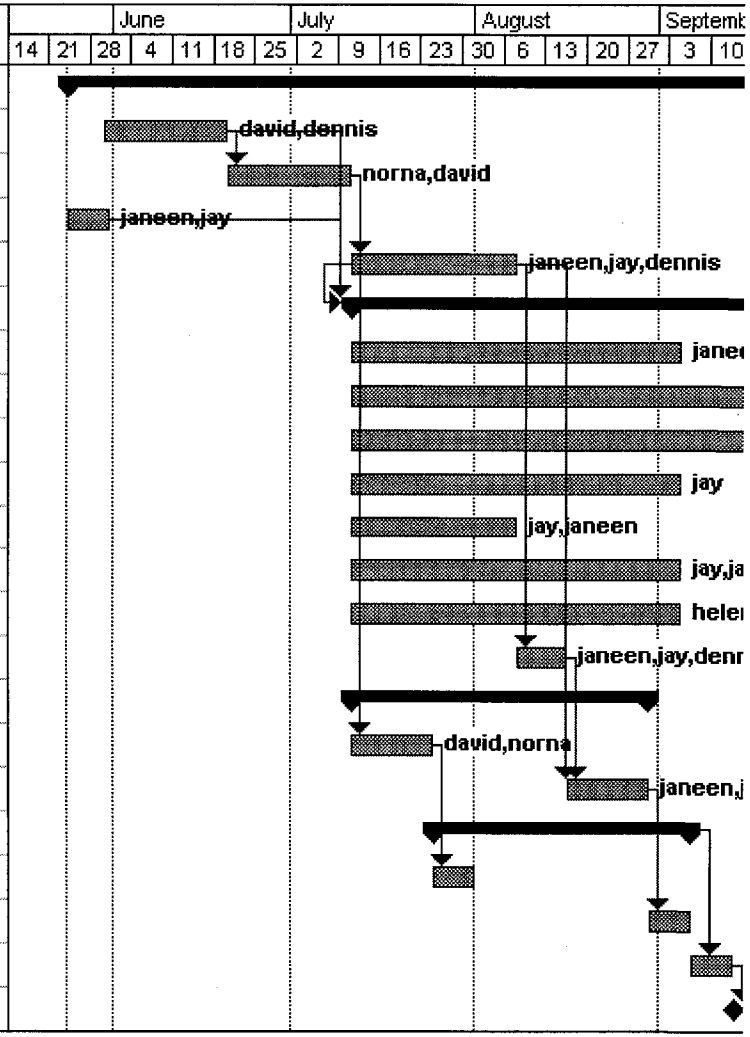
BATCH START

STAPLE OR DIVIDER

LIGO II Construction Proposal Outline					
Chapter	*Description*	*Lead Author*	*Lead Estimator*	*Reference Documents Included on CD-ROM*	*Lead Author*
1	Executive Summary	**Sanders**		1999 LSC White Paper	
				1999 Conceptual Project Book	
2	Astrophysics Motivation and Scientific Goals	**Lazzarini**, Thorne, Prince			
	Estimate of Sensitivity Needed for Each Type of Astrophysics Source	, Finn			
	Description of LIGO II Science Requirements From This Estimate				
3	Reference Design Baseline Definition	**Sanders**, Shoemaker		LIGO II System Design Requirements Document	Fritschel
	Narrative Description of LIGO II Reference Design			Any noise calculation memos	Fritschel, Strain, Finn
	LIGO II Reference Design Parameters and Comparison With LIGO I			Braginsky and Thorne papers on noise	Braginsky, Thorne
	Reference Design Sensitivity Goal and Noise Estimates				
	Reference Design Tradeoff Analysis				
	Reference Design Options				
4	Program Plan	**Sanders**		Draft LIGO II Project Management Plan	Sanders
	LIGO Laboratory Role and Responsibilities			LIGO Annual Report (most recent ?)	Lindquist
	LIGO Scientific Collaboration Role and Responsibilities			LIGO Quarterly Report (most recent)	Lindquist
	GEO Collaboration LIGO II	Hough et al		LIGO II Proposal for LIGO Operations (2002-2007)	Lindquist
	ACIGA Collaboration in LIGO II	McClelland			
	Method of Accomplishment				
5	LIGO II Detector Research and Development Overview				
	Organization of Research in Progress	**Sanders**			
	Interferometer Configuration Research Plan	**Strain**		SWG Web Site	
	Lasers and Optics Research Plan	**Gustafson**		Lasers & Optics Web Site	
	Suspension and Isolation Research Plan	**Shoemaker**		STAIC Web Site	
6	Work Breakdown Structure	**Sanders**		LIGO II WBS Dictionary	Sanders, Coyne
	Level 3 WBS Dictionary (LIGO.4.**XX**)				
7	Facility Modifications	**Sanders**, Asiri	**Asiri**		
	Overview			Site Drawings ?	
	Requirements				
	Reference Design Description				
	Research and Development				
	Work Plan and Subsystem Schedule				
8	Seismic Isolation	**Shoemaker**	**Asiri, Bork**, Mason	Design Requirements Document	
	Overview			Conceptual Design Document	
	Requirements			Evaluation Criteria Document	
	Reference Design Description			Isolation Approach Decision Memo	
	Research and Development			Publications from R&D	
	Work Plan and Subsystem Schedule				
9	Suspension	**Shoemaker,GEO**	Coyne, **Heefner**	Design Requirements Document	
	Overview		**, Romie**	Conceptual Design Document	
	Requirements			Publications from R&D	
	Reference Design Description				
	Research and Development				
	Work Plan and Subsystem Schedule				
10	Prestabilized Laser	**Camp, Savage**	**King,**	180 W Laser Specification	
	Overview		Gustafson, **Abbott,**	PSL Design Requirements Document	Savage
	Requirements			Conceptual Design Document	
	Reference Design Description				
	Research and Development				
	Work Plan and Subsystem Schedule				
11	Input Optics	**Camp**, Reitze	**Reitze,Ouimette**	DRD	Reitze
	Overview			CDD	Reitze
	Requirements				
	Reference Design Description				
	Research and Development				
	Work Plan and Subsystem Schedule				
12	Core Optics Components	**Camp**, Gustafson	**Billingsley**	DRD	Billingsley, Kells
	Overview		**Billingsley**	CDD	Billingsley, Kells
	Requirements				
	Reference Design Description				
	Research and Development				
	Work Plan and Subsystem Schedule				
13	Support Optics (repeated for:				
	Stray Light Control (SLC)	Smith	Smith	DRD and CDD documents	Smith
	Active Optics Compensation (AOC)	Zucker	Zucker	Compensation Results	Zucker
	Output Mode Cleaner Design	ACIGA			
	PO Mirror Assembly and Telescope Design	Smith	Smith		
	Initial Alignment System (IAS)	K. Mason	K. Mason		
	Overview				
	Requirements				
	Reference Design Description				
	Research and Development				
	Work Plan and Subsystem Schedule				
14	*Interferometer Sensing and Control*	Coyne, Zucker,Fritschel	Coyne, Zucker	DRD	Coyne, Zucker
	Overview		, Ouimette	CDD	*Coyne, Zucker*
	Requirements			Results of RSE experiments	Mason
	Reference Design Description				
	Research and Development				
	Work Plan and Subsystem Schedule				
15	Data Acquisition, Networking and Supervisory Control, Diagnostics	Lazzarini, Bork, (Fritsch	Lazzarini, Bork		

	Overview				
	Requirements				
	Reference Design Description				
	Research and Development				
	Work Plan and Subsystem Schedule				
16	Support Equipment	Asiri, Coyne	Asiri		
	Overview				
	Requirements				
	Work Plan and Subsystem Schedule				
17	Computing and Data Analysis	Lazzarini	Lazzarini		
	Overview				
	Requirements				
	Reference Design Description				
	Research and Development				
	Work Plan and Subsystem Schedule				
18	Installation	Coyne	Coyne		
	Overview				
	Requirements				
	Reference Design Description				
	Work Plan and Installation Schedule				
19	Project Management	Sanders	Lindquist	Draft Project Management Plan for LIGO II	Sanders
	Overview				
	Management				
	Project Controls				
	QA Services				
	Systems Engineering			System DRD	
	Documentation				
	Administration				
	General Computing				
20	LIGO II Schedule	Sanders	Sanders, Coyne	some big schedule file from Primavera ?	Frey
	Schedule Planning Assumptions				
	Methodology				
	The LIGO II Design Process				LIGO I Design Process
	Top Level Milestones				
	Relationship to LIGO Laboratory Operations and LIGO I Schedule				
	Schedule Options and Phasing Options				
21	LIGO II Cost Estimate	Sanders	Sanders, Lindquist	LIGO II Cost Estimating Plan	Sanders, Lindquist
	Cost Estimate Methodology			LIGO II Cost Estimating Tool Document	Kratochwill, Frey
	Cost Estimate Summary				
	Cost Drivers				
	Risk Areas and Contingency				
	Funding Profile				
	MRE Construction Request				
	MRE R&D Request				
22	Responsibilities/Resources/Staffing	Sanders	Sanders	MOU's and Attachments	Petrac
	Staffing Estimate and Assumptions				
	Managing Non-Laboratory Participation				
	GEO Participation	Hough			
	ACIGA Participation	McClelland			

ID	Task Name	Duration	Start	Finish	Predecessors	Resource Names
23	**Suspensions**	**94 days**	**5/24/00**	**10/2/00**		
24	Design Requirements	3 wks	5/30/00	6/19/00		david,dennis
25	Conceptual Design	3 wks	6/20/00	7/10/00	24	norna,david
26	WBS Dictionary	5 days	5/24/00	5/30/00		janeen,jay
27	Development Plan	4 wks	7/11/00	8/7/00	25	janeen,jay,dennis
28	**Cost Estimate**	**60 days**	**7/11/00**	**10/2/00**	**24,27SS,26**	
29	structure	8 wks	7/11/00	9/4/00		janeen
30	assy fixtures	12 wks	7/11/00	10/2/00		janeen
31	install fixtures	12 wks	7/11/00	10/2/00		janeen
32	control elect & SW	8 wks	7/11/00	9/4/00		jay
33	sensors	4 wks	7/11/00	8/7/00		jay,janeen
34	actuators	8 wks	7/11/00	9/4/00		jay,janeen
35	ribbons/fibers	8 wks	7/11/00	9/4/00		helena
36	Schedule	1.33 wks	8/8/00	8/16/00	27	janeen,jay,dennis
37	**Proposal Chapter**	**36.67 days**	**7/11/00**	**8/30/00**		
38	req & design	2 wks	7/11/00	7/24/00	25	david,norna
39	plan	2 wks	8/16/00	8/30/00	27,36	janeen,jay
40	**Review**	**31.67 days**	**7/25/00**	**9/6/00**		
41	req & design	1 wk	7/25/00	7/31/00	38	
42	plan, schedule, cost	1 wk	8/30/00	9/6/00	39	
43	revise proposal input	1 wk	9/6/00	9/13/00	40	
44	completed	0 days	9/13/00	9/13/00	43	



To: Fred Asiri <fba@ligo.caltech.edu>
Subject: [Fwd: deliverables outline]

Fred,
Here is the outline of a development plan for the SEI from Joe for a
starting point.

DennisReceived: from 131.215.125.1.ligo.caltech.edu (ligo [131.215.125.1])
by ligo.caltech.edu (8.9.3/8.9.3) with ESMTP id NAA00350;
Tue, 23 May 2000 13:50:32 -0700 (PDT)
Received: from lsuligo.phys.lsu.edu (IDENT:root@lsuligo.phys.lsu.edu [130.39.176.72])
by 131.215.125.1.ligo.caltech.edu (8.9.3/8.9.3) with ESMTP id NAA11592;
Tue, 23 May 2000 13:52:22 -0700 (PDT)
Received: from [130.39.245.132] (joseph.ligo-la.caltech.edu [130.39.245.132])
by lsuligo.phys.lsu.edu (8.9.3/8.8.7) with ESMTP id PAA09416;
Tue, 23 May 2000 15:51:35 -0500
Mime-Version: 1.0
X-Sender: giaime@lsuligo.phys.lsu.edu (Unverified)
Message-Id: <v04220800b5509f28c770@[130.39.245.132]>
Date: Tue, 23 May 2000 15:51:19 -0500
To: Dennis Coyne <coyne@ligo.caltech.edu>,
"Gary H. Sanders" <sanders@ligo.caltech.edu>
From: "Joseph A. Giaime" <giaime@lsuligo.phys.lsu.edu>
Subject: deliverables outline
Content-Type: multipart/mixed; boundary="============_-
1253007411==_============"
X-Mozilla-Status2: 00000000

Dennis & Gary,

Enclosed is that rough and tentative schedule I was referring to during our phone call today.

I haven't had time to "typeset" it, so the columns might not line up for you...

-Joe


deliverables.txt

Joseph A. Giaime, Assistant Prof.
Department of Physics and Astronomy, Louisiana State University
Baton Rouge LA 70803 USA email: giaime@phys.lsu.edu
tel. at LSU: 225 388-5794, Fax. 225 388-5855
at LIGO: 225 686-3169

Activity	Participants	Deliverable	Milestones
Conceptual Design	All	Rough Design	2Q00: Conceptual design
Prototype Design	All	Detailed frame design	3Q00: ready for bidders
		Detailed pod design	3Q00: ready for bidders
		Sensors & Actuators	3Q00: fully defined
		Dynamic model	3Q00: done
		Thermal model	3Q00: done
		Electronics & control	3Q00: specified
Prototype Construction	JILA,SU	Mechanical fab	4Q00: fab done
		Sensor & Actuators	4Q00: ready to install
		Electronics & control	4Q00: ready for test
Prototype supervisory & control sys Tests	SU,JILA,LSU	(Tests at ETF)	2Q01: test results
UHV tests	MIT, ??	Pathfinder for frame production	3Q00: method chosen
		Vac tests of UHV pod	4Q00: construction done
		Wiring design	4Q00: complete
		Installation tooling	4Q00: preliminary design
LASTI tests	MIT, All	Complete Design and bids out	2Q01: Design complete and reviewed
		Production	3Q01: Contracts let

Installation 1Q02: Installed in LASTI!

BATCH START

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LIGO-II Work Breakdown Structure (WBS) Dictionary

1 General Comments:

All research, development, design, construction, assembly and of the LIGO-II instrument are covered under this WBS structure, organized by subsystems.
The design is separated into three sequential phases:

- Requirements/Conceptual Design Phase (CD): The conceptual design and requirements task encompasses the development of a documented set of requirements (Design Requirements Document) in conjunction with the systems engineering group and the development of a documented conceptual design (Conceptual Design Document) which is responsive to the requirements. A project review of the design (Conceptual Design Review, CDR) is held at the end of this phase.
- Preliminary Design Phase (PD): The preliminary design task encompasses the development of a documented set of refined requirements (Design Requirements Document) in conjunction with the systems engineering group and the development of a documented preliminary design (Preliminary Design Document) which is responsive to the requirements. A project review of the design (Preliminary Design Review, PDR) is held at the end of this phase.
- Final Desgn Phase (FD): The final design task encompasses the development of a set of documentation which is sufficient to build the subsystem including an overall detailed design description (Final Design Document) which is responsive to the requirements. A project review of the design (Final Design Review, FDR) is held at the end of this phase. The final design documentation includes reports of supporting simulations, analyses, tests, as well as drawings, fabrication specifications, procurement plans, and assembly and installation procedures.

0 LIGO

Root WBS denotes the overall LIGO project.

0.4 LIGO-II Construction

All research, development, design, construction, assembly and of the LIGO-II instrument are covered under this WBS structure, organized by subsystems.
The installation of the LIGO-II instrument is also part of this WBS, but is handled as a separate WBS element, not prt of the subsystem WBS elements.

0.4.1Facility

All facility modifications and upgrades to support the LIGO-II instrument are included under this WBS element.

0.4.2Seismic Isolation (SEI)

The seismic isolation subsystem (SEI) is the integrated electromechanical, structural and electronic system used to provide an isolated support for the sensitive in-vacuum components. The isolation includes in-band vibration isolation, micro-seismic peak reduction (total rms position and velocity reduction) and tidal motion compensation. The SEI subsystem also provides for at least 4 degree of freedom DC positioning (side-to-side, fore-and-aft, vertical and yaw) over a range sufficient for initial alignment and drift compensation.
The SEI system applies to both the BSC and HAM chamber installations.
The SEI system also includes:
The electrical wiring to connect the active payloads (suspensions and sensors) to electronics outside the vacuum system, including the vacuum-tight feedthrough connections.
All seals associated with structural support through the vacuum envelop (including flexible bellows if required).
The payload elements supported and isolated by the SEI subsystem include the in-chamber component of the suspension subsystems, in-vacuum interferometer sensing and control (ISC) sensors (if required), input optics components (e.g. Faraday Isolators and fixed mount relay optics) and ancillary optical components (pick-off mirrors, beam reducing telescopes, baffles and beam dumps of the Support Optics Subsystem (SOS)).

0.4.2.1 Subsystem Management

All tasks associated with management of the SEI subsystem are covered in this WBS element, including management oversight of the R&D, design and fabrication phases of the effort. The management function entails monitoring and reporting costs and progress against the development plan, assessment and minimization of development risk by allocation and coordination of resources and appropriate planning.

0.4.2.2 SEI R&D

0.4.2.2.1 Seismic Isolation R&D - Caltech (SEI)

0.4.2.2.2 Stochastic Noise R&D - MIT (STO)

0.4.2.2.3 Seismic Isolation R&D – Stanford

0.4.2.2.4 Seismic Isolation R&D – JILA

0.4.2.2.5 Seismic Isolation R&D – LSU

0.4.2.3 SEI Design

0.4.2.3.1 SEI Conceptual Design/Requirements

0.4.2.3.2 SEI Preliminary Design

0.4.2.3.2.1 Sensor Design

0.4.2.3.2.2 Actuator Design

0.4.2.3.2.3 Electronics Design

0.4.2.3.2.4 SEI/HAM Design

0.4.2.3.2.4.1 System Design/Simulation

0.4.2.3.2.4.2 Mechanical Design

0.4.2.3.2.4.3 Assembly Procedure & Tooling Design

0.4.2.3.2.4.4 Installation Procedure & Tooling Design

0.4.2.3.2.4.5 Prototype Fabrication

0.4.2.3.2.4.6 Prototype Testing

0.4.2.3.2.5 SEI/BSC Design

0.4.2.3.2.5.1 System Design/Simulation

0.4.2.3.2.5.2 Mechanical Design

0.4.2.3.2.5.3 Assembly Procedure & Tooling Design

0.4.2.3.2.5.4 Installation Procedure & Tooling Design

0.4.2.3.2.5.5 Prototype Fabrication

0.4.2.3.2.5.6 Prototype Testing

0.4.2.3.3 SEI Final Design

0.4.2.3.3.1 Sensor Design

0.4.2.3.3.2 Actuator Design

0.4.2.3.3.3 Electronics Design

0.4.2.3.3.4 SEI/HAM Design

0.4.2.3.3.4.1 System Design/Simulation

0.4.2.3.3.4.2 Mechanical Design

0.4.2.3.3.4.3 Assembly Procedure & Tooling Design

0.4.2.3.3.4.4 Installation Procedure & Tooling Design

0.4.2.3.3.4.5 Prototype Fabrication

0.4.2.3.3.4.6 Prototype Testing

0.4.2.3.3.5 SEI/BSC Design

0.4.2.3.3.5.1 System Design/Simulation

0.4.2.3.3.5.2 Mechanical Design

0.4.2.3.3.5.3 Assembly Procedure & Tooling Design

0.4.2.3.3.5.4 Installation Procedure & Tooling Design

0.4.2.3.3.5.5 Prototype Fabrication

0.4.2.3.3.5.6 Prototype Testing

0.4.2.4 SEI Fabrication

0.4.2.4.1 Mechanical Fabrication

0.4.2.4.2 Electronics Fabrication

0.4.2.4.3 Software Coding

0.4.2.4.4 First Article Testing

0.4.2.4.5 Assembly

0.4.3Suspension (SUS)

All suspended optics assemblies for the interferometer are covered under this WBS element, including input optics (mode cleaner, mode matching telescope optics and relay optics), output optics (mode cleaner and relay optics) and core optics (Fabry-Perot cavity optics, power and signal recycling cavity optics). Other optics or electro-optics which may need to be suspended are part of the associated subsystem and are not part of this WBS element (e.g. a suspended reference cavity for the PSL subsystem is not part of this WBS element). There are a few different suspension designs required to meet performance requirements, space constraints and variation in the dimensions/geometry of the optics. Commonality of the design elements and components is a goal within the suspension effort.
This is a summary level WBS element only; no costs are allocated to this WBS element.

0.4.3.1 Subsystem Management

Technical management of the subsystem is covered in this WBS element. This is a level of effort task (the level may vary according to the development phase).

0.4.3.2 Suspension R&D

All research & development across the entire LIGO Science Collaboration (LSC) related to suspensions for LIGO-II are reported to, and coordinated by, the Suspension subsystem leader.
This is a summary level WBS element only; no costs are allocated to this WBS element.

0.4.3.2.1 Suspension R&D - Caltech Fiber/Optics Components

TBW

0.4.3.2.2 Suspension R&D – TNI

TBW

0.4.3.2.3 Suspension R&D – GEO

TBW

0.4.3.2.4 Suspension R&D – Stanford

TBW

0.4.3.2.5 Suspension R&D – Syracuse

TBW

0.4.3.3 Suspension Design

All suspension design activities are covered under the following WBS elements.
This is a summary level WBS element only; no costs are allocated to this WBS element.

0.4.3.3.1 Conceptual Design/Requirements

All suspension design work and costs associated with the Conceptual Design Phase are allocated to this WBS element. The principal deliverables from this element are the Design Requirements Document and the Conceptual Design Document. This WBS element is completed when a successful Design Requirements Review (DRR) has been held and the Preliminary Design Phase is initiated.

0.4.3.3.2 Preliminary Design

All suspension design work and costs associated with the Preliminary Design Phase are allocated to this WBS element. The principal deliverables from this element are the revised Design Requirements Document (if required), the Preliminary Design Document a prototype(s) and associated prototype test results. This WBS element is completed when a successful Preliminary Design Review (PDR) has been held and the Final Design Phase is initiated.
Activities and associated costs, which cannot be allocated to the elements below this level, may be defined at this level, such as: preparation of the design review documentation and conducting the design review.

0.4.3.3.2.1 Ribbon/Fiber Process Design

The engineering and process design for the reliable fabrication of silica fibers or ribbons needed in the suspension are covered in this WBS element. The principal deliverables of this WBS element are a preliminary process specification, preliminary ribbon or fiber prototypes and associated testing of their strength, uniformity and suitability for the suspension system.

0.4.3.3.2.2 Optic/Ribbon Attachment Design

Move this WBS element to the Core Optics Component (COC) structure.

0.4.3.3.2.3 Sensor Design

The design activities for the local damping sensors of the suspensions are allocated to this WBS element. The principal deliverables of this WBS element are a preliminary design description including physical drawings and electronic circuit schematics of the read-out/interface, a tested prototype and test report.

0.4.3.3.2.4 Actuation Design

The design activities for the suspension actuators are allocated to this WBS element. The actuators include both magnetic voice coil actuators and electrostatic actuators. (The photon actuator is not part of this WBS element.) The principal deliverables of this WBS element are a preliminary design description including physical drawings and electronic schematics of the drive/interface circuit, a tested prototype and test report.

0.4.3.3.2.5 BSC Suspension Design

The suspensions for optics housed in the BSC chambers (attached to an interface with the SEI subsystem at their tops) are covered under this WBS element.
This is a summary level WBS element only; no costs are allocated to this WBS element.

0.4.3.3.2.5.1 System Design/Simulation

Overall design trade-offs and simulations of the integrated control and system dynamics of the BSC suspension preliminary design are covered in this WBS element. The deliverable from this element is a documented simulation model and a report on comparisons of the simulation of the performance of the preliminary design against requirements and against prototype testing.

0.4.3.3.2.5.2 Mechanical Design

All activities associated with the preliminary mechanical design of the BSC suspension are covered in this WBS element (except or those associated with other preliminary design phase elements such as the sensor design, actuator design and the assembly and installation tooling design). This relates principally to the design of the structure(s) used to interface to the SEI system, suspend the multiple pendulum, mount the sensors and actuators and cage or 'safe' the suspended masses. The principal deliverables of this WBS element are a preliminary design description including physical drawings and schematics, a tested prototype and test report.

0.4.3.3.2.5.3 Control System Hardware & Software Design

All activities associated with the preliminary control system design of the BSC suspension are covered in this WBS element. The principal deliverables of this WBS element are a preliminary design description including a system block diagram, a control block diagram, a hardware layout drawing, a software development plan, electronic circuit schematics of any required custom control and interface electronics, a tested prototype and test report.

0.4.3.3.2.5.4 Assembly Procedure & Tooling Design

All activities associated with the design and definition of a procedure for the physical assembly and test of the BSC suspension are covered in this WBS element. The principal deliverables of this WBS element are a preliminary assembly specification, drawings of assembly tools and fixtures, prototype assembly tools and fixtures and a report on an assembly trial.

0.4.3.3.2.5.5 Installation Procedure & Tooling Design

All activities associated with the design and definition of a procedure for the physical installation and in-situ test of the BSC suspension are covered in this WBS element. The principal deliverables of this WBS element are a preliminary installation specification, drawings of installation tools and fixtures.

0.4.3.3.2.5.6 Prototype Fabrication

Activities and costs associated with the fabrication of integrated BSC suspension prototypes are covered in this WBS element. Prototype fabrication of components (e.g. sensors, actuators, etc.) are covered under other WBS elements; This WBS element is strictly for the development of two complete integrated BSC suspensions that are tested stand-alone. One prototype is to be used in air principally for assembly and installation testing. The other prototype is to be used in a vacuum chamber for use in control system testing. The deliverables for this WBS element are two complete BSC prototype

suspensions, one set of assembly tools and a susupension test stand including limited data acquisition capability to support testing.

0.4.3.3.2.5.7 Prototype Testing

Activities and costs associated with the testing of integrated BSC suspension prototypes are covered in this WBS element. Prototype testing of components (e.g. sensors, actuators, etc.) are covered under other WBS elements; This WBS element is strictly for the testing of the two complete integrated BSC suspensions (from 0.4.3.3.2.5.6). A test report on the assembly, installation, fit, function and (to the extent possible) performance of the suspensions is a deliverable of this WBS element

0.4.3.3.2.6 HAM Suspension Design

0.4.3.3.2.6.1 System Design/Simulation

0.4.3.3.2.6.2 Mechanical Design

0.4.3.3.2.6.3 Control System Hardware & Software Design

0.4.3.3.2.6.4 Assembly Procedure & Tooling Design

0.4.3.3.2.6.5 Installation Procedure & Tooling Design

0.4.3.3.2.6.6 Prototype Fabrication

0.4.3.3.2.6.7 Prototype Testing

0.4.3.3.3 Final Design

0.4.3.3.3.1 Ribbon Process Design

0.4.3.3.3.2 Optic/Ribbon Attachment Design

0.4.3.3.3.3 Sensor Design

0.4.3.3.3.4 Actuation Design

0.4.3.3.3.5 BSC Suspension Design

0.4.3.3.3.5.1 System Design/Simulation

0.4.3.3.3.5.2 Mechanical Design

0.4.3.3.3.5.3 Control System Hardware & Software Design

0.4.3.3.3.5.4 Assembly/Installation Design

0.4.3.3.3.5.5 Prototype Fabrication

Activities and costs associated with the fabrication of integrated BSC suspension prototypes are covered in this WBS element. Prototype fabrication of components (e.g. sensors, actuators, etc.) are covered under other WBS elements; This WBS element is strictly for the development of complete integrated BSC suspensions that are tested in the LASTI system at MIT. Two complete BSC prototype suspensions including one set of assembly and installation tools and fixtures are deliverables of this WBS element.

0.4.3.3.3.5.6 Prototype Testing

Activities and costs associated with the testing of integrated BSC suspension prototypes are covered in this WBS element. Prototype testing of components (e.g. sensors, actuators, etc.) are covered under other WBS elements; This WBS element is strictly for the testing of complete integrated BSC suspensions that are tested in the LASTI system at

MIT. A test report on the assembly, installation, fit, function and (to the extent possible) performance of the suspensions is a deliverable of this WBS element. While labor and infrastructure support will be provided by the LASTI system, all labor for the assembly, installation and test of the suspension prototypes should be allocated to this WBS element.