Draft Pre-ship Report on
Part I of the Acceptance Tests for the HIRES CCD Upgrade

Sean Adkins
W.M. Keck Observatory

July 7, 2004
Version 1.2

Table of Contents

Table of Contents

Table of Contents

Figures

Tables

1 INTRODUCTION

An upgrade is under development for the CCD detector and related systems of the High Resolution Echelle Spectrograph (HIRES) on the Keck I telescope at the W.M. Keck Observatory (WMKO).

The HIRES CCD Upgrade will replace the host computer, add new disk storage and replace the detector and associated electronics along with the dewar and the field flattening optics. The current intent is to make the upgrade package a "plug and play" interchange with the current detector and related components.

The components to be replaced are shown in block diagram form in figure 1.

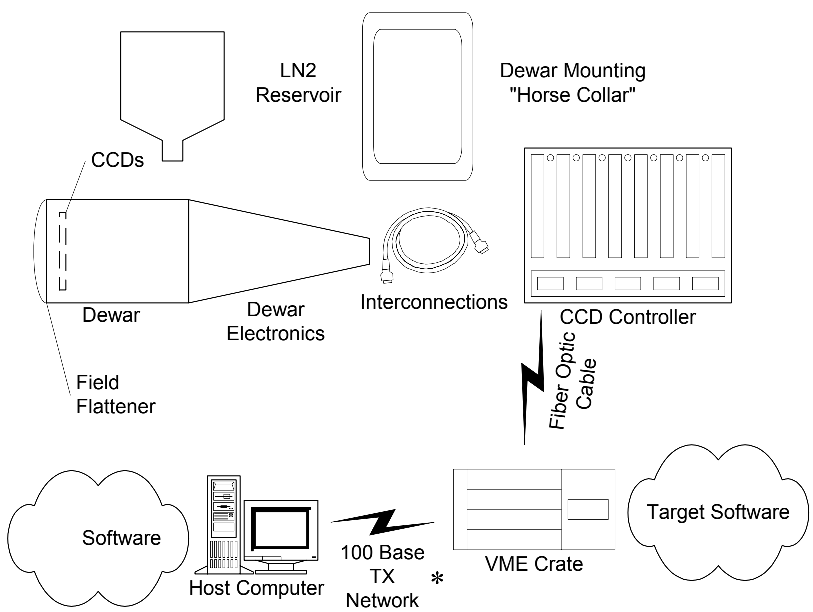


Figure 1: Upgraded Components

The current HIRES Instrument has operated since commissioning with an engineering grade CCD detector with a 2048 x 2048 format and 24 micron pixels. There have been several improvements in CCDs suitable for HIRES since the instrument was commissioned. These improvements include:

- higher pixel counts
- smaller pixels
- improved quantum efficiency, particularly at short wavelengths
- faster readout rates
- lower read noise

The upgrade will bring the performance of HIRES to "state of the art" levels. HIRES will again be the most sensitive high resolution optical spectrograph in astronomy.

2 SCOPE AND APPLICABILITY

This document reports the results from Part I of the acceptance test in the Acceptance Test Plan (ATP) for the HIRES CCD Upgrade. This report has been written using test data supplied by UCO/Lick and inspections and tests performed by Sean Adkins, Grant Hill and Grant Tolleth.

This is revision 1.2 of the document and it is the final version for review by WMKO and the UCO/Lick HIRES CCD Upgrade project team.

3 RELATED DOCUMENTS

Cowley, David. *HIRES CCD Upgrade for The Keck 1 Telescope, Mauna Kea, Hawaii,* Revision 2.91. Santa Cruz, California: UCO/Lick Observatory, University of California Santa Cruz, July 24, 2002.

Adkins, Sean. *HIRES CCD Upgrade Requirements, Draft*, Revision 1.1. Waimea, Hawaii: W.M. Keck Observatory, March 24, 2003.

Vogt, Steven S., Geoffrey W. Marcy and R. Paul Butler. *A New CCD Mosaic for the Keck Observatory High Resolution Spectrometer (HIRES) to Improve the Detection of Terrestrial Mass Extrasolar Planets.* Waimea, Hawaii: W.M. Keck Observatory, August 20, 2003.

Adkins, Sean. *Draft Acceptance Test Plan for the HIRES CCD Upgrade*, Version 1.2. Waimea, Hawaii: W.M. Keck Observatory, November 5, 2003.

4 REVISION HISTORY

Revision	Date	Author	Reason for revision / remarks
1.0	December 8, 2003	SMA	Original Issue
1.1	December 9, 2003	SMA	Revisions to add current information, and incorporate WMKO comments
1.2	July 7, 2004	SMA	Revisions to incorporate new information

Due to the difficulties in documents with moderately complex formatting such as this one, the Microsoft Word "Track Changes" feature is not useable. To see the changes in this document since the previous revision, use the "Tools, Track Changes, Compare Documents" drop down menu sequence and compare this document to the previous version. It is not recommended that you attempt to print the results. The file name of the previous version of this document is "HIRES CCD Upgrade PS Report.1.1.doc", dated December 9, 2003.

5 OVERVIEW

The ATP consists of two major parts. The first part of the ATP has been performed prior to the pre-ship review by the instrument team and WMKO personnel. The second part of the ATP will be performed after first light as part of the on-sky engineering tests of the upgrade.

The purpose of the ATP is to verify that the HIRES CCD Upgrade meets the observatory requirements and to establish detailed values for key performance parameters. This is done through three kinds of verification: by test, by inspection and analysis, and by demonstration. In general UCO/Lick performed the verifications by test and WMKO performed the verifications by inspection and analysis. The verifications by demonstration required the participation of both UCO/Lick and WMKO

6 SUMMARY

This report results from the tests performed after the HIRES upgrade dewar was disassembled for cleaning in December 2003. At several points in this report test data will be provided for tests made on individual devices in the UCO/Lick CCD Laboratory prior to the initial installation of the science detector mosaic in 2003, and for tests performed during June and July 2004 after re-integration of the dewar in May 2004.

A significant effort was made to investigate the dewar contamination problems and to obtain the facilities and materials needed for proper cleaning. This effort has succeeded in producing a very clean dewar, and no further signs of contamination have been noted.

An effect causing a change in the appearance of the surface of CCD2[1], and to a lesser extent CCD1 persists. This effect, which has been described as "battleship gray" (BG) occurred some time after the dewar was pumped and cooled. 12 measurements of the QE performed over a 27 day period after the dewar was re-integrated indicate that the QE of CCD2 is stable in spite of the reappearance of the BG effect. This effect is now believed to be a property of the CCD and not due to contamination.

While the process of developing the HIRES CCD Upgrade has been difficult, it is nearing a satisfactory completion except for one very unfortunate event. This is the failure of the "A" amplifier on CCD2. This failure is believed to have been caused by shorting of the CCD interface board output connector inside the dewar by copper particles falling into the connector during the QE measurements.

During the early part of the re-integration a test procedure that permitted making QE measurements of the fully integrated dewar was developed and this procedure required tilting the dewar from its normal horizontal looking orientation. The copper particles are believed to have originated from the copper blocks used to connect each CCD assembly to the cold straps in the

[1] See § 9.1 for details on the designations and placements of the CCDs.

dewar. These blocks have tapped through holes, and stainless steel screws were used to attach the blocks to the cold straps. Additional vented screws have now been installed in each of these holes in order to prevent a re-occurrence of this problem. Since no spare CCD devices are available, when all of the CCD mosaic must be read out (the most common requirement) the system will have to be operated in single amplifier per CCD readout mode, resulting in a readout time of 60 seconds per exposure.

6.1 CCD Controller Power Supply Access

The construction of the CCD controller has resulted in a difficult procedure to access the power supplies for service. The layout is crowded and lacks aesthetic appeal. However, no electrical spacing requirements appear to have been violated, and a written procedure will be supplied to aid in disassembly for power supply replacement.

6.2 CCD Controller Wiring

Power distribution in the controller has been done with a very large number of terminal blocks, and many of the crimp connections have not been made with a controlled cycle crimp tool. The wire types used are correct for the voltages involved, and no hazards appear to exist as a result of the wiring.

6.3 Footlocker Cooling Access Provisions

The requirements for the upgrade requested a means for a rapid transition of the footlocker to air-cooling in the event of a glycol system failure. This was not done, and as a compromise a service access panel on the lower right side of the footlocker (see Figure 11) has been converted to easier access through the use of thumbscrews. The airflow this will provide is not optimal as it is at the bottom adjacent to the fans. However, since the fans draw air down through the electronics this will probably be sufficient when the low power dissipation and temperature rise is taken into account.

6.4 Spares Testing

A number of electronics spares will be provided with the upgrade as described in section 9.7.2. Tests on 7 of the approximately 18 spares have not been completed, but UCO/Lick indicates that these tests will be completed prior to shipment of the HIRES CCD Upgrade.

6.5 Software Status

There are some issues with crashing of the "advanced stats" feature of the display software to be resolved. The "dashboard" display for the instrument includes an icon representing the CCD mosaic that is rotated 90° with respect to the mosaic image display.

6.6 Documentation Status

The documentation is incomplete.

6.7 Recommendations

Although there are some outstanding issues with the software and documentation it does not appear that there is any reason why the HIRES CCD Upgrade should not ship as planned for installation in late July 2004.

7 APPLICABLE STANDARDS

The HIRES CCD Upgrade must conform to at least a minimum set of standards related to safety and common observatory practices. It is recognized by WMKO that the HIRES CCD Upgrade was designed and largely implemented prior to the increased emphasis on standards compliance that the observatory is now requesting on new instrument projects. However, considerations of safety and compatibility require that WMKO inspect the upgrade using certain standards as a guide to correct practices in design and construction. These standards are listed in Table 1.

Table 1: Minimum Applicable Standards

Source (Organization or Standardizing Body)	Number	Title
ANSI	ANSI Y14.34M-1996	Parts Lists, Data Lists, And Index Lists: Associated Lists
ANSI	ANSI Y14.1-1995	Decimal Inch Drawing Sheet Size And Format
ANSI	ANSI Y14.3M-1994	Multi And Sectional View Drawings
ANSI	Y14.5M-1982 (R1988)	Dimensioning and Tolerancing
ANSI	ANSI Y14.17-1966	Fluid Power Diagrams
ASME	Y14.100M-2000-2001	Engineering Drawing Practices
CARA	KSD 8	KTL: the Keck Task Library
CARA	KSD 3	Software Items for Acceptance Review
CARA	KSD 50	Keck II C Style and Coding Standards
CARA	KSD 201	How to Set Up a config.mk Build
CARA	KSD 210	WMKO Software Standards
County of Hawaii	1995 edition	Hawaii County Code 1983 (1995 edition)
FCC	Title 47 CFR Part 15	Radio Frequency Devices
International Code Council (ICC)	IBC-2003	2003 International Building Code
National Fire Protection Association	2002 edition	National Electric Code
OSHA	Title 29 CFR Part 1910	Occupational Safety And Health Standards
Telcordia	GR-63-CORE	NEBS™ Requirements

8 COMPLIANCE REVIEW

8.1 Compliance Matrix for Requirements

A compliance matrix for the Draft HIRES CCD Upgrade requirements, revision 1.1 is presented in the following pages. The matrix lists in each row the referenced requirements by section number title and page number. Subsidiary requirements within a section indented in subsequent table rows.

The fourth column of the matrix, “Compliance”, indicates the level of compliance and manner of compliance. The fifth column indicates how compliance is verified. An example is shown in Figure 2.

Section	Title	Page	Compliance	Verify	Notes
7	Overall System Definition	5	100%, by design	I	

Figure 2: Example compliance matrix row

The level of compliance is shown as a value from 0% to 100% in steps of 25%. The manner of compliance indicates where in the development process the compliance will be achieved. Recommendations for describing the manner of compliance are as follows:

“**by design**”: indicates that the compliance will be achieved in the detail design phase of development

“**by fabrication**”: indicates that the compliance will be achieved in the full scale development phase of development

“**by configuration**”: indicates that the compliance will be achieved when the instrument is configured with other systems not part of these requirements

“**by test**”: indicates that compliance will be achieved during testing; this includes the selection of component values to meet specific parametric performance requirements for example

“**by procedure**”: indicates that compliance will be achieved by establishing and documenting an operational procedure for the instrument at installation "**by documentation**": indicates that compliance will be achieved by documentation provided with the instrument at installation

The verify column indicates the manner in which compliance will ultimately be verified, the values used are as follows:

T = verify by test
I = verify by inspection
D = verify by demonstration

The last column is used to provide notes that explain compliance values of less than 100%.

Requirement Reference					
Section	Title	Page	Compliance	Verify	Notes
7	Overall System Definition	5	100%, by design	I	
8	Optical Requirements	6			
8.1	Performance Requirements	6			
8.1.1	Overall System	6	n/a		withdrawn to part II of the ATP
8.1.2	Detector	7			
8.1.2.1	PSF	7	n/a		withdrawn
8.1.2.2	Fringing	7	not given, by design	T	best efforts
8.1.2.3	Format	7	100%, by design	I	
8.1.2.4	Fill Factor	8	n/a		withdrawn
8.2	Implementation Requirements	9			
8.2.1	Overall System	9	100%, by design	I	
8.2.2	Field Flattener Throughput	9	100%, by fabrication	T	
8.3	Design Requirements	9			
9	Mechanical Requirements	10			
9.1	Performance Requirements	10			
9.1.1	Detector	10			
9.1.1.1	Format	10	100%, by design	I	
9.1.1.2	Mosaic	10	100%, by design	I	
9.1.2	Vibration	10	n/a		withdrawn
9.2	Implementation Requirements	10			
9.2.1	Focus Adjustment	10	n/a		withdrawn
9.2.2	Accessories	11			
9.2.2.1	Decker Plates	11	0%, by fabrication	I	not required
9.2.2.2	Dark Cover	11	100%, by fabrication	I	
9.2.2.3	Special Tools	11	100%, by fabrication	I	
9.3	Design Requirements	11			
9.3.1	Overall Dimensions	11	100%, by design	I	
9.3.2	Configuration	11			
9.3.2.1	Space Envelope	11	100%, by design	I	
9.3.2.2	Access for Cross Disperser Swaps	12	100%, by design	I	
9.3.2.3	CCD Controller Enclosure	12	75%, by design	I	
9.3.2.4	Service Access	12	50%, by design	I	
9.3.2.5	Connector and Cable Mounting	12	100%, by design	I	
10	Electronic/Electrical Requirements	13			
10.1	Performance Requirements	13			
10.1.1	Overall	13			
10.1.1.1	Power Dissipation	13	100%, by design	T	
10.1.1.2	Compatibility	13	100%, by design	I	
10.1.1.3	Temperature and Humidity	13	100%, by design	T	
10.1.2	Detector Performance	14	n/a	T	best efforts
10.1.2.1	Cosmetic Defects	15	n/a	T	best efforts
10.1.3	Detector and CCD Controller	16	100%, by design	T	
10.2	Implementation Requirements	16			
10.2.1	Code Compliance	16	100%, by design	I	
10.2.2	Detector Format	17			
10.2.2.1	Mosaic	17	100%, by design	I	
10.2.2.2	CCD Architecture	17	100%, by design	I	
10.2.3	CCD Controller	17			
10.2.3.1	Gain	17	100%, by design	T	
10.2.3.2	Readout Clock Rates	17	100%, by design	T	
10.2.3.3	Readout Configurations	17	83%, by design	T	amplifier "A" on CCD2 non-functional, forcing full mosaic readouts to be in single amplifier mode
10.2.3.4	Binning	17	100%, by design	T	
10.2.3.5	Windowing	17	100%, by design	T	
10.2.3.6	Readout Formats	19	100%, by design	T	
10.2.3.7	Exposure Control	19	100%, by design	T	
10.2.4	Wiring and Interconnections	19			
10.2.4.1	Connector and Cable Mounting	19	100%, by design	I	
10.2.4.2	Cable and Wire Routing	19	75%, by design	I	
10.2.4.3	Internal Wiring	19	100%, by design	I	
10.2.4.4	Interconnections	19	75%, by design	I	
10.2.4.5	Cable and Wire Ratings	20	100%, by design	I	
10.2.4.6	Grounding	20	90%, by design	I	
10.2.4.7	Code Compliance	20	100%, by design	I	
10.3	Design Requirements	20			
10.3.1	Exposure Control	20	100%, by design	D	keywords implemented and simplified operating mode provided
10.3.2	Connector and Cable Mounting	20	100%, by design	I	
11	Software Requirements	21			
11.1	Performance Requirements	21	100%, by design	T	
11.2	Implementation Requirements	21	100%, by design	T	
11.2.1	CCD Controller Software	21	100%, by design	T	
11.2.2	VME Crate Software	21	100%, by design	T	
11.2.3	Host Software	21	100%, by design	T	
11.2.4	Image Display	22	100%, by design	T	
11.2.5	Graphical User Interface	22	100%, by design	T	
11.2.6	Echelle Simulator	23	100%, by design	T	
11.2.7	Deliverables	23	90%, by design	T	some spares have not yet been tested
11.3	Design Requirements	23			
11.3.1	Keyword System	23	100%, by design	T	
11.3.2	Data File Formats	24	100%, by design	T	
12	Interface Requirements	25			
12.1	Performance Requirements	25			
12.1.1	Cooling Hold Time	25	100%, by design	T	meets minimum requirements
12.1.2	Implementation Requirements	25			
12.1.2.1	LN2 Fill	25	100%, by design	I	
12.1.2.2	Stray Light	25	n/a	T	
12.1.2.3	Vacuum	25	100%, by design	T	
12.1.3	Design Requirements	25			
12.1.3.1	LN2 Fill	25	100%, by design	I	
13	Reliability Requirements	26	100%, by design	T	
14	Service and Maintenance Requirements	27	75%, by design	T	service access to CCD controller power supplies poor
15	Spares Requirements	28	100%, by fabrication	I	
16	Documentation Requirements	29			
16.1	Drawings	29			
16.1.1	Introduction	29			
16.1.2	Drawing Standards	29			
16.1.2.1	Format	29	100%, by fabrication	I	

Requirement Reference					
Section	Title	Page	Compliance	Verify	Notes
16.1.2.2	Title Block	29	100%, by fabrication	I	
16.1.2.3	Parts Lists, Data Lists and Index lists	29	100%, by fabrication	I	
16.1.2.4	Assembly Drawings	29	100%, by fabrication	I	
16.1.2.5	Detail Drawings	30	100%, by fabrication	I	
16.1.2.6	Multi and Sectional View Drawings	30	100%, by fabrication	I	
16.1.2.7	Fluid Power	30	100%, by fabrication	I	
16.1.3	Dimensions and Tolerances	30	100%, by fabrication	I	
16.1.4	Finishes	30	100%, by fabrication	I	
16.2	Manuals	30			
16.2.1	Operating Manuals	30	TBD, by fabrication	I	not yet provided
16.2.2	Maintenance Manuals	30	TBD, by fabrication	I	not yet provided
16.3	Software	31	TBD, by fabrication	I	not yet provided
16.4	Test Data	31	80%, by fabrication	I	electronic form and raw data to be supplied

8.2 Analysis and Comment

Overall the level of compliance is good given the fixed budget and the fact that developmental CCD devices are being used, which are one of kind and for which no alternatives or spares exist.

9 RESULTS OF THE PART I ACCEPTANCE TESTS

The part I acceptance tests were performed at the UCO/Lick facilities in Santa Cruz prior to the pre-ship review for the HIRES CCD Upgrade. Unless otherwise specified all tests were performed with the dewar cooled, the science grade CCDs installed, the CCDs at operating temperature, and the upgrade system fully integrated, also described as the "full-up" system.

Fully integrated means that the science grade detectors were installed in the dewar and connected to the actual CCD controller, target computer and host computer to be delivered with the upgrade. Where ever practicable all interconnections utilized the actual cables to be used in the final installation, but these cables were not grouped and routed in a manner similar to the anticipated installation. The tests were performed in a laboratory environment that did not duplicate the conditions of operation in the HIRES enclosure on the Keck I telescope.

9.1 Optical

The HIRES detector is a mosaic of three CCDs. These devices are all developmental types manufactured by MIT Lincoln Labs (MIT/LL). The CCD test descriptions in this document refer to the CCD devices in the mosaic by a two number designations. One of these is a mosaic position number, i.e. CCD1, CCD2 and CCD3. The other designation is a device reference number determined at the time of manufacture. This number consists of the device lot number, followed by a dash, which is then followed by the wafer number from that lot, followed by another dash, and finally the device number from that wafer. For example 2-2-1 means lot 2, wafer 2, device 1.

The mosaic position numbering corresponds to the CCDs as seen from the front of the dewar with the flex cable connections at the bottom. This configuration is shown in UCO/Lick drawing H-9604, "CCD Mosaic Numbering & Orientation", revision B, dated May 9, 2003. A portion of this drawing is reproduced in Figure 3. As the figure shows, CCD1 is the left most device, and CCD3 is the rightmost device. Figure 3 also indicates the device reference numbers for each CCD.

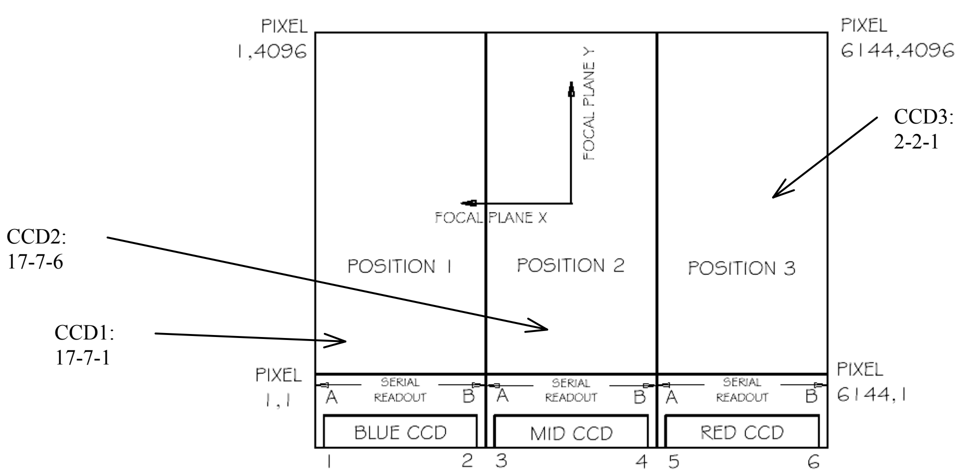


Figure 3: CCD Mosaic and device designations

9.1.1 Verification by Test

9.1.1.1 CCD Performance

During testing of the dewar with the science grade CCDs significant problems with contamination were encountered. The characteristic “rainbow” effect of contaminants were visible on the surface of the CCDs, and a drop in the near UV QE of CCD1 and CCD2 was noted, accompanied by a redward shift in the peak response which was also consistent with a contaminant film on the surface of the CCDs. An additional effect causing a change in the appearance of the surface of CCD2, and to a lesser extent CCD1was also noted. This effect, which was described as “battleship gray” (BG) occurred some time after the dewar was pumped and cooled. It was thought that this might be due to contamination since it had not been observed during testing of individual devices in the UCO/Lick CCD Laboratory test dewar.

These problems resulted in the decision in December 2003 to remove the CCD mosaic from the dewar and perform tests on CCD2 to better understand the BG effect. This also provided the opportunity to thoroughly clean all of the dewar components based on a procedure supplied by WMKO.

A residual gas analyzer (RGA) was used to investigate the nature of the possible contaminants and also to evaluate the effect of various cleaning procedures. As a result of the cleaning efforts a very clean dewar was obtained as evidenced by RGA measurements shown in Table 2. This table shows RGA measurements made on the dewar after complete re-integration of the science grade detectors and supporting components.

Table 2: RGA Measurements after dewar cleaning and re-integration

Specie	Partial Pressure, microtorr	% Constituent
H_2	5	53.7
N_2	2	19.6
Ar	0.9	18
O_2	0.08	1.1
CO_2	0.07	0.6
CO	N.A.	6.1
H_2O	0.03	0.2
He	0.009	0.1
CH_3	N.A.	0.5
Total		**99.9**

It should be noted that during testing it was determined that the zeolite getter in the dewar was a source of significant outgassing (particularly of H_20 and O_2), even after baking the zeolite at 250 °C overnight. As a result the zeolite getter was deleted from the dewar.

The graph in Table 3 shows the QE and fringing amplitude for each CCD as measured by Mingzi Wei in the UCO/Lick CCD Laboratory and reported on the dates shown in the table.

It is believed that the QE values are mean values for the entire CCD after correction for non-uniformity of the illumination. It is believed that the fringing amplitude values are a percentage of maximum signal at the indicated wavelength.

No details on the measurement techniques, statistical uncertainty of the measurements or the traceability of the measurements was available.

After re-integration the dewar was cooled and operated continuously from June 6, 2004 through July 5, 2004. QE measurements were made every other working day during this period. Data are available as of this report for CCD2, at wavelengths between 320 nm and 500 nm. These data are shown in the fourth column of Table 3, and represent average of 12 measurements at each wavelength over the time period of June 9, 2004 through July 5, 2004. The error in these measurements is estimated at 2%. It should also be noted that the there are differences between the mechanical and optical arrangements of the CCD Laboratory measurements and those made on the fully integrated dewar, so direct comparison of the QE values obtained in the two measurements may not be possible.

Table 3: CCD Data

Device	***CCD1: 17-7-1***	***CCD2: 17-7-6***	***CCD2: 17-7-6***	***CCD3: 2-2-1***
Date of Report	***10/7/03***	***2/20/03***	***7/6/04***	***4/29/03***
Wavelength, nm	***QE, %***	***QE, %***	***QE, %***	***QE, %***
320	92.6	94.4	88	16.7
350	91.1	94.2	82	18.0
400	78.2	84.0	71	60.8
450	84.7	85.2	75	74.7
500	80.6	82.6	75	80.7
600	78.8	77.4	-	83.0
650	76.1	74.1	-	87.1
700	77.0	76.1	-	89.9
800	67.6	69.4	-	88.4
900	45.5	44.4	-	65.3
950	32.1	30.9	-	40.8
1000	13.8	12.7	-	13.6
1050	1.4	1.3	-	2.1
	Fringing, %	**Fringing, %**		**Fringing, %**
800	11.8	"small"		2.6
900	15.4	-		-
1000	48.0	22.0		2.2

Figure 4 is a graph of the QE of the three CCD devices and the recent measurements for CCD2. For comparison the QE of the original HIRES detector is also shown.

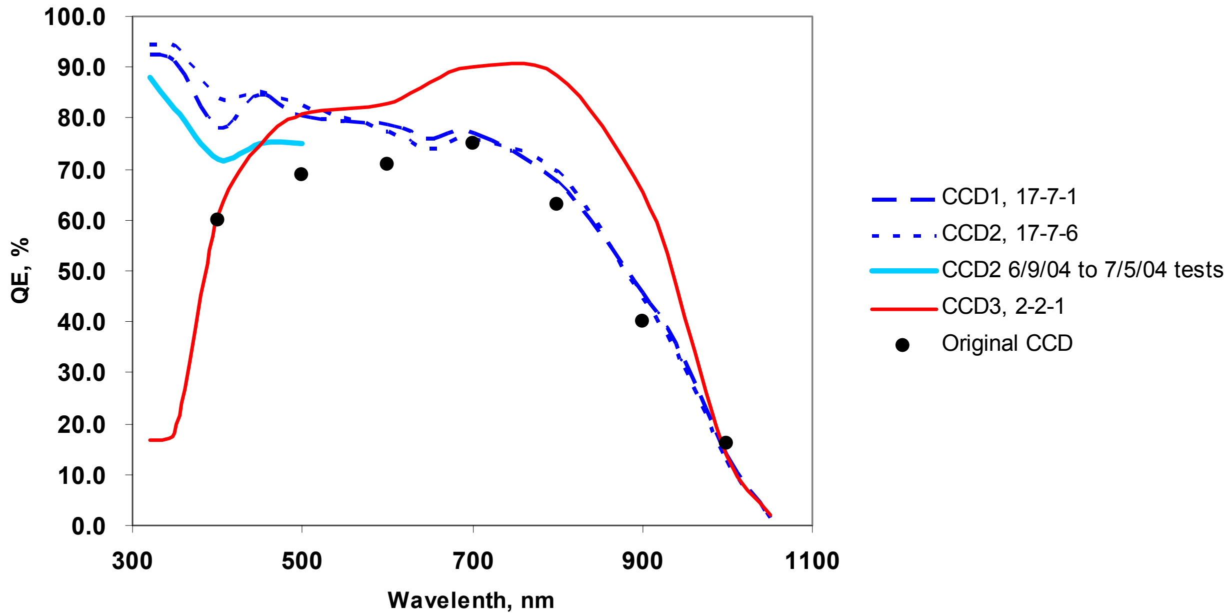


Figure 4: CCD QE

All three CCD devices are MIT/LL CCID20 devices. The devices designated 17-7-1 and 17-7-6 are devices optimized for responsivity at the blue end of the spectrum using a special backside treatment performed by Mike Lesser. Both of these devices exhibit some QE non-uniformity at the blue end of the spectrum in the form of small "pin holes" where the short wavelength QE is lower than the mean value (typically by several percent). This is thought to be due to the fact that the devices were reprocessed and problems with surface quality or cleanliness impaired the effectiveness of the backside treatment in small areas, resulting in the QE pin holes.

CCD3, the device designated 2-2-1 is a thinned device having a boron implant with laser annealing. The laser annealing produces a QE non-uniformity that is most noticeable at the blue end of the spectrum and visually resembles a "brick wall" pattern. Table 4 lists the non-uniformity values for this device due to the brick wall pattern.

Table 4: CCD3 (2-2-1) QE non-uniformity

Wavelength, nm	*QE, %*	*QE variation, %*
320	16.7	49.1
350	18	58.9
400	60.8	12.2
450	74.7	7

The brick wall pattern is described as being of very low amplitude ("almost none") at wavelengths longer than 450 nm.

9.1.1.2 Field Flattener Throughput

The graph in Figure 5 shows the expected transmission of the new field flattener based on measurements made by Lawrence Livermore National Laboratory of a witness sample coated at the same time as the field flattener. The transmission shown in Figure 5 was made after Sol-gel coating and prior to curing. A curve for transmission after curing is not available because the witness sample was lost.

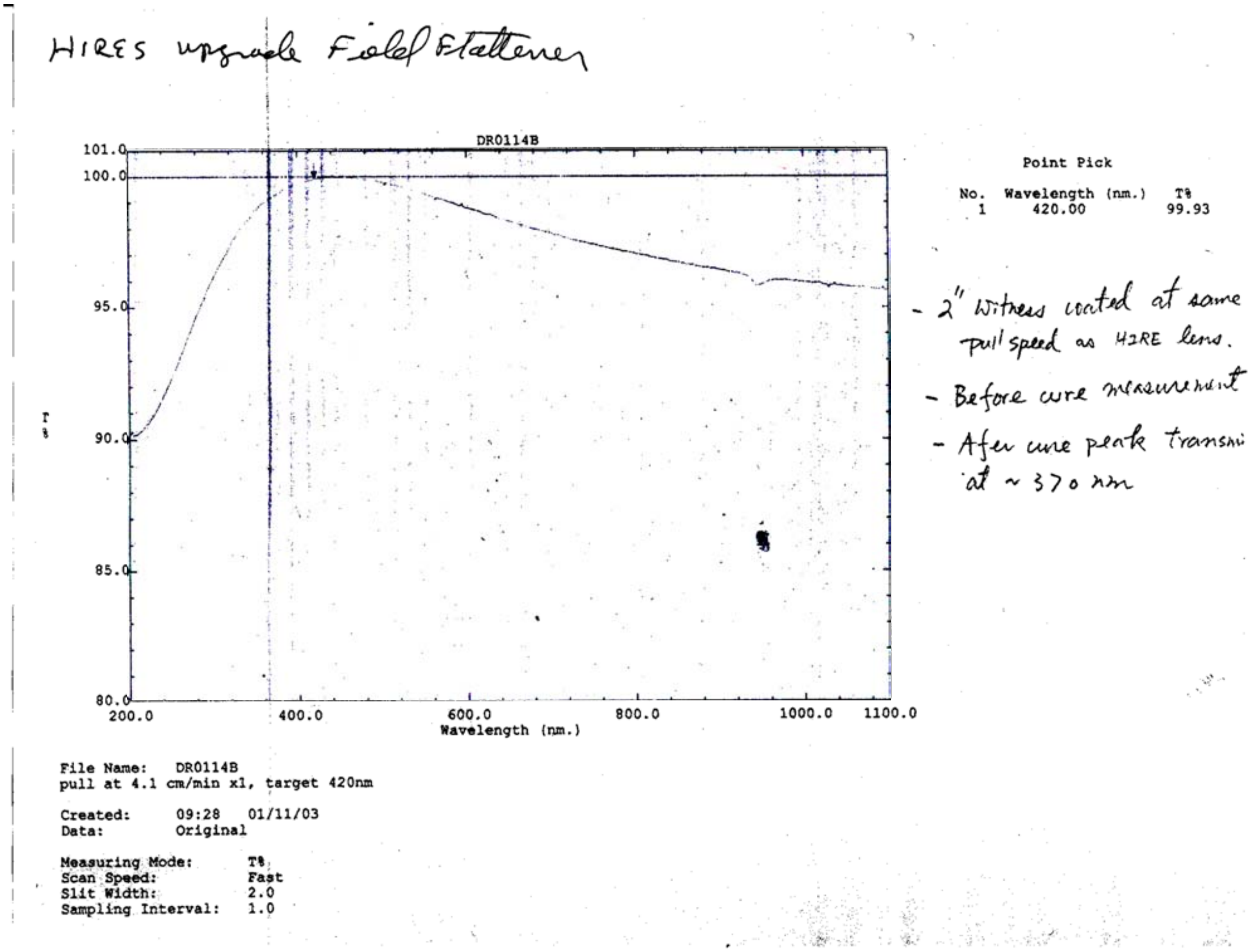


Figure 5: Field Flattener Transmission

9.1.2 Verification by Inspection and Analysis

The conformance of the HIRES CCD Upgrade to WMKO optical requirements was confirmed by inspection and analysis as described in the following sections.

9.1.2.1 Detector Format

The integrated dewar was inspected to confirm the presence of three CCDs arranged as shown in Figure 6. The arrangement of the CCDs is documented in UCO/Lick drawing H-9604, “CCD Mosaic Numbering & Orientation”, revision B, dated May 9, 2003.

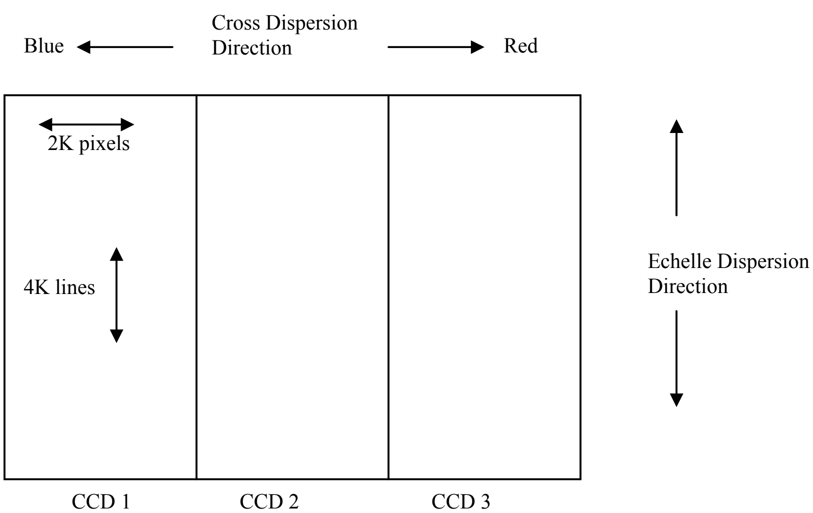


Figure 6: CCD Image Format

CCD1 is a blue response optimized CCID20 device, identification number 17-7-1. CCD2 is a blue response optimized CCID20 device, identification number 17-7-6. CCD3 is a red response optimized CCID20 device, identification number 2-2-1. The cross-reference between these identification numbers and the UCO/Lick part numbers is given in UCO/Lick drawing H-9440, “CCD Top Assembly”, revision B, dated September 23, 2003.

9.1.3 Verification by Demonstration

There were no requirements for verification of optical requirements by demonstration.

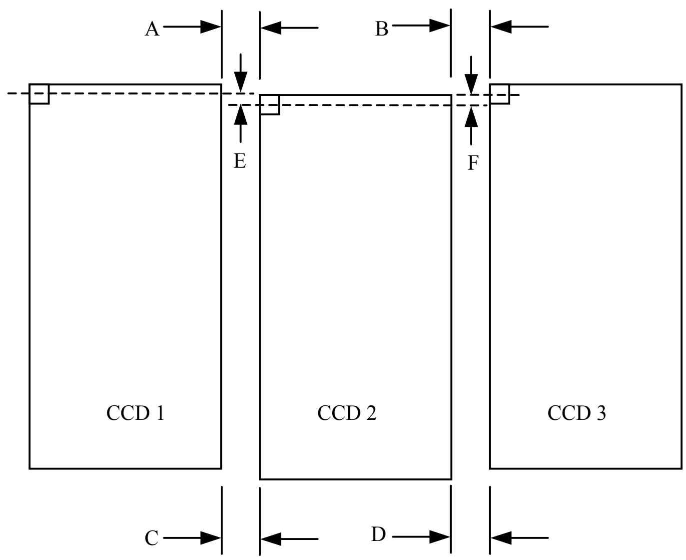
9.2 Mechanical

9.2.1 Verification by Test

The HIRES CCD Upgrade mechanical performance was confirmed by tests as described in the following sections.

9.2.1.1 Detector Mosaic

A measurement in tabular form for the mechanical configuration of the detectors in the mosaic as shown in Figure 7 was requested but this data has not been supplied.



Measurement	*Units*	*Notes*
Gap between devices: A, B, C, D	µm	1
Offset between rows: E, F	µm	2

Notes:

1. The measurement of the gap between devices corresponds to straightness in table 2.
2. The offset between device rows should be determined with respect to the same reference pixel on each device (pixel 1).

Figure 7: Detector Mosaic Mechanical Measurements

It is believed that the changes in the flatness of the mosaic as a result of the disassembly, cleaning and reassembly are minimal as the alignment of the individual devices in the mosaic was originally adjusted by precision machining of spacer blocks.

At the time the mosaic flatness was measured, (October 29, 2003) the peak-to-peak variation in flatness of the detector mosaic was 22 µm. The gaps between the devices were 100 µm, ± 30 µm.

This was the tightest spacing that could be achieved without risking a collision between the devices.

The measurements of the Mosaic flatness are detailed in UCO/Lick drawing H-9439, "CCD Mosaic Assembly", revision F, dated November 6, 2003. Analysis of the flatness with respect to focus was made by Steve Vogt and this analysis indicates that the focus sensitivity is low over the mosaic except at the edges. The deviations from flatness in the mosaic do affect focus at the edges. At the three edges where focus sensitivity is the greatest the flatness of the mosaic deviates in the direction that actually improves focus. The effect of the maximum variation in flatness was assessed using a Zemax model and the worst case focus errors due to variations in flatness are predicted to degrade the full width half maximum (FWHM) by no more that 15%.

Figure 8 shows the deviations from flatness as measured at 5 locations on each CCD. The measurement locations are shown in Figure 9.

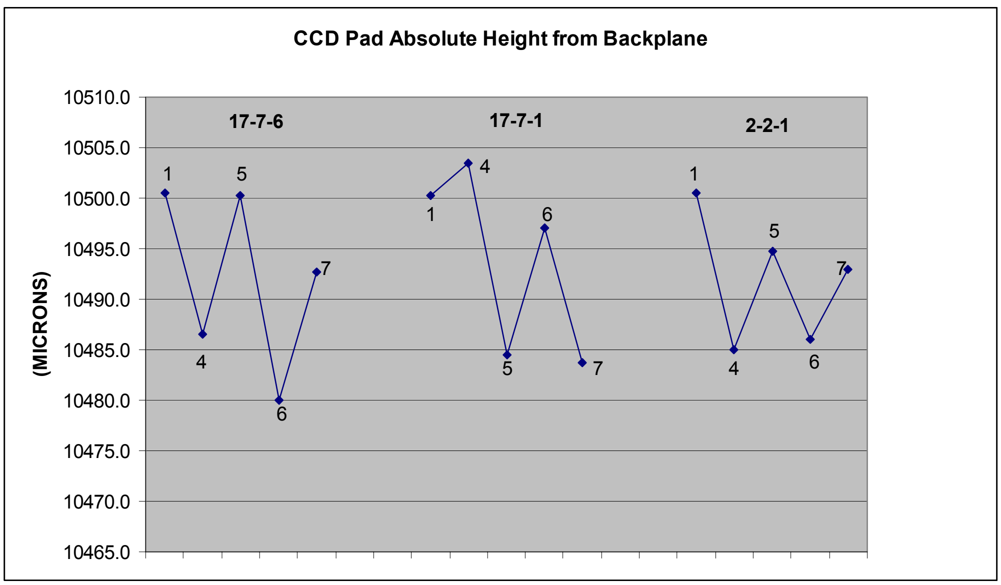


Figure 8: CCD Mosaic Flatness Deviations

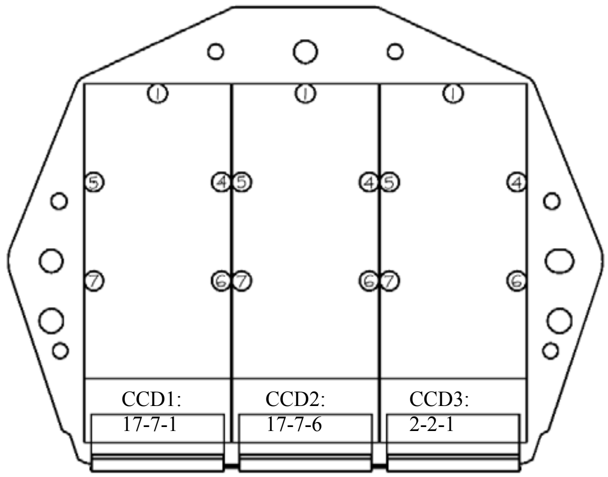


Figure 9: Measurement Locations for CCD Flatness

A statistical evaluation of the measurement uncertainty and a complete description of the conditions and method of measurement have been requested but have not yet been received.

For reference the requirements for the detector mosaic are given in Table 5.

Table 5: Detector Mosaic Mechanical Performance Parameters[2]

Parameter	*Min.*	*Typ.*	*Max.*	*Units*	*Notes*
Gap between devices	50	60	100	μm	1
Straightness	-	±20	-	μm	
Flatness	-	±10	-	μm	2

Notes:

1. The minimum gap has been chosen to ensure that the worst-case deviation from two parallel edges (straightness) does not cause the devices to collide.

2. The three chips must be co-planar to the extent that the PSF does not vary by more than 10% between chips.

It should be noted that after installation in the dewar the mosaic is tilted with respect to the field flattener mounting interface at the front of the dewar. Analysis by Steve Vogt indicates that this tilt will have a minimal impact on performance.

[2] See page 10 of related document *HIRES CCD Upgrade Requirements, Draft*, Revision 1.1

9.2.1.2 Temperature Test Configuration

The temperature test was performed in an environmental chamber. Figure 10 shows the HIRES Upgrade components in the environmental chamber. The dewar was mounted in the spare horse collar and placed in a normal operating orientation. The footlocker was also placed inside the chamber in proximity to the dewar. The ion pump controller was located outside of the chamber.

Figure 10: Upgrade components in environmental chamber

A multi-channel temperature logger using thermocouples was used to record temperatures at the measurement points listed in Table 6.

Table 6: Temperature Measurement Points

Designation (see Figure 11)	**Location**
Dewar	Exterior of dewar just behind front flange
Inside bottom	Inside the footlocker below the heat exchanger on the side opposite the side access panel (see Figure 11)
Chamber	On one of the mount hanger turnbuckles above the top of the footlocker
CCD1, CCD2, CCD3	The temperature sense diodes located at the CCD devices
Far panel	Center of outside surface of one footlocker side panel (see Figure 11)
Inside top	Inside the footlocker in a top corner above the electronics (see Figure 11)
HX	On the end of the heat exchanger in footlocker (below the electronics), at the end opposite the coolant connections
Coolant	Footlocker heat exchanger input coolant supply temperature
CCD Controller	At top of CCD electronics card cage inside footlocker

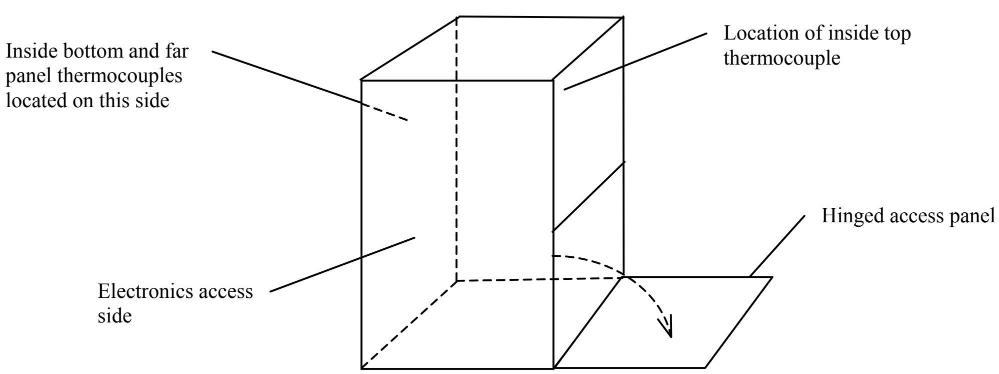


Figure 11: Footlocker Temperature Measurement Points

9.2.1.3 Detector Cooling

The results of cold test #2 are shown in Figure 12. This was the final cold test performed to confirm that the dewar thermal performance was acceptable.

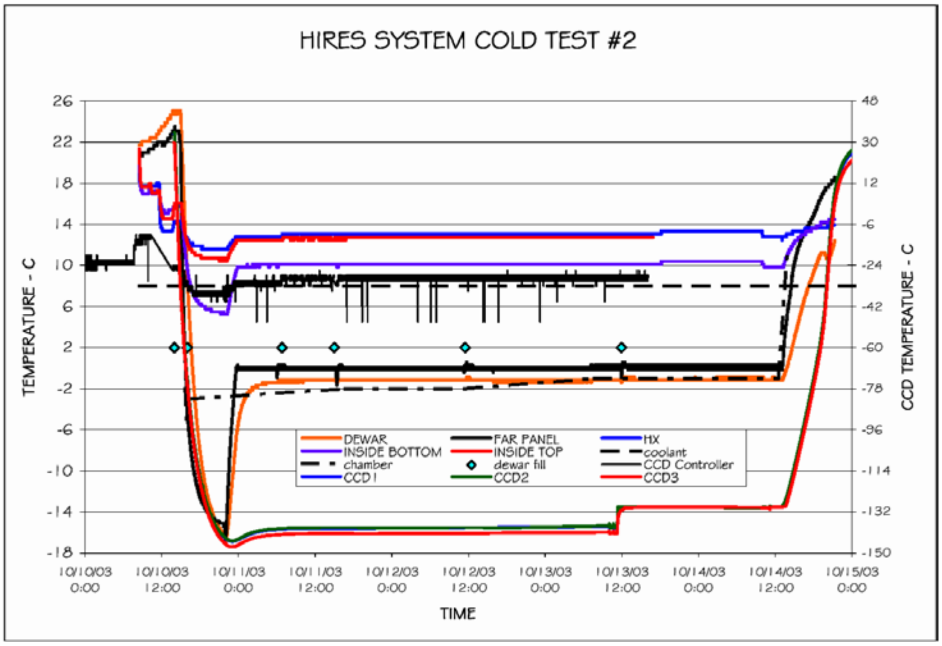


Figure 12: Results of Cold Test #2

The graph in Figure 12 shows the temperature measurements obtained over a 5 day period. A stable temperature was achieved approximately 6 hours after the second LN_2 fill of the dewar. During subsequent fills at approximately 24 hour intervals the temperature remained stable. The last fill was made at 12:00 on the fourth day of the test. The LN_2 was then allowed to completed evaporate in order to determine the cooling hold time.

During the test the ambient temperature in the chamber was between -2 and -1 ºC.

The first two and one-half days of the test were conducted with the CCD temperature stabilizing system disabled. This system was activated at approximately 12:00 on October 13, and the step in temperature measured by the CCD temperature sense diodes that occurs at this shows that the temperature control system is operational and subsequently maintained the temperature of the CCDs at approximately -130 ºC, which is the desired operating temperature.

9.2.1.4 Dewar Vacuum Integrity

During each cold test the ion pump current was monitored as an indication of vacuum integrity. The graph in Figure 13 corresponds to the temperature measurements shown in Figure 12 but without the CCD temperatures and with the addition of the ion pump current measured during the test.

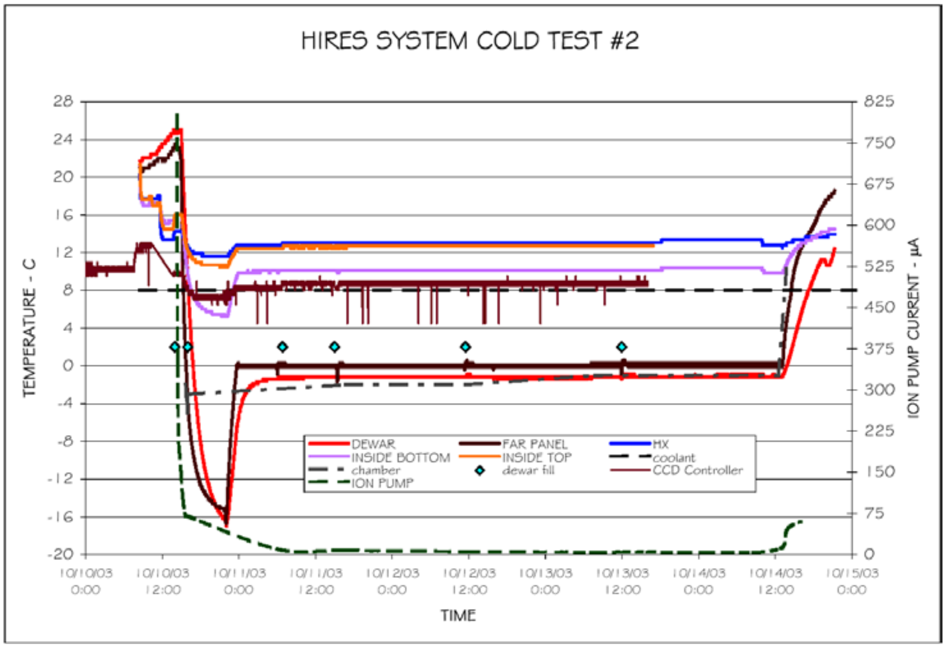


Figure 13: Cold Test #2 Ion Pump Current

The average value of the ion pump current from 12:00 on day 2 of the test through 12:00 on day 4 of the test was 10 µA and was essentially constant indicating that the vacuum integrity of the dewar is acceptable.

Data was not gathered during the testing after re-integration of the dewar but the observed ion pump currents were consistent with continued vacuum integrity.

9.2.2 Verification by Inspection and Analysis

The conformance of the HIRES CCD Upgrade to WMKO mechanical requirements was confirmed by inspection and analysis as described in the following sections.

9.2.2.1 Detector Format

This inspection has been performed in section 6.1.2.1.

9.2.2.2 Overall Dimensions

UCO/Lick built the original HIRES system and using drawings from the original design and also information obtained from measurements of the existing HIRES configuration, the new components were designed to be compatible with the existing HIRES enclosure and configuration.

The components were inspected to confirm that they matched the expected dimensions and that they will fit through the entry door to the existing HIRES enclosure on the right Nasmyth platform of Keck I.

9.2.2.3 Configuration

Based on the design approach described in section 9.2.2.2 it is expected that the new components will be compatible with the existing HIRES configuration. It does not appear that any of the new components will interfere with cross disperser swaps.

9.2.2.4 Service Access

The upgrade components listed in Table 7 were inspected to verify that adequate provision has been made for service access.

Table 7: Service Access Provisions

Component	**Adequate Service Access?**		**Comments**
	Yes	No	
Detector (dewar) Electronics	✔		Special tools and procedure required
CCD Controller Enclosure	✔		Power supply re & re difficult
VME Crate	✔		

Figure 14 shows the dewar electronics. The preamplifier cards are connected to the CCD devices via hermetic SMB bulkhead connectors. Power and control signals are routed through three hermetic multi-pin feedthrough connectors. As the figure shows the preamplifier boards are relatively easy to access. The boards which provide analog signal switching and interface the clock and video signals to the CCD controller extend straight back from the dewar bulkhead and plug directly into the multi-pin hermetic feedthrough connectors mounted on the bulkhead. They are designed to minimize the interconnection lengths. The multi-pin hermetic feedthrough connectors have a fairly high insertion force, and a special tool is provided, shown in Figure 15 to extract these boards. When the dewar is full assembled two shrouds enclose the electronics, one covers the preamp boards and a second one covers the rear portion of the analog switch boards and the power filter board.

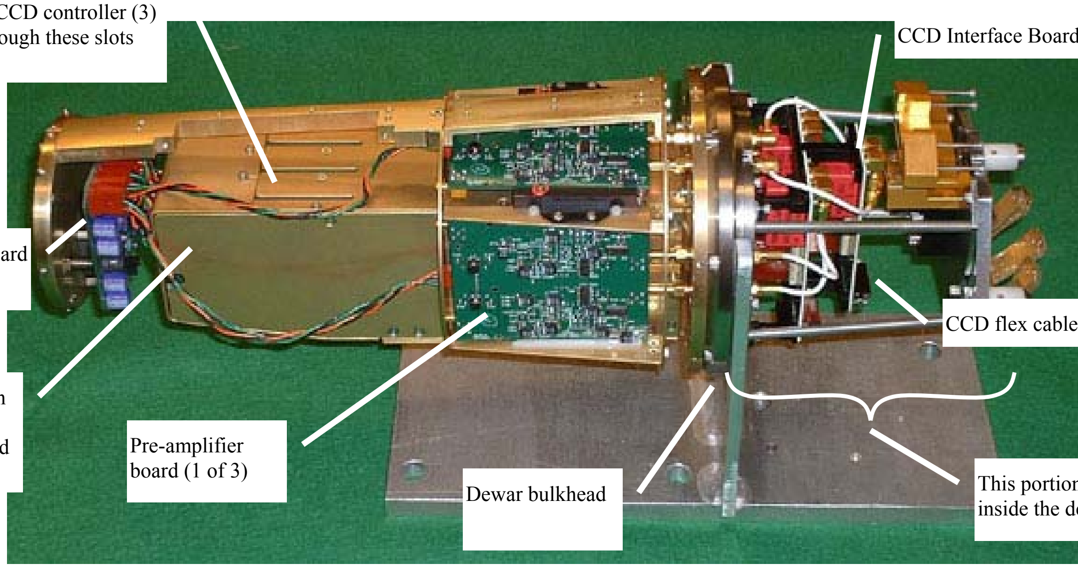


Figure 14: Dewar Electronics

Figure 15: Analog Switch Board Extractor

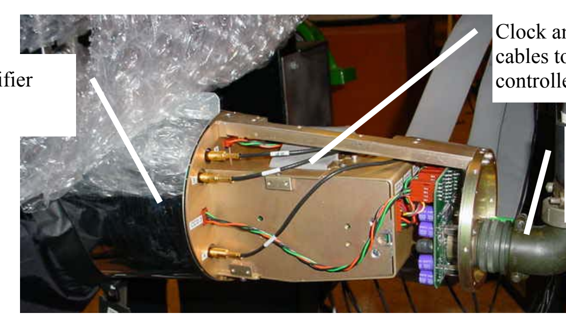


Figure 16: Dewar Electronics with Connections

Figure 16 shows the dewar electronics during testing, connected to the CCD controller and with the pre-amplifier shroud installed.

Figure 17 shows front and rear views of the CCD controller. The power supplies are located on the right hand side of the controller when looking at the controller from the rear. Figure 16 shows a detail of the power supply section to indicate the difficulties of accessing the power supplies for service.

Figure 17: CCD controller

front (left) and rear (right)

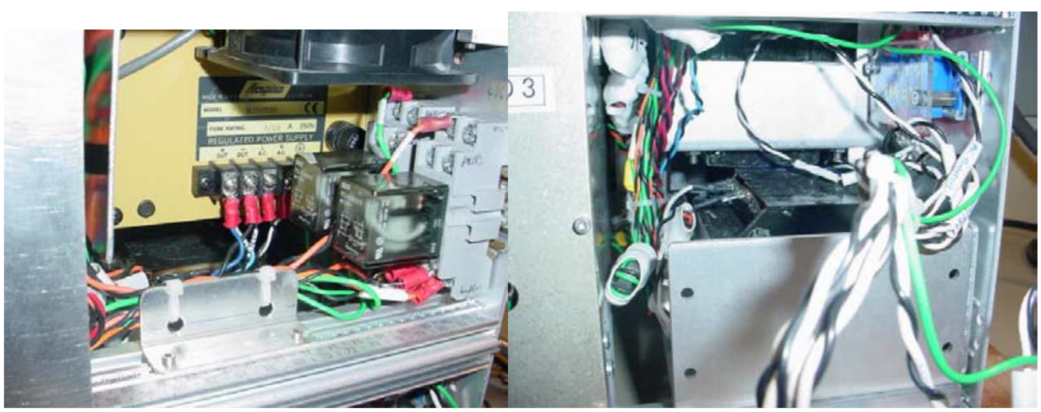


Figure 18: View of interior of controller

Behind the upper cover panel noted in Figure 15 (left) and behind the power inlet panel (right)

There are three power supplies in the CCD controller, and all three are mounted to a combination of internal brackets and the CCD controller side panel. Access holes are provided in the side panel to access screws required for power supply removal. A procedure that details how to dissemble the CCD controller to access and remove the power supplies has been supplied by UCO/Lick.

Extractors (see section 6.7.1.1.2) are supplied for the CCD controller cards. It should be noted that the current design of the SDSU-II timing board does not permit use of an extractor of any kind.

Figure 19 shows the miscellaneous control and interface module. This contains a series of 3U high plug in units that provide power for the optically isolated digital I/O from the CCD controller, and modules to sense the LN_2 level and control the auto-fill. The CCD temperature sensing and shutdown circuitry is also contained in this module. This module mounts below the CCD controller in the footlocker. All of the routinely serviced components in the module are plug in units accessed from the front.

Figure 19: Miscellaneous control and interface module

9.2.3 Verification by Demonstration

The conformance of the HIRES CCD Upgrade to WMKO mechanical requirements was confirmed by demonstration as described in the following sections.

9.2.3.1 Air Cooling Provisions

The footlocker containing the CCD controller and miscellaneous control and interface module is normally cooled by a heat exchanger supplied with a continuous flow of glycol from the telescope glycol facility. The footlocker is insulated and normally sealed to prevent air exchange with the HIRES enclosure environment. In the event of the loss of coolant flow it is necessary to provide a means to transition to air-cooling by opening the footlocker to allow air exchange with the HIRES enclosure.

Figure 20 shows the footlocker without electronics or front and rear cover panels. The lower right hand portion of the side panel is hinged and can be opened to provide air cooling. The panel is held in place with 11 thumbscrews with red plastic heads. A label on the side panel indicates that these screws should be removed to open the access panel in the event of a cooling loss.

Figure 20: Footlocker without electronics or front and rear cover panels

This procedure will take some time to perform, but it is thought to be acceptable because the power dissipation inside the footlocker is reasonably low as indicated by the temperature test results discussed in section 9.3.1.2.

9.3 Electronic/Electrical

9.3.1 Verification by Test

The HIRES CCD Upgrade electronic and electrical performance was confirmed by tests as described in the following sections.

9.3.1.1 Power Dissipation

The power consumption of the footlocker electronics was measured and is approximately 6 watts.

9.3.1.2 Temperature and Humidity Testing

Figure 12 in section 9.2.1.3 shows the results of cold test #2. Included in this graph are measurements that indicate the temperature rise due to power dissipation in the footlocker electronics.

The average temperature at the inside bottom of the footlocker during the test was approximately 12 ºC above the ambient, and the rise at the inside top of the footlocker during the test was approximately 15 ºC above ambient. During the test the ambient temperature in the chamber was between -2 and -1 ºC.

The capabilities for environmental testing at UCO/Lick are limited to temperatures above the dew point as the test chamber is not in a humidity-controlled environment. The test chamber itself also lacks the ability to control humidity. The relative humidity at the time of the tests is unknown.

For reference the anticipated operating conditions are shown in Table 8.

Table 8: Operating Environment

Parameter	*Min.*	*Typ.*	*Max.*	*Units*	*Notes*
Temperature	-5	0	+30	°C	Average annual temperature at 4,205 meters is 0 °C
Humidity	0	-	95	%	Relative, non-condensing
Altitude	0	4,146	4,200	M	Above sea level, the nominal Keck altitude is 4,146 M

9.3.1.3 Detector

9.3.1.3.1 CCD Performance

As previously described, the HIRES detector is a mosaic of three CCDs. These devices are all developmental types manufactured by MIT Lincoln Labs (MIT/LL). Full up system measurements of the dark current for each CCD after re-integration of the dewar have been made in the laboratory and are given in Table 9.

Table 9: Detector Performance Data

Parameter	*Value*	*Units*	*Notes*
Dark Current	3.1	e^-/pixel/hour	Device 17-7-1 at -130 ºC
Dark Current	5.0	e^-/pixel/hour	Device 17-7-6 at -130 ºC
Dark Current	2.9	e^-/pixel/hour	Device 2-2-1 at -130 ºC

Residual charge measurements were requested, but have been deferred until commissioning. Residual charge behavior during testing has been observed as follows:

1. At flux levels just above saturation to approximately 2 times saturation no significant residual charge is seen in a subsequent dark frame (taken after a device reset).
2. At higher flux levels the residual charge seen in a subsequent dark frame can be several counts, and seems to take several hours to decay.
3. The amount of residual charge may be effected by wavelength, with more persistent residual charge effects resulting from broad band (white light) exposures of several times the saturation level.

Further investigation and quantitative measurements of the residual charge behavior of the CCDs should be made during commissioning.

No details on the measurement techniques, statistical uncertainty of the measurements or the traceability of the dark current measurements is available.

9.3.1.3.2 Cosmetic Defects

A map in machine-readable form, and in graphical form, of the cosmetic defects for each CCD has been requested but not yet supplied.

For reference cosmetic defects are defined as follows:

Bad column: a bad column is one that contains at least 100 hot or dark pixels.

Hot Pixel: a pixel is considered hot when the spontaneous generation rate is greater than 100 e^-/pixel/hour.

Dark Pixel: a pixel is considered dark when the responsivity over the wavelength range of 0.3µm to 1.1µm is less than 80% of the local mean signal.

Trap: traps are pixels where any charge held temporarily is greater than 200 e^-.

9.3.1.4 Detector and CCD Controller

9.3.1.4.1 Detector Performance Data

Table 10 gives performance data for the CTE, full well capacity and gain for each device. These measurements were made by Mingzi Wei in the UCO/Lick CCD Laboratory.

Table 10: Detector Performance Data

Device / ***Parameter***	***17-7-1***	***17-7-6***	***2-2-1***	***Units***	***Notes***
Serial CTE	excellent	excellent	excellent	ratio	
Parallel CTE	excellent	excellent	excellent	ratio	
Full Well Capacity	122,000	>115,000	140,000	e^-	
Gain, left amplifier, also designated amplifier "A"	0.52	0.55	0.55	e^-/DN	
Gain, right amplifier, also designated amplifier "B"	0.58	0.51	0.61	e^-/DN	

The term "excellent" for CTE is believed to mean a CTE of 0.99999 or better.

No details on the measurement techniques, statistical uncertainty of the measurements or the traceability of the measurements was available.

After re-integration of the dewar the measurements shown in Table 11 were made using the full-up system in the laboratory. All measurements were made with the CCDs operating under closed loop temperature control at a set point of -130 °C with the fastest readout speed (5.5 usec/pixel) and a 200 nsec serial clock overlap.

Table 11: Detector Performance Data, after Re-integration

Device ***Parameter***	***17-7-1***	***17-7-6***	***2-2-1***	***Units***	***Notes***
Serial CTE	0.999998	0.999998	0.999990	ratio	
Parallel CTE	1.0	1.0	1.0	ratio	
Full Well Capacity	N.A.	N.A.	N.A.	e^-	
Gain, left amplifier, also designated amplifier "A", low gain mode	1.20	1.13	1.26	e^-/DN	
Gain, right amplifier, also designated amplifier "B", low gain mode	1.14	1.20	1.18	e^-/DN	
Gain, left amplifier, also designated amplifier "A", high gain mode	0.48	0.45	0.50	e^-/DN	
Gain, right amplifier, also designated amplifier "B", high gain mode	0.46	0.48	0.47	e^-/DN	

It should be noted that amplifier A on CCD2 (17-7-6) failed during re-integration and is not useable under any normal HIRES readout operating conditions.

In the "high gain" mode (keyword CCDGAIN set to "high") an additional gain of 2.5 is provided by the pre-amplifier circuitry on the CCD controller video boards.

After re-integration measurements of the full-up system in the laboratory showed the maximum signal levels before saturation to be 81,000 e^- in low gain mode and 32,500 e- in high gain mode.

9.3.1.4.2 Linearity

After re-integration of the dewar the measurements shown in Table 12 were made using the full-up system in the laboratory. All measurements were made with the CCDs operating under closed loop temperature control at a set point of -130 °C with the fastest readout speed (5.5 usec/pixel) and a 200 nsec serial clock overlap.

Table 12: Detector Non-linearity

Device / *Parameter*	*17-7-1*	*17-7-6*	*2-2-1*	*Units*	*Notes*
Non-linearity, left amplifier	-0.65, +0.61	-0.25, +0.32	-0.44, +0.40	%	1
Non-linearity, right amplifier	-0.25, +0.30	-0.20, +0.25	-0.23, +0.29	%	1

Notes:

1. Worst case deviation from a least squares fit to the photon transfer curve

9.3.1.4.3 Noise

After re-integration of the dewar the measurements shown in Table 13 were made using the full-up system in the laboratory. All measurements were made with the CCDs operating under closed loop temperature control at a set point of -130 °C with the fastest readout speed (5.5 usec/pixel) and a 200 nsec serial clock overlap.

Table 13: Detector Read Noise Performance

Device / *Parameter*	*17-7-1*	*17-7-6*	*2-2-1*	*Units*	*Notes*
Read Noise, left amplifier, low gain mode	2.2	N.A.	2.9	e^-	
Read Noise, right amplifier, low gain mode	2.3	2.3	2.7	e^-	
Read Noise, left amplifier, high gain mode	2.0	N.A.	2.6	e^-	
Read Noise, right amplifier, high gain mode	2.1	2.1	2.5	e^-	

No details on the measurement techniques, statistical uncertainty of the measurements or the traceability of the measurements was available.

9.3.1.4.4 Crosstalk

Crosstalk is described as "below the level that can be measured".

9.3.1.4.5 Spurious Charge Generation

Measurement requested but not supplied.

9.3.1.4.6 Temperature Control

Temperature measurements from cold test #2 are described in sections 9.2.1.3 and 9.3.1.2. Temperature stability and operating temperature values appear to be satisfactory based on the data obtained in cold test #2.

9.3.2 Verification by Inspection and Analysis

The conformance of the HIRES CCD Upgrade to WMKO electronic/electrical requirements was confirmed by inspection and analysis as described in the following sections.

9.3.2.1 Code Compliance

All components and cables were visually inspected to confirm compliance with all requirements of the National Electric Code and any local codes applicable to the final installation. The results of this inspection are summarized in Table 14.

Table 14: Electric Code Compliance Items

Item	In Compliance?		Comments
	Yes	No	
AC Line Connections – wire type and color, strain relief, connector types, methods of termination	✔		
Internal wiring – ratings and color codes	✔		
Labeling	✔		
Fuses and Breakers – type, ratings, location, labels	✔		
Protective grounding	✔		An additional ground strap between the footlocker internal frame and the AC power inlet panel on the footlocker was requested and has been added.
Enclosure of live parts	✔		

It should be noted that many of the crimp connections in the CCD controller and other electronic modules have been made with a simple crimp tool that does not provide a controlled cycle crimp. When this was noted it was requested that UCO/Lick purchase a controlled cycle crimp tool from the manufacturer of the crimp terminals they are using. This has been done, and crimp terminations made since that time (August 2003) have used this tool.

9.3.2.2 Compatibility

The dewar electronics enclosure, CCD controller enclosure, VME crate and all interconnecting cables were inspected for shield design and integrity. The grounding of power supplies and enclosure components was also inspected. With the exception of the CCD video and clock cables which have the shield terminated to a metal back shell connector, a pigtail and banana plug next to the associated multi-pin connector is used to connect each cable shield to ground.

Grounding integrity for the footlocker enclosure was verified, and as indicated in Table 14 an additional grounding strap was requested between the footlocker internal frame and the AC power inlet panel. Grounding integrity of the CCD controller cage and the miscellaneous control and interface module was also verified.

9.3.2.3 Service Access

See section 6.2.2.5.

9.3.2.4 Wiring and Interconnections

All wiring and interconnections were visually inspected to confirm that all observatory requirements have been complied with. The results of this inspection are summarized in Table 15.

Table 15: Wiring and Interconnection Inspection Items

Item	In Compliance?		Comments
	Yes	No	
Connector Types	✔		Connector types were selected by UCO/Lick and appear to be acceptable for the purpose.
Connector and cable mounting	✔		
Cable and wire routing	✔		
Internal wiring – ratings and color codes	✔		
Interconnections – wire types and shielding	✔		
Grounding of shields and enclosures		✔	As noted in section 9.3.2.2 pigtail connections are used for some cable shields.

No change to the pigtail connection of the cable shields has been requested.

9.3.3 Verification by Demonstration

The conformance of the HIRES CCD Upgrade to WMKO electronic and electrical performance requirements was confirmed by demonstration as described in the following sections.

9.3.3.1 Readout Time

Readout time is defined as the time from the completion of the exposure to the time when the image data is ready to transfer to disk. The readout times for the complete system are given in Table 16.

Table 16: Readout Times

Mode	Time, seconds	Notes
Dual amplifier, no binning	35	1
Dual amplifier, binned by 2 in the spatial direction	25	1
Dual amplifier, binned 2 x 2	15	1
Single amplifier, no binning	60	
Single amplifier, binned by 2 in the spatial direction	39	
Single amplifier, binned 2 x 2	25	

Notes:

1. Dual amplifier mode not usable if the CCD pixel values corresponding to amplifier A on CCD2 are required to be valid during readout.

9.3.3.2 Gain

Two user selectable amplifier gain settings per CCD controller video channel are available and working. The low gain setting corresponds to unity gain in the pre-amplifier circuitry on the CCD controller video boards and the high gain setting corresponds to a gain of 2.5 in the pre-amplifier circuitry on the CCD controller video boards.

The high gain setting results in an average system gain of 0.473 e^-/DN. The low gain setting results in an average system gain of 1.185 e^-/DN.

No rationale for the selection of these gain settings in terms of observing procedures for HIRES has been provided, but it is believed that the high gain setting will be of limited utility due to saturation.

9.3.3.3 Readout Clock Rates

Three user selectable clock rates common to all three CCDs are available and appear to be working. The clock rates are designated “fast”, “normal”, and “slow”. The exact speed of the normal and slow settings has not been provided. A rationale for the selection of these clock rates in terms of observing procedures for HIRES has also not been supplied. It has been observed by

UCO/Lick that the performance improvements obtained from the use of the normal or slow speeds are minimal.

9.3.3.4 Readout Configurations

Provisions have been made to allow the user to select between using one or two amplifier outputs from each CCD for the readout process. Note that in dual amplifier mode the pixel values for the pixels corresponding to amplifier A on CCD2 will not be valid.

9.3.3.5 Binning

The requested pixel binning modes have been provided. It should be noted that CCD devices used in the upgrade have serial register pixels and summing wells with capacities equal to the full well of a single device pixel. This must be taken into account when determining exposure levels for images where binning will be used.

Requested but not yet supplied for each binning mode supported is an analysis of the nature of the first and last binned row and column for each amplifier output on each CCD. An indication of whether pre-scan columns are included in any of the binned columns has also not yet been provided.

9.3.3.6 Windowing

The requested windowing features have been provided.

9.3.3.7 Readout Formats

The requested readout formats have been provided.

9.3.3.8 Exposure Control

The CCD controller hardware supports different exposure times for each CCD. Simple software support has been provided to permit use of this feature.

Exposures may be set in 1 second increments, 0 time exposures are allowed.

9.4 Safety

9.4.1 Verification by Test

There are no requirements for verification of safety by test.

9.4.2 Verification by Inspection and Analysis

The conformance of the HIRES CCD Upgrade to WMKO safety requirements has been confirmed by inspection and analysis as described in the following sections.

9.4.2.1 Mounting of Components

The mounting or mounting provisions of each CCD upgrade component (LN_2 reservoir, dewar, horse collar, CCD controller enclosure, VME crate) appear to be appropriate and safe. The mounting of the footlocker in the HIRES enclosure should be inspected during installation. The horse collar will be mounted using the same arrangement as presently used and it is assumed that this is safe and acceptable.

With the exception of the difficult access to the power supplies in the CCD controller as described in section 9.2.2.4 the mounting of all internal components and assemblies is consistent with good engineering practice and standards.

9.4.2.2 Electrical Safety

See section 6.3.2.1.

9.4.3 Verification by Demonstration

The conformance of the HIRES CCD Upgrade to WMKO safety requirements will be confirmed by demonstration as described in the following sections.

9.4.3.1 Cooling and Temperature

The CCD temperature monitoring system was tested during cold test #2 and functioned properly.

9.4.3.2 Covers and Interlocks

There are no cover interlocks in this system.

9.5 Software

9.5.1 Verification by Test

The HIRES CCD Upgrade software performance has been confirmed by tests as described in the following sections.

9.5.1.1 Reliability

Since the re-integration has been completed the system has operated for two periods of more than 189 hours without a reset. During each time period intermittent operation took place for user testing by WMKO and for QE measurements as described in § 9.1.1.1.

9.5.1.2 Error Recovery

9.5.1.2.1 Data Disk Full

The software is required to automatically select a new directory if the disk pointed to by the OUTDIR keyword is full. This has been tested and found to perform properly. Due to the fact that keyword values are established before the file write begins, the data directory location value in the header will be incorrect when a full disk causes selection of a new directory.

This test will be repeated during commissioning.

9.5.1.2.2 Loss of Communications

This test has been deferred to commissioning. For reference the tests required are described in the following paragraphs.

For each the items listed below, test the behavior of the system and document it. Whenever possible it is expected that the system will perform in a manner that permits recovery from this condition without loss of data. When that is not possible it is expected that the system will not “lock up” or otherwise crash without first providing a useful diagnostic message or warning to the operator.

1. Network/data connections:
    a. Host to CCD crate
    b. Host to public network
    c. CCD crate to CCD controller
2. Power cycling
    a. Host
    b. CCD crate
    c. CCD controller

3. Hardware resets
    a. Host
    b. CCD crate
    c. CCD controller

Please test all of the logical combinations of the above. Provide a full description of the system behavior and recovery action(s). Provide a full description of the test conditions and methods.

9.5.2 Verification by Inspection and Analysis

The tests requested in this section have not been completed. Descriptions of each of the requested tests are provided for reference.

9.5.2.1 Coding

A review of the source code shows that it is well documented and consistent with KSD 201 and KSD 210.

9.5.2.2 Keywords

The keywords supported by the HIRES upgrade software have been reviewed by WMKO and all of the keyword changes appear to be satisfactory. Further documentation of the keyword changes will be supplied by UCO/Lick.

9.5.2.3 Data File Formats

Data files produced by the HIRES upgrade software have been evaluated for compatibility with third party tools as follows:

1. Using IRAF + ds9 + mscred + mscdisplay:
    - images displayed correctly
    - it was necessary to adjust some of the software parameters of the third party tools
2. The IRAF task mscexamine worked for most of the things that were tried
    - In those cases where it didn't it is possible that the tester had assumed that certain keystroke operations he was familiar with from the task imexamine had been ported to mscexamine

9.5.2.4 FITS Header

A sample file from the HIRES upgrade software was provided to the Keck archive project, and Hien Tran of the archive project team has indicated that the FITS header is satisfactory from the archive project's point of view.

9.5.3 Verification by Demonstration

The HIRES CCD Upgrade software performance has been confirmed by demonstration as described in the following sections.

9.5.3.1 Image Display

The results of a review of the operation of the host software image display software are given in Table 17.

Table 17: Host Software Image Display

Item	Feature Provided? Yes	Feature Provided? No	Comments
Mouse operation to adjust image contrast	✔		
Menu option or button to invert the gray scale of the displayed image	✔		
Single mouse click re-centers the image	✔		
Regions can be selected for the following statistical operations: 1. Minimum pixel value 2. Maximum pixel value 3. Standard deviation of pixel values 4. 1st and 2nd moments for pixel values	 ✔ ✔ ✔ ✔		Via a “simple stats” menu in a window limited to a maximum of 150,000 pixels. An advanced stats menu is also provided where this limitation can be overridden.
A menu option or button in conjunction with a mouse selection will allow display of a one dimensional slice through the image, showing pixel value versus pixel number	✔		
A menu option will be provided to allow loading images from disk for display and manipulation	✔		
A menu option will be provided to allow printing an image to a hard copy device	✔		Feature provided but not tested by WMKO.

9.5.3.2 Graphical User Interface

The results of a review the operation of the host software GUI provided for control of the CCD detector and controller readout system is given in Table 18.

Table 18: Host Software GUI Features

Item	Feature Provided? Yes	Feature Provided? No	Comments
CCD controller gain selection	✔		A pop-up window containing a warning appears when starting an exposure with high gain selected.
CCD readout clock rate selection	✔		A pop-up window containing a warning appears when starting an exposure with the normal or slow readout modes selected.
CCD readout configuration	✔		
CCD pixel binning	✔		
CCD row and column windowing	✔		
Readout format selection	✔		
Exposure control setting	✔		

9.5.3.3 Echelle Simulator

The Echelle simulator has been modified to match the format of the new detector mosaic. Operation of the simulator has been confirmed by UCO/Lick. Adjustment and calibration will be performed during commissioning.

9.6 Interface

9.6.1 Verification by Test

The HIRES CCD Upgrade interface performance has been confirmed by tests as described in the following sections.

9.6.1.1 Cooling Hold Time

The temperature data of Figure 12 and Figure 13 may be interpreted to determine the cooling hold time as shown in Table 19. The times in Table 19 are the elapsed time from last LN_2 fill which took place at 12:00 on the fourth day of the test as shown in the graph of Figure 13.

Table 19: Cooling hold time

Item	Description	Time (hrs)
1	Start in rise of ion pump current	24.5
2	All heater voltages reach zero	25.5
3	First recorded CCD temperature fluctuation	23

Using 23 hours (item 3) for the time all the LN_2 is expended, the 90% cutoff is calculated to be 20.7 hours.

9.6.2 Verification by Inspection and Analysis

The conformance of the HIRES CCD Upgrade to WMKO interface requirements will be confirmed by inspection and analysis as described in the following sections.

9.6.2.1 LN_2 Fill

An overflow shield to prevent freezing of the associated o-ring has been provided for the LN_2 fill connection on the LN_2 reservoir and is shown in Figure 21.

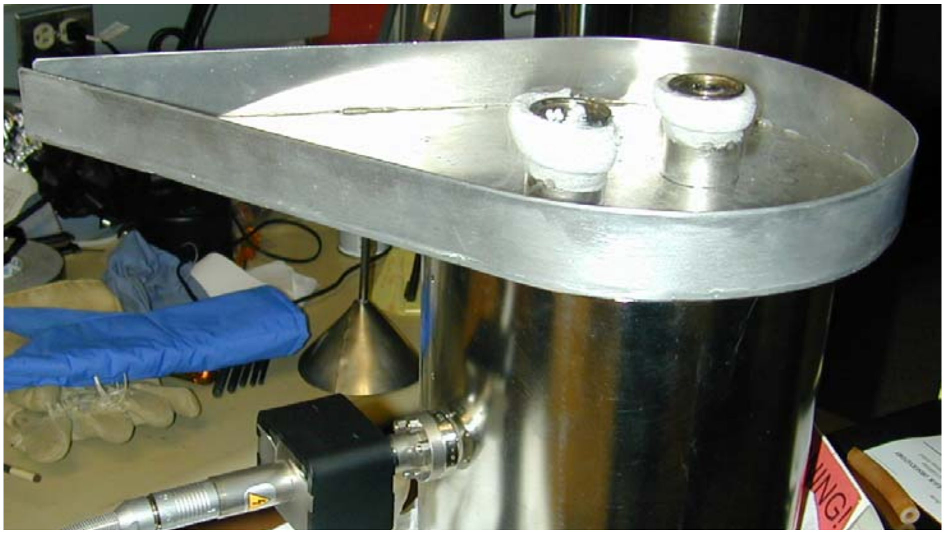


Figure 21: LN_2 Overflow shield

In the event of auto-fill Failure, manual fill must be possible without entering the Hires enclosure. This is the case with the existing setup and the components involved in the upgrade will be will be replaced with components identical in form, fit, and function.

9.6.2.2 Stray Light

Internal to the footlocker are a number of LED indicators. It is believed that this enclosure will be light tight when all covers are in place. This will need to be verified during installation. The fiber optic cable for the CCD controller will exit the footlocker via conduit and should not be a source of stray light.

There are no other sources of stray light associated with any of the upgrade components.

9.6.2.3 Vacuum Connections

The dewar vacuum connections are identical to the present dewar in HIRES. The ion pump supplied by WMKO has been used for all tests with the science grade CCDs including cold test #2.

9.6.2.4 Cooling Connections

The footlocker glycol cooling connections and plumbing has been inspected and has been implemented consistent with WMKO standards and appears satisfactory. A photograph of the cooling system is shown in Figure 22.

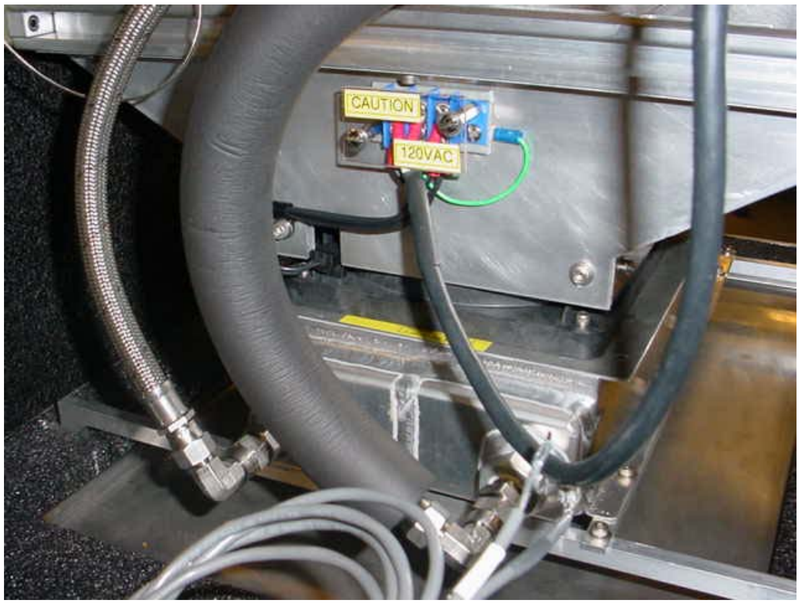


Figure 22: Footlocker cooling system

9.6.3 Verification by Demonstration

There are no requirements for verification of the interface by demonstration.

9.7 Deliverables

The availability of the deliverables listed in the following sections has been confirmed by inspection.

9.7.1 Upgrade Components

The availability of the HIRES CCD Upgrade components is summarized in Table 20.

Table 20: HIRES CCD Upgrade Deliverables

Item	Deliverable Provided?		Comments
	Yes	No	
Dewar complete with field flattener, 3 CCD detector mosaic, electronics and all hardware and interconnections	✔		
Dewar system mounted in horse collar	✔		
WMKO supplied ion pump integrated	✔		
CCD controller complete with all circuit boards, power supplies, interconnections and packaging	✔		
VME crate complete with all circuit boards, backplane, interconnections and packaging	✔		Testing not complete
CCD controller enclosure with glycol cooling provisions	✔		
LN_2 reservoir with auto-fill connections and overflow shield	✔		
Tools and accessories	✔		
Host Software	✔		
Target Software	✔		
CCD controller software	✔		
Documentation		✔	Incomplete

9.7.1.1 Accessories

The availability of the HIRES CCD Upgrade accessories listed in the following sections has been confirmed by inspection.

9.7.1.1.1 Dark Cover

A new dark cover will be supplied.

9.7.1.1.2 Special Tools

The special tools listed in Table 21 will be provided.

Table 21: HIRES CCD Upgrade Special Tools

Special Tool
Extended hex socket head wrench for device roll adjustment
Analog switch board extraction/insertion tool
Leach board extraction tool
61 pin plug wrench
Dewar electronics box tool set (3 pieces)

It should be noted that the current design of the SDSU-II timing board does not permit use of an extractor of any kind.

9.7.2 Spares

The spares listed in Table 22 will be provided. The availability and test status of each spare is indicated in the table.

Table 22: HIRES CCD Upgrade Spares

Spare Part	Supplied?	Tested?
1 spare of each power supply (3 pieces)	Yes	Yes
1 spare of each configuration of CCD interconnect cable (internal to dewar)	?	?
1 spare CCD pre-amp board	Yes	Yes
1 spare CCD interface analog switch board	Yes	No
1 spare CCD interface power filter board.	Yes	No
1 spare utility support board and daughter board	Yes	No
1 spare power monitor board	Yes	Yes
1 spare power and footlocker interface board	Yes	No
1 spare fan failure board	Yes	No
1 spare AC module	Yes	Yes
1 spare shutter controller	Yes	Yes
1 spare solid state relay module	Yes	Yes
1 spare power supply card	Yes	Yes
3 CCD shorting plugs	?	?
1 spare 61 pin cable interconnect board	Yes	No
1 spare 61/68 pin connector adapter assembly	Yes	Yes
1 spare 68 pin CCD cable assembly	Yes	Yes

Documentation has been supplied that indicates the test status of each spare, and the test status each spare as of the date of this report is reflected in Table 22. Tests of the remaining spares will be completed prior to shipment. The availability of spare dewar internal CCD interconnect cables has not been confirmed. The availability of the CCD shorting plugs has not been confirmed.

9.7.3 Documentation

All documents have been requested in electronic form on CD-ROM and printed in bound hardcopy form. The electronic form of documentation should be supplied in the editable file format of the software used to create the documentation and also in the Adobe® Portable Document Format (PDF) file format.

The documentation items are listed in Table 23 along with the status of each documentation item. UCO/Lick has indicated that the incomplete items should be delivered by the end of the commissioning period.

Table 23: Documentation Items

Documentation Item	Complete?	Notes
Complete set of all mechanical drawings	Yes	
Complete set of all electronic/electrical drawings	No	1
Parts lists and bills of materials for all assemblies and sub-assemblies	Partially	2
Operating manuals	No	
Maintenance manuals	No	
Software documentation (see KSD 3)	No	
Test data and reports	Yes	3

Notes:

1. Schematics and board layouts exist, descriptions are incomplete as is the web page that organizes the electronic/electrical documentation.
2. Bills of materials have not been supplied for the electronic/electrical assemblies.
3. Electronic forms of the test data and raw data have not yet been supplied.

10 GLOSSARY

Table 24 defines the acronyms and specialized abbreviations used in this document.

Table 24: Glossary of Terms

Term	**Definition**
ATP	Acceptance Test Plan
CCD	Charge Coupled Device
CTE	Charge Transfer Efficiency
FWHM	Full Width Half Maximum
HIRES	High Resolution Echelle Spectrograph
IRAF	Image Reduction and Analysis Facility
LN_2	Liquid Nitrogen
MTF	Modulation Transfer Function
N.A.	Not Available
n/a	not applicable
PSF	Point Spread Function
QE	Quantum Efficiency
RGA	Residual Gas Analyzer
TBD	To Be Determined
WMKO	W.M. Keck Observatory