LASER INTERFEROMETER GRAVITATIONAL WAVE OBSERVATORY
- LIGO -
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40 Meter Recycling Electronics Design Requirements

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Abstract

This technical note describes the design requirements for the 40 Meter Interferometer recycling electronics. These electronics will be designed and installed as part of the recycling configuration planned for the 40 Meter Interferometer in 1996. Specifically excluded from this document are the requirements for the 33 MHz reference system which are covered in document number TBD.

1 INTRODUCTION

1.1. Purpose

The purpose of this is to describe and document the design requirements for the recycling electronics to be designed and installed as part of the recyled interferometer configuration.

1.2. Scope

This document covers the design and performance requirements for all electronics to be used in the recycled interferometer configuration with the exception of the 33 MHz reference system, the RF photodetectors and demodulation electronics. Thses devices are covered in document number TBD.

1.3. Definitions

1.4. Acronyms

- CDS- Control and Data System
- LIGO- Laser Interferometer Gravitational-wave Observatory
- MTBF- Mean Time Between Failure
- MTTR- Mean Time To Repair
- TBD- To Be Determined

1.5. Applicable Documents

1.5.1. LIGO Documents

1.5.2. Non-LIGO Documents

2 GENERAL DESCRIPTION

2.1. Product Perspective

The recycling electronics described in this document, and the 33 MHz reference system, RF photodetectors and down conversion electronics described in document number TBD specify the servo electronics, controls and monitors that form the various cavity length control systems for the recycled interferometer configuration that will be installed on the 40 meter interferometer on the Caltech campus. The requirements and the design are for the most part based on existing electronics and systems that are part of the current 40 meter interferometer. The systems that are new to the 40 meter interferometer are:

- Recycling cavity length control formed by the recycling mirror and associated electronics and controls,

- 33 MHz reference system, RF photodetectors and down conversion electronics described in document number TBD.

The existing common mode, differential mode and beam splitter servo electronics will be redesigned and repackaged to incorporate a design similar to that to be used for electronics in the LIGO interferometers. This redesign and repackaging will include the addition of a LIGO CDS computer interface to all functions, a LIGO CDS operator console, LIGO CDS networks and a LIGO CDS control and monitoring system.

In addition to providing a reliable and servicable system for use on the 40 meter interferometer the use of LIGO-like CDS controls and monitoring will allow the LIGO CDS group to gain practical experience in developing, installing and maintaining a complex interferometer control and monitoring system prior to the final design of systems to be used on the LIGO interferometers in Washington and Louisiana.

2.2. Product Functions

The function of the recycling electronics can be divided into the following:

- Recycling Mirror Servo Electronics
- Beam Splitter Servo Electronics
- Common Mode Servo Electronics
- Differential Mode Servo Electronics.

A block diagram of these functional groups in the context of the 40 meter interferometer is shown in the figure below.

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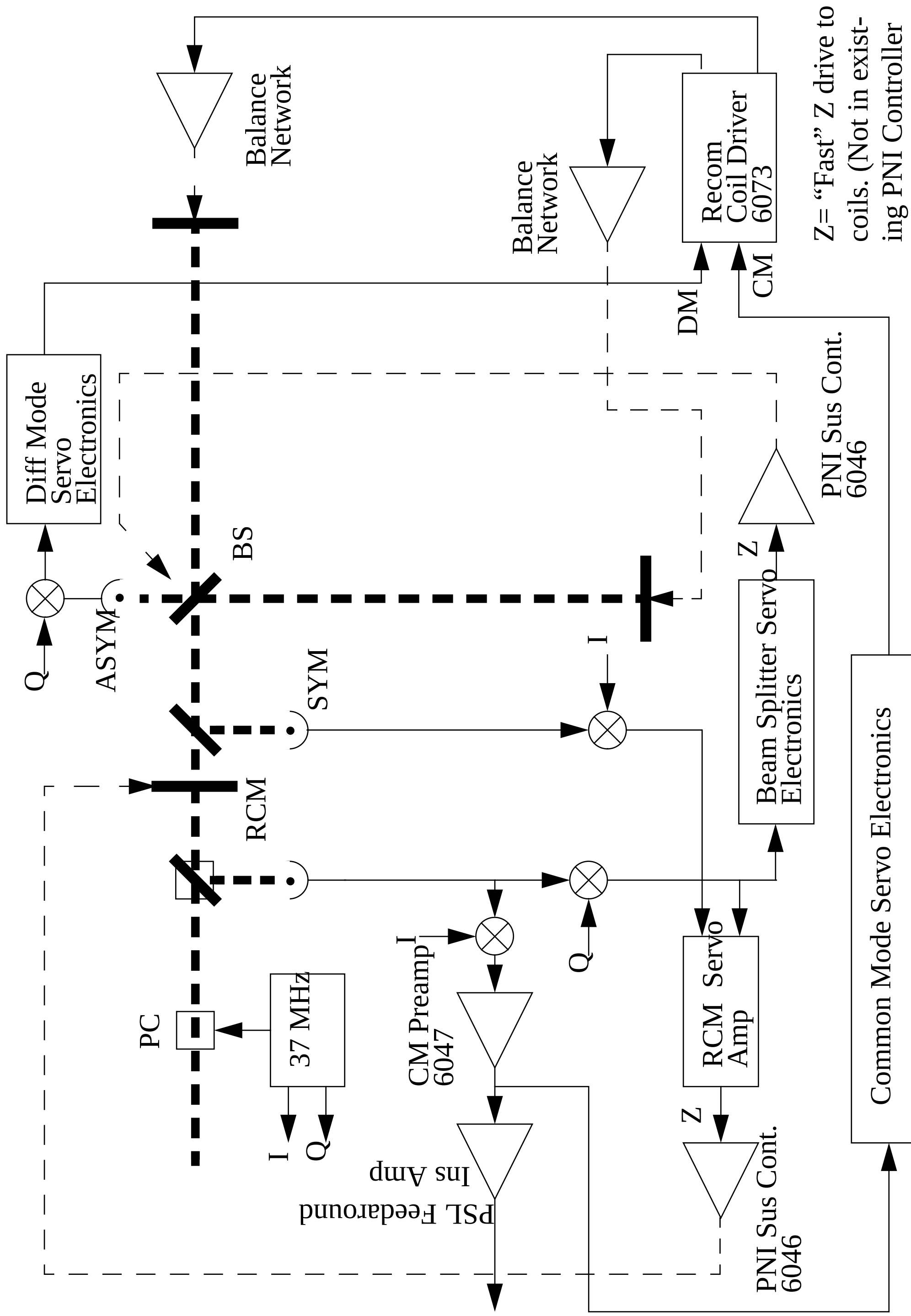

Figure 1: Block Diagram of Recycling Electronics

2.3. General Constraints

2.3.1. Equipment Locations

Due to space limitations and the configuration of the 40 meter interferometer, the electronics for the recycling system must be confined to a single 19 inch rack located near the east vertex chamber of the interferometer. These constraints only apply to the bulk of the electronics and not to any line drivers or preamplifiers that may be used to boost signals closer to the devices being controlled or monitored.

Permanent or fixed operator consoles will be located in the control room and work area adjacent to the 40 meter interferometer.

2.3.2. Vacuum Cabling and Devices Internal to the Vacuum Chamber

Vacuum cabling, connectors, feedthroughs and devices internal to the vacuum chamber must adhere to the established vacuum qualification, cleaning and maintenance procedures that have been established for the 40 meter interferometer.

2.3.3. Computer Networks and Network Equipment

The recycled interferometer controls shall utilize the existing CDS network and networking equipment located in the 40 meter laboratory. Connection of devices within the laboratory or the control area adjacent to the laboratory shall be via 10baseT connections. Existing cabling and network hubs utilize category 5 cabling with RJ-45 connectors.

2.4. Assumptions and Dependencies

The following assumptions have been made in the preparation of these requirements:

1. The suspension system and controls currently being developed for the 40 meter or the existing suspension sysem and controls may be used for the orientation and damping of the end masses.
2. The suspension system and controls currently being developed for the 40 meter will be used for control of the RCM and the beam splitter. Note that this will require the addition of a longitudinal drive input to be incorporated into the controller.
3. The exisiting transfer functions for the beam splitter, common mode and differential mode servos will be used in the recycled interferometer configuration with only “minor” changes or additions.
4. The 33 MHz reference system, RF photodetectors and demodulation electronics will be provided as part of another design outside the scope of this requirements document. For the purposes of this document it has been assumed that the signals required by each of the servos have been down converted to base band as shown in system block diagram in section 2.3 of this document.

3 REQUIREMENTS

3.1. Characteristics

3.1.1. Performance Characteristics

3.1.1.1 Recycling Mirror Servo Electronics

A block diagram of the recycling mirror servo electronics in the context of the interferometer is shown in Figure 1: Block Diagram of Recycling Electronics.

3.1.1.1.1 Transfer Function

The following table summarizes the poles, zeros and nominal DC gain of the recycling mirror servo electronics.

Table 1: Recycling Mirror Servo Electronics Poles and Zeros

Poles (Hz)	*Zeros (Hz)*	*Nom. DC gain*
TBD	TBD	TBD dB

3.1.1.1.2 Input and Output Noise

The output referred noise current of the beam splitter servo electronics shall be less then $(TBDnA)/(\sqrt{Hz})$ at 100 Hz and all line related spikes shall be less than TBDnA rms.

3.1.1.1.3 Indicators, Monitors and Controls

3.1.1.1.4 Test Inputs, Outputs and Functions

Test inputs, monitors and controls shall be provided such that the closed loop transfer function of the recycling mirror servo can be measured while the servo loop is closed.

A means of openning the servo loop and injecting a test signal into the recycling mirror suspension controller shall be provided. Openning of the servo loop shall be accomplished without removing cables or disconnecting devices.

3.1.1.2 Beam Splitter Servo Electronics

3.1.1.2.1 Transfer Function

The beam splitter servo electronics shall have two modes of operation:

- Acquire Mode: used to acquire lock
- Run Mode: used after the servo has acquired lock

The switching between these modes of operation shall be controllable by the operator via the operator display. Although it not a requirement at this time, the design shall not preclude mode control via automatic sequencing or locking software algorithms.

The following table summarizes the poles, zeros and nominal DC gain of the beam splitter servo electronics for each mode.

Table 2: Beam Splitter Servo Electronics Poles and Zeros

Mode of Operation	*Poles (Hz)*	*Zeros (Hz)*	*Nom. DC gain*
Acquire Mode	0.4, 600, 600, 1.17K, 1.17K	4.4, 4.4	100 dB
Run Mode	0.4*, 1, 30, 70,70, 100, 600*, 600*, 1.17K*, 1.17K*	4.4*, 4.4*, 4.4, 10	100 dB

- *These poles and zeros are the same as in acquire mode.

A means of adjusting the nominal DC gain +20dB and -40dB in 1 dB increments shall be incorporated into the design of the beam splitter servo electronics. In addition, a means of inverting the nominal DC gain shall be provided.

3.1.1.2.2 Input and Output Noise

The output referred noise current of the beam splitter servo electronics shall be less then $(85nV)/(\sqrt{Hz})$ at frequencies greater than 100 Hz and all line related spikes shall be less than TBDnA rms.

3.1.1.2.3 Amplifier Saturation and Dynamic Range

The design shall be such that no part of the circuitry saturates prior to the output stage.

3.1.1.2.4 Test Inputs, Outputs and Functions

Test inputs, monitors and controls shall be provided such that the closed loop transfer function of the beam splitter servo can be measured while the servo loop is closed.

A means of opening the servo loop and injecting a test signal into the beam splitter suspension controller shall be provided. Opening of the servo loop shall be accomplished without removing cables or disconnecting devices.

A means of testing the open loop transfer function and performance of the servo electronics shall be incorporated into the design. Due to the high DC gain requirements of the system this will require test inputs and monitors and transfer function bypass circuitry.

3.1.1.3 Common Mode Servo Electronics

3.1.1.3.1 Transfer Function

The following table summarizes the poles, zeros and nominal DC gain of the common mode servo electronics up to the recombination coil driver. The transfer function of the recombination coil driver from the common mode input to the output for each arm is summarized in table TBD. The recycling common mode servo electronics shall have the same response. Note that the response of the common mode preamp is dependent on the mode of operation that has been selected. The transfer function of the common mode preamp for each mode of operation is summarized in table TBD.

Table 3: Common Mode Servo Electronics Poles and Zeros up to the Recombination Coil Driver

Current Module	*Schematic #*	*Poles (Hz)*	*Zeros (Hz)*	*Nom. DC gain*
Common Mode Preamp *	6047	See table TBD	See table TBD	See table TBD
Mode Cleaner PZT Filter **	6063	10, 106K		29 dB
HV Amp ***	6064	3, 3, 3, 2K, 2.13K	30, 100, 560, 1K	110 dB
50:1 Divider	N/A			-34 dB
Arm 1 Coil Driver ****	6072	0.1, 0.66, 0.66, 0.66, 0.66, 10.6, 19.4, 20.8	0.3, 0.3	17.6 dB

- *12 and 24 MHz notch filters with a Q of TBD shall be incorporated into the front end of the design.
- **A 2.4 (?)KHz notch filter with a Q of TBD shall be incorporated into the design.
- *** Traps at 4.2 KHz, 4.8 KHz and 9.1 KHz with Qs of TBD shall be incorporated into the design. In addition, the current design provides for +20 and +40 dB gain boosts that may be selected. The design shall incorporated these selections.
- ****The four poles at 0.66 Hz are a 4 pole butterworth low pass filter. The butterworth response shall be incorporated into the design.

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Table 4: Summary of Response of Recombination Coil Driver for Common Mode Servo

Signal Path	*Poles (Hz)*	*Zeros (Hz)*	*Nom. DC gain*
Common Mode Input to Arm 1 Output	796		0 dB, inverting
Common Mode Input to Arm 2 Output	796		0 dB, non-inverting

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Table 5: Summary of Common Mode Preamp Response for each Mode of Operation

Operating Mode	*Poles (Hz)*	*Zeros (Hz)*	*Nom. DC gain*
Normal and Bypass Off			0 to 20 dB, adjustable
Boost and Bypass Off	194	19.4K	40 to 60 dB, adjustable
Normal and Bypass On	338, 798, 4M*	3.21K, 338K	80 to 100 dB, adjustable
Boost and Bypass On	194, 338, 798, 4M*	3.21K, 19.4K, 338K	120 to 140 dB, adjustable

- *The 4MHz pole shall be incorporated into the front end of the amplifer design and is there to prevent saturation of subsequent bypass amplifers.

3.1.1.3.2 Input and Output Noise

The output referred noise current of the beam splitter servo electronics shall be less then $(TBDnA)/(\sqrt{Hz})$ at 100 Hz and all line related spikes shall be less than TBDnA rms.

3.1.1.3.3 Indicators, Monitors and Controls

A gain inversion switch shall be incorporated into the design of the common mode servo electronics. The position of the switch shall be selectable by the operator.

3.1.1.3.4 Test Inputs, Outputs and Functions

Test inputs, monitors and controls shall be provided such that the closed loop transfer function of the common mode servo can be measured while the servo loop is closed.

A means of openning the servo loop and injecting a test signal into the arm longitudinal drive coils in the common mode configuration shall be provided. Openning of the servo loop shall be accomplished without removing cables or disconnecting devices.

3.1.1.4 Differential Mode Servo Electronics

3.1.1.4.1 Transfer Function

The differential mode servo electronics shall have two modes of operation:

- Acquire Mode: used to acquire lock
- Run Mode: used after the servo has acquired lock

The switching between these modes of operation shall be controllable by the operator via the operator display. Although it not a requirement at this time, the design shall not preclude mode control via automatic sequencing or locking software algorithms.

The following table summarizes the poles, zeros and nominal DC gain of the differential mode servo electronics for each mode.

Table 6: Differential Mode Servo Amplifier Poles and Zeros

Mode of Operation	*Poles (Hz)*	*Zeros (Hz)*	*Nom. DC gain*
Run Mode	1*, 8K, 8K, 8K, 8K**, 15K, 15K, 15K, 15K**	100*, 800, 1500, 1500	38 dB
Acquire Mode	8K, 8K, 8K, 8K**, 15K, 15K, 15K, 15K**	800, 1500, 1500	38 dB

- *These poles and zeros are added in run mode.
- ** These poles are a 4 pole 8KHz and 15 KHz Butterworth.

A means of adjusting the nominal DC gain +20dB and -40dB in 1 dB increments shall be incorporated into the design of the differential servo electronics. In addition, a means of inverting the nominal DC gain shall be provided

The following table summarizes the poles, zeros and nominal DC gain of the differential mode servo electronics up to the recombination coil driver. The transfer function of the recombination coil driver from the differential mode input to the output for each arm is summarized in table TBD. The recycling differential mode servo electronics shall have the same response.

Table 7: Differential Mode Servo Electronics Poles and Zeros up to the Recombination Coil Driver

Current Module	*Schematic #*	*Poles (Hz)*	*Zeros (Hz)*	*Nom. DC gain*
Arm 2 Coil Driver *	6074	3, 177, 396, 8.4K, 8.5K, 8.6K, 9.95K, 19.4K	155, 168, 177, 553, 900	48 dB, +/-6 dB, adjustable, inverting

- *The arm 2 coil driver has two modes of operation, acquire and run. In the acquire modethe 3 Hz pole and the 168 Hz zero are not present. In addition, the nominal DC gain is 22 dB. These modes of operation shall be incorporated into the design and shall be selectable by the operator.

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Table 8: Summary of Response of Recombination Coil Driver for Differential Mode Servo

Signal Path	*Poles (Hz)*	*Zeros (Hz)*	*Nom. DC gain*
Differential Mode Input to Arm 1 Output			0 dB, inverting
Differential Mode Input to Arm 2 Output			0 dB, inverting

3.1.1.4.2 Input and Output Noise

The output referred noise current of the beam splitter servo electronics shall be less then $(5nV)/(\sqrt{Hz})$ at 100 Hz and all line related spikes shall be less than TBDnV rms.

3.1.1.4.3 Indicators, Monitors and Controls

3.1.1.4.4 Test Inputs, Outputs and Functions

Test inputs, monitors and controls shall be provided such that the closed loop transfer function of the differential mode servo can be measured while the servo loop is closed.

A means of openning the servo loop and injecting a test signal into the arm longitudinal drive coils in the differential mode configuration shall be provided. Openning of the servo loop shall be accomplished without removing cables or disconnecting devices.

3.1.1.5 Recycled Interferometer System Controls

3.1.1.5.1 Indicators, Monitors and Controls

All output currents to suspension coils shall be monitored by the recycled interferometer control and monitor system. Output current limiting shall be incorporated into the design. The design shall limit the amount of energy deposited in any coil to less than TBD joules over TBD seconds.

The high voltage output to the mode cleaner PZT shall be monitored.

The following table summarizes the operator alarms and interlocks that shall be incorporated into the design.

Table 9: Alarms

Alarm	*Severity*
Arm 1 coil drive greater than TBD mA	Major
Arm 2 coil drive greater than TBD mA	Major
BeamsSplitter coil drive greater than TBD mA	Major
Recycling mirror coil drive greater than TBD mA.	Major

3.1.1.5.2 Test Inputs, Outputs and Functions

3.1.2. Physical Characteristics

3.1.2.1 Electronic Equipment Housings

To the extent possible and reasonable the following shall be applied to the recycling electronics.

- All equipment shall be housed in standard 19 inch racks.
- Standard 6U VME enclosures with VME, dummy or split backplanes shall be used, as appropriate, for custom and commercial modules.
- Custom electronics modules shall be 6U VME format and shall follow the design standards imposed by the LIGO CDS group.

3.1.2.2 Cabling and Connections

All cabling and connection of electronics modules and devices shall be in accordance with standard LIGO CDS grounding and shielding policies.

All field cabling shall be run in the cable trays that are provided below the vacuum chamber.

3.1.3. Interface Definitions

3.1.3.1 Interfaces to other 40 meter subsystems

3.1.3.1.1 Mechanical Interfaces

The following table summarizes the mechanical interfaces to other 40 meter subsystems.

Table 10: Mechanical Interafces to Other 40 Meter Subsystems

Interface	*40 meter Subsystem*	*Characteristics*

3.1.3.1.2 Electrical Interfaces

The following table summarizes the electrical interfaces to other 40 meter subsystems.

Table 11: Electrical Interafces to Other 40 Meter Subsystems

Interface	*40 meter Subsystem*	*Characteristics*
Fast Z input to Recycling Mirror Suspension Controller	Recycling Mirror Suspension Controller	Input Impedance: TBD Transfer Function: 1mA/mA Connector: TBD
Fast Z input to Beam Splitter Suspension Controller	Beam Splitter Suspension Controller	Input Impedance: TBD Transfer Function: 1mA/mA Connector: TBD
Longitudinal Coil Drive to Arm 1	Arm 1 Longitudinal Coil	
Longitudinal Coil Drive to Arm 2	Arm 2 Longitudinal Coil	

3.1.3.1.3 Optical Interfaces

N/A

3.1.3.1.4 Stay Clear Zones

3.1.3.2 Interfaces external to 40 meter subsystems

3.1.3.2.1 Mechanical Interfaces

3.1.3.2.2 Electrical Interfaces

The following table summarizes the electrical interfaces to systems external to the 40 meter interferometer.

Table 12: Electrical Interafces to non- 40 Meter Subsystems

Interface	*System*	*Characteristics*
Rack AC Power	Laboratory AC Power System	Voltage: 115 VAC, +TBD, -TBD Current: 16 A max. Frequency: 60 Hz
Operator Console AC Power	Laboratory AC Power System	Voltage: 115 VAC, +TBD, -TBD Current: 16 A max. Frequency: 60 Hz

3.1.3.2.3 Stay Clear Zones

3.1.4. Reliability

The Mean Time Between Failure (MTBF) for components shall be greater than TBD.

3.1.5. Maintainability

The Mean Time To Repair (MTTR) for components shall be less than TBD

3.1.6. Environmental Conditions

The recycling electronics 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

Table 13: 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 recycling electronics design must accomodate atmospheric pressure changes from a maximum of 15.2 psia to a minimum of 14.2 psia.

3.1.6.1.3 Seismic Disturbance

N/A

3.1.6.2 Induced Environment

3.1.6.2.1 Electromagnetic Radiation

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

The recycling electronics shall not produce electromagnetic emissions greater than TBD.

3.1.6.2.2 Acoustic

Recycling electronics and associated control components shall be designed to produce the lowest levels of acoustic noise as possible and prctical. In any event, acoustic noise levels greater than TBD will not be produced.

3.1.6.2.3 Mechanical Vibration

Recycling electronics and associated control components shall not produce mechanical vibrations greater than TBD.

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

Such items as units of measure to be used (English, Metric) should be listed and any other general items, such as standard polishing procedures 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 purple or otherwise protected in a manner to be approved.*

3.2.1.2 Materials

All recycling electronics and equipment to be placed inside the 40 meter vacuum chamber shall be in accordance with the LIGO list of approved vacuum materials. LIGO document number TBD.

3.2.1.3 Processes

All recycling electronics and equipment to be placed inside the 40 meter vacuum chamber shall be cleaned in accordance with the LIGO 40 meter vacuum cleaning standards. LIGO document number TBD.

3.2.2. Component Naming

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

3.2.3. Workmanship

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

3.2.4. Interchangeability

The recycling electronics and equipment 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 recycling electronics and associated components shall be designed and laid out in a manner consistent with applicable standard human engineering 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 developed in the course of the design:

- TBD

3.3.2. Design Documents

The folowing design documents shall be provided:

- Recycling Electronics Hardware Design and Description
- Recycling Electronics Software Design Document

3.3.3. Engineering Drawings and Associated Lists

Engineering drawings, schematics, wire lists and cable routing lists shall be produced for the recycling electronics. 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 recycling components
- Manuals for all CDS produced electronics and software.

3.3.5. Documentation Numbering

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

3.3.6. Test Plans and Procedures

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

3.4. Logistics

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

3.5. Precedence

In the event of conflicts between this requirement document and other LIGO documents, this document shall take precedence.

3.6. Qualification

Qualification of various components and systems shall be in accordance with section 4 of this document.

4 QUALITY ASSURANCE PROVISIONS

4.1. General

4.1.1. Responsibility for Tests

The CDS group shall be responsible for performing all tests, including development of appropriate test plans and procedures.

4.1.2. Special Tests

4.1.2.1 Engineering Tests

TBD

4.1.2.2 Reliability Testing

Reliability evaluation/development tests shall be conducted on items with limited reliability history that will have a significant impact upon the operational availability of the system.

4.1.3. Configuration Management

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

4.2. Quality conformance inspections

Design and performance requirements identified in this specification and referenced specifications shall be verified by inspection, analysis, demonstration, similarity, test or a combination thereof per the Verification Matrix, Appendix 1 (See example in Appendix). Verification method selection shall be specified by individual specifications, and documented by appropriate test and evaluation plans and procedures. Verification of compliance to the requirements of this and subsequent specifications may be accomplished by the following methods or combination of methods:

4.2.1. Inspections

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

4.2.2. Analysis

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

4.2.3. Demonstration

Demonstration may be used for determination of qualitative properties and performance of an item and is accomplished by observation. Verification of an item by this method would be accomplished by using the item for the designated design purpose and would require no special test for final proof of performance.

4.2.4. Similarity

Similarity analysis may be used in lieu of tests when a determination can be made that an item is similar or identical in design to another item that has been previously certified to equivalent or more stringent criteria. Qualification by similarity is subject to Detector management approval.

4.2.5. Test

Test may be used for the determination of quantitative properties and performance of an item by technical means, such as, the use of external resources, such as voltmeters, recorders, and any test equipment necessary for measuring performance. Test equipment used shall be calibrated to the manufacture's specifications and shall have a calibration sticker showing the current calibration status.

5 PREPARATION FOR DELIVERY

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

5.1. Preparation

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

5.2. Packaging

Procedures for packaging shall ensure cleaning, drying, and preservation methods adequate to prevent deterioration, appropriate protective wrapping, adequate package cushioning, and proper containers. Proper protection shall be provided for shipping loads and environmental stress during transportation, hauling and storage.

5.3. Marking

Appropriate identification of the product, both on packages and shipping containers; all markings necessary for delivery and for storage, if applicable; all markings required by regulations, stat-

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

6 NOTES

N/A

APPENDIX 1 QUALITY CONFORMANCE INSPECTIONS

The following table shows the methods of testing that will be used for verification of quality conformance.

Table 14: Quality Conformance Inspections

Paragraph	*Title*	*I*	*A*	*D*	*S*	*T*