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- LIGO -
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Vacuum Feedthrough and Cabling Design Requirements Document

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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 chamber.

1 INTRODUCTION

1.1. Purpose

The purpose of this document is to outline the mechanical and electrical requirements for the electrical vacuum feedthroughs and cabling to be used within and to penetrate the LIGO vacuum chamber. 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 chamber. 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 chamber.

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

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

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

1.4. Acronyms

- BPCU- Beam Pointing Control Unit
- CDS- Control and Data System
- DRD- Design Requirements Document
- ICD- Interface Control Document
- MTBF- Mean Time Between Failure
- MTTR- Mean Time To Repair

1.5. Applicable Documents

1.5.1. LIGO Documents

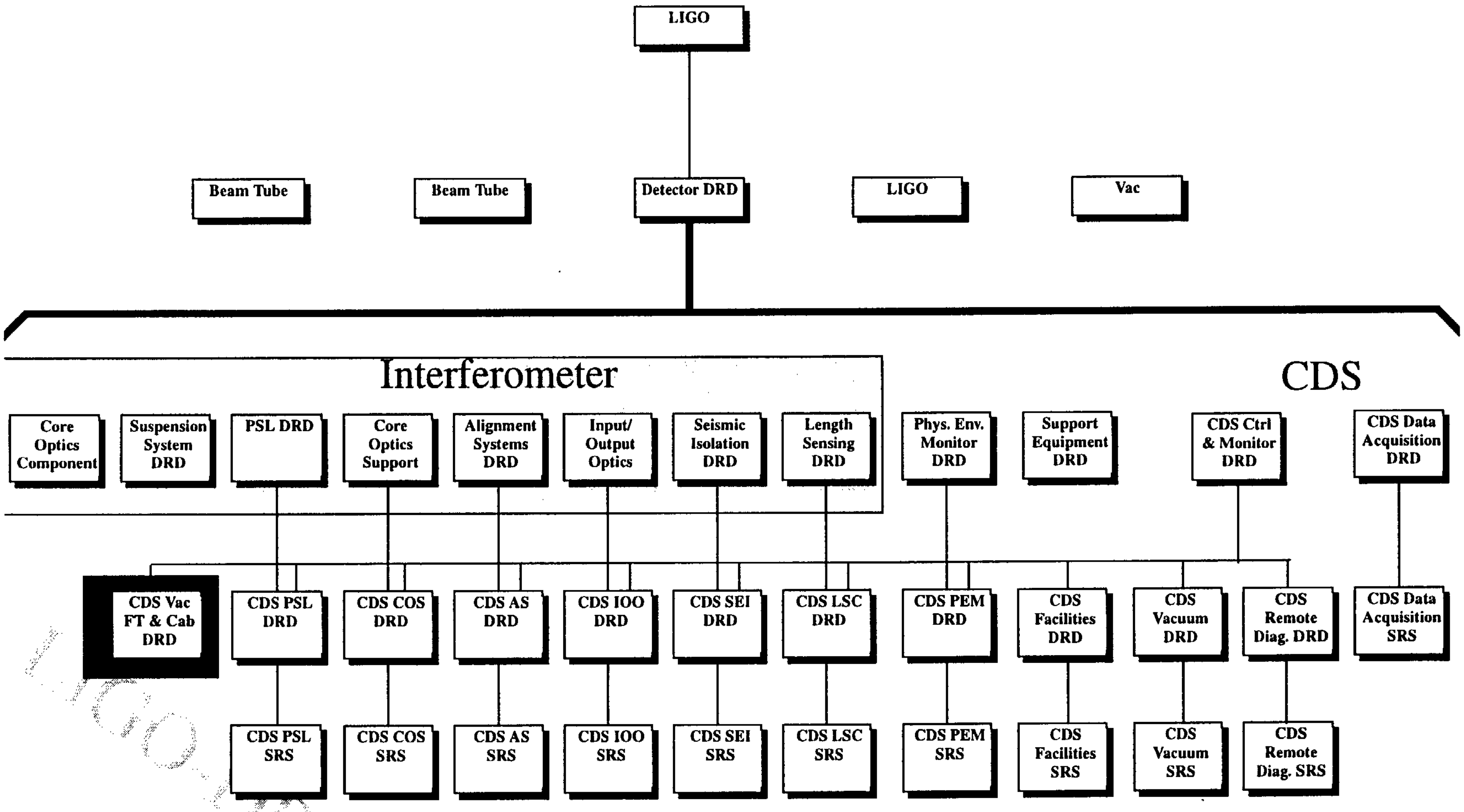
- *LIGO Vacuum Compatible Materials List* - LIGO E960050-A-E
- *LIGO Vacuum Compatibility, Cleaning Methods and Procedures*-LIGO E960022
- *LIGO Detector Naming Convention*- LIGO T950111
- *Seismic Isolation Design Requirements Document*- LIGO T9600065

1.5.2. Non-LIGO Documents

2 GENERAL DESCRIPTION

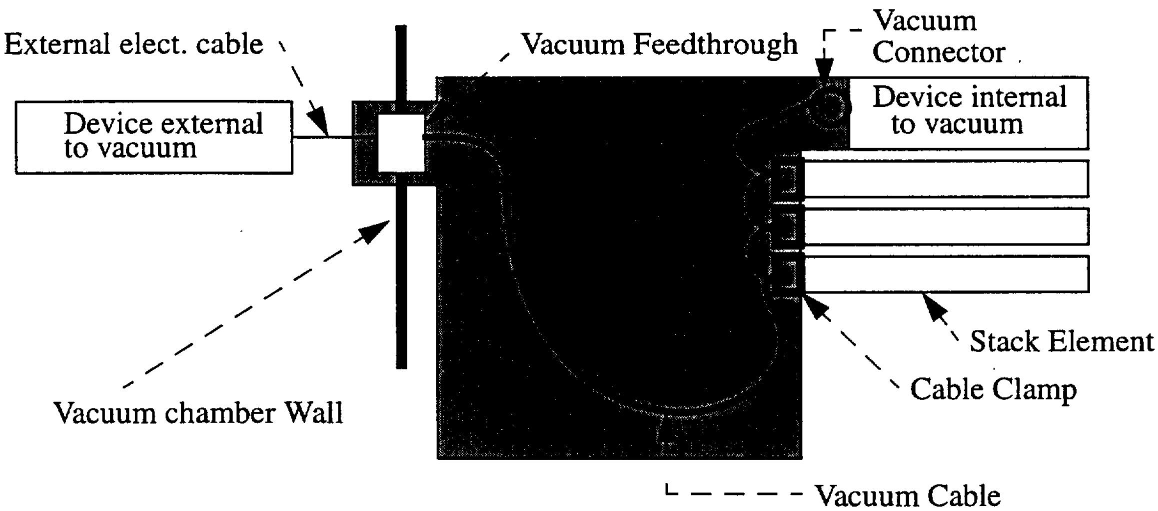
2.1. Specification Tree

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


LIGO
Beam Tube
Beam Tube
Detector DRD
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

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 chamber and equipment outside the vacuum chamber. Many of the devices within the vacuum chamber 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 *LIGO Vacuum Compatibility, Cleaning Methods and Procedures* (LIGO-E960022-00-D).

2.5. Assumptions and Dependencies

3 REQUIREMENTS

3.1. Characteristics

3.1.1. Performance Characteristics

3.1.1.1 Vibration Isolation

The requirements for the vacuum cabling used to transport signals to elements located on the optics platforms that have vibration isolation are explicitly outlined and stated in the Seismic Isolation Design Requirements Document, LIGO Document No. T9600065. Wiring attached to the seismic isolation mass elements must not degrade the isolation performance of the stack as per this document. Key requirements from T9600065 are listed below, but all requirements in T9600065 take precedence should a conflict arise.

- Cabling shall be firmly clamped to each successive stage of the seismic isolation to prevent this cabling from conducting vibration around the isolation system.
- In the case of multiconductor cables, each wire must be firmly fixed in place so that its effective mass at the clamped area is comparable to the mass of the stage to which it is clamped.
- The strain rate (stiffness of the cable) for free lengths of cable[1] clamped to isolation stages must be less than 10 N/m.
- The mass of the free lengths of cable must be less than $3 \bullet Q$ kg, where Q is the mechanical quality for oscillation of the free cable length.
- Free lengths of cable must be placed so that they cannot possible touch other surfaces except where they are clamped.
- Cabling must not "crackle" when vibrated under operating conditions[2]. This may be ensured either by choice of material or by the method in which the material is mounted.

1. "Free length" indicates the length of cable that is between clamps connecting two stages or connecting the lowest stage to any non-isolated surface.
2. "Crackle" refers to the sound made by upconversion when a low-frequency (inaudible) motion of the cable is made. (Thin plastic wrap often crackles when subjected to large slow flexing.)

3.1.1.2 Electrical Requirements

The following table is a summary of the electrical requirements. The list of typical applications is not meant to exhaustive, but illustrative of typical uses of each type of cabling.

Table 1: Electrical Requirements

Type of Cabling	*Ratings*	*Typical # Signals/Stack*	*Typical Application*
Multi-Conductor Low Voltage	Insulation- 300 VDC Working Voltage- 24 VDC nom. Max. Current- 150 mA Loss- 0.5 ohms/meter (#32 wire equiv.) Crosstalk- >60db chan to chan isolation @ 10KHz for entire cable length Shielding-100% coverage Twisting- 6 twists/meter	50	Suspension coil drive, LED drive BPCU Pico Motor drive
Multi-Conductor High Voltage	Insulation- 1000 VDC Working Voltage- 200 VDC nom. Max. Current- 10 mA Loss- 0.5 ohms/meter (#32 wire equiv.) Crosstalk- >60db chan to chan isolation @ 10KHz for entire cable length Shielding- 100% coverage Twisting- 2 twists/meter	6	BPCU Mirror drive
Coax/Transmission Line	Impedance- nom. 50 ohms Loss- 4 dB/ 100 meter at 10 MHz (RG174 equiv) Max. Power- 5 watts Shielding- TBD dB/meter atten at 10 MHz Insulation- 1000 VDC	0*	Pockels Cell Modulation

*It should be noted that the baseline designs for the LIGO detectors do not include any systems that would require in-vacuo coaxial/transmission line cabling.

3.1.2. Physical Characteristics

3.1.2.1 Shielding of Conductors

The design shall provide for the shielding of conductors as per the cable types in Table 1, "Electrical Requirements," on page 10.

3.1.2.2 Pairing and Twisting of Conductors

The design shall provide for the pairing and twisting of conductors as per the cable types in Table 1, "Electrical Requirements," on page 10.

3.1.2.3 Characteristic Impedance

The design shall provide for cables with a characteristic transmission line impedance of 50 ohms +/- 5 ohms.

3.1.2.4 Maximum Cable Length

The design shall provide for a maximum cable length of 50 feet measured from the vacuum feedthrough to the device to be connected inside the vacuum chamber for all cable types listed in Table 1, "Electrical Requirements," on page 10.

3.1.2.5 Cable Dressing and Routing

The design shall provide a means for dressing and routing cables within the vacuum chamber. This shall include:

- Fasteners- used to attach the cables to the vacuum chamber
- Routing Guidelines

3.1.3. Interface Definitions

3.1.3.1 Interfaces to other LIGO detector subsystems

3.1.3.1.1 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 2: 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?

3.1.3.1.2 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 3: Vacuum Cabling and Feedthroughs Detector Electrical Interfaces

Vacuum Cabling and Feed Through Component	*Other System or Subsystem*	*Characteristics*
Multi-Conductor Low Voltage	Suspension Signals BPCU Signals	50 pin D Ceramaseal feedthrough (model #14444-02-W) mounted to optics platform
Multi-Conductor High Voltage	BPCU Mirror Drive	50 pin D Ceramaseal feedthrough (model #14444-02-W) mounted to optics platform
Coax/Transmission Line	IOO Pockels Cells	SMA connector

3.1.3.1.3 Optical Interfaces

N/A

3.1.3.1.4 Stay Clear Zones

TBD

3.1.3.2 Interfaces external to LIGO detector subsystems

3.1.3.2.1 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 Systems ICD.

Table 4: 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 chamber	Conflat flange
Cable Fasteners	Vacuum equipment, vacuum chamber	TBD

3.1.3.2.2 Electrical Interfaces

N/A

3.1.3.2.3 Stay Clear Zones

N/A

3.1.4. Reliability

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

3.1.5. Maintainability

Mean Time To Repair (MTTR): TBD

3.1.6. Environmental Conditions

3.1.6.1 Natural Environment

3.1.6.1.1 Temperature and Humidity

Table 5: Environmental Performance Characteristics

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

3.1.6.1.2 Atmospheric Pressure

N/A

3.1.6.1.3 Seismic Disturbance

N/A

3.1.6.2 Induced Environment

3.1.6.2.1 Electromagnetic Radiation

TBD

3.1.6.2.2 Acoustic

N/A

3.1.6.2.3 Mechanical Vibration

N/A

3.1.6.2.4 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 6: Vacuum Equipment Bake Out Characteristics

Temperature	*Duration*	*Frequency*
+170 C, max.	1000 Hours	1 cycle per year

3.1.7. 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.

3.2. Design and Construction

3.2.1. Materials and Processes

3.2.1.1 Finishes

TBD

3.2.1.2 Materials

3.2.1.2.1 Vacuum Compatibility and Contamination

Cabling must satisfy the requirements for vacuum compatibility listed in *LIGO Vacuum Compatibility, Cleaning Methods and Procedures* (LIGO-E960022-00-D)

3.2.1.2.2 Approved Materials

A list of the currently approved materials for use inside the LIGO vacuum envelope can be found in *LIGO Vacuum Compatible Materials List* (LIGO E960050-A-E).

3.2.1.3 Processes

All materials designed for use within the LIGO vacuum chamber shall be cleaned in accordance with *LIGO Vacuum Compatibility, Cleaning Methods and Procedures* (LIGO-E960022-00-D). All materials used in the system shall be able to meet all performance requirements after being subjected to the processes outlined in this document.

3.2.2. 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.

3.2.3. 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.

3.2.4. 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 chamber.

3.2.5. 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.

3.2.6. Human Engineering

N/A

3.3. Documentation

3.3.1. Specifications

TBD

3.3.2. Design Documents

TBD

3.3.3. 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.

3.3.4. Technical Manuals and Procedures

3.3.4.1 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*

3.3.4.2 Manuals

N/A

3.3.5. Documentation Numbering

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

3.3.6. Test Plans and Procedures

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

3.4. Logistics

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

3.5. Precedence

In the event of conflict of requirements between this document and other documents the order of precedence shall be:

- *LIGO List of Approved Vacuum Materials*- LIGO Document No. TBD
- *LIGO Vacuum Compatibility, Cleaning Methods and Procedures* (LIGO-E960022-00-D)
- *Seismic Isolation Design Requirements Document*- LIGO T9600065
- this document.

3.6. 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 7: Quality Conformance Inspections

Paragraph	*Title*	*I*	*A*	*D*	*S*	*T*
3.1.1.1	Vibration Isolation		X			X
3.1.1.2	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				
3.1.2.1	Shielding of Conductors	X				
3.1.2.2	Pairing and Twisting of Conductors	X				
3.1.2.3	Characteristic Impedance		X			X
3.1.2.4	Maximum Cable Length		X			X
3.1.2.5	Cable Dressing and Routing	X				
3.1.6.2.4	Vacuum Equipment Bake Out		X			X
3.2.1.	Materials and Processes	X				