600 Series Camera System User's Manual

P/N 2269B

TUCSON, ARIZONA

TABLE OF CONTENTS

1 Introduction

The 600 Series Camera System is a multi-port (from one to four ports)16-bit camera that is cooled to cryogenic temperatures (-70^{o}C to -120^{o}C) using a re-circulating refrigerant cooler. This camera system can read out at up to 400,000 samples per second from each port. It offers high precision, high stability and relatively short 16-bit readout times from 4-port CCDs.

1.1 600 Series Camera System Overview

The 600 Series camera system consists of three primary units: the camera head, the electronic control chassis and the camera cryo-cooler. The camera head contains the CCD with its preamplifier(s). In the head also are the clock drivers, temperature and pressure measurement hardware and video signal buffer circuits. The electronic control chassis contains power supplies for the camera, the DSP-based camera controller and the analog processors and digitizers. The cryo-cooler is described in later sections and comes with a separate manual as well.

The 600 Series supports simultaneous readout of the CCD sensor through multiple ports. For this reason, the analog signal components may or may not be multiple units, depending upon the configuration ordered. This manual occasionally refers to analog electronic channels in the plural; your camera may have only a single channel.

1.1.1 SICCD - The Important Distinction

Spectral Instruments manufactures precision digital imaging systems utilizing scientific grade CCDs. Innovative and detailed mechanical and electronic design coupled with careful component specification and system manufacture give the ultimate in stable, high dynamic range digital imaging. Spectral Instruments has invented the term Scientific Imaging CCD with SICCD as the symbol that captures this high precision and high quality character of your camera. This label occurs throughout our documentation as a shorthand reminder of those high precision and high quality aspects of your camera system.

1.1.2 CCDs And How They Work

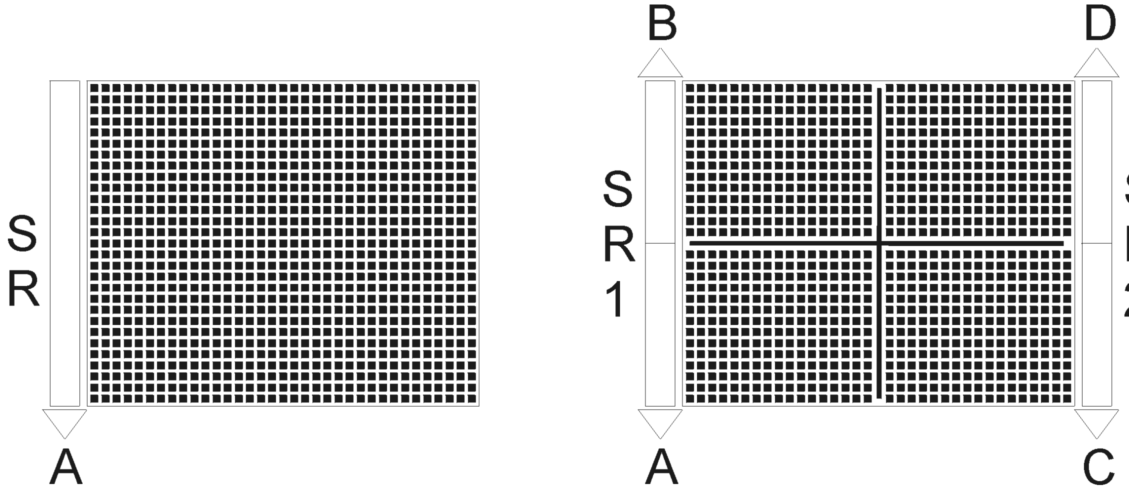
CCDs are used in a variety of consumer electronic products. A large assortment of CCD sizes and types are available because of the popularity of this sensor for low-cost digital imaging cameras. Most of these CCDs are not scientific grade. Moreover, they are operated so as to give you a “TV” image - that could, but usually does not, end up as a low-precision numeric image in your computer by using a computer card called a “frame grabber”.

CCD cameras that produce high quality digital images are designed to produce the precision digital image and not a TV image. They are cooled well below ambient temperature to reduce dark signal and they are operated in “slow readout mode” to minimize readout noise.

Digital images are organized in a row/column format. Image elements (pixels) emerge from a corner of the sensor. A sensor with more than one active corner produces more than one stream of pixels during readout. Figure 1., below, illustrates a single-port and a four-port CCD.

Referencing the left-hand portion of Figure 1., the center checkered region is the imaging area. It is called the parallel register. To read out the CCD, the grid of pixels is moved, one row at a time to the left, along columns, into the serial register, labeled SR. Once a row is moved into the serial register, it is then moved, one pixel at a time to the output node, shown as a triangle and labeled A. A column is a line of pixels consisting of one pixel from each row. The CCD does not readout columns, it reads out rows. But many characteristics of the image that results are shared by all of the pixels at the same location in each row (the same column) so they are analyzed as columns of information. Defects involving multiple pixels are almost always column defects.

The address of the first pixel out of a CCD camera is row 0 column 0. Readout occurs along rows, so the second pixel address is row 0 column 1. For a sensor with 512 imaging pixels in a row and 512 rows, pixel 513 has the address row 1, column 0. The last pixel out is row 511, column 511.



One Port CCD **Four Port CCD**

Figure 1.

It is possible to move more than one row into the serial register before the serial register is moved into the output node. It is also possible to move more than one pixel at a time from the serial register into the output node before it is digitized. This process is called binning. The total number of pixels is reduced in each direction by the amount of binning in that direction. The effective size, on the parallel register, of each binned “super” pixel is enlarged. This decreases the resolution of the image read by the binning factors (which may be different for rows and columns).

Referencing now the right-hand side of Figure 1., since the CCD illustrated supports four-port readout there are two serial registers labeled SR1 and SR2. Each serial register is divided into two halves, which is shown figuratively as a white line in the parallel register. The parallel register can also be divided and that is shows as a vertical white line. Neither white line exists in the CCD nor in the image that is read out four ports, the divisions are presented as white lines for clarity in showing how the single sensor is effectively divided into quadrants for four-port readout. The first pixel comes out A,B,C and D at the same time. They are combined into a single data stream with pixel data from A then pixel data from B then C and finally D. This pixel data stream has pixels from all of the quadrants interleaved. Software sorts them out so they are presented properly. The columns are still horizontal on the figure and rows are vertical.

Spectral Instruments’ SI-Image software package displays the first pixel, the 0,0 pixel, at the lower left-hand side of your display. The pixels in each row are displayed vertically. Row numbers increment from left to right in the display.

1.1.3 Cooling The CCD - Why/How - Implications Of Temperature

SICCD cameras are cooled to reduce the image contaminant called dark signal. Images accrue this unwanted signal at a rate that decreases as the temperature of the CCD is lowered. Usually it is not the dark signal that is the problem (it could be subtracted from the image), it is the noise associated with the dark signal. That noise cannot be subtracted; it must be prevented.

A CCD camera can be cooled too much. If the temperature of the CCD is lowered below approximately -120^{o}C, the performance of the sensor starts to be adversely affected.

The 600 Series camera system employs a cryo-cooler that is capable of lowering the temperature of the CCD below -120^{o}C. Spectral Instruments determines the optimum operating temperature for the particular CCD you selected and sets that value as the operating temperature. There is no reason to run warmer, as performance only degrades due to dark signal. There is good reason not to run colder, as the CCD may cease to operate properly. The operating temperature of your camera is a factory selected parameter that can be changed - but shouldn’t.

1.1.4 Sensitivity Of The Camera

SICCD cameras are designed to “see in the dark”. They do so quite well. You can’t permanently hurt your camera by exposing it to too much light although, if you have done so, it may affect the ability to make precise measurements of low light level scenes until after you have warmed up the camera and then cooled it back down again.

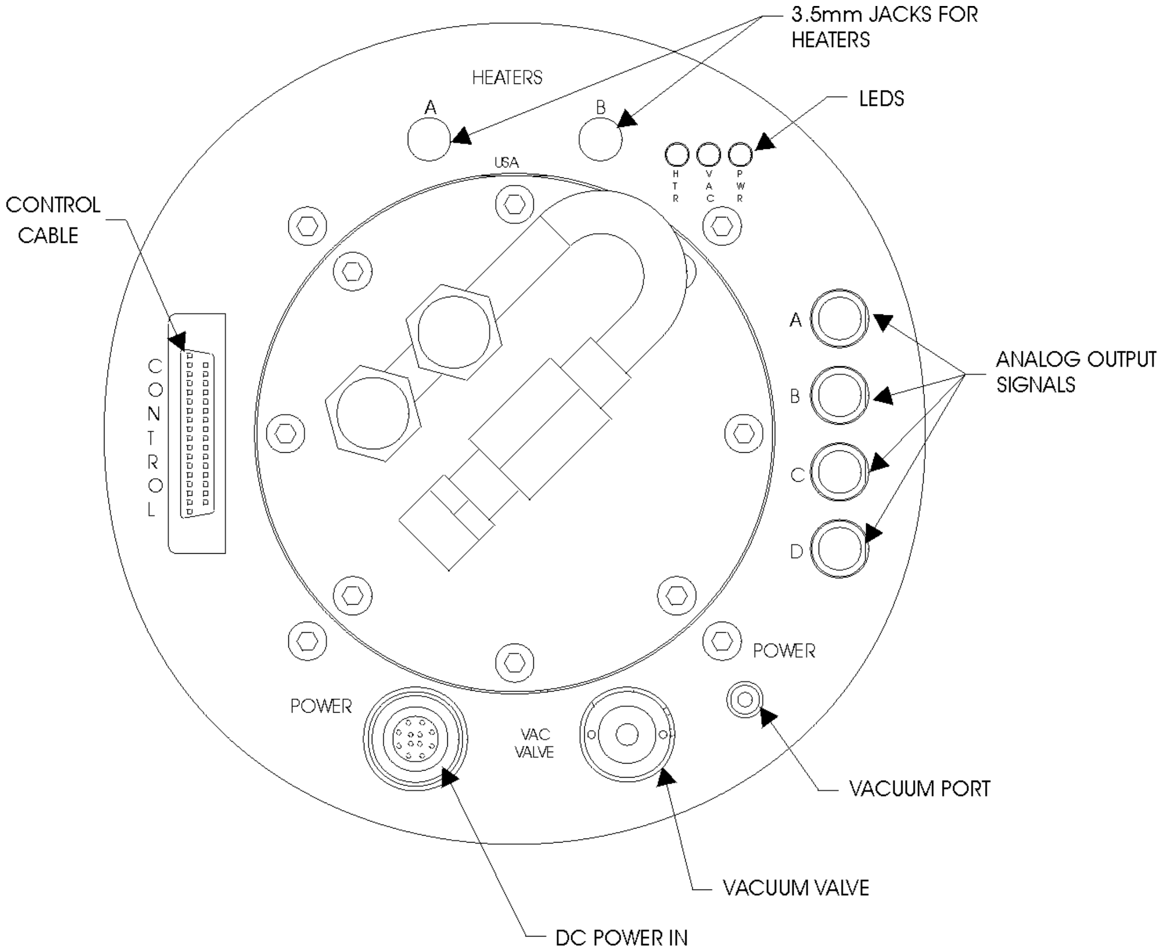


FIGURE 2.
Series 600 Camera Head Connectors

Dark images are a good way to find out how much light is leaking into your equipment. An image obtained with no external light coming through the normal path provides a view of how much light is coming from extra-normal paths. This camera can see light leaks very well! To realize the full potential of your SICCD camera, it, and the equipment to which it is attached, must be light tight.

1.2 The 600 Series Camera Head

The camera head back cover is shown in Figure 2. It contains 3 indicator lights: a green light labeled PWR indicates that DC power is present; an amber light labeled VAC indicates when vacuum service is required and a green light labeled HTR indicates when the CCD temperature regulating heater is active. The amber VAC warning light is illuminated if the pressure in the CCD chamber is above a preset value (normally 10 Torr). If the VAC light is illuminated for a cryo-cooler equipped camera at room temperature, it indicates damage could occur to the CCD if the cryo-cooler is turned on. Check the pressure readout from the camera before turning on cooling to the camera head!

The two major electrical connectors on the camera head back cover are labeled POWER, and CONTROL. They connect to the electronics chassis via a 12-pin round connector and a 50-pin high density connector respectively. The four twin-ax connectors, labeled A, B, C, and D, are the video outputs from the CCD. These connect to analog processor inputs A through D on the electronics chassis. The connector labeled, HEATER A, connects to the camera window heater. The connector labeled HEATER B connects to another heater identical to HEATER A.

1.2.1 The CCD Chamber

As mentioned in Section 1.1.3, the CCD is cooled to reduce dark signal. Just as your eyeglasses fog when you come out of the cold into a warm room, cold objects condense moisture from the surrounding air. The CCD is maintained inside a sealed evacuated chamber to insure that moisture does not condense on the CCD or its electronics. Such condensation damages the CCD.

In a lens-based camera, the chamber aperture seal is a fused-silica window of such a diameter that the CCD sensor is not vignetted by a f/0.9 incoming beam. Faster incoming beams may vignette in the corners. The CCD sensor is located 12.2 mm behind the front surface of the window. The window thickness is 3 mm. Fiber-optic based cameras seal the chamber at the fiber optic.

The 600 Series camera head is cooled by a closed cycle cryogenic refrigerator that includes a cold head capable of attaining temperatures as low as –190°C. The cold head is permanently inside the vacuum chamber through an O-ring seal so the camera body does not get cold – only the CCD. A heater is used to warm the CCD to the operating temperature; typically between –70°C to –100°C. The cold head has two self-sealing quick-disconnects that allow the camera to be easily unhooked from the compressor lines. A micro-heater around the window prevents the window from frosting due to radiative cooling by the very cold CCD that is immediately behind the window.

As shown in Figure 3., two different bolt circles are provided for mounting the camera head to your application. One is a ¼-20 threaded screw hole set aligned with the rows and columns of the CCD. The other is a ¼" clearance hole set aligned at 45° to the rows and columns of the CCD.

A third hole pattern appears on the front face of the camera head. This 6-hole 6-32 blind tapped set is used for attaching shutters or other application optics to the front of the camera head. These are not to be used for supporting the camera!

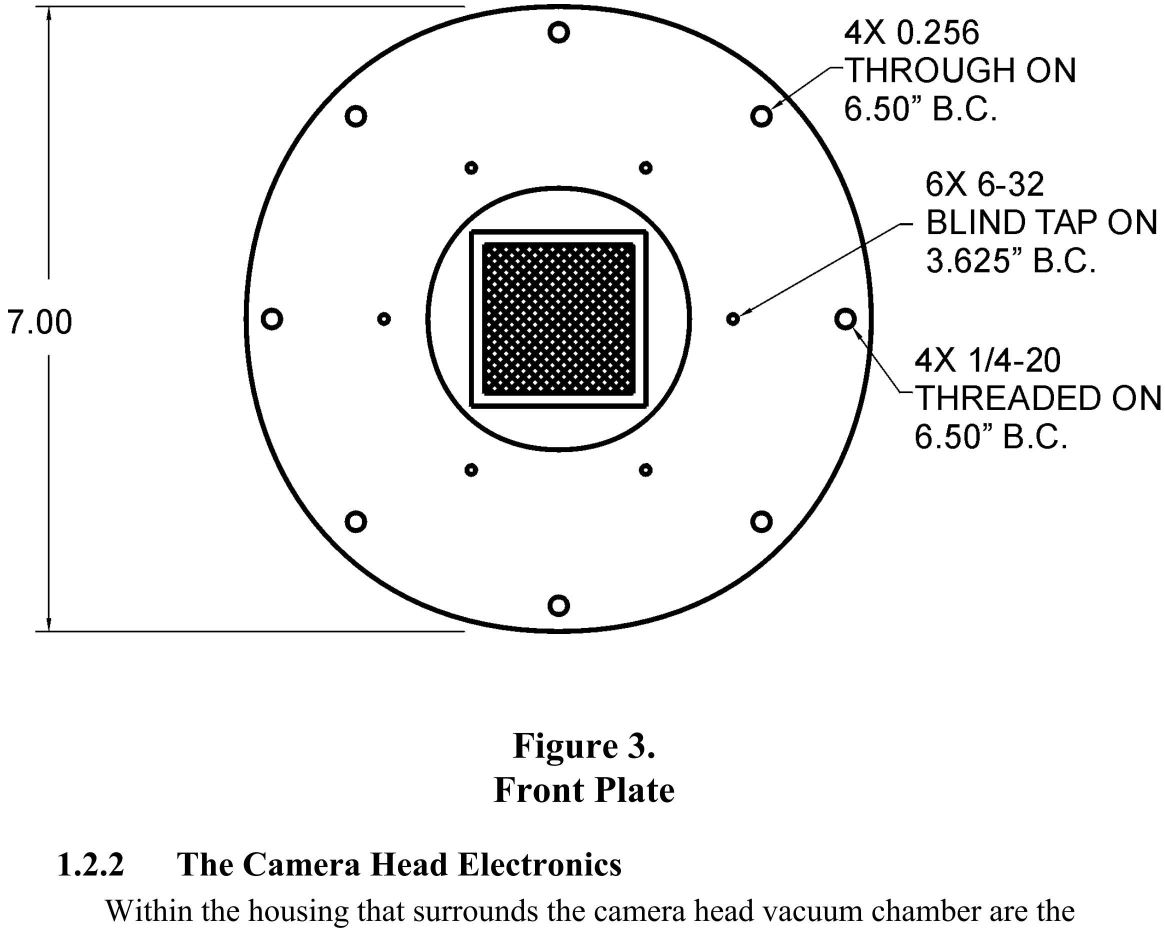


Figure 3.
Front Plate

1.2.2 The Camera Head Electronics

Within the housing that surrounds the camera head vacuum chamber are the circuit boards that connect the CCD to the controller. There are three types of connectors and each type connects through the camera housing to a specific circuit board. The connectors are labeled as shown on Figure 3. The video outputs are multiple although only one output may be active on your camera. Any inactive video connectors are covered.

WARNING*: It is very important to turn off the power to the camera electronics unit before connecting or disconnecting the camera power connector either at the camera head or at the camera electronics unit!*

The SICCD camera is buffered against electrical transient events - radiated or conducted - through the power line. This buffering suffices for coexistence of the camera with typical laboratory conditions.

WARNING: *It is an important requirement that the camera system incoming power mains be filtered against exceedingly strong transients such as that produced by lightning.*

1.2.3 Hooking Up Your Camera To Your Equipment

A detailed description of the system setup and interconnect process is provided in Section 2.3. The most important system aspect of connecting the camera to your application is understanding the effect that very small voltage differences among grounds can have on images obtained from your SICCD camera. Various lines, bars, chevrons or wood-grain patterns can occur in the background of low light images (they show up in the bias especially well). These patterns are of no significance when imaging high light level scenes but can disturb low light images and are exceedingly annoying as the eye is very good at picking out such patterns even if the amplitude is not statistically measurable.

Spectral Instruments has designed a camera that is essentially bias-pattern-free when it is operated from a single power source as directed in Section 2.3. If that camera is mechanically connected to some apparatus that is at a different ground potential than that of the power source, small currents flow through the camera body. These small currents are always visible in the image; they are always undesirable!

If the camera and the equipment cannot be grounded to the same point, it may be necessary to introduce an electrical insulator (including screws) where the camera physically is attached to your equipment.

1.2.4 Shutters And Timing Considerations

The camera controller provides millisecond resolution in timing your SICCD camera. That resolution is useful when the camera is shuttered by equipment that responds in tens of milliseconds.

The camera is also designed to obtain "images upon external signal". This is known as "triggered mode". In this mode the camera is programmed to clear charge continuously with the CCD staring into the application waiting for a trigger event. The trigger event is provided by the application. The camera ceases clearing **immediately** (within 0.5 microseconds) upon receipt of the trigger and stares into the application accumulating an image. At some later time the camera is readout out. In this "triggered" mode, the camera control electronics operates in microsecond resolution appropriate to streak tube or pulse-triggered imaging.

When a SICCD camera is shuttered by a conventional multi- or twin-blade shutter mechanism, there are several built-in delays that occur and must be considered when obtaining short exposures.

A good twin-blade shutter requires at least 8 milliseconds to open and close. A ten millisecond exposure with such a shutter means that the integration time is effectively 26 milliseconds for the center of the image and is 10 milliseconds for the edge of the image. The resulting variation in effective exposure is very noticeable. The exact pattern observed depends upon the type of shutter. In every instance, you must not expect uniformly exposed images when the exposure times are within a factor of 10 of the shutter delay times. Large shutters can take more than 50 milliseconds to open and close.

While it is possible, in principle, to correct for shutter-caused patterns in a flat field illumination, shutters are electro-mechanical devices that do not exhibit the stability over time required so as to be removed effectively by flat fielding.

1.2.5 Lenses, Light Paths and Vignetting

Spectral Instruments does not provide a lens! This is because most applications that can utilize the precision of SICCD already provide an image plane at which the SICCD camera is positioned. A lens is only useful for imaging with the camera "straight out of the box" and is usually discarded immediately thereafter.

There is always some variation across the image of a "uniformly illuminated" application. It is exceedingly difficult to obtain a uniform illumination field and most equipment vignettes to some extent. There are methods to compensate for this vignetting and they are discussed in detail in Section 4.

One type of application that is frequently troublesome for imaging artifacts is the “long focal ratio”. When the camera is exposed to light that is nearly collimated, that beam acts to expose very small dust specks on the window. The camera is assembled with great care to eliminate any dust on the inside of the window. The outside of the window is also cleaned and the camera is shipped with a protective cover to keep the window clean. Life conspires to change that. Dust particles collect on the outside of the window. Only those customers who have applications involving highly collimated incoming beams will notice. What they will notice are “little donuts”. These are shadows of the dust particles on the outside of the window. They can be corrected for by a process discussed in Section 4. but if your application does not include image correction you will see the dust in a collimated beam illumination of the camera.

Cleaning the outside of the window is not recommended. Section 5.7 describes how to clean the window of your camera if such activity is really necessary.

1.3 The 600 Series Camera Controller

The controller is housed in a 5” high 19” wide rack-mount chassis. A power-on switch is located on the front panel. All cables enter from the rear of the controller. A table top cover is optionally available. Figure 4. shows the rear of the controller where the connectors attach.

1.3.1 The Controller Electronics

The electronics controller contains the DC power supplies that supply voltages necessary for operating the CCD. It also contains the DSP micro-processor and the signal processing modules that provide dual slope integrator digitization of the video signal.

The round 12 pin power connector (CAMERA HEAD POWER) and 50 pin high density connector (CAMERA HEAD CONTROL) connect to cables leading to the camera head. They are used for camera head power and digital timing/control signals respectively.

The 68 pin high density connector (COMP.) carries control signals from, and digital image data to, the computer interface card. The signal format is parallel differential pixel data with pixel, line and frame clocks and a RS422 serial communications interface. This connector follows the AIA standard for 16 bit digital electronic cameras.

The cryo-cooler relay connector (COMPRESSOR) is used to control power to the cryo-cooler in cameras equipped with low temperature protection.

Four twin-ax connectors on the back panel are for video input to analog processors 1 through 4. These connect to the video outputs on the camera head. Unused video inputs are covered with metal caps.

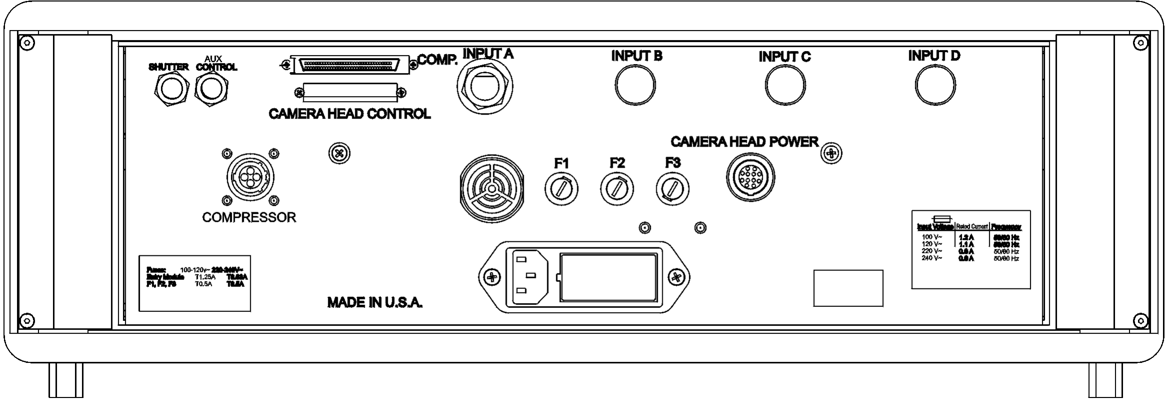


Figure 4.
Camera Electronics Unit – Rear View

The shutter connector (SHUTTER) is a recessed 6.5 mm 2-pin Lemo receptacle used to connect to an electronic shutter solenoid. The standard system drives a shutter with a 6-volt coil.

A second recessed 6.5 mm 4-pin Lemo receptacle (AUX CONTROL) on the back panel provides auxiliary input and output signals whose function is established by a custom hardware and software configuration.

The alarm buzzer is used to indicate an error condition including camera head cables not connected, or CCD temperature too low. It also sounds briefly when the camera system is initialized.

1.3.2 Power Requirements

The controller operates on incoming AC power in the 48 to 62 Hz frequency range and can run on 100, 120, 220 or 240 volts. A power entry module allows the power selection to be changed. The fuses required for the incoming mains are located in the power entry module.

1.3.3 Power-On Startup Sequence

When the power is turned on the DSP is idle. Static voltages are applied to the CCD but the camera is not "running". The DSP must be downloaded with a program for the specific CCD to be operated and the number of ports to be used.

Until that program download occurs, no imaging activity can occur. Downloading a "wrong" program is not injurious to the CCD but the camera won't image properly until the correct program is downloaded.

Before the DSP can be downloaded it must be reset into a known initial state. The DSP is initialized whenever the ASCII "break" condition is maintained in the serial communication line, within the AIA protocol, for 50 milliseconds or more. The 50-millisecond break must be followed by a 10-millisecond quiescent time.

After the break has reset the DSP, the DSP monitors the serial communication line on the AIA cable from the host computer. Each character is echoed back to the host as an acknowledgment that it was received.

After the reset, the DSP is ready to be downloaded with an operating program for that camera head. This is a special "**.bin**" file that is included with your shipment. After that file has been transmitted to the controller, the DSP proceeds to check the camera head. Three short beeps on the audio alert indicate that this process has completed. If an error occurs, the audio alert is turned on steadily. The controller must be re-initialized or the power turned off to reset this signal! Section 8.2 discusses errors and how to handle them.

Now the DSP is ready to operate the CCD in response to the various camera configuration and imaging commands transmitted by the software you have selected to use to run the camera.

1.4 The 600 Series Camera Cable Set

1.4.1 Controller To Camera Head

Three cables are required for a single port camera: a) DC power cable which is a round 12 pin cable; b) 50 pin high density camera head signal cable and c) twin-ax video cable. For a multi-port camera, the appropriate number of twin-ax video cables is provided. The twin-ax video cables are color coded on the ends so it is easy to identify both ends of each video line.

All of these cables are reversible so either end can be connected to the controller. They are bundled inside a nylon cable jacket to form a single conduit so they can be manipulated as a one cable.

1.4.2 Controller To Computer

The connection to the computer interface module is a 68-pin high density AIA-standard digital imaging cable. This cable is reversible so either end can be connected to the controller.

1.4.3 Shutter Connector

If a shutter is supplied, that cable is also included within the cable conduit between the controller and the head. The shutter cable is not the same on both ends so this cable determines the orientation of the conduit between the camera head and the camera electronics unit. The controller has a 2-pin shutter connector port, labeled SHUTTER, for cameras that use a standard 6 volt coil shutter.

1.4.4 Cryo-cooler Relay Interconnect

Some cameras must never get too cold. To prevent this from occurring, for those cameras, the cryo-cooler is supplied with an external with a power relay switch that inhibits cooling if the temperature drops below the prescribed limit. The 4-pin connector labeled compressor is provided to connect to the cryo-cooler thermal interlock relay.

1.4.5 The Shutter And External Control Ports

The camera shutter connects to a Lemo connector which is available as LemoUSA part number FGG.0B.302.CLAD52Z. The wire must not be bigger than 22 gauge and the cable must be between 4.1 and 5.0 mm in diameter.

The external control also connects to a Lemo connector which is available as LemoUSA part number FGG.0B.304.CLAD56Z. The wire must not be bigger than 22 gauge and the cable must be between 5.1 and 5.5 mm in diameter.

1.5 The Cooling System

1.5.1 System Description

The CryoTiger cryo-cooler is a single-compressor system that is capable of removing up to 4 watts at an operating temperature of -190°C. It is a cascaded cryogenic refrigeration system that uses special gas as the refrigerant. It includes pre-charged gas lines in flexible metal-shields. The cables are connected, without leaking, through special connectors. It requires two open-end wrenches (a 5/8" and a ¾") to make or break the connection at either the compressor or the camera head. As mentioned in the manual for the cryo-cooler, two wrenches must be used so as to avoid applying torque to the connector within the compressor or the camera head. The ability to disconnect the camera head from the cooling system increases the versatility and the reliability of the 600 Series cameras.

1.5.2 Hooking Up The Cryo-cooler

The CryoTiger cooling lines are pre-charged. They are end-for-end reversible except that one end may terminate in a 90° bend, which is preferentially located at the compressor. These lines are different - but only in their markings. One is the supply line, the other is the return line. The supply line is marked as such by a SUPPLY label in red ink. The RETURN line is also marked as such but in green ink. The connectors are identical. It is important not to make an incorrect connection. An incorrect connection can result the CryoTiger failing to cool. While the two lines are mechanically identical, once they have been hooked up to the camera head and to the compressor they become differentiated by the function they provide and must remain so.

When installing the fluid lines, it is important to properly align them with the axis of the mating fitting so that threads on the lines and the connectors join easily. The lines are not overly flexible and it is important to make the connection with the camera head in such a position that the lines can easily be manipulated to a “straight-in-shot” to the fitting.

1.5.3 Running The Cryo-cooler

The Cryo Tiger is able to quickly cool the camera head to a temperature low enough that the camera window could frost in a high humidity environment.

WARNING: *It is necessary to operate the camera electronics with the window heater turned on for at least 30 minutes before the cryo-cooler is turned on to prevent condensation on the window.*

The CryoTiger is designed for continuous operation. To avoid problems with AC line transients affecting the performance of the 600 Series camera, we recommend that the cryo-cooler and the camera both be plugged into a single filtered AC line or a UPS system. The cryo-cooler must be plugged into the same power strip that powers the camera controller in order to avoid ground loops.

Some 600 Series cameras include a relay that turns off the cryo-cooler if the temperature becomes too cold, if the DSP ceases running or if the camera controller power is turned off. These cameras require an explicit host computer command to the DSP to turn on cooling.

The coolant lines are flexible and designed to bend with a minimum radius of 1/2 meter. These lines are, however; not designed to flex a lot at the minimum 1/2 meter radius.

1.5.4 Disconnecting The Cryo-cooler

WARNING*: The CryoTiger and the camera head must be at room temperature before the lines are disconnected. This typically requires at least three hours after the compressor is turned off.*

Failure to allow the system to warm up before disconnecting the lines could allow a small amount of refrigerant to escape from the system. The system has a limited reservoir so any loss in pressure affects the maximum cooling capacity. The cryo-cooler requires service if much refrigerant is lost.

Disconnecting the cryo-cooler is also a two-wrench activity. The coolant lines must be allowed to come straight out of the fitting so there is no lateral torque on the lines as they are disconnected.

1.5.5 Servicing The Cryo-cooler

If the CryoTiger compressor must be serviced, it must be returned to one of the APD factory service centers. There are no user serviceable components inside the cryo-cooler. The pressure gauge indicates the operating pressure for the unit. If the pressure becomes too low the cryo-cooler will not cool the camera. Low gas pressure can be corrected by field service personnel using a service bottle of the appropriate gas. See the list of field service components in Section 6. for a list of the different gas service bottles.

2. Receiving Your 600 Series Camera System

The 600 Series camera system is shipped in double-walled heavy-weight cardboard boxes that are industry standard for fragile electronic equipment. Do not discard these cartons if the equipment is to be transported.

2.1 Shipping Configuration

Three cartons hold the entire system. The cryo-cooler and cooling lines are in one box along with a line cord and a manual from APD. The 600 Series camera head is in a double box with shock absorbing material separating the two boxes. The third box contains the electronic control chassis along with the camera cables, the PDCI computer interface module and its cable.

The test report is included with the camera electronics. The SI-Image software is shipped in the same box with the PDCI interface module.

2.1.1 Incoming Inspection Of Cartons

Inspect the cartons to make certain that there is no visible damage. Check for puncture-type damage. If there is any evidence of damage, have the packages inspected by your local freight carrier so that responsibility for damage to the camera components is borne by the carrier.

2.1.2 Opening The Cartons

Open the cartons in such a manner that they can be reused. Once the camera has passed acceptance tests, these cartons can be opened up so they lie flat to minimize storage space. It is important to use these or equivalent packing materials if the camera system is to be transported.

2.2 Environment Requirements For 600 Series Cameras

2.2.1 Temperature - Humidity - Pressure

The camera system operates at temperatures from 60^oF (15^oC) to 95^oF (35^oC). The camera system operates at relative humidity from 10% to 50%. The camera is rated to operate from sea level to 10,000 feet.

2.2.2 Electrical Requirements

The camera system runs on regular AC power as long as the frequency is between 48 Hz and 62 Hz and the voltage is 100, 120, 220 or 240 volts ±2%. The requirements for the fuses are described in Section 2.3.2.

The system must be protected against line surges by using a surge-suppresser in the incoming AC power line.

2.2.3 Other Requirements

The 600 Series components must be protected from aggressive atmospheric conditions such as are the result of operating in salt laden air or in air that contains corrosive chemical vapors.

The equipment must not be exposed to dripping liquids. Airflow into the controller must not be restricted.

2.3 Assembly Of The Camera System

Camera assembly consists of verifying proper AC line voltage setting, connecting AC line power to the electronics chassis, connecting power, signal, and video cables between the electronics chassis and camera head, and connecting the computer interface cable to the PDCI, computer interface card.

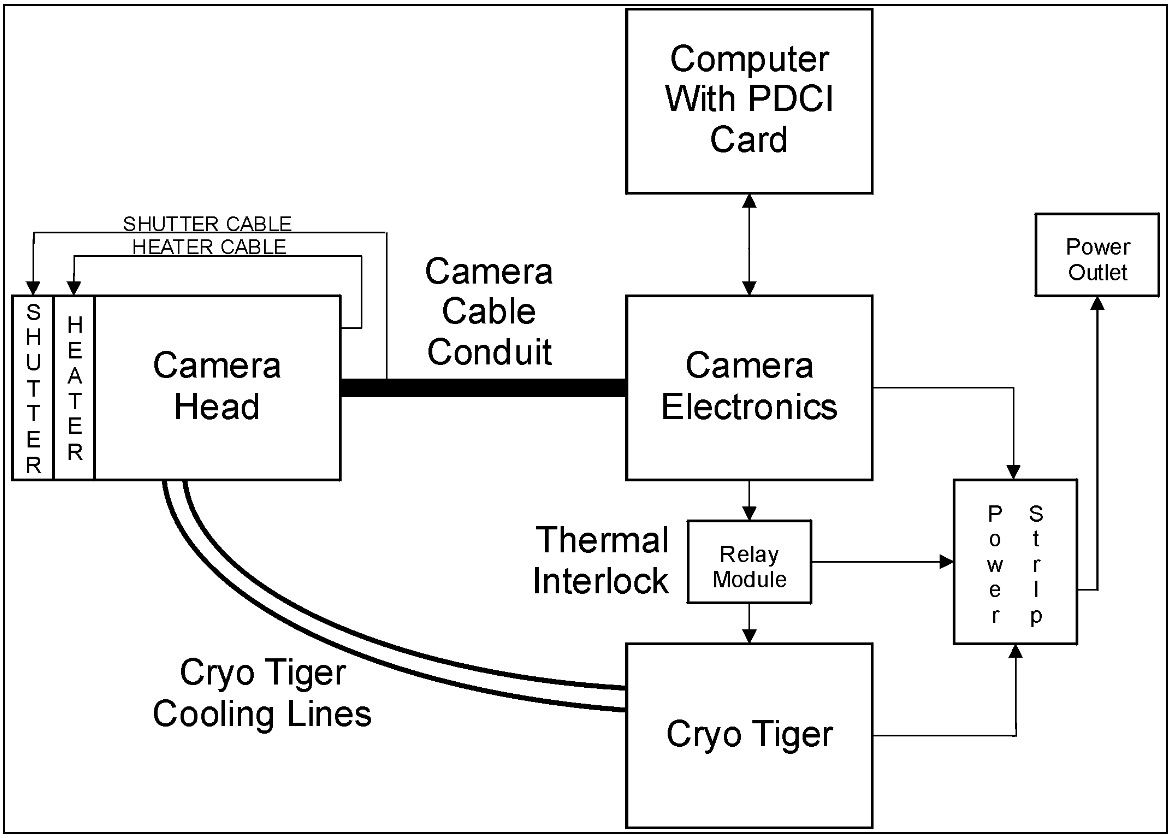


Figure 5.
Series 600 Interconnect Diagram

NOTE: Connect the AC power of the camera, computer, and cryo-cooler to a single AC outlet or plug strip. Failure do to this will result in low-level periodic noise in the camera readout due to ground loops.

Figure 5. shows how the 600 Series camera components connect and how the power must be connected. See Figures 2., 4. and 7. for additional details.

2.3.1 Assembly Of The Camera Head

Assembly of the camera head principally involves mounting the head onto a test fixture or onto your equipment. Normal precautions should be taken against handling damage.

The cable assembly for the camera head window heater must be plugged into the HEATER A port on the back of the camera head.

2.3.2 Assembly Of The Camera Electronics

The AC power setting must be verified or set to the proper configuration <u>before power is applied to the controller</u>. The power-entry module has a recessed IEC male connector for the power cord. To the right of this recessed male plug is a fuse module that has an indicator for the current power configuration. The indicator is a white dot that appears to the right of one of the four power settings marked in the black plastic on the fuse holder. The indicator MUST agree with the mains power that will be used.

If the indicator does not show that the camera controller is set to the proper AC power, it must be changed. This is accomplished as follows:

1) Make certain that the power is not plugged into the controller!

2) Using a small flat-head screw driver, insert it into the small recess on the left hand side of the fuse holder module. Gently pry the fuse holder out of the module. Inside, fuses are visible. Inspect the fuse values. For 220/240 mains, the fuses must be T0.63 fuses. For 110/120 mains the fuses must be T1.25 fuses. All of the fuses are 5-20 (metric) fuses and they must be TUV approved.

3) Using a small pair of pliers or strong tweezers, carefully remove the very small circuit board assembly that resides on the right hand side of the cavity exposed when the fuse holder was removed. This is a 2-part power selector. The circuit board, inserted with the correct power indicated at the leading edge of the circuit board, actually makes the proper power connection to the power entry module. The small plastic indicator can be "wiggled around" so as to point its dot in the opposite direction. The effect of repositioning the dot is to move it up or down to indicate the proper power selection when the unit is reassembled. Once the dot is opposite the power label you selected, replace the circuit board assembly.

4) Insert the fuse holder module and inspect the power setting now indicated by the white dot. If it is not correct then redo steps 2 and 3 until it is correct.

5) The three fuses (labeled F1, F2 and F3) for the DC power supplies must be correct for the incoming line voltage. All three fuses are identical and are T0.5 for 100/110 volts incoming power and T0.25 for 220/240 voltage.

Once the AC power setting on the electronics unit has been set up for the local AC power, assembly of the electronics unit consists of hooking up the cables to the camera head. All of the cable types are unique and cannot be interchanged.

The video cables must be matched from the same port letter on the camera head as on the electronics unit. Interchanging video cables is not injurious to the camera. The image will not be reconstructed properly if the ports do not agree. The video cables are color coded so it is easy to identify both ends of each cable.

The shutter connector does not receive anything if the camera is not equipped with a shutter.

2.3.3 Assembly Of The Cooling System

For cryo-cooler installation, refer to the cryo-cooler manual. Note the requirement to allow the cryo-cooler to sit upright for at least four hours after it has been tilted from the upright position. It is reasonable to presume that any time the cryo-cooler has been transported it has been tilted.

For camera systems that are cold-limit protected, a relay that is operated by the camera controller is installed in a small module that is itself powered by an AC power adapter. The relay control output of the camera controller must be connected to the cryo-cooler before the unit will operate. The cryo-cooler can be switched on only under software control after all power on self-tests are successfully completed. The cryo-cooler will not turn on for 45 seconds after the command is sent to the controller to turn on cooling. This delay is built into the solid state relay used to turn on the compressor. It is used to prevent the compressor from switching on when the back pressure is high.

2.3.4 Software Installation

Camera control and imaging software is provided by Spectral Instruments. This imaging software, called SI-Image, is supplied on a CDROM. The installation disk contains a setup.exe installation program that automatically detects the operating system (Win9x or WinNT) and installs the appropriate driver and camera interface .dll into a directory path that you may redefine as part of the installation.

Obtain administrative privileges as appropriate for the OS and install the software. Leave the CDROM in the drive and turn off the computer to install the PDCI hardware interface module. When the computer is turned on again, log on as a normal user to run the software. Note that running the software as administrator requires a re-boot cycle to again be able to run the software as a normal user.

2.3.5 PDCI Parallel Digital Camera Interface

The PDCI interface card is a PCI bus parallel data interface card for the Spectral Instruments 500 and 600 series cameras. It accepts camera image data at rates up to 10 MHz and directs it to computer memory by bus-master direct memory access. It also transmits and receives RS422 levels for camera communications.
Turn off your computer and install the PDCI card in any available PCI slot.
When the computer is switched back on, a Windows operating system will find that the card has been installed and finish the installation.

The PDCI interface card connects to the camera controller by a 68-pin high density cable. The cable is straight-through male-to-male and can be reversed.

2.3.6 Software Operation

The software is typically installed into the directory containing other program files. Two icons are provided, one to run the program and the other to uninstall it. Execute the run icon to start the program.

Once the program screen appears, the pull-down labeled Operate provides a control to initialize the camera. When this has finished properly, the camera will sound three “beeps” and is then ready to operate. A manual., Part # 1874, is provided as a .pdf file on the CDROM that contains the software.

2.4 Startup

After the software is installed, the camera head has been connected to the controller and the controller cable connected to the PDCI interface, the system is ready to operate.

Two conditions must be met before the cryo-cooler can be turned on: a) four hours must have elapsed since it was last transported such that it could have been tilted more than 30^{o} off of upright; b) the camera electronics unit must have been turned on so the camera is operating and stabilized for about one half hour before the cryo-cooler is turned on.

The second requirement provides the necessary time for the camera window heater to bring the window to proper temperature. This must occur before the cryo-cooler is turned on since the window can frost quickly if the low-power window heater has not had time to stabilize the window.

So, if the above conditions have not been met, the cryo-cooler must not be turned on yet but that does not prevent the camera from operating - it just limits the types of images that can be obtained until the camera is finally able to be cooled to operating temperature.

2.4.1 Power-On Condition And Indicators

When the unit is switched on, the PWR indicator on the camera head illuminates. The amber VAC light may illuminate after several seconds if the warm-camera pressure is above 10 torr. This indicates that the pressure is rising and that the next time the camera is turned off and then back on again the pressure may have risen such that the convective heat load prevents the cryo-cooler from turning on. It means that service is required soon.

2.4.2 Power-On Self Test

The DSP is in an indeterminate state when the camera system is turned on. It remains in that state until it is reset from the host computer. This is accomplished by sending a 50-millisecond break to the camera controller followed by a 10-millisecond pause. After the break is received the DSP is ready to be programmed.

The next thing that must occur is a program must be downloaded into the DSP memory. This occurs from your software running in the host computer which opens the *.bin file supplied with the camera and sends it to the DSP. Now the DSP beeps three short beeps on the alarm and performs a power-on-self-test (POST).

The POST consists of establishing communication with the camera head, to make certain that a head is plugged in, and then checking the power to the camera head to make certain that cable is plugged in. Finally, the DSP checks that the camera head temperature is not below the low temperature limit established for the camera head.

If any error condition prevails, the DSP turns on the alarm, which runs continuously thereafter until the camera electronics unit is turned off or it is re-initialized. If the POST is successful the DSP is ready to receive commands to operate the camera.

2.5 Commanding The Camera

The controller accepts a limited number of commands and parameters from the host computer. The commands are all single ASCII letters, which can be upper case or lower case. No termination characters, such as carriage return, are necessary to initiate the command. Only those characters that are part of the command set are valid (the command set is listed in Appendix D). Termination characters are treated as invalid commands and thus should **never** be transmitted. For any valid command, the command is echoed back to the host, the command is executed and then a reply of an ASCII Y is sent, to indicate successful completion of the command, or a reply of an ASCII N is sent to indicate that the command is invalid.

If a command requires a parameter or parameters, it (they) must be sent as 32-bit binary word(s) with the most significant byte sent first, immediately after the command letter is sent. The controller knows from the command what sort of parameter(s) is/are expected and waits for transmission of requisite number of bytes. The parameter(s) is/are not echoed. The controller waits for the bytes so it is important that every command that requires a parameter be given the proper number of bytes. After the parameter is received the command is echoed and executed. If the parameter is out of range for that command a N reply is issued and the command is not executed.

Commands from the host computer that ask the camera for status or configuration receive the information before the command is echoed. These numbers are also 32-bit and are sent with the most significant byte first.

2.6 Initial Tests

The tests below assume that the camera has **not** been cooled at all. To assure the camera is functional before it is cooled, it is reasonable to run through initial imaging tests with a warm camera. Final performance metrics cannot be undertaken until the camera has cooled down to its operating temperature.

There are several configurations the 600 Series camera can assume. For some of them it is not possible to “take an image” without fully integrating the camera into the equipment. This manual uses tests for which a dark environment is sufficient.

The following also assumes that the SI-Image program is used to run the camera. Any other operational software will work as long as the equivalent camera operations can be commanded from within that software.

2.6.1 Types Of Images

SICCD cameras provide access to all of the components of an image. These are:

1) the electrical offset introduced to keep all of the pixel values as positive integers,
2) 2) the dark image which includes the bias and shows the sensitivity of the camera to thermal signal and
3) 3) the light image at which the camera was directed. The light image includes the dark and the bias images.

Bias images exhibit low-level spatial structure that is stable over time but are affected by the way the camera is set up to image. The bias image is a uniform array of low-level “speckles” superimposed upon on a background offset. The value of the offset SICCD cameras provide access to all of the components of an image. These are: 1) also depends upon the way the camera is set up to image. Some structure is usually visible along one edge of the bias image. This stable structure reflects the analog readout electronics responding to startup transients involved in beginning each row read out. Bias images also incur some thermal signal if the readout is slow and the camera is warm. This thermal signal introduces a ramp effect from one side of the bias image to the other. Referring to Figure 1., the thermal signal is uniform along rows and increases along columns.

Dark images are bias images along with the thermal signal accrued over the exposure time. Dark accrues more or less uniformly over the entire sensor although some areas of the CCD contribute thermal image at a higher rate than other areas. This non-uniformity is stable for a given exposure but can vary by 25% in localized areas.

Very bright "speckles" appear in dark images – in fact, they sometimes appear in bias images as well. These are the record in the CCD sensor made by the passage of highly energetic particles. Classical CCD imaging literature calls these particles "cosmic rays", in this manual they are referred to as spurious events. They are random in occurrence and must be located and eliminated by any of a number of methods described in Section 4.

2.6.2 Default Camera Readout Format

The default image size, as delivered by Spectral Instruments, reads out more pixels than the illuminated pixels. This readout mode calls for "overscan" pixels as well as illuminated pixels. Appendix A contains an illustration of overscan readout mode.

When overscan readout is employed, the images that result depend upon the design of the CCD sensor itself. Table 1. in Appendix A includes the settings necessary to overscan some representative CCDs. The illustration shows you how to relate each of the tabulated parameters to the image read from the camera.

The best image for showing all of the components of overscan readout is a dark exposure with a cold camera looking into an application that has a small light leak! This circumstance results in the light-sensitive pixels being differentiated from the masked pixels and those from the "imaginary" bias pixels that do not exist on the CCD sensor.

In a dark image, the signal from those pixels that are exposed to the same dark signal integration time all have the same brightness. With overscan, darker pixels show up along one edge of the image. These are readout pixels that did not integrate dark signal - they are the "imaginary" bias pixels that do not exist on the CCD sensor. Adjust the windowing of the software to show low pixel values as gray levels and you will see two distinctly different (in a warm camera) levels along one side of the image. The brighter level corresponds to physical pixels on the sensor, some of which may be masked to incoming light but can still detect dark signal. The other pixels are not physically on the sensor but rather are generated by reading past the physical extent of the edges of the CCD sensor.

2.6.3 Dark Image - Warm Camera

Insure that all external illumination is extinguished and obtain a ½ second dark image. The result is a dark image from a warm camera - a gradient in brightness shows up with the brighter pixels on the side of the image away from the serial register. This gradient results from those pixels farther away from the serial register having been exposed to more dark signal because they spent more time accumulating dark charge from the CCD during the readout itself than did those on the other side.

Some number of very bright spots may be visible. Most of these are pixels that generate an excess of dark signal compared to the average; they are hot pixels. These will, for the most part, disappear when the sensor is cooled. In fact, the warm dark image may be downright ugly - but it will clean up remarkably when the sensor is cooled.

Hot column defects are also visible. The test report lists the hot and dark columns on your sensor when it is operating at normal temperature.

3. Cooling The Camera

After the camera electronics have run for an hour and the cryo-cooler has sustained an vertical posture for the required four hours, it is time to turn on cooling. The camera head requires about one hour to achieve the operating temperature range and another 1/4 hour to become fully stabilized. Once the camera head has become thermally controlled it is possible to verify camera performance metrics as described below.

3.1 Image Quality

Now that the camera head is cold, a bias image is a uniform array of speckles with a low-level structure along the low-numbered columns. The image is really uniform, or else there is a light leak where the camera head joins the application or within the application itself.

A 300 second dark image is also uniform! The cold-CCD dark image integrates both internal dark sources and extraneous light and is therefor sensitive to light leaks in a way that short exposures are not. Light leaks are not uniform so they are revealed in dark images.

Large scale curves (quarter circles typically) or swirls in the 300-second dark are to be expected and reflect the non-uniform generation of dark signal as a function of position on the wafer, at which this CCD was built. Such patterns are normal and completely removable except that the increased noise (typically less than ½ count) is a permanent feature of longer exposures.

All “hot column” effects, except those noted in the test report, disappeared. Some number of bright speckles are clearly visible. These are now mostly “spurious events” with a few hot pixels contributing to the “cosmic ray count.”

Hot pixels are readily identified by obtaining a number of 300-second darks and performing a temporal median filter among the ensemble to determine those that are persistent. These pixels should be marked as defective and ignored.

3.2 Performance Metrics

Continuing to avoid exposing the CCD to light, it is time to measure some performance parameters. The SICCD camera meets three primary performance metrics, which can be verified without excessive time or instrumentation. These are:

3.2.1 Noise

The camera readout noise is determined by obtaining a bias image and noting the rms of the ensemble of pixels in a region of the image that does not contain some sort of cosmetic defect or spurious event. The camera test report shows the conversion factor from counts to electrons for each readout speed and attenuation state. Multiply the rms value by the conversion factor for the settings you are using to determine the noise in electrons. The result will be the noise reported in the test report 10%.

This test is sensitive to structure in the bias and at the factory, the noise is determined by subtracting two bias images to eliminate the structure. The result has twice the noise contribution so the rms of the difference image is divided by √2.

3.2.2 Dark Signal Generation Rate

Having insured, by Section 3.1, that all light leaks have been extinguished, it is possible to look at the second most important camera performance metric - the dark signal generation rate.

It is mandatory that the camera not have been exposed to any light signal since it was most recently cooled or else this measurement is subject to errors due to residual image retained in the CCD while the CCD is cold.

Obtain a 300 second dark image with a freshly cooled camera head and determine the mean signal from a region of the sensor that does not include any hot columns. Obtain a bias image at the same readout rate and attenuation settings and determine the mean value from the same region adjusted in location to avoid spurious events. From the mean count value of the dark, subtract the mean count value of the bias. Multiply the difference by the conversion factor for the attenuation used and divided by 300 to yield the dark signal generation rate in electrons per pixel per second. The result will agree with the test report within 10%.

Note that it may be necessary to bin - combine signal on the CCD sensor before readout - by four rows and four columns in order to increase the accuracy of measuring the dark signal. If this is done, the above dark signal calculation must be changed to divide the result by 16 since 16 physical pixels contributed to each measured "super" pixel.

3.3 Other Metrics

A number of other performance parameters are specified for SICCD cameras. All of these require a more elaborate setup to evaluate and are beyond the scope of this document.

If another metric is vital to your application, that performance metric - and its method of evaluation - have been established between Spectral Instruments and yourself and a process set up to validate that metric on each of your cameras.

4. Using The Camera

4.1 Kinds Of Images

An image obtained from a SICCD camera is made up of:

a) a dc offset, or bias, introduced to assure all pixel values are positive integers,
b) the thermal signature of your camera - the dark signal image, and
c) the target image at which you pointed your camera.

For bright targets, the bias and the dark may be negligible. For faint targets, especially those requiring a long exposure to get enough signal, the bias and dark must be subtracted.

4.1.1 Bias Images

The dc offset, or bias, is stable over a matter of days provided the environment is "laboratory." SICCD cameras on telescopes, where 40°F differences day-to-night are routine, require more frequent bias calibration images.

The dc offset, which provides the average value of the bias image, is introduced to be able to use the full range of the Analog-to-Digital Converter (ADC) by guaranteeing that the smallest signal will ever be greater than 0. Otherwise, one bit of the ADC is needed to tell whether a number is positive or negative. This halves the useful range of the ADC.

Structure in a bias image is typically due to transients that occur in SICCD-type cameras when a new row or column is started to be readout. These transients are small but the precision with which the camera electronics measures things is so high as to be able to "see" them.

The most important thing to understand about the bias image is that it is completely and irrevocably linked to the readout mode. This is because the transients visible in the bias image are totally different when a subarray is read, when the binning is different, when the attenuation is different. In short, when anything changes in a readout mode, the bias image changes - ever so slightly.

These small variations in offset over the image are important when you are fully utilizing the SICCD character of your camera. For many imaging activities the bias can be included with the dark as described in the next section.

4.1.2 Dark Images

A CCD sensor records incoming photons and converts them to electrons stored in an array of picture elements (pixels). Unfortunately, the structure upon which the CCD is formed also contributes thermal photons that result in indistinguishable electrons. These electrons obey identical Poisson statistics, which means that they also contribute noise. The noise from dark signal is the square root of that signal. An image with 16 electrons of dark signal contributes four electrons to the total system noise for that image. If you look only at readout noise and dark noise without considering image noise (reasonable for measuring the dark areas between bright areas) it doesn't take a lot of dark signal to mitigate a low-noise camera electronics design.

To reduce the impact of dark signal, Spectral Instruments 600 Series cameras utilize a refrigerated cooling system that allows the CCD to be operated at as low a temperature as is consistent with that CCD continuing to operate as a SICCD sensor. The low temperature limit for most CCDs is about -120^{o}C. At such temperatures, the dark signal may average one electron per pixel every twenty minutes (the actual value varies significantly with pixel size and somewhat among manufacturers).

Dark signal noise combines with readout noise as the square root of the sum of the squares (this is called quadrature). For a camera with a readout noise of four electrons and a dark signal of four electrons, the combined noise is 5.6 electrons. For a camera that is running at one thermal electron per 10 minutes, this means that it is possible to integrate for forty minutes before the noise from a dark image significantly degrades the total noise figure for the system.

Dark signal is not uniform in its distribution over an image. Variations in dark signal generation rate are all (but one - preamp glow) related to inhomogeneities in the sensor or in the substrate upon which it is built. Quarter circle (for a 1K x 1K sensor) or full circle (for larger sensors) bands are routinely visible in a 10-minute dark image. These bands are: a) low level and b) readily visible. The variation to be expected - the dark signal non-uniformity (DSNU) - can be as high as 25% for some CCDs. It is rarely less than 10%. Because the stable dark image patterns are visible and because the dc level is significant to low-light-level imaging it is important to correct for dark before quantitative analysis is performed.

4.1.3 Light Images

Light images are what you are after. They all offer their own individual "quirks" when it comes to making quantitative measurements. The most important of these "quirks" relates to non-uniform illumination. If you want to know how much signal is contributed by an event in one area compared to a similar event in another area you need to be assured that there is no instrumental effect affecting the measurements. There usually is!

The basic process for correcting light images is called “shading correction” in some literature, it is called “flat fielding” in other literature. If you can get a measure of the shading effect then you can compensate for it - although you can never recover the reduced signal in the shaded areas. This reduced signal means that the signal-to-noise ratio (SNR) is ever poorer in a shaded region than it is in a non-shaded region. The only fix for this problem is preventative - it is not recuperative.

4.2 Problems With Images - The Master Image Solution

4.2.1 Bias Images

If the read noise on your SICCD camera system is 4 electrons; that read noise applies to every image read from that camera. If you readout a bias image and then readout a second bias image they each have four electrons of noise. If you subtract the two of them to eliminate the dc offset and any structure, the result is very flat but has a noise of 5.65 electrons.

The same thing happens when you subtract a bias image from any other image - the noise increases somewhat.

Since the bias image is stable with time, for a stable operating environment, it is possible to create a master bias image that is the average of many individual bias images. This master bias has virtually no noise and can be used to provide a better bias offset and bias structure corrector than a “fresh-off-the-camera” bias with standard readout noise.

It is possible to use this master bias with small incremental dc offsets to correct for changes in the dc bias with time. The easiest way to implement this is to obtain an occasional “fresh” bias and determine the difference in the mean between the “fresh” bias and the master bias. To within ± ½ count the master bias can be adjusted to the current bias level of the camera without needing to obtain a new master bias. In this manner, the master bias provides a very accurate image of the bias structure. You adjust the dc level of this structure image to meet the current camera performance.

Almost every change in the behavior of the camera electronics is revealed in the bias image. The intrinsic conversion factor and the dark signal generation rate are the only parameters that are not essentially revealed in the bias from a 600 Series camera.

In order to maintain a camera performance record it is useful to generate a new master bias at regular intervals. It is necessary to renew the bias every time the system is moved or the environment is changed. Retain old master bias images in an archive along with a record of the noise level of the system at each epoch. Such a log is invaluable in detecting low level drifts in the camera electronics and/or the coupling of the camera to the application.

4.2.2 Dark Images

For a 600 Series camera, the dark image is equivalent to the bias image unless a very long (typically greater than five minutes) exposure is obtained. If all of the exposures to be obtained from your 600 Series camera are going to be the same duration with the camera in the same environment there is no need to obtain separate bias and dark images as master images. Average a large number of identical exposure dark images and you have a master dark+bias image.

Unfortunately it isn't quite that easy. Spurious bright or hot events show up in dark images. These are occasionally visible in bias images but the frequency is low enough that they disappear in the average that makes the master bias. Dark images, because they "sit" on the CCD for some tens of minutes, show numerous bright pixels. Some of these are single-pixel (probably hot pixels) and some of these are multi-pixel "blobs" or "streaks". These are images of the path taken by some exceedingly energetic particle as it passed through the sensor. These are called "cosmic rays" in classical CCD imaging literature. We call them spurious events because their source is likely much nearer than the general cosmos. Some buildings or sites virtually "glow in the dark". Glass products are notorious for thorium decay emissions that are very energetic. Brick buildings have particularly high natural background radioactivity that generates high spurious event count rates.

The best method of building up a master dark image is to select an exposure time that is the longest exposure you expect to use where this master dark image will be the reference. Obtain some number of dark images at this exposure and perform a temporal median or coincidence filter among them. Such a filter detects and rejects random bright pixels. For a given level of noise reduction, it takes more images using the median filter to obtain the same degree noise reduction that a smaller number of averaged images provides. The effective exposure time is that for each image, not the sum!

The result is a noise-free master dark + bias image with hot pixels. A decision must be made as to what constitutes a pixel so hot that is must be discarded. That determination is strongly a function of the application.

From this master dark image, subtract the master bias image formed above and record the resulting bias-corrected master dark image as the master dark image (with the effective exposure time also recorded somewhere).

Hot pixels must be discarded at some point. It is preferable to generate a master dark image that is hot-pixel-free since the end use of the master dark is for it to be scaled by the ratio of the exposure times for the target image and the master dark. Hot pixels don't scale as typical background dark signal pixels so they should be removed from the master dark image. Furthermore, having them gone from the master dark image makes it much easier to scale the display of the master dark image so as to see the dark image structure.

As with master bias images, it is very informative to retain the master dark images in an archive.

4.2.3 Light Images

The major extra-normal characteristic of a light image is the variation in attenuation experienced by photons traveling to each pixel. If they are all attenuated - but equally - the problem becomes one of scaling. Usually there is a strong spatial component to the attenuation so it is not possible to measure the counts of an event "here" and compare it to the counts of a similar event in the same image "over there" without having previously applied a correction for the spatial attenuation.

How to determine the spatial attenuation? The "pat" answer is to use a uniform illumination at the input of your application and record the image that results. Again, some averages are important because this master image is going to be used to divide into each target image and in this instance the photon noise in the flat image is inserted into each target image.

Uniform illumination comes somewhere between "eternal life" and the "elixir of youth" as holy grails to be sought after - unobtainable! The degree of difficulty is determined entirely by the application. In many instances the application was not designed so that a uniform illumination source could easily be introduced. Self-luminescent targets are most difficult. Microscopes are the most impossible instrument.

Never-the-less, it is essential to invent some means of introducing a known illumination pattern (even if it is not flat - so long as it can be modeled) and averaging some number of images that result.

Pinholes in front of wide-angle scattering fixtures, integrating spheres, LEDs and electro-luminescent panels are all options. For some applications it may be necessary to invent quite a complicated fixture to perform the measurement. It is typically necessary to perform this measurement only once.

Using the most uniform illumination possible, average a number of images that are exposed so that the bright regions are somewhat over ½ full scale. Exclude hot pixels found in the master dark image. Bilinear interpolation from the row-column quadrant neighbors is the easiest method.

Subtract the master bias image from the master flat image. Scale the master dark image by the ratio of the exposure time of the master flat image to the effective exposure time of the master dark image. Subtract the result from the master flat image. The result is a fully corrected master flat image that can be used on any target image obtained with the same equipment setup and readout mode.

4.3 Correcting Images

The preceding section discussed obtaining master calibration images. Presumably you now have a master bias, a master dark and a master flat image for the current configuration of your application and for the readout mode you are going to use.

Note that one-each of these master images is required for each configuration of the image readout, attenuation, binning etc.

4.3.1 Why

If you are just looking for something - you don't need to do a lot of image correction unless that something is at the noise limit of the image and may be affected by patterns in the bias+dark. In this case you need a master dark of the same duration - one that includes the bias. Subtract it and view away.

Similarly if you are looking for something among a sequence of images taken under the same conditions you usually don't need to correct individual images in the sequence unless patterns affect visibility and even then, forming the consecutive image derivative eliminates all regular patterns.

To inter-compare one region of an image with another you first need to correct for the variation in attenuation over the imaged field of view. No necessity to do separate bias and dark, all that is required is a uniform illumination image that has the same exposure time and has not been corrected for bias or dark.

After multiplying your target image by a constant and dividing it by the flat image you have a correct target image. You can measure a n x m pixel region here and another there and obtain means or sums over these regions where the differences are now due to events in the image and not to artifacts in the light path.

If sequences are to be compared with other sequences obtained at a different time with a possibly slight difference in environment, it is necessary to reduce the light images to as close to an absolute scale as possible. For this you need all three calibrators.

4.3.2 How

The three calibration constituents must each be manipulated differently. The master bias is used as is. The master dark image must be multiplied by the ratio of the exposure time of the target image to the effective exposure time of the master dark image. For most imaging systems this scaling is by integer values, as floating point images are not usually used.

When you actually apply an image correction, the target image must first be multiplied by the mean of the master flat image before it is divided by the flat image in order to preserve the significance in integer format images. Select a “typical bright” area in the master flat, set a region of interest and determine the average value in this region of interest. Record the value of the mean in this master flat image “bright area”. This mean is the multiplier or “scaling parameter” you will use to scale all target images that will be corrected using this master flat image.

Now you have a master bias, a master dark that has been corrected for hot pixels and an master flat with a scaling parameter. You are ready to proceed to correct a target image.

Bring up the target image and subtract the master bias. Multiply the master dark by the ratio of the exposure times and subtract it from the target image. Multiply the target image that has now been bias and dark corrected by the scaling parameter obtained above. This step requires that the result be an extended precision image. Either floating point or signed long will suffice.

Now divide the scaled target image by the master flat image. This step requires promoting the master flat image to the same type as you selected for the scaled target scene image before the division. It may also require a demotion of the result to a shorter word-length afterwards.

The result is a new version of the target image where the shading pattern is removed. This is a flat-fielded target image.

4.3.3 Limitations On The Flat Field Process

A flat field correction process depends upon stability in the illumination and the attenuation. CCDs are strongly wavelength sensitive. The quantum efficiency variation across the sensor is different for different wavelengths of incoming light. Therefor, flat field images vary with the color of the incoming light – especially if that light is in a very limited wavelength band. The target images and the master flat images must be exposed to nearly the same color of light.

The flat field is also sensitive to illumination angle of the incoming light. Since collimated light shows up many optical defects, such as dust, in a way that wide angle illumination does not, it is important that master flats and target images are both obtained with similar (if not identical) illumination beams.

4.3.4 Understanding The Scaling Effects

The example posited above derived the scaling number from the brightest area in the master flat image. After correction, the values of pixels in the target image are essentially unchanged in the area of the ROI from which the mean was determined. Any number you might have used would work for scaling the target image to preserve significance in the pixel values provided it is large enough. It does not guarantee that the magnitude of the pixel values is now "correct".

Provided that the master flat image and the target images are restricted to exposures producing images that are less than half full scale, the scalor 30000 retains the theoretical maximum pixel value. For general inter-comparison among a number of images even the scalor 10000 is OK as the dynamic range is retained.

Clearly, the value of the scalor affects the magnitude of the resulting images. For inter-comparison among a number of different sets of images or sequences of images a constant scalor for the entire set is essential - as is a constant setup so the same master flat field image reflects the spatial attenuation and the constant scalor assumption is valid.

To determine the base and scale factor to reduce images to an absolute scale requires introduction of known objects into the application "field". Most measurements are relative. You look for changes in intensity within an image or from image to image. Few measurements require absolute measurement scales.

5. Camera System Warranty And Service

The 600 Series camera is warranted for 12 months after shipment. Any failure that occurs within that period, that is not due to mishandling or operating the camera under conditions that void the warranty, is repaired at no charge to you. Opening either the camera head or the camera electronics voids the warranty - except that those camera heads with internal vacuum ports may be opened for the express purpose of pumping the camera.

5.1 The Warranty Conditions

The camera is warranted against failure of any component and against failure due to manufacturing processes for the warranty period.

Operation of the camera under environmental conditions that are outside of the operating specifications voids the warranty.

The camera system is not warranted against damage from mishandling or for damage that occurs from natural or man-caused conditions such as flood, fire, wind, lightning etc.

5.2 Returning A Camera For Service

A 600 Series camera can only be serviced at the factory. You must obtain a Return Material Tracking number from Spectral Instruments customer service department before any camera component is returned for service.

5.3 Diagnosing A Camera Problem

There are no user serviceable components in either the camera head or the camera electronics unit and it is highly likely that the user could exacerbate a problem by attempting to “open something up.” Spectral cameras are assembled in a anti-static clean room to insure the safety of the CCD and the cleanliness of the camera interior. Only the following diagnostic procedures are authorized. Section 8., troubleshooting, describes in detail how to perform the diagnostic tests that are permitted. The result of such tests is primarily to distinguish between a cable problem (bad connection or broken cable), a camera problem and an application problem.

5.3.1 Fuses

If the camera does not turn on when plugged into the appropriate mains power a fuse could be the problem. If this is a first-time turn on for the camera system and it fails to power up, check that the power setting indicated on the power entry module is appropriate for the incoming power. The small white dot indicates which of the four available power settings the system configured. It MUST be correct for the camera to operate. If the controller was plugged into mains power with the wrong power setting, a fuse could easily have burned out. This is especially the case running a 220-volt camera on 100 or 110 volt power because the installed fuse is only half the required rating for the lower voltage.

If the PWR indicator on the camera head does not come on and the controller fans are not running, the cause is probably a blown fuse or fuses. The user serviceable fuses are located in the power entry module. The procedure for setting the power entry module for the correct power is given in section 2.3.2. The fuse ratings are also given in section 2.3.2.

Test the continuity of the fuse(s) using the resistance setting (or “beep”) of a VOM and replace any failed fuse. Replacement fuses must be TUV approved 5x20 type as no other fuse fits the holder properly.

5.3.2 Missing Signal - Video Cable(s)

The video cable(s) are the only cables that can be disconnected without interfering with the operation of a camera - that is to say, without turning off the power to the camera electronics unit.

Disconnecting the video cable can provide some useful information. A camera with more than one port is provided more than one video cable. In this instance, interchanging video cables between video ports also can provide some level of diagnostics.

When a camera seems to have changed its performance characteristics, it is important to be able to obtain the standard types of images referred to in Section 2.5. One of those images is the bias. When the video cable is disconnected at the camera controller the resulting image is a very quiet bias if the camera analog signal processor is operating properly. Determining the difference between a bias image with the camera head video cable plugged in and with it disconnected can assist in determining some sorts of camera problems.

On a camera system with more than one video port, an apparent failure in one of the video ports can be traced to the camera head or the camera electronics unit by swapping the video cables and determining if the problem follows the cable or the port. This information allows the possibility of swapping a field replaceable component if the failing module can be reliably determined.

5.4 Determining When To Refresh The Vacuum

5.4.1 Measuring The Camera Head Pressure

A Spectral Instruments 600 Series camera head includes a sensor that measures the pressure inside the camera head. This sensor operates over a pressure range from 10^{-2} torr to ~10 torr. A facility is provided within the 600 Series camera head status feedback to report the current camera head pressure. Software supplied by Spectral Instruments incorporates this capability into a user status report on the pressure inside of the camera head vessel.

When the camera vacuum has been recently refreshed, the pressure readout from a warm camera head is typically less than 2 torr. As this camera cools, the camera head "cryo-pumps" until the pressure indicator is off scale to the low-pressure end of the scale.

As the camera head pressure degrades due to molecular diffusion through the O-rings, the "warm" camera head pressure reading shows the rise in internal pressure. When the "warm camera" internal pressure reaches 2 torr, it is time to refresh the camera head vacuum by pumping the camera head.

The pressure at which refreshing the vacuum is required is different for different camera applications. The 2-torr value given above is a typical limit for cameras where the CCD is not in close proximity to the camera window. For your camera, refreshing the vacuum may be required at a lower pressure than 2 torr.

5.4.2 Why Pump

A SICCD camera is operated at a reduced temperature in order to eliminate the effects of thermal signal (dark signal) in images obtained from the camera. This reduced temperature affects several camera components.

When the camera head pressure rises so much that the convective heat load overwhelms the cryo-cooler, the camera does not cool down at all.

The first effect of a camera with an elevated pressure, but still low enough to cool the CCD, is upon the camera head window which is less than 0.5" from the CCD. The window is cooled by the proximity to the CCD because of: a) radiative cooling and; b) convective cooling. Spectral Instruments incorporates a low level heater around the window to counteract the normal radiative load. The convective load from a slight vacuum can overwhelm this heater and cause the window to "frost" on the outside during initial cooldown causing water to condense on the window exterior. This condition results in a clearly visible pattern in flat scene images.

The second effect is that the camera will not cool.

The CCD contains an accurate internal thermometer, which is the dark signal generation rate. When the dark signal has doubled, the temperature has increased by about 6°C. Ultimately, it is the performance of the camera in the application environment that dictates the importance of refreshing the vacuum. If the camera exhibits evidence of condensation, or if it has too high a dark signal generation rate the vacuum should be refreshed.

5.5 Refreshing The Camera Vacuum

The Spectral Instruments 600 Series camera provides a valved port for refreshing the vacuum inside the camera head. It is necessary to refresh the vacuum when the infusion of air through the camera head O-rings raises the pressure higher than 10 torr. Failure to service the camera when the pressure has risen above 10 torr risks damage to the CCD sensor inside the camera head.

The two forms of the 600 Series cameras require somewhat different processes to get at the vacuum port and the vacuum valve. Figure 6. shows how 600 Series cameras that have externally accessible vacuum ports can be identified. Section 5.5.1 below describes the equipment required to pump cameras with either internal or external port access.

5.5.1 Equipment Required

The cutaway in Figure 7. depicts a camera with an internally accessible vacuum port. Figure 6. shows how the camera looks from the back side when the vacuum port is accessible from outside the camera head cover. If the vacuum valve and vacuum port are not visible externally, the cover must be removed to obtain access to the valve and port as shown in the cutaway.

5.5.1.1 Vacuum Pump And Vacuum Hose

For both internal and external valve cameras, the basic vacuum pumping equipment is identical. A vacuum pump that can pump to 10^{-3} torr is recommended. Pumping to 10^{-2} will suffice. The pump must be safeguarded against vacuum oil contamination by an appropriate filter if the pump system is not oil-free. Table 1, below, provides a parts list of suitable vacuum pumping equipment. The list below itemizes a pump station that can be obtained through the Kurt J. Lesker company at 4414 Highway 75 S., Sherman, TX 75090 (1-800-245-1656). The other parts are available from the McMaster-Carr and Swagelok catalogs. The entire kit can be purchased from Spectral Instruments as Part # 2268 “Assy, field service vacuum pump system”.

1	ED-A37122919	Kurt J. Lesker	220-volt 1.5 cfm mechanical pump
1	ED-A37122902	Kurt J. Lesker	110-volt 1.5 cfm mechanical pump
1	MMA-077-2QF2	Kurt J. Lesker	220-volt Micromaze foreline trap
1	MMA-077-2QF	Kurt J. Lesker	110-volt Micromaze foreline trap
1	ED-A46220000	Kurt J. Lesker	Exhaust mist filter
1	QF10-16-ASRV	Kurt J. Lesker	Adaptive centering ring
3	QF16-075-SRV	Kurt J. Lesker	centering ring
3	QF16-075-C	Kurt J. Lesker	Aluminum clamp
1	QF16XFNPT4	Kurt J. Lesker	Female Pipe Adapter
1	48805K38	McMaster-Carr	Type 316 SS Instrumentation Threaded Pipe Fitting - Adapter Female-male
1	48805K71	McMaster-Carr	Type 316 SS Instrumentation Threaded Pipe Fitting - Hex coupling
1	54875K13	McMaster-Carr	72” Hi-Pressure Flexible SS Braided Hose Assembly NPT M-M
1	SS-4-UT-1-4	Swagelok	¼” Cajon fitting - ¼” male pipe thread

Table 1.
Parts List For A Vacuum Service Pump

Note that both 110 volt and 220 volt part numbers are listed but only one each pump and foreline trap are required.

The exhaust filter is screwed into the exhaust port of the pump using standard teflon tape. The foreline trap is mounted onto the vacuum inlet port to the pump using an adaptive centering ring and an aluminum clamp. Onto the opposite side of the micromaze filter, another adaptive centering ring and clamp hook up to the female pipe adapter.

It is necessary to bake out the foreline trap by hooking up the wires to an AC voltage source. It is important to shield the exhaust mist filter from the heat generated in the Micromaze filter if this filter is baked out on the pump. Note that baking the Micromaze filter on the pump with the pump running and the hose end sealed is the recommended process in order to most rapidly exhaust the water vapor.

Screw the female-male adapter into the female pipe adapter so that the 3/8” hose can be connected to the pump. At the camera head end of the hose, use the hex coupling to attach the Cajon™ fitting to the vacuum hose.

5.5.1.2 Vacuum Hose Fitting

The vacuum port on a 600 Series cameras is a ¼" metal tube that extends from the vacuum valve. The end of the vacuum hose that connects to the camera head must be equipped with some suitable attachment mechanism for sealing to this ¼" metal tube. A ¼" Swagelok Cajon™ fitting for a ¼" metal tube vacuum port is recommended.

5.5.1.3 The SI Vacuum Valve Actuator

The SI 620 camera head with an externally accessible vacuum port is equipped with a proprietary valve that can be operated through a special valve actuator. This actuator is SI part number 2212. An actuator is shipped with each camera in an envelope attached to the camera head. It is recommended that the actuator remain with the camera head so it is readily available when required.

5.5.2 The Refresh Process

It is frequently desirable to refresh the vacuum without disturbing the alignment of the camera to the application. If the camera is mounted into the application so that the vacuum port (whether external or internal) is accessible, then it is only necessary to warm up the camera to room temperature in order to pump it. External vacuum port cameras can be pumped while the camera is running but not cooling - this provides a built-in temperature monitor and a vacuum gauge.

First turn off the cryo-cooler. Allow the camera head to warm up until the temperature of the CCD is approximately 20^{o}C (this will take three to four hours).

5.5.2.1 Purging The Vacuum Pump And Hose

The vacuum hose should be stored at atmospheric pressure with plug in the end of the hose so it can be kept clean between uses. A piece of ¼" brass that has rounded ends makes an adequate plug. The first step is to make certain that the camera end of the hose is plugged up and then turn on the pump so as to refresh the vacuum in the hose. This guarantees that the hose is clean.

5.5.2.2 Accessing The Internal Vacuum Port

Turn off the power to the camera controller and disconnect the camera head power, video and control cables as well as the shutter and window heater cables.

Remove the four M5 SS Socket Head Cap screws holding the cover onto the camera head. Carefully move the camera cover back up the cryo-cooler lines and anchor it to the gas lines using tape..

Refer to the cut-away section of Figure 7. which illustrates a vacuum hose attachment to the ¼" vacuum port on the camera.

5.5.2.3 Attaching The Vacuum Hose To The Camera

Remove the camera head vacuum valve cap, if one is covering the vacuum port, and set it aside for the duration of the vacuum refresh.

Turn off the vacuum pump and remove the vacuum plug from the end of the hose. Attach the hose to the ¼" camera head vacuum fitting and clamp securely. Turn on the vacuum pump and purge the line again.

Make certain that the vacuum system is operating properly and that the vacuum hose is properly connected as you are about to open the vacuum valve to the camera head. Damage could occur to the CCD if errors are made.

A vacuum gauge in the line between the camera head and the vacuum pump is a valuable asset to assure that the entire pumping system + hose are operating at a pressure $< 10^{-2}$ torr.

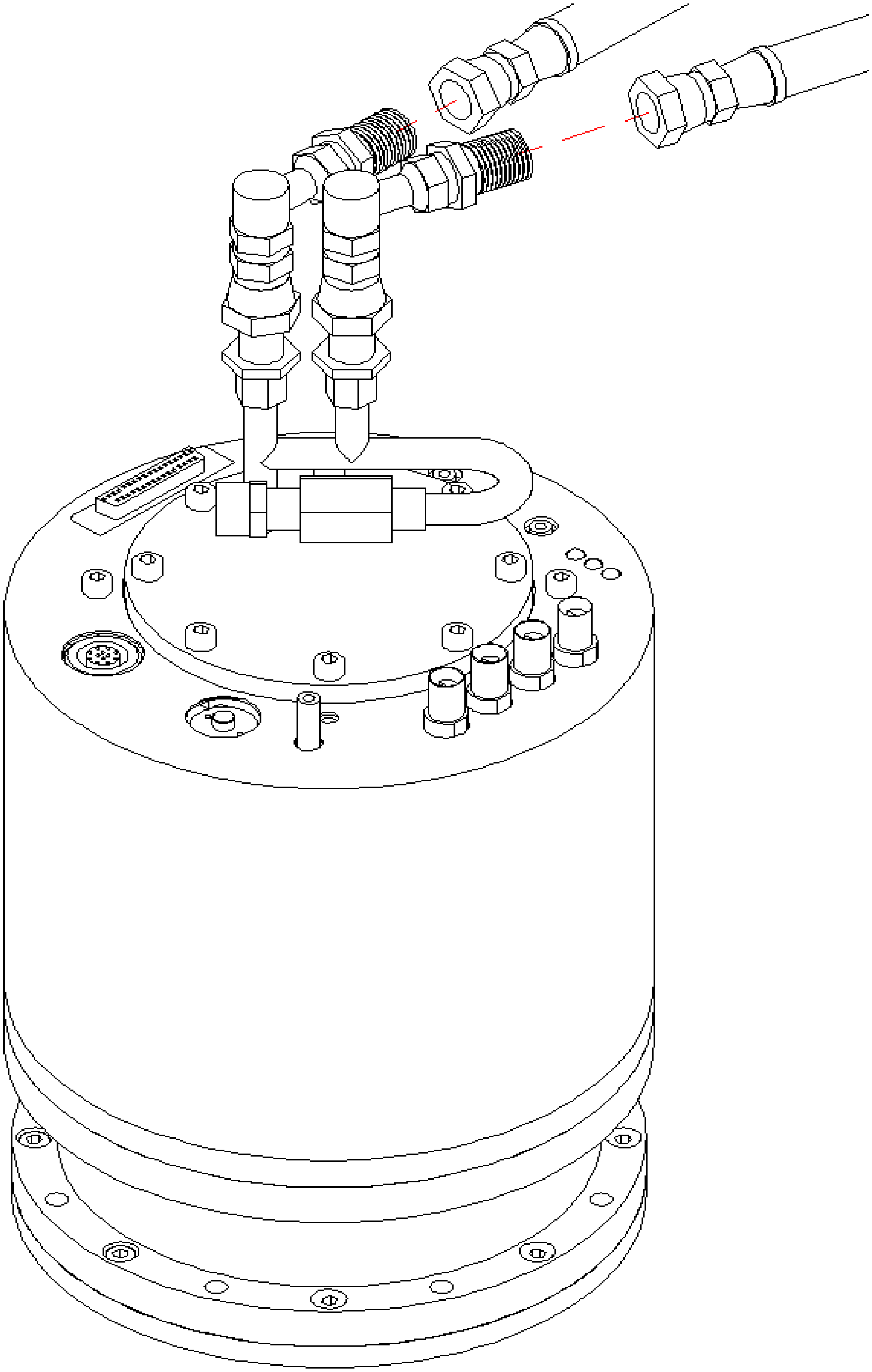


Figure 6.
Illustration Of External Vacuum Port Series 600 Camera Head

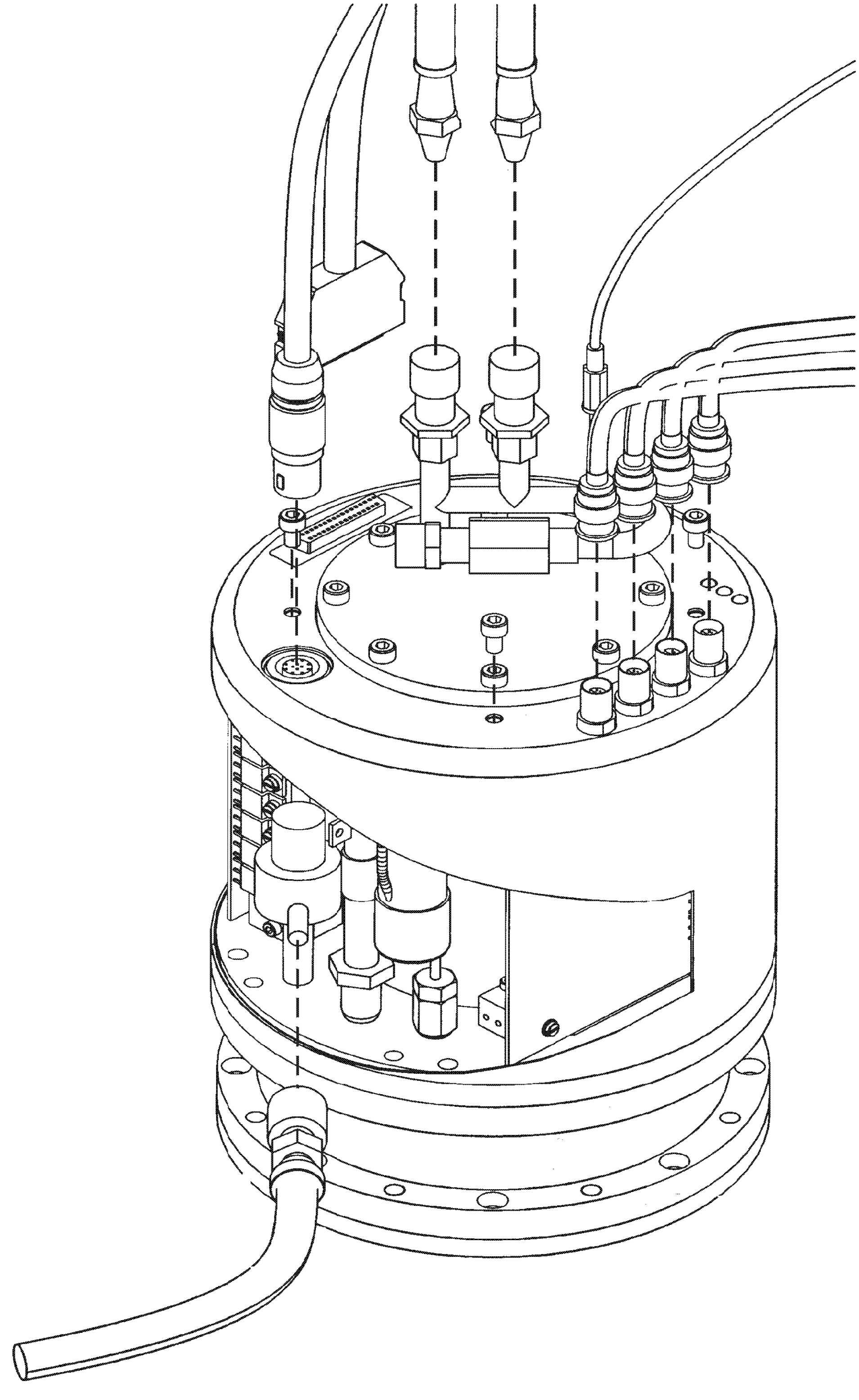


Figure 7.
Illustration Of Internal Vacuum Port Series 600 Camera Head

5.5.2.4 Pumping The Internal Vacuum Port Camera Head

WARNING: *If the camera head is suddenly vented damage to the CCD is likely.*

With the vacuum pump running and the vacuum hose securely attached to the camera, rotate the green vacuum valve 3 full turns counter clockwise (as viewed from the back of the camera head) to open the valve. Run the pump with the valve open for approximately 3 hours.

Rotate the green vacuum valve clockwise (as viewed from the back of the camera head) to close the valve. Gently turn the valve until it resists further attempts to turn it clockwise indicating that the valve is properly seated.

Turn off the vacuum pump and remove the vacuum hose from the camera head. Slide the cover back down over the camera head. Replace the four M5 screws. Insert the plug into the vacuum.

Connect the camera head cables to the camera electronics unit. Turn on the power to the camera electronics unit but leave the cryo-cooler turned off.

5.5.2.5 Pumping The External Vacuum Port Camera Head

With the vacuum pump running and the vacuum hose securely attached to the camera, open the valve by removing the metal cover over the vacuum valve port and inserting the vacuum valve actuator (SI part # 2212) into the vacuum valve port on the back of the camera head, Figure 6. The actuator has two pins on the end, which, upon rotation of the actuator, will engage matching receptacles in the camera head vacuum valve. The valve into which the actuator is inserted will show a visible gap between the top of the valve and the “C” spanner lock on the top end of the valve stem.

Rotate the vacuum valve actuator 3 full turns counter clockwise (as viewed from the back of the camera head) to open the valve. The first turn will take up the slack until the “C” spanner lock is engaged and then the valve will exhibit a noticeably different “feel” as the valve opens. Run the pump with the valve open for approximately 3 hours.

Rotate the vacuum valve actuator clockwise (as viewed from the back of the camera head) to close the valve. Gently turn the valve until it resists further attempts to turn it clockwise indicating that the valve is properly seated.

Turn off the vacuum pump and remove the vacuum hose from the camera head. Insert the vacuum hose plug into the vacuum hose and turn on the vacuum pump so as to purge the vacuum hose once more. Insert the camera head vacuum valve cap over the vacuum valve.

5.5.2.6 Verification Of The Camera Vacuum

If the camera was not already running to monitor the temperature and pressure during the pumping process, start the application software (the software used for this step must be able to read and report the camera head pressure). The pressure reported must be below 10^{-2} torr else the camera head vacuum refresh process failed.

Call Spectral Instruments Customer Service for assistance on how to proceed if the vacuum refresh process failed.

5.6 The Thermal Protection Circuit

Some cameras requires that a thermal protection circuit to be stabilized before the cryo-cooler is turned on. This is the window heater on the camera head. Normal operating mode for these cameras calls for the electronics unit to be operating for approximately one hour before the cryo-cooler is turned on so the low-power window heater circuit can establish the appropriate thermal environment.

For thermally protected cameras, whenever the incoming mains power turns off and then back on, the DSP must be re-initialized before the cryo-cooler relay is allowed to be turned back on.

5.7 Cleaning The Window

Cleaning the window is not a recommended practice as it is hard to make the window better by cleaning unless it is done very carefully. Cleaning could be required when shadows formed by out-of-focus dust specks interfere with normal operation of the camera. If the camera head was mishandled and fingerprints got on the window they must be removed by cleaning.

Cameras that are integrated with a lens in a close-coupled imaging fixture rarely require cleaning the window for two reasons: a) the tight connection typical of fast lens attachment to a camera doesn't allow many openings for dust to get on the window, and b) fast imaging systems are not sensitive to dust on the window.

5.7.1 Equipment Required

A high intensity light, such as is used for critical inspection of parts, where the lamp is mounted on the end of a flexible wand

An optical "duster" which is a can of non-abrasive non-aggressive compressed gas designed to clean optics
A small plastic fiber "probe" in a collet
A lint-free wipe, a Texwipe TX1010 lint-free wipe is recommended
A small quantity of methanol, ethanol and/or toluene

5.7.2 The Process

Set the camera on its side so that the shutter/window is easily accessible. Set up the high-intensity light probe so that a grazing incident beam can be directed at the window.

If a shutter is mounted onto the front of the camera, it must be removed before the window can be cleaned. Disconnect the shutter power cable. If one is attached, also disconnect the shutter output status cable. Carefully unscrew the shutter and set it aside.

This leaves the window exposed so the camera must be handled carefully to avoid scratching the window. The window is held onto the front of the camera by the vacuum inside the camera.

Turn on the high-intensity light and critically examine the front of the window by shining the light onto the window at a high incidence angle.

If you don't see anything - don't do anything. If you see a speck of light "glinting" off a particle first try dislodging the particle using the probe. Cautiously assist the probe with light "whiffs" from the duster.

If there is a smudge on the window apply acetone or toluene to a small area on the lint free cloth and wipe gently to dissolve the material. Check for lint and remove if any is observed.

Screw the shutter back onto the front of the camera and plug in the connectors.

Install the camera head into the application.

6. Field Replaceable Components

6.1 Cables

6.1.1 Camera Head Cables

The controller to camera head electrical cables are bundled into a protective flexible nylon conduit with shrink wrap closures on each end. The ensemble and the components have part numbers as listed in Table 2.

Item	Part #	Description
1	2106	Cable, 600S Power/Signal/Shutter, 1 Channel 27’
2	2106-1	Cable, 600S Power/Signal/Shutter, 1 Channel 12’
3	2008	Cable, 600S Power/Signal, 1 Channel 12’
4	2008-1	Cable, 600S Power/Signal, 1 Channel 27’
5	2000	Cable, 600S Power/Signal, 4 Channel 12’
6	2000-1	Cable, 600S Power/Signal, 4 Channel 27’
7	1665-10	Cable SCSI2 50 Pos. Make 12 ft
8	1665-11	Cable SCSI2 50 Pos. Make 27 ft
9	1666-10	Cable, 600 Series DC power, 12’
10	1666-11	Cable, 600 Series DC power, 27’
11	1671	Cable, Twin axial 12’ White
12	1671-1	Cable, Twin axial 12’ Red
13	1671-2	Cable, Twin axial 12’ Green
14	1671-3	Cable, Twin axial 12’ Yellow
15	1671-4	Cable, Twin axial 27’ White
16	1671-5	Cable, Twin axial 27’ Red
17	1671-6	Cable, Twin axial 27’ Green
19	1671-7	Cable, Twin axial 27’ Yellow

Table 2.

Individual cables can be ordered to replace those that fail or a replacement ensemble cable can be ordered. When an individual replacement is ordered, it cannot easily be installed in the conduit although this task is not impossible.

6.1.2 Camera Controller To PDCI Cable

The camera controller to PDCI cable part numbers are given in Table 3.

Item	Part #	Description
7	1664-10	Cable, SCSI2 68 Pos. Male 25ft
8	1664-5	Cable, SCSI2 68 Pos. Male 60ft

Table 3.

6.1.3 Cryo-cooler Refrigerant Lines

The two cryo-cooler refrigerant lines for any system are identical although once in use they are differentiated as SUPPLY and RETURN. The part number is are given in Table 4. below. They can be replaced as required. Both labels are supplied on a replacement configuration. Determine which line is to be replaced and apply the appropriate marking to the replacement line - discard the other label.

Item	Part Number	Description
1	2266	Gas line, Cryotiger Std. Flex straight-90 PT-16 10’
2	2266-1	Gas line, Cryotiger Std. Flex straight-90 PT-16 25’
3	2266-2	Gas line, Cryotiger Std. Flex straight-90 PT-16 5’
4	2267	Gas line, Cryotiger Std. Flex straight-90 PT-30 10’
5	2267-1	Gas line, Cryotiger Std. Flex straight-90 PT-30 25’

Table 4.

6.1.4 Cryo-cooler Interlock Cable

The Cryo-cooler thermal protection cable is Part # 1808. It can be readily replaced as required.

6.2 The PDCI Card

The PDCI card is Part # 1527. There are no switches or settings that need to be set up for a replacement PDCI card if it is used with SI-Image software. The card has a provision for an external serial input if your software must use a standard comm port rather than the UART on the PDCI module. To use an external serial communication source the two jumpers on J5 must be moved from INT to EXT and the serial. A cable must connect between your RS232 source and the 5-pin header on the module at J4. This cable can be acquired from Spectral Instruments as Part # 2301. It is also identical to the cables used in standard computer mother boards to bring RS232 signals to a plug-in slot.

This module contains a second (shorter length) 5-pin header at J3 that is used only with special cameras that require data format translations. This header is open for standard cameras.

Finally, the single row eight-pin (one empty) header at J6 is not to be used as it provides factory access to downloading the firmware in the module. Mess with this header and the firmware download could be lost!

6.3 The Camera Controller

Spectral Instruments maintains a complete service record for every camera system shipped so a replacement controller can be set up with the same conversion factor and offset as the original equipment. The serial numbers of the camera head and controller (combined) drives the proper replacement configuration.

The baud rate at which the camera operates is set on the mother board inside of the controller. The standard factory setting is 19,200 baud. If you are using a different baud rate it is necessary to remove the cover to the controller and move the jumper to the proper setting as indicated on the silk screen printed adjacent to the baud rate jumper pins.

Four baud rates are available: 9600, 19200, 38400 and 57600. They are selected by the two jumpers on JP1 and JP2. No jumpers selects 9600, a jumper only on JP1 selects 19200. A jumper only on JP2 selects 38400 and both jumpers installed selects 57600.

6.4 The Camera Head

Spectral Instruments maintains a complete service record for every camera system shipped so a replacement head can be set up the same as the original equipment. The serial number of the original camera head drives the proper replacement configuration.

6.5 The CryoTiger Compressor

The compressor is part number 1797 or 1797-1 for PT-30 or PT-16 gas respectively. Depending upon the nature of the problem, the camera head and coolant lines may also need to be returned for service if the system lost refrigerant due to a compressor failure.

A service pack of refrigerant gas can be obtained from Spectral Instruments or from a nearby APD service center. Two different types of gas are used depending upon the thermal load of the camera. PT-30 gas is used with all of the fiber bonded camera heads. Otherwise the gas is PT-16.

WARNING: *Do not use the wrong gas type as the system will not operate properly!*

Refer to the APD Cryo-Tiger manual for more information about the location of service centers.

The APD Cryogenics part numbers for the gas top-off bottles are:
91582530 for PT-30 and 31582516 for PT-16.

7. System Operation And Safety

7.1 Electrical Requirements

7.1.1 Incoming Power

The camera system must be connected to properly installed incoming mains AC power. It is important that an electrical transient surge protector be included somewhere in the incoming mains AC power to the camera system.

7.1.2 Power Cords

For U.S. shipments, two AC power cords are provided. No power cords are provided for shipments outside of the U.S.

7.1.3 Power Required

The camera electronics unit requires 150 watts of steady state power. The cryo-cooler requires 500 watts of steady state power. The turn-on transient for the camera electronics is negligibly higher than the operating condition. At turn-on the cryo-cooler draws 750 watts for 10 seconds before assuming operation conditions.

7.2 Physical Operating Conditions

7.2.1 Temperature

The operating temperature range for the camera system is 15^{o}C to 35^{o}C. The non-operating temperature range for the camera system is -10^{o}C to 50^{o}C. Note that it is a requirement that the camera be allowed to stabilize within the operating temperature range before it is turned on.

7.2.2 Humidity

The operating humidity range for the camera system is 10% R.H. to 50% R.H. The non-operating humidity range for the camera system is 5% to 95%. Note that it is a requirement that the camera not be operated when condensation is forming on any of the camera components.

7.2.3 Altitude

The camera system is rated to operate from sea level to 10,000 feet in elevation. The non-operating altitude range is the same.

7.2.4 Vibration

The camera system must not be subject to either high-impact (> 3.5g) forces or to steady state low-level mechanical vibration. Shock absorbing interfaces must be used in instances where either condition might otherwise be exceeded.

7.2.5 Aggressive Vapors

The camera system must not be exposed to aggressive vapors. Specifically, salt-laden air causes micro-crystals of salt to form on all of the components inside the camera electronics unit and the camera head. These ultimately lead to low-level signal interconnects which could damage the CCD.

Any other corrosive air will also introduce faults that could damage the CCD.

The air flowing over the fan and consequently over the components must also not contain micro-particles that can build up into macro-particles that are electrically conductive because of potential damage to the CCD if low-level signal interconnects result.

7.3 Warnings

7.3.1 CryoTiger System

The CryoTiger cryo-cooler comes with a manual. In that manual a number of warnings are listed. These warnings must all be respected else a serious failure could occur.

The CryoTiger cryo-cooler uses refrigerant that is flammable. If a gas leak occurs the room should be vented immediately.

Of high importance are those warnings relating to disconnecting the refrigerant lines from either the camera head or the compressor. It is very important that each and every disconnect occurs only after the camera system is at ambient temperature. This may take up to three hours after the cryo-cooler is turned off.

It is necessary to operate the camera electronics with the window heater turned on for at least one hour before the cryo-cooler is turned on.

7.3.2 Electrical System

The camera system must be protected from electrical transient events that come over the mains power system. Failure to adequately isolate the camera from electrical transients risks damage to the CCD.

7.3.3 Camera Electronics - Camera Head

Never disconnect the power cable or the signal cable between the camera head and the camera electronics unit while the latter is powered on. This power cable delivers operating voltages to all of the static and clocked voltages at the CCD. If this should occur, the alarm is turned on and remains on until the controller is re-initialized.

7.3.4 Opening The System

The camera head has no user-serviceable components that are accessible by removing covers. One exception is the cover on the back of the camera head for those camera heads with an internal vacuum refresh valve. In this instance, the precautions given in section 5.5 must be followed else damage could occur to the CCD.

The camera controller cover can be removed to change the baud rate as described above. Turn off the power, unplug the AC line cord and disconnect the camera head cables before opening the camera electronics unit.

7.3.5 Refreshing The Vacuum

The camera must be at room temperature before the vacuum is refreshed.

7.3.6 The Camera Window

The camera window is recessed only 0.005 inches behind the front flange of the camera. If the camera front is exposed, be very careful not to set it down on something that could scratch the window!

The window is not held in by a retaining ring. The vacuum inside the chamber holds the window against the O-ring. If the vacuum is lost entirely, the window will stay mounted if it is not “touched” due to surface tension of the vacuum grease. If the vacuum is lost, be as careful as possible in pumping the camera head so that the window does not become dislodged.

If the window should become dislodged call Spectral Instruments customer service immediately for advice on what to do next.

8. Troubleshooting

8.1 Image Quality Issues

The following image quality items do not exhaust the possible image quality syndromes but these are common ones. The discussion here is to assist in determining whether or not the problem can be rectified in the field.

8.1.1 No Image

This condition can range from “all zeros in the image” to “just a bias” to “fully saturated images.” Treating these three alternatives in order:

8.1.1.1 All Zeros

Zero is very difficult to produce through the video signal processing system. It implies that something has “railed”. It is not possible for the video cable to have a short that produces a zero since a DC offset is introduced in the analog processing system to move “no signal” up to some non-zero DC level going into the ADC.

Disconnect the video cable from the camera electronics unit. If the “zeros” persist the problem is in the camera electronics unit. If a normal bias is recorded then the problem is in the camera head. There is nothing that can be done by the customer in either case except that it may not be necessary to return both the camera head and the camera electronics unit.

8.1.1.2 Just A Bias

“Only a bias” image implies that the video signal from the camera head has disappeared. If the camera has been operating properly and suddenly ceases to produce images it is important to look at “what has changed”. If the camera was moved or anything disconnected check that the camera has been properly reinstalled. Check that the video cable is properly connected both at the camera head and at the controller.

Next, it is necessary to make certain that the problem is in the camera. If the camera is warm obtain a 1-minute dark. If it is cold, obtain a 10-minute dark. Either image will exhibit the characteristic pattern of a dark image from a CCD camera if the CCD is working and connected to the electronics unit that is also working. If the image is still very flat without any gradients or bright spots then the CCD is truly not providing image data.

If a dark image is observed, check the application interface to see if the source of illumination is blocked or not enabled somehow because the camera is working. Look for an inoperative shutter module.

If no dark image is observed, the next item to check is that the video cable is connected properly. It is important to carefully examine the noise level on the bias image because, if the CCD is operational it will provide more noise than is read from the ADC only. If the RMS is < 0.95 counts then the CCD is not contributing to the signal and the camera head is suspect. If the RMS is > 1.05 counts it is probable that something else has failed.

A broken video cable also could be at fault. If the video cable is bundled with the power and communications cables it is unlikely that the video cable is damaged. Nevertheless, inspect the cable and the two ends of the video cable to make certain that no damage is seen.

Finally, the video cable is a twin-axial cable. There are three components to this cable - each of which must exhibit continuity from one end to the other. The outer shell at each end of the cable must be connected and not be shorted to either of the interior pins. The two internal pins must also be connected and not crossed. Note the difference in appearance of the two pins - one is recessed more than the other. When checking continuity check the recessed pin on one end with the pin that is not recessed on the other. If the cable checks out good then something inside has failed and the system must be returned for service.

8.1.1.3 Fully Saturated Image

A fully saturated image is equivalent to an "all zeros" image - it is difficult to obtain from the analog signal processing system. However; the light from even a darkened room is enough to saturate the CCD. Again, disconnect the video cable and determine whether the saturated condition persists. If it does, the problem is in the camera electronics unit, which must be returned for service. If it does not then the camera head is suspect.

In the latter case it is important to make certain that the camera is not exposed to extraneous light that is now "leaking" into the camera head. Attempt to darken the incoming light path and obtain a few-second dark image. If the saturated condition persists it is necessary to remove the camera head from the application and cover it completely with a dark shroud and repeat the dark image. If the saturated condition persists the camera head has failed and must be returned for service.

8.1.2 Streaks In The Image

Streaks occur in numerous forms. The most common source of streaks is a failure in the shutter to close fully and the image starts shifting while the shutter is still closing or remains partially open. Some streaks result from low level instabilities in the electrical environment around the 600 Series camera head.

8.1.2.1 Shutter Problems

Shutters have a finite lifetime and should be considered as a regular service item. The sign of shutter failure is smearing of bright image areas in the direction away from the serial register. An image that contains discrete bright spots will show streaking from the site of the bright spot toward high-numbered rows. If the shutter is only beginning to fail the streaking may not extend all of the way to the end of the image. Replace the shutter and see of the problem goes away.

8.1.2.2 General Streaking

These are patterns all over the image. They may be bands or they may be limited to individual columns. Rows rarely streak. Sometimes herring bone patterns march diagonally across the image and these are always related to pickup of external signals during readout.

First detach the video cable to the camera electronics unit. If streaks persist then the problem is in or at the camera electronics unit. Attempt to electrically isolate the camera electronics unit so that no extraneous ground paths exist. Otherwise, the camera electronics unit must be returned for service.

If streaks disappear when the video cable is disconnected, remove the camera head from the application environment and isolate it electrically from the application equipment. If the streaks are still visible, ground loops are eliminated and something has changed in the camera head which must be returned for service. If the streaks go away there is an extraneous low level electrical circuit between the camera head and the application that must be eliminated.

8.1.3 Noisy Image

Noise indicates a signal intrusion into the application environment or a camera failure.

8.1.3.1 Isolation And Detection

It is recommended that you consult with Spectral Instruments if you have a noise pattern that is not cured by either plugging the computer, the camera and the cryo-cooler into the same plug strip or electrically isolating the camera head from other equipment.

If the problem persists there is either a problem with the camera or a camera cable or the external source of electrical noise is too great for laboratory apparatus to operate.

8.2 The Error Audio Alert

The audio alert is turned on whenever the camera controller detects a problem with the camera. It is turned on and remains on until the controller is turned off.

The camera head error status indicates which fault has occurred. These fault conditions are not reset until the next POST. The error status is contained as two bits in the camera head status word as documented in the camera control language manual.

8.2.1 No Camera Head Communication

This condition is checked during the POST. It is not checked again until another POST occurs.

The test that is performed is for the 50-pin SCSI-type cable not plugged in or not properly seated. If the audio alert comes on after a POST and the camera head power light is illuminated either the camera head is too cold or communication with the head could not be established.

A communication fault could occur at either end of the cable. Check the pins on both ends to see that none have been bent over by improper connection. This cable must be plugged “straight in” without trying to start one end.

8.2.2 No Camera Head Power

This condition is checked during the POST. It is not checked again until another POST occurs.

The test that is performed is for the power cable not plugged in or not properly seated. If the audio alert comes on after a POST and the camera head power light is not illuminated either a power supply has failed or the cable is not properly seated.

A power cable fault could occur at either end of the cable. Check the pins on both ends to see that none have been bent over by improper connection. This cable has a knurled ring at the connector on either end of the end of the cable. To disconnect it you must pull the ring away from the mating panel along the axis of the cable to free the locks. It is necessary perform the same “pulling action” to properly insert the cable into the connector. After the cable is seated release the ring to engage the locks.

8.2.3 CCD Too Cold

This condition typically arises from having turned off the power to the camera controller while leaving the CryoTiger running. The only recourse is to turn off the CryoTiger and allow the camera to warm up to room temperature again. Then turn the camera controller on and wait for approximately one hour for the window heater to stabilize before turning the cryo-cooler on again.

8.3 The Camera Seems Not To Be Stable

Instability can result from a component drifting out of tolerance within the camera system. It is first necessary to determine whether or not the observed instability is due to a camera problem.

As illustrated in Appendix A, it is possible to readout the CCD using overscan mode. Turn off the cryo-cooler and warm up the camera head. Set up the readout so that overscan pixels are read in the serial direction. Insure that enough overscan pixels are read that some number of “imaginary” pixels are readout.

Set up the application so that the camera to operate at speed and attenuation 0 and insure that it is in a “dark” configuration. Obtain a sequence of images over the time scale of the instability. Record and plot the mean value in the “imaginary” bias overscan, the dark overscan and the image area. There should be no difference between dark overscan and the image area. If there is, light is leaking into the “dark” environment. Eliminate the light leak and see if things improve.

If the illuminated pixels are equivalent to the dark overscan pixels, then see if the bias signal is drifting by more than five counts in an hour. If it is the camera must be returned for service.

8.4 Camera Reports The Proper Temperature But Dark Is High

High dark with the temperature reported at the set-point usually indicates a warm CCD. First set the speed and attenuation to 0 and obtain a five-minute dark image with the CCD in a dark environment. Select a region of interest where there are no hot column defects and record the mean value of the image in the ROI. Next obtain a bias image and record the mean from the same ROI. Refer to the conversion factor for speed and attenuation 0 as recorded in the test report. Subtract the bias mean from the dark mean. Multiply the result by the conversion factor and divide that result by 300. The result is the dark signal in electrons per pixel per second. That value should agree with the test report to within 10%. If the dark signal is too high something is wrong.

The usual cause of reported high dark turns out to be a light leak in the application. It does not take very much like leaking into the application to mimic high dark current. If possible, blank off the CCD front and see if the symptom disappears. Otherwise be as careful as possible to shut off all room lights and application illuminators and repeat the dark measurement. If it decreases at all, there was a light leak and the problem is still possible additional light leaking into the camera.

If there is absolutely no light leak, then how much too high a dark current reading is an indicator. If it is just a little too high, check the pressure reading inside the camera head. If it is above 2 torr it is possible that the CCD is being warmed by convection. In any event, a pressure at or above 2 torr is time to pump the camera.

If the dark is very much too high it is possible that the CCD has become separated from the cold block where the temperature is measured. To determine if this is the case (and incidentally to also fix the problem if it is) allow the camera to warm up to room temperature and then cool it back down. If the problem persists and the pressure is below 2 torr and the temperature indicated for the CCD is OK, then it is possible that the cooling capability of the cryo-cooler is at margin.

8.5 Camera Does Not Cool

Two possibilities exist: one is that the vacuum needs to be refreshed, the other is that the cryo-cooler needs to be recharged. If the camera pressure is high and the dark is high the camera needs to be pumped. If the camera pressure is not high it is likely that the cryo-cooler needs to be refilled. Try pumping first any way as that is a quicker service that does not require taking the system out of service.

The manual for the cryo-cooler indicates the static (non-operating) pressure range for various cooling. If the pressure falls below the recommended range the compressor needs to be recharged by APD.

If the cryo-cooler needs to be serviced it can be sent to one of the service centers listed in the APD manual. Alternatively, the camera can be returned to SI for recharging the cryo-cooler.

8.6 Condensation On The Camera Window

Two possibilities exist: one is that the vacuum needs to be refreshed, the other is that the window heater fuse has opened. The other heater can be used in case HEATER A has failed. It is possible to carefully test the voltage coming out of the HEATER A port. This is a 24-volt power source.

WARNING: *Testing the fuse must be done carefully else the fuse will surely become open. Use a proper audio cable with opened ends that can be safely connected to a VOM.*

Appendix A

CCD Readout Format

A refresher on row/column terminology. Figure 8., below, shows a single port readout image. The physical orientation on the page matches the way that SI-Image shows it on the screen of your computer. Your software may present the image in a different orientation. The readout proceeds along rows moving from column 0 to column 1 to column 2 … until column n-1 is read out from row 0. The next row is shifted into the serial register and columns 0 through n-1 are read out. Columns are the fast-moving subscript in a two dimensional notation, rows are the slow-moving subscript. The fourth pixel read from a CCD sensor has the imaging **coordinates** of row 0, column 3.

Figure 8. illustrates various components of an image obtained from a CCD with overscan applied to the readout format. Not all CCDs will look this way - it depends upon the way the CCD mask set is designed.

Table 2, below, compiles the various image components for each of three different CCDs read out with overscan.

To make overscan work the following two steps are required:

1: Set the parallel readout dimension to be larger than the active imaging pixels - how large depends upon how much you need to see in the overscan image. Table 2 includes a recommended format for each CCD.

2: Set the normal pre-scan and post-scan pixel count to 0. These are parameters that are downloaded into the DSP as readout determinants.

The following notes are possibly useful - going down the letters/numbers in sequence:

A This sets the total number of readout pixels expected in the parallel direction. There is not as much interesting information in parallel overscan as there is in serial overscan but some things do show up right at the end of the active area so read some extra parallel pixels.

A1 Some CCD manufacturers separate the serial register from the parallel register by masked pixels. Data reading out of these rows is not differentiated by the Series 600 DSP firmware.

A2 These are the imaging rows on the sensor.

A3 These are extra rows that are read out after the imaging rows. These rows traverse the entire imaging area and all of these extra rows spend equal time on the CCD so they should all see exactly the same dark signal and/or light leak. They should all look alike! They won't! The first "extra" row (and possibly one or two more rows) capture any charge that didn't get shifted out with the row that preceded it. This is where trapped charge shows up. A plot of the first overscan row should look like a dark signal row-plot. It shows some columns that are "high" because of the deferred charge that leaks out after the readout. At this column address the next few rows may also show some of this deferred charge. There is a limit on the amount of deferred charge that is allowed before the trap in that column is statutorily a defective column.

B This sets the total number of readout pixels expected in the serial direction. There is a lot of interesting information in the serial overscan. This is because CCDs are typically designed to incorporate masked pixels for dark signal determination and overscan readout shows them up. The low-cost TV CCD cameras typically read this signal as a voltage to be subtracted from the rest of the image so as to correct for the DC offset due to the thermal image.

B1 The serial register is really a separate structure from - although it is intimately connected with - the parallel register. It is usually longer than the number of columns in the parallel register. The extra pixels in the serial register are typically called pre-scan and post-scan. However, this terminology usually also includes the dark masked pixels which are actually on the parallel register. Spectral Instruments calls the extra pixels in the serial register pre-extension and post-extension. Note that it is quite possible to extend the post-extension into imaginary non-existent pixels and the difference between post-extension and imaginary pixels is usually negligible. So, B1 is the number of serial register pixels read before any parallel pixels (masked or not) are encountered.

B2: The serial register pre-mask pixels are actually physical pixels in the parallel array which are covered with some sort of opaque mask so as to exclude light. The location of and the degree to which these masked pixels are truly dark varies by CCD manufacturer. They are usually included so that TV CCD readout can adjust the dark reference offset before reading the row.

B3: This is the dimension of the illuminated pixels in each row read from the sensor.

B4: These pixels are also masked so they don't see incoming light.

B5: The serial register post extension combines both physical serial register pixels for which there are no corresponding columns on the CCD sensor with "imaginary" pixels that result from the readout circuits clocking more times than there are net serial pixels to clock. The analog system does not care where pixels come from. It just reads out an array of N x M pixels and you can make the size suit your own purposes. It is not possible to add extra "imaginary" pixels at the beginning of the array but you can have as many as you like at the end of the array.

CCD	A	A1	A2	A3	B	B1	B2	B3	B4	B5
	Parallel Readout Dimension	Parallel Pre-Mask	Parallel Illuminated Pixels	Parallel Over-Scan	Serial Readout Dimension	Serial Pre-ext.	Serial Pre-Mask	Serial Illuminated Pixels	Serial Register Post Mask	Serial register Post Ext.
TK1024	1050	0	1024	26	1120	48	2	1024	2	48
SI003	1050	0	1024	26	1056	16	0	1024	0	16
KAF 16800	4128	20	4098	10	4145	35	0	4098	0	12

Table 5.

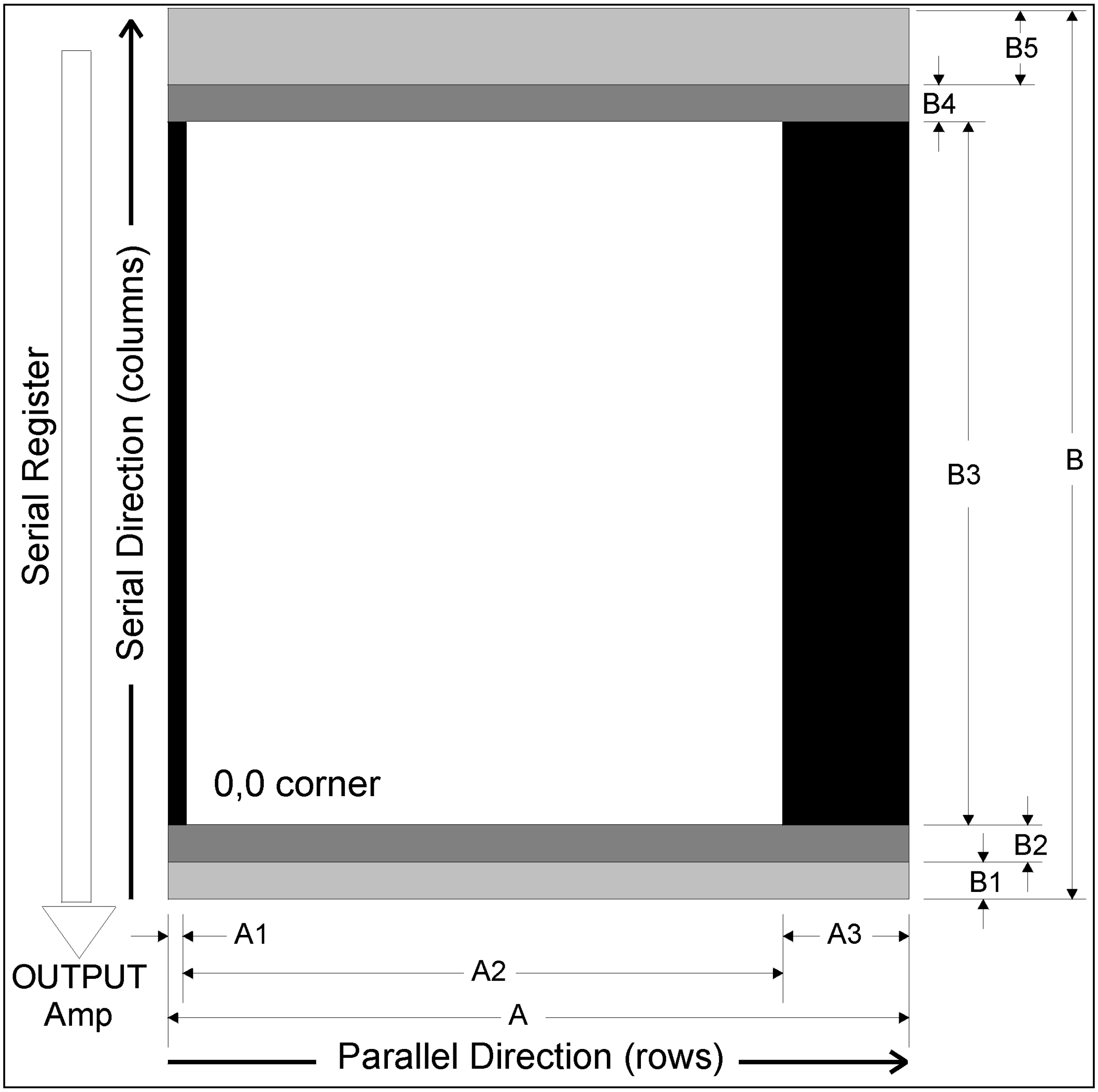


Figure 8.

CCD Readout Format

Appendix B

Multi-Port CCD Readout Parameters

600 Series cameras support readout through more than one port. This feature only works with those CCDs that are designed to split the readout into more than one output amplifier. It is always possible to read out a multi-port CCD through one single port. The port to be used is controlled by parameters that are sent to the DSP from the host computer. These parameters relate to the "phasing" of the serial and parallel registers and whether the registers are split. Reference Figure 9., below, to visualize multi-port readout. Quadrant 1 is read through the A output, quadrant 2 through the B output. It is possible just to use the B output instead of the A output. Clearly to use the "B" end, the serial register must do something different when pixels are to exit B as opposed to exiting A. The serial phasing parameter selects how pixels shift in the serial register. Again, this election is only an option for the standard one-port readout DSP firmware operating a CCD with more than one good output amplifier. The same circumstance pertains to the way the parallel register behaves. Pixels can be shifted left (to A & B) or right (to D & C) by the phasing parameter.

The Series 600 cameras all have the ability to readout 1-port, 2-ports or 4-ports. The parameter that governs splitting the serial and parallel registers coupled with the two parameters that control the phasing allow pixels to be routed rather arbitrarily. The exception is that one cannot readout 2-port through the A and D or through the B an C outputs as the serial registers must run the same direction and cannot run in opposite directions.

Multi-Port CCD Image Pixel Data Format

The pixels come out of a four-port readout camera in "round-robin" mode. First one from port A, then one from port B, then one from port D and finally one from port C. This happens because a single clocking scheme is used on the single CCD. All row and column shifts occur simultaneously. There is symmetry at the center of the array. Subarray readout is possible but the subarray is presumed to be symmetric about the center. Similarly, binning can be selected - it occurs the same at all readout ports.

The data arrives in your computer interleaved as it is readout. It is necessary for your software to reconstruct a proper image from the interleaved data stream.

Single-Port CCD Image Orientation

Referencing Figure 9. again, note the arrows in each quadrant. The arrows point diagonally toward the opposite corner denoting the direction in which a readout proceeds. Switching between A and B outputs flips the image vertically. The SI-Image software always places the first pixel at the lower left hand corner of the screen - regardless of the output from which it emerged! Switching from A or B to C or D flips the image right-to left. Re-orienting the image must be handled by your software if the origin of the image and its mapping to the application is important.

Over-Scan in Multi-Port CCD Readout

Using the 4-port model, you can have post-scan but your display software must deal with the result. All of the pre-scans and pre-extensions are available (as long as you are content with them being in all four quadrants identically. There is no post mask, no post scan in either direction. Some idiosyncrasies occur as different vendors handle the split parallel and serial registers. These are handled in the specific DSP firmware. This firmware is specific to the CCD being readout multi-port. Buried within this firmware are the mechanisms required to handle the idiosyncrasies.

The configuration parameters include several that are related to multi-port operation of the camera. When single port readout is selected, the serial registers shift toward A and D when the serial phasing parameter is set to 0. They shift to B and C when this parameter is set to 1. Similarly, when single port readout is selected the parallel register shifts toward the A-B side, labeled SR1 in Figure 11 below. When the parallel phasing parameter is set to 1 the parallel register reverses shift direction toward SR2.

When two-port readout is selected, the presumption is that the parallel register is split. For this situation the parallel phasing parameter must be set to 0. This leaves the left and right sides shifting toward SR1 and SR2 respectively. If the parallel phasing parameter is set to 1 for two-port readout the parallel direction reverses and the registers shift toward the center. This produces no image at all.

When four-port readout is selected, the presumption is that both the parallel and serial registers are split. For this situation the parallel phasing parameter must be set to 0 and the serial phasing parameter must be set to 0. This leaves the left and right sides shifting toward SR1 and SR2 respectively and the serial registers shifting toward their respective output port. If the parallel phasing parameter is set to 1 for four-port readout the parallel direction reverses and the registers shift toward the center. Similarly, if the serial phasing parameter is set to 1 for four-port readout the serial registers shift away from their respective output nodes. Either of these situations produces no image at all.

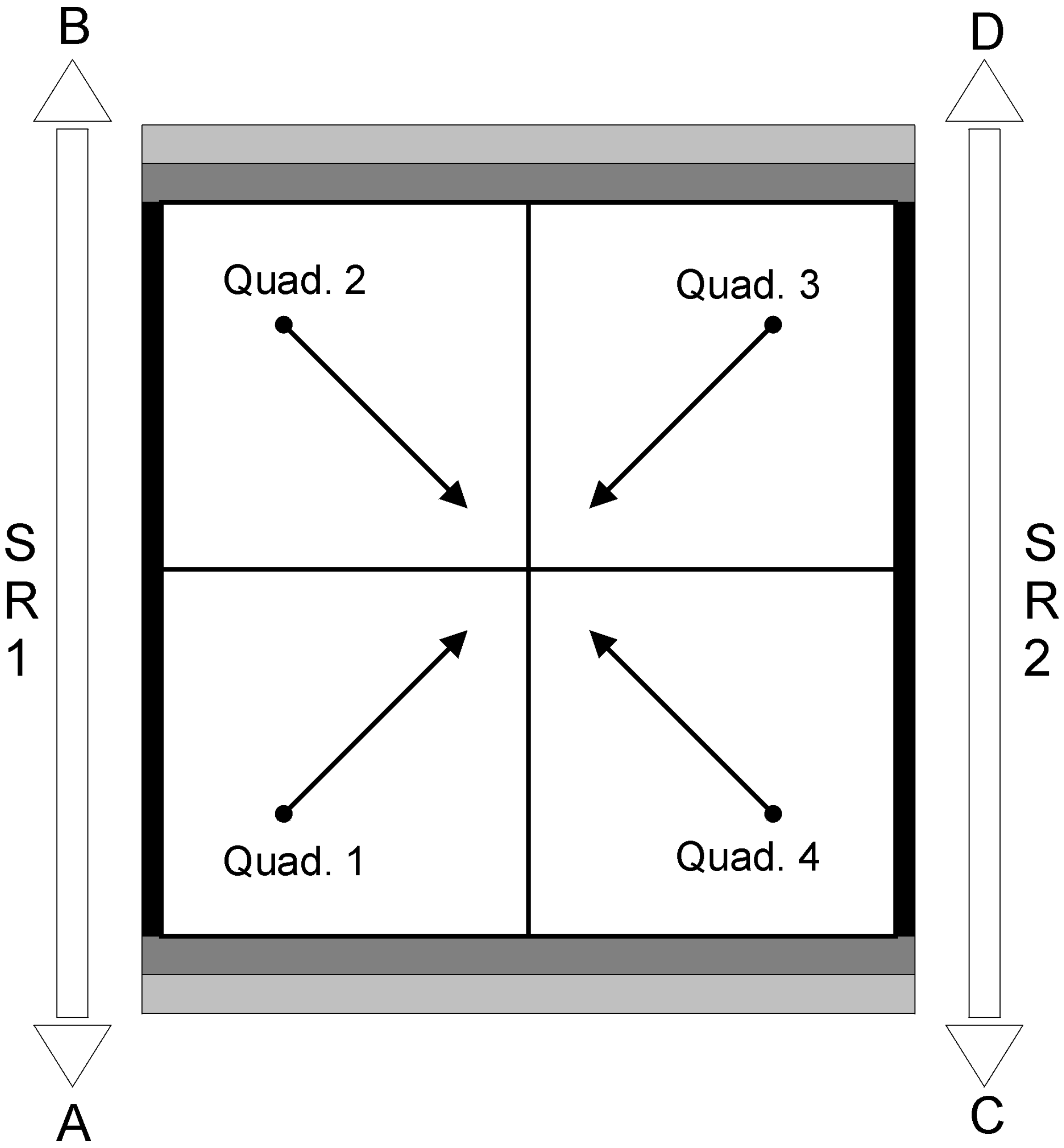


Figure 9.
Multi-Port CCD Readout Format

Serial Phasing	Serial Split	Action
0	0	Shift to A and C outputs
1	0	Shift to B and D outputs
0	1	Split both serial registers and shift to all four output amplifiers
1	1	Invalid! Charge shifts to the center of the serial registers

Table 6.

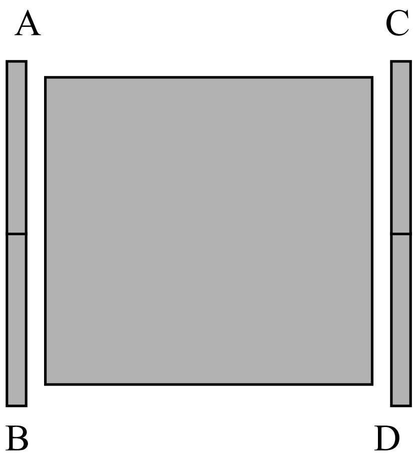


Figure 10.

Parallel Phasing	Parallel Split	Action
0	0	Shift to A/B outputs (depends upon serial split)
1	0	Shift to C/D outputs (depends upon serial split)
0	1	Split and shift to A/B and C/D outputs
1	1	Invalid! Charge shifts to the center of the CCD

Table 7.

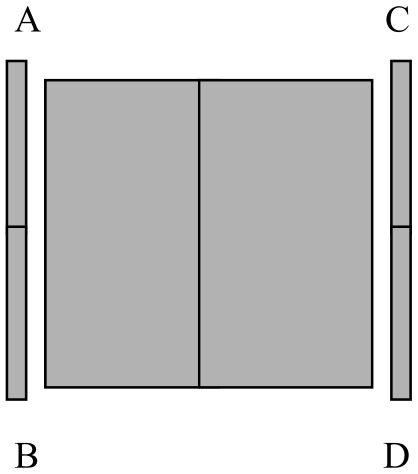


Figure 11.

Appendix C

Sensitivity And Attenuation

SICCD cameras are designed to use CCDs that have a very large intrinsic signal capacity – or full well. The full well capacity is specified in electrons and ranges from 40,000 to more than 500,000 electrons in each pixel depending upon CCD type. A 600 Series camera that employs a 16-bit ADC converts the signal of the CCD into numbers that range from 0 to 65535. A 12-bit ADC converts signal of the CCD into numbers that range from 0 to 4095. The sensitivity is the relationship between the analog to digital converter output (ADUs) and the number of electrons in a pixel and is expressed as e^-/ADU. Sensitivity values typically range from < 1. to > 50 e^-/ADU. Note that our sensitivity is called gain in classical CCD imaging literature.

In order to quantify images to a higher accuracy, it is possible to operate a SICCD camera at a smaller sensitivity setting so that the numeric range of the ADC maps to fewer image electrons. This is accomplished by attenuating the signal in the readout process. It means that high signal image areas saturate the electronics so the lower light level regions can be measured more accurately.

SI cameras provide a user-selectable attenuation. The highest level of attenuation is state 3, the lowest, the default state, is 0. Changing the attenuation from 3 to 0 decreases the conversion factor. This permits more accurate measurement of low light areas in an image while giving up the ability to measure bright areas in that same image because they will have saturated the measuring circuit.

Operating a SICCD camera at the lowest attenuation number provides the most accurate measurement of background signals in low light level images. This is the attenuation setting used to measure the intrinsic system noise.

The sensitivity of a SICCD camera is determined by two factors: a) the attenuation, which switches among discrete levels, and b) the dual slope integrator setting. The dual slope integrator (DSI) setting determines how long each pixel is sampled (integrated) before it is digitized. The longer the output node voltage (the pixel or super pixel signal) is integrated, the better the readout because the noise is decreased.

Increasing the integration time changes the sensitivity of the camera independent of the attenuation. Longer DSI values slow down the readout (changing the attenuation does not slow down the readout) and decreases the sensitivity number. Table 7., below, tabulates a selected set of DSI settings and the effective pixel read time and the equivalent readout rate.

DSI Sample Time Parameter	Pixel Read Time In Microseconds	Pixel Readout Rate In Kilohertz
(or 1)	2.50	400
15	4.0	250
25	5.00	200
75	10.0	100
175	20.0	50
375	40.0	25

Table 7.

Appendix D

G2 Command Set

The G2 command set is common to both Series 500 and Series 600 cameras. The commands are described in detail in Spectral Instruments document 1870x where x is the current revision number.

For any of the exposure commands, the following sequence occurs:
1) echo the command
2) open shutter and turn off continuous clear
3) set the timer to the value in the exposure time parameter (in milliseconds)
4) send the Y reply
5) wait for the timer interrupt
6) close the shutter
7) wait for the time (in milliseconds) set by the shutter close delay parameter
8) read the current CCD region of interest (subarray) and send image data to the host
9) turn on continuous clear

In the command documentation below, exceptions to this process are noted for each command. Once readout starts the readout must end before the DSP responds to any further commands.

Note that a delay is implemented after the shutter close step but no delay is included with the shutter open step even though it takes approximately the same time to open the shutter as to close it. The reason a shutter open delay is not implemented is that it is not needed for image fidelity as is required for the shutter close (you don't want to start shifting while the shutter is still closing) and it would extend the minimum exposure time unless such a delay is manipulated dynamically by application software.

The test image is a ramp that starts with 0 and increments y one for each image datum sent. The size of the test image is set by the serial and parallel read length parameters and is not affected by binning.

The location of the region of interest read out from the CCD is entirely specified by entries in the readout parameter table. It is important to note that no serial prescan parameter is implemented but rather the application software must treat every image readout as a subarray with an explicit serial origin parameter at least equal to the serial register pre-extension plus any dark masked columns. It is also important that the serial postscan parameter be computed and set to the number of the pixels remaining in the serial register after the selected pixels have been read out. Failure to delete postscan pixels can provide some very interesting overlap effects in the region of interest.

The serial and parallel configuration of the CCD in each camera is provided with the test report for that camera.

The number of pixels read from the camera is mapped onto the sensor by the binning parameters. All of the origin and postscan parameters are unbinned pixels. It is possible to read off of the end of the CCD by setting the read length parameters larger than the physical sensor size. It is possible to readout the prescan and any dark masked pixels by setting the serial and parallel origins to 0. The total number of pixels read from the camera must be even else the camera interface will hang waiting for the last odd pixel.

Command	Function	Parameter(s)	Reply
A	open shutter	none	Y
B	close shutter	none	Y
C	generate test image timed exactly as in an exposure but send the test image instead	none	Y
D	expose and read CCD	none	Y
E	read CCD without exposure (no shutter-open but with shutter close)	none	Y
F	receive readout parameters from host 32 4-byte parameters are expected	serial origin 0 - 8190 serial read size 1 - 8190 serial binning 1 - 8190 serial postscan 0 - 8190 parallel origin 0 - 8190 parallel read size 1 - 8190 parallel binning 1 - 8190 parallel postscan 0 - 8190 exposure time 0 - 16777215 continuous clear 0 - 1 DSI sample time 0 - 4095 analog attenuation 0 - 3 port 1 offset 0 - 4095 port 2 offset 0 - 4095 port 3 offset 0 - 4095 port 4 offset 0 - 4095 TDI delay time 0 - 4095 skipped lines 0 - 4095 14 cells undefined 0	Returns Y if params are all within range, else returns N
G	receive one readout parameter from host	offset 0 - 31 parameter as above	Returns Y if param is in range, else N
H	transmit readout parameters to host 32 4-byte parameters are sent	none	Y
I	transmit status to host 16 4-byte parameters are sent (see status parameter table)	none	Y

J	receive configuration parameters from host in 1/10 degree Kelvin units	instrument model > 0 instrument SN > 0 hardware revision > 0 serial phasing 0 or 1 serial split 0 or 1 serial size 0 - 8190 parallel phasing 0 or 1 parallel split 0 or 1 parallel size 0 - 8190 parallel shift delay 0 - 4095 number of ports 1 - 4 shutter close delay 0 - 4095 CCD temp. offset 0 - 4095 backplt temp. offset 0 - 4095 CCD temp. setpoint 0 - 4095 data word size not used MPP mode disable 0 or 1 spare (8 cells) 0 controller SN > 0 analog part number > 0 analog revision > 0 hardware revision > 0 spare (3 cells) 0	Returns Y if params are all within range, else returns N ♦
K	receive one readout parameter from host	offset 0 - 31 parameter as above	Returns Y if param is in range, else returns N
L	transmit configuration parameters to host 32 4-byte parameters are sent	none	Y
● M	store current configuration table in eeprom	none	Y
N	send remaining exposure time to host 4-byte time is sent, 0 is no exposure in progress	none	Y
O	abort exposure (cannot stop an in-progress readout)	none	Y
P	transfer configuration from eeprom to the configuration table in RAM	none	Y

Q	restart the program	none	Y
R	clear the parallel register one time	none	Y
S	turn on the external relay	none	Y
T	turn off the external relay	none	Y

Command Table

♦ For a setpoint of -73°C the setpoint parameter should be 2000.

● This command changes the stored configuration table. It should be used only if absolutely necessary and you should have saved a copy of the original configuration parameters in case an error is made. If the camera electronics unit is turned on without a camera head attached, in addition to sounding the audio alert, the generic configuration parameters loaded into the DSP firmware will be available to be read from by the host. This configuration parameter set does not include camera specific information such as serial numbers and part numbers.

Param #	Description
0	CCD temperature in 1/10°Kelvin units
1	not used in a Series 600 camera
2	vacuum chamber pressure code (0 - 4095)*
3	spare 4
4	spare 5
5	spare 6
6	spare 7
7	spare 8
8	shutter status (0 = closed, 1 = open)
9	XIRQA status (0 = none pending, 1 = XIRQ occurred)
10	spare
11	spare
12	spare
13	spare
14	spare
15	spare

Status Parameter Table

Parameter Number	Description	Location	Value Range
0	Instrument Model	Head	0 - 9999
1	Head serial #	Head	0 - 9999
2	Head hdw. revision	Head	>0
3	Serial reg. phasing	Head	0 , 1
4	Serial reg. split	Head	0 , 1
5	Serial reg. size	Head	0 - 8190
6	Parallel reg. phasing	Head	0 , 1
7	Parallel reg. split	Head	0 , 1
8	Parallel reg. size	Head	0 - 8190
9	Parallel shift delay	Head	0 - 4095
10	Number of ports	Head	(0)1 - 4
11	Shutter close delay	Head	0 - 4095
12	CCD temp. offset	Head	0 - 4095
13	Bkplate temp. offset	Head	0 - 4095
14	CCD temp. setpoint	Head	0 - 4095
15	Data word size	Head	not used
16	MPP mode disable	Head	0 , 1
17	spare	Head	not used
18	spare	Head	not used
19	spare	Head	not used
20	spare	Head	not used
21	spare	Head	not used
22	spare	Head	not used
23	spare	Head	not used
24	spare	Head	not used
25	Controller serial #	Controller	0 - 9999
26	Analog card part #	Controller	0 - 9999
27	Analog card revision	Controller	0 - 25
28	Controller hdw. rev.	Controller	0 - 9999
29	spare	Controller	not used
30	spare	Controller	not used
31	spare	Controller	not used

Configuration Parameter Table

* The pressure parameter returned is between 0 and 4095. The parameter returned is converted to a pressure using the following look-up table:

Reading From Camera	Pressure in Torr	Reading From Camera	Pressure in Torr
169	0.00	1621	1.00
266	0.01	1957	2.00
481	0.05	2126	3.00
654	0.10	2233	4.00
878	0.20	2304	5.00
1048	0.30	2356	6.00
1176	0.40	2395	7.00
1281	0.50	2421	8.00
1367	0.60	2440	9.00
1446	0.70	2457	10.0
1512	0.80	2545	20.0
1568	0.90	2573	20.0

Pressure Conversion Table