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- LIGO -
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Vacuum Feedthrough and Cabling Design Requirements Document

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This is an internal working note
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Abstract

This technical note is being generated to outline the design requirements for the vacuum feedthroughs and vacuum cabling that are to be used for LIGO. It covers the vacuum compatibility, seismic isolation and electrical requirements for all vacuum feedthroughs and cabling to be used within and to penetrate the LIGO vacuum vessel.

1 INTRODUCTION

1.1. Purpose

The purpose of this document is to outline the mechanical and electrical requirements for the vacuum feedthroughs and cabling to be used within and to penetrate the LIGO vacuum vessel. These requirements will be used to guide the design and verify performance of the components developed during the design process. Once the design has been completed, the materials and processes developed will be used by other systems and subsystems to provide for their vacuum cabling and feedthrough needs.

1.2. Scope

The requirements listed in this document pertain only to the cables, harnesses, mounting devices , vacuum feedthroughs, and vacuum connectors that are used within and to penetrate the LIGO vacuum vessel. The largest user of the devices developed in response to these specifications will be the suspension systems for each of the suspended optics. Other uses for the devices could include modulation signals to Pockels Cells in the Input Optics.

It is the goal of this document and the pursuant design process to produce devices, materials and guidelines that will meet imposed requirements in the following areas:

- Vacuum Compatibility and Contamination
- Mechanical/Vibrational Isolation
- Electrical Signal Compatibility including shielding to reduce induced and transmitted interference, current rating, impedance, etc.

1.3. Definitions

Vacuum Connector- connectors that are used inside the LIGO vacuum vessel.

Vacuum Feedthrough- a connector that is used to penetrate the vacuum vessel. It can be a multiple pin or coaxial connector. When installed properly it will not compromiser the vacuum vessel integrity.

Vacuum Cabling- cabling that is used to route signals inside the vacuum vessel.

Cable Clamp- a mounting device that is used to securely fasten cables to the seismic stack elements or other components wih the vacuum vessel.

1.4. Acronyms

- CDS- Control and Data System
- DRD- Design Requirments Document
- ICD- Interface Control Document
- MTBF- Mean Time Between Failure
- MTTR- Mean Time To Repair

1.5. Applicable Documents

1.5.1. LIGO Documents

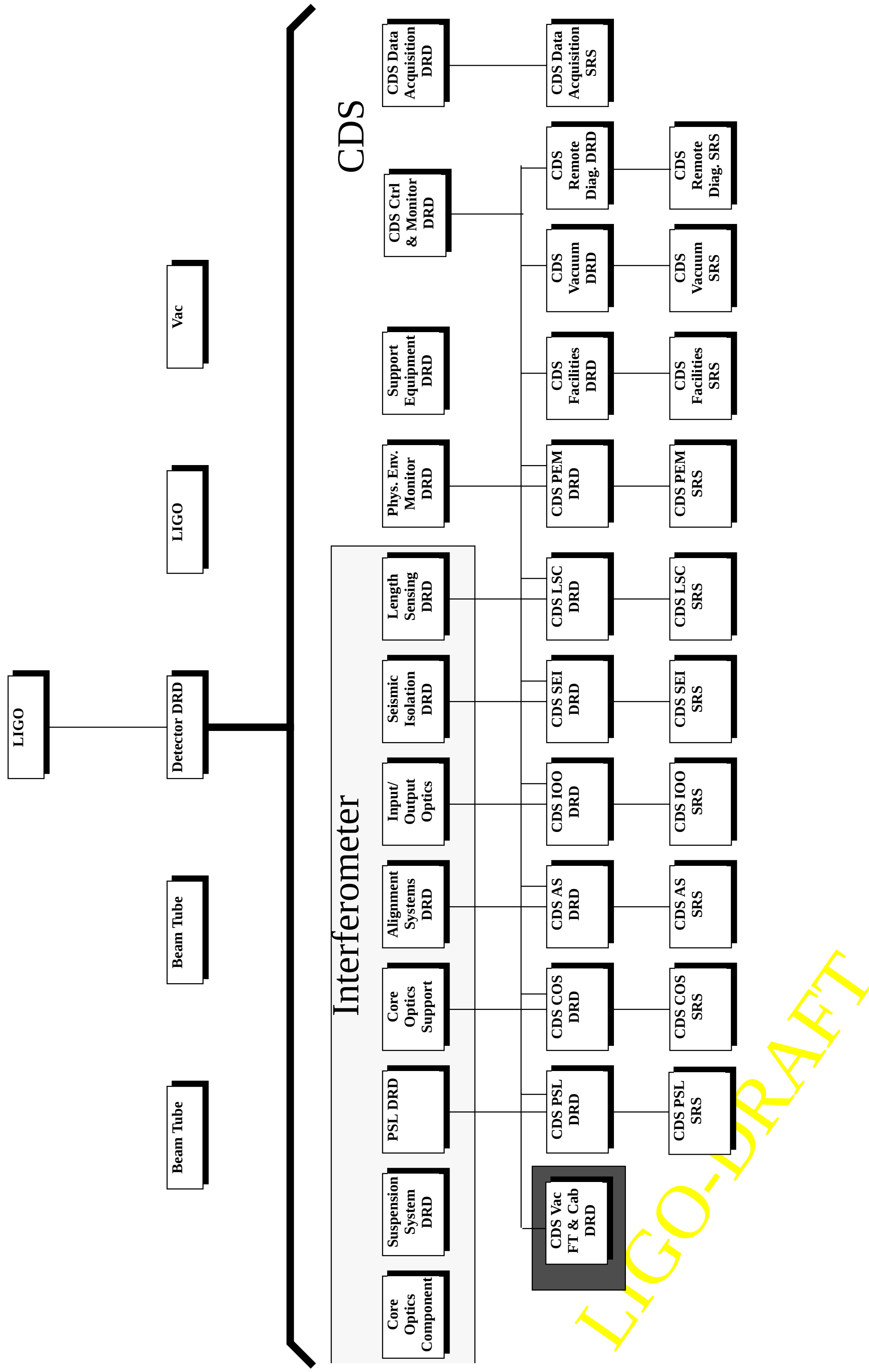
- LIGO List of Approved Vacuum Materials- “~jordan/materials/vacpdoc”
- LIGO Acceptance Process for Vacuum Systems Containing Optics- LIGO working paper (A. Abramovici, April 1993), Document TBD
- LIGO Detector ICD- LIGO Document TBD
- LIGO Detector Naming Convention- LIGO document TBD
- LIGO Detector Implementation Plan- LIGO document TBD
- LIGO Drawing Preparation Standard- LIGO Document TBD

1.5.2. Non-LIGO Documents

2 GENERAL DESCRIPTION

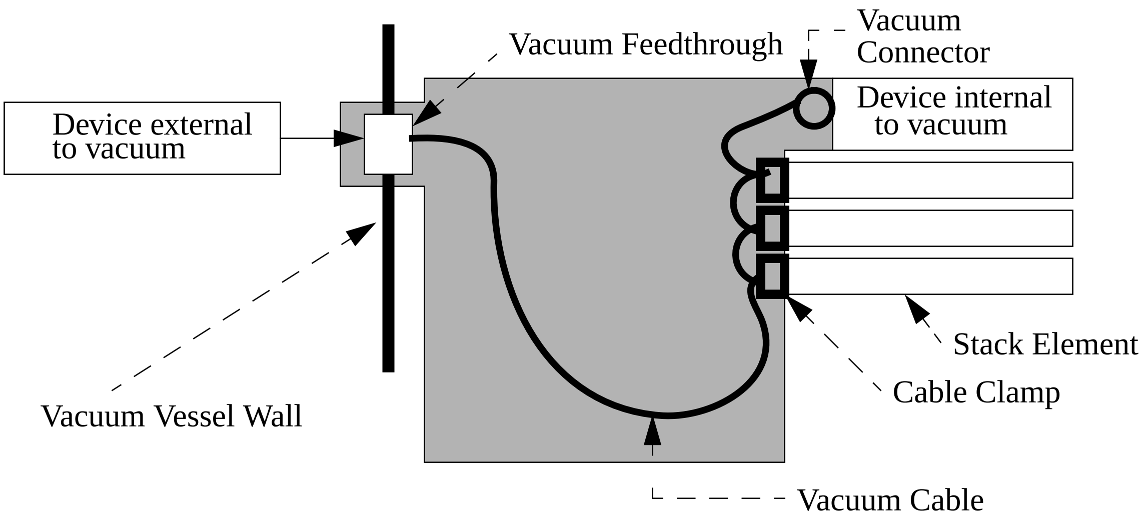
2.1. Specification Tree

This document is part of an overall LIGO detector requirement specification tree. This particular document is highlighted in the following figure.


LIGO
Detector DRD
Beam Tube
Beam Tube
LIGO
Vac
Interferometer
CDS
Core Optics Component
Suspension System DRD
PSL DRD
Core Optics Support
Alignment Systems DRD
Input/ Output Optics
Seismic Isolation DRD
Length Sensing DRD
Phys. Env. Monitor DRD
Support Equipment DRD
CDS Ctrl & Monitor DRD
CDS Data Acquisition DRD
CDS Vac FT & Cab DRD
CDS PSL DRD
CDS COS DRD
CDS AS DRD
CDS IOO DRD
CDS SEI DRD
CDS LSC DRD
CDS PEM DRD
CDS Facilities DRD
CDS Vacuum DRD
CDS Remote Diag. DRD
CDS Data Acquisition SRS
CDS PSL SRS
CDS COS SRS
CDS AS SRS
CDS IOO SRS
CDS SEI SRS
CDS LSC SRS
CDS PEM SRS
CDS Facilities SRS
CDS Vacuum SRS
CDS Remote Diag. SRS
LIGO-DRAFT

2.2. Product Perspective

The materials, techniques and procedures developed for the vacuum cabling and feedthroughs will be used as a component by a variety of detector subsystems. The figure below shows a typical configuration. The pieces that are part of the vacuum cabling and feedthrough subsystem are in the shaded region.



2.3. Product Functions

The vacuum cabling, connectors and feedthroughs are used to transport electrical signals between equipment located inside the LIGO vacuum vessel and equipment outside the vacuum vessel. Many of the devices within the vacuum vessel are located on the optical tables mounted to the seismic isolation stacks.

2.4. General Constraints

All materials, cleaning process, etc. are subject to the restrictions and procedures imposed by the LIGO Acceptance Process for Vacuum Systems Containing Optics- LIGO working paper (A. Abramovici, April 1993), Document TBD.

2.5. Assumptions and Dependencies

3 REQUIREMENTS

3.1. Introduction

Requirements flow down tree from Detector DRD should be included in this section.

3.2. Characteristics

3.2.1. Performance Characteristics

3.2.1.1 Vibration Isolation

Wiring attached to the seismic isolation mass elements must not degrade the isolation performance of the bare stack at all frequencies ≤ 100 Hz. At frequencies $\geq$ 100Hz, the seismic noise must contribute no more than 1/10 of the total interferometer noise budget. Assuming the input vibration spectrum is twice the LIGO Standard Seismic Noise Spectrum, $2 \times 10^{-7}(\mathrm{Hz/f})^2\ \mathrm{m}/\sqrt{Hz}$, each stage of isolation must provide $\approx$ 26 dB of isolation at 100 Hz. Mechanical resonances in the wiring should not cause vibrational peaks in the spectrum above the vibration isolation level at 100 Hz. Table 1 summarizes the requirements.

Table 1: Seismic isolation requirements

Input seismic spectrum	$2 \times 10^{-7}(\mathrm{Hz/f})^2\ \mathrm{m}/\sqrt{Hz}$
Interferometer noise requirement per test mass at 100 Hz	$7 \times 10^{-20}\ \mathrm{m}/\sqrt{Hz}$
Seismic noise contribution per test mass at 100 Hz	$7 \times 10^{-21}\ \mathrm{m}/\sqrt{Hz}$
Suspension transfer function	$(0.74/\mathrm{f})^2$
Motion of optics platform at 100 Hz	$1.3 \times 10^{-16}\ \mathrm{m}/\sqrt{Hz}$
Required isolation transfer function	6.4×10^{-5}
Required isolation per stage of the 4-stage stack at 100 Hz	26 dB/stage
Required isolation per stage at frequencies $\geq$ 100 Hz	$\geq$ 25 dB

3.2.1.2 Electrical Requirements

The following table is a summary of the electrical requirements.

Table 2:

System	*# conductors*	*Characteristics*	*Location*
Suspension	LED Drive- 10 PD Readback- 10 Coil Drive- 10 TOTAL - 30 (15 pairs)	V max= +/- 15 Volts I max= =/- 150 mA Frequency < 10 KHz	Every suspended optic
Modulation Pockels Cells	1 ea. Coax or matched transmission line	P max= 5 watts Impedance= 50 ohms +/- TBD Shielding/Emitted Radiation= TBD Loss< 20dB per 100 meters 10 MHz<freq<100 MHz	One per modulation Pockels Cell in Input Optics
BPCU	Mirror Drive- 6 Motor Drive- 4 TOTAL- 10 (5 pairs)	Vmax= +150 Volts Imax= 10 mA Frequency< 1 KHz	At output of Input Mode Cleaner

3.2.2. Physical Characteristics

3.2.2.1 Seismic Isolation Stack Wiring

These requirements apply only to the wiring that is used to transport signals from devices mounted on the seismic stack optics tables.

3.2.2.1.1 Wiring Mass, Mode Frequency and Q

To prevent the wiring from introducing resonant peaks in the displacement spectrum of the optics platform, the following requirements shall be met.

- The total mass of the wiring between each stage is ≤ 80 g
- The Q of resonant modes of the wiring is < 10

The first transverse mode frequency is ≤ 50Hz

3.2.2.1.2 Mounting of Wiring at Each Isolator Stage

The wiring must be rigidly fastened at each stage in a manner which prevents the transmission of high frequency vibrations up the isolation stack. An effective way of doing this is to mount the wiring to the stack and have at each stage a cable clamp assembly which acts as an impedance mismatch. It is recommended that three clamps be used per stage. A free length of wiring should exist between each successive clamp. Wiring with insulation that creeps under pressure such as teflon shall be clamped with spring loaded washers. Any grooves into which the wiring is clamped shall be shallow enough so that the metal conductor can be pinched should the insulation flow away.

3.2.2.1.3 Wiring Length Between Each Stage

The free length of wiring between stages should be ~ 1.5 times the minimum distance between stages.

3.2.2.2 Common Physical Characteristics

3.2.2.2.1 Shielding of Conductors

The design shall provide for the shielding of conductors.

3.2.2.2.2 Pairing and Twisting of Conductors

The design shall provide for the pairing and twisting of conductors.

3.2.2.2.3 Characteristic Impedance

The design shall provide for cables with a characterisitc transmission line impedance of 50 ohms +/- TBD ohms.

3.2.2.2.4 Maximum Cable Length

The design shall priovide for a maximum cable length of 50 feet measured from the vacuum feedthrough to the device to be connected inside the vacuum vessel.

3.2.3. Interface Definitions

3.2.3.1 Interfaces to other LIGO detector subsystems

3.2.3.1.1 Mechanical Interfaces

The mechanical interfaces are as specified in the table below. Exact design details of each interface shall be added to the LIGO Detector ICD and are the responsibility of each of the subsystems that use the vacuum feedthrough and cabling designs.

Table 3: Vacuum Cabling and Feedthroughs Detector Mechanical Interfaces

Vacuum Cabling and Feed Through Component	*Other System or Subsystem*	*Characteristics*
Stack mounting clamps	Seismic stack element	10/32 tapped holes?

3.2.3.1.2 Electrical Interfaces

The electrical interfaces are as specified in the table below. Exact design details of each interface shall be added to the LIGO Detector ICD and are the responsibility of each of the subsystems that use the vacuum feedthrough and cabling designs.

Table 4: Vacuum Cabling and Feedthroughs Detector Electrical Interfaces

Vacuum Cabling and Feed Through Component	*Other System or Subsystem*	*Characteristics*
Suspension Cabling	Suspension Signals	Multi-pin connector
Pockels Cells Cabling	IOO Modulation Pockels Cells	TBD
BPCU Cabling	BPCU Signals	Multi-pin connector

3.2.3.1.3 Optical Interfaces

N/A

3.2.3.1.4 Stay Clear Zones

TBD

3.2.3.2 Interfaces external to LIGO detector subsystems

3.2.3.2.1 Mechanical Interfaces

The mechanical interfaces to non-Detector systems are as specified in the table below. Exact design details of each interface shall be added to the LIGO Detector ICD.

Table 5: Vacuum Cabling and Feedthroughs non-Detector Mechanical Interfaces

Vacuum Cabling and Feed Through Component	*Other System or Subsystem*	*Characteristics*
Vacuum feedthrough connectors	Vacuum equipment, vacuum vessel	TBD

3.2.3.2.2 Electrical Interfaces

N/A

3.2.3.2.3 Stay Clear Zones

N/A

3.2.4. Reliability

The Mean Time To Failure for all components shall be greater than 30 years.

3.2.5. Maintainability

Mean Time To Repair (MTTR): TBD

3.2.6. Environmental Conditions

3.2.6.1 Natural Environment

3.2.6.1.1 Temperature and Humidity

Table 6: Environmental Performance Characteristics

Operating	*Non-operating (storage)*	*Transport*
+0 C to +50 C, 0-90%RH Outside the vacuum vessel	-40 C to +70 C, 0-90% RH	-40 C to +70 C, 0-90% RH

3.2.6.1.2 Atmospheric Pressure

N/A

3.2.6.1.3 Seismic Disturbance

N/A

3.2.6.2 Induced Environment

3.2.6.2.1 Electromagnetic Radiation

TBD

3.2.6.2.2 Acoustic

N/A

3.2.6.2.3 Mechanical Vibration

N/A

3.2.6.2.4 Vacuum Equipment Bake Out

All materials used in the system shall be able to meet all performance requirements after being subjected to a vacuum equipment bake out. The table below summarizes the expected environment during a bake out.

Table 7: Vacuum Equipment Bake Out Characteristics

Temperature	*Duration*	*Frequency*
+TBD	TBD Hours	TBD cycles per year

3.2.7. 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 for forklift. All items over 100 lbs. which must be moved into place within LIGO buildings shall have appropriate lifting eyes and mechanical strength to be lifted by cranes.

3.3. Design and Construction

3.3.1. Materials and Processes

3.3.1.1 Finishes

TBD

3.3.1.2 Materials

3.3.1.2.1 Vacuum Compatibility and Contamination

The vacuum compatibility and contamination properties of any materials used in the vacuum cabling and feedthroughs shall be subject to the guidelines in LIGO document TBD.

3.3.1.2.2 Approved Materials

A list of the currently approved materials for use inside the LIGO vacuum envelope can be found in the file “~jordan/material/vacpdoc”.

3.3.1.3 Processes

All materials designed for use within the LIGO vacuum vessel shall be cleaned in accordance with the LIGO Acceptance Process for Vacuum Systems Containing Optics- LIGO working paper (A. Abramovici, April 1993), Document TBD. All materials used in the system shall be able to meet all performance requirements after being subjected to the processes outlined in this document.

3.3.2. Component Naming

All components shall identified using the LIGO Detector Naming Convention (document TBD). This shall include identification physically on components, in all drawings and in all related documentation.

3.3.3. Workmanship

All details of workmanship shall be of the highest grade appropriate to the methods and level of fabrication and consistent with the requirements specified herein. There shall be no evidence of poor workmanship that would make the components unsuitable for the purpose intended. All electronic circuits and wiring shall be consistent with good engineering practice and fabricated to best commercial standards.

3.3.4. Interchangeability

The vacuum feedthrough and cabling shall be replaceable as an entire unit. The unit includes: feedthrough connector, all wiring, seismic stack clamps and connectors used to interface to devices inside the vacuum vessel.

3.3.5. Safety

This item shall meet all applicable NSF and other Federal safety regulations, plus those applicable State, Local and LIGO safety requirements. A hazard/risk analysis shall be conducted in accordance with guidelines set forth in the LIGO Project System Safety Management Plan LIGO-M950046-F, section 3.3.2.

3.3.6. Human Engineering

N/A

3.4. Documentation

3.4.1. Specifications

TBD

3.4.2. Design Documents

TBD

3.4.3. Engineering Drawings and Associated Lists

Any drawings to be provided and any standard formats that they must comply with, such as shall use LIGO drawing numbering system, be drawn using LIGO Drawing Preparation Standards, etc.

3.4.4. Technical Manuals and Procedures

3.4.4.1 Procedures

Procedures shall be provided for, at minimum,

- *Initial installation and setup of equipment*
- *Normal operation of equipment*
- *Normal and/or preventative maintenance*
- *Troubleshooting guide for any anticipated potential malfunctions*

3.4.4.2 Manuals

N/A

3.4.5. Documentation Numbering

All documents shall be numbered and identified in accordance with the LIGO documentation control numbering system LIGO document TBD

3.4.6. Test Plans and Procedures

All test plans and procedures shall be developed in accordance with the LIGO Test Plan Guidelines, LIGO document TBD.

3.5. Logistics

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

3.6. Precedence

TBD

3.7. Qualification

TBD

4 QUALITY ASSURANCE PROVISIONS

4.1. General

4.1.1. Responsibility for Tests

TBD

4.1.2. Special Tests

4.1.2.1 Engineering Tests

TBD

4.1.2.2 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.

4.1.3. Configuration Management

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

4.2. 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, Appendix 1. 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:

4.2.1. Inspections

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

4.2.2. Analysis

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

4.2.3. 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.

4.2.4. 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.

4.2.5. 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 manufacture's specifications and shall have a calibration sticker showing the current calibration status.

5 PREPARATION FOR DELIVERY

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

5.1. Preparation

Equipment shall be appropriately prepared. For example, vacuum components shall be prepared to prevent contamination.

5.2. 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.

5.3. Marking

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, stat-

utes, and common carriers; and all markings necessary for safety and safe delivery shall be provided.

6 NOTES

APPENDIX 1 QUALITY CONFORMANCE VERIFICATION MATRIX

Table 8: Quality Conformance Inspections

Paragraph	*Title*	*I*	*A*	*D*	*S*	*T*
3.2.1.1	Vibration Isolation		X			X
3.2.1.2	Electrical Requirements		X			X
3.2.2.1.1	Wiring Mass, Mode Frequency and Q		X			
3.2.2.1.2	Mounting of Wiring at Each Isolator Stage	X				
3.2.2.1.3	Wiring Length Between Each Stage	X				
3.2.2.2.1	Shielding of Conductors	X				
3.2.2.2.2	Pairing and Twisting of Conductors	X				
3.2.2.2.3	Characteristic Impedance		X			X
3.2.2.2.4	Maximum Cable Length		X			X
3.2.6.2.4	Vacuum Equipment Bake Out		X			X
3.3.1.	Materials and Processes	X				