LS4 Telescope and Camera Hardware Manual
DRAFT 2025 Jul 14

This document is intended for both observers and technical operators, but a separate LS4 observing manual will be created to describe observing procedures.

1. System Overview

The LS4 camera is a mosaic of 32 2Kx4K fully depleted CCDs with high sensitivity at red optical wavelengths. These are the same CCDs used by the Dark Energy Camera for the Dark Energy Survey. At the prime focus of the ESO 1.0-m Schmidt Telescope, the LS4 camera covers an area of ~20 sq. degs. It replaces the 100 Megapixel QUEST camera previously installed by Yale University and is dedicated to the detection and follow up of supernova and other transients. As with the previous La Silla-QUEST survey, the ESO Schmidt telescope is operated by a scripted program that automatically schedules repeated observations of selected fields. Once the dome is opened, the observations are autonomous. However, all observations can also be performed under observer control.

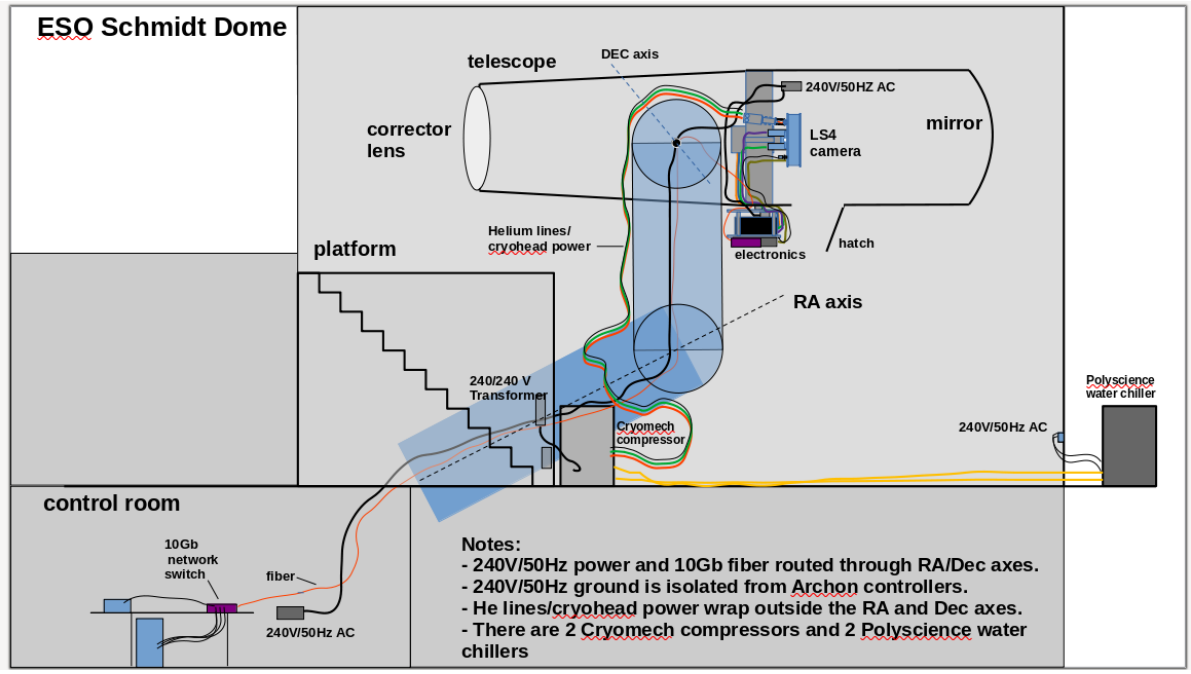

Figure 1. Overview of system components

There are several systems that allow the camera to function (see Figs. 1, 2, and 3). The camera sits on a focus hub near the center of the telescope. The readout electronics sit on a rack bolted to the outside of the telescope. Compressed air and Helium lines run from the floor of the dome up the camera, wrapping around the RA and Dec axes of the telescope. Helium and air compressors sit on the dome floor near the telescope and in a nearby utility room. Water chillers needed to cool the compressors sit outside the dome on the catwalk. Computers to control the camera and telescope sit in the control room one floor below the telescope. A high-speed internet fiber (10 Gbps) and an AC power cable (240V/50 Hz) run from the control room, through the interior of the RA and Dec axes, into the telescope, and then out to the electronics rack.

The camera is cooled by two Gifford-McMahon cryoheads that use compressed Helium expanding against a piston to remove heat from the expanding volume. A pair of high and low pressure He lines (supply and return) connect to each cryohead. Each cryohead is connected by a copper strap to a copper rod that penetrates the back of the camera dewar. The cyroheads are bolted to the vanes that support the focus hub. When the camera position is moved through focus, the copper strap and surrounding vacuum bellows flex to accommodate its relative motion.

In addition to the Helium lines there is a compressed air line to operate the pneumatic shutter and a clean, dry air line to prevent humid ambient air from condensing on the dewar window. An oil-lubricated air compressor supplies the pneumatic air. An oil-free compressor supplies the clean air. Both supplies are filtered through air-drying filters. The pneumatic air supply can be disconnected from the shutter valve and reconnected to the pneumatic dewar valve when need to open the dewar vacuum.

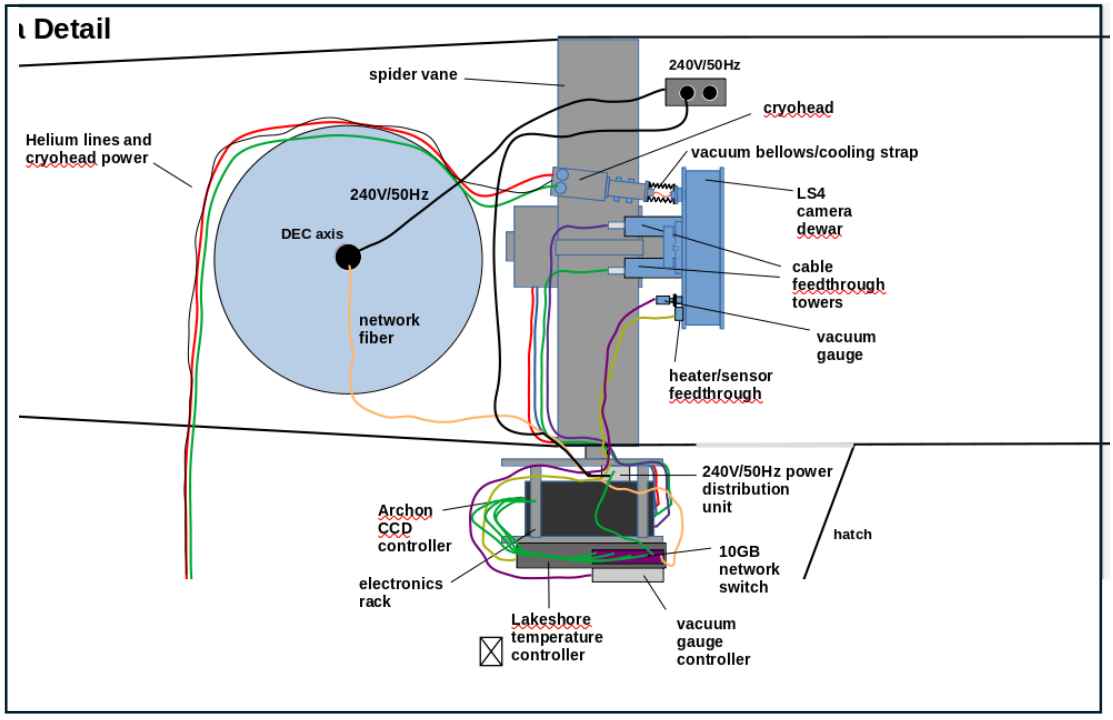

Figure 2. Detail of camera systems

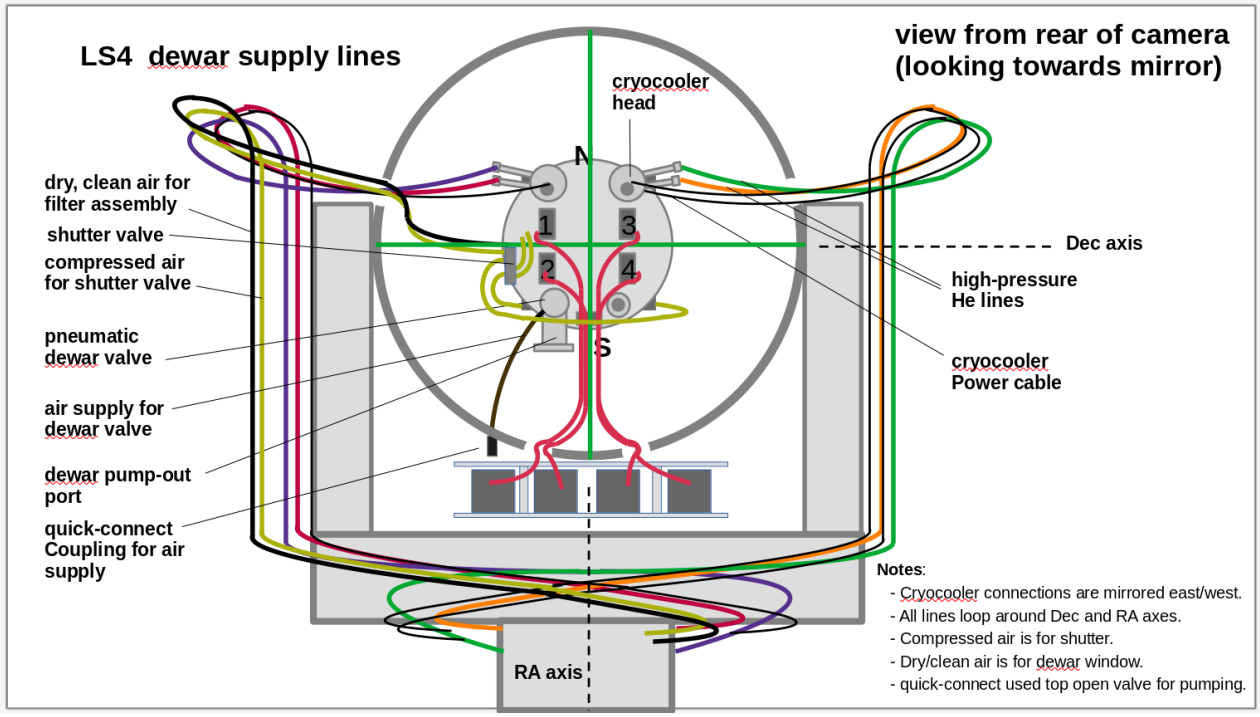

Figure 3. Supply lines for camera

2. Camera Dewar and Shutter Assembly

The 32 CCDs of the LS4 camera are aligned into a 4 x 8 array as shown in Figure 4. Each CCD has 2048 columns (east to west) and 4096 rows (north to south). Normally each chip is read out by two amplifiers (left and right) that split the pixel data into two sub images (L and R), each with 1024 columns and 4096 rows. The area spanned by the array is not precisely square because of small gaps between the CCDs.

The window of the camera dewar is a lens that flattens the telescope's curved focal surface (see Fig. 5). Immediately forward of the window is a filter frame that admits a tray with four square filters. Each filter covers one quadrant of the array (NE, NW, SE, and SW) as shown by Fig. 4.

Forward of the filter tray is a shutter consisting of two blades that open outward (see Fig. 5). The motion is driven by a single piston with air ports at both ends. A five-way solenoid valve is used to alternate the flow direction of the two ports from in/out to out/in, with the return flow directed two one of two vents. The times to open and close depend on the supply pressure and the resistance of the vent lines.

Inside the camera dewar is an aluminum focal plate to support the CCDs and provide a thermal path for heating and cooling. Aluminum nitride power resisters attached to the back of the focal plate provide heat. Also attached are platinum RTD temperature sensors. Copper straps on opposite sides of the focal plate connect to copper rods that penetrate the backplate. Additional copper straps connect these rods to two cryoheads. An external temperature controller drives the resistor current to maintain a constant focal plate temperature.

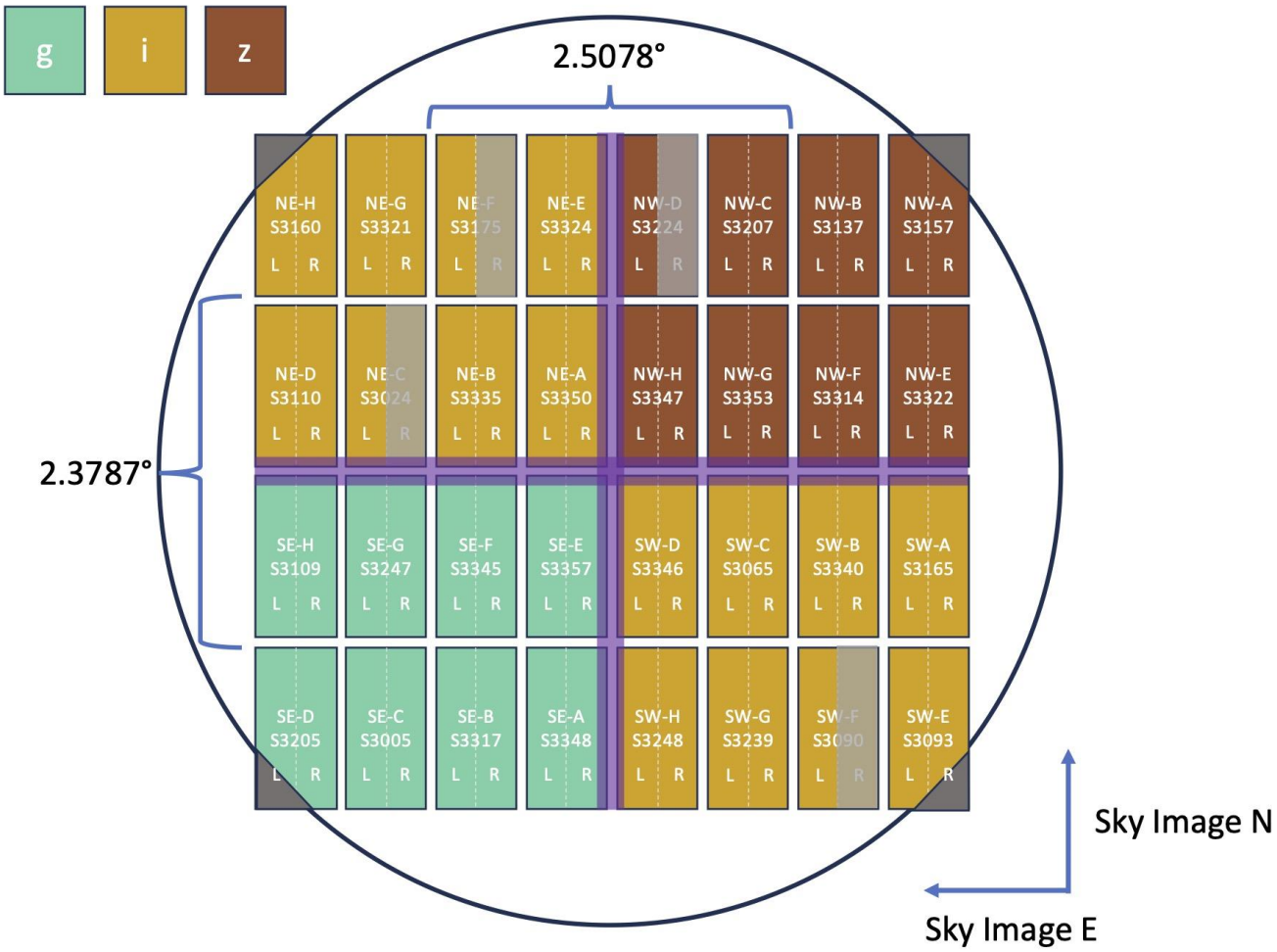

Figure 4. CCD and filter layout for camera

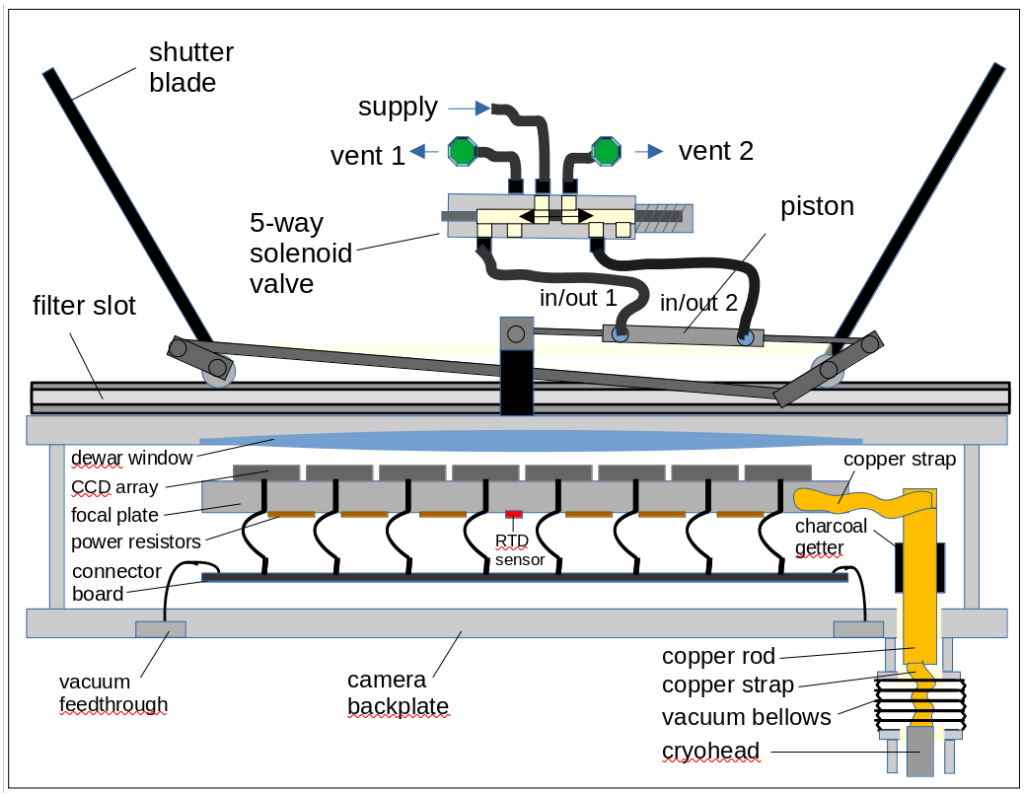

Figure 5. Components of camera dewar and shutter

3. Camera Readout Electronics

The readout system for the LS4 camera consists of 4 identical STA Archon controllers, one for each quadrant of the array. Each controller simultaneously drives the bias voltages and clocking signals of eight CCDs while digitally sampling both the left and right readout amplifier of each device. All the controllers share a common signal to synchronize the clocking and sampling of the entire array. The controllers can be configured to readout the entire array through the left, right, or both amplifiers of each CCD. Each devices receives configuration parameters and instructions and returns requested data at ~1 Gbps speed over an ethernet connection.

A link to the operating manual for the controllers is provided below.

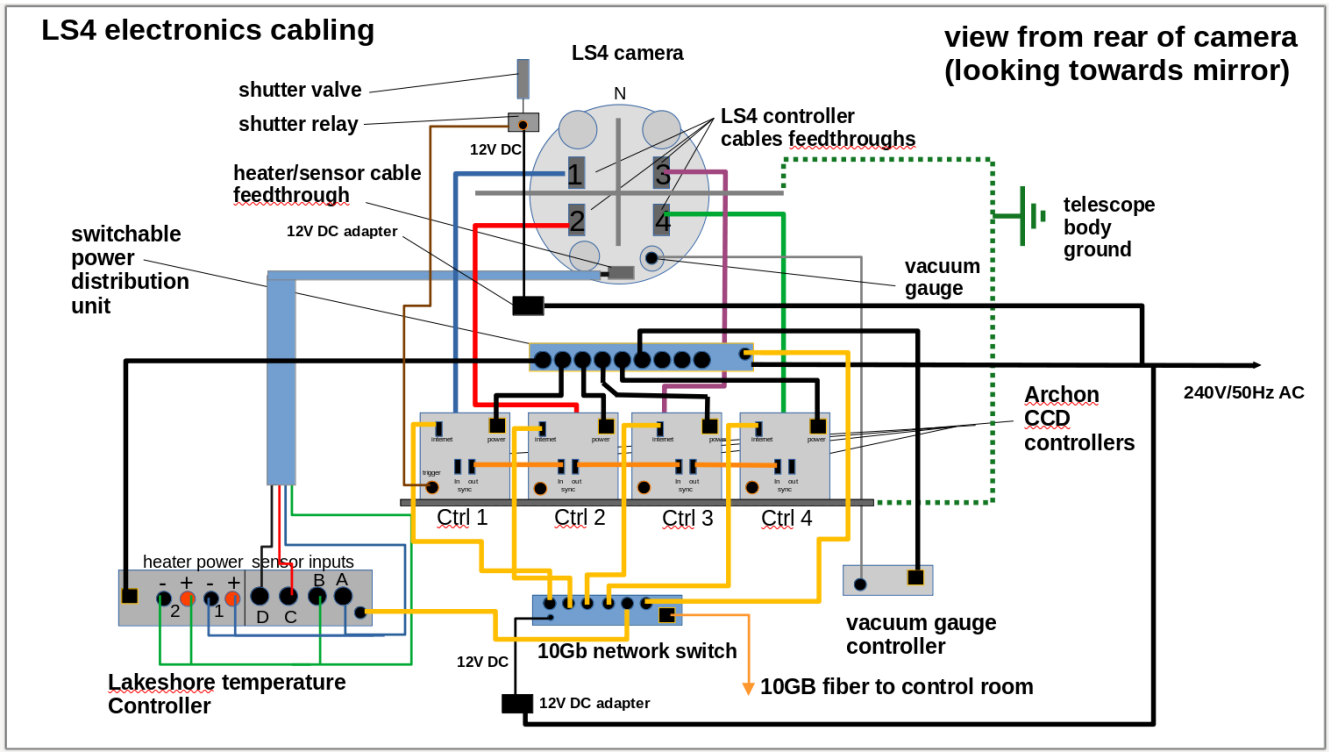

Figure 6. Cable connections to control system

Figure 6 is a schematic showing all the connections between the camera, the controllers, and other components of the readout and control system. For each Archon controller (labeled "ctrl1"to "ctrl4") a separate ribbon cable (represented by blue, red, purple, and green lines) carries all the required signals in both directions to the matching CCDs through a dedicated feedthrough on the back of the dewar. The designated lead controller ("ctrl1") generates the synchronization signal (orange) passed from one controller to the next. The lead controller provides a trigger signal (brown) to drive the camera shutter relay. All 4 controllers are commanded through ethernet connections (yellow) supplied by a 10 Gbps network switch. They are powered through a remotely switchable distribution strip. The chassis grounds of the controller are intentionally isolated from the power ground. Instead, the chassis are grounded through their mounting rack to the telescope body which also grounds the camera body.

4. Camera Temperature and Vacuum Gauge Controllers

Figure 6 shows the connections to the camera temperature and vacuum gauge controllers. The temperature controller uses two independent control loops (A and B shown by blue and green lines) to read the respective RTDs on the east and west side of the focal plate and supply current to the respective power resistors on the focal plate (through outputs 1 and 2). The controller also reads two additional RTDs (on the CCD connector board and on the charcoal getter) through inputs C and D (red and black lines). The temperature controller can be programmed and monitored remotely with an ethernet connection made at the local network switch. The vacuum gauge controller reads a gauge on the dewar backplate (grey line) to monitor the internal dewar pressure. Except for the internet switch, all devices are powered through the switchable distribution strip.

A link to the operating manual for the Lakeshore 336 temperature control is provided below.

5. Telescope Control

The telescope control system (TCS) runs on a dedicated PC with digital I/O cards that read out the RA and Dec axis encoders. In response to commanded slew or track command, the TCS throttles the respective servo amplifiers that drive the RA and Dec motors. The TCS receives commands either from a local console or from a serial port. To control the dome's position the TCS reads a position encoder and provides power through a relay to the motors that rotate the dome. To control the dome shutter, the TCS reads the open/close state through limits switch on the shutter and powers relays that engage the hydraulic system that opens and closes the shutter. The TCS also controls the focus position of the camera by driving a stepper motor connected to the focus hub. The TCS servo amplifiers are powered through an interlock system that powers off the servos when a limit condition occurs (e.g. telescope points too close to the horizon, or insufficient oil pressure supplied to the RA bearing).

The Comsoft PC-TCS manual (see link below) provides instructions for operating the telescope.

6. Camera Control

6.1 control network

Figure 7 shows the network configuration for the ethernet-interfaced components of the camera control system. The devices mounted on telescope (four CCD controllers, the temperature controller, and the power distribution unit) are linked through a single network switch on the telescope to an identical network switch in the control room. With a single multimode fiber running between them, these two switches allow a bulk transfer rate of 10 Gbps along the fiber and 2.5 Gbps between devices on the same switch.

In the control room, two computers are link to the hardware on the telescope. One is a workstation ("**ls4-workstn**") to run the observing software and receive the raw image data. The other is a smaller computer ("**ls4-nuc"**) to support preprocessing, online analyses, and data transfer to offsite storage facilities. A third network switch in the control room (labeled "**La Silla network switch**") links these two computers to each other, to the local mountain network managed by ESO, and to networks in the USA through a dedicated, line-of-site radio link with a receiver at Cerro Tololo.

To maximize the bandwidth for transferring image data from the controllers, five separate subnetworks are defined: **ctrl0-network**, **ctrl1-network, ctrl2-network**, **ctr3-network**, and **ctrl4-network** (black, red, green, purple, and blue lines). The first is dedicated to low bandwidth (~100 Mbps) traffic between ls4-workstn, ls4-nuc, the camera temperature controller, and the power distribution unit on the telescope. Each of the remaining four subnetworks are reserved for high-bandwidth (~1 Gbps) traffic between ls4-workstn and the respective controller. Four dedicated network adaptors are provided by ls4-workstn for this purpose.

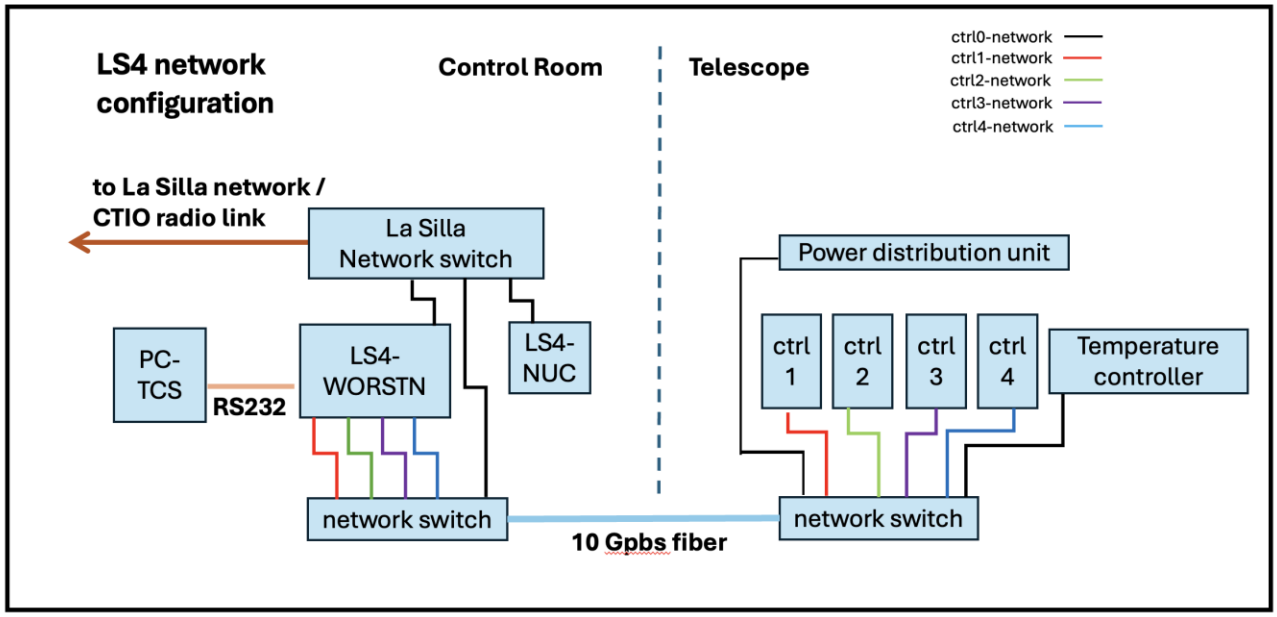

Figure 7: LS4 network configuration

6.2 control software

The ls4-workstn computer runs a program named "**ls4-ccp**" (the "LS4 Camera Control Program") to configure and operate the LS4 camera. This handles all communications with the four CCD controllers including commands to configure, synchronize, expose, readout, and transfer the image data when a readout completes. An additional program ("**archongui**") provides a convenient interface to adjust controller parameters (biases voltages, clocking patterns, and sample timing).

So that client programs may interface with the LS4 camera, ls4-ccp continuously listens for commands on a dedicated TCP socket. For example, the client program that schedules nightly observations connects to this socket and sends commands to expose and readout the camera each time it acquires a new observation .

Both ls4-workstn and ls4-nuc run Ubuntu Linux. Most programs are open source and coded in Python or C++. The source code for ls4-ccp and archongui are respectively available at https://github.com/dlrabinowitz/ls4_control and http://www.sta-inc.net/archon/.

For more information on the operation of the LS4 camera, see the LS4 software manual linked below (TBD)

7. Normal Maintenance Procedures

7.1 daily hardware checks

- **Check pressure in the Helium compressors.**
  These should be close to the nominal pressures recorded on first start up.

- **Check in/out flow to water chillers.**
  The lines leaving the cryocooler will be warm. The return lines will be cool. Check for nominal temperatures on each line.

- **Check air compressors.**
  The flow rate of the clean dry air should be nominal. The auto-cycling air dryer should be operating as usual. The automated release valve of the oil-cooled compressor should be evacuating air from the compressor tanks at regular intervals to expel condensed water vapor. After each release, the compressor should cycle on to restore nominal pressure.

- **Check temperature of camera focal plane, connector board, and getter.**
  The focal plane temperature should be stable to ~0.1 deg C. The connector board and getter temperatures should be stable to ~10 deg C.

- **Check dewar vacuum pressure.**
  If the pressure exceeds 1 mTorr the dewar will need pumping.

- **Check telescope pointing.**
  Before nightly operations begin, the telescope should be sitting at its normal stow position. If not, check for nominal motion of the telescope using the TCS console to change its position. Restore to normal stow position.

- **Check dome shutter.**
  Make sure dome shutter is closed before the sun rises. If not, check dome shutter motion using TCS console. If shutter does not open and close normally, schedule service to correct the problem before operations begin.

- **Check the dome position.**
  Make sure the is positioned so that the dome shutter is facing south. If not, check the dome rotation using the TCS console. If it does not rotate, or the readout of the encoder does properly follow the dome rotation, schedule service before operations begin.

7.2 camera pumping (every 2 months, or as needed)

When the camera vacuum exceeds 1 mTorr, warm up/pump the camera as described by this document: Camera Pumping Instructions. This is a two-day procedure.

7.3 water chiller service (every 3 months)

Clean out the filters on the water chillers. Check the fluid levels. Top off with 1/2 glycol and ½ purified water.

7.4 cryohead service (every year)

Every 10,000 hours of operation, the cryoheads must be disassembled to clean and replace worn components. This is a delicate procedure requiring a trained technician. The procedure is documented here: Cryomech AL60 service instructions

7.5 cryocooler Helium charge (every 4 years or as needed)

After a long period of operation, the cryocompressors may need to be recharged with ultra-pure Helium. The procedure is described here: Cryomech Helium charging instructions.

8. Trouble Shooting

TBD

9. Additional Documents and Manuals

Telescope**:**

PC-TCS manual

Pointing correction

Dome shutter limit switches

Camera:

STA Archon user manual

LBNL 2Kx4K CCD manual

Cryocoolers:

Cryomech AL60-CP103 cryocooler manual

Temperature control:

Lakeshore 336 temperature controller

Pressure:

Granville Phillips 375 Pressure Gauge

Granville Phillips 475 Pressure Gauge

Pumping Station:

Varian Sentorr Gauge Controller

Varian Turbo Pump

Air Supply:

O'Keefe Compact and Point-of-Use air dryers

Filters:

LS4 Filter Information

9. Contacts for Technical Support

For additional technical support not provided by this manual, the following contacts may be helpful.

Camera and Telescope Control Software

David Rabinowitz
Yale University
New Haven, CT USA
+1 203 432-3391
david.rabinowitz@yale.edu

PC-TCS and telescope hardware:

Greg Stafford
Tucson, AZ USA
+1 520 241 3210
grstafford@yahoo.com

Archon Controllers

Greg Bredthauer
Semiconductor Technology Associates, Inc
San Clemente, CA USA
+1 949 481 1595
greg.bredthauer@sta-inc.net

CCDs

Kenneth Lin
Lawrence Berkeley National Laboratory
Berkeley, CA USA
+1 978 399 9468
kennethlin@lbl.gov

Thomas Diehl
Fermilab National Accelerator Laboratory
Batavia, IL USA
+1 630 840-8307
diehl@fnal.gov