LASER INTERFEROMETER GRAVITATIONAL WAVE OBSERVATORY
- LIGO -
CALIFORNIA INSTITUTE OF TECHNOLOGY
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

Document Type	**LIGO-T960107-00 - Cxx**	7/17/96

LIGO Interferometer Diagnostics System Design Requirements

R. Bork

Distribution of this draft:

This is an internal working note
of the LIGO Project.

California Institute of Technology
LIGO Project - MS 51-33
Pasadena CA 91125
Phone (818) 395-2129
Fax (818) 304-9834
E-mail: info@ligo.caltech.edu

Massachusetts Institute of Technology
LIGO Project - MS 20B-145
Cambridge, MA 01239
Phone (617) 253-4824
Fax (617) 253-7014
E-mail: info@ligo.mit.edu

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

1 INTRODUCTION

1.1. Purpose

The purpose of this document is to define the basic functional requirements for the Interferometer Diagnositics System (IFODS). The IFODS, along with Control and Monitoring Systems (CMS) and Data Acquisition System (DAQS), is to be a primary, integrated component of the LIGO Control and Data System (CDS).

1.2. Scope

The scope of this document is to outline the primary functional requirements of the IFODS. As this document is being written during the early phases of interferometer design, specific system test procedures may not be developed for some time. However, the basic functionality of the IFODS must be defined at this early stage to allow design and development time. Therefore, this document is intended to define the general requirements and capabilities of the system such that the IFODS infrastructure can be developed with the basic tools to incorporate exact test procedures as they are developed. When those procedures are defined, their requirements will be specified in separate documentation and referenced by and/or appended to this document.

1.3. Definitions

1.4. Acronyms

- AI Analog Input
- CDS Control and Data System
- CMS Control and Monitoring Systems
- DAQS Data AcQuisition System
- GUI Graphical User Interface
- IFO Interferometer
- LDF Limited Data Frame
- LIGO Laser Interferometer Gravitational Wave Observatory
- MTBF Mean Time Before Failure
- MTTR Mean Time To Repair
- PEM Physical Environment Monitoring
- RH Relative Humidity
- TBD To Be Determined

1.5. Applicable Documents

T950054-C Global CDS Control and Monitoring Design Requirements Document

T950120-C Global CDS Control and Monitoring Conceptual Design

M950046-F LIGO Project System Safety Management Plan

L950003 LIGO Document Numbering System

T950111 LIGO Naming Conventions

E950090 Detector - Civil Construction ICD

T9960083-A Derivation of CDS Rack Acoustic Noise Specifications

T960009 LIGO Data Acquisition System Design Requirements Document

T960010 LIGO Data Acquisition System Conceptual Design

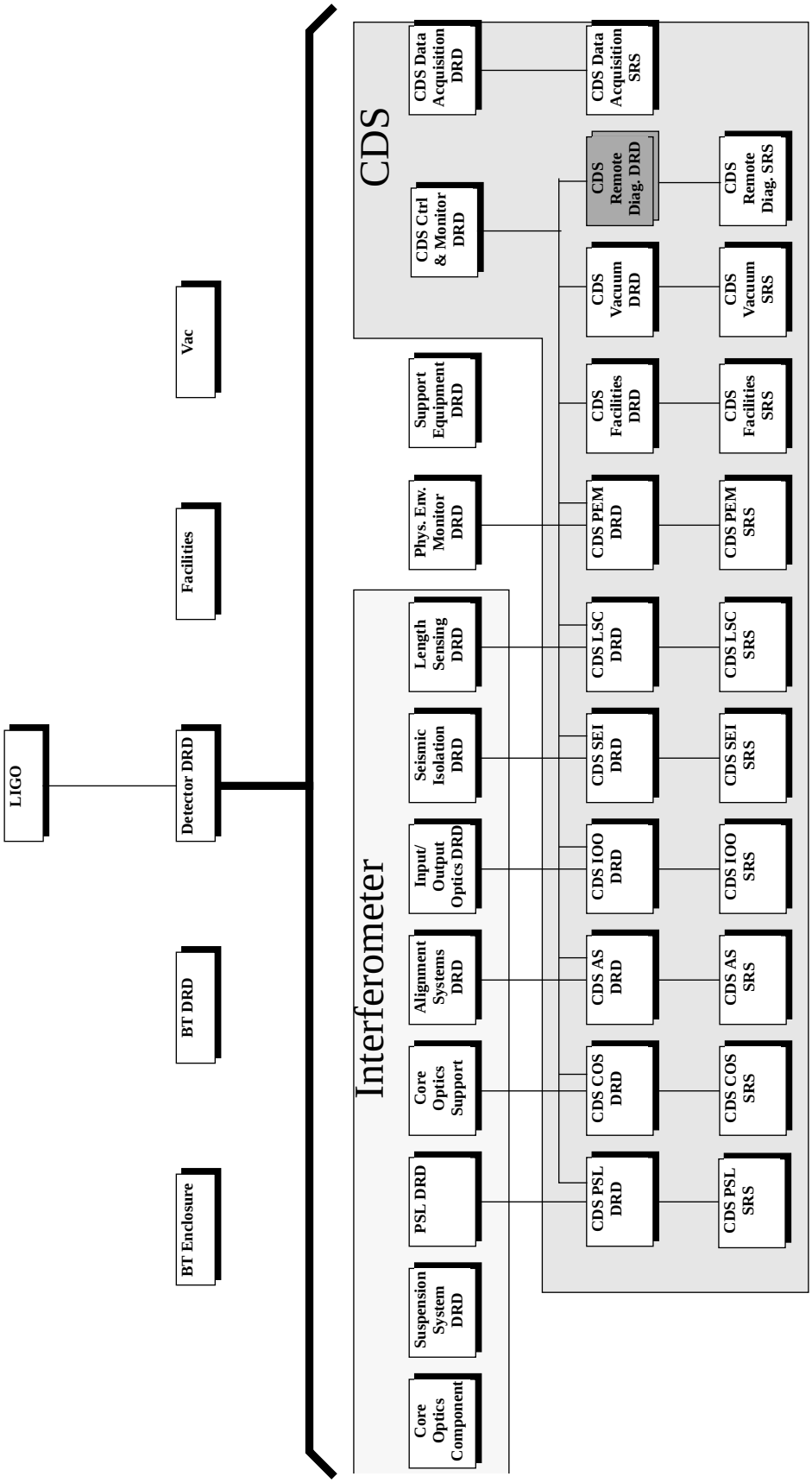
T960031 CDS Online Diagnostic and Readout Functions

T96xxxx Preliminary Notes on Diagnostic Tests and Analysis for CDS

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
BT Enclosure
BT DRD
Facilities
Vac
Interferometer
Core Optics Component
Suspension System DRD
PSL DRD
Core Optics Support
Alignment Systems DRD
Input/ Output Optics DRD
Seismic Isolation DRD
Length Sensing DRD
Phys. Env. Monitor DRD
Support Equipment DRD
CDS
CDS Data Acquisition DRD
CDS Ctrl & Monitor 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 LIGO CDS is divided into three functional components, which must be tightly integrated, as shown in Figure 1: CDS Components. These components are defined as:

- Control & Monitoring Systems (CMS): Provides for the control and monitoring of LIGO interferometers and other scientific instruments, along with the LIGO vacuum systems. It also provides the basic infrastructure for the CDS, which includes such functions as networks, timing, and operator stations.
- Data Acquisition System (DAQS): Provides for the acquisition of all LIGO data integral to gravitational wave analysis and data for use by the IFODS.
- IFO Diagnostics System (IFODS): Provides on-line processing and display of data from the control & monitoring and data acquisition systems for the purposes of diagnosing, characterizing and improving interferometer performance; provides various automated test routines and virtual test instruments.

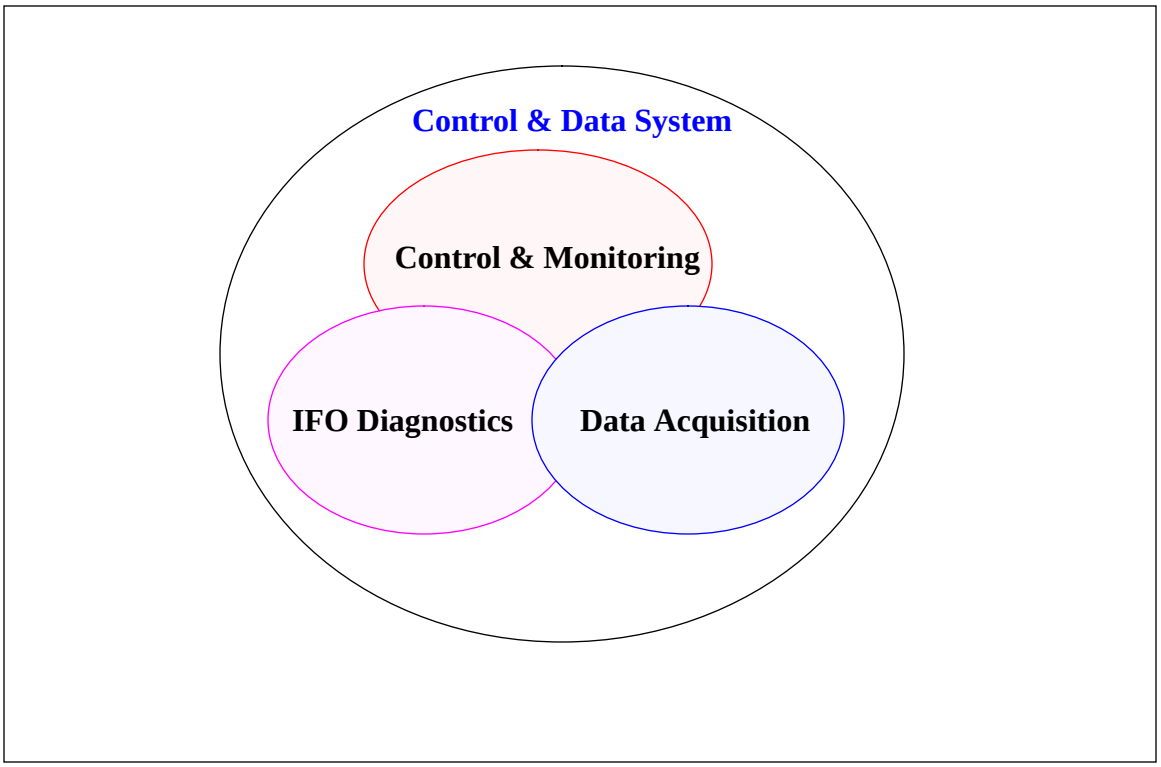


Figure 1: CDS Components

2.3. Product Functions

The primary functions of the IFODS are:

- Interface to the DAQS and provide data analysis and presentation to LIGO operators.
- Provide the interfaces into standard test equipment, such as control and spectrum analyzers and oscilloscopes, with data presentation to operators.

- Provide for the injection of test signals into control system test points and provide any necessary high speed data acquisition as necessary to analyze the test results.
- Provide automated test setup facilities and the ability to communicate appropriate setup commands to the DAQS and control and monitoring systems.
- Provide for video capture and display.
- Provide for the presentation of data as audio outputs for use by operators in quickly analyzing interferometer performance.

2.4. Interfaces

The IFODS must interface with:

- CDS networks to send data to / receive data from control and monitoring systems, as well as to provide communications with operator stations.
- Directly with TBD IFO controls at test points for the injection of test signals and to acquire high speed test data.
- DAQS via CDS and DAQS private networks for the analysis and display of DAQS data and to introduce IFODS into the DAQS data storage system.
- TBD special test equipment, such as control and spectrum analyzers, oscillascopes, etc.

2.5. General Constraints

2.5.1. Standards

Certain standards have been, are being, developed by the CDS group which are documented under the “Control and Monitoring” functions, such as network infrastructures, timing and software. The IFODS shall adher to these standards, particularly where the IFODS interfaces to other CDS systems.

2.5.2. Availability

LIGO is designed to operate continuously, 24hrs/day, 365 days/year. In initial LIGO interferometers, it is anticipated that as few as three gravitywave events will be detected in the course of a year. Therefore, the IFODS must have a high reliability and availability to meet the operational requirements of LIGO.

2.6. Assumptions and Dependencies

2.6.1. Special Test Equipment

The actual special purpose test equipment, such as control and spectrum analyzers, which the IFODS is to provide interfaces to, is not supplied by the IFODS.

2.6.2. Subsystem Automated Testing

While the IFODS is to provide a general infrastructure for performing diagnostic tests, diagnostics and testing particular to interferometer subsystems are to be defined and developed under the auspices of those interferometer systems.

3 REQUIREMENTS

3.1. Characteristics

3.1.1. Performance Characteristics

3.1.1.1 Standard System Tests

The IFODS shall provide a standard set of applications which perform automated tests on the LIGO interferometers. The exact list of tests and the procedures for each is TBD and will be covered under separate documentation. As those are developed, they shall be referenced and/or appended by/to this document.

3.1.1.2 Test Generation Tools

To assist in the development of test procedures and the software necessary to execute them, the IFODS shall provide, at minimum, scripting provisions to define test sequences. More desireable is a set of graphical tools with which predefined objects may be linked to define sequences and data flow (such as state transition diagrams or tools such as AVS provides). These tools shall allow saving and recall of test configuration files for later runtime test application.

3.1.1.3 Test Coordination

The IFODS shall provide the necessary runtime software, including Graphical User Interfaces (GUI), to control and monitor the diagnostic tests. This shall include the functionality to:

- Start/stop test procedures
- Schedule automatic running of tests
- View the state of tests and the state of IFO systems being affected.
- Force states (jump to any step in the procedure)
- Present state/status of the test procedure, including errors and pending transition rules
- Determine if the LIGO systems/devices affected by the tests are in the proper state for the selected tests to be performed.

3.1.1.4 CDS Communications

The IFODS shall provide the networking hardware and software to communicate commands to and receive data from the CMS and DAQS portions of the CDS, as necessary to set those systems to particular states or sequence their devices for the execution of test procedures.

3.1.1.5 Waveform Generation

The IFODS shall provide the capability to generate user defined analog waveforms for injection into CMS test points. Tools shall be provided to define random waveforms, save them to file, and later recall and insert them into a test procedure. Waveform generators shall provide:

- 16bit D/A outputs
- Output rates to 2.5M samples/sec
- Continuous, single burst, or burst/idle/burst waveform generation
- 65K word waveform buffers

- Bipolar output range to +/-10V
- ‘Start of output’ synchronization pulses

The total number of waveform channels to be provided and their locations are TBD.

3.1.1.6 Data Capture

While data is to be available to the IFODS from control and monitoring systems at up to 10Hz and the DAQS at up to 20KHz, various interferometer tests will require snapshot data at higher rates. Therefore, the IFODS shall provide waveform digitizers for this purpose, with data acquisition rates and range TBD.

3.1.1.7 Audio

The IFODS shall provide the capability to directly connect microphones or signals from the CMS and DAQS and play back those signals in real-time via speakers attached to operator consoles. This playback feature shall also be provided at TBD locations throughout the LIGO site. Features to be included are:

- Selectable input sources
- Selectable inline filter functions
- Volume control
- Optional blanking on trigger

3.1.1.8 Video

The IFODS shall provide TBD video cameras at TBD locations. The IFODS shall provide the facilities to transport and display the video signals at operator consoles. Features to be provided are:

- Standard video display rate (30 frames/sec)
- Moderate resolution (128x128)
- Good bit depth/dynamic rane (16 bit/pixel)
- Standard video controls (brightness, contrast, dark, gamma controls)
- Camera setting controls (aperture, shutter, blanking, sync, positioning)
- Image processing
  - > Cursor line slice to intensity vs. position graph
  - > centroid calculation and marker display
  - > beam diameter calculation
  - > gaussian fit calculation
  - > intensity contour overlay or false color
  - > mirror/flip

3.1.1.9 Data Processing

To support automated tests and test instrument functions, the IFODS shall provide a standard set of data processing routines. These are to include:

- FFT to 32Ksamples
- FFT windowing functions
- TBD digital filters
- Standard math, including vector multiplication, averaging, median and standard devia-

tions
- Application of user selected prewhitening filters (from TBD catalog)
- Independently selectable pulse template shape(s)(from TBD catalog)

3.1.1.10 Data Presentation

The IFODS shall provide a standard set of display types, as initially proposed in T960031 CDS Online Diagnostic and Readout Functions, and excerpts from that document are included here as requirements in the following subsections.

3.1.1.10.1 Power Spectra

Power spectra display capabilities shall be provided with the following general features:

- ~1024 points, DC-20, 200, 2kHz options
- “live” update, persistence, waterfall display options
- log magnitude vs. linear frequency (optional log-log)
- Axis range controls
- Update procedure completes in real-time (i.e. t_proc < 1/2*f_max)
- Cursors and markers
- Trend plots of selected frequency bins or band averages to daughter display window
- Standard pan/zoom features
- Overlay “reference” spectrum trace (snapshot or recalled from library)

3.1.1.10.2 Pulse Height Analyzer

A pulse height analyzer display function shall be provided with the following general features:

- Scans one or more channels for “significant” pulses (above user settable threshold)
- Histograms number of pulses/energy bin vs. energy over previous N seconds for each channel
- User selected prewhitening filter
- Selectable pulse template shape(s)
- Simultaneous histograms for 1-5 template shapes
- Configurable “dead time” and multicount reject features (linked w/filter selections)
- Can trigger oscilloscope display of buffered time series data (raw or filtered version) for “big” events above a user selectable threshold.
- Snapshot, store/recall, overlay reference

3.1.1.10.3 Fast Scope

The IFODS shall provide multichannel digital oscilloscope functions. These functions shall have the ability to connect to DAQS data streams or the IFODS waveform digitizers. This display function shall include all of the “standard” oscilloscope front panel setting capabilities, as well as allow selection of channel(s) to be viewed.

3.1.1.10.4 Time Series

The IFODS shall supply standard time series or trending displays. This function shall include ability to:

- Plot multiple channels in selectable colors
- Roll and pause modes
- Horizontal and vertical scale selections
- Typical 500 pt. display resolution (hi/lo envelope or avg. if data pts > display pts. for selected timebase)
- Timebase 1sec/cm to 500sec/cm on screen

3.1.1.10.5 XY Plotting

The IFODS shall provide XY plotting of selectable slow (<=10Hz) signal channels as dots in a plane. Features are to include:

- Multiple signal pairs per display(coded by “dot” shape and color, text legend)
- Offset adjusts
- Gain adjust for each channel (track X&Y, independent X&Y option)
- Persistence mode
- Freeze mode to hold dot positions on logic trigger or command

3.1.1.11 Data Distribution

3.1.1.11.1 Displays

The IFODS shall provide the necessary network connections to run its various displays from operator workstations in the LIGO Facility Control Room (FCR) or on any other computer connected to CDS networks which support X windows.

3.1.1.11.2 Data Files

The IFODS shall provide server routines to allow access to its snapshot and other data which may be stored in its short term storage systems. Connection shall be via CDS networks.

3.1.2. Physical Characteristics

3.1.2.1 Electronic equipment housings

To the extent possible and reasonable, all IFODS electronic equipment shall be housed in standard 19” racks.

3.1.2.2 Weight Limits

IFODS equipment to be housed within the OSB shall not exceed weight limits imposed by the building raised floor loading capacities.

3.1.3. Interface Definitions

3.1.3.1 Interfaces to other LIGO detector subsystems

3.1.3.1.1 Mechanical Interfaces

It is intended that, to the extent possible, IFODS use electrical equipment housings provided by CDS control and monitoring systems. As such, the mechanical interfaces to these systems are:

- 19” equipment racks
- VME crates

3.1.3.1.2 Electrical Interfaces

3.1.3.1.2.1 Direct Analog Signal Connection

The interface for direct analog connections shall be at the designated cable patch panels provided by control and monitoring systems of the CDS, located within CDS racks at various locations throughout the LIGO LVEA, and mid and end stations.

3.1.3.1.2.2 Network Connections

Slow (<10Hz) data will be provided by various CDS control and monitoring systems via CDS networks. The CDS control and monitoring infrastructure shall provide a CDS network connection at all points required by the IFODS.

If special networks not generally supported by the control and monitoring systems are required for IFODS data transmissions, those networks shall be provided by the IFODS.

3.1.3.1.2.3 Electrical Power

Electrical power for IFODS equipment co-located in equipment racks with those provided by CDS control and monitoring systems shall be provided at plug strips within the racks. Both surge protected only and UPS supplied power will be available.

3.1.3.1.3 Optical Interfaces

None.

3.1.3.1.4 Stay Clear Zones

3.1.3.2 Interfaces external to LIGO detector subsystems

3.1.3.2.1 Mechanical Interfaces

TBD.

3.1.3.2.2 Electrical Interfaces

TBD.

3.1.3.2.3 Stay Clear Zones

As per the Detector - Civil Construction and Detector - Vacuum Equipment Interface Control Documents.

3.1.4. Reliability

The Mean Time Before Failure (MTBF) for the IFODS shall be greater than TBD.

3.1.5. Maintainability

The Mean Time To Repair (MTTR) for any IFODS component shall be less than TBD.

3.1.6. Environmental Conditions

The IFODS shall meet all performance requirements when exposed to all specified natural and induced environments.

3.1.6.1 Natural Environment

3.1.6.1.1 Temperature and Humidity

All IFODS equipment shall meet the following temperature and humidity requirements.

Table 1: Environmental Performance Characteristics

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

3.1.6.1.2 Atmospheric Pressure

The IFODS equipment design must accommodate atmospheric pressure change from a maximum of 15.2 psia to a minimum of 14.2 psia.

3.1.6.2 Induced Environment

3.1.6.2.1 Vibrations

IFODS equipment shall not produce mechanical vibrations greater than those specified in TBD.

3.1.6.2.2 Acoustic Noise

IFODS equipment shall be designed to produce the lowest levels of acoustic noise as possible and practical. In any event, IFODS equipment shall not produce acoustic noise levels greater than that defined in LIGO T960083-A, Derivation of CDS Rack Acoustic Noise Specifications.

3.1.6.2.3 Electromagnetic Radiation

The IFODS shall not degrade due to electromagnetic emissions as specified by IEEE C95.1-1991.

The IFODS shall not produce electromagnetic emissions beyond those specified in TBD and shall comply with the LIGO EMC Plan.

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

- Ambient Environment: Surface-to-surface contact between dissimilar metals shall be controlled in accordance with the best available practices for corrosion prevention and control.
- External surfaces: External surfaces requiring protection shall be painted or otherwise protected in a manner to be approved.

3.2.2. Component Naming

All tagging and naming of IFODS equipment shall be in accordance with LIGO naming standards as described in T950111 LIGO Naming Conventions

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, modules and wiring shall be consistent with good engineering practice and fabricated to best commercial standards.

3.2.4. Interchangeability

The IFODS shall be designed to maximize interchangeability and replaceability of mating components. Using the Line Replaceable Unit (LRU) concept, the designs shall be such that mating assemblies may be exchanged without selection for fit or performance and without modification to the section, the unit being replaced or adjacent equipment. Mature, performance proven, standard, commercially available equipment shall not be modified unless it impacts safety.

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

The IFODS shall be designed and laid out in a manner consistent with applicable standard human engineering practices. Particular attention shall be paid to layouts of operator consoles/stations, work space and environmental conditions.

3.3. Documentation

3.3.1. Specifications

The following specifications shall be provided as part of the design process:

- Software Requirements Specification (SRS) for all software to be developed as part of the system.
- Interface Control Document (ICD)

3.3.2. Design Documents

The following design documents shall be provided:

- System overall design.
- System software design.

3.3.3. Engineering Drawings and Associated Lists

Engineering drawings, schematics, wire lists and cable routing lists shall be produced for the IFODS. To the greatest extent possible and practical, electronic copies shall be maintained and available on-line. All drawings shall be formatted according to LIGO standards.

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

The following manuals shall be provided:

- All manuals provided by commercial vendors for IFODS components.
- Manuals for all IFODS custom designed electronics and software.
- IFODS User's Manual

3.3.5. Documentation Numbering

All documents shall be numbered and identified in accordance with L950003 LIGO Document Numbering System.

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 conflicts between this requirement document and other LIGO documents, the order of precedence shall be in accordance with the LIGO Requirement Specification Tree.

3.6. Qualification

The IFODS design shall be qualified through a series of reviews as prescribed in the LIGO Detector Implementation Plan.

Qualification of various IFODS components and subsystems shall be in accordance with Section 4 of this document.

4 QUALITY ASSURANCE (QA) PROVISIONS

4.1. General

This system shall be tested in accordance with applicable LIGO QA standards.

4.1.1. Responsibility for Tests

The LIGO CDS group shall be responsible for performing and documenting all tests associated with the IFODS.

4.1.2. Special Tests

Due to their critical nature, the isolation valve interlocks shall undergo extensive testing to ensure proper operation.

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

6 NOTES