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

Technical Note	**LIGO-T950054-02 - Cxx**	8/5/96

CDS Control and Monitoring Design Requirements Document

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1 INTRODUCTION

1.1. Purpose

This specification establishes the performance, design, development and test requirements for the Control and Monitoring functions of the Control and Data System (CDS) of the Laser Interferometer Gravitational Wave Observatory (LIGO).

1.2. Scope

The specific items to be designed and implemented through use of this requirement specification are the common, high level control and monitoring systems for LIGO. These include:

- LIGO control room systems, including operator consoles.
- Computer networking systems
- Timing systems to accurately timestamp LIGO data, both for control and monitoring and for LIGO data acquisition.
- High level control and monitoring application and development software.

In addition, this document provides high level requirements upon the design of all LIGO control and monitoring subsystems, for which more detailed requirements documents will be prepared.

Expressly excluded from the scope of CDS and this document are:

- A LIGO personnel safety system
- A Facility Control and Monitoring System (FCMS). This is a system which would monitor building and site functions, such as HVAC, site security monitoring, chilled water systems, etc.

1.3. Definitions

1.3.1. Deterministic

1.3.2. Physical Input/Output Channels

Physical I/O channels are defined as those software data channels which directly receive data from / send data to VME I/O module channels. The point of I/O reference is the control system software.

1.3.3. Virtual Input/Output Channels

Virtual I/O channels are ones which strictly communicate data between software modules.

1.3.4. CDS Diagnostic Data Channel

A CDS diagnostic data channel is one which is not required for operation of the system, other than to provide diagnostic information to allow verification of proper system operation.

1.3.5. Real-time Software

Real-time software is defined as that software which is deterministic in its task scheduling and duration. Throughout this document, this term refers to software which runs on the PSL VME uprocessor under control of a real-time operating system (VxWorks).

1.3.6. Non-Real-time Software

Non-real-time software refers, in this document, typically to that software which runs under the UNIX operating system. This is due to the non-deterministic scheduling and task duration under this operating system.

1.4. Acronyms

AC : Alternating Current

AMS

API: Application Programmer's Interface

ASC: Alignment Sensing and Control

CDS: Control and Data System

COC: Core Optics Components

COS: Core Optics Support

DAQS: Data Acquisition System

DRD: Design Requirements Document

FCMS: Facility Control and Monitoring System

FCR: Facility Control Room

GUI: Graphical User Interface

HMI: Human-Machine Interface

HVAC

Hz: Hertz

IFO: Interferometer

I/O: Input/Output

IOO: Input/Output Optics

IXS: Information eXchange Services

LIGO

LRU:

LSC: Length Sensing and Control

LVEA: Laser and Vacuum Equipment Area

MTBF: Mean Time Before Failure

MTTR: Mean Time To Repair

OSB: Operations Support Building

PEM: Physical and Environment Monitoring

POSIX

PSL: Pre-Stabilized Laser

SEI: Seismic Isolation

SRS: Software Requirement Specification

TBD: To Be Determined

1.5. Applicable Documents

1.5.1. LIGO Documents

- LIGO Detector Implementation Plan
- LIGO Project System Safety Management Plan LIGO M950046-F

1.5.2. Non-LIGO Documents

- IEEE C95.1-1991 on electromagnetic emissions

2 GENERAL DESCRIPTION

2.1. Specification Tree

This document covers the highest level of CDS control and montoring requirements. This document is shown in perspective to the LIGO requirement specification tree in Figure 1: LIGO Detector Requirement Specification Tree.

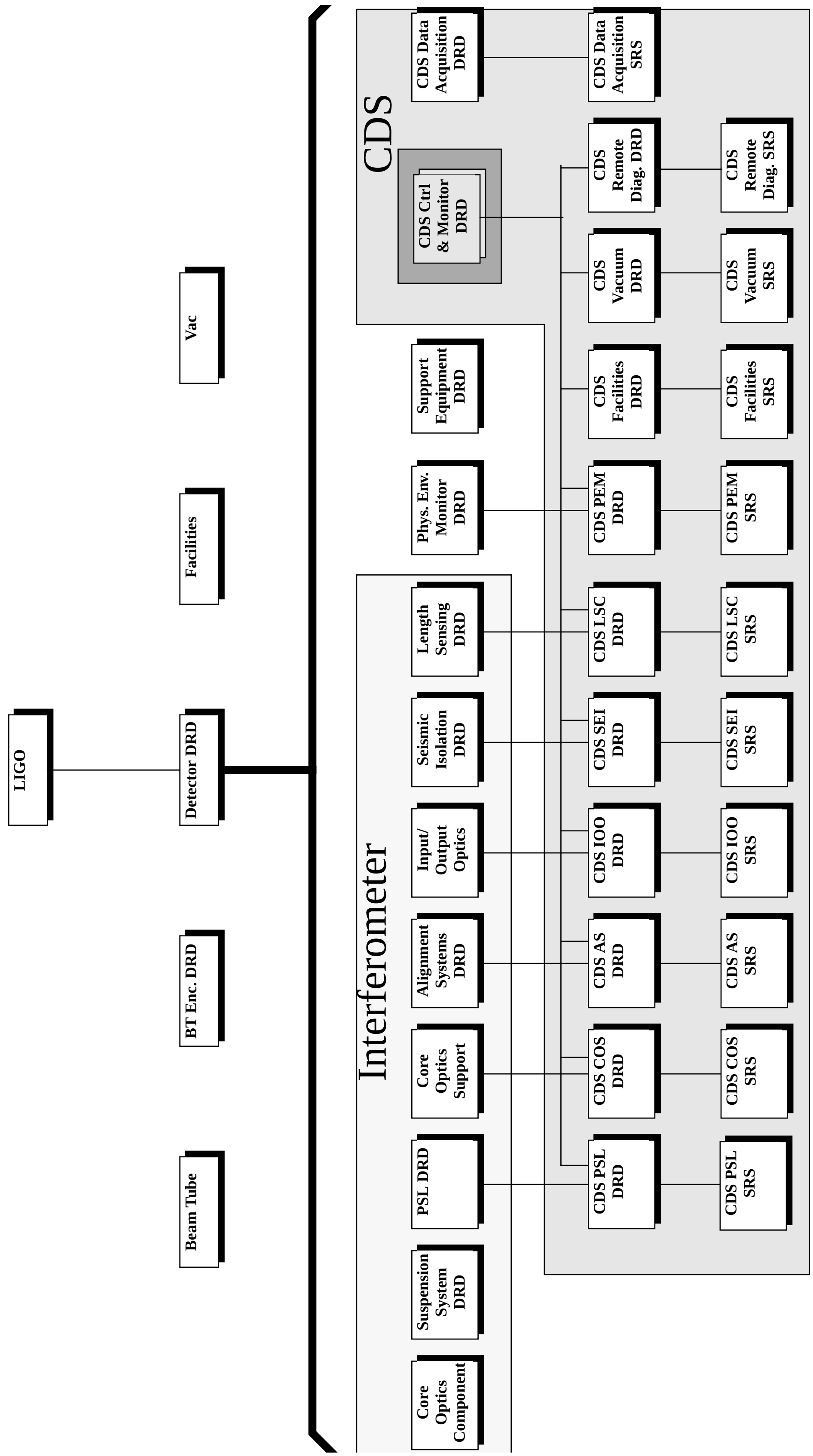

Figure 1: LIGO Detector Requirement Specification Tree

2.2. Product Perspective

A system division and connections to other LIGO systems is shown in the following figure. Due to highly differing requirements, the CDS Data AcQuisition System (DAQS) has been separated out, and, as shown in Figure 1: LIGO Detector Requirement Specification Tree, is covered in a separate requirement specification. The CDS control & monitoring overlaps the DAQS, as it will provide for some of the infrastructure required by that system.

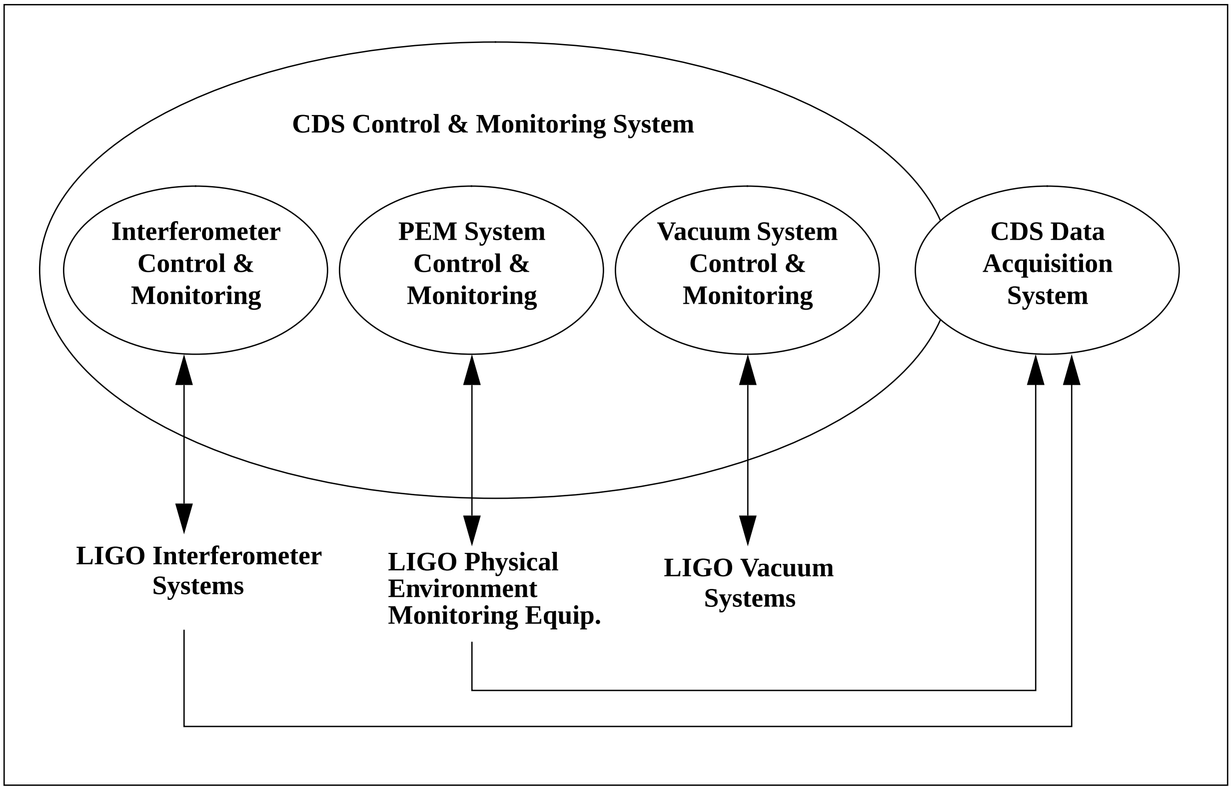

Figure 2: CDS Control & Monitoring Perspective

2.3. Product Functions

The CDS control and monitoring system will provide the following functions:

- All electronics and software, as necessary, to remotely operate and monitor all LIGO scientific systems.
- Communications among the various computers involved in control and monitoring activities, and connections to LIGO general computing facilities.
- Accurate timestamping of LIGO data.
- All electronics and software, as necessary, to provide for closed loop control of LIGO detector and PEM systems.
- All electronics and software, as necessary, to provide information on the performance of the LIGO systems as an operational detector.

- All electronics and software, as necessary, to interface to the LIGO vacuum system equipment and provide closed loop control.

For descriptive purposes, a block diagram of a possible CDS layout is shown in the following figure. The shaded area depicts those functions to be incorporated into the CDS control and monitoring system.

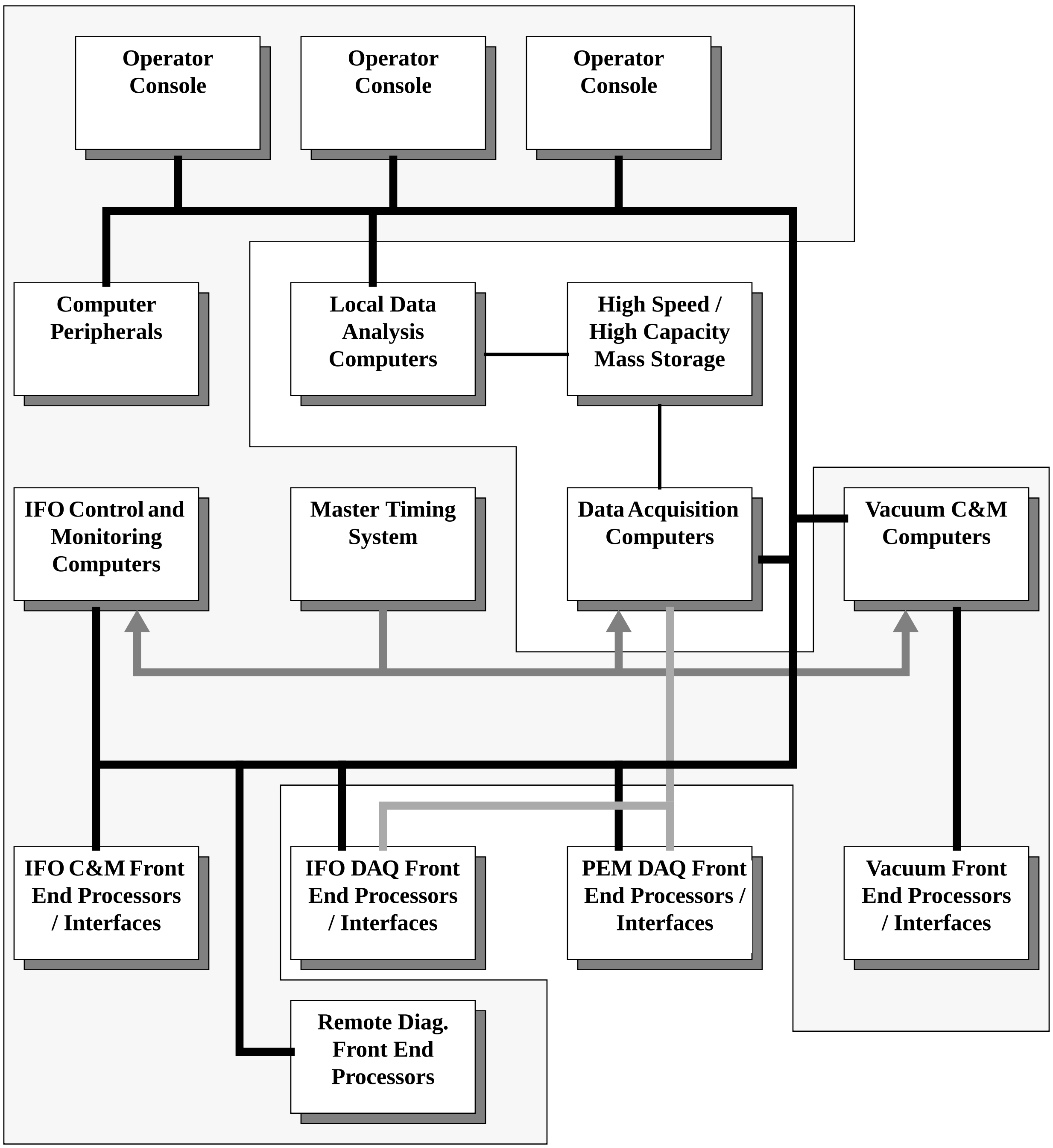

Figure 3: CDS Block Diagram

2.4. General Constraints

The following subsections give some general background information on LIGO which directly affects the CDS control and monitoring system. This overall LIGO design imposes some design constaints on CDS, which will later be reflected in the requirements sections of this document.

2.4.1. LIGO Sites

LIGO is designed to detect gravitational waves through the use of laser interferometer technology. Laser interferometers are to be installed at two sites: Hanford, WA and Livingston, LA.

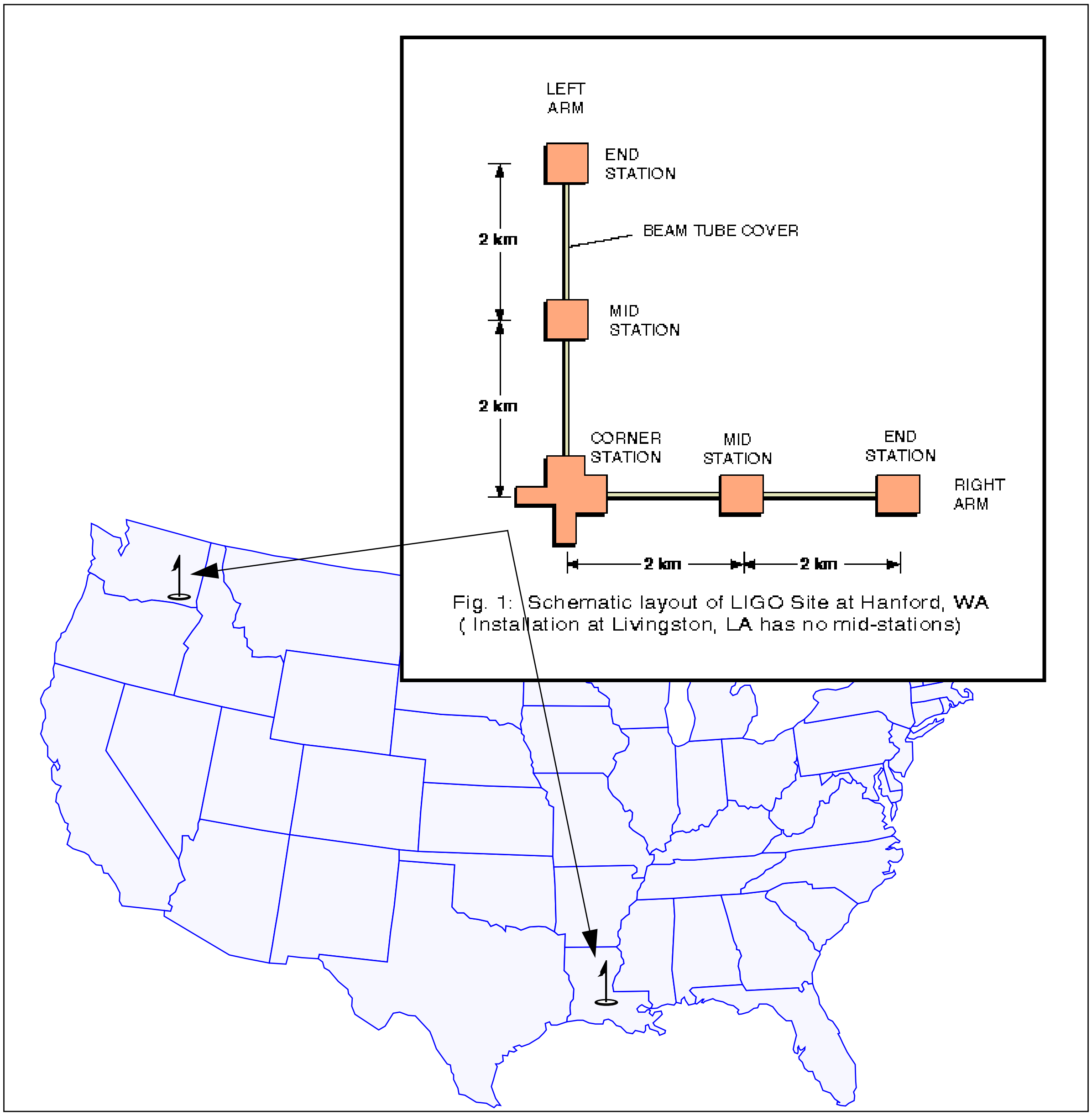

Figure 4: LIGO Site Overview

The layout of a LIGO site imposes several issues on CDS. One major design issue is the distances involved. Equipment will be located in the buildings shown along the LIGO arms, at up to 4km from the central building (Laser - Vacuum Equipment Area (LVEA)), and the adjacent Operational Support Building (OSB), which will house the LIGO Facility Control Room (FCR). While, at present, equipment requiring control and monitoring is only located in these buildings, future equipment may be installed within the Beam Tube Enclosures (BTE) which connect these buildings.

The two LIGO facilities must operate as sychronous devices to perform their design function. Therefore, the CDS system must provide synchronous timing information to two sites located thousands of miles from each other, such that the data from the two detectors may be correlated.

While most control and monitoring operations are planned to take place local to the LIGO sites, remote monitoring capabilities must be available elsewhere. This would include at Caltech and MIT, along with possible future research facilities throughout the world.

2.4.2. OSB Layout

Areas are being designed within the OSB at each site to house CDS components and provide for operations space. A conceptual layout is shown in Figure 5: OSB Conceptual Design (Partial). The size and placement of these areas will constrain the space useage for CDS equipment, as well as cable routing to equipment to be controlled within the LVEA and other LIGO buildings. Note that this is only a conceptual layout, shown only for informational purposes, and that official facility drawings should be used for space layout/constraints.

2.4.3. Initial Interferometers

The Washington site will initially be equipped with two interferometers: a 4K and a 2K. Louisiana will contain a single 4K. It is anticipated that the number of instruments per site will increase over time to a maximum of 6. Therefore, the initial CDS design and implementation must provide for modularity and expansion capabilities.

2.4.4. Equipment Locations

Equipment to be controlled and monitored will be located primarily in the LVEA and mid and end station buildings and maintenance building (located adjacent to the LVEA). However, certain PME equipment, such as accelerometers and RGA analyzers, will be located along the beam tubes at TBD intervals, which also require CDS connections.

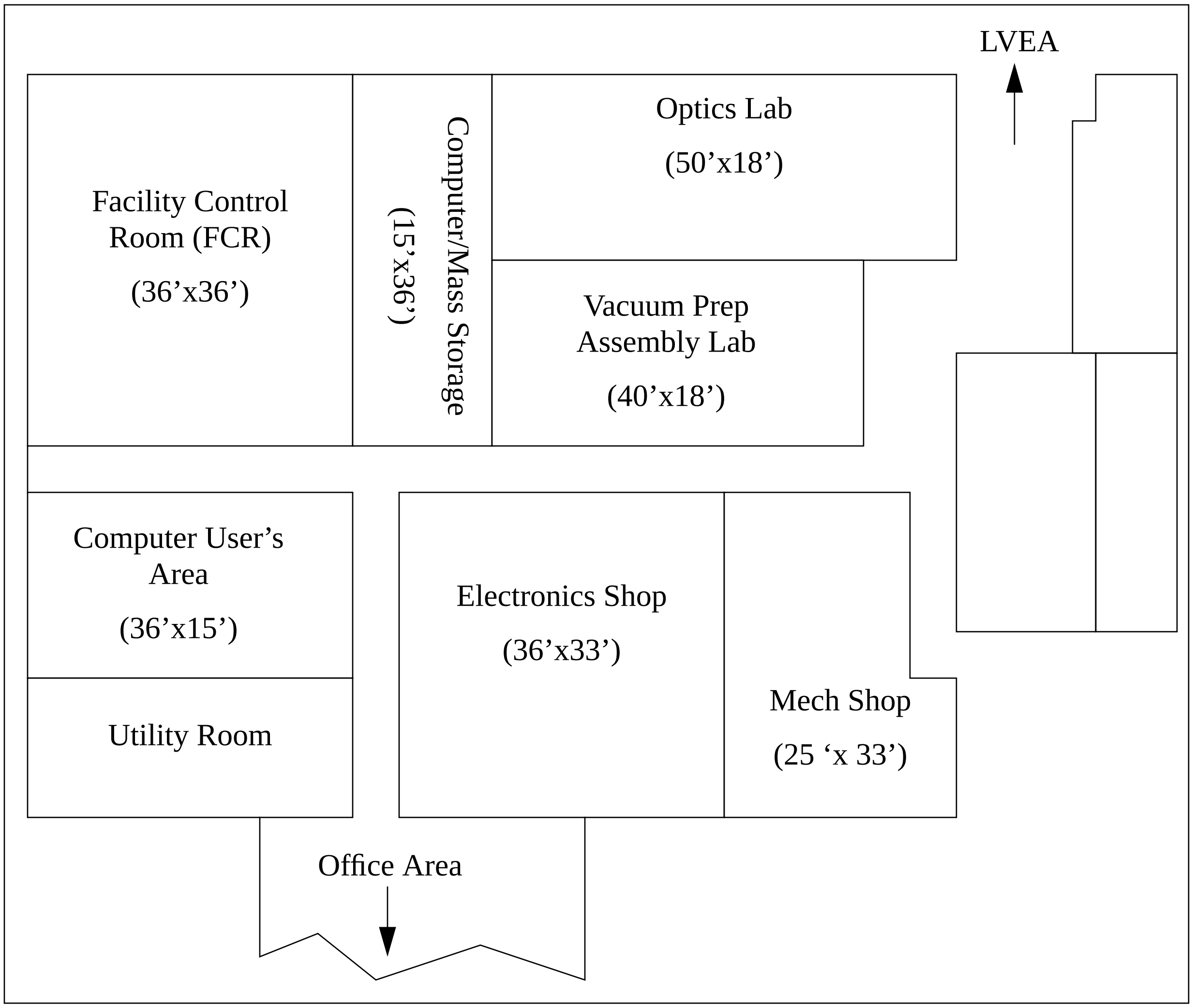

Figure 5: OSB Conceptual Design (Partial)

2.5. Assumptions and Dependencies

Since the design of LIGO systems which require control and monitoring is not complete and the CDS must be developed concurrently in order to meet LIGO schedules, certains assumptions and estimates have been made in order to specify CDS performance requirements. These are summarized in the following sections.

2.5.1. I/O Channels

The following table provides an estimate of the number of I/O channels per interferometer as seen by control and monitoring processors. This table does not include channels to be acquired by the DAQS, which are listed in the DAQS DRD.

Table 1: Estimated I/O Channels Per Interferometer

System	*Signals*	*No. of Units*	*Total*
PSL	100	1	100
Input Optics - Suspensions (9) - WFS - Optical Levers	 50 20 10	 9 2 9	 450 40 90
Core Optics - Suspensions - Misc	 50 20	 6 6	 300 120
ASC - Optical Levers - WFS - Cameras	 10 20 10	 6 5 15	 60 100 150
LSC	100	1	100
PEM	100	1	100
Total			1410

2.5.2. Network Bandwidth Estimates

Estimations of the primary network bandwidth drivers is shown in Table 2: LIGO CDS Network Bandwidth Requirements. The estimations are derived as follows:

1. Data Acquisition System (DAQS): From each IFO, 6Mbytes/sec of data must be acquired, transported and archived. To meet this throughput demand, the network must have, at minimum, a factor of two higher bandwidth.
2. ASC/LSC: These requirements were derived from the ISC Inter-Station Signal Transmission (LIGO T960057-I) document, Table 1. These numbers apply if ASC/LSC designs in fact require signal transmissions between buildings. The actual designs are TBD and may or may not be required and/or the technology used may or may not be standard computer networks e.g. may be analog lines.
3. Video: Various video cameras will be deployed for use in ASC, IFO Diagnostics and FMCS. The numbers shown indicate network rates for medium resolution video at 30 frames/sec. Site totals are derived assuming that 10 cameras/composite camera video are actively being viewed at CDS workstations at any given time.
4. General Controls: Conservative estimate that 1000 channels are being monitored continuously from 10 locations, all at 10Hz update rates.
5. Data Burst: Other contributors to network bandwidth are burst data sources, such as high speed data snapshots for IFO diagnostics. These could contribute at much as another 1Mbyte/sec at random times.

Table 2: LIGO CDS Network Bandwidth Requirements

System	*Bandwidth*	*Hanford*	*Livingston*
Data Acquisition	12MByte/sec/IFO	24MByte/sec	12MByte/sec
ASC/LSC	46KByte/sec/IFO	92KByte/sec	46KByte/sec
Video	250KByte/sec/ transmitter	2.5MByte/sec	2.5MByte/sec
General Controls	400KBytes/sec/IFO	0.8MByte/sec	0.4MByte/sec
Data Burst	1MByte/sec	1MByte/sec	1MByte/sec
Totals		28.4MByte/sec	16.0MByte/sec

3 REQUIREMENTS

3.1. Introduction

In general, the CDS control and monitoring system shall provide the following:

- All electronic hardware and software as necessary to provide closed loop control and monitoring of LIGO interferometers, vacuum and physical environment monitoring equipment.
- All electronics hardware and software, as necessary, to provide for remote operation and monitoring of all LIGO scientific systems..
- All data storage and retrieval facilities as necessary to support LIGO control and monitoring functions and operating staff.
- All hardware and software as necessary to support the interconnection of all LIGO control and monitoring functions into an integrated system.
- All software tools as necessary to develop, operate, and maintain the control and monitoring system.

These general requirements are detailed in the following subsections, grouped by the following categories:

- General: Those requirements of a general nature which apply to all CDS control and monitoring subsystems, whether they are specified in this document, or later specified in more detailed documents at level lower in the LIGO specfication tree than this document.
- Central Computing Services: This covers computing systems to be provided centrally at the OSB at each site, including the FCR.
- Data Communications: This includes networking services to be provided at each site and connections to other remote locations.
- Timing System: System which provides accurate timing information to all LIGO systems.

- Software: General requirements placed on all CDS control and monitoring software development and specific requirements for software development for high level CDS control and monitoring systems.

3.2. Characteristics

3.2.1. Performance Characteristics

3.2.1.1 General Requirements

3.2.1.1.1 LIGO Modes of Operation

The CDS shall provide services appropriate to the various phases of the LIGO complex, including installation, commissioning, maintenance, machine development, observation and tuning.

3.2.1.1.1.1 Installation

The CDS shall provide aids for installation personnel or contractors to ensure that components are installed and connected properly. These will include specific diagnostics to verify installation and unit integration and automatic diagnostics to locate problems. These procedures, as well as the installation database information, must be available for subsequent maintenance.

3.2.1.1.1.2 Commissioning

The CDS shall provide facilities to diagnose problems and to learn the parameter settings necessary for observation. The control system shall provide visibility of diverse information and flexibility of control. During commissioning, processes will be recorded for automation during the observation mode.

3.2.1.1.1.3 Maintenance

The CDS shall provide facilities to check components for faults and to ensure that equipment operates properly after maintenance.

3.2.1.1.1.4 Machine Development

The CDS shall provide facilities to advance the knowledge of interferometer dynamics, with the goal of gaining higher performance. More detailed measurements than usual may be needed to determine such properties as noise sources and instabilities. Flexibility will be required to acquire new signals on short notice, as well as to test new control programs.

3.2.1.1.1.5 Observation

In Observation mode, LIGO is in full operation and in a mode to detect and analyze gravity wave signals.

3.2.1.1.1.6 Tuning

Tuning requires the problem-solving and parameter optimization facilities developed for the commissioning phase. Automatic procedures developed during commissioning will be used to minimize tuning time.

3.2.1.1.2 CDS Modes of Operation

Equipment in the control system is operated in modes parallel in a general sense to the modes of the LIGO facility as a whole. However, the control system is required to be in the Observation mode - this is, in full operation - whenever LIGO is in any mode other than ‘Maintenance’.

3.2.1.1.3 Operational Capacity

3.2.1.1.3.1 Estimate of Initial LIGO Data Channels

The following table gives an estimate of the number of LIGO I/O points which the CDS shall be required to control/monitor.

Table 3: CDS Data I/O Channels

Parameter	*IFO (each)*	*Vacuum*	*Other Systems*
Control and Monitoring I/O Points	1000	500	500

3.2.1.1.3.2 Flexibility and Expansion

- The design and implementation of the CDS shall feature modularity and expandibility, such that it can be easily expanded to handle ten times the initial I/O estimate.
- The system shall be configured in a manner that does not prevent the utilization of new technology as warranted in future upgrades.
- The system shall provide facilities to users for experimental application programs to be incorporated into the system rapidly and flexibly and in such a way that it is clear to users that they are experimental and not a completely tested and sanctioned part of the system.

LIGO is an experimental facility and will continue to develop and change. It is crucial the the CDS be capable of adapting to changes in the LIGO complex.

3.2.1.1.4 Separation of Systems

The design of the CDS control and monitoring system shall be such as to allow independent, autonomous operation of:

- Each LIGO interferometer
- LIGO vacuum systems
- LIGO data acquisition systems

3.2.1.1.5 Power Distribution

Facility power distribution will be provided in accordance with the Parsons-LIGO DCCM and LIGO facility design documents. From the interface point described in these documents, CDS shall be responsible for distributing power to all CDS racks/components, and all other interferometer systems which require it.

3.2.1.1.6 Cabling

CDS shall be responsible for all cabling associated with CDS systems, as well as that required by interferometer and PEM equipment. This cabling shall be routed within areas described in the Parsons-LIGO DCCM and LIGO facility design documents.

3.2.1.2 Central Computing

3.2.1.2.1 Facilities

3.2.1.2.1.1 Facility Control Room

The CDS shall provide the necessary equipment and software for control of LIGO from the FCR at each site. This control area shall contain:

- Sufficient operator consoles to support the LIGO modes of operation. This may involve more consoles during the commissioning phase, with a reduction in the final operational phase.
- Consistent views of all interferometers and support systems.
- Printers and any other necessary hardcopy devices.
- Methods to access all LIGO CDS information, including design information and manuals.

All equipment assigned to the central control area shall be designed to fit within an area of TBD square feet.

3.2.1.2.1.2 Computer/Mass Storage Area

A central equipment or computer room space will be provided at each site for installation of CDS central computing and networking equipment. All such equipment provided by CDS shall be designed to fit within the CDS designated areas of the OSB.

3.2.1.2.2 Central Compute Services

The CDS shall provide compute and file servers and peripheral equipment as necessary to support:

- Resources required by operator stations, such as Human-Machine Interface (HMI) display files.
- Database stores for exchange of data between the CDS and other LIGO compute services.
- Hardcopy of control system data.
- Collection of data from lower level processors at a central location.
- Organization and synchronization of that data for higher level analysis and control.
- Retrieval point for other systems.
- High level data coordination of data collection sequences.
- Stand-alone operation of various LIGO CDS subsystems.
- Boot services for all LIGO CDS processors.
- CDS development tools and source code.

3.2.1.2.3 Operator Interface Systems

3.2.1.2.3.1 FCR

3.2.1.2.3.1.1 FCR Computers

A uniform and predictable operator environment will be provided in the form of computer workstations. The general requirements for the workstations are:

- Mountable in a 19" rack cabinet, either directly or on a shelf mounted in the rack.
- Configurable with a minimum of three, 19" high-resolution (1280 x 1024 minimum) bit-mapped displays.
- Multi-media capability i.e. capacity to display video as well as computer generated text and graphics.
- Minimum internal storage capacity for the computer operating system and minimal application code storage.
- Support single keyboard, mouse and or trackball and knob interfaces.

3.2.1.2.3.1.2 FCR Furnishings

The CDS control and monitoring system shall provide all equipment furnishings for the FCR. All FCR equipment will be housed in suitable low bay 19" racks or equivalent furnishings. Each console shall have sufficient space to house necessary rack-mountable test equipment and video systems along with the computer equipment. Sufficient counter or table top area will be provided to support two operators at a console.

In addition to console space for CDS provided equipment, the CDS shall provide for the mounting of FCMS operator interface equipment. This equipment will be provided by others and require TBD space.

General office furnishings, such as chairs, desks, etc., shall be provided by others.

3.2.1.2.3.1.3 Ergonomics

The CDS equipment in the FCR shall be laid out in such a fashion as to:

- Allow sufficient desk top space on/near operator consoles for paperwork, such as manuals, procedures, log books.
- Allow space and informational display viewing area for multiple operators and scientific staff (up to 15 during commissioning).
- Allow for two operators on shift to operate LIGO from a stationary position, ie does not require constant movement by the operators between computers/consoles.
- Allow maximum viewing of operator consoles and LIGO information from the glass wall area of the FCR.

3.2.1.2.3.2 Field Units

In addition to central, fixed consoles at the FCR, the CDS shall provide TBD portable computers which shall have the capability to be positioned near the actual equipment to be operated. These portable units shall provide the capability to give the operator the same system views as the fixed, central stations.

3.2.1.2.4 Mass Storage Systems

3.2.1.2.4.1 General

The CDS shall provide for all mass storage of data required for the control and monitoring of LIGO.

Data storage is divided here into three categories:

- On-line Data: Stored data which must be retrieved quickly by on-line LIGO systems.
- On-line Archive Data: Data which is on-line, in the sense of being readily available, but does not require high performance retrieval.
- Off-line Data: Historical data which must be kept, but is not readily available to the system ie requires human user action, such as loading of a tape into a tape drive.

In addition, data is divided by lifetime within each category: temporary and permanent. Temporary is defined as data stored within a category for less than 30 days. Permanent is considered any time period longer than 30 days.

3.2.1.2.4.2 Operational Capacity

To first order, the CDS shall provide sufficient mass storage to hold all data needed by the CDS to function. This data would include all necessary operating systems and control applications

Table 4: CDS Control and Monitoring Mass Storage Requirements

	Storage Capacity Requirements (MBytes)	
Category	*Temporary*	*Permanent*
On Line Data	2000	5000
On Line Archive	10000	20000
Off Line Data		100000

3.2.1.2.4.3 Data Access

Archive data access shall be available from all CDS computers, site general computing workstations, and to servers at Caltech and MIT.

3.2.1.2.4.4 Data Security

Security shall be provided as necessary to avoid corruption or destruction of archive data.

3.2.1.2.4.5 Data Backups

Equipment and software shall be provided to perform backups on all CDS data on a daily basis.

3.2.1.2.4.6 Equipment Location

Data archive equipment shall be located in the designated Mass Storage area within the OSB at each LIGO site.

3.2.1.3 Data Communication Sytems

3.2.1.3.1 Site networking

3.2.1.3.1.1 Standards

The LIGO networking system and protocol shall be a commercially available, ISO standard networking and/or communication system.

3.2.1.3.1.2 Data rates

The total network bandwidth shall exceed by a minimum factor of two the data rates inferred by numbers given in Table 2: LIGO CDS Network Bandwidth Requirements of this document.

3.2.1.3.1.3 Data delivery

The data networks shall provide deterministic message delivery wherever the network is employed as part of a real-time closed loop.

3.2.1.3.1.4 General Computing Networks

The CDS shall provide networking connections as necessary with LIGO site general computing and off-line analysis systems.

3.2.1.3.2 Inter-site Communications

The CDS shall provide connections to networks provided by LIGO to interconnect the two LIGO sites, as well as LIGO user universities.

3.2.1.4 Remote Diagnostics

The CDS shall provide for LIGO Interferometer Diagnostics. Interferometer Diagnostics is defined as:

- General electronics and software as necessary to remotely access and display information from special test equipment, such as o’scopes, signal analyzers, logic analyzers, etc.
- High performance instrumentation and software, as necessary, to provide overall LIGO detector performance measurements and fault diagnostics.
- High performance instrumentation and software, as necessary, to provide individual/multiple detector subsystem performance measurements and fault diagnostics.

The following subsections only provide a brief requirement summary. Detailed requirements for Interferometer Diagnostics shall be provided as part of the CDS design task in a Remote Diagnostics DRD, as listed in 3.4.1. Specifications.

3.2.1.4.1 Virtual instruments.

The CDS shall provide for the remote control of TBD test equipment (such as o’scopes, logic analyzers, spectrum analyzer, etc.) with a representation of the equipment faceplate on a computer screen. This graphic display would be interactive, allowing the equipment to be set up as if from the actual equipment knobs and buttons.

3.2.1.4.2 Automatic measurements using virtual instruments.

The CDS shall provide software, which, on the selection of a single graphic display icon, sets up instruments and signal paths, and communicates appropriate instructions to the rest of CDS to automatically perform TBD predefined measurements.

3.2.1.4.3 High speed transient data

The CDS shall provide monitoring functions, which, when thresholds are exceeded, automatically take high speed (up to 5M samples/sec) pre/post trigger samples of the TBD defined signals.

3.2.1.4.4 High speed data snapshot.

The CDS shall provide for high speed data snapshots of TBD signals (as in previous section) on operator request.

3.2.1.4.5 Video Systems

The CDS shall provide for all video systems associated with the LIGO interferometers. **This does not include those video systems as provided by a separate FMCS to monitor LIGO facilities.**

3.2.1.5 Voice Communications

Telephone communications will be provided at each LIGO site at a central punchdown panel within each building (by others). It is intended that these phone lines then be distributed to the FCR and to locations in the LVEA and mid and end stations at CDS provided racks. Therefore, each CDS rack shall provide the necessary space for installation of these phone lines and a phone jack.

3.2.1.6 Timing Information

3.2.1.6.1 Absolute Time

The CDS shall provide a method to allow timestamping all CDS data with a Universal Time Code. Data timestamping functions shall have a minimum resolution of 1usec and accuracy of better than 10 usec.

3.2.1.6.1.1 Synchronization Clocks

The CDS shall provide TTL timing clocks, synchronized to UTC, for the synchronized acquisition of data by the control and monitoring system and the CDS data acquisition system. Available clock rates shall include:

- 1 Hz
- 256 Hz
- 512 Hz
- 1024 Hz
- 2048 Hz
- 16384 Hz
- 32768 Hz

3.2.1.7 Software

In general, the CDS shall provide all software, as necessary, to control and monitor the LIGO scientific systems. Figure 6: CDS Software Components breaks out the software which is to be provided and is specified in the following sections.

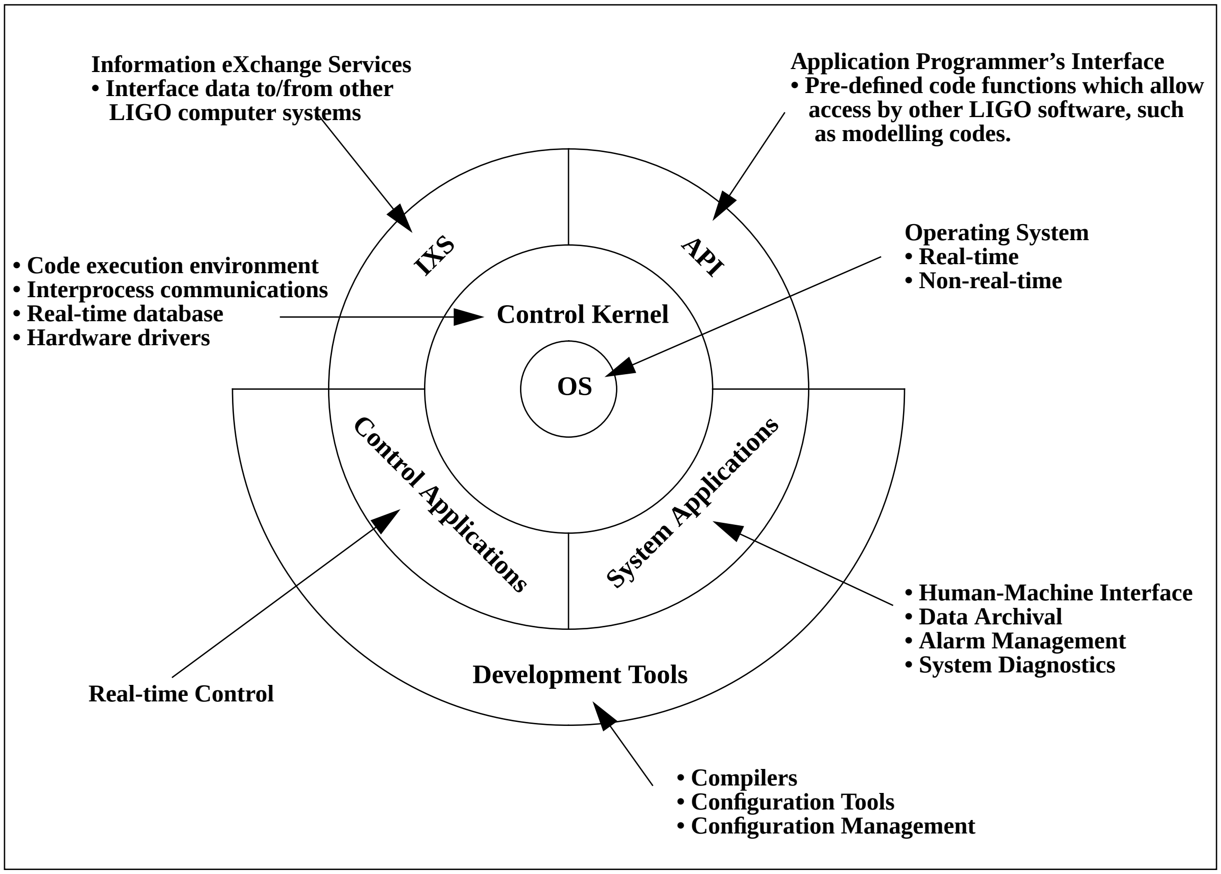

Figure 6: CDS Software Components

3.2.1.7.1 Operating Systems

The CDS shall employ and support POSIX compliant operating systems for both real-time and non-real-time code development and execution.

3.2.1.7.2 Controls Kernel

The CDS shall provide a control kernel, or application execution environment, meeting the requirements descibed in the following subsection.

3.2.1.7.2.1 Inter-process and intra-processor communications.

This communication structure shall allow access to any defined control variable in any processor of the CDS to be accessible by any other process running on any other/same processor of the CDS. This access link shall be made through the variable name tag. This name tag shall be a standard developed by CDS and approved by LIGO management.

3.2.1.7.2.2 Real-time database functions

The CDS software kernel shall support a real-time database for extraction/setting of information from CDS hardware and software modules. This database shall include:

- Data descriptions
- Timestamp and value update rates.
- Address specifications for hardware interfaces.
- Conversion specifications for calculating values to engineering units from raw transducer values.
- Alarm limit specifications
- Monitoring mechanisms to notify data users when values change.
- Data archival deadbands and automatic archiver notification.
- Security provisions to allow data access only to authorized users.

3.2.1.7.2.3 Scheduling

The CDS real-time kernel shall support deterministic scheduling of control software applications by:

- Time period (periodic scan/polling) at rates from 10 Hz to 1/10Hz.
- On interrupt, from CDS hardware interfaces.
- On event, from CDS and other software.

3.2.1.7.2.4 Hardware drivers

The CDS kernel shall provide all software drivers as necessary to communicate with:

- CDS I/O modules, which interface to the operating equipment.
- CDS network communication systems.

3.2.1.7.2.5 Real-time boot services

The CDS kernel software shall provide facilities for booting all processors involved in real-time control. This includes downloading all necessary operating systems and all CDS kernel software and control applications from a remote file server.

- This reboot shall occur automatically upon AC power application or physical processor reset. It shall also be available remotely on operator request. All real-time processors shall be capable of rebooting in less than 5 minutes.
- Reboot and downloading of new software to a CDS processor shall not require reboot and/or reconfiguration of more than the processor(s) affected i.e. the entirety of CDS shall not have to be taken off-line and restarted.

3.2.1.7.2.6 Monitor Tasks

CDS shall provide system monitor tasks which provide diagnostic examination of all CDS process performance. This shall include CPU usage, task scheduling, process states, and I/O module status.

3.2.1.7.3 System Applications

System Applications are defined as those software applications which provide general control services.

3.2.1.7.3.1 Human-Machine Interface (HMI)

The CDS shall provide HMI in the form of Graphical User Interfaces (GUI) running in a windowing environment. This software shall provide the following display capabilities:

- Color graphic drawings which relate devices to system diagrams.
- Interactive icons to change display pages, change equipment states, or to start/stop predefined applications and sequences.
- Numeric data to 9 significant figures with optional exponential notation.
- Array data in the form of 2D plots, with up to 10 plots overlaid in the same window, with dynamic operator selection of channel(s) to be displayed, adjustable time and vertical scales, overwrite and clear capabilities.
- Textual data pages (parameter pages), with dynamic selection of channels to be displayed.
- Drag and drop functionality between CDS display pages and other system applications.
- Interactive entry of setpoints, either through text entry from a keyboard, mouse driven ‘slider’, or via a knob rotation device(s).
- Display screen dump to hardcopy device.

3.2.1.7.3.2 Data Archive

The CDS shall provide the capability to archive all CDS monitor and setpoints.

3.2.1.7.3.2.1 Archival Modes

The CDS shall provide for data archival in two modes:

- On change: Data being monitored has exceeded a settable deadband
- At preset time intervals: The archival function shall be capable of being triggered on user defined time intervals, from one second to one day periods.

3.2.1.7.3.2.2 Archival Rates

TBD

3.2.1.7.3.3 Data Retrieval from Archives

3.2.1.7.3.3.1 Data Display Formats

The CDS shall provide archive data presentation in the form of:

- Graphical, 2D plots of signal vs. time and signal vs. signal (XY plots).
- Ascii test listings of data.

3.2.1.7.3.3.2 Data Sorting

Data shall be capable of being retrieved by:

- File Name

- Signal Name
- Time Frame

3.2.1.7.3.3.3 Data Retrieval Rates

TBD

3.2.1.7.3.4 Alarm Management System

The CDS shall provide an Alarm Management System (AMS), which provides for the detection, enunciation, display and archival of alarm conditions.

3.2.1.7.3.4.1 Alarm Setpoints

The CDS system shall provide for the setting of alarm setpoints around monitored signals. Four alarm setpoints shall be provided: 2 High alarm limits and 2 Low alarm limits. These limits shall be settable to severity states of ‘Major’ (alarm condition) or ‘Minor’ (Warning condition). These alarm signals shall be accessible by the rest of the CDS system by signal name and have settable monitors in order to facilitate automatic responses to alarm conditions.

All changes in alarm setpoints shall be archived by the CDS for later inspection and post fault analysis.

3.2.1.7.3.4.2 Alarm Tree Design

The AMS shall provide a means to define the alarms into a fault tree structure.

3.2.1.7.3.4.3 Alarm Enunciation

The AMS shall provide an icon, displayable on all operator stations, which enunciates the overall alarm status by facility, system or subsystem. This icon shall flash and provide an audible beeping noise on change of alarm status. It shall indicate red when an alarm condition exists and yellow when a warning condition exists.

3.2.1.7.3.4.4 Alarm Display

The AMS shall provide for a detailed display of the alarm tree defined during the design phase. This display shall include:

- Alarm status of each tree branch, indicating Red for alarms and Yellow for warnings.
- A means to fold out the tree to locate the exact alarming monitor or to collapse the tree presentation for an overview observation.
- Icons which, when selected by the operator, provide additional information about the signal/alarm, guidance as to the cause/resolution of the problem, and can activate automatic sequences in response to the alarm conditions.
- Icons which, when selected by the operator, acknowledge the alarm state. This shall stop the audible beep enunciation.

3.2.1.7.3.4.5 Alarm Archival

All defined alarm conditions shall be archived. This archival shall occur whenever an alarm state changes. Included in this archival shall be:

- Time of occurence
- Signal Name
- Alarm Severity
- Signal Value

3.2.1.7.3.4.6 Archival of Operator Response to Alarms

The AMS shall archive when and which alarm was acknowledged by operations staff.

3.2.1.7.3.5 Save and Restore

The CDS shall provide software as necessary to allow operators to take a ‘snapshot’ of LIGO CDS setpoints and readings, and store them to a file for later use in resetting the detectors to the same operating state. This software shall provide:

- Maximum flexibility in defining which channels are to be included in a snapshot i.e. a snapshot does not have to be made on the entirety of CDS channels, but rather can be subdivided by operations staff into reasonable LIGO subsystems of data.
- A means to define those channels which are to be included in the snapshot.
- A means to review the snapshot data list prior to saving or restoring settings.
- Ability to concatenate multiple save/restore files.

3.2.1.7.3.6 System Diagnostics

The CDS control and monitoring system shall provide for internal self-diagnostics. The system diagnostics shall support fault isolation to a specific module or subsystem device which can be subsequently removed and replaced.

The system diagnostics shall include both hardware and software diagnostics routines, which upon detecting an abnormal condition, reports this information to standard diagnostics displays and the archive list.

A standard diagnostic display set shall be provided and incorporate the following functions:

- Diagnostic displays shall be arranged in a logical hierarchy.
- The highest level shall be accessible via a single keystroke or icon selection. Once at this level, the user shall be able to move to any level of the diagnostic hierarchy.
- The system status display shall provide the current status of every system device. Devices with a diagnostic alarm shall be identified by a red indicator.

3.2.1.7.3.7 Development Tools

To enhance code production in the design, prototype and development cycle of the CDS control and monitoring software, the CDS shall provide a set of software configuration tools. These shall include:

- Graphical Display generation tools.
- Real-time database configuration tools.
- Sequence processing development tools.
- Data archival setup tools.
- Save and restore setup tools.

- All necessary compilers and makefiles.
- Configuration management tools.

3.2.1.7.3.8 Control Applications

In general, CDS shall provide all necessary LIGO specific software applications to control and monitor the interferometers, vacuum and PEM systems. The detailed requirements for these applications shall be developed by the CDS as listed in 3.4.1. Specifications.

3.2.1.7.3.9 Application Programmer's Interface (API)

It will become necessary, over time, to allow access to the CDS system from other LIGO developed software, such as modelling codes or high level control algorithms. This software will typically be written in Fortran or C. To facilitate the use of these standard programming languages to interface into the CDS provided system, an Application Programmer's Interface (API) shall be provided. This is to include TBD pre-defined scripts and linkable subroutines/objects, which may be compiled along with user's software, to access and/or operate within the CDS system.

3.2.1.7.3.10 Information eXchange Services (IXS)

Information within the CDS may be required to be extracted for various LIGO reporting procedures or other use. This information would typically be sent to commercial database, spreadsheet or report generation software. To facilitate this extraction of data, the CDS shall provide TBD interface software, as necessary, to reformat CDS data to the format required by the external software.

3.2.2. Physical Characteristics

3.2.2.1 Electronic equipment housings

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

3.2.2.2 Weight Limits

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

3.2.3. Interface Definitions

3.2.3.1 Detector Systems

Interfaces to the LIGO interferometers and PEM shall be as defined in the various CDS interferometer subsystem and PEM DRDs, as listed in section 3.4.1. Specifications. As part of the CDS design process, all interfaces shall be included in the Detector Interface Control Document (ICD). In general, the CDS shall interface to detector components at the optics device to be controlled/monitored i.e. provide a cable connection at the device.

3.2.3.2 Non-Detector Systems

3.2.3.2.1 Stay Clear Zones

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

3.2.3.2.2 Vacuum Systems

Interfaces to the LIGO vacuum system shall be as defined in the CDS Vacuum System DRD, which shall be in agreement with the ICD provided by the vacuum equipment manufacturer.

3.2.3.2.3 Facilities

3.2.3.2.3.1 Equipment Placement

Interfaces to the LIGO facilities include mounting areas for equipment, right of ways for cables, electrical power and grounding, and telephone connections. These CDS interfaces to facilities shall be as described in the Parsons-LIGO Design Configuration Control Document.

3.2.3.2.3.2 Site Power and Facilities Equipment Monitoring

The CDS shall interface to and monitor current monitors placed on power lines to the site and high current facilities equipment. The site facilities contractor will provide and install the current monitors.

3.2.3.2.4 FMCS

The CDS shall provide mounting equipment and space within the FCR for the FMCS operator station provided by the site facilities contractor.

3.2.4. Reliability

The Mean Time Before Failure (MTBF) for the CDS control and monitoring system shall be greater than TBD.

3.2.5. Maintainability

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

3.2.6. Environmental Conditions

The CDS control and monitoring system shall meet all performance requirements when exposed to all specified natural and induced environments.

3.2.6.1 Natural Environment

3.2.6.1.1 Temperature and Humidity

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

Table 5: 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

3.2.6.1.2 Atmospheric Pressure

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

3.2.6.2 Induced Environment

3.2.6.2.1 Vibrations

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

3.2.6.2.2 Acoustic Noise

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

3.2.6.2.3 Electromagnetic Radiation

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

The CDS shall not produce electromagnetic emissions beyond those specified in TBD.

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

- 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 purple or other-

wise protected in a manner to be approved.

3.3.1.2 Materials

All CDS equipment to be placed within LIGO vacuum systems shall be in accordance with the LIGO list of approved vacuum materials.

3.3.1.3 Processes

All CDS equipment to be placed within LIGO vacuum systems shall be processed in accordance with LIGO standards TBD.

3.3.2. Component Naming

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

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

3.3.4. Interchangeability

The CDS 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.

3.3.5. Safety

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

The CDS 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.

3.4. Documentation

3.4.1. Specifications

The CDS shall provide the following detailed requirement specifications for CDS subsystems:

3.4.1.1 Interferometer

- CDS PSL DRD
- CDS PSL Software Requirements Specification (SRS)
- CDS Alignment Sensing Control (ASC) DRD
- CDS ASC SRS
- CDS Input/Output Optics (IOO) DRD
- CDS IOO SRS
- CDS Seismic Isolation DRD
- CDS Seismic Isolation SRS
- CDS Length Sensing Control (LSC) DRD
- CDS LSC SRS
- CDS PEM DRD
- CDS PEM SRS
- CDS Core Optics Support (COS) DRD
- CDS COS SRS

3.4.1.2 Vacuum System

- CDS Vacuum System Controls DRD
- CDS Vacuum System Controls SRS

3.4.1.3 Facilities

- CDS Facilities Monitoring DRD
- CDS Facilities Monitoring SRS

3.4.1.4 Remote Diagnostics

- CDS Remote Diagnostics DRD
- CDS Remote Diagnostics SRS

3.4.2. Design Documents

As a direct result of this specification, the following design documentation shall be provided with the CDS:

- CDS Design Document
- CDS Software Development Plan (SDP)
- CDS Software Style Guide
- CDS Electronics/Hardware Standards Document

3.4.3. Engineering Drawings and Associated Lists

Engineering drawings, schematics, wire lists and cable routing lists shall be produced for the CDS. 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.

3.4.4. 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

The following manuals shall be provided:

- All manuals provided by commercial vendors for CDS components.
- Manuals for all CDS produced electronics and software.

3.4.5. Documentation Numbering

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

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

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.

3.7. Qualification

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

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

4 QUALITY ASSURANCE PROVISIONS

QA shall be provided in accordance with the *LIGO Project Quality Assurance Plan*, LIGO-M960076-00-P.

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

APPENDIX 1 DRR ACTION ITEMS

RECOMMENDED ACTION ITEMS

REQUIREMENTS FLOWDOWN

1. Concern: Some important requirements which will influence the CDS are TBD at present, including vibration and acoustic emission, electromagnetic compatibility, and reliability and maintainability.
   Action: (Coyne)
   - 1.1 Define limits for vibration and acoustical emission
   - 1.2 Define limits for electromagnetic emissions from CDS equipment
   - 1.3 Define requirements for reliability and maintainability
2. Concern: The need for wide bandwidth control signals to the end station from the vertex for e.g., length control is not indicated.
   Action: (Zucker) Provide preliminary needs to CDS, for length and for alignment signals to end/mid station; and for intensity/position monitors from end/mid station (see Zucker, "Inter-Station Signal Transmission Requirements", LIGO-T960057)
   Action Taken: Requirements of T960057 have been incorporated.
3. Concern: The signal count is based on an extrapolation of the 40m prototype and should be re-examined.
   Action: (Shoemaker) Prepare and deliver to CDS best present estimate of signal counts.
4. Concern: Real-time signal processing delays may represent severe limits on distributed control systems bandwidth, if loops are closed digitally through the network. Plans imply few analog loops between crates.
   Action: (Zucker)
   - 4.1 Establish preliminary bandwidth requirements.
   - 4.2 Explicit estimations of resulting information throughput to be made, including models for control system filters, and used to check and refine communications/computation capabilities.
5. Concern: Connection to PEM within the BTE has not been considered.
   Action: (Weiss) Incorporate preliminary PEM requirements into the CDS requirements and the CDS conceptual design.
6. Concern: Communications cabling which runs between station buildings must survive the temperatures in the BTE when a BT bake-out occurs.
   Action: (Bork) Choose cabling (fiber/copper) and placement (in/outside BTE) to accommodate environmental demands.
   Action Taken: Network communication cable is to be direct burial outside of BTE. Some cabling will be run inside of BTE for PEM, but further bakeout analysis has shown that temperature rise in BTE will be minimal.

CDS INTERNAL REQUIREMENTS/SPECIFICATIONS

7. Concern: There may be interference between control room users. Assuming protocols are followed, it is not clear how inadvertent conflicts are to be avoided.
   Action: (Bork) PDR should clarify methods that prevents inadvertent interference, while not hampering operations.
8. Concern: The distributed clock frequencies are not identical to the acquisition frequencies.
   Action: (Bork) Clarify reasoning or make identical.
   Action Taken: Clocks have been made identical.
9. Concern: A limited set of diagnostics/calibration functions are given in the documentation.
   Action: (Bork) Indicate that this aspect of CDS is being addressed elsewhere (System Integration) and minimize discussion.
   Action Taken: Diagnostics and calibration will be resolved as part of IFO diagnostics requirements/designs.
10. Concern: There is a need for connection of temporary instrumentation that is not reflected in the baseline.
    Action: (Shoemaker) Provide CDS with requirements for data acquisition and control of temporary instrumentation located in LVEA, mid, end that uses other communications protocols: GPIB, RS422, etc.
11. Concern: No discussion of a history log of operators' inputs or of the resulting instrument states; similarly, the possibility of event tracking e.g., mouse input for debugging.
    Action: (Bork) Please add, using some discretion about what is logged.
    Action Taken: Requirement has been added.
12. Concern: No stated requirement for implementing, capturing and storing "scripts."
    Action: (Bork) Impose a general requirement for using scripts in the operation of the detector and the VE.
    Action Taken: Requirement has been added.
13. Concern: Vacuum control racks adjacent/joined to IFO controls racks may compromise isolation of facility & technical power and GNDs.
    Action: (Bork) Impose requirements to insure all signal & safety grounds are property implemented without current paths between VE & IFO/technical systems.
    Action Taken: LIGO EMI Plan will be followed in all installations.