LASER INTERFEROMETER GRAVITATIONAL WAVE OBSERVATORY

LIGO Laboratory / LIGO Scientific Collaboration

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Universal Suspension Subsystem Design Requirements Document

Revision -04: Dennis Coyne

Revision –03: Jay Heefner, Dennis Coyne

Revision –02: Dennis Coyne, Janeen Romie

Revision –01: Phil Willems, Peter Fritschel, David Shoemaker, Norna Robertson

Distribution of this document:
LIGO Science Collaboration

This is an internal working note
of the LIGO Project.

California Institute of Technology
LIGO Project – MS 18-34
1200 E. California Blvd.
Pasadena, CA 91125
Phone (626) 395-2129
Fax (626) 304-9834
E-mail: info@ligo.caltech.edu

Massachusetts Institute of Technology
LIGO Project – NW17-161
175 Albany St
Cambridge, MA 02139
Phone (617) 253-4824
Fax (617) 253-7014
E-mail: info@ligo.mit.edu

LIGO Hanford Observatory
P.O. Box 1970
Mail Stop S9-02
Richland WA 99352
Phone 509-372-8106
Fax 509-372-8137

LIGO Livingston Observatory
P.O. Box 940
Livingston, LA 70754
Phone 225-686-3100
Fax 225-686-7189

http://www.ligo.caltech.edu/

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Change Record

Revision	Date	Changes
01	26 Jan 2001	Initial release in support of the SUS Requirements and Conceptual Design Review
02	9 Jun 2005	Revised in support of the SUS Preliminary Design Review, Part 1 (focused on BSC SUS requirements). Numerous changes.
03	29 Jun 2005	Revised in support of the SUS Preliminary Design Review, Part 2, focused on BSC SUS Electronics requirements & design. Numerous changes, including some clarifications/refinements on the wording in the non-electronics sections as well.
04	7 Dec 2005	1) Added duration for the non-operating, low temperature, in-vacuum bake 2) Removed comments and clarified a few items mostly in the electronics requirements (sections 2.6.4.1 and 2.8.1)

Table of Contents

Appendices

Table of Figures

Table of Tables

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1 Introduction

1.1 Purpose and Scope

The purpose of this document is to define engineering and implementation requirements common to all the Advanced LIGO Suspension systems. The scope of this document is limited to general engineering requirements (not performance requirements) which apply to the Suspension Subsystem (SUS).

1.2 Applicable Documents

- E960022, LIGO Vacuum Compatibility, Cleaning Methods and Qualification Procedures
- E960050, LIGO Vacuum Compatible Materials List
- E010613, Generic Requirements and Standards for Detector Systems
- E030084, Hybrid OSEM Assembly Specification
- E030350, Drawing Requirements
- E030513, LASTI Prototype Suspension Controller Operation Manual
- E030518, Mode Cleaner Triple Suspension Assembly Specification
- E030546, Suspension Controls Prototype Test Plan
- E030647, Advanced LIGO Detector Subsystem Interface Control Document
- E040329, Advanced LIGO Quadruple Pendulum Suspension Failure Modes and Subsequent Repair Approaches
- M950046, System Safety Management Plan
- M950090, "Guidelines for Detector Construction Activities", M950090
- M960001, LIGO Laser Safety Program
- M980140, LIGO Hanford Observatory Emergency Action Plan
- M990034, LIGO Hanford Observatory Contamination Control Plan
- M990148, LIGO Livingston Observatory Laser Safety Plan
- M990184, LIGO Livingston Observatory Emergency Action Plan
- M000009, LIGO Livingston Observatory Security Procedures
- M020131, LIGO Hanford Observatory Laser Safety Plan with Added Engineering Controls and Interlock Hardware
- M040088, RODA on OSEM Counts and Responsibilities for SUS Prototypes
- M040091, RODA on Covers for Advanced LIGO Optics
- M040112, LIGO Livingston Laser Safety Plan

- M050174, RODA on Requirement for SUS Features to Aid in Initial Alignment
- M050175, RODA on Initial Alignment Requirements on COC Coating Reflectivity
- T010103, Advanced LIGO Suspension Conceptual Design Document
- T010007, Cavity Optics Suspension Subsystem Design Requirements Document

1.3 Definitions

See E010613, Generic Requirements and Standards for Detector Systems for a complete list of acronyms and names.

2 Requirements

2.1 Physical Characteristics

All Advanced LIGO suspensions must fit within the LIGO vacuum chambers as presently built with Advanced LIGO SEI isolation systems. For the ITM, ETM, BSC, and FM suspensions this will be the BSC chambers. For the other suspensions this will be the HAM chambers.

2.2 Interfaces External to LIGO Detector Subsystems

The final assembly and installation procedures must be compatible with LIGO site constraints and sequencing. Assembly and installation procedures must also be compatible with each site's relevant emergency action plan, security procedures, laser safety procedures and any other safety procedures in place. A number of these are listed above under Applicable Documents.

2.3 Interfaces to LIGO Detector Subsystems

The key document that records the interfaces between the detector subsystems is E030647. RODAs are used to record decisions and agreements between members of one subsystem and between subsystems. The RODA Status Page may be found at http://www.ligo.caltech.edu/~coyne/AL/project_management/RODA/RODA_status.htm

Concerning the interface between COC and SUS, it is the SUS subsystem intent to protect and cover the optics whenever possible except for those times when the optic surfaces need to be available for ear bonding or alignment studies. A RODA, M040091, has been signed that details this agreement.

Concerning the interface between AOS, IAS and SUS, it is the SUS subsystem intent to include in the structure design and fabrication aids for alignment, including crosshairs at a fixed distance from the centerline of the optic and mounting provisions for an alignment prism. A RODA, M050174, has been signed that details this agreement.

2.4 Reliability

This section does not include/address accidents (e.g. personnel applying excess current to an OSEM) or failures by design of other subsystems (e.g. inadequate AOS beam blockage allows fiber/wire to be cut.) This section applies to nominal operating conditions.

The failure rate for the ensemble of all in-vacuum components in all suspensions shall be at least 5 years per interferometer at the 99% probability level.

The failure rate for the ensemble of all in-air components/equipment shall be at least 6 months at the 99% probability level.

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2.5 Maintainability/Repairability

The spares policy, which includes the extent to which the spare optics and masses shall be built up into full assemblies and tested/characterized, has not been defined at this point. This policy will affect the Mean Time To Repair (MTTR) requirements detailed below. If the time to acquire a replacement component will prevent the repair-time requirements from being achieved, then sufficient spares of that component shall be kept at the sites.

2.5.1 In-air components

The Mean Time To Repair (MTTR) in-air components shall be less than one day. Spares for all in-air components will be kept at the sites.

2.5.2 In-vacuum components

Failure scenarios and their subsequent repair approaches are detailed in Advanced LIGO Quadruple Pendulum Suspension Failure Modes and Subsequent Repair Approaches, E040329. Another document detailing repair approaches for HAM cavity suspensions will be created in the near future. The first document discusses whether, for a given scenario, the repair needs to be done by removing the entire suspension and SEI system (called a cartridge installation/de-installation) or by only removing the bottom of the suspension out the side chamber door. The BSC suspension designs should minimize the necessity of a cartridge de-installation whenever possible, to reduce the mean time to repair. The suspensions in HAMs are expected to be individually removable(i.e. never by removing the entire seismic isolation system).

2.5.2.1.1 Suspension fibers/ribbons

It will likely not possible to perform repairs on the fused silica suspension fibers and ribbons in-situ, due to the fact that the welding of the ribbons and fibers will be carried out using a CO_2 laser that is located outside of the chamber. Broken fibers and ribbons will require that the suspension be removed to some extent. The time to make such repairs should not exceed two days, excluding chamber opening, venting, pumpdown and facility preparation. It also does not include the preparation time for fabricating, characterizing and choosing the replacement fibers or ribbons. The two day period does include time to clean up the fragments of glass and any other debris resulting from the failure.

2.5.2.1.2 Wires

The length of time to repair a wire is dependent on the location of the wire and any secondary damage inflicted by the failure. Designs have been implemented to allow for the optics and blades to be locked in place and positioned such that the majority of the wires may be replaced relatively easily. Wire repair is done with a spare, pre-loaded, pre-tested clamp-wire-clamp assembly. Drum ended wire design/implementation will be carried out such that repair may be accomplished in a timely manner. The time to install a replacement wire should not exceed two days, excluding chamber opening, venting, pumpdown, facility preparation and spare wire assembly preparation. The two day period does include time to clean up the fragments of glass and any other debris resulting from the failure.

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2.5.2.1.3 Optic ears

In the event of an ear being damaged, the test mass optic must be removed and replaced with another. It is our assumption now that test mass spares (in process and shelf) will not have ears bonded. However, it is our assumption that ears will be bonded to penultimate mass spares. So, time must be allowed for a test mass spare to be selected, a set of ears to be bonded and cured and the test mass optic to be re-installed. The whole process shall take no more than fifty days, but the time to switch out the optic and replace it, once the ear is bonded, should not exceed two days, excluding chamber opening, venting, pumpdown and facility preparation.

2.5.2.1.4 Sensors and actuator

Sensor/actuators and actuator parts shall be replaceable with the suspension system in-situ. The time to make such repairs shall not exceed two days, excluding chamber opening, venting, pumpdown and facility preparation.

2.5.2.1.5 Magnets

Magnets which are used for force actuation with a coil (not those used for eddy current damping) are attached in two ways. They are screwed into the metal masses and bonded onto the optical material masses. It is assumed that ears and magnets will be bonded onto spare penultimate masses, as all are identical. Replacement of magnets, by replacement of optics shall not exceed 14 days, excluding magnet assembly/optic preparation, chamber opening, venting, pumpdown and facility preparation. Replacement of a screwed in magnet, shall not exceed 2 days, excluding magnet/flag/standoff preparation, chamber opening, venting, pumpdown and facility preparation. It is assumed the excursions into the chamber will include finding and removing the broken magnet assembly parts.

2.5.2.1.6 Mechanical adjustments

It is our requirement that any mechanical adjustments that need to be made, including but not limited to re-alignment of the eddy current dampers, realignment of sensors/actuators and actuators with respect to magnets, shall take no more than two days, with a goal of 4 hrs, excluding chamber opening, venting, pumpdown and facility preparation.

2.6 Environmental Conditions

The suspension system will be assembled at the Observatories from easily transportable parts (by commercial handlers in provided shipping containers).

2.6.1 Natural Environment

Assembly Description (for background; not a statement of requirements): The fused silica fibers will be fabricated at the observatories and stored in a carefully controlled low-humidity low-dust atmosphere. Each suspension will be assembled, with clean parts, once in an outbuilding at the sites, with metal masses. It will then be partially disassembled, if required. It will then be wrapped in UHV foil and double bagged in C.P. Stat. It will then be stored in shipping containers in a building, as opposed to outdoors. It is assumed that the fused silica fibers will be welded onto the suspension masses near the appropriate chamber, in a clean room. It is assumed that the suspensions will be transported very short distances once the fibers are welded in place.

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2.6.1.1 Temperature and Humidity

The temperature and humidity conditions for the various locations and major assembly and installation steps is indicated in Table 1 below.

Table 1 Environmental Performance Characteristics

Condition	Temperature and Humidity	Comments
Non-Operating: Storage of non-fused silica parts & sub-assemblies	10C to 38C, 0 to 90 % RH (non-condensing)	storage indoors, but with minimal conditioning Any special storage containers to maintain cleanliness are provided by SUS
Non-operating: storage of fused silica fibers in special containers	Facility: 15C to 27C, 0 to 45% RH[1] Containers: 15C to 27C, <1% RH	Container storage in environment typical of extremes for lab and office spaces Low humidity containers for fiber/ribbon storage are provided by SUS
Non-operating: storage of COC/bonded-ear assemblies	Facility: 15C to 27C, 0 to 45% RH[2]	Containers for storage are provided by COC.
Non-operating: accelerated creep bake	maraging steel blades are loaded and held down in position with set screws (within ~+/1mm), and baked in air at 100 deg C for 110 hour to as an anti-creep measure	SUS sub-assemblies are baked. The oven is provided by SUS.
Non-operating: low temperature, in-vacuum bake	46C, in-vacuum (<10^{-6} torr) for a duration of 7 days per episode, with a total of 10 episodes over the life of the equipment	to accelerate pumping water out of the LIGO vacuum system
Assembly with non-fused silica parts	Facility: 15C to 27C, 0 to 45% RH in a class 100 cleanroom	For example in the staging building high bay under a BSC cleanroom. Cleanroom provided by FAC.

[1] Ref: Parsons Engineering, LIGO Building Specifications, Doc # (CHECK THAT RH IS CONSISTENT WITH LIGO BLDGS)

[2] Ref: Parsons Engineering, LIGO Building Specifications, Doc # (CHECK THAT RH IS CONSISTENT WITH LIGO BLDGS)

Condition	Temperature and Humidity	Comments
Assembly with fused silica parts	Facility: 15C to 27C, 0 to 45% RH in a class 100 cleanroom TBR: a class 10 clean volume may be required. COC is evaluating cleanliness requirements.	Assembly with fused silica parts requires welding. Welding equipment & procedures are provided by SUS. To be performed in the LVEA or VEA adjacent to the chamber under a cleanroom provided by FAC.
Transport/handling of parts	standard shipping environments	no special transport or handling equipment is anticipated. SUS provides all packaging and shipping containers for SUS parts. COC provides special handling/storage container and shipping containers for the optics and the optic/ear assembly.
Transport/handling of Assembly with non-fused silica parts	In transport: 10C to 38C, 0 to 90 % RH (non-condensing) standard lifting/handling equipment used with extreme caution and SUS defined procedures. Transport from assembly area to storage area and to LVEA/VEA spaces is via an air-ride van	All transport of SUS final assemblies (without the fused silica components) is within an observatory – no commercial transport.
Transport/handling of Final Assembly (with fused silica components)	Facility: 15C to 27C, 0 to 45% RH in a class 100 cleanroom (TBR; class 10 cleanroom)	Transport/handling of the final assembly is only within the LVEA or VEA. Only SUS tooling/fixtures and the overhead crane are used for final assembly handling.
Operation of in-vacuum components	23C +/- 2C high vacuum (~10^{-9} torr)	LIGO vacuum
Operation of components external to the vacuum	23C +/- 2C RH typical of office environment (numerical values?)	LVEA, VEA, CDS Rack Room

2.6.1.2 Seismic Environment

The following three subsections address severe, moderate and minor ground motion environments and associated requirements, in accordance with "Generic Requirements and Standards for Detector Subsystems" document[3]. Since each of the SUS assemblies are attached to an SEI optics table, the seismic environment for SUS is then not (in principal) simply the ground motion environment, but is (potentially) modified by the SEI structural system. Assumptions with regard to the effect of the SEI system in defining the seismic environment for SUS are defined in each of following subsections.

2.6.1.2.1 Severe Earthquake Motion

Requirement: The SUS system must survive a static equivalent load of 0.4 g in any horizontal direction and 1.1 g in the vertical direction, simultaneously. Allowable failures , for loads which equal or exceed the above, are as follows:

- failure of the ribbons/fibers
- failure of wires in the suspensions
- failure of the ear to optic bond, but not failure of the optic (i.e. the optic should be capable of re-use without compromise to its thermal noise performance)

Derivation of the Requirement: In operational modes, all of the SUS assemblies consist of a caging and reaction frame, structure, and one or two suspended chains of masses. During strong ground motion episodes, the actuation forces used for active damping and global length and alignment control will be inadequate to keep the suspended masses under control. In fact, the motion will exceed sensing and actuation dynamic ranges and feedback control will be disabled. Likewise, feedback in the SEI subsystem will also be disabled and it will not provide any active suppression of the ground motion. The HEPI hydraulic actuators will provide some passive damping, but the HEPI system will not provide active isolation since the range of the inertial and displacement sensors will be exceeded. In addition the range of the HEPI hydraulic actuators is only 2 mm, whereas the ground motion will be on the order of 100 mm.

The caging/reaction structure and the chain(s) of suspended mass(es) are kinematically and dynamically separate structural systems and will respond differently to the seismic environment. The suspension point and the base of the cantilevered caging structure are essentially coincident at the interface with the SEI optics table (about 10 cm offset with rigid structure). The motion at this interface point depends upon the SEI structural system. The lowest frequencies of the SEI structural system[4] are the passive, quasi-rigid body frequencies of the Internal Seismic Isolation (ISI) system, which range from about 2 Hz to about 9 Hz. In this frequency range the seismic ground motion is amplified, as indicated in the Generic Requirements & Standards document. The elastic design spectrum presented in the Generic Requirements & Standards document is calculated for a structural system with 5% of critical damping (or Q = 10). The damping associated with the SEI quasi-rigid body modes (which involve flexure of a set of maraging steel blades and rod flexures) is much less – perhaps as little as 0.0001 damping, which implies a large amplification

[3] D. Coyne, Generic Requirements and Standards for Detector Systems, E010613-01.

[4] K. Smith, ASI, Post-CDR Design Assessments of BSC Structure, ASI document No. 20009033-A, 15 oct 2004, LIGO document number pending.

factor. However, the two, quasi-free, internal stages of the SEI system have mechanical stops which limit motion to ~0.5 mm. Consequently the large amplification, at the quasi-rigid body mode frequencies, cannot be realized due to the nonlinearity of the mechanical gap/stops. When up against the mechanical stops, the composite SEI structural system should have a damping factor close to 5% and its fundamental frequency will be on the order of 20 Hz (the first mode of the stage 0 or SEI support structure). The SEI mechanical stops are hard stops, so one can expect very little loss and the impacts will generate high frequency impulses on top of the filtered low frequency ground motion.

The motion of the suspended masses would also tend to be higher than the motion presented at the suspension point, due to the high Q of the suspension modes at frequencies from about 0.5 Hz to 12 Hz. However, the suspension masses are caged and can only move about 1 mm before impacting on the stops. The motion of the optics table at the structural resonances of the SUS caging structure (about 100 Hz) is attenuated passively by the SEI system (other than the impulsive events at every ground motion reversal).

It is difficult to say with any certainty the equivalent static load associated with a strong seismic ground motion event without running a time domain, non-linear response analysis. Most of the time the SEI stages will be against their stops and the small gaps, between the mechanical limit stops, can be roughly approximated as a sloppy bolted joint. From these heuristic arguments, a static equivalent acceleration of 0.4 g in the horizontal direction would seem an adequate basis for design. In addition due to the coupled mode structure of the SEI system, it seems prudent to also design for a vertical static equivalent load of 0.1 g (in addition to the nominal 1 g).

2.6.1.2.2 Moderate Earthquake Motion

Requirement: The SUS system must survive, without any failures, a static equivalent load of 0.11 g in any horizontal direction and 1.03 g in the vertical direction, simultaneously.

Derivation of the Requirement: The same heuristic arguments in the section above on severe earthquake induced motion apply for the moderate earthquake motion defined in the "Generic Requirements and Standards for Detector Subsystems" document; The peak ground motion associated with the moderate earthquake level is about 36 mm. Consequently we adopt the maximum static equivalent accelerations from the elastic design spectrum in the "Generic Requirements and Standards for Detector Subsystems" document for the horizontal and vertical directions.

2.6.1.2.3 Minor Ground Motion

Requirement: All SUS systems must be able to operate through the 95th percentile limits of ground motion defined in E. Daw's long term study[5] of the LIGO seismic environment and filtered through the SEI system. NOT AN OPERATIONALLY USEFUL STATEMENT OF REQUIREMENT; NEED TO REVISE

[5] E. Daw, Long Term Study of the Seismic Environment at LIGO, Class. Quantum Grav., 11 Mar 2004, P040015-00

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2.6.1.3 Magnetic Fields

Comment [LIGO1]: Recommend talking with Robert Schofield on this; may be dominated by motion of the SEI platform wrt surrounding fields.

The magnetic field in the vicinity of the suspension OSEMs and magnets is potentially dominated by the emission of the SEI actuators. The Interface Control Document (ICD) between SEI and SUS/UK (for the BSC chamber), E050159, imposes limits on the magnetic field and field gradient.

2.6.2 Magnetic Damping

Something somewhere about limiting damping via slotted components

2.6.3 Electrostatics

Something somewhere about restrictions on materials and proximity to limit the probability of generation and forces due to electrostatic charges

2.6.4 Induced Environment

2.6.4.1 Electro-Magnetic Interference and Compatibility

The SUS electrical/electronics equipment shall meet the Electromagnetic Interference (EMI) and Electromagnetic Compatibility (EMC) requirements stipulated in the "Generic Requirements and Standards" document. In particular SUS electronics will comply with the following two documents:

- LIGO EMI Control Plan and Procedures, E960036-A
- M. Zucker, "LIGO Interferometer Electronics EMC Requirements", E020986-01

In particular, as stated in E960036-A:

- LIGO digital electronics shall conform to FCC Part 15, Subpart J regulations for radiated nd conducted emissions form Class B computing devices
- LIGO digital and analog electronics shall conform to the selected portions of MIL-STD-461E called out in LIGO-E960036-A, for both electromagnetic emission and susceptibility to ambient environment
- LIGO-E960036-A also calls out requirements on DC Power Supplies, Circuit Shielding and Grounding (digital, baseband analog and RF) as well as cabling standards.

In addition to the requirements document listed above, there are several other documents that may be of use during the design phase of the project. These documents are:

- LIGO- E040288-00-C, “Installation of RFI Mitigated HEPI System at LLO”
- LIGO- E020350-08-R, “EMC, Shielding and Grounding Retrofit Plan”

In the event of conflict between requirements stated in the aforementioned EMC requirements document and the latter mention documents, the requirements document takes precedence.

The following list is a short summary of some of the key points of the EMC Requirements document.

- Analog and digital circuitry/modules to be housed in separate racks or enclosures
- No switching power supplies or DC-DC converters are allowed in analog racks or the (L)VEAs
- No computers (no CPUs or circuits with high speed clocks other than ADC, DAC modules) in the (L)VEAs
- No equipment requiring 60Hz in the (L)VEA
- No fans in the (L)VEAs
- Shielded, twisted pair or coax cables should be used for signals. Shielded, twisted pair should be used for all non-RF signals. Coax may be used for RF if imbalance is acceptable.
- Equipment placed in the (L)VEAs should be minimized and limited to necessary pre-amplifiers and other circuits required to meet demanding performance requirements

2.6.4.2 Acoustic

SUS equipment shall be designed to produce the lowest levels of acoustic noise as possible and practical. In accordance with the "Generic Requirements and Standards" document:

- Cooling fans will not used in the LVEA or VEA areas
- Broadband acoustic noise level of SUS equipment in the LVEA will be less than: 3×10^{-5} Pa/√Hz at 10 Hz , 3×10^{-7} Pa/√Hz at 1 kHz and above
- Racks and crates in the CDS Rack Area shall be no noisier than the EMI-tight Dawn crate[6] and Knurr Rack currently used at LLO.

2.6.4.3 Mechanical Vibration

Mechanical vibration from the subsystem shall not increase the vibration amplitude of the facility floor within 1 m of any other vacuum chambers and equipment tables by more than 1 dB at any frequency between 0.1 Hz and 10 kHz. Limited narrowband exemptions may be permitted subject to LIGO review and approval.

2.7 Transportability

All items shall be transportable by commercial carrier without degradation in performance. As necessary, provisions shall be made for measuring and controlling environmental conditions (temperature and accelerations) during transport and handling. Special shipping containers, shipping and handling mechanical restraints, and shock isolation shall be utilized to prevent damage. All containers shall be movable by forklift. All items over 100 lbs. which must be moved into place within LIGO buildings shall have appropriate lifting eyes/provisions and mechanical strength to be lifted by cranes.

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[6] S. Marka, Notes on the Acoustic Emission of VME Crates at LIGO, 25 Apr 2003, LIGO-T030075-00

Any special handling equipment will be provided by the SUS subsystem to the installation (INS) group/effort.

2.8 Design and Construction

2.8.1 Electronic Requirements

2.8.1.1 Signal Levels and Types

2.8.1.1.1 Analog Inputs to CDS Analog to Digital Converters

The actual analog to digital converters to be used in AdL have yet to be chosen. The following should be used as design guidelines when designing interface circuitry.

- Input Voltage: +/-10 volts, differential
- Input Impedance: >1Kohm
- Input-referred noise: <200nV/√Hz for freq>100Hz, 200nV/√Hz @10Hz[7]. More generally, gains should be adjustable so that the entire dynamic range (e.g. 10 V) is used, and then the noise should be limited by front end (ADC) noise, not the signal conditioning circuitry.
- Sample Rate: 16384 (and perhaps submultiples)samples/second, nominal
- CMRR: >68dB at 100KHz

2.8.1.1.2 Analog Outputs from CDS Digital to Analog Converters

The actual digital to analog converters to be used in AdL have yet to be chosen. The following should be used as design guidelines when designing interface circuitry.

- Output Voltage: +/-10 volts, differential
- Drive capability: 1Kohm load shunted by 1000pF capacitance
- Output-referred noise: 200nV/√Hz for freq>100Hz, TBD @10Hz[8]
- Sample Rate: 16384 samples/second, nominal

2.8.1.1.3 Binary Outputs from CDS Modules

Binary outputs from CDS digital control modules to analog circuitry are typically used for on/off control of such things as mode switches, relays, power switches. The actual output of the CDS modules will be of the open collector type. Therefore, the interface circuitry on the module being controlled shall provide all necessary pull-up resistors and electrical isolation required. The specifications for the binary outputs are:

- Switching Voltage: 5 volts minimum, 30 volts maximum

[7] The numbers for the input referred noise voltage of the ADC are based on tests recently conducted on the Analog Devices AD7679 ADC. In these tests, it was found that the input referred noise voltage of the ADC is less than 100nV/√Hz for freq>10Hz, but the input range was +/-5 Volts.

[8] Output noise voltage for DACs is based on measured output noise of the present LIGO VME-based DACs manufactured by Frequency Devices.

- Switching Current: 1 amp maximum
- Switching Time: < 1milli-seconds
- On-state voltage: 2 volts maximum

2.8.1.1.4 Binary Inputs to CDS Modules

Binary inputs to CDS digital control modules from analog circuitry are typically used to monitor the state of such things as switches, and comparators. The specifications for the binary inputs are:

- On-State voltage (logical 1): > 2 volts
- Off-state voltage (logical 0): <0.8 volts
- Maximum input voltage: TBD
- Input impedance: >1Kohm

2.8.1.2 Read-back of system status

The state of a circuit must be capable of being read back to the controlling hardware. The success of all binary instructions to a module from CDS must be verifiable via a return signal derived from the controlled hardware.

2.8.1.3 Propagation of signals

In general, all low frequency (DC-10MHz) signals that are propagated from rack to rack, or from one location to another, shall be differential on both the transmitting and receiving end. Exceptions to this rule will be handled on a case by case basis. RF signals (Freq>10MHz) can use coaxial cables, but special attention must be paid to the termination of the shield so as to not compromise the grounding and shielding of the system.

2.8.1.4 Connector and Cable Types

List of acceptable connector and cable types, strain reliefs

Rules for determining which end gets the male and female connector.

Cables shall be point to point with no splitting of cables between multiple connectors with the possible exception of wiring harnesses internal to the vacuum system or internal to chassis.

2.8.1.5 Power Supplies and Available Voltages

2.8.1.6 Test Points

All designs shall have adequate internal and external test points to aid in troubleshooting and functional testing with a minimum of disassembly. Test points on circuit boards can be in the form of pads or clip points and must be clearly identified on the board and the schematic. External test points shall utilize appropriate connectors. Inputs should incorporate circuitry to prevent inadvertent connection of signals into the circuit, i.e. on/off switches. Outputs should be buffered to prevent circuit failure upon connection of shorts, low impedance loads, voltage sources, etc.

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2.8.2 Electrical Requirements

2.8.2.1 Circuit Protection

All circuits shall be designed such that the following situations will not cause permanent damage:

- Short or low impedance load connected to output
- Removal or application of one or more of the required power supplies
- Reversal of input power

Fuses and/or circuit breakers may be used for protection, but there must be a local indication that the fuse has blown or the circuit breaker has tripped. Fuses should be easily replaceable and not require desoldering of the device.

2.8.2.2 Local Voltage Regulation

Bulk DC power will be distributed from racks located outside the (L)VEAs. The available voltages are listed in section 2 of this document. Local regulation of this distributed power will be required at the rack, subrack and/or the chassis level.

2.8.2.3 Design Modularity

In an effort to reduce the number and types of spares required and lower the MTTR for a system, circuits and systems should be designed to be as modular as possible. Common functions should be grouped into modules or chassis that perform a well-defined function. Uniformity of component selection and circuit design across modules is recommended

2.8.2.4 Component Availability

All components used in the design shall be readily available from multiple distributors or manufacturers. In the event that an acceptable component is not available from multiple sources, the final production should include adequate spares of the component to cover the expected lifetime of the device. To as great an extent as possible, designs should not include components that are slated by the manufacturer for obsolescence.

2.8.3 Materials and Processes

These are requirements on the materials used in the design and the processes used in assembly.

2.8.3.1 Finishes

Surface-to-surface contact between dissimilar metals shall be controlled in accordance with the best available practices for corrosion prevention and control. Extra-vacuum surfaces requiring protection shall be painted LIGO blue or otherwise protected in a manner to be approved. Metal components intended for vacuum service shall have quality finishes on all surfaces, suitable for vacuum. All sharp edges and corners shall be rounded. All materials shall have non-shedding surfaces. Aluminum components used in the vacuum shall not have anodized surfaces.

Tight fit/tolerance sliding contacts should be avoided if possible in the LIGO vacuum. If necessary then low outgassing, vacuum compatible, solid, non-organic lubricants should be used, in accordance with E960050, LIGO Vacuum Compatible Materials List.

2.8.3.2 Fasteners

All fasteners shall be imperial thread (not metric thread).

All in-vacuum fasteners shall use oversize tapped threads to prevent galling, in accordance with E030350, Drawing Requirements.

Unless other overriding design considerations dictate an alternate set of materials, or thread treatment, all in-vacuum fasteners shall comply with the following requirements to prevent galling and reduce particulate shedding. If an alternate design choice is recommended, then this choice must be shown by test[9] not to gall after LIGO cleaning procedures and service in vacuum:

> Aluminum: LIGO aluminum in-vacuum parts that are expected to be disassembled (such as clamps for securing optical table components into the aluminum optics table) must use stainless steel screws in Nitronic-60 (N60) thread inserts for the tapped holes, to reduce the amount of generated particles and to reduce the risk of galling. For parts that are disassembled rarely, stainless steel screws shall be used in 0.005" oversize tapped aluminum parts.
>
> Stainless Steel: Silver-plated, stainless steel screws shall be used in 0.005" oversize tapped stainless parts.

2.8.3.3 Materials for Vacuum Service

2.8.3.3.1 SUS Approved and Provisionally Approved Materials

SUS will use only materials from the list of approved, or provisionally approved materials for initial and advanced LIGO given in:

E960050-B, LIGO Vacuum Compatible Materials List

or request qualification of materials not on this list (note that approval is a lengthy process, and requests must proceed critical design decisions by XXX months). Pending Changes for Rev. C of the vacuum materials list will add approved, or provisionally approved, status for the following materials which SUS intends to use:

- 24 conductor + shield cable from Accu-Glass, containing Kapton insulation and PEEK thread braiding. This cable is used by SEI and SUS.
- Coax cable from ADE, containing Teflon insulation. This cable is used by SEI for ADE position sensors and by SUS for the electrostatic drive actuation signal.

2.8.3.3.2 SUS Materials & Components Qualification Processes

The basic reference for the procedures by which materials and components are qualified for service in the LIGO vacuum system is:

E960022-B, LIGO Vacuum Compatibility, Cleaning Methods and Qualification Procedures

[9] Testing similar to that reported in T040111, Galling Tendencies and Particles Produced by Ultra Clean Screw Threads

Deleted: 3

Pending Changes for Rev. C that are specifically relevant to SUS are as follows:

- integrate in the cleaning/air bake/FTIR sampling and evaluating that was performed on the large parts for Initial LIGO
- put in a qualified increase in the bake temperatures for 6061-T6 aluminum

2.8.3.3.3 SUS Materials in the queue for acceptance testing:

The following materials, which SUS intends to use, are in the vacuum qualification testing queue (no priority ordering is implied here):

- DuPont Flexible Circuits. The whole part to be constructed of 'flexi' i.e. no 'rigid' sections. (Stuart Aston, Univ. of Birmingham, SUS/UK subsystem)
  - Start Laminate: Kapton (LF8515)

    (document link: http://www.dupont.com/fcm/products/H-73244.pdf

  - Coverlay (x2): Kapton (LF0110)

    (document link: http://www.dupont.com/fcm/products/H-73245.pdf

  - DuPont Pyralux Series - Kapton / Acrylic Adhesive system.

    (document link: http://www.dupont.com/fcm/products/H-73246.pdf
- Glenair Micro-D connector, part number MWDM2L-9SSM-432. (Stuart Aston, Univ. of Birmingham, SUS/UK subsystem)
  Comprised of Beryllium Copper, Phosphor Bronze, Gold, Nickel, Aluminum 6061 and A380 alloys, "Liquid Crystal Polymer (per MIL-M-24519)", Stainless Steel 300 series, Hysol Epoxy #C9-4215 (black) potting and (if supplied with wires) silver-plated copper, with either TFE or Tefzel Teflon insulation
- MMG nickel plated Nd-B-Fe magnets (Helena Armandula, SUS subsystem)
  Comprised of sintered 24% Neodimium, 75% Iron, 1% Boron by weight and may contain traces of fully alloyed Cobalt and Dysprosium. The coating is electroless nickel, 10-15 um thick on top of a thin copper layer.
- Vacseal adhesive (Helena Armandula, SUS subsystem)
  Although approved for use in Initial LIGO, Vacseal has not been tested to Adv. LIGO requirements as yet.

2.8.3.4 Processes

2.8.3.4.1 Cleaning

All materials used inside the vacuum chambers will be cleaned in accordance with E960022-B, LIGO Vacuum Compatibility, Cleaning Methods and Qualification Procedures. Final cleaning & vacuum preparation of parts should be performed after all processing has been completed, if at all possible. Cleaning shall be performed at intermediate steps to insure cleanliness when subsequent fabrication or assembly steps limit the effectiveness of final cleaning; For example the OSEM coil former and coil wire will be cleaned and vacuum baked prior to winding. Care will be taken to insure proper handling in processing steps following intermediate cleaning steps.

The various suspensions will use 2 or 3 different types of Optical Sensor and Electro-Magnetic actuator (OSEM) assemblies. The assembly procedure for the "Hybrid OSEM" (used on the Recycling Mirrors Suspension and Mode Cleaner Suspension), including cleaning steps in given in E030084-02, "Hybrid OSEM Assembly Specification". A similar procedure will be developed for all OSEM variants used in the suspension assemblies.

Parts or assemblies shall be capable of disassembly for cleaning, or joined in such a way as to facilitate cleaning and vacuum preparation procedures; i.e., internal volumes shall be provided with adequate openings to allow for wetting, agitation and draining of cleaning fluids and for subsequent drying.

All SUS parts will be detergent and solvent cleaned in ultrasonic baths and then vacuum baked, and qualified for LIGO vacuum service with an RGA measurement, with the exception of the lower structure of all BSC suspensions (and potentially the upper structure of the combined FM/ITM suspension). These large components will be detergent cleaned and air baked, with qualification for LIGO vacuum service via an FTIR test. In all cases the procedures will comply with E960022.

2.8.3.4.2 Welding

2.8.3.4.2.1 Metal

None of the SUS component welds form a pressure vessel. In general the SUS components are stiffness critical structure, not strength critical, so that weld strength is not an issue. The principal concern for SUS welds is vacuum cleanliness.

Before welding, the surfaces should be cleaned (but baking is not necessary at this stage) according to the UHV cleaning procedure(s). All welding exposed to vacuum shall be done by the tungsten-arc-inert-gas (TIG) process. Welding techniques for components operated in vacuum shall be in accordance with the best ultra high vacuum practice, such as the SLAC "Technical Specification for Vacuum Systems", SLAC-TN-86-6 (section VI. Welding and Brazing and Appendix I.D)

In particular all vacuum welds shall be full penetration wherever possible to eliminate trapped volumes or difficult to clean crevices, i.e. virtual leaks. All weld procedures for components operated in vacuum shall include steps to avoid contamination of the heat affected zone with air, hydrogen or water, by use of an inert purge gas that floods all sides of heated portions.

The welds should not be subsequently ground (in order to avoid embedding particles from the grinding wheel).

The SUS group intends to use the Initial LIGO Seismic Isolation System: Fabrication Process Specification, E970063, as a guide for welding requirements and process sequence, as well as the associated detailed processing procedures developed by Allied Engineering to implement E970063 (e.g. "Cleaning Process Control Procedures: S/S Support Tubes and Alum HAM & BSC Weldments", C981212-00).

Weld preparation details shall be called out on the drawings developed by SUS. Each of these welds will be worked out with a welder experimentally to insure full penetration and minimal heat distortion of the parts (e.g. as part of the prototype development efforts). The specific examples in the SEI "weld configuration & weld procedure" drawing, D972202 will serve as initial guidance for the SUS welding details. These weld preparation details are all for full penetration welds suitable for in-vacuum service. They are typically for joining aluminum plate from 0.25 to 0.75 inches thick.

2.8.3.4.2.2 Fused Silica

Requirements for welding fused silica fibers or ribbons to fused silica ears (which are bonded to a suspended mass) are pending completion of the enabling R&D.

2.8.4 Component Naming

A standard naming convention for all SUS components shall be developed, documented and uniformly applied in all SUS documentation, in order to avoid confusion and conflicts with names from other LIGO subsystems. The SUS naming conventions will be an input to a revision to the current LIGO Naming Convention, E950111-A.

2.8.5 Interchangeability

Because the various suspensions differ substantially in optic size, material, number of pendulums, and type of reaction chains, most of their components are not expected to be interchangeable, with the exception of the following:

- There will be 2 or 3 types of Optical Sensing and Electro-Magnet (OSEM) assemblies used on the suspensions. However, suspension designs will use these basic designs in common as mush as practical.
- In general the magnet/standoff/flag assembly is common to all suspension assemblies.
- The intent is to design OSEM read-out electronics modules and OSEM drive electronics modules so that component values can be readily changed to accommodate the dynamic range and noise requirements of a particular suspension, i.e. as much as possible the electronics hardware can be adapted for service with any suspension.
- Suspension dog clamps (used to secure the suspension mechanical assembly to the optics table) will be common in design, at least for HAM and BSC suspension types.

2.8.6 Safety

A hazard/risk analysis shall be conducted in accordance with guidelines set forth in the LIGO Project System Safety Management Plan, M950046-F, section 3.3.2.

2.8.6.1 Personnel Safety

The only personnel safety risks identified for the SUS subsystem are as follows:

2.8.6.1.1 Laser Safety

Welding fused silica fibers, or ribbons, to fused silica ears is performed with a high power CO2 laser. Safety procedures will be developed as part of the basic welding procedure and delivered to the LIGO project at the completion of the enabling R&D. A Standard Operating Procedure (SOP) will be developed for each LIGO Facility at which laser welding is to be performed (currently this is envisioned to include the LIGO-MIT LASTI Lab as well as the two LIGO Observatories). Each SOP will be compliant with the relevant LIGO Laser Safety Plan:

LIGO Livingston Observatory Laser Safety Plan, M040112-07

LIGO Hanford Observatory Laser Safety Plan, M020131-01

LIGO LASTI Laser Safety: Kavli Institute/MIT safety plan

Note that when SUS performs alignment of components within the assembly, as part of the assembly process, the laser intensity is not anticipated to be high enough to require laser safety measures. When an intense laser source is used for alignment of the optics in situ, it is the responsibility of the AOS subsystem to provide a laser safety plan compliant SOP.

2.8.6.1.2 Heavy Items

The SUS assemblies and many of the SUS parts are quite heavy. Detailed procedures, and where necessary special handling fixtures/tools, will be developed for handling and lifting SUS components and assemblies in support of assembly and installation phases. These procedures and fixtures will be built with machine and personnel safety in mind, particularly overturning for the long (~ 2 meter) quadruple suspension assemblies.

2.8.6.1.3 Blade Spring Release

A lot of energy is stored in the elastic deflection of the maraging steel springs of the suspensions. The design must allow for sufficient safety margin to insure that fracture does not occur. In addition, the blade springs must be caged or stopped so that fingers can't get pinched or impacted. The tooling and procedures for loading the springs in particular must protect the assembler from accidental injury.

2.8.6.1.4 High Voltage

2.8.6.2 Machine Safety

The following are required in every suspension design to assure safety of the equipment:

2.8.6.2.1 Suspended Mass Stops

To protect the magnet/flag assemblies and masses (or optics) from hard or unintended impact, limit stops must be provided in the design. These stops serve to protect the suspension components from handling loaded, accidental bumping during assembly and installation and earthquake events.

2.8.6.2.2 Design Factor of Safety (FS)

For metallic structures, the FS should be a minimum of 1.25 for yield and 1.4 for ultimate. For the bonds of composite structures (metallic or non-metallic), the FS shall be a minimum of 2.0 for ultimate. For non-metallic, brittle structures, the FS should be a minimum of 3.0 for ultimate stress. All of these FS are to be used with minimum ("S basis" or equivalent) yield and ultimate values for the material[10].

2.8.6.2.3 Proof Testing

Proof testing on the actual end articles must be performed for the following SUS elements:

- all magnet/standoff/flag bonds

[10] S-Basis material values are defined as the value for which 99% of a normal distribution have a higher value with a 95% confidence. S-basis material properties are provided in "Metallic Materials Properties Development and Standardization (MMPDS)", Jan 2003, DOT/FAA/AR-MMPDS-01 (Note: This is the replacement for MIL-HDBK-5.)

- all ear to mass/optic bonds
- all fused silica fibers or ribbons

Proof testing is to be performed to a factor of 1.2 over the maximum service load. The ear bond and fiber/ribbon proof testing shall be done in an inert environment to minimize flaw growth.

2.8.6.2.4 Inert Environment for Fused Silica Fibers or Ribbons

To minimize flaw growth, the fused silica fibers or ribbons are to be kept in an inert environment (free of moisture) as much as possible. In particular the fibers are to be stored in a moisture free environment. Ribbons or fibers are to be proof tested before welding into a suspension assembly.

2.8.6.2.5 Coil Over-current Protection

Excessive current into the OSEM coil when in the vacuum system risks excessive outgassing and potential for causing an open condition (which requires an vent and entry into the vacuum system to replace). Over-current protection will be used at all times to prevent this failure mode.

2.8.7 Human Engineering

The suspensions must be attached to the isolation platforms with a minimum of force and torque. The design will include fasteners that can accommodate this requirement and allow space for this to be accomplished.

The suspensions will in general consist of components that are both heavy and delicate and require precise positioning for assembly. The assembly and installation fixtures listed in a following subsection shall account for this.

The suspensions when assembled will have delicate optics hanging separated by very small gaps. The assembly, installation, and repair procedures shall include measures to prevent errors that may damage these optics. They shall also minimize the likelihood that the fused silica suspension ribbons or fibers will be touched.

2.8.8 Assembly and Maintenance

Assembly fixtures and installation/replacement procedures shall be developed in conjunction with the SUS hardware design. These shall include (but not be limited to) fixtures and procedures for:

- assembly of the in vacuo components in a clean room (class 100) environment
- initial alignment of the SUS components
- installation/removal/replacement of the actuator components
- installation/removal/replacement of the SUS stage elements in general
- installation/removal/replacement of the fused silica suspension fibers
- installation/removal/replacement of the suspension wires

All assembly procedures must be written by the SUS working group and tested by 'third parties', with appropriate feedback to design and procedure.

The BSC suspensions shall be assembled outside the vacuum chambers and attached to the seismic isolation platform there, and the whole shall be installed into the chamber by the 'cartridge' installation procedure. The assembly/installation procedures for BSC SUS's must be consistent with those for the SEI. The HAM SUS's shall be installed into the chamber from the side and attached to the already installed SEI.

The special handling fixtures/tooling are deliverable items for the SUS subsystem. A description of the basic installation handling steps and equipment for SUS installation into BSC chambers is given in G050245-00. An installation arm fixture intended for use in transporting SUS BSC assemblies onto a Payload Positioning Fixture, within a BSC chamber, is described in T050073-01. A Payload Positioning Fixture, which serves to lift, position and align a BSC/SUS, is described in T050071-00.

2.9 Documentation

2.9.1 Specifications

The following specifications will be developed during the course of design and development:

- Interface Control Documents (ICD) between SUS/US and SUS/UK and every other subsystem. These partial ICD documents are then subsumed into the overall ICD, E030647, by reference/incorporation.
- OSEM Specification
- OSEM Drive Electronics Specification
- Electro-Static Drive Electronics Specification
- Suspension Welded Structure processing specification (covering pre-cleaning for welding, welding practice/procedures, heat treatment, post welding machining if required)
- Suspension UHV cleaning and FTIR sampling specificaiton

2.9.2 Design Documents

The following are the intended major design documents to be updated and revised at least as frequently as reviews for the major subsystem development phases (Requirements/Conceptual Design, Preliminary Design, Final Design, Fabrication) in accordance with M950090, "Guidelines for Detector Construction Activities", M950090

- T010103-04, Adv. LIGO Suspension System Conceptual Design
- T010007, Cavity Optics Suspension Subsystem: Design Requirements Document
- LIGO SUS Prototype/Test Plans. A test plan for the SUS controls prototypes has been written -- E030546, Suspension Controls Prototype Test Plan. A test plan for the noise prototypes is pending.
- LIGO SUS Installation and Commissioning Plans

In addition to these documents there are many technical documents supporting the design development.

2.9.3 Engineering Drawings and Associated Lists

A complete set of drawings suitable for fabrication must be provided along with Bill of Material (BOM) and drawing tree lists. All drawings shall meet the requirements stipulated in E030350, LIGO Drawing Requirements.

All engineering documentation (drawings, BOMs, specifications, procedures, test reports, etc.) shall use the LIGO drawing numbering system and the LIGO Document Configuration Control system.

2.9.4 Procedures

Procedures shall be provided for, at minimum,

- OSEM Assembly, e.g. E030084, Hybrid OSEM Assembly Specification
- Suspension Mechanical Assembly, e.g. E030518, Mode Cleaner Triple Suspension Assembly Specification
  These procedures should be accompanied by video recording of key assembly steps to illustrate the written procedure and facilitate training.
- Fiber/Ribbon Welding
- Ear Bonding
- Initial installation and setup of equipment
- Normal operation of equipment
- Normal and/or preventative maintenance
- Troubleshooting guide for any anticipated potential malfunctions

2.9.5 Manuals

Manuals shall be provided for, at a minimum:

- OSEM Drive/Readout Electronics
- Electro-Static Drive Electronics
- Suspension Controller, e.g. E030513, LASTI Prototype Suspension Controller Operation Manual
- Manual for Suspension Testing

2.9.6 Documentation Numbering

All documents shall be numbered and identified in accordance with the LIGO documentation control numbering system. See E030350, Drawing Requirements for details.

2.9.7 Travellers

2.9.7.1 Vacuum Preparation Traveller

All parts that are installed in the LIGO vacuum system must have a vacuum preparation travller completed. NEED MORE DESCRIPTION, LINK TO TRAVELLER FOR, GOOD EXAMPLE

2.9.7.2 Electronics Travellers

NEED REFERENCE TO ELECTRONICS TRAVELLER FORM, GOOD TRAVELLER EXAMPLE, …

2.9.7.3 Critical Process Travellers

Travellers for any other key or complex processes that require careful QA should be developed and utilized as needed.

2.10 Test Plans and Procedures

Fabrication, assembly and installation phase testing plans and associated procedures are to be developed to address quality assurance and to comply with the Verification Matrix in the appendix.

In general, all designs require the following:

- Test Plan for the module or subsystem being designed. This test plan should fully test the function of the circuit or system and should include, but not be limited to transfer functions, channel-to-channel crosstalk, nominal currents and voltages, list of necessary test equipment and test fixtures. In addition to the “standard” functional tests, the plan should include tests for out of band noise and oscillations. An excellent example of a test plan for a module can be found in LIGO T040189-00, “Common Mode Servo Board Test Procedure”.
- Test Report and Electronics Travelers for each component supplied
- Functional description and block diagrams. For more complex components or subsystems, a complete user manual including a troubleshooting guide and maintenance manual should be supplied.
- Bill of Materials
- Schematics for board and system level

2.11 Logistics

The design shall include a list of all recommended spare parts and special test equipment required.

3 Quality Assurance Provisions

This section includes all of the examinations and tests to be performed in order to ascertain the product, material or process to be developed or offered for acceptance conforms to the requirements.

3.1 Responsibility for Tests

Testing of suspensions components shall be the responsibility of the suspensions working group and of LASTI.

3.2 Reliability Testing

Reliability evaluation/development tests shall be conducted on items with limited reliability history that will have a significant impact upon the operational availability of the system. This includes in particular:

- fused silica ribbons or fibers and bonded attachments, shall be individually strength-tested (proof tested) before installation in the suspensions; see section 2.8.4.2.3.
- OSEM photodiodes and emitters shall be burn-in tested to get stability of operation and weed out infant mortality

3.3 Configuration Management

Configuration control of specifications and designs shall be in accordance with the LIGO Detector Implementation Plan.

3.4 Quality Conformance Inspections

Design and performance requirements identified in this specification and referenced specifications shall be verified by inspection, analysis, demonstration, similarity, test or a combination thereof per the Verification Matrix (TBD). Verification method selection shall be specified by individual specifications, and documented by appropriate test and evaluation plans and procedures. Verification of compliance to the requirements of this and subsequent specifications may be accomplished by the following methods or combination of methods:

3.4.1 Inspections

Inspection shall be used to determine conformity with requirements that are neither functional nor qualitative; for example, identification marks.

3.4.2 Analysis

Analysis may be used for determination of qualitative and quantitative properties and performance of an item by study, calculation and modeling.

3.4.3 Demonstration

Demonstration may be used for determination of qualitative properties and performance of an item and is accomplished by observation. Verification of an item by this method would be accomplished by using the item for the designated design purpose and would require no special test for final proof of performance.

3.4.4 Similarity

Similarity analysis may be used in lieu of tests when a determination can be made that an item is similar or identical in design to another item that has been previously certified to equivalent or more stringent criteria. Qualification by similarity is subject to Detector management approval.

3.4.5 Test

Test may be used for the determination of quantitative properties and performance of an item by technical means, such as, the use of external resources, such as voltmeters, recorders, and any test equipment necessary for measuring performance. Test equipment used shall be calibrated to the manufacturer's specifications and shall have a calibration sticker showing the current calibration status.

4 Preparation for Delivery

Packaging and marking of equipment for delivery shall be in accordance with the Packaging and Marking procedures specified herein.

4.1 Preparation

Vacuum preparation procedures as outlined in LIGO Vacuum Compatibility, Cleaning Methods and Procedures, E960022, shall be followed for all components intended for use in vacuum. After wrapping vacuum parts as specified in this document, an additional, protective outer wrapping and provisions for lifting shall be provided.

Electronic components shall be wrapped according to standard procedures for such parts including electro-static discharge mitigation bags.

4.2 Packaging

Procedures for packaging shall ensure cleaning, drying, and preservation methods adequate to prevent deterioration, appropriate protective wrapping, adequate package cushioning, and proper containers. Proper protection shall be provided for shipping loads and environmental stress during transportation, hauling and storage. The shipping crates used for large items should use for guidance military specification MIL-C-104B, Crates, Wood; Lumber and Plywood Sheathed, Nailed and Bolted. Passive shock witness gauges should accompany the crates during all transits.

For all components that are intended for exposure in the vacuum system, the shipping preparation shall include double bagging with Ameristat 1.5TM plastic film (heat sealed seams as practical, with the exception of the inner bag, or tied off, or taped with care taken to insure that the tape does not touch the cleaned part). The bag shall be purged with dry nitrogen before sealing.

4.3 Marking & Travelers

Appropriate identification of the product, both on packages and shipping containers; all markings necessary for delivery and for storage, if applicable; all markings required by regulations, statutes, and common carriers; and all markings necessary for safety and safe delivery shall be provided.

Identification of the material shall be maintained through all manufacturing processes. Each component shall be uniquely identified. The identification shall enable the complete history of each component to be maintained (in association with Documentation “travelers”). A record for each component shall indicate all weld repairs and fabrication abnormalities.

For components and parts which are exposed to the vacuum environment, marking the finished materials with marking fluids, die stamps and/or electro-etching is not permitted. A vibratory tool with a minimum tip radius of 0.005" is acceptable for marking on surfaces which are not hidden from view. Engraving and stamping are also permitted.

Appendix A: Quality Conformance Inspections

TBD

Table 2 Quality Conformance Inspections

Paragraph	Title	Inspection	Analysis	Demonstrate	Similarity	Test