# LIGO-M000202-A-M
# ADVANCED LIGO SUSPENSIONS DEVELOPMENT PLAN

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May 15, 2001

## Overview

The Advanced LIGO suspensions development is and will be performed by a broad collaboration between the LIGO Lab, the GEO600 project, and the LSC. This document records an understanding of how this development will be organized, especially regarding the large effort necessary to design, construct, and test prototype suspensions in LASTI. As such, it will serve both as a manifesto stating the research necessary to design the Advanced LIGO suspensions and as a charter describing the organization of the collaboration that will design and qualify the suspensions.

The development of suspensions can be broadly divided into two parts: research into performance of the components of the suspension, in particular the test mass mirrors and suspension wires; and design of complete suspensions that give adequate isolation and control without impairing noise performance. These two areas overlap substantially, but the latter in particular will require detailed orchestration of several laboratories and substantial resources to successfully design, prototype, and test the suspensions.

This research effort will be broadly separated into two design phases: a Preliminary Design Phase, to be followed by a Final Design Phase.

## Research and Development Issues

What follows is a partial list of research issues that require resolution for a successful suspension design. It is not meant to exclude other issues that may arise.

The choice between fused silica and sapphire test masses will depend in part on the thermal noise performance of the two materials. Verification of the intrinsic losses of large optics made from both materials must be done. Measurement, and if necessary, reduction of the additional losses due to the surface polish and mirror or electrostatic driver coatings is also required. Qualification of the thermal noise introduced by attachments must be done.

The strength and reliability of the attachments to the test and penultimate masses must be qualified as acceptable for Advanced LIGO. This may also influence the choice of fused silica or sapphire for the test mass material.

The decision to use ribbons rather than fibers for the fused silica suspensions will require improvements to the breaking strength of suspension ribbons, improved ribbon fabrication procedures, and understanding of the dynamics of ribbon twist.

The suspension sensors' noise must be reduced to a level where it does not increase the technical noise beyond Advanced LIGO requirements. The actuators must be developed with sufficient range to control the suspension, again without introducing thermal or technical noise.

The suspensions themselves must be designed to keep all resonant frequencies save violin modes or internal mirror modes below 10Hz or below the thermal noise limits, except possibly for very narrow (and thus easily filtered) noise peaks. This may require the development of novel penultimate masses.

Excess noise in the complete suspension will need to be limited. Lock acquisition in complex suspensions will need to be demonstrated and understood. Local damping techniques will need to be verified. Electrostatic charging of the test masses will need to be reduced to a level that does not impair control or increase thermal noise.

**Table 1: ADVANCED LIGO SUS Prototype Tests Summary**

| Milestones | Date |
|---|---|
| SUS Conceptual Design | 1Q00-3Q01 |
| SUS Design Requirements Review (DRR) | 3Q01 |
| Preliminary Design Phase | 3Q01-4Q02 |
| 30kg quad prototype delivered to MIT for test | 3Q01 |
| *Controls* prototypes delivered to LASTI for test (1 BSC/COC & 2 HAM Cavity Optics suspensions) | 1Q02-3Q02 |
| SUS Preliminary Design Review (PDR) | 4Q02 |
| Final Design Phase | 4Q02-3Q04 |
| *Noise* prototypes delivered to LASTI (2 BSC/COC & 5 HAM Cavity Optics suspensions) | 2Q03-3Q03 |
| SUS Final Design Review (FDR) | 3Q04 |
| Begin production procurement | 3Q04 |
| SUS assembly begins at sites | 4Q04 |
| SUS installation starts | 3Q05 |

**Conceptual Design**

The Design Requirements Documents will be written together by the LIGO Lab and GEO, and will be completed by 3Q01. The Design Requirements Review will then occur in 3Q01 with a review board composed of knowledgeable personnel from both groups.

The Conceptual Design Document (CDD) will be written by GEO with assistance from the LIGO Lab, principally for interface design and compatibility. It will be an updated version of the LIGO-T000012, LIGO II Suspension: Reference Designs document, and will be completed in 3Q01.

With this short schedule, there will likely be many items as yet to be determined (TBDs) in the document, which is acceptable. The CDD is a work in progress and will be updated as changes and advancements occur. The Conceptual Design Review will occur after completion of the document. The same review board for the DRR will oversee the CDR.

**Preliminary Design**

Beginning in 1Q01, a LIGO Lab scientist has visited GEO for approx. 6 months to assist design, research and development issues for the Advanced LIGO suspensions and to coordinate LIGO Lab activities with the GEO design effort, as well as to assist in installation of GEO600. This will coincide with the construction of a prototype quad suspension with a 30kg dummy test mass at GEO for damping and control tests at MIT starting in 3Q01. LIGO Lab personnel will visiting GEO sites to learn about design and to aid with any design or technological issues that cannot be addressed by GEO alone, with emphasis on interface, assembly, handling, and installation issues. Also at this time, GEO and the LIGO Lab will develop designs for three Advanced LIGO suspensions: a 40kg test mass BSC quadruple pendulum suspension and two HAM triple pendulum cavity optic suspensions, one for a recycling mirror and one for a mode cleaner mirror. These three suspensions are considered to be a small but representative sample of the different types of cavity optics suspensions required by Advanced LIGO. A fourth type of suspension, the HAM Auxiliary Optics suspension, will be based on a LIGO I suspension (nominally a single pendulum.) The LIGO Lab and GEO will jointly design the mechanical suspension structure. The LIGO Lab will document the design and component drawings, design and document the installation fixtures, and will procure the mechanical parts for prototypes of the three suspensions using machine shops and vendors who may participate in the production for Advanced LIGO. GEO will design and document the assembly fixtures and design, document, and procure the 'front end' electronics (analog electronics that directly connect to the actuators and local sensors) and the actuators and local sensors, with support from the LIGO Lab, especially regarding interface and fabrication standards. The LIGO Lab will design, document, and procure all digital electronics and high voltage supplies. These protoypes will be tested at LASTI by the LIGO Lab staff around 3Q02, with support from GEO.

The BSC/COC and HAM Cavity Optics suspension controls prototypes for LASTI are to demonstrate mechanical and controls requirements, but not all noise (electrical or mechanical) requirements. Therefore, they can utilize aluminum masses rather than fused silica or sapphire and can use metal suspension wires. Similarly, electronics for these prototypes may not be final, but will be functionally complete.

After the controls prototypes have been tested, there will be a Preliminary Design Review. The Preliminary Design Review for the suspensions may be broken up into more than one review for the various suspensions, as warranted by the complexity and degree of difference between designs. The goal of the PDR is to determine whether the designs meet the requirements and where improvement is needed. The review board will be composed of knowledgeable personnel from both groups and from the LSC. Once the preliminary design is accepted, the final design phase will begin.

**Final Design**

The final design phase is meant to improve the preliminary design, based on late research results, design decisions, and problems uncovered with the preliminary prototypes. The LIGO Lab will lead the design of all varieties of suspensions for Advanced LIGO, in close collaboration and consultation with GEO, and will incorporate data from the LASTI tests. The LIGO Lab will produce the appropriate drawings, specifications and documentation that will allow for timely fabrication, assembly and installation of the Advanced LIGO suspensions, also in collaboration with GEO.

In 2Q03, noise prototypes, consisting of 2 BSC/COC and 4 HAM Cavity Optics suspensions, will be delivered to LASTI. In addition to complete controls, they will have fused silica fibers or ribbons and sapphire or fused silica test masses and will set limits on the thermal and excess noise in the Advanced LIGO suspensions. They will likely have components in common with the controls prototypes they replace. These prototypes will be tested singly and in various interferometer configurations to understand various aspects of thermal noise, suspension control, and interferometer lock acquisition and operation. The LIGO LAB will be responsible for all design, documentation, and procurement of materials necessary to construct, install, and test the prototypes.

Again, there may be separate final design reviews (FDR's) for the various suspensions, and the review board composed of knowledgeable personnel from both groups and from the LSC. The goal of the FDR is to determine that the suspension design is adequate for use in an Advanced LIGO detector. A Final Design package will be prepared prior to the Final Design Review that includes detailed drawings and specifications, procurement and contract information, inspection and test documentation, and assembly and installation documentation.

**Fabrication, Assembly and Installation**

The LIGO Lab will direct the procurement, fabrication, assembly and installation activities with the assistance of GEO. The suspensions will be assembled, tested, and queued for installation at the LIGO sites in optics labs prepared for this work.