

**New Folder Name L160 CDS**

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**LIGO** PROJECT  
CALIFORNIA INSTITUTE OF TECHNOLOGY

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<b>Some preliminary notes on the LIGO Control and Data System (CDS)</b>			
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## 1 Purpose

This note is intended as a trigger for further discussions. It lists, in a rather unstructured way some of the ideas which come to my mind when trying to organize my work. Please do not take it as specification or anything definite. It is a basis for discussions and I would appreciate receiving your comments and other reactions. Please check whether the emphasis is on the arguments you think it should be. Check it especially for things which are completely missing.

## 2 Structure of LIGO

LIGO, as seen from the Control and Data System (CDS), is structured in sites, systems, subsystems, local units, etc. The essential feature of this subdivision is to organize it in such a way as to minimize the cross connections between the various units. Cross connections can be:

- functional connections
- physical connections (e.g. optical path)
- signal (cabling) connections

The functional subdivision will normally not reflect the physical structure of LIGO.

## 3 Functional description of LIGO

In order to be able, to specify the LIGO CDS, the LIGO plant has to be described in a functional way giving all necessary information for interfacing it with CDS. This functional description, while geared towards the interfacing with CDS, will certainly be useful for other purposes as well.

The functional description will be organized according to the functional structure mentioned above. It will be a top-down description of all units which may require connections to CDS. For convenience it is advisable to extend the same type of functional description also to those units of LIGO which will not be connected to CDS. The description has to take into account not only the connections necessary for normal operation of LIGO, but also the needs during commissioning and troubleshooting of the plant.

The functional description will be organized by plant items, not according to the types of equipment. This will potentially increase the size of the description, but this can be limited by using cross references to the description of similar units.

Each unit has to be described in terms of

- name of the unit
- who is responsible for the unit
- short description of component units
- location of the equipment
- list of units to which to be connected functionally
- commissioning procedure
- normal operation procedure
- detailed description of the remote/local operation
- Maintenance requirements (relevant to CDS)
- detailed signal list for all external connections
- functional code (see page 7)

**3.1 Unit Name** It is important to establish unique and clear unit names. Similar objects in different parts of the system should be named with similar terms.

**3.2 Unit responsibility** Each unit should have clearly assigned responsible person(s) who are familiar with the unit to a sufficient detail, to be contacted for any query concerning the unit.

**3.3 Unit component description** This is normally a short description of the physical components, their spacial arrangement. It often consists of lists of items giving make and type of equipment.

**3.4 Location of the equipment** This is a description of the physical lay-out of the unit, indicating the relative and absolute positions of all components.

For the definition of locations it is very useful to agree on a universal coordinate system for the entire LIGO.

**3.5 Functional description** The functional description is normally arranged into three sections:

- functional connections
- normal operation
- commissioning
- maintenance and troubleshooting

The functional connections regard connections between parts of the same unit and connections with other units.

The description of normal operation should include all possible aspects of routine operation, including possible automatic start-up procedures, alignment procedures, etc.

The commissioning aspects regard both the initial commissioning of the plant as well as the re-commissioning after a plant shutdown (either planned or unexpected)

An important aspect is to consider from the beginning the unit's operational aspects for planned maintenance and for troubleshooting. In the present context it is important to define early in which of these operations CDS can or should be involved and which of them are to be executed exclusively in local mode (see page 14).

**3.6 Signal lists** The most important tool for interfacing CDS with the LIGO plant are comprehensive signal lists. These signal lists should be established very early in the definition procedure. In the initial phases of the project they should be considered as working tools not as reference documents.

The signal lists should include for every single signal at least the following information;

- unique signal name
- unique signal code (see page 7)
- signal description
- source unit
- destination unit
- type of signal (analogue, digital with number of bits, ...)
- input or output (with respect to CDS)
- for analogue signals:
  - signal type (voltage, current)
  - signal range
  - frequency of signal
  - sampling frequency or frequencies
  - for analogue plant monitoring signals in addition:
    - lower alarm threshold
    - lower notification threshold
    - upper notification threshold

- upper alarm threshold
- signal storage requirements (for fast signals)
- trend recording requirements (for slow signals)

In order to be able to handle the enormous amount of information (my estimate is that there will be certainly several thousand signals) the use of a flexible, user-friendly and powerful database is required from the very beginning. This signal database will initially contain only a restricted number of fields for each entry. It will grow in both “directions”: the number of signals will increase as more components of the plant are added; it will increase possibly even more “horizontally” in step with the increased level of detailed information available for each signal.

The signal database will eventually have to be linked to the other databases described below (see page 7). The signals will have to “connected” to the (copper or fibre optic) cables on which they travel. These cable in turn will be “connected” to physical units.

#### 4 Plant structure

It has to be decided whether to aim at a plant functional structure with a fixed number of layers or an open number of layers. This influences on the naming conventions (see page 7).

I could envisage a fixed three layer structure for the functional description of LIGO, and consequently of CDS:

- site:  
(Hanford, Livingston, Caltech, MIT)
- subsystem  
(Vacuum, General Services, Auxiliary Physics, Interferometer #n, ...)
- local unit  
(Prestabilized Laser, Mode Cleaner, Conditioning Optics, Optical Interferometer, Auto-Alignment, ...)

A rough estimate indicates that there would be about 22 subsystems. I do not know how many local units there will be per subsystem. A desirable number would be around 20.

Figure 1 shows a tentative functional block diagram of LIGO. This illustrates the concept of site and subsystem subdivision. In this figure I have subdivided each of the remote sites in the following way.





**4.1 Vacuum subsystem** The vacuum subsystem includes the entire vacuum plant with all its auxiliaries independently of their location on site.

At present I do not know whether there will be just one CDS interface with "the" vacuum system or there will be a number of CDS components interfaced to various units in the vacuum system. The main difference between the two options is that in the first case the vacuum system is a single system capable of complete operation without the presence of CDS. In the second case centralized operation of the system requires the availability of CDS.

**4.2 General Services subsystem** This system could contain the following units:

- monitoring of the electrical mains
- temperature monitoring in various places
- general information on the operational status of equipment
- interface with building monitoring system (see page page 15)
- interface with closed circuit TV (see page page 18)

#### **4.3 Auxiliary Physics subsystem**

This subsystem could re-group a number of auxiliary measurements required for the interpretation of the interferometer data. It will contain the following measurement units:

- seismic measurements
- ambient noise measurements
- cosmic ray measurements

**4.4 Personnel Safety Subsystems** The Personnel safety systems (see page page 15) are completely independent subsystems whose status information is made available to CDS. No commands can be issued by CDS to the personnel safety systems.

**4.5 Interferometer subsystems** At present I would imagine that each Interferometer, including its auxiliaries constitutes one subsystem. Each Interferometer is composed of the following local units:

- prestabilized laser
- mode cleaner
- conditioning optics

- optical interferometer
- auto-alignment
- suspension
- seismic isolation

**4.6 CDS “subsystem”** CDS is to be formally considered another subsystem of LIGO. Internally it is structured according to the LIGO plant to which it is connected (see page 12)

## 5 Coding Conventions

We should establish very soon coding conventions for the entire LIGO. This applies to everything from entire subsystems down to signal names. The purpose is mainly to create a unique identifier for every single object we may be talking about.

When establishing a coding convention, one has to select basically between mnemonic and non-mnemonic (numbering) schemes. There is an infinity of possibilities. My personal preference is for mnemonic systems. They are generally better accepted by users and are less error prone. On the other hand they have two disadvantages:

- they are less economic in length which costs computer power and memory (but both are cheap today)
- only the first codes which you assign are obvious, and you quickly come to situations with naming conflicts

Another important aspect is the careful distinction between type description and type naming convention as opposed to item description and naming. For example the Draft ICD Handbook is a type description of one interferometer subsystem. In LIGO there will eventually be nine of these units; therefor there will be only one type description, but nine item based descriptions.

## 6 Database

In order to handle the information compiled in the functional descriptions, we need a suitable database which will initially contain things like:

- signal descriptions
- unit names

This database will quickly grow and contain information on various aspects of the plant, like

- cables,
- equipment types
- equipment items,
- location of equipment

## 7 Tasks of CDS

The tasks of CDS are to provide the following functions to the LIGO plant:

- acquisition of physics data
- handling of physics data
- acquisition of plant status data
- handling of plant status data
- handling of plant alarms
- remote<sup>1</sup> plant start and stop
- remote plant diagnostics
- remote plant operation
- data transfer to remote sites (other organizations)

CDS does not provide the following functions:

- feedback control
- personnel safety functions

**7.1 Physics data acquisition** This is the prime task of CDS: the acquisition of data from

- the interferometers
- auxiliary physics measurement (seepage 6)

**7.2 Physics data handling** The physics data handling system receives acquired data from all subsystems which produce physics relevant data. The data are continuously monitored for suspect events.

Some data channels are continuously stored. Other data channels are only completely stored if they were collected during time windows around suspect events. If they were not acquired during such a window, they are stored in a drastically reduced form.

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<sup>1</sup> for definition see page 14

All acquired physics data require

- short term storage
- continuous analysis

All data to be fully stored require

- packaging
- “shipment” to long term storage

All data to be stored in reduced form require

- data reduction
- packaging
- “shipment” to long term storage

**7.3 Plant data acquisition** CDS monitors the status of the entire plant on a continuous base. This includes data from all relevant plant components. CDS maintains a complete plant status image (PSI). PSI is the base for all plant related activities of CDS (commands and monitoring).

**7.4 Plant data handling** Plant data handling provides the functions:

- continuous monitoring of analogue signals
- continuous monitoring of digital signals
- alarm generation

Typically the continuously monitored signals are checked on whether they are within allowed limits. If warning or alarm thresholds are exceeded alarm messages are generated and sent to the operator consoles.

**7.5 Remote plant operation** CDS provides the tools for remotely operating the entire plant. This includes

- issuing of single commands to single units under human operator control and responsibility (remote manual mode)
- the generation of automatic or semi-automatic sequences of plant commands (remote automatic mode)

In both cases plant interlocks are implemented within CDS. Please note that these interlocks have to be backed up in the local units (see page 15). A typical problem in this area is to decide which interlocks to build in and how to allow for bypassing them.<sup>2</sup>

## 7.6 Operator Interface

Consoles provide the only operator interface to LIGO in remote operation. Consoles are interacting with the plant via the corresponding CDS subsystems. Consoles are not involved in any other plant related activities. All plant related automatic processes run on the subsystem components of CDS. Consoles are the only user interfaces to these processes. The basic concept is that the failure of a console or console-subsystem connection does not alter the plant status nor does it interrupt plant operation.

Consoles can be expected to be subsystem-dedicated, i.e. one console can issue commands to all components of exactly one subsystem. No console is allowed to issue commands to more than one subsystem. This is necessary to avoid conflicts in plant commands. Consoles may read data from any subsystem at any time (provided that such reading does not change the subsystem status).

Re-assigning a physical console to another subsystem is possible but is not considered part of normal operation.

Consoles that interact with physics data acquisition components may functionally be different from those which interact only with the plant components. It could well be that there will be two types of consoles (identical hardware, but running different software):

- plant operation consoles
- physics data consoles.

*7.6.1 Plant operation consoles* Plant operation consoles provide the following functions:

- access to plant status information by means of
  - mimic diagrams
  - signal lists

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<sup>2</sup> My experience is that people put a lot of interlocks in which they need to take out afterwards or which they bypass afterwards, especially in non-operating situations (commissioning and troubleshooting)

- issuing of commands to the plant
- alarm handling
- trend recording for slowly changing signals (e.g. temperatures, pressures)

**7.6.2 Physics data consoles** Physics data consoles provide all functions of the plant operation consoles, plus the following functions to handle “fast” data:

- data display
- access to all data handling programs

## 8 Requirements for CDS

There are a number of general requirements for CDS most of which stem from the fact that LIGO is a large installation, and not a laboratory experiment; at the same time it is a physics experiment which will change over time.

One basic problem of CDS is the fact that its expected lifetime (one computer generation is about five years) is much shorter than the expected lifetime of the plant to which it is interfaced (20 years). There is no recipe to overcome this (unless you decide to burn down LIGO once its computer system is outdated).

The following is a general list of requirements which apply to both hardware and software components of the system.

**8.1 Modularity** The system should not be monolithic; it should be build in a modular way from well defined building blocks. This allows for an easy increase of the power of the system and for the gradual modernization by replacing components.

**8.2 Flexibility** The system has to be extremely flexible in order to be able to cope with future requirements of the experiment. LIGO is as big as an industrial plant, but it is a physics experiment.

**8.3 Expansibility** LIGO will grow with time. The signal numbers per unit will grow with time. Requirements are initially nearly always underestimated<sup>3</sup>.

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<sup>3</sup> I lived a beautiful example of this: In 1978 when I joined the JET fusion experiment, physicists there estimated the amount of data per shot to be around 200 kBytes; JET today acquires routinely around 20 MBytes per shot

**8.4 Reliability** LIGO and its CDS have to be reliable for two important reasons: LIGO is required to operate on a 24-hour / 365-day basis in order to be useful especially when in coincidence mode. LIGO is large and access to plant components is tedious and time consuming.

**8.5 Internal standardization** The limitation of the number of different types components (internal standardization) helps meeting all four of the before mentioned requirements.

## **8.6 Industry standards**

The use of industry standards wherever possible, often reduces the development cost and risk, and again normally improves reliability. In addition it renders the system, if well chosen, more resistant against changes in the market place.

**8.7 Compatibility with other experiments** Compatibility with other institutions (mainly VIRGO) is another requirement which has both technical and commercial reasons.

**8.8 Standardization of local interfaces** The standardization of the interfaces (signals) between CDS and the local equipment is an important aspect of the local unit design.

**8.9 Self-diagnostics** In order to make the system reliable, CDS has to be equipped from its very beginning with extensive self-diagnostics.

## **9 Structure of CDS**

CDS has to reflect the structure of the plant to which it is connected.

As LIGO, it will internally be organized in systems, subsystems, local units, etc. Many of these will correspond one-to-one to components of the LIGO plant. In addition, there will also be units which do not correspond to plant components. (examples: internal diagnostics unit for CDS, all hardware components of CDS)

As mentioned before, CDS is to be formally considered another subsystem of LIGO. At present I can see the following functional structure (see Figure 1):

- site supervisor systems
- subsystem interfaces
  - local unit interfaces



In addition to the CDS components which structurally correspond to plant units there are some components which do not have such counterparts:

- supervisor systems
- timing system(s)
- data handling subsystems (see page 8)
- operator consoles (see page 10)

**9.1 Supervisor systems** At both remote sites the local CDS equipment will work functionally under a supervisor system. Tasks of the supervisor systems include:

- status monitoring of all CDS equipment at the site
- interface to the local personnel safety system
- handling of the site timing system

**9.2 Timing System** The Timing System provides precise time reference for all data acquisition channels independent of their location. It consists of two separate timing systems at both observatory sites. The two systems are synchronized.

The system precision is xxx  $\mu$ s.

Timing system information at the sites is locally transmitted via fibre optic cables.

Timing system synchronization between sites uses the GPS satellite based system.

### 9.3

## 10 Local unit requirements

All local units should be as self-contained as possible. This means they should have as few external links (both functional and physical) as possible. They should be equipped with extensive self-diagnostics.

It has to be carefully checked whether some subsystems should also be required to be capable of local operation without the availability of CDS. I could imagine that such a requirement has to be put to the vacuum system.

## 11 Modes of Operation

Local units or subsystems may work in different modes of operation:

- **local mode:** in this case the equipment is operated by an operator near to the equipment using manual controls typically arranged on a local control panel
- **remote mode:** in this case the operator uses (a part of) CDS; he operates the equipment from a CDS console.

The term remote refers to the fact that the equipment is operated not directly by the operator, but through (parts of) CDS.

Remote mode operation can be carried out in different ways: Remote operation can refer to the plant in normal operation as well as under commissioning or troubleshooting.

Remote operation can be executed from consoles placed in different locations (“mobile consoles”): the console can be

- near the equipment
- in the site control room
- at a remote site (Caltech, MIT, anywhere on Internet)

It can be envisaged that normal operation will take place from consoles in the site control room in Hanford and Livingston.

It is obvious that the mobile console concept requires that at any time only one console may be active for a given subsystem. Care has to be taken to avoid multiple consoles.

The fact that a unit can be operated either remotely or locally requires that all units be equipped with a local/remote switch. There are two problems related to this:

Care has to be taken in assigning which entities can be placed independently from each other in either remote or local mode; basically the choice is between a single switch for an entire subsystem (unlikely!) or at the local unit level or even below that (if more levels were to be defined). My experience is, that you can commit big errors here!

The second aspect is the secure handing of the handing over control from local to remote and vice versa. Imagine a simple key operated local/remote switch on a local panel somewhere on the site. You have to guarantee that you cannot put the unit into remote without being sure, that the corresponding part of CDS is operational. Vice versa you should not be able to put

the unit into local mode without the consent of the CDS or its operator. There are local/remote interlock schemes for handling these cases, but they have to be built-in from the beginning, a retrofit is prohibitively complicated (and will never be done).

## **12 Plant protection**

CDS will provide all necessary plant monitoring facilities to provide the remote operator with the necessary information. It will provide all possible interlocks for the operation of the plant.

But CDS cannot guarantee the protection of the plant in case of plant faults or external intervention nor can it guarantee to be itself absolutely fault-free. All local units have to be designed with a maximum of built-in self-protection. No local unit may depend on CDS for its own integrity. This includes necessary protection also against failure (erroneous action) of CDS.

It has to be investigated, whether an independent, centralized second layer of plant protection is required for LIGO. Such a system should be very robust and possibly crude. Its tasks are to intervene and prevent any major damage to the plant (not to people — see below).

## **13 Personnel Safety**

CDS cannot provide functions which are required to protect people from possible dangers. Personnel safety has to be provided by independent measures. This does not exclude that CDS may provide an additional layer of interlocks intended also for personnel safety.

## **14 Building Monitoring**

It has to be decided whether or not to incorporate the tasks of general building monitoring (of those parts of the buildings which are not LIGO-operation related) into the CDS. Such building monitoring tasks can regard:

- fire detection system
- indoors climate in various locations
- outdoors meteorological conditions
- doors
- status of electrical supply

As the LIGO sites will eventually be operated on a 24-hour / 365-day basis, it is well conceivable that such building monitoring should be incorporated into CDS especially as the same type of monitoring is to be done for the LIGO-operation related buildings in any case.

Another solution could consist in buying a turn-key building monitoring and alarm system and interfacing it (partially) to CDS (A minimum of interfacing is required in any case, e.g. monitoring of plant mains supply).

A specific problem with turn-key systems will be cabling, as LIGO presents longer distances than most of these systems are made for (no fibre optic transmission).

## 15 Physical Lay-out

The physical arrangement of CDS equipment is in principle independent of the functional arrangement. However there will be many cases where the functional requirements are difficult to fulfill in their ideal form. The main aspects which will play a role are:

- space limitations
- accessibility of equipment
- signal transmission speed limitations
- signal transmission quality considerations
- “cross talk” between critical LIGO components and components of CDS
- cost

**15.1 Field equipment** In placing the CDS field equipment a number of factors are important:

- fast electrical signals require short connections
- it is easy (and cheap) to transport digital signals over long distances on fibre optic cables; this applies generally also to computer networks
- the use of fibre optic transmission for analogue signals is normally much less attractive; the cost of these links is high and often technically unsatisfactory (drift problems)
- accessibility could well become a key issue; if CDS equipment is placed near to LIGO interferometer components, any access to this equipment may disturb the operation of LIGO

**15.2 Control room(s)** While all CDS consoles are, in principle, mobile, they will normally be placed in control rooms. I envisage three control rooms for LIGO:

- Caltech Remote Control Room