



*LIGO Laboratory / LIGO Scientific Collaboration*

CALIFORNIA INSTITUTE OF TECHNOLOGY  
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LIGO-T1000311-v7

*Advanced LIGO*

12 March 2013

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TransMonSUS Assembly & Installation  
Hazard Analysis

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**Signature Sheet**

Each of the undersigned has carefully reviewed the contents of this hazard analysis and believes it has adequately identified potential personnel safety hazards and risks. The safety of the personnel carrying out the procedures or using the equipment addressed by this hazard analysis is considered to be at an acceptable level.

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**DIRECTORATE REVIEW & APPROVAL IS NOT  
REQUIRED FOR THIS HAZARD ANALYSIS**

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Albert Lazzarini, LIGO Directorate Date

## CHANGE LOG

Date, version	Summary of Changes
2012-08-11 V5	<ul style="list-style-type: none"><li>• Updated document format according to template F1000028-v4.</li></ul>
2012-10-31 V6	<ul style="list-style-type: none"><li>• Changed title</li><li>• Added assembly and installation procedures</li><li>• Added hazards</li></ul>
2014-03-12 V7	<ul style="list-style-type: none"><li>• Removes the assembly and installation procedure sections (and references to these sections) because they were far too lengthy. It was too difficult to see the hazards because of all of the technical detail (which is best left in the references procedures).</li></ul>

## 1 Scope

The purpose of this document is to identify potential hazards, analyze their consequences, and evaluate proposed methods and systems to manage those hazards in support of the assembly and installation of the aLIGO TransMonSUS (TMS). This is done by developing a description of the intended assembly and installation, its support systems and proposed safety systems. Potential hazards are identified and analyzed with the aim of identifying and evaluating safety functions and systems that will be relied upon to manage the hazards. A protocol is established to help ensure that safety functions are realized through the design and operational process.

## 2 Summary of Hazards

The major potential hazards to equipment and personnel during the assembly of this suspension include:

- 1) Personnel Injury from Lifting Heavy Assemblies
- 2) Hazards Due to Lifting Mechanism and Dropped Loads
- 3) Injury from Wires Under tension
- 4) Injury from Sudden Release of Tensioned Blade Springs
- 5) Pinching/Cutting of Hands and Bumps to the Head, Etc.
- 6) Hazards Caused by Failure of Lifting Equipment
- 7) Injury during Optical Alignment of External 1064nm and 532nm Beams
- 8) Vacuum Contamination
- 9) Damage to ETM Quad Suspension and Mirror
- 10) Damage to TMS Equipment by External Personnel Working In the Vicinity

Each hazard is described in detail later in this document.

## 3 Overview

The Transmission Monitor Suspension (TMS) is an in-vacuum component that is located behind the ETM (End Test Mass) and is mounted to the internal seismic isolation (ISI) optics platform inside the BSC, as shown in **Figure 1**.

The TMS consists of three sub-assemblies: 1) suspension frame and top mass with springs and controls, 2) ISC TMS Optical Assembly, and 3) TMS Telescope.

The TMS Telescope reduces the size of the interferometer (IFO) beam transmitted through the ETM. The reduced TMS beam is used for monitoring the alignment of the IFO beam. The TMS is also used for injection of the green laser beam used in the Arm Length Stabilization (ALS) scheme. Finally, the TMS also accommodates probe beams for the Hartmann sensor that monitors the curvature of the ETM HR surface.

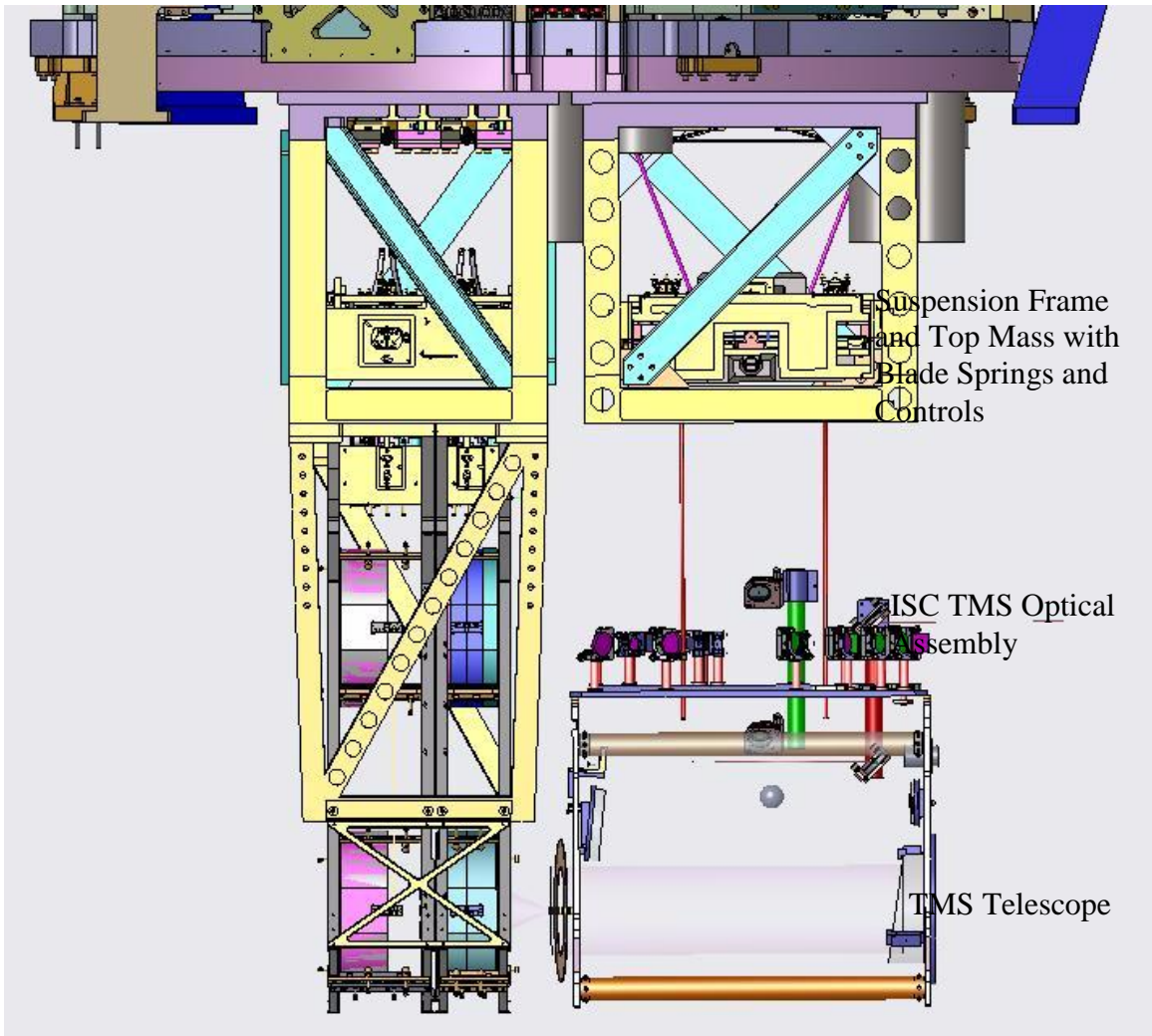


Figure 1: TMS shown behind the ETM quad

#### 4 Related Documentation

LIGO-M070360	Advanced LIGO Safety: Processes and Guidelines
LIGO-M950046	LIGO Project System Safety Plan
LIGO-M020131	LIGO Hanford Observatory Laser Safety Plan with Added Engineered Controls and Interlock Hardware
LIGO-D0901880	aLIGO AOS Transmission Monitor System Assembly
LIGO-D1101307	Tooling Layout aLIGO TMS Telescope Safety Supports
LIGO-E1201012	TransMonSUS Assembly & Installation Procedure
LIGO-T1000674	Wire Safety Procedure for Suspensions
LIGO-T1100603	TMS Telescope Alignment Procedure

LIGO-T1100258	TMS Telescope Alignment
LIGO-T1100474	ISC Alignment Sources
LIGO-T1200049	aLIGO Transmission Monitor Suspension Installation Plan
LIGO-E1000097	ETM TransMon Telescope_SUS Installation Plan
LIGO-E1100841	TMS Transportation-Installation Restraint Procedure

## 5 Hazard Analysis

### 5.1 Personnel Injuries, or Equipment Damage, from lifting, or falling, heavy assemblies

#### 5.1.1 Mounting the ISC Table Assembly to the TMS Telescope

Four people will lift the ISC Table Assembly and place it on top of the TMS Telescope. The ISC Table Assembly weighs approximately 115 lb., and this procedure may cause a strained back.

#### 5.1.2 Mounting the AOS ETM Telescope Upper Suspension Frame and Top Mass to the Tele-opt Table (Bosch Frame)

A Genie lift, with special lifting forks attached and with the legs splayed appropriately to avoid tipping over of the load, will lift the Upper Suspension Frame and Top Mass up to the underside of the Tele-opt Table Frame Plate D1100807 on the Bosch Frame. The Upper Suspension Frame and Top Mass weigh ~ 273 lbs (124kg), and serious damage to the equipment and injury to personnel would occur if the load were to fall. Safety Hazards when using the Genie Lift are addressed in E1100520, which must be read before transporting the Upper Suspension Frame and Top Mass. Be careful to balance the load so that the Genie lift will not tip over and cause damage to TMS equipment and serious injury to personnel.

When clamping the Upper Suspension Frame to the Bosch Frame Table, falling objects may injure personnel. All personnel should be aware that objects such as nuts and bolts and tools could fall while someone is working at height. Hard hats and safety shoes must be worn at all times.

#### 5.1.3 Transporting and Mounting the Upper Suspension Frame and Top Mass to Cartridge

The Upper Suspension Frame and Top Mass will be immobilized. The Genie lift with special lifting forks attached and adapter lift tool will be used to transport and lift the Upper Suspension Frame and Top Mass up to the ISI table on the Cartridge placed on top of the Test Stand. This portion of the TMS Assembly weighs 273 lbs (124kg), and serious damage to the equipment and injury to personnel would occur if the load were to fall.

When clamping the Upper Suspension Frame to the ISI Optical Table, falling objects may injure personnel. All personnel should be aware that objects such as nuts and bolts and tools could fall while someone is working at height. Hard hats and safety shoes must be worn at all times.

### 5.2 Hazards Due to Working with Wires under Tension.

The TMS assembly has numerous sets of wires under tension. The wire segments are cut to the desired lengths, cleaned and then assembled into tension clamp-wire-clamp assemblies before they are attached to the full TMS assembly. The proper wire assembly procedure, T1000674, should be followed to avoid the tensioned wire springing out of the wire fixture and puncturing the skin. Glove



liners should be worn as a protective layer, and safety glasses must be worn at all times when the wires are under tension to prevent injury in the unlikely event that a wire breaks or a wire clamp slips, resulting in the release of a fast moving wire end or shrapnel.

The following assembly procedures involve wires under tension.

### **5.2.1 D1101166 TMS Upper Suspension Wire Assembly**

The wire used in the D1101166 TMS Upper Suspension Wire Assembly is pre-stretched with a load of approximately 136 lbs, which may be hazardous unless safety procedures are followed.

### **5.2.2 D1101163 TMS TELESCOPE SUS WIRE ASSEMBLY**

The wire used in the D1101163 TMS Telescope Sus Wire Assembly is pre-stretched with a load of approximately 88 lbs, which may be hazardous unless safety procedures are followed.

## **5.3 Sudden Release of Tensioned Blade Springs**

The following assembly procedures involve tensioned blade springs.

### **5.3.1 Pre-loading of Suspension Blades**

In the event that the tension in the springs should suddenly be released, a wire attached to the spring may break or a wire clamp may slip, resulting in the release of a fast moving wire end or shrapnel object. Safety glasses must be worn at all times when the springs are under tension. Be aware of injury to exposed fingers during assembly work; use proper tools where possible for assembly instead of putting fingers in close proximity to blades. Follow proper assembly procedures.

The following procedures may cause injury to personnel if safety precautions are not followed.

#### **5.3.1.1 Pre-loading of Top Mass Suspension Blades**

The pre-load (blade straightening) of the Top Mass Suspension Blade is applied by using the Straightening Tooling Assy - Quad Top Stage Blade Tooling D060370. The top blade springs are each pre-loaded with approximately 140 lbs.

#### **5.3.1.2 Pre-loading of TMS Telescope Suspension Blades**

The TMS Telescope Suspension blade springs are loaded to approximately 90 lbs by means of hanging weights (see D060403 Picture Book Assembly process). After the blades have been straightened, the tips will be captured in the pre-loaded position by attaching the blade tip clamps.

### **5.3.2 TMS Transportation-Installation Restraint Procedure**

There is also a hazard to personnel working in close proximity by the sudden release of stored spring energy during step 5 of the E1100841 restraint procedure due.

## **5.4 Pinching/Cutting of Hands and Bumps to the Head, Etc.**

Each team member should inspect to his/her satisfaction the prospective part to be handled to determine if that part has a potentially hazardous sharp edge. Hands may also be pinched when assembling parts to one another, but this can be mitigated with proper attention to handling the parts. During the assembly inside the vacuum chamber, personnel should be mindful of where they stand and move so as to not damage nearby objects or bump their heads, knees, etc. Damage from accidental bumps can be mitigated by being spatially aware of the working area and by spotting each other.

Injury may occur during the following procedures:

#### **5.4.1 Mounting the ISC Table Assembly to the TMS Telescope**

The ISC Table will be attached to the TMS Telescope using the attachment hardware. This procedure may result in fingers being pinched.

#### **5.4.2 Suspending the TMS Telescope Frame Assembly/ISC Table Assembly from the TMS Optical Table Support Bridge Assy D1100531**

The TMS Optical Table Support Bridge Assy D1100531 will be placed on the work table to straddle the combined TMS Telescope Frame Assembly/ISC Table Assembly structure. The suspension straps will be attached from the Support Bridge to the ISC Table Assembly, and the Support Bridge feet adjusted to raise the TMS Telescope Frame Assembly/ISC Table Assembly structure approximately 1/8 inch above the work table. This procedure may result in fingers being pinched.

#### **5.4.3 Balancing the Combined TMS Telescope Frame Assembly/ISC Table Assembly**

The combined TMS Telescope Frame Assembly/ISC Table Assembly will be lifted approximately ¼ inch above the assembly table by raising the leveling pad feet of the Balance Bridge iteratively until the TMS Telescope Frame Assembly/ISC Table Assembly is supported by the TMS Tele-Opt Table Balance Bridge Pin that is mounted to the TMS Tele Alignment Support Bridge Assembly. The assembly will be balanced by shifting the cylinders and pitch and roll masses on the underside of the ISC optical table to place the center of gravity of the entire structure at the balance point. This procedure may cause a pinched finger hazard.

#### **5.4.4 Pull Back Procedure**

During the Pull Back Procedure, pinching or crushing of fingers could occur if the ISC Optical Table assembly were to become free from the Seismic Stop restraint and swing toward the Quad structure.

#### **5.4.5 Mounting the AOS ETM Telescope Upper Suspension Frame and Top Mass to the Tele-opt Table (Bosch Frame)**

The Upper Suspension Frame and Top Mass weigh ~ 273 lbs (124kg). Personnel should take care to minimize the risk of pinching or crushing fingers while installing the Upper Suspension Frame.

#### **5.4.6 Transporting and Mounting the Upper Suspension Frame and Top Mass to Cartridge**

The Upper Suspension Frame and Top Mass weigh ~ 273 lbs (124kg). Personnel should take care to minimize the risk of pinching or crushing fingers while installing the Upper Suspension Frame to the ISI table on the Cartridge placed on top of the Test Stand.

#### **5.4.7 Installing the TMS in the BSC**

The protruding corners of the TMS Telescope Safety Support Beam Assembly may cause head injury if it is inadvertently bumped while inside the BSC.

### **5.5 Hazards Due to Failure of Lifting Equipment**

Safety Hazards when using the Genie Lift are addressed in E1100520, which must be read before transporting heavy objects. Be careful to balance the load so that the Genie lift will not tip over and cause damage to TMS equipment and serious injury to personnel.

### **5.6 Hazards Due to Optical Alignment of External 1064nm and 532nm Beams**

The steering mirrors and periscope mirrors will be adjusted to align the external 1064nm and 532nm reference beams with the ISC Optical Table optical path and the TMS Telescope optical path.

The alignment laser presents a laser eye hazard, and an appropriate laser safe operating procedure must be followed.

### **5.7 Vacuum Contamination**

The vacuum system will be open during installation of the TMS Assembly into the BSC, as described in section **Error! Reference source not found.** This process has the potential of contaminating the vacuum environment; for example, a glove tear while working inside the vacuum chamber, or the use of contaminated tools. All work must be done in positive pressure clean rooms and all personnel must wear appropriate Class A garb; standard Class A cleanliness procedures must be practiced at all times.

### **5.8 Damage to ETM Quad Suspension and Mirror**

- 1) The TMS will be installed inside the BSC in close proximity to the quad suspension and the ETM mirror. A protective barrier will be placed temporarily between the TMS and the quad suspension structure during the installation process; however, in spite of this protective barrier, dropping tools or other hard object onto the quad structure may cause serious damage to the structure and to the supporting elements of the mirror, as well as the mirror itself.
- 2) Also during the Pull Back Procedure, damage to the ETM Quad Suspension and ETM could occur if the ISC Optical Table assembly were to become free from the Seismic Stop restraint and swing toward the Quad structure.

### **5.9 Damage to TMS Equipment by External Personnel Working In the Vicinity**

Whenever anyone is working inside the chamber in the vicinity of the TMS, the transport chains and other securing braces must be attached to restrain the TMS assembly from swinging and hitting a nearby object, thereby causing damage to the object or to the TMS equipment itself as a result of external applied forces.

### 6 TMS Hazard Analysis Severity Table

Item #	Hazard	Cause	Effect	Unmitigated Severity	Unmitigated Probability Level	Unmitigated Risk Index	Comment	Mitigation	Mitigation Severity	Mitigated Probability Level	Mitigated Risk Index
1	Lifting heavy assemblies	Lifting heavy assembly without support	Injury to personnel, damage to equipment	marginal	occasional	3C	Total assembly weighs 115 lbs	Wear steel toed shoes. Use 2 persons for masses over 40lbs and under 80 lbs. Use lifting equipment for masses over 80 lbs.	Minor	improbable	4E
2	Dropped parts	Slipping from personnel hands	Damage to parts, feet and toes	minor	probable	4B	Maximum weight is 10 lbs.	Wear steel toed shoes. Do not store tools or other loose items on ledges at elevated heights. Do not stand under the suspension when someone is working at elevated height.	minor	improbable	4E
3	Working with wires under tension	Wire end curls over and hits skin Catastrophic failure of wire, or wire releasing from clamp, or wire end pointing outwards	Injury to personnel, damage to equipment	Marginal	Remote	2D		Wear safety glasses Follow detailed procedures. Use glove liners and do not hold wire taut when cleaning.	Minor	Occasional	4C

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Item #	Hazard	Cause	Effect	Unmitigated Severity	Unmitigated Probability Level	Unmitigated Risk Index	Comment	Mitigation	Mitigation Severity	Mitigated Probability Level	Mitigated Risk Index
4	Sudden release of tensioned blade spring	Catastrophic failure of wire, or wire releasing from clamp	Injury to personnel, damage to equipment	Critical	Remote	2D		Guards installed above springs limit their movement in the event of loss of tension. Wear safety glasses	Minor	Remote	4D
5	Pinching/cutting of hands and bumps to the head	Injured by dog clamps, touching sharp edges, accidentally walking into suspension, allowing swung back baffle to swing rapidly	Minor head injury Minor finger and hand injury	minor	probable	4B		Wear head gear when practical during installation	minor	improbable	4E
6	Failure of lifting equipment	Failure to inspect equipment, improper operation	Injury to personnel, damage to equipment	critical	occasional	2D		Follow the Safety Procedures outlined in E1100520	minor	remote	4D
7	Laser hazard	Direct or reflected laser beam entering eye	Retinal damage	critical	occasional	2C		Follow standard LIGO laser safety procedures	minor	remote	4E
8	Vacuum Contamination	Exposed Vacuum Chamber; removal of covers/wraps	Damage to environment	Marginal	Occasional	3C		All parts handled in clean rooms outside of vacuum; all personnel dressed in Class A approved garb	Minor	Remote	4D

Item #	Hazard	Cause	Effect	Unmitigated Severity	Unmitigated Probability Level	Unmitigated Risk Index	Comment	Mitigation	Mitigation Severity	Mitigated Probability Level	Mitigated Risk Index
9	Damage to ETM Quad Suspension and Mirror	Dropping tools, or touching the mirror with any object or body part	Damage to quad suspension assembly	critical	probable	2B	Quad assembly has critical alignment and fragile fused silica fiber suspension	1) Secure the TMS with chains and transport brackets 2) A rigid barrier will be erected between the quad suspension and the TMS 3) Awareness of staying clear of the quad suspension	minor	remote	4D
10	Damage to TMS Equipment by External Personnel	Bumping of freely suspended TMS Assy	Damage to flexure and SUS	marginal	occasional	3C		fasten transport brackets whenever personnel are working in vicinity	minor	remote	4D

Hazard Severity	Category	Definition
Catastrophic	1	Death or permanent total disability, system loss, major property damage or severe environmental damage.
Critical	2	Severe injury, severe occupational illness, major system or environmental damage.
Marginal	3	Minor injury, lost workday accident, minor occupational illness, or minor system or environmental damage.
Minor or Negligible	4	Less than minor injury, first aid or minor supportive medical treatment type of occupational illness, or less than minor system or environmental damage.

Probability	Level	Individual Item
Frequent	A	Likely to occur frequently or continuously experienced.
Probable	B	Will occur several times in the life of an item.
Occasional	C	Likely to occur some time in the life of an item.
Remote	D	Unlikely but possible to occur in the life of an item.
Improbable	E	So unlikely, it can be assumed occurrence may not be experienced.

SEVERITY OF CONSEQUENCE	PROBABILITY				
	E Improbable	D Remote	C Occasional	B Probable	A Frequent
1 Catastrophic					
2 Critical					
3 Marginal					
4 Negligible					

Hazard Risk Index
1A, 1B, 1C, 2A, 2B, 3A
1D, 2C, 2D, 3B, 3C
1E, 2E, 3D, 3E, 4A, 4B
4C, 4D, 4E

Risk Code Criteria
Unacceptable
Undesirable (Directorate decision required)
Acceptable with review by Directorate
Acceptable without review