3 WBS 1.3 Front End Electronics

3.1 Overview of the DECam Front End Electronics .............................................. 2
3.2 DECam Monsoon System ................................................................................. 6
  3.2.1 DECam Master Control Board (WBS 1.3.2.7) ........................................... 7
  3.2.2 12-Channel Acquisition Board (WBS 1.3.2.8) ....................................... 8
  3.2.3 Clock Board ............................................................................................ 10
  3.2.4 Crate Implementation and Mapping to the Focal Plane ......................... 12
  3.2.5 Power Supplies (WBS 1.3.2.9.6) .............................................................. 17
3.3 Dewar Electronics ........................................................................................... 17
  3.3.1 Aluminum Nitride Board (WBS 1.3.2.1) ................................................. 18
  3.3.2 JFET Source Follower (WBS 1.3.2.3) .................................................... 19
  3.3.3 Internal Cabling (WBS 1.3.2.3) .............................................................. 20
  3.3.4 Preamplifier Cards (WBS 1.3.2.3) ......................................................... 20
  3.3.5 Vacuum Interface Board (WBS 1.3.2.4) ............................................... 20
3.4 Grounding Scheme .......................................................................................... 22
  3.4.1 Telescope-to-Cage Assembly Grounding Connections .......................... 23
  3.4.2 Cage Assembly Grounding Connections .............................................. 23
  3.4.3 DECam Grounding Connections ............................................................ 24
  3.4.4 Cable Shielding and Noise Reduction .................................................... 25
3.5 Heater Electronics .......................................................................................... 26
References .............................................................................................................. 28
### 3.1 Overview of the DECam Front End Electronics

The Front End Electronics for the Dark Energy Camera must read out a large array of CCDs. As shown in Figure 2-1, the DECam focal plane will consist of 62 science CCDs, 4 guide CCDs and 8 alignment CCDs. The science CCDs are 2k×4k devices, while the guide and alignment CCDs are 2k×2k devices. The readout requirements are that the science and alignment CCDs will be read out together at a rate of 250 kpixels/s with <15e$^{-}$ rms noise. The guide CCDs will be read out separately.

Each LBNL CCD which is read out will be provided with its own set of clock and bias signals. No sharing of signal path occurs between individual CCDs. This means that we must provide 15 clock signals and 5 bias signals for each device. Each CCD also provides two video outputs. Figure 3-1 shows the CCD circuit pads and Table 3-1 lists all DECam supplied signals along with their function and nominal voltage levels. To read out the full focal plane, we must supply 1110 (74x15) clocks and 370 (74x5) bias voltages.

The Monsoon readout system, illustrated in Figure 3-2, is the choice of the collaboration for use with CCD characterization teststands and a slightly modified version of Monsoon will be installed on DECam. Monsoon is a crate-based image acquisition system developed by the National Optical Astronomy Observatory (NOAO). It is an open source system available for community use. Because we are using Monsoon now in our characterization of CCDs for the R&D phase of the DECam Project, we have the advantage of using the experience we gain towards the implementation of the production readout system. Monsoon offers the advantages of being crate-based, relatively compact and low power. There is also an experience base upon which we may draw, as well as a substantial amount of software development upon which to build.

The Monsoon system consists of three types of boards. The Master Control Board (MCB) is the system interface. It controls all backplane functions, such as reading and writing to registers, as well as the readout of the CCDs. It communicates with a host computer through a fiber optic interface cable. All data are also delivered through this optical interface.

A second type of Monsoon board being used in our CCD characterization testing is the 8-Channel CCD Acquisition Board (ACQ8). This board currently provides eight channels to digitize the CCD video outputs as well as supplying 32 bias voltages.

The third type of Monsoon board currently in use is the Clock and Bias Board (CBB). This board provides 32 clock outputs and 40 bias outputs. Each clock output has independently adjustable low and high rail values.

We have decided that DES is best served by some customization of the Monsoon boards. These customizations will increase the channel density to meet our space constraints and...
improve the flexibility and reliability of the final system. The customized boards which constitute the DECam Monsoon system are described in the following sections.

Figure 3-1  Block diagram of the LBL CCD showing signal pads.
Table 3-1  Signals provided to individual CCDs.

<table>
<thead>
<tr>
<th>Signal</th>
<th>Function</th>
<th>#Signals supplied to CCD</th>
<th>Nominal clock voltage – high (V)</th>
<th>Nominal clock voltage – low (V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clock Signals:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>V1, V2, V3</td>
<td>Vertical clocks</td>
<td>3</td>
<td>-2.5</td>
<td>5.5</td>
</tr>
<tr>
<td>TG</td>
<td>Transfer gate</td>
<td>1</td>
<td>-2.5</td>
<td>5.5</td>
</tr>
<tr>
<td>F1, F2, F3</td>
<td>Frame clocks</td>
<td>0(^a)</td>
<td>-2.5</td>
<td>5.5</td>
</tr>
<tr>
<td>H1, H2, H3</td>
<td>Horizontal clocks</td>
<td>6(^b)</td>
<td>-3.5</td>
<td>8.5</td>
</tr>
<tr>
<td>SW</td>
<td>Summing well</td>
<td>2(^b)</td>
<td>-4</td>
<td>5</td>
</tr>
<tr>
<td>RG</td>
<td>Reset gate</td>
<td>2(^b)</td>
<td>-6</td>
<td>0</td>
</tr>
<tr>
<td>Bias Voltages:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>OG</td>
<td>Output gate</td>
<td>1(^c)</td>
<td>3.5</td>
<td></td>
</tr>
<tr>
<td>Vr</td>
<td>Reset drain</td>
<td>2(^d)</td>
<td>-12.5</td>
<td></td>
</tr>
<tr>
<td>Vdd</td>
<td>Output drain</td>
<td>1(^c)</td>
<td>-22</td>
<td></td>
</tr>
<tr>
<td>Vsub</td>
<td>n+ substrate</td>
<td>1(^c)</td>
<td>40</td>
<td></td>
</tr>
<tr>
<td>n+</td>
<td>n+guard</td>
<td>1(^c)</td>
<td>floats</td>
<td></td>
</tr>
<tr>
<td>p+</td>
<td>p+guard</td>
<td>0(^f)</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

Total clock signals supplied per CCD: 15\(^e\)
Total bias signals supplied per CCD: 5\(^e\)

\(^a\) Frame transfer feature not used
\(^b\) Clocks are supplied separately to each half of the CCD
\(^c\) Same bias level applied to both halves of CCD
\(^d\) Bias level is independent for each CCD half
\(^e\) n+guard is treated as though it were a clock level
\(^f\) Referenced to bias voltage return
Figure 3-2  Block Diagram of the Monsoon system being used to characterize CCDs. All these boards are available from and supported by NOAO.
3.2 DECam Monsoon System

The DECam Monsoon Electronics closely follow the design of the original NOAO Monsoon boards with some important customizations specific to DECam requirements. The Master Control Board will be modified to use an open source optical communication link. The 8-Channel Acquisition Board will be redesigned to contain 12 channels and customized for our bias voltage needs. The Clock and Bias board will redesigned as a Clock Board capable of delivering 135 clocks rather than the 32 available in the original. These modifications are required in order for us to fit our electronics into the limited space available on the imager vessel. These changes will be described in more detail in subsequent sections.

Like the original Monsoon system, all DECam Monsoon main modules have the format of a 6U 160mm CompactPCI card. All transition, or rear modules, have a 6U 120mm format. Just as with the original Monsoon modules, a CompactPCI backplane is used; however most of the pin functions have been reassigned.

Figure 3-3 is a block diagram representing a 6-slot backplane which allows for the readout of up to 18 CCDs. This implementation makes use of a Master Control Board, two Clock Boards and three 12-Channel Acquisition Boards. DECam also makes use of a 4-slot backplane which contains a Master Control Board, one Clock Board and two 12-Channel Acquisition Boards which can read out up to nine CCDs.
Engineers at IFAE, Barcelona, Spain have already successfully modified the current NOAO MCB and the Monsoon readout software to use the S-Link protocol. The 6-slot backplanes will read out 18 CCDs, or 36 channels at a rate of 250KHz, or which allows for sustained data transfers of up to 160 MBS. The High Energy Physics community. DECam will use the HOLA/FILAR set of cards available from Curtiss-Wright, the SL100 or SL240.

3.2.1 DECam Master Control Board (WBS 1.3.2.7)

The DECam Master Control Board serves as the hardware interface between the Monsoon crate and the user. The original MCB made use of a commercial optical link available from Curtiss-Wright, the SL100 or SL240. The SL100/SL240 provide sustainable bidirectional data transfer rates of 105/247 MBS. Because of concerns over the future availability and support of these modules, a decision was made to switch the optical link to S-Link. S-Link is an open source optical link which is in wide use within the High Energy Physics community. DECam will use the HOLA/FILAR set of cards which allows for sustained data transfers of up to 160 MBS.

The 6-slot backplanes will read out 18 CCDs, or 36 channels at a rate of 250KHz, or every 4us. This leads to a data rate of:

\[
\text{36 channels/backplane } \times \text{18 bits/channel } \times \text{250,000 readouts/s } \Rightarrow \text{20.2 MBS.}
\]

Engineers at IFAE, Barcelona, Spain have already successfully modified the current NOAO MCB and the Monsoon readout software to use the S-Link protocol.

Figure 3-3 Block diagram of the DECam Monsoon system. All three board types have been re-designed and customized for DECam.
The other change being made to the MCB concerns the control of inter-crate synchronization. In order to reduce readout noise from a multi-crate system, we wish to synchronize the operation of multiple backplanes. The current MCB uses a set of daisy chain signals passed between MCBs to accomplish synchronization. This concept works well for a small number of crates which are located closely together, but will not work well for DECam. Cable delays and the number of backplane sections required to readout the science data make it necessary for us to modify the synchronization scheme and open up a wider synchronization window.

Therefore, the new DECam MCB will maintain all the functionality of the original MCB while allowing for the switch to S-Link as the optical communication link and the use of a wider synchronization window.

3.2.2 12-Channel Acquisition Board (WBS 1.3.2.8)

The original 8-Channel Acquisition Board has performed well in the lab during CCD characterization. However, space is very limited near the prime focus cage where the electronics are located and it was necessary to find a way to build a module with a denser channel count. We examined the 8-Channel Board and determined that we could make room for an additional 4 channels by combining a large FPGA (Field Programmable Gate Array) and two CPLDs (Complex Programmable Logic Device) into a denser and smaller FPGA.

In addition, we customized the bias voltage outputs to match our DECam requirements and included the ability to read out the value of a Resistance Temperature Detector (RTD) located near each CCD.

3.2.2.1 12-Channel Acquisition Module (WBS 1.3.2.8.1)

The primary function of the 12-Channel Acquisition Module (ACQ12) is to digitize the analog video signals from the CCDs and send these data over the Monsoon system bus to the Master Control Board. Secondary functions include generating and reading back CCD bias voltages, monitoring temperatures, and storing calibration data.

The CCD video signals are sent through a sensitive analog front end which performs correlated double sampling (CDS) of the waveform. The resulting voltages are digitized with a fast 18-bit analog to digital converter (ADC) and stored in memory on the acquisition board.

In addition to the analog front end circuits and ADCs, the ACQ12 board contains 60 independent DAC channels for setting bias and offset voltages and 48 telemetry channels for reading back the bias voltages and external temperature sensors.

A prototype version of the board has been developed and is in use. Pictures of both sides of the board can be seen in Figure 3-4.
3.2.2.2 12-Channel Acquisition Transition Module (WBS 1.3.2.8.2)

The 12-Channel Acquisition Transition Module (ACQ12T) plugs into the rear of the crate behind the ACQ12 main module. It has several functions. Analog power comes into this card, is filtered and then passed into the main module. All Input/Output signal connections required by the ACQ12 take place through connectors located on the ACQ12T – this includes connections for the input video signals, the input RTD signals, and the output bias voltages. Over-voltage protection is provided on all output bias voltages. In addition, the ACQ12T has optional differential to single-ended receivers for the video signals and contains the high voltage drivers which set the CCD substrate level. Photographs of the prototype board are shown in Figure 3-5.
3.2.3 Clock Board

The original Monsoon Clock and Bias Board (CBB) contained 32 clock and 44 bias voltage outputs. Because we wish to have independent clock drivers for each CCD, or a total of 15 clocks per CCD as shown in Table 3-1, this meant that one CBB could only provide clocks for two CCDs. Thus, we needed to design a module which would provide a higher density of clock signals. The CBB design was examined and we determined that if we eliminated the bias voltages from the design and combined the control logic into a single denser FPGA, we could free up enough space to produce a new Clock Board which contained enough clock drivers for 9 CCDs.

3.2.3.1 Clock Module (WBS 1.3.2.5)

The new DECam Clock Board (CB) has been designed to provide clocks for 9 CCDs and it includes 145 (9x15) clock outputs. In order to accomplish this, the CB design first
creates 3 groups of 15 clock signals, or 45 clocks. Each of these 45 clocks is fully programmable with independent control over the high and low voltage rails. We then take each of these 3 sets of 15 clocks and apply 3 output buffers to each signal for a total of 145 clock signals, or enough to drive clocks to 9 CCDs. In this manner, we lose the ability to control clock voltage levels on a CCD by CCD level, but maintain it at the level of a group of three CCDs. CCD characterization testing shows that it should not be difficult to group 3 or more CCDs together and have them operate optimally with the same level of clock settings.

Photographs showing the prototype Clock Board are contained in Figure 3-6. The Clock Board, designed by engineers at CIEMAT in Madrid, Spain, has been used successfully in the lab to collect CCD data.

3.2.3.2 Clock Transition Module (WBS 1.3.2.6)

The Clock Board Transition Module (CBT) plugs into the rear of the crate behind the Clock Board main module. The CBT is a simple module. Analog power for the Clock Board comes into this module, is filtered, and then passed to the Clock Board through unbussed backplane pins. The module also contains low pass filters and over-voltage protection for each of the 145 clock outputs as well as the clock signal output connector. Engineers at IFAE in Barcelona have produced a prototype of the board which is pictured in Figure 3-7.
3.2.4 Crate Implementation and Mapping to the Focal Plane

The Monsoon system used for the readout electronics normally utilizes a 6-slot backplane. One of the slots is occupied by the Master Control Board (MCB). The other slots are available for the Clock Board (CB) and the 12-Channel Acquisition Board (ACQ12). The ACQ12 can read out six CCDs, and the CB can drive clocks to nine CCDs. Using three ACQ12s and two CBBs in the 6-slot backplane, 18 CCDs can be read out. With three backplanes 54 CCDs could be implemented. Since that is insufficient, the decision was made to build the crates with two independent backplanes. But with the limited space near the prime focus cage, there is not enough space for two 6-slot backplanes. There is enough space, however, for a 6-slot and a 4-slot backplane. The 4-slot still needs an MCB, and can contain 1 CBB and 2 ACQ12s. This allows readout of up to nine CCDs, with one ACQ12 board not fully utilized. In two of the crates, the 4-slot backplanes are used for science, providing readout for a total of up to 72 CCDs,
leaving 2 spare CCD readouts. The third 4-slot backplane implements the 4 guide CCDs, leaving 5 spares.

3.2.4.1 Readout Crates (WBS 1.3.2.9)

The DECam crate shown in Figure 3-8 has dual 6-slot and 4-slot backplanes for a total of ten slots of main Monsoon modules on the right side, and ten slots for 120mm transition cards on the back side to the left. The transition cards get cabled to the Vacuum Interface Board (VIB) which connects them to the CCDs. At both ends of the crate there are air plenums to re-circulate the air through the Monsoon modules and transition cards. There is also an air plenum for the power supplies. There is a water-cooled heat exchanger at each end of the Monsoon modules, and two fans at each end of the transition cards. Two more fans at each end of the power supply plenum force some of the cooled air through the power supplies; the rest blows through the transition cards.

Separate DC power supplies will be used to power the fans, which must be powerful enough to overcome the pressure drops in the heat exchangers. The DC supplies will also power the crate supervisory system.

A crate supervisory system, described in Section 4.2.4.3, will communicate with the Instrument Control System (ICS) through opto-isolated signals, control and monitor power supply power-up sequencing and shutdown, monitor all the power supply voltages, monitor the crate temperature, vary fan speed to keep a constant temperature, and monitor all fans for proper operation.

![Diagram of DECam Crate](image)

Figure 3-8 DECam Crate before heat shields are installed.
3.2.4.2  Crate Cooling (WBS 1.3.2.9)

The thermal requirements\(^{10}\) for the DHE crates call for a constant (±2°C) operating temperature for the Monsoon electronics. In addition, the outside of the crate must be kept near ambient temperature, and should not radiate more than 20 watts. This is to ensure there is no thermal disturbance of the viewing.

The crate will be encased with an insulated heat shield (see Figure 3-9), with a thin aluminum outer layer which will be near ambient temperature. The amount of insulation is limited by the space available, and varies from 1” to 3” on different faces of the crate. The insulation used will be polyisocyanurate, which has a coefficient of thermal conductivity \(\lambda\) of about 0.02 W/mK. The total surface area of the crate, not counting the face next to the barrel, is about 0.66m². For an average insulation thickness of 2” (1/20 m) and for a maximum temperature difference of 30°C, the total heat radiated would be

\[
Q = \frac{\lambda A \Delta T}{L} \approx 8 \text{ W.}
\]

Since the crate ends must be limited to 1” of insulation, a better estimate is 10 W; this meets the requirement of < 20 W radiation.

The air flow is a closed system\(^{11}\) (see Figure 3-10), since the Monsoon cards will have front panels, followed by about 2” of insulation. In the front air plenum, the air flow is forced through a chilled water heat exchanger in front, is cooled, flows across the Monsoon cards and is heated, flows through the second heat exchanger into the back plenum and is cooled again. There the air flow splits into 2 paths. Two fans force some of the air up into the power supply plenum, and 2 other fans force some of the air across the Monsoon transition cards. At the front plenum, 2 more fans force the air from the transition cards into the plenum, and 2 more fans force the air from the power supply plenum into the front plenum. These 8 fans are necessary to overcome the pressure drop of the air flow through the 2 heat exchangers.

A refrigeration unit will be required to be on the main floor of the telescope building. To run the 3 DHE crates in parallel, it will require a capacity to dissipate 1500 W at a flow of 2 gallons per minute and output of 45 pounds per square inch at about 10°C.
Figure 3-9  DECam crate with heat shields.
3.2.4.3 Slow Controls (WBS 1.3.2.11)

Slow Controls monitoring of the DECam crates is accomplished through the Internal Crate Supervisor which will provide independent, immediate protection of systems in the DECam Monsoon crates. It will also send information back to the Instrument Control System (ICS). The ICS must be able to control crate sub-systems by turning off/on the system power supplies and adjusting fan speeds to keep air temperatures balanced within the crate. The ICS will also be able to interrogate the crate to identify the cause of failure.

The Internal Crate Supervisor consists of the Internal Crate Controller board (ICC) and the Fan Controller Board (FCB). The ICC and FCB will be run from power supplies independent from the Monsoon system power supplies. These independent supplies will also provide power for the cooling fans in the Monsoon crates.

The ICC is located behind the MCB in the transition card area. The ICC will communicate with the ICS via optically-isolated wires. The microprocessor-based board provides communication to the ICS, plus controls and monitors the fan controller board.
and crate system power supplies. The controller will monitor crate system voltages, temperature, and fan faults. It will respond immediately to a fault condition and take the appropriate actions to protect the crate hardware, i.e., shut down the power supplies if necessary. Then the ICC will send the signal to the ICS for further interrogation. The ICC will keep all Monsoon system power supplies off until it receives a signal from the ICS.

The FCB is located in the crate power supply area. The FCB will monitor system temperature and fan speeds and control the speed of all the fans, except the internal fans on the Vicor power supply. The FCB will generate fan rpm and over-temperature faults and send them to the ICC. The FCB will also pass a temperature signal to the ICC so the ICC can measure system temperature and pass it to the ICS, if needed.

3.2.5 Power Supplies (WBS 1.3.2.9.6)

The power requirement for a fully loaded 6-slot backplane is expected to be about 225Watts average or 270Watts peak. This has been calculated by measuring our prototype modules. In order to provide this power, a modular commercial switching power supply will be incorporated into the crate design as shown in Figure 3-8. One supply will be provided in each crate. This supply will provide power for both the 6-slot backplane and 4-slot backplane. Custom filters and shielding will be located at the output lugs of the commercial supplies to reduce radiated and conducted noise.

3.3 Dewar Electronics

The electronics inside the DECam dewar consists of each CCD mounted to an aluminum nitride board, a JFET source follower located near the CCD, a kapton cable, a pre-amplifier board and a Vacuum Interface Board. Prototypes of each of these pieces exist, as shown in Figure 3-11, and have been tested in our Multi-CCD Test Vessel (MCCDTV). Using these prototypes, we have successfully read out four adjacent CCDs at a rate of 3.7 µs per pixel and less than 10e- rms noise. Each piece will be described in further detail below.
3.3.1 Aluminum Nitride Board (WBS 1.3.2.1)

The aluminum nitride (AlN) CCD backing hybrid, shown in Figure 3-12, functions to provide a mechanical backing to each CCD sensor for mounting. It serves to route CCD signals from the sensor to a 37-pin nanominiature series connector and provides for the mounting of a temperature sensor.

The AlN Backing Hybrid will be approximately the same size as the CCD sensor, but slightly narrower so that the edge wirebond pads on the CCD sensors can be used to wirebond from the sensor to the AlN backing hybrid. The thickness of the hybrid will be ~1mm to provide mechanical stiffness and to maintain flatness. All metallization will be on the top surface and will be gold. Solder pads will be located near the center of the hybrid for a 37-pin nanominiature series connector and for a temperature sensor. A non-outgassing solder dam will protect the gold traces coming from the connector and temperature sensor.
3.3.2 JFET Source Follower (WBS 1.3.2.3)

A small circuit board is currently used to insert a JFET source follower after the CCD output amplifier. By using this source follower, the circuit of which is shown in Figure 3-13, we are able to reduce the output impedance of the video driver from a few thousand ohms to less than 200 ohms. This increases the drive capability, decreases signal response time and allows us to increase our data acquisition rate.

We anticipate that this small JFET board will be integrated into a stiffened portion of the kapton cable as the project proceeds.
3.3.3 Internal Cabling (WBS 1.3.2.3)

A kapton cable is used to carry the CCD signals between the CCD and the Vacuum Interface Board. We plan on building a four layer kapton cable. The outer layers of the cable will serve as ground/shield layers and the inner layers will carry all signals. The cable (shields and signals) will be divided into two parts, with roughly half of the cable used to carry clock signals and the other half used to carry bias voltages and the video signals. The cable is expected to be about 10 inches long.

3.3.4 Preamplifier Cards (WBS 1.3.2.3)

We plan on installing a pre-amplifier circuit at the far end of the kapton cable on a little circuit board that mates with the Vacuum Interface Board. This board allows us to apply some gain to the video signal and further reduce the output impedance of the driver.

3.3.5 Vacuum Interface Board (WBS 1.3.2.4)

Two vacuum interface board assemblies are used to route the clock, bias and video signals from the Monsoon readout electronics through the Dewar wall of the camera. Once the signals are inside the Dewar, they are routed over the kapton cables which plug into the VIB at one end and into connectors on the AlN boards to which the CCDs are wire-bonded.
Two VIB assemblies, referred to as VIB-A and VIB-B, are used to minimize the cable lengths to the Monsoon crates. The two VIBs are mechanically independent of the other and are free to expand or contract during the cool-down/warm-up of the Dewar. The two VIB assemblies penetrate the Dewar wall and are perpendicular to the wall. Each VIB is permanently attached to a vacuum flange; an O-ring on the flange creates a vacuum seal with respect to the wall of the Dewar.

Figure 3-14 shows the board outline and other features of both the VIB-A and VIB-B boards. The VIB is L-shaped, to bring the external cable connectors in line with the connectors on the Monsoon transition cards.

1. All horizontal positions are marked relative to the center of the Dewar (x=0.0)
2. The green areas indicate where the VIBs go through the vacuum wall flange.
3. All dimensions are in mm.

The VIB-Interface (VIBI) cards are part of the Kapton cable assembly. There is one VIBI for every CCD in the camera focal plane.

VIBI cards plug into the VIB and are mechanically secured with screws that mate with threaded posts resident on the VIB (see Figure 3-15).
3.4 Grounding Scheme

System Grounding will be divided up in three sections: 1) the grounding connections between the telescope structure and the cage assembly, 2) the grounding connections between the cage assembly and the DECam unit plus the grounding connections within the cage assembly, 3) the grounding connections between and within the various DECam components. In each section, all grounding connections and configurations are to be carefully controlled. The goals in each case are to 1) provide safety ground connections (since AC supply voltages will be greater than 50 volts and the currents supplied at these voltages are greater than 10 mA) to all metallic components, 2) to provide as "clean" as possible a zero voltage reference to these metallic components. The term "clean" here is used to mean that there should be no active or induced supply/return currents flowing through these metallic components.

The guiding concept used to achieve these goals is to connect all of these components in a series of "star ground" configurations so that each metal component is connected to the grounding reference at only one point through low impedance connecting hardware (wide tinned copper braids with lug terminals). In addition, this grounding scheme needs to place as much importance on the electrical isolation of various metallic components as well as on the electrical connections of metallic components and cables.

Another aspect of the grounding scheme is not "grounding" in the sense of the strict definition but is to very carefully control the designated signal and power supply current paths and their associated return current paths. This is done by controlling the connections to and from ground/return planes of circuit boards and crate backplanes, by controlling any and all cable shield connections, and by controlling the connections to/from electrical chassis components. All of these controlled connections are an effort to eliminate any ground loops between chassis and cable shields and to minimize any current loops that could cause the reception or transmission of induced noise voltages. A PowerPoint document was presented during the September '07 Front End Electronics DECam Workshop. This document was generated to provide a detailed plan and guidelines as to exactly how to deal with this multitude of grounding and shielding connections.

The ultimate determination of the success or failure of these grounding and shielding connection configurations will be the noise counts of the acquisition system. Various configurations will be tested as more components are added to the DECam system and cage assembly. With each successive addition or system change (both during testing prototypes and during the actual installation), the grounding and shielding configurations will be evaluated to minimize the noise count. Additional interim testing can be done using oscilloscopes and current meters (to determine the relative currents in each component under test). Also, electric or magnetic field probes can be used to determine if there are any strong fields that could cause noise coupling. However, the actual noise
measurements must be done using the acquisition system since the noise levels (<15 e⁻ counts rms) are too small to be observed directly.

### 3.4.1 Telescope-to-Cage Assembly Grounding Connections

By design, the entire cage assembly is to be electrically isolated from the rest of the telescope and building's grounding configuration. The cage assembly is the metal structure that supports the DECam, barrel assembly, the AC distribution, and any other auxiliary components needed for operation. This isolation most likely will be done at the juncture between the supporting beams or "fins" and the cage's metal struts or between the telescope's ring assembly (the large ring that provides mechanical support between the telescope's structure and the cage assembly) and the fin's attachment points. The actual point will be determined by mechanical support needs and will be accomplished using G-10 fiberglass (or similar material with the necessary mechanical strength) insulating washers or plates.

The grounding connection between the building and the cage assembly is through a single grounding cable. This cable should be as large as possible and stranded (not solid copper) to provide the minimum impedance as possible to the building's grounding connection. The grounding cable also is to be the only connection between the building and/or telescope's grounded metal and the cage assembly's metal. This is to ensure that no AC return current will flow through the cage assembly's metal and down to the building/telescope's ground structure. This grounding cable should run from the building's AC power center and grounding structure up to the AC distribution point within the cage assembly. This point will serve as the primary star ground for the DECam and cage assembly. During normal operation, all AC return current shall flow within the main AC power cable conductors and not through this grounding cable. In the event of a fault condition (a short between the AC supply's "hot" conductor and the cage's metal), this cable will carry the fault current to the main breaker panel. This fault current is NOT to be allowed to travel through the building or telescope's metal structure.

Any conduit or power cable shield is to be connected at one end only (preferably at the building's AC panel) and isolated from the cage's metal at the AC distribution chassis using an isolating coupling at that end. This same isolation requirement goes for any other metal tube or cable that goes from the building's telescope service center up to the cage assembly. The reason for the electrical isolation points being as close to the cage assembly as possible is to prevent a long "antenna-like" conductor from being connected to the cage's metal or various components within that assembly and thus serve as a path for induced (through magnetic fields) or coupled (through electric fields) noise voltages and currents, respectively.

### 3.4.2 Cage Assembly Grounding Connections

As stated previously, the point at where the main grounding cable attaches to the cage assembly's metal (at the AC power distribution point) is to serve as the cage's primary
star ground point. Attached to this point should be the ground cable for the DECam, the ground cable for the barrel assembly components (the hexapod and the shutter/filter changer), and the ground cable for the imager vessel's cryogenic gate valve and ion pump. All of these grounding cables need to be as short as possible and as large as possible to provide a solid, low-impedance path for any low frequency (LF) and high frequency (HF) noise currents. A large-gauged flat tinned-copper braid and terminated using large lugs is ideal. Since the grounding connections are made using these short grounding cables ONLY, it is important that these cage components be electrically isolated from each other. Any metal to metal contact between the components' metal components will defeat the controlled grounding connections and therefore provide possible conducted noise current paths as well as forming possible ground loops within the cage assembly. The isolation points will be: 1) between the DECam (the imaging vessel and its associated electronic hardware) and the barrel assembly, 2) between the gate valve and the imaging vessel, 3) between the ion pump and the imaging vessel. The point of isolation for the DECam will be between the C5 lens cell and the barrel's C5 mounting plate.

The barrel assembly (after the C5 cell), will probably not be electrically isolated from the cage's mounting hub due to the mechanical strength needs at this point. Thus, the barrel with the shutter/filter changer, and the hexapod (a large, dual-ring structure connected by six adjusting struts) will be treated as one unit electrically and will have metal-to-metal contact with the cage's horizontal metal spars. However, this metal-to-metal contact should not be relied upon for the grounding connection (due to paint, bolt contact, corrosion, HF impedance of solid steel, etc.). Thus, a grounding cable will connect the hexapod and barrel assembly to the cage's primary star ground point. This grounding cable/braid will run as close to the cage metal as possible.

### 3.4.3 DECam Grounding Connections

The DECam unit consists of the imaging vessel or dewar, the three front end electronics crates, and the other slow controls and/or heater control crate. All of these listed components will be electrically isolated from each other. The only electrical connections between these components' metal chassis will be through the grounding cables. Thus, the DECam will have its own star ground point. Here, the control of these connections, including any cable shield connections, is of the highest priority. Any conductive noise path to inside the dewar or to the electronics' analog video inputs within the front-end crates will directly and adversely affect the noise seen on these analog inputs and thus diminish the ability to achieve the readout noise below the maximum of $<15 \text{ e}^{-\text{rms}}$.

It is important to note that the DECam components' safety ground is also implemented by the use of these grounding cables or straps. Thus, the AC power to the front-end and slow-controls crates' power supplies will be through the use of two-conductor cables and not through the use of the standard three-prong power cords. If a standard 110 VAC three-prong power cord is used, the safety wire (third prong) in that power cord will provide a second grounding path between two different metal components and thus open
up the possibility of unwanted noise being conducted to the crates DC power return path. Therefore, any operation of AC powered equipment on the DECam installation should be allowed ONLY after the ground cables/straps are properly installed.

Within the imaging vessel, the CCDs are mounted on an aluminum disk that serves as the focal plate for support of the CCD array's focal plane. Each CCD is electrically isolated from each other (at this plate) as well as electrically isolated from the plate itself in order to protect the CCDs from any ESD that may occur and thus damage the CCD or CCDs. This aluminum plate is isolated from the imaging vessel's stainless steel walls through the use of isolating pylon mounts. Originally, the focal plate was meant to be floating with respect to the imaging vessel's wall. However, a means of providing a controlled grounding connection between the plate and the vessel's wall will be provided in order to keep the focal plate metal at a solid zero-reference or ground potential. If left floating, any AC voltage potential from a cable or wire near or on the focal plate can use the focal plate to conduct a displacement noise current to the CCD or CCDs substrate voltage. Here, it is thought best to provide the option of grounding the focal plate or leaving it floating.

Also inside the imaging vessel, there are heaters and their associated wiring that can conduct noise to the inside of the vessel and therefore find a possible path to the CCD output signals. In this case, the imaging vessel is viewed as an electrical enclosure and the methods used to bring slow signals or voltage wiring into an electrical enclosure are implemented. These methods include the proper cable shield connections and signal filtering.

Inside the vessel, there is also a liquid nitrogen cooling tube that forms almost a complete loop and then exits the vessel. Earlier, it was stated that any conduit or metal tube or conductor that originates down in the telescope's service area must be electrically isolated from the cage assembly or its components. This point of isolation should be as close to the cage assembly or its component as possible. Since the liquid nitrogen is pumped up from this service area, the metal cryogenic tube must be electrically isolated from the imaging vessel as close as possible to the imaging vessel's cryogenic coupler or fitting. Any noise currents originating from outside of the vessel and then conducted to the inside of the vessel, on the outside surface of this loop, will radiate noise to the components within the vessel. Therefore, any conductor exiting the electrical enclosure of the vessel needs to be kept as short as possible.

### 3.4.4 Cable Shielding and Noise Reduction

Another part of the grounding and shielding plan's scope is to determine and control as much as possible signal currents and their respective current return paths. Through the use of proper cable shield connections and ground plane connections, most capacitive-coupled and conducted noise currents should be able to be routed away from any critical signal path. The idea is to "force" the noise currents to use the ground or zero-reference conductors as the noise current return path. Here, the use of sufficient capacitive bypassing and filtering is particularly important. This applies to noise from other signals within the CCD electronics (crosstalk) as well as noise currents from external sources.
To minimize the effects of magnetic coupling for noise, the control of power and signal return paths are implemented where possible. The most effective method to minimize magnetic noise transmission is to minimize current loop areas. Any loop that transmits a magnetic field is also susceptible to picking up magnetic fields. Therefore, multiple current return paths for a particular signal or power supply have the possibility of forming a loop that will thus develop a noise voltage within that loop (signal or ground noise). To minimize loop areas and utilize magnetic self-shielding, shielded twisted-pair cables should be used for both signal and power supply currents wherever possible.

3.5 Heater Electronics

To maintain a stable temperature inside the dewar, a number of heating elements have been incorporated into the focal plate design. Each of these Heaters has a resistance of 25 ohms, a maximum operating voltage of 20VDC and a maximum current of 0.8 amps.

The temperature will be monitored by a set of National Instruments Controllers (NI cFP-A0-210) which read out RTDs mounted on the focal plane. These modules will provide a voltage input to a set of custom electronics which will deliver a varying current to the heating elements. A schematic of this closed-loop system is shown below in Figure 3-16.
Figure 3-16 Block Diagram of the Heater Control System.
References

1 Monsoon Image Acquisition System:
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3 “Monsoon 8 Channel CCD Acquisition Board”, P. Moore, NOAO Document MNSN-AD-08-004 (September 2005)

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