## CANADA-FRANCE-HAWAII TELESCOPE CORPORATION

# Instrument Design Specifications

Revision 2.6a July 21, 2011

Instrument Specifications

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# Instrument Specifications

## Preface

During instrument design and fabrication many technical requirements pertaining to the CFHT telescope and related facilities are invariably required. We have attempted to incorporate the most important of these into one manual in order to provide you with a single, coherent reference, with emphasis placed on instrument maintainability

Many of the requirements reflect rigid conditions imposed by existing telescope systems; others are of an operational nature. While many details outlined here are negotiable, our goal will be to provide not only an instrument that works well, but also one that is maintainable by talented, but not necessarily expert, staff, located at a remote site, working under non-ideal conditions.

Departures from the requirements which are not covered explicitly in the instrument contract should be discussed with the CFHT technical and scientific staff at as early an opportunity as possible. Generally speaking, for deviations from these requirements, a written agreement with the CFHT detailing both the proposed deviations and their purpose will be required.

Please remember that during contract evolution, CFHT will emphasize robust instrument operation and serviceability, and the delivery of comprehensive instrument documentation. In order to provide engineering support, instruments must be capable of being operated in a stand-alone mode using an instrument-specific intelligent controller. Documents detailing the operation and maintenance of the instrument are required at final acceptance tests.

In order to maintain an orderly project development, CFHT will assign an in-house instrument project scientist and instrument project engineer to oversee CFHT's interests in the project and to provide liaison between your team and CFHT staff. These individuals will be your primary contacts at the observatory. All communications with CFHT regarding the project should be channeled through them. Generally, communications of an important nature should be in writing (e-mail or letter).

While developing instrument interfaces, please keep in mind that most of CFHT's original equipment was acquired through contracts to other institutions. Much of this equipment has subsequently been modified and upgraded at CFHT. In general, the originating institutions have not been apprised of these changes. Similarly, older CFHT documents may not reflect current device status. Therefore, if you require information not contained in this manual, please request current versions directly from the CFHT project staff. Do not assume that other institutions' documents pertaining to CFHT are up to date.

Generally during the final stages of development, CFHT conducts instrument acceptance tests at the developer's facility prior to delivery to Hawaii. It has proven useful for both the developer and CFHT to divide these tests into several – usually three - stages, starting early in the final assembly of the instrument or assembly of a critical subsystem. Our aim is to assist the developer in providing an instrument that will function reliably in the CFHT environment, and to provide CFHT technical staff with sufficient exposure to the inner workings of the instrument to effectively and knowledgeably address technical problems that arise in the course of subsequent routine operation.

# 1. INSTRUMENT SPECIFICATIONS

## 1.1. Introduction:

This document outlines the design details CFHT requires be incorporated into its instruments. For the most part these requirements are the product of the observatory's science and technical staff's hard-won experience in supporting equipment at the telescope and address many of the issues that make real-time instrument support by our staff possible.

To ensure that instruments arriving at the observatory can come on-line quickly, both instrument developers and CFHT need a set of guidelines and checklists that establish the observatory's minimum list of requirements. This manual establishes a basic list. More specific details will be included in the instrument contracts.

Contractors should be aware that costs associated with the implementation of the requirements of this manual are considered to be included in the instrument contract price. Modifications to any of the requirements, should CFHT agree to them, can be obtained, after mutual written agreement, either by specific references in the Contract or, subsequently, by other written agreements with CFHT signed for both parties by their respective designated contract authorities.

CFHT defines three categories of instruments, visitor, guest, and facility. These differ in how they are built, supported, and offered to the community.

- 1. A visitor instrument is built by an external agency. It is not supported by CFHT staff. It is not offered to the community by CFHT, though the external agency may do so. A visitor instrument is not subject to the requirements of this document; however, awareness, at least, is strongly encouraged.
- 2. A guest instrument is built by an external agency through a contract with CFHT. It will be supported by CFHT staff. It is offered to the community by CFHT. It is subject to the requirements of this document.
- 3. A facility instrument is built by CFHT, normally using subcontracts with external agencies. It will be supported by CFHT staff. It is offered to the community by CFHT. It, and all subcontracts, are subject to the requirements of this document.

## 1.2. Site

### 1.2.1. Thermal and Humidity Environment

Instruments that will be operated in the dome environment will be stored and operated in both the telescope dome environment and in heated laboratories. Therefore,

- 1. The design operating temperature range for such an instrument, and all associated equipment, shall be from -10°C to +30°C.

The dome environment experiences the full range of humidity from extremely dry to full condensed.

- 2. The design operating relative humidity range for such an instrument and all associated equipment shall be from 0% to 100%.

Hardware may be protected from this environment by using climate controlled cabinets. The design can assume the availability of dry air (<5% humidity) to purge cavities. Either pipe nozzle or barbed hose fittings may be used.

Under storage the relative humidity can be expected to occasionally exceed 100 %. In particular, storm systems, which often arrive quickly, can elevate the humidity in the dome to well above saturation. The resulting condensation, which subsequently often freezes, is usually limited to exposed instrument surfaces.

- 3. The instrument design shall incorporate sufficient protection to ensure that condensation will not occur on critical surfaces. A light, sheet-metal shell over exposed optical and mechanical components should suffice. As described in 1.5.2.1, electronics must be fully enclosed.
- 4. As noted in section 1.10.5, a heavy-duty, weatherproof instrument cover is also required with the instrument.

Instrument components designed for operation in enclosed rooms in the observatory building do not experience as large a temperature range.

- 5. The design operating temperature range for such components shall be +10°C to +30°C and the design operating relative humidity range shall be from 10% to 80%.

### 1.2.2. Altitude

- 1. The instrument shall be designed for operation at altitudes between sea level and 5000 m.
- 2. Maximum electrical power dissipations shall be de-rated by 40% due to the reduction in air density experienced at the summit.
- 3. High voltage systems shall be rated for operation at an altitude of 5000 m or higher, including increased susceptibility to arcing.

### 1.2.3. Seeing and Image Quality Control

In an attempt to eliminate self-induced image quality degradation, the observatory has implemented a policy of reducing to a minimum all power dissipated at the telescope.

Considerable attention should therefore be given to minimizing power dissipation within the instrument. In particular:

- 1. The instrument shall include a means for heat extraction. Glycol is available on the telescope and in storage on the 5$^{th}$ floor. The maximum permissible dissipation to the environment shall be 50 watts.
- 2. The instrument design shall include a detailed power budget.

### 1.2.4. Remote Operation

Observing is controlled by personnel in Waimea.

- 1. Instrument design shall not assume the availability of personnel at the summit during observations.
- 2. The normal schedule of daytime summit personnel covers only four days a week. The instrument design shall therefore not require daily intervention. Cryogenic systems must be suitable for unattended operation for at least a week.
- 3. The target for instrument exchange duration is about five hours, including removal of the previous instrument, installation of the new instrument, and checkout of the installation – including any calibrations requiring on-site personnel. The instrument design should not necessitate complicated procedures on exchange day.

## 1.3. Mechanics

CFHT prefers metric hardware.

### 1.3.1. Modular Design

- 1. Instruments shall be modular.
- 2. All major systems and subsystems shall be easily removable from the instrument body. In particular, module removal shall be possible, preferably by hand, with easily accessible lifting points, while the instrument is mounted on the telescope, without requiring major instrument disassembly. The goal is facilitating repairs, so this applies particularly to electronics and moving parts. Any items not removable should be identified and discussed during the design reviews.
- 3. Access to instrument modules via the removal of a rigid, lightweight cover is acceptable, provided that cover removal and installation is possible while the instrument is on the telescope. Such a cover shall be fastened using captive hardware and shall have lifting handles if it is heavier than 5 Kg.
- 4. The operating state of the instrument shall not be affected by cover removal. In particular, cables and connectors shall not be mounted to any removable cover.
- 5. It shall not be necessary to remove any covers to install the instrument on the telescope or remove it from the telescope.

### 1.3.2. Operational Pointing Limits

- 1. The telescope is slewed to all elevations from zenith to horizon, at all position angles. All instrument components that are mounted on the telescope shall be capable of surviving this motion without losing alignment. In addition these components shall be capable of operating at all elevations above 20° at all position angles.
- 2. The instrument and associated equipment shall not impose pointing limits on the telescope. In particular, Cassegrain instruments, including all associated detectors and equipment, shall clear both the polar axis horseshoe and south pier by at least 100 mm. See 1.10.6 for appropriate dimensions. Any requests for exceptions shall be discussed during the design reviews.

### 1.3.3. Permissible Weights and Moments

Maximum permissible instrument weights and moments for the Cassegrain Bonnette are detailed in Table 1. Assume zenith-to-horizon telescope pointing limits when calculating these moments.

| Mounting Face | Maximum Weight | Maximum Moment about center of mounting face | Maximum Moment about optic axis |
|---|---|---|---|
| C1 | 100 kg | 600 Nm | Unknown |
| C2 | 300 kg | 1800 Nm | Unknown |
| C3 | 450 kg | 2700 Nm | Unknown |
| C4 | 750 kg | 4500 Nm | Unknown |
| Side Ports | 50 kg | 150 Nm | Unknown |
| Heavy Instrument Mounting Pads | Unknown | Unknown | Unknown |

**Table 1 - Maximum Permissible Instrument Weights and Moments for the Cassegrain Bonnette**

Since the prime focus upper ends are currently dedicated to specific instruments, there are currently no available guidelines for prime focus instrument weights and limits.

The mass distribution of instrument parts attached to the telescope shall be discussed during the design reviews.

### 1.3.4. Cassegrain Rotation

Instruments designed for mounting at the Cassegrain focus must account for the rotation of the whole Cassegrain environment over a range of 180° or specify that rotation must be locked out. Rotation may be required by the instrument itself or by other operational needs.

### 1.3.5. Actuator and Encoder Mounts

- 1. Devices, such as motors, solenoids and encoders, shall be mounted in a manner that allows their quick removal and replacement. Removal of an associated mechanical module can be required if the module can be quickly removed by hand from the instrument while it is on the telescope.
- 2. In order to allow quick device removal, cabling to all devices and modules must terminate in an accessible connector (see section 1.5.8.2), both at the device and at any associated mechanical module interfaces.

### 1.3.6. Indexing of Traveling Components

- 1. Devices and assemblies that are driven between fixed locations shall incorporate a precise mechanical stop to define their rest positions. Devices shall not be indexed by the opening or closure of a limit switch that controls motor power.
- 2. Limit switches or similar power interrupting devices can be used to indicate that a device has reached a predetermined position, and should be used to remove power from a motor when a device drives beyond normal operating limits.

Further specifications are given in section 1.5.13.

### 1.3.7. Keying

- 1. Any parts that must be mounted in a particular orientation shall be keyed in some way.

### 1.3.8. Materials

Stainless steel, anodized aluminum, or other corrosion-resistant alloy is preferred for structural elements.

- 1. Where mating aluminum parts will be separated on a regular or semi-regular basis, stainless steel threaded inserts such as “Helicoils” are required.

Stainless steel metric fastening hardware is preferred. If stainless steel is used for the structural elements, the fastening hardware shall be of a different type.

The dome environment is harsh, with condensation an ever-present fact of life. Carbon steel parts, even those with a rust inhibiting surface treatment such as Parkerization, rust quickly.

- 2. Carbon steel is permitted only if it is protected by a hard and durable protective paint or Cadmium plating.
- 3. Carbon steel fastening hardware is NOT permitted.

### 1.3.9. Paints and Surface Treatments

Paints are an acceptable surface treatment as long as they are hard and durable. Several modern epoxy enamels such as “Imron” or “Algrip” are satisfactory.

- 1. Lightly sprayed paint or similar surface treatments, especially on surfaces with inadequate surface preparation, tend to chip and flake easily and are unacceptable.

1.3.9.1. General Paints

- 1. All surfaces are to be primed with two coats of red oxide primer (Rust-Oleum #7669 or equivalent).
- 2. All surfaces are then painted with two coats of gray Kelgard #1700·222 or equivalent (standard paint for structures) or white Kelgard #1700-061 or equivalent (standard paint for structures).
- 3. For vacuum applications Z306 urethane Aeroglaze or equivalent should be used instead.

1.3.9.2. Powder Coating

Three specifications cover the possibilities for powder coating.

- 1. MIL-C-24712A - Coatings, Powder. This specification covers powder coatings for interior steel, aluminum, copper-nickel, and bronze equipment, furniture and electrical box surfaces and for exterior steel, aluminum, copper-nickel, and bronze surfaces exposed to marine atmosphere, high humidity, seawater, and weathering.
- 2. MIL-A-8625F - Anodic Coatings for Aluminum and Aluminum Alloys. This specification covers the requirements for six types and two classes of electrolytically formed anodic coatings on aluminum and aluminum alloys for non-architectural applications.
- 3. MIL-A-63576A - Aluminum Oxide Coatings, Lubricative, for Aluminum and Aluminum Alloys. This specification covers the requirements for an electrochemical process for building a Lubricative anodic coating on aluminum and aluminum alloys. The unsealed anodic coating is impregnated with polytetrafluoroethylene (PTFE) or coated with a resin bonded material containing PTFE.

1.3.9.3. Anodizing

Anodizing is an acceptable surface treatment for aluminum but should be avoided inside vacuum vessels. Choose one of the following based on finish requirements.

- 1. Anodize per MIL-A-8625, Type II, Class 1 (clear, thickness 1.8 to 25 microns).
- 2. Anodize per MIL-A-8625, Type II, Class 2 (dyed black, green, red, etc., most commonly used, thickness 1.8 to 25 microns).
- 3. Anodize per MIL-A-8625, Type III, Class 1 (clear and hard, thickness 50 to 75 microns).
- 4. Anodize per MIL-A-8625, Type III, Class 2 (dyed and hard, thickness 50 to 75 microns).

Note: Type III coatings must have tapped holes plugged prior to anodizing.

- 5. Chem film per MIL-C-5541 (clear, no thickness)

1.3.9.4. Zinc Plating

Zinc plating can be used on steels.

- 1. Use Zinc Chromate SC-2 per ASTM-B-633-98, Type II (black, thickness 75 to 125 microns, for parts smaller than 1 meter x 1 meter x 30 centimeters).

Parts are not evenly coated. Mask areas that are critical.

- 2. Use Zinc Chromate per ASTM-B-633-98, Type II (clear or gold - Fe/Zn5, thickness 75 to 125 microns, for parts smaller than 1 meter x 2 meters).

This is an automated process with very even coating. Masking of critical areas is recommended.

1.3.9.5. Cadmium Plating

Cadmium plating can be used on various metals.

- 1. Use Electroless Nickel Plate per SAE-AMS-26074

Cadmium plating is available in several classes

i) Class 1 - As plated, no subsequent heat treatment (a bake for hydrogen embrittlement relief is not considered a heat treatment).

ii) Class 2 - Heat treated to obtain required hardness. May be used on all metals not affected by heating to 260°C and above.

iii) Class 3 - Aluminum alloys non-heat treatable, processed to improve adhesion of the nickel deposit.

iv) Class 4 - Aluminum alloys, heat treatable, processed to improve adhesion of the nickel deposit.

And it is available in several grades.

i) Grade A – 25 micron minimum thickness.

ii) Grade B – 12 micron minimum thickness

iii) Grade C – 37 micron minimum thickness.

This process is used for low outgassing requirements.

Masking of tapped holes is required if Grade A or Grade C are used and on any surfaces that cannot have a buildup of finish.

This is a very smooth finish. Surface requirements can be met down to 32 RMS.

1.3.10. Component Identification

Metal parts shall be identified by etching or engraving a part number onto the part in a visible location or be called out in assembly drawings and in part catalog drawings.

## 1.4. Software

Instrument contracts are normally handled separately from contracts for related data acquisition/user interface software that runs on CFHT computers. The latter is normally provided by in-house CFHT software development staff and is not specifically addressed in this manual.

Instrument contracts may include development of data reduction software. Such development shall be specifically itemized in the instrument contract. Any reduction software required to meet the instrument scientific requirements shall meet all applicable section 1.6 requirements.

Control code, algorithms, and documents required for dedicated instrument control are considered to be part of instrument controllers. These are addressed in detail in section 1.6 of this manual under Instrument Control and are normally provided by the instrument contractor.

### 1.4.1. NEO

NEO (nominally "New Environment for Observing") is a CFHT-developed programming environment for data acquisition. It acts as the interface between our queue observing system and the instrument. It also provides for command line interaction with and scripting control over the instrument that is used by queue and can be used by other interfaces. In the queue environment we usually do not provide graphical interfaces in NEO; the graphical interface is to the queue system. Low-level engineering interfaces, as described in section 1.6, are allowed to exist outside of NEO.

- 1. User interface and data acquisition software written to run on CFHT computers must use the NEO software architecture under Linux.

We prefer that short-term visitor instruments provide their own computers and acquisition systems.

NEO's center is a program called "director" which accepts command lines from queue, a user, or a script. Running under director are "agents", possibly on other computers, which do instrument and camera control. Each command is passed on to the appropriate agent, the agent carries out the command, and director returns a completion pass-or-fail indication. This process is single threaded.

For multi-threaded agents we use intent, action, and wait commands. The intent command allows the agent to get set for an action command, e.g., a new target position is provided to the telescope control system agent which can tell the telescope control system to go choose guide stars but not move the telescope. The action command tells the agent to start the intended command, e.g., tell the telescope control system to start slewing the telescope. The wait command is given after all actions that can be parallelized are active; it is the only command that blocks for completion. Further details are available from the CFHT software group. Agents can be provided as part of the instrument contract as appropriate.

The camera control agent is a special case.

- 2. If the images acquired are to enter the CFHT archive system, we require that our camera agent "DetCom" be used.

DetCom controls the detectors, creates the image FITS file, and initiates FITS header creation. The other agents that have FITS header information are queried for their values, which are added to the image file.

### 1.4.2. Status Server

A program called the "Status Server" keeps medium term status information. Values such as exposure time, current filter, telescope position, and weather data are saved there. FITS headers are generated by the various director agents and written to the Status Server. Temperature and telescope position based focus calculation coefficients are saved by the Status Server. Any status that should be monitored for error conditions, e.g., detector temperature or cryovessel vacuum levels, can have an alarm trigger equation associated with it to cause mail and phone messages on error.

### 1.4.3. Other CFHT Queue-Related Software

The queue observing system includes databases and user interface programs. These allow observation planning and execution through NEO. Any changes to the CFHT software environment needed to support a new instrument will be the responsibility of CFHT, based on discussions with the instrument scientists on the intended instrument use.

### 1.4.4. Remote Observing

The observatory is operated remotely from Waimea at night with no on-site night time staff at the summit. Instruments must be designed to accommodate this operation mode. This imposes some restrictions on the hardware and software design, as noted in other parts of this document.

### 1.4.5. Queue

CFHT normally operates in Queue Mode. Observation requests are prepared by astronomers and saved in a database. Each night observations are selected based on priorities, weather conditions, and observability, and carried out by CFHT's Remote Observers. Calibration data are shared and applied equally to all observations.

CFHT desires to continue operations in Queue Mode. Any instrument proposal requiring astronomer presence at the summit will have to be justified.

### 1.4.6. Data Reduction Pipelines

Each instrument project shall include provision for data reduction. Two flavors of reduction must exist. The first is "quick-look" or "real-time", which is used by CFHT operators to verify instrument operation and grade each observation against requested constraints like seeing, absorption, and resolution. The second is the full reduction "production" pipeline used by CFHT, usually at the end of each run, and available to Principle Investigators.

Quick-look typically uses representative calibration frames; full reduction uses all applicable calibration frames. Quick-look usually produces an image for display, but that image is not archived. Full reduction produces an image file for archiving and distribution. There is usually a special version of the full reduction that interacts with CFHT databases. Both produce image quality assessments such as image quality or signal to noise ratio.

A pipeline should compensate for artifacts and systematic errors caused by the sky, the site, the telescope, and the instrument. It should not attempt any analysis or interpretation of observations except as needed to characterize and correct the observation. For imaging instruments, the pipeline should not resample the focal plane. For spectrometers, the pipeline should extract the spectrum without unnecessary interpretation of the lines.

## 1.5. Electronics

### 1.5.1. Environment

The CFHT observatory can present extreme environmental conditions for electronic systems. Accordingly, system designers must pay special care to environmental restrictions.

- 1. Electronics systems for use on the telescope, or in the 5th floor environment shall be capable of operation between -10°C and +30°C.
- 2. Electronics systems for use on the telescope, or in the 5th floor environment shall be rated for relative humidity ranging from 0% to 100%.
- 3. Electronics systems for use in the remainder of the building shall be rated for operation between +10°C and +30°C, at relative humidity ranging from 0% to 80%.

Electronics may be protected from the 5th floor environment by climate controlled cabinets.

Cooling effectiveness is reduced due to the lower air density (roughly 60% of sea-level air pressure) at the observatory. As a working rule, derating a system by 40% will usually accommodate the lowered cooling efficiency at the summit.

### 1.5.2. Packaging

#### 1.5.2.1. Chassis type

- 1. Chassis for 5th floor use shall be fully enclosed.
- 2. Standard, 19-inch rack mounting chassis are recommended for stand-alone use. 19-inch racks are available in the computer room. Mountings for short 19-inch racks are provided at Cassegrain focus.
- 3. Access panels shall be equipped with quick release, captive hardware. Plastic hardware for these applications is NOT permitted.
- 4. Electronics mounting must be reviewed with CFHT during each design review.

#### 1.5.2.2. Busses

- 1. Any busses used shall be standard, commercially available busses.

#### 1.5.2.3. Circuit cards

All commercially supplied and custom designed circuit cards shall be printed circuit boards (PCBs). Other card types such as Speedwire or Wire Wrap are not permitted.

- 1. All PCBs shall be fabricated to appropriate industrial standards.
- 2. All circuit cards shall have all components permanently identified.
- 3. All circuit boards shall have markings to identify their subsystems and instrument. Silkscreen markings are preferred.
- 4. No wired changes or wires soldered to integrated circuit pins are permitted.

### 1.5.3. Circuit Access

#### 1.5.3.1. Board replacement

- 1. All electronic circuits shall be easily accessible for removal and replacement with the instrument mounted on the telescope or on its handling cart.
- 2. All electronic circuits should be easily accessible for maintenance and troubleshooting with the instrument mounted on the telescope or on its handling cart.

1.5.3.2. Modular design

- 1. Circuits shall be of a modular design using circuit boards. The use of card cages, versus direct mounting of circuit boards, is recommended.
- 2. Access to card cages should be through doors or panels that are hinged or removable and use quick release hardware.

1.5.3.3. Test points and extenders

- 1. Circuit boards shall contain test points.
- 2. Test points should be directly accessible on the board from the front of the card cage.
- 3. An extender shall not be required to access basic test points. However, an extender board must be supplied with all systems that require extending cards for detailed troubleshooting.
- 4. Use of extender cards shall not preclude normal system operation.

1.5.3.4. Connections to cards

- 1. Connections to instrument circuit cards shall be made through a chassis mounted connector panel, and then to the circuit card. Direct connections from external devices to a local controller or circuit card are not permitted.

In general, rear connections to circuit cards are favored.

- 2. When connections are made to plug-in circuit cards, provisions shall be made for extending the connection to permit operating the card on an extender.

1.5.3.5. Buss test access

- 1. Buss-oriented systems shall provide an easily accessible buss test point. This may be through an appropriate card for backplane type busses.

1.5.4. Maintenance

In recognition of the remoteness of the observatory, special considerations such as unobstructed, free access to the instruments, its subassemblies, boards and components shall be made for system maintenance. Additionally, operational requirements may dictate the capability for quick return to service.

If any of the components (hardware or software) of the instrument are proprietary, CFHT requires that vendor-supplied maintenance of that component be offered as a cost option.

1.5.5. Status Lights

LED or other status indicators on equipment are very useful. However, extraneous light at the telescope is not permitted. Any such indicators on telescope mounted instruments or associated hand paddles shall incorporate a means for turning off or covering these lights. Tape is not acceptable.

1.5.6. Power Sources

1.5.6.1. Observatory power

- 1. AC 120 volt 60 Hz power connected through a single, standard 3 prong, grounded connection is available. A minimum of 1000 VA is available on each circuit. Circuit protection devices shall be provided and be panel mounted, accessible for resetting or changing, and their purpose shall be clearly and permanently labeled on the panel.

1.5.6.2. Instrument power supplies

- 1. Instruments shall incorporate their own power supplies.

- 2. All instruments using internal power supplies shall have easily accessible means of testing power supply operation. Some recommended solutions are LED's, test points, and independently readable voltage sensors. This point is covered in detail in section 1.5.10.1.
- 3. In order to reduce power dissipation, switching power supplies shall be used wherever possible. Use of linear power supplies should be restricted to very high sensitivity analog hardware, such as detector support hardware. Even in such cases, the suitability of a properly filtered switching supply should be investigated.

1.5.6.3. Remote power

Any part of an instrument that might need to be power cycled or rebooted shall get its power from a Remote Power Controller (RPC). This RPC shall be part of the instrument. See **Error! Reference source not found.** for the recommended manufacturer.

1.5.7. Wiring and Cabling

1.5.7.1. Wiring, cables and fiber optics supplied with the instrument.

- 1. All cables required for the operation of the instrument, both while on the telescope and while in a stand-alone mode, shall be provided with the instrument.
- 2. External fiber optics used for communications shall be 62.5/125 μm SC terminated if possible.

1.5.7.2. Termination

- 1. Hardwired cable or wire harness termination is not permitted. Both ends of all cables shall terminate in a connector. All devices such as motors, encoders, actuators, etc., shall be connected to the instrument through a connector at the device.

1.5.7.3. Chassis wiring

- 1. All wiring internal to electronics chassis, with the exception of panel controls and indicators, shall be terminated at standard board interconnections or back plane connections.

1.5.7.4. Cable construction

- 1. Cables between electronic junction boxes and panels shall be constructed of insulated, multi-stranded conductors using a wire gauge appropriate to the expected worst case current loads. The insulation shall be either color coded or labeled by printing or hot stamping, including signal name and plug/pin names.
- 2. Cables fabricated with several individual conductors or conductor pairs shall be contained within an exterior protective sheath, such as tubing, or webbing. When possible, standard, commercially available cable should be used in preference to making custom cable bundles. To prevent the weight of a cable from being supported by individual conductors within connectors, the cable sheath must be mechanically clamped to the backshell of the connector.
- 3. All heavy cables shall be strain relieved at the connectors. Heavy cables shall be provided with an additional mechanical strain relief attached to the cable sheath, separate from the connector.
- 4. All external fiber optics cables that run through the telescope or span across multiple floors in the observatory shall be jacketed and have a rating for installation in risers.

1.5.7.5. General purpose instrumentation cabling system

- 1. All cabling between telescope-mounted instruments and the control rooms shall use the CFHT general-purpose-instrumentation cabling wherever possible.

This point is covered in the Telescope Facilities Reference manual. Instruments using the instrumentation cabling shall incorporate the available cable shielding, with appropriate chassis and ground connections. Voltages on this cabling shall not exceed 50 volts peak.

1.5.7.6. Ribbon cable

- 1. Ribbon cable is generally not permitted outside of instrument chassis. It is not permitted as an interconnection between electronic chassis, or between chassis and panels or handsets.
- 2. Ribbon cable may be used within electronic chassis, but should terminate at a connector panel, where heavy-duty connectors and cables can carry the signals to the external devices.

1.5.8. Connectors

1.5.8.1. Marking

- 1. All connectors between electronics boxes, or between boxes and CFHT equipment, shall be clearly and permanently labeled on panels and on both ends of all cables. This labeling must be consistent with a simplified interconnection diagram provided in the electronics manual.
- 2. Minimum marking for a chassis connection is a connector number - e.g. J4.
- 3. Minimum marking for a cable connector is a device and connector number, e.g.,

  BLUE WIDGET, J4
- 4. Long cables, which are permanently installed on the telescope, in control consoles, or in the building cable trays, shall be marked at both ends to indicate the cable connections. Minimum marking includes the intended connection on the proximate end, and the destination and connection at the other end, e.g.,

  BLUE WIDGET, J4; TO GREEN PANEL, J1

1.5.8.2. Connector types

The following connectors are recommended for all CFHT instruments. Other types of connectors are discouraged for new construction. If other types of connectors are preferred in a particular application, CFHT must approve their use.

1.5.8.2.1. MS connectors

- 1. Use of military (MS) connectors, with quick-release bayonet locks, is strongly recommended where connectors will be frequently connected and disconnected, or subject to strain or other external forces.
- 2. MS connectors shall be of the crimp type, and shall have built in strain relief.
- 3. Multiple MS connectors at the same location or on the same assembly must be unique. That is, it must not be possible to make improper connections. This shall be implemented through use of varied connector types, or through alternate keying of the connector shells.
- 4. Use of screw-on type MS connectors, or solder type MS connectors is not permitted.
- 5. MS connectors are not recommended for multiple fiber optic connections.

1.5.8.2.2. Fiber connectors

- 1. Use of SC duplex fiber connectors where frequent disconnections and connections are anticipated is highly recommended.
- 2. Use of SC, ST, FC and FDDI connectors is acceptable.
- 3. Use of MS connectors is strongly discouraged.

1.5.8.2.3. "D" connectors

- 1. Use of "D" style connectors (e.g., D, DD, micro D, etc.) connectors is permitted for internal connections which are not frequently connected and disconnected, and not subject to undue strain or external forces. Their use is not permitted for external connections.
- 2. Protective shells and strain relief must be used on all "D" style connectors. Standard brass connector shells provide poor strain relief and their use is discouraged. Alternatives should be investigated and used.
- 3. "D" style connectors shall be of the crimp type. Solder type connectors shall not be used.
- 4. "D" style connectors shall be provided with either screw lock hardware or slide lock hardware to secure connectors to the connector panel.

1.5.8.2.4. Coaxial connectors

- 1. Standard BNC and 00 gauge "LEMO" connectors are recommended.
- 2. Crimp BNC connectors are preferred over solder type.
- 3. Cable and shell type shall be matched so that an effective strain relief is provided.

1.5.8.2.5. ZIF (Zero Insertion Force) connectors

- 1. Use of ZIF connectors is recommended when connectors are built into mating hardware, and must align and mate when the hardware is assembled.
- 2. Contact CFHT for approved types of ZIF connectors.

1.5.8.2.6. RJ45

- 1. Use of standard, plastic, RJ45 connectors is permitted for Ethernet connections. For use on the telescope they shall be enclosed in MS connectors.

1.5.8.2.7. Plastic connectors

- 1. The use of plastic connector shells, plastic backshells, and plastic strain relief is not permitted outside of instrument chassis.
- 2. Use of mass terminated plastic connectors is not permitted outside of instrument chassis.

1.5.8.2.8. Strain Relief

- 1. All connectors used outside of chassis shall have an effective method of strain relief, so that loads are not taken on individual conductors.
- 2. Cable reinforcement at strain relief points, using jackets or sleeves, is encouraged.

1.5.8.3. Physical connections

- 1. All connector hardware shall be captive.
- 2. All connectors used outside of chassis shall have a positive means of physically securing the connector to the mating connector on the chassis. Twist locks, screw locks, slide locks, and other hardware provided by the manufacturers are usually sufficient.

1.5.8.4. Connector Placement

In addition to the connectors for instrument controllers, all instrument control and status signals shall be available at an accessible, external connector panel on the instrument. This panel is supplied for the purposes of troubleshooting and diagnostics. A laptop with displays that give full access to all signals shall be deemed a "panel" for this requirement, and the display code is subject to section 1.6 requirements.

The connector panel, local controllers, and any status displays shall be accessible while the instrument is on the telescope and while it is on its handling/storage cart.

1.5.9. Heat Output of Devices

- 1. CFHT is continually upgrading the telescope facility to improve image quality. To this end all non-essential sources of heat on or around the telescope should be eliminated. To further these efforts, contractors shall provide a detailed heat budget for both the complete instrument and for individual devices.

1.5.10. Diagnostic Design Requirements

- 1. Instruments shall be designed with diagnosis and troubleshooting in mind. Diagnostic design planning is critical in meeting operational goals of minimum equipment downtime. The following guidelines should be considered in the planning stages when designing new subsystems. Subsystem and module fault indications should be machine readable where possible. Where this is not possible, the following identification requirements shall be met.

1.5.10.1. Subsystem Level Fault Identification

- 1. Subsystem power supply voltage levels shall be monitored with threshold circuits driving lighted indicators such as LEDs. The indicators shall be clearly visible at the front of the subsystem enclosure and marked with the nominal voltage of the corresponding power supply. An unlighted indicator signifies that the corresponding voltage is below tolerance. A switch may be provided to activate the indicators if the equipment is mounted in a location that precludes illumination. Power supply voltage monitor test jacks shall also be provided on the front of the subsystem enclosure. The subsystem power switch and primary fuse shall also be accessible from the front of the enclosure. All of these features may be placed behind doors or panels.

1.5.10.2. Module Level Fault Identification

- 1. Subsystem modules or boards shall have visible fault indicators wherever feasible. They may be located behind a cover or panel, but shall be easily accessed. Module fault indicators shall show positive illumination only when a fault is detected. Transient or intermittent module faults shall have latching indicators with manual resets. Fault indicators shall be specific to the module on which they are located. Test points and test jacks helpful in fault identification shall also be easily accessed without physically removing a module or extending it from its normal operating environment.

1.5.11. Hardware Design Considerations

- 1. The hardware shall incorporate a modular design. Functions shall be separated to different subassemblies or boards to facilitate troubleshooting and isolation of problems.
- 2. Axial or surface mounted components are acceptable. Use of devices with ball grid array mounting is discouraged.
- 3. The means, hardware and software, to read, write and verify files in situ on all applicable programmable devices shall be provided. CFHT must have access to all intellectual property related to custom designed firmware in as much as is required to fully understand the detailed operation of the firmware, be it microcontroller code, PLC code or PLD/FPGA circuit. When selecting potential programmable devices the availability and potential future availability of the programmable device shall be taken into consideration. Wholesale assembly language programming on micro-controllers or DSPs is highly discouraged when a high-level language compiler is available. C is the preferred programming language.

- 4. Programmable devices requiring removal and off-board programming shall be socketed.

1.5.12. Selection of Electronics Solutions

The following recommendations are made to contractors for choosing CFHT instrument electronic control systems and hardware.

1.5.12.1. Use of Commercially Available Parts

- 1. CFHT requires, wherever possible, the use of Commercial, Off-The-Shelf (COTS) components, parts, subassemblies, circuit boards, interface PCB's, controllers, computers, etc. In cases where multiple commercial solutions exist, CFHT shall be contacted for aid in determining the preferred solution(s).
- 2. CFHT recognizes there are some areas of all instruments for which commercial units are unavailable in which case custom solutions are acceptable.
- 3. CFHT requires the provider to obtain written agreement or contractual reference from CFHT for all non-commercial systems when valid commercially available solutions exist.
- 4. CFHT requires that modified commercial assemblies, circuit boards, components, etc. be identified. Any spare commercial entities requiring modification shall be modified and tested prior to delivery to CFHT.
- 5. Although this can sometimes be difficult to assess, preference shall be given to well-established suppliers of off-the-shelf devices who are in the position to provide replacements and support over the lifetime of the instrument, and who have established US distributors. This is particularly applicable to devices providing unusual solutions or that use custom buses specific to a certain manufacturer that interface directly to the instrument. Generic devices that are easily obtainable from alternate suppliers are exempt from this rule.

In particular, CFHT requests the use of the solutions shown in Table 2.

| Area | Hardware |
|---|---|
| Motion control | Galil controllers |
| Generic control and monitoring | Allen-Bradley PLCs |
| Temperature control | Lakeshore controllers |
| Remote power control | BayTech |
| Terminal access | Pearle terminal servers |
| Ethernet switches | Allied-Telesyn |

**Table 2 - Requested Hardware Solutions**

See section 1.6.1 for software support provided for these devices.

- 6. When more than one Ethernet connection is needed to an instrument, a local switch shall be provided.

1.5.12.2. Use of Existing CFHT Solutions

- 1. In situations where commercially available, off the shelf solutions are not available, the circuit or system shall be a duplicate of an existing CFHT solution, if at all possible.

1.5.12.3. Hierarchy of Desired Solutions

The following is the list of solutions in preferred order:

- 1. Duplicate of commercially available solution in use at CFHT
- 2. Commercially available solution
- 3. Duplicate of a non-commercial solution available in use at CFHT
- 4. Original contractor designed solution

1.5.13. Motion Control Assemblies

Motion control assemblies refer to any electro-mechanical system that physically moves under control of a remote control panel or computer.

1.5.13.1. Limit switches

- 1. Most motion control systems have physical limits beyond which they must not be driven. If not capable of continuous, unimpeded operation they must be protected by electrical limit switches.
- 2. Direct acting switches, which sever motor power, are preferred over indirect switches, which operate through electronic logic.
- 3. End-of-travel switches that do not themselves remove motor power require mechanical or other means of device protection if the mechanism is driven into the mechanical stops.
- 4. “Soft” limits operating through the computer, which are backed up by direct acting, “hard” limit switches, are both acceptable and desirable.
- 5. All end-of-travel switches must be capable of unassisted reverse motion off the limit switch. For D.C. motor-driven devices this is most easily achieved by means of diodes across the switches.
- 6. It shall not be possible to drive a system, which is on an end-of-travel limit switch, farther into the limit. This applies to both manual and computerized operation.
- 7. When possible, sealed non-contact switches such as Hall Effect or magnetic reed switches shall be used to limit wear and contamination issues. Use of optical switches is discouraged because of stray light.

1.5.13.2. Multiposition devices

These are devices with a few discrete positions.

- 1. The drive system shall be simple.
- 2. Use of single-speed DC motors and encoding and position control with switches is generally acceptable.
- 3. A mechanical registration system, such as a spring-loaded detent roller, Geneva mechanism, etc., shall be built into multiposition systems to assure accurate positioning with the motor powered off.
- 4. Bi-directional operation, to minimize operating time, is desirable.

1.5.13.3. Continuous position devices

These are devices requiring fine positioning but which do not need to be actively and continuously servo controlled.

- 1. These devices shall be capable of operation in either direction. We generally require that the approach to a desired position be from a consistent direction if stepper-motor (non-servo) systems are used.
- 2. Stepping motor systems shall be designed to operate at greatly reduced holding power or with power off when not moving. The system shall not move when power is removed or

applied. In particular, the phases energized at power-on shall be identical to those at power-off.

- 3. Stepping motor systems may be operated without an absolute encoder if a reliable and precise initial reference is provided. Mechanical limit switches do not generally provide the required long-term accuracy.
- 4. Commercial stepping motor controller modules are acceptable provided that they permit low or no power holding operation.

#### 1.5.13.4. Servo Controlled Devices

A servo system is a control system that drives its motor based on direct feedback from a position or velocity encoder.

- 1. It is important that servo control assemblies minimize heat near the optical path and in the image detection areas. Motors and amplifiers shall be powered only when movement is required. Remote location of high-powered servo amplifiers is preferred if reliable operation can be demonstrated.
- 2. Due to the electrical noise associated with the telescope environment, control loops shall be kept as short as possible.
- 3. Cables shall be well shielded and good grounding techniques shall be employed to prevent interference with detector signals.
- 4. Consideration shall be given to the structural configuration of the environment to prevent servo operation from exciting structural resonances.
- 5. Servo systems with mechanical travel restrictions shall have adequate limit switch protection.
- 6. Commercial servo system solutions that provide limit protection through micro-controllers shall be protected by an additional layer of direct-acting, hardware limit switches.
- 7. Radio frequency interference generated by servo amplifiers or computers shall be shielded so as not to interfere with astronomical detectors or other instrument systems.
- 8. CFHT currently supports DC motor servo control solutions from Galil.

#### 1.5.13.5. Indexing or Homing

Any device that does not have an absolute encoder shall provide a reliable, repeatable method for determining an initial reference point, the “index” or “home” position.

- 1. The controlling session agent shall be able to determine when a device needs re-indexing.
- 2. For devices controlled by a dedicated controller (e.g., Galil or PLC), the controller shall maintain indexing status, i.e., if the controlling session agent is restarted, re-indexing should not be necessary.

Typically this is done by offsetting the reported position range so it does not include the position reported when the controller is turned on.

### 1.5.14. Instrument to Host Communication

- 1. 100 megabit or gigabit Ethernet is the preferred means of communication between the instrument and host computers. RS-232 is acceptable. Both are available on the telescope and in the computer room.

- 2. CAT5e twisted-pair terminated into a RJ45 connector is the standard physical connection. Duplex 62.5/ 125 um multimode fibers terminated into FDDI or SC connectors are available on the telescope and in the computer room if isolation is required.
- 3. If a standalone computer is provided as part of the instrument, its console shall be made available remotely. RS-232 or RS-485 connections are available for serial consoles. If a graphical console is required, a Keyboard/Video/Mouse (KVM) switch shall be provided with the instrument.

### 1.5.15. Imaging Detectors

CFHT requires that dedicated imaging detectors and associated control electronics be provided with the instrument. This includes science imaging detectors, guider system, and photon counting devices.

## 1.6. Computer Systems

Instrument and detector control at CFHT typically involve the following computer systems:

i) Instrument Control Computers

An "Instrument Control Computer" is a local controller supplied with the instrument and used to control instrument devices directly. It is provided by the instrument contractor. Instrument control computers tend to be mechanical system controllers rather than full-fledged computers. Recommendations are given in section 1.5.12.1, and the interface to our observing environment (NEO) is given in section 1.6.3.

ii) Imaging Detector Control Computers

A "Detector Control Computer" is a local controller supplied with an imaging detector and is used to control detector read out and the shutter, if applicable. The detector control computer is usually a DSP based system adjacent to and connected directly to the detector, and it normally uses optical fibers to transmit pixel data to a "Detector Host". If the vendor provides the detector for the instrument, the recommendations in section 1.6.1.1 should be followed for hardware, and section 1.6.3 must be followed for the interface to NEO.

iii) Imaging Detector Host

A "Detector Host" is a Linux or Real-Time Linux based computer including an interface that accepts the pixel data stream from the detector control computer. Detector hosts operate in the summit computer room controlled environment. The detector control agent "DetCom" runs on the detector host. Detector host hardware, normally provided by CFHT, is briefly described in section 1.6.1.2, and the software is briefly described in section 1.6.3.

iv) Real Time Control Computers

Any special computers needed to meet real time processing requirements, e.g., adaptive optics measurement and reduction, shall be discussed with CFHT and included in the instrument contract.

v) Data Acquisition and User Interface Computers

The "Data Acquisition" and "User Interface" computers are part of the CFHT provided infrastructure. The data acquisition computer runs the acquisition control software, including director and any local agents. The user interface computer has three displays that display X Window System output from the acquisition computer. The data acquisition computer can also run quick-look pipelines and displays.

vi) Telescope Control System Computers

The "Telescope Control System" (TCS) computers are also part of the CFHT provided infrastructure and are the only computers that directly control the telescope. Real time control is provided by an Input-Output Controller (IOC) running VxWorks and the Experimental Physics and Industrial Control System (EPICS). The IOC generates all signals needed for slewing, tracking, and guiding the telescope, reads all telescope position encoders, and controls some CFHT provided instrument adapters ("bonnettes" in CFHT parlance). A user interface computer provides a graphical interface for telescope operation.

Normally an instrument does not interact with the TCS computers. For an instrument that operates under the queue system, the queue system sends telescope positioning requests to TCS through the tcs agent and waits for completion before taking exposures. For an instrument that operates outside of the queue system, the observer provides object lists to the CFHT observing assistant (telescope operator) who controls the telescope through the TCS graphical interface. The one exception is offsets and guiding corrections generated by an instrument guider; we provide a software interface that allows guiding by the instrument. This interface accepts Right Ascension and Declination offsets and error corrections in arc seconds, normally at 1 Hz.

vii) Data Reduction Computers

Any special computers needed to meet the data reduction requirements of section 1.4 shall be discussed with CFHT and included in the instrument contract.

There can be additional computers needed for an instrument. Two examples are guide computers and adaptive optics control computers.

### 1.6.1. Instrument Control Computers

Instrument control includes moving motors, reading switches, monitoring temperatures and vacuum systems, and power switching. CFHT requests that the following software libraries/agents be used for controlling these recommended devices.

i) Motors and switches - CFHT has developed a library that runs under Linux or VxWorks to control Galil controllers over their RS-232 or Ethernet connections. We also have a motion control record for higher-level control under EPICS.

ii) Temperature monitoring and control - CFHT has an agent that communicates with the Lakeshore controllers for precise control.

iii) CFHT provides a library for communication with Allen-Bradley PLCs.

iv) Power switching - CFHT has an agent that allows remote/automatic control of BayTech power outlets.

v) More complex instrument control - For any instrument control that is outside the capabilities of the above options, for example adaptive optics correction or precise timing, we recommend a PC running Linux, possibly with real time Linux and/or EPICS. However a proposal suggesting this option will need justification.

#### 1.6.1.1. Imaging Detector Control Computers

Except for MegaPrime, CFHT uses San Diego State University (SDSU) - now Astronomical Research Cameras (ARC) - a.k.a. Leach, controllers for detector control.

#### 1.6.1.2. Imaging Detector Hosts

CFHT uses a version of our standard Linux system hardware that supports the older PCI bus needed by the Leach fiber interface cards. We use a modified version of the Leach astropci driver and a locally written driver called lotuspci. Any imaging detector system provided with an instrument should use the same set up.

#### 1.6.1.3. Other Possibilities

VxWorks based real time hardware systems are possible though discouraged.

#### 1.6.1.4. Local Control

A local, stand-alone terminal computer may be used for development and maintenance, but it shall not be required for operations on the sky. CFHT suggests that common maintenance functionality also be available from the instrument control agent.

### 1.6.2. Instrument Controllers

#### 1.6.2.1. Communications

CFHT supports three communications media.

i) RS-232 - standard asynchronous serial communications
ii) Ethernet™ - as defined by IEEE 802.3 using 10BASE-T, 100BASE-T, and 1000BASE-T over CAT5e twisted pairs
iii) Optical fiber - detector pixel streams

1.6.2.2. Protocols

The interface computer shall initiate all communications. The interface computer shall command all instrument configuration changes. The agent or controller may independently maintain configurations, e.g., atmospheric dispersion compensation may be adjusted as part of the agent operation. The agent or controller shall keep status information updated in the Status Server.

i) RS-232 communications to the instrument should be DCE standard at 9600 baud, 8 data bits, no parity, with XON/XOFF handshaking, and full duplex communication, if possible.
ii) Ethernet communications shall use UDP or TCP/IP protocols. Host names, IP addresses, and port numbers must be settable by CFHT.
iii) There is no protocol specified for pixel streams on optical fibers.

1.6.3. Instrument and Detector Control Software

Control software exists at four levels.

i) PLC "code" is subject to the requirements under Electronics in section 1.5.11, the interface to the requirements in section 1.4 and deliverables requirements in section 1.9.3 but not to other requirements in this section or in section 1.4.
ii) DSP code is usually written in assembly language but is otherwise considered software under section 1.4 and section 1.6.3. DSP code is subject to deliverables requirement in section 1.9.3.
iii) Other contractor supplied software running on contractor supplied hardware shall meet the requirements of section 1.4 and section 1.6.3.
iv) All software running on CFHT supplied hardware shall meet the requirements of section 1.4 and section 1.6.3.

The top-level software shall be compatible with the director/agent model. Interfaces between lower levels naturally depend on the functional requirements, but CFHT suggests that all control network traffic to real computers be director/agent based, i.e., that agents run on the hosts "closest" to the controlled hardware. For network-based processors like Galil controllers this would be the session host computer.

Responsibility for software design, development, and testing will be discussed during project negotiations.

1.6.3.1. Low Level Device Control Interfaces

Low-level device control, whether done on a computer with directly attached hardware interfaces or by a PLC or Galil-type controller over a serial or Ethernet connection, shall provide command and status interfaces to higher-level software. The command interface shall include:

i) Device position requests - the command includes an absolute target position in appropriate engineering units (e.g., millimeters, microns, degrees of angle, or degrees of temperature, but not encoder counts), an offset target position in the same units, or a logical name for a position. The position request command normally does not start any movement; it only registers an intent to make a move at some future time. This allows scheduling multiple movements in a single threaded environment. Examples might be "filter r" indicating that the next filter change should be to the r filter and "focus abs 4.0" requesting that the next focus move be an absolute move to 4.0 mm. For simple devices, the position and move requests can be combined, e.g., filter change requests are typically handled this way.

Position request commands return immediately, with success based on proper command format and possibly acceptable device status.

ii) Device move requests - the command indicates that a previously given position request is to happen. An example might be “filter go” indicating that the previous “filter r” command is to happen. Move request commands return immediately, with success based on proper command format and possibly acceptable device status.

iii) Device wait requests - the command indicates that all previous position and move requests must complete. This is the only blocking command, not returning until the move has finished, and returning success only if the device is in the requested position and failure otherwise. An example might be “filter wait” where a success return in the example case means that the r filter is stopped/locked in the beam. If a wait command is given after a position request but without a move request, the wait command implies a move request.

iv) Immediate requests - the command indicates an action request that will complete in less than a second or some configuration option that completes immediately. These commands are allowed to complete before returning success or failure. Examples might be “shutter open”, “exposuretime 10”, or “filename next”. Immediate requests are not to be used for longer actions, even if the instrument itself is blocked until completion; other activities may be doable in parallel.

All non-immediate requests shall have time-outs defined. If a request does not complete within the time-out, it shall be deemed to have failed and shall cause an error condition.

Position and move requests can be combined.

The status interface shall include a method for returning complete device status to the caller, normally via the Status Server. Note that in the director/agent model there are no status commands per se; if the device control is done directly by an agent as is usually the case, see the next subsection for status output.

Error conditions shall be logged and cause a command failure. Automatic retries and/or recovery are acceptable but should not be used to hide non-functional hardware.

#### 1.6.3.2. Agent Level Device Control Interfaces

The agent command interface is as described in the previous subsection, providing position, move, wait, and immediate requests. Command sequences will be given to the agent based on scheduling needs at a higher level, i.e., the intelligence needed to schedule multiple actions is kept up in session level scripts that know all the operations needed to accomplish an observation.

Except in a few special cases, agents do not return any instrument status values directly. As a side effect of move/wait commands, they update fields in the Status Server describing the current state of their controlled devices. At all times the Status Server values shall indicate the current device state, with a 1 Hz maximum update rate. In addition there shall be two special commands, “beginfits” which causes exposure start and dummy exposure end FITS header values to be recorded into the Status Server, and “endfits” which records any exposure end header values.

Failure returns are handled by the director/agent interface. Logging is provided by director via the cfht_logv() function. Messages come in debug, logonly, informational, status, warning, error, and progress types.

Debug and logonly messages are generally not visible to the user. Informational messages appear in white; status, in green; warning, in yellow; and error, in red. Progress messages appear in a popup with a completion bar and percentage done value.

Logonly messages are to be used to record all useful operation detail, in both successful and unsuccessful conditions.

Informational messages can be used to show progress. Status messages are used to show the beginning and ending of major steps in carrying out commands. Warning messages are used to log concerns that do not stop observing.

Error messages indicate command failure. In general there should be no more than one error message output for a failed command just before the command returns, and it should be fairly general. All details on the error should have already output as logonly messages by lower levels of code that know the exact circumstances.

Agents usually provide three operational modes. Observing mode provides all the commands needed for queue operation. Safe mode provides dummy commands for anything that can interact with the telescope, used when the associated instrument is not actually on the telescope.

Engineering mode adds additional engineering level commands to observing mode such as low-level device control, parameter setting, or debugging.

CFHT provides libraries and a template program for developing agents. Whether CFHT or the instrument provider creates any necessary agents is open for discussion during system design.

#### 1.6.3.3. Imaging Detector Control DSP Interfaces

The recommended imaging detector control interface is the one provided by the CFHT detector controller program, DetCom. DetCom is primarily an SDSU controller oriented program, though a version of it is used with the SHARC DSP chips used on MegaCam.

If there is a requirement for a special interface, it shall provide for initialization, loading DSP code, setting exposure parameters, exposure control, read out, and maintenance functions.

CFHT creates image files using the Flexible Image Transport System (FITS) conventions. A special interface shall provide several commands for setting FITS headers in all image files created. All files written by this interface shall pass the *cfitsio* verify program *fitsverify* tests. The control program shall also provide an interface to the Status Server FITS header convention.

#### 1.6.3.4. Power Up State

For any device that loses state when it is powered off (e.g., it uses incremental encoders), it must be possible for the control software to determine that power has been cycled. A “home” command shall be provided to recover to a known state. Any configuration change requests before the home command shall fail. No device movement shall occur on powering up the device or its controller.

#### 1.6.3.5. Communication with TCS

CFHT provides code to access telescope parameters. The Queue system controls all telescope pointing. An instrument is allowed to request offsets and send guider corrections. An instrument is also allowed to request focus changes. All telescope parameters, e.g., right ascension, declination, and dome position, are stored in the Status Server. CFHT also provides routines for higher speed access to hour angle, right ascension, and declination directly in TCS.

#### 1.6.3.6. Asynchronous Operations

The director environment is specifically designed for synchronous operations. When asynchronous control is needed, e.g., for an atmospheric dispersion compensator or a guider, an agent can start a subprocess to handle background operation of the continuous subsystem.

### 1.6.4. Software Standards

The following paragraphs define the direction for CFHT standards.

#### 1.6.4.1. Languages

CFHT recommends the use of the C language for compiled programs and bash for scripted programs. User interfaces can be developed in GTK or Java. Any variations should be discussed early in the design phase. Perl, Tcl/Tk, and Python are available, but they are not actively used for instrument software. CFHT requests that variable names and comments be in English.

For user interfaces, note that observational software is operated in command line mode by the queue system and requires very little interaction. Graphical interfaces may be needed for guider acquisition and visualization, for example, but instrument control is strictly command line driven. Instrument configuration displays may be developed for engineering and maintenance purposes, but they will not be used for observing.

1.6.4.2. Format

The general formatting for C programs is defined by the indent program parameter file at http://www.cfht.hawaii.edu/Software/.indent.pro . This uses a slightly modified version of GNU indent version 2.2.9 (at http://www.cfht.hawaii.edu/Software/indent-2.2.9-CFHT.tgz) with comment indents to a fixed column and case sub statements with a separate indent amount.

See the samples described in the next subsection.

The general formatting for bash scripts is similar to the C formatting, though it uses 4-space indentation. Open braces ("{") for functions go on the function name line. The "; then" of an if statement goes at the end of the last line of the if condition. See http://www.cfht.hawaii.edu/Software/Functions.sh for a sample. This is our bash script library module.

The use of case and underscores in variable names varies. CFHT requests that project provided code be consistent.

The use of typedef in C code is required; there should be no uses of "struct" in references to local structures. The enum construct should be used to define names for multi-valued field constants.

1.6.4.3. Commenting

CFHT recognizes that commenting is an individual art but requests that the following general pattern be followed. Each file should start with the creating institution's legalese; this will be retained at CFHT. Next should be a general description of the file contents, including a list of routines, if appropriate. The end of the header comments has been an RCS log in C files, though we will drop that with SVN. bash scripts generally do not have RCS logs to save on interpretation time.

Each data structure should be preceded by a block text comment describing each field. If the structure is complex, there should be a simple drawing in the comments, and a good drawing in the external documentation.

Each routine should be preceded by a block text comment describing the routine. There should be sections giving a description of the routine, how it is called, the input parameters, the output parameters, what the function return value is, and an explanation of any global variables referenced. The routine description audience is a caller of the routine, though internal algorithms and/or caveats can also be included.

Major sections of code should have comments describing their purpose. Individual lines should not have comments except to explain tricks or anything unobvious.

C code samples are available under http://www.cfht.hawaii.edu/Software/ in ss_api.h and ss_api.c, which are part of the Status Server interface and in dlog.h and ConfigFile.c, which are part of the PLC interface.

1.6.4.4. Building

CFHT uses a GNU make Makefile system for building and installing code, presently make version 3.81. The build portion understands compiling C, C++, and IDL code. The install portion also understands bash and Perl scripts, named "*.sh" and "*.pl", respectively. All project provided code shall use this system. See section 1.6.4.7 to obtain a copy.

#### 1.6.4.5. Error Handling

All code shall check for error returns. All system calls that can reasonably be expected to fail must be checked to make sure they did not. This includes malloc(3) and file input/output, for example, but does not normally include printf(3) and friends, which should be called as

```
(void)printf("foo\n");
```

, for example. scanf(3) and friends should be checked to make sure the correct number of fields was scanned.

All project provided code shall be written with functions that provide a method for detecting errors resulting from their being called. CFHT requests that this be handled with an explicit PASSFAIL type return value of PASS or FAIL. These are defined in cfht.h - see section 1.6.4.7 to obtain a copy. Functions that return null pointer values or special integer values (e.g., -1) should be avoided. Immediately preceding each FAIL return should be a logonly message including all locally available information about why an error is being returned.

#### 1.6.4.6. Revision Control

CFHT currently uses RCS for revision control, but we will be migrating to SVN in the near future.

#### 1.6.4.7. CFHT Environment

At CFHT our software is stored on an automounted file system under "/cfht". At a project site it can be installed under any convenient spot and will build relative to that. A partial copy of our software tree is available on request.

### 1.6.5. Data Reduction Pipelines

In addition to the above requirements, quick-look and production pipelines are expected to meet the following requirements.

#### 1.6.5.1. Licensing and System Requirements

- 1. The software package shall be licensed as open source, meaning the source code can be redistributed by CFHT to its users and can be modified or extended.
- 2. Any external software dependencies including interpreters and libraries shall be identified and shall also be open source.
- 3. The software package shall be portable, meaning it includes instructions and tools to install and configure on a host computer.
- 4. The software shall run and be tested on a modern distribution of the GNU/Linux operating system.

#### 1.6.5.2. Software Design

- 1. The pipeline organization should be modular as much as possible. Specifically, it shall be possible to change a subset of the processing recipes without replacing the entire pipeline software.
- 2. If the pipeline depends on an external database, the interaction should be implemented in plain SQL without the use of stored procedures.
- 3. Nothing in the software design shall preclude the simultaneous execution of multiple instances of the pipeline on the same machine.
- 4. The pipeline should include a configuration system that is separate from the executable software.
- 5. The pipeline shall include some facility for debugging and verifying its operation including log files.

#### 1.6.5.3. Operational requirements

- 1. The pipeline shall be capable of robust non-interactive operation. An operator may be required to configure the pipeline for changes in instrument configuration and in response to unusual circumstances but shall not be required to interact in the normal execution of the pipeline.
- 2. All software components shall respond to and handle errors consistently. An error in any of the processing steps shall result in an error condition at the highest level of operation.
- 3. The production pipeline should be interruptible. It should be able to recover from an interruption without manual cleanup and without significant re-work.
- 4. The minimum performance of a pipeline shall be sufficient to keep pace with observing. Specifically, the quick-look pipeline should reduce each image before the next in finished, and the production pipeline should be able to process one night of data in less than 12 hours.
- 5. The quick-look pipeline shall be capable of giving near-real-time feedback to the telescope operator of the estimated quality of a recent observation in terms of signal to noise, image quality, or other parameter relevant to the instrument.
- 6. The output of the production pipeline shall be formatted to facilitate archiving and distribution. Typically this means a single FITS file that may be multi-extension or multi-dimension.
- 7. The output of the production pipeline should maximize the legacy value of the observation.

## 1.7. Optics

### 1.7.1. Component Mounting

Optical components shall be mounted in cells that are removable from the instrument. Removal shall be possible while the instrument is on its handling cart. Removal should also be possible while the instrument is on the telescope.

Cell mounting hardware and hardware geometry shall maintain optical alignment during installation and removal of the cell from the instrument, preferably without use of optical alignment fixtures or specialized alignment tooling. Where a specific orientation is required, the mount shall be keyed.

### 1.7.2. Coatings

All optical coatings shall be sufficiently robust to withstand repeated cleanings. In particular, the use of soft (non-hardened) antireflection or transmissive coatings is NOT acceptable.

### 1.7.3. Alignment Fixtures and Tooling

All optical alignment fixtures and specialized alignment tooling shall be provided with the instrument. This includes mechanical and optical parts but not generally available electronic and optical test equipment.

### 1.7.4. Special Optical Test Elements

All special optical elements used for testing of the optics (Computer Generated Hologram (CGH), custom null lenses, etc.) shall be provided with the instrument.

### 1.7.5. Component Identification

All optical elements shall be identified by a component label with an arrow indicating the direction of light propagation engraved on the edge of the optics and on the edge of their cells

### 1.7.6. Component Centering or Alignment Marks

Where requested by CFHT, large optics shall be provided with engraved markings at their optical centers, or with other identifying marks to be used for alignment.

### 1.7.7. Warning Labels

Mounting hardware for delicate or unusual optics shall be provided with appropriate warning labels, identifying the nature of the caution to be taken, e.g.,

CAUTION: CRYSTAL OPTICS, FRAGILE SURFACE COATINGS, EXPOSED CROSS HAIRS

## 1.8. Design Reviews

All facets of an instrument development contract shall undergo formal design reviews. These reviews are managed by CFHT. CFHT reserves the right to require design changes to ensure that the resulting instrument meets specifications and will operate in the CFHT environment. Depending on project complexity and functions, there may be instrument and subsystem design reviews. These may be combined as needed.

CFHT encourages regular consultation with CFHT staff during the development process. All designs shall be preceded by a Requirements document and review and a Functional Specifications document and review. CFHT may request one, two, or three design review stages, depending on the complexity of the development proposed. Larger projects may be required to conduct a Conceptual Design Review (CoDR) and probably a Preliminary Design Review (PDR). All projects shall have a Final Design Review (FDR).

Note that the general design order is optical, mechanical, electrical, and finally software. The mechanical design depends on the optical design. The electronics design depends on what mechanics need controlling. The software design depends on what electronics are provided. Camera controller development parallels the general instrument sequence as does data reduction and analysis software.

### 1.8.1. Design Stages

At various stages of the design process, it may be prudent to build models or prototypes to explore the design space. This is encouraged and should be discussed during contract negotiations or at the latest during the Conceptual Design Review. Models and prototypes shall not become part of the delivered instrument.

#### 1.8.1.1. Requirements Document

Prior to design initiation, project personnel and CFHT shall agree on the requirements to be met. This entails the production and review of a requirements document by a collaboration of project and CFHT staff. The resulting document shall guide the design process. For most projects appendices to the project contract serve as the requirements document.

#### 1.8.1.2. Functional Specifications Document

Following the requirements document acceptance, the project staff shall prepare a functional specification document. This document shall provide a description how each requirement is to be met, on the level of, e.g., the mechanical stages to be used, the general electronics to be proposed, the software modules to be written, or the kind of optical design to be created. After this document’s review, there should be agreement on the direction the actual design will take.

#### 1.8.1.3. Conceptual Design Review

Large projects shall present a Conceptual Design Review (CoDR). For a CoDR the project staff shall prepare an initial design document in advance. For each section of the functional specifications document there should be a description of how that function will be implemented. The purpose is to get an overall design worked out and discussed. The goal is an agreement on the major design points with confidence that the design team is prepared to do a preliminary design.

#### 1.8.1.4. Preliminary Design Review

Most projects shall present a Preliminary Design Review (PDR). For the PDR the project staff will prepare an intermediate design documents in advance. The purpose is to get the high and intermediate level design agreed on. The document should provide a level of detail between that of the CoDR and FDR documents, i.e., it should describe most of the whys and how’s without being detailed enough to start building the instrument. A proposed list of spares shall be included.

After the PDR, all parties should feel satisfied that the requirements will be met by the detailed design. Normally the optical design is completed by the time of the instrument PDR.

1.8.1.5. Final Design Review

All projects shall present a Final Design Review (FDR). The project staff will prepare final design documents that will completely specify all details necessary to build the instrument satisfying all the requirements. A final list of spares shall be included. After the FDR is successfully completed, work on the hardware and/or software may commence. Until this time no physical components or lines of software should have been touched. The only exception is ordering components with long lead times as agreed with the CFHT instrument project manager.

During the FDR there will be initial discussions of acceptance testing. This will normally lead to a brief outline of what tests will be needed to verify that the requirements are met by the instrument.

1.8.2. Mechanical Designs

1.8.2.1. CoDR

The CoDR shall point to key requirements and discuss the projected mechanical designs. A 3-D conceptual design model encompassing all major parts, materials, and functionality of the overall system should be evaluated. Proposed experiments and prototypes for the design to support design reliability and maintainability shall be established. Preliminary finite element analysis or simulations for critical design features must be shaped. A Draft interface definition document shall be formed.

1.8.2.2. PDR

The PDR shall display how all of the requirements are being met in the mechanical design. An updated 3-D detailed design model demonstrating all major and minor parts, materials, and functionality of the overall system should be presented. Experiment findings and prototype results for the design concept shall be demonstrated. Intermediate supporting finite element analysis or simulation findings should be critiqued. All material and vendor selections should be fleshed out and the baseline interface definition document shall be confirmed. Major long lead items should be identified.

1.8.2.3. FDR

The FDR shall present the final design in a finished state before fabrication, assembly and integration of components and subsystems commence. It shall include a finished 3-D system model presenting all major and minor subassemblies, parts, components, and hardware. It shall include a complete drawing data package including a system level drawing tree, bill of materials, and system level assembly and subassembly detailed drawings. Final design prototype demonstrations and experimental results shall be supplied. The design documentation shall present a schedule showing subsystem and component level fabrication activities and testing. It will cover a proposed risk mitigation plan and decision points for fabrication problems. Manuals and procedures for troubleshooting and assembly with a table of contents shall be provided. Specific instructions given for specialized handling or storage requirements will be required.

1.8.3. Electronic Designs

1.8.3.1. CoDR

The CoDR documents for electronic designs, which include motion control system (Galil) and command and control system (PLCs), shall include, where applicable, conceptual system design, draft interface definition document, and preliminary analyses or simulations.

1.8.3.2. PDR

The PDR documents shall include, where applicable updated preliminary system design, interface definition document, detailed analyses or simulations, prototype results, preliminary system, subsystem, schematic and interconnect drawings, flow charts of DSP, PLC, PLD, FPGA or microcontroller code, identification of major components, error analyses, and design verification in relation to the Functional Specification Document.

#### 1.8.3.3. FDR

The FDR is the last stage prior to the final fabrication, assembly and integration of components and subsystems. FDR documents shall include, where applicable, updated PDR documents, detailed schematics, interconnect and layout drawings, risk assessment, proposed manuals with table of contents, and handling and storage document.

### 1.8.4. Software Designs

#### 1.8.4.1. Functional Specifications Document

This document shall propose the set of functions the software will provide. These are logical functionality, not programming language functions. For an agent, for example, this could detail the commands to be implemented and their operation. The document should cover each requirement indicating how the requirement will be met.

#### 1.8.4.2. CoDR

Very large software projects and smaller projects by groups unfamiliar with the CFHT software environment may be required to present a CoDR. At a CoDR a document describing the overall software design and methodology shall be available. It will discuss the underlying hardware environment that the software is to control, the ways the software will interface to the CFHT environment described in this document, and the initial proposed solutions for meeting the requirements document.

At this point there shall have been no lines of delivered code written.

#### 1.8.4.3. PDR

After the basic software design is understood medium and large projects shall present a PDR document and discussion. This document shall review the requirements and discuss how they are to be met. It shall describe the control and data flow at the level of major modules.

At this point there may be the start of interface definitions in program files, but still no lines of delivered code should have been written.

#### 1.8.4.4. FDR

Prior to any major coding effort there shall be an FDR. It will discuss a detailed design document that includes data structure definitions, control flow, command processing, instrument control, interfaces with the CFHT system, and status and error reporting. The detail shall be sufficient for a coder to implement the software. There shall be a test plan outline.

At this point the data structure definitions should be fairly complete, and function stubs may exist matching the proposed program structure, but relatively little code should have been written. The goal of the FDR is to obtain approval of the design so that coding can begin.

#### 1.8.4.5. Code Reviews

Major software development shall include code reviews with CFHT personnel. Code reviews will be informal in that no extra preparation is expected. They are intended to verify that the software will fit into the CFHT environment and to begin CFHT staff familiarization.

### 1.8.5. Optical Designs

The optical design shall be completed at the time of the instrument PDR.

#### 1.8.5.1. CoDR

The CoDR document shall present the design solution or solutions developed to meet the requirements laid out in the requirements document. The document shall include the advantages and disadvantages of the various design solutions. At the discretion of CFHT, the CoDR and the PDR may be combined into one review if the optical system is deemed simple enough.

#### 1.8.5.2. PDR

After the basic form of the design is agreed on, a PDR document and discussion shall be produced. This document shall contain details of the optical design including basic fabrication tolerances and interface requirements for the mechanical mounting of the optics. Also included will be all analyses and simulations necessary to demonstrate compliance of the design with the requirements.

#### 1.8.5.3. FDR

The FDR is the last review prior to fabrication of optical components. The FDR documents shall include optical fabrication drawings with all specifications necessary for fabrication included, a tolerance analysis demonstrating that the fabrication specifications will allow the optics to meet the requirements, final mechanical interface specifications approved by the mechanical design group, necessary updates to all analyses and simulations from the PDR document, and a list of proposed tests to show conformance with requirements.

## 1.9. Documentation and Deliverables

### 1.9.1. General

- 1. The detailed manuals and drawings outlined below are considered part of the instrument and are assumed to be included in its contract purchase price.
- 2. Each document page shall contain a page number and a release date or version number.
- 3. All documentation shall be written in English.
- 4. The documentation shall be sufficient to inform any preventive or corrective maintenance on the instrument.

#### 1.9.1.1. Manuals

- 1. Manuals shall be provided on computer media in a format compatible with Microsoft WORD software.
- 2. Each manual shall contain, apart from the text:

  i) a Title or Cover Page
  ii) a Table of Contents
  iii) a List of Illustrations
  iv) an Index

#### 1.9.1.2. Drawings

- 1. All drawings shall be numbered using a CFHT agreed format.

#### 1.9.1.3. Spares

- 1. All spares agreed on during the design reviews shall be delivered.

### 1.9.2. Mechanical

#### 1.9.2.1. Drawings

- 1. All mechanical drawings and illustrations shall be provided on computer media in formats readable and modifiable by AutoDesk, AutoCAD or AutoDesk Inventor.
- 2. An overall detailed assembly drawing with multiple views or 3-view cutaway drawing shall be provided showing all major and minor subassemblies.
- 3. A complete set of assembly drawings and dimensioned fabrication drawings sufficient to fabricate any component of the instrument shall be provided.
- 4. All parts shall be numbered and dimensioned.
- 5. Commercial parts shall be identified on the drawings together with:

  i) the manufacturer's name,
  ii) the manufacturer’s part or model number,
  iii) the quantity required.
- 6. There shall be a master drawing list giving a structural idea of the overall design in a drawing tree.
- 7. Either European or North American drawing standards are acceptable, but must be clearly identified on the drawings.
- 8. All special symbols shall be identified in a separate symbol table provided as an instrument drawing.

1.9.2.2. Manuals

- 1. Mechanical Assembly Procedure and Maintenance manuals shall be provided. They shall contain:

  i) instructions for the mechanical assembly and disassembly of all major modules,
  ii) all specialized assembly procedures,
  iii) alignment procedures,
  iv) a list of all specialized tools required for instrument maintenance or adjustment,
  v) a list of all commercial parts used in the instrument, including, for each:
    - 1. an overview of the instrument operation,
    - 2. a drawing reference number indicating the assembly in which the part is used,
    - 3. the manufacturer's name, address, telephone number, and web address,
    - 4. the model or part number,
    - 5. a manufacturer's specification sheet,
    - 6. the supplier's, name, address, telephone number, e-mail address and web address.

  vi) a maintenance plan including preventive maintenance procedures and schedules.

1.9.2.3. Tools

All special tools needed for instrument assembly, disassembly, and maintenance shall be provided.

1.9.3. Electronics

1.9.3.1. Drawings

- 1. A system block diagram detailing signal flow, major subsystems and functions shall be provided.
- 2. A drawing detailing overall system component layout, cable interconnections, connector identifications, and cable names shall be provided.
- 3. Detailed wiring interconnection diagrams shall be provided for each cable, showing:

  i) connector types,
  ii) connector pinouts,
  iii) connector names or labels,
  iv) signal and cable names,
  v) wiring color codes, if used.

- 4. Detailed electronics circuit diagrams shall be provided for all circuits, indicating:

  i) device numbers or labels,
  ii) device types,
  iii) device pinouts,
  iv) all interconnections,
  v) a circuit board name.

- 5. All changes or jumpers on circuit boards shall be highlighted.
- 6. All signal paths and power runs shall be clearly identified, and signal directions indicated.
- 7. All references to signals and connections from and to other drawings or devices shall be clearly identified.

- 8. Circuit timing diagrams shall be provided.
- 9. Electronic symbols should follow the US ANSI standards.
- 10. Logic notation should be consistent with the device manufacturer's symbols. The use of "inverted" logic symbols is not acceptable.
- 11. Diagrams shall be compatible with a recent/current version of OrCAD. They shall include schematic layout and PCB layout forms.
- 12. Gerber files for PCB creation shall be included.

1.9.3.2. Manuals

- 1. A written systems and operational description shall be provided.
- 2. A detailed written description of circuit cards and subsystem functions, including critical signals and timing shall be provided.
- 3. Flow chart, source and binary listing of the contents with sufficient comments, of all programmable devices including PLCs, DSPs, PLDs, FPGAs, PROMs and microcontrollers.
- 4. A list of all commercial components shall be provided, including:

  i) a drawing reference number indicating where the part is used,
  ii) the manufacturer's name, address, telephone number, and web address,
  iii) the model or part number,
  iv) a data or manufacturer's specification sheet,
  v) the supplier's, name, address, telephone number, e-mail address and web address.

1.9.4. Control

1.9.4.1. Drawings

- 1. A loop block diagram for all servo systems shall be provided indicating components, summing points and signal paths.
- 2. Open and closed loop gain and phase response curves (transfer-functions) shall be provided for all servo systems. Bode plot approximations are acceptable whenever system poles and zeros are adequately spaced.
- 3. Flow diagrams showing the interrelation and timing of all "firmware" routines shall be provided.

1.9.4.2. Manuals

- 1. A written control system overview, detailing system operation shall be provided.
- 2. A written firmware system description providing a detailed explanation of the operation of each code module, including required inputs and all possible outputs shall be provided.
- 3. A complete, documented and commented firmware listing in assembly or higher-level language shall be provided.
- 4. For servo systems, the transfer function of each loop component, together with system open loop and closed loop transfer functions shall be provided in the form of algebraic expressions.

1.9.5. Software

Software deliverables are source code, internal program documentation, and user manuals.

#### 1.9.5.1. Source Code

During development CFHT staff shall be provided read-only access to all deliverable source code in the development tree for the instrument. A copy of the source tree sent regularly to CFHT is acceptable.

The source code for all included software shall be provided in a format readable by a Linux PC-based system. This is to include host-based programs and lower level instrument controller software, such as LabView programs used for maintenance, PLC code, Galil programs, and DSP code. Any approved variation from the CFHT build system must include build/compile instructions and any non-standard tools required.

CFHT must be able to make changes to the delivered code, recompile, debug, and test the changes, and run the modified program with the instrument. This subsection is to be interpreted so as to allow that to happen.

The use of any proprietary systems that do not meet this subsection must be discussed with and approved by CFHT before the FDR.

CFHT requests that the delivery is in the form of the RCS or SVN repository used during project development.

#### 1.9.5.2. As Built Documentation

The FDR document should be updated to match the actual implementation and provided in machine-readable form. LaTex or Word .doc or .docx files are acceptable. As with the source code, CFHT must be able to maintain the documentation to match code changes.

This documentation's goal is facilitating code understanding. It should include at least the following sections.

i) summary of requirements
ii) summary of functional specification
iii) overall code organization
iv) data structure description - This will include diagrams, field definitions, and how the structures fit into the overall organization.
v) functional flow and/or data flow - The intent here is to describe how each of the requirements is handled by the code; not a function-by-function description, but a pointer into the code and an idea of what happens.

After studying this document one should be able to find the code section that handles each requirement. The low level comments in the code would then be expected to complete the understanding of processing the requirement.

#### 1.9.5.3. User Manuals

A user manual or manuals shall be provided covering all aspects of using the software. This is to include the observing interface and any maintenance or engineering interfaces the software provides. The manuals must be provided in one of the formats described in section 1.9.5.2.

### 1.9.6. Optics

#### 1.9.6.1. Optical Fabrication Drawings

- 1. A complete set of optical specification drawings sufficient to fabricate all custom optics, or other commercial optical components shall be provided in AutoDesk compatible format.
- 2. An overall optical assembly drawing showing all optical components and systems, the directions and positions of major optical rays, and the direction of any available adjustments shall be provided.

1.9.6.2. Optical Design Documents

- 1. Conformance data for all custom optical components showing that the components met specification shall be provided in electronic format.
- 2. Spot diagrams detailing critical device performance over the design field and spectral range shall be provided in electronic format.
- 3. As-built optical model(s) for all instrument optical systems shall be provided electronically in Zemax format when possible. If Zemax format is not possible, as-built optical model listing(s), sufficient to re-create the model(s) in Zemax, for all instrument optical systems shall be provided electronically in text format.

1.9.6.3. Manuals

- 1. Optical alignment instructions detailing in particular any preferred procedures, and the use of alignment fixtures and tooling shall be provided.
- 2. An optical efficiency budget giving the efficiency of each surface and an overall optical efficiency for the instrument shall be provided.
- 3. A list of mirror and anti-reflection-coatings for each surface, shall be provided, detailing:

  i) the manufacturer's name, address, telephone number, e-mail address and web address,

  ii) type of coating and its specifications,

  iii) optical efficiency of coatings, including efficiency tracings files.
- 1. A list of all custom optical components detailing all necessary manufacturing specifications shall be provided.
- 2. A list of all commercial optical components shall be provided, including:

  i) the manufacturer's name, address, telephone number, e-mail address and web address,

  ii) the model or part number,

  iii) a datasheet or copy of catalogue entry,

  iv) the supplier's name, address, telephone number, e-mail address and web address.

## 1.10. Storage and Handling

### 1.10.1. Instrument

- 1. An instrument shall be provided with lifting points above its center of gravity and any necessary spreader bars or handling equipment required for mounting the instrument on the telescope or onto its handling cart.

### 1.10.2. Storage/Handling Cart

- 1. The instrument shall be provided with a handling cart that shall hold the instrument in the orientation normally used on the telescope. The cart is intended for instrument storage and for handling while off the telescope.
- 2. Instruments intended for use at the Cassegrain focus shall be mounted on the handling cart in such a way as to not inhibit the mounting of the instrument to the Cassegrain Bonnette.
- 3. The cart shall have locking, soft plastic wheels at least 150 mm in diameter and, if for use at the Cassegrain focus, jack screws at each corner.
- 4. Access to the instrument by an overhead crane or other handling equipment will not be impeded while the instrument is on the cart.
- 5. The instrument will be capable of performing all electromechanical functions while on the cart. Access to control electronics, connectors and power supplies for routine maintenance and troubleshooting of the instrument shall not be impeded by the cart structure.
- 6. The cart shall have at least one pair of lifting points, together with all necessary spreader bars or specialized slings to permit transportation of the cart plus instrument by crane.
- 7. The cart shall contain an open shelf onto which all necessary fastening hardware and tools for mounting the instrument to the telescope can be stored.

### 1.10.3. Handling Electronics Equipment

- 1. All auxiliary electronics or control equipment not mounted as part of the instrument shall be rack mounted in 19” racks, using standard rack panels.
- 2. Storage shelves or drawers for all associated cables, hoses etc. shall be provided with the handling cart or with associated electronics storage.

### 1.10.4. Weight and Moment Identification

- 1. Labels shall be affixed to the cart and electronics racks indicating instrument weight and moments about the instrument mounting face.

### 1.10.5. Cover

- 1. The instrument shall be provided with a weatherproof cover with closures sufficient to allow component access and ease of cover installation and removal. The cover should be in the form of a fitted, polyethylene tarp.
- 2. The cover shall be identified by the instrument name in 100 mm high, white letters affixed to it.
- 3. The cover shall be designed to fit over the instrument and its storage cart and reach to within 100 mm of the floor.

1.10.6. Attachment to the Telescope

- 1. Captive hardware shall be used to fasten an instrument or part of an instrument to the telescope.
- 2. An instrument or part of an instrument that must be attached to the telescope in a particular orientation shall have clear markings indicating the orientation. Preferably this would be an "N" on a north facing vertical surface or an "N" with an arrow indicating north on the northern section of a horizontal surface.

Equipment that is attached to the telescope is limited in size. The following paragraphs give a general description of the clearances. An instrument design that approaches these values must be considered in detail at the design reviews.

1.10.6.1. Cassegrain Bonnette

The mounting surface of the Cassegrain Bonnette is 2.97 meters above the floor when the telescope is parked at zenith. On the Cassegrain environment west side there are two electronics boxes extending about 11 cm and 28 cm below the mounting surface with about 139 cm between them.

There is a platform lift (the "Blue Platform") available for positioning instruments for attachment to the Cassegrain Bonnette mounting surface. Its minimum height is 81 centimeters above the floor, leaving a maximum of 2.16 meters clearance for an instrument and its handling fixture. The platform's capacity is 907 kilograms, and its reach is above the Cassegrain Bonnette mounting surface.

A Cassegrain instrument must not come within 0.1 meters of the south pier as the telescope swings north or of the horseshoe as the telescope swings south. Values for the actual clearances (i.e., not including the 0.1 m) are shown in **Error! Reference source not found.** for the telescope pointing directly north at various altitudes.

| Telescope altitude | On axis | 47 cm off axis | Plate to ? |
|---|---|---|---|
| 37 | 184 cm | 166 cm | south beam |
| 42 | | 181 cm | bottom edge of south beam |

**Table 3 - Clearance to south pier, telescope to north**

The same information is shown in Table 4 for the telescope pointing directly south at various altitudes.

| Telescope altitude | On axis | 57 cm off axis | Plate to ? |
|---|---|---|---|
| 30 | 247 cm | | horseshoe |
| 35 | | 232 cm | horseshoe |
| 37 | | 277 cm | horseshoe |
| 38 | 285 cm | | black box above motors |
| 42 | | 288 cm | horseshoe |
| 45 | 322 cm | | crash bar |
| 45 | | 317 cm | horseshoe just above motors |

**Table 4 - Clearance to horseshoe, telescope to south**

The "off axis" values indicate when an approximately 1 meter "thick" instrument first contacts the telescope. The "plate to ?" entries indicate what the instrument would touch.

1.10.6.2. Top Ring

For instruments mounted at prime focus, their maximum height is 7.3 meters.

1.10.7. Freight elevator

The telescope is on the fifth floor of the observatory building. There is a freight elevator for transferring items from the first floor to the fifth. The elevator is rated at 8,000 pounds (3,600 kilograms), the door opening is 2.1 by 2.1 meters, and the floor is 2.1 by 1.98 meters.

## 1.11. Acceptance Tests

- 1. In general, contractors should expect acceptance testing to be divided between assembly tests and inspections, tests of the integrated instrument at the fabrication site, and a final instrument acceptance test on site at CFHT.
- 2. The testing shall include operating cold tests.
- 3. CFHT reserves the right to request and conduct on-site inspections of the instrument and reviews of project development during instrument development, fabrication, assembly, and testing.
- 4. Specific details of inspection and acceptance tests should be agreed upon in writing between the contractor and CFHT well before the tests are to be conducted. It remains the contractor's responsibility to detail these tests to CFHT's satisfaction. In the event that a list of tests agreeable to CFHT is not provided, CFHT reserves the right to impose whatever tests it deems essential to guarantee the successful operation of the instrument.
- 5. Instruments will generally NOT be deemed acceptable for delivery to the observatory unless all associated documents and diagrams outlined in this manual are available at the time of final inspection at the developer's site.

### 1.11.1. Electro-Mechanical

Instrument acceptance testing shall also include the following.

- 1. Assembly and disassembly procedures – the CFHT staff will follow the assembly and disassembly manual to take the instrument apart, examine all parts, put the instrument back together, and align the instrument.

The instrument will be stress tested to ensure its capability to operate in the summit environment.

- 2. All parts of the instrument that are mounted on the telescope will be tested individually (where appropriate) and as a complete system in an environment at -10° Celsius through all movement ranges at angles from zenithal to 60 degrees zenith distance in north/south/east/west directions. The instrument must operate and maintain alignment through these tests. The complete instrument will also be tested both powered off and powered on but not operating at all telescope angles from zenithal to horizontal in north/south/east/west directions and must maintain alignment through these tests. For these tests the instrument shall be supported by the normal mounting face used to attach it to the telescope.
- 3. All parts of the instrument that are not mounted on the telescope but will be in the open, 5th floor will be tested in an environment at -10° Celsius.
- 4. All parts of the instrument that are situated in enclosed rooms will be tested in an environment at 10° Celsius.

### 1.11.2. Software

Prior to software delivery CFHT will conduct acceptance testing of any project provided software. The first stage will be a review of the FDR test plan outline as implemented and pursued, followed by an evaluation of the test results.

The developed test plan should include unit testing in which all the code is exercised, integration testing in which the hardware and software pieces are shown to work as a system, and functional testing which shows how all of the project requirements are met. After a successful review, CFHT will conduct its own functional testing of the whole system.

1.11.3. Optical

Prior to instrument delivery, CFHT will conduct acceptance tests on all of the optical systems contained within the instrument. The test plan will be based on, but not limited to, the proposed tests from the FDR document.

The final test plan shall include tests to demonstrate compliance with all requirements. In some cases (e.g., total transmission), the test may be an analysis based on as-built measurements instead of a direct measurement, but this should only be done when direct measurements are extremely impractical. In general specialized test equipment needed to perform the tests will be provided by the contractor.

## 1.12. Training

The instrument constructor shall provide training sufficient to allow CFHT technical staff to:

i) mount/dismount the instrument from the telescope,
ii) verify correct operation,
iii) operate the instrument,
iv) perform sufficient troubleshooting to identify failed subassemblies, and
v) perform all preventive and corrective maintenance of the instrument.

The travel and per diem costs of this training will be covered by CFHT on a per incident basis. All other costs of providing this training are part of the contract for supplying the instrument.

## 1.13. Glossary

These acronyms are used in this document.

| | |
|---|---|
| 10BASE-T | 10 Megabit per second Ethernet over CAT5 cable |
| 100BASE-T | 100 Megabit per second Ethernet over CAT5 cable |
| 1000BASE-T | 1 Gigabit per second Ethernet over CAT5e cable |
| AC | Alternating Current |
| ANSI | American National Standards Institute |
| ARC | Astronomical Research Cameras (formerly SDSU) |
| BNC | Bayonet Neill-Concelman (co-axial cable connector) |
| CAT5 | Category 5 (dual twisted pair cable for network connections) |
| CAT5e | Category 5 Extended (dual twisted pair cable for 1 Gigabit network connections) |
| CFHT | Canada-France-Hawaii Telescope |
| CGH | Computer Generated Hologram |
| CoDR | Conceptual Design Review |
| COTS | Commercial, Off-The-Shelf components |
| DC | Direct Current |
| DCE | Data Computer Equipment (the computer end of RS-232 cables) |
| DD | Double Density |
| DSP | Digital Signal Processor |
| EPICS | Experimental Physics and Industrial Control System |
| FDDI | Fiber Distributed Data Interface (a fiber connector) |
| FDR | Final Design Review |
| FITS | Flexible Image Transport System (a convention for astronomical image files |
| FPGA | Field Programmable Gate Array |
| GNU | Gnu's Not Unix (a computer programming organization) |
| GTK | Graphics Tool Kit (an X windows system graphics programming library) |
| IDL | Interactive Data Language (a programming language for data analysis and graphical display) |
| IEEE | Institute for Electrical and Electronics Engineers |
| IOC | Input/Output Controller (an EPICS computing element) |
| IP | Internet Protocol |
| LED | Light Emitting Diode |
| LEMO | A connector manufactured by the Swiss LEMO Corporation |
| KVM | Keyboard/Video/Mouse switch for accessing multiple consoles remotely |
| MS | MicroSoft |

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| NEO | New Environment for Observing (the CFHT data acquisition programming environment) |
| OAP | Observatory Automation Project (a CFHT project allowing observing from Waimea) |
| PC | Personal Computer |
| PCB | Printed Circuit Board |
| PCI | Peripheral Component Interconnect (a PC bus) |
| PDR | Preliminary Design Review |
| PLC | Programmable Logic Controller |
| PLD | Programmable Logic Device |
| PROM | Programmable Read-Only Memory |
| PTFE | Polytetrafluoroethylene (Teflon) |
| RCS | Revision Control System (a software management system) |
| RJ45 | (more properly called an 8P8C - a connector for network cables) |
| RS-232 | (more properly called RS-232C - a specification for terminal/computer communication) |
| SC | Siemon Connector (a fiber optic cable connector) |
| SDSU | San Diego State University (a detector controller developed there) |
| SHARC | Super Harvard ARChitecture (an Analog Devices DSP chip) |
| SVN | SubVersioN (a software management system) |
| TCP | Transmission Control Protocol |
| TCS | Telescope Control System |
| UDP | User Datagram Protocol |
| US | United States |
| VA | Volt-Amps |
| XOFF | transmission OFF (serial communications stop) |
| X | the X Window System |
| XON | transmission ON (serial communications start) |
| ZIF | Zero Insertion Force (a type of integrated circuit socket) |