Series 800 Camera System User's Manual

P/N 2500

TUCSON, ARIZONA

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1 Introduction

This manual documents the standard Series 800 (S800) camera. Features that pertain to a specific version of a camera are described in detail in Appendix G. It is recommended that you read that section before operating your camera.

The S800 is a multi-port (from one to four ports) 14- or 16-bit camera where the CCD can be cooled to temperatures in the range of -40^{o}C using a thermoelectric cooler. This camera system can read out at up to 1,000,000 pixels per second from each port for multi-port CCDs. It reads out at up to 4,000,000 pixels per second as a single port camera. It offers high precision, high stability and relatively short readout times.

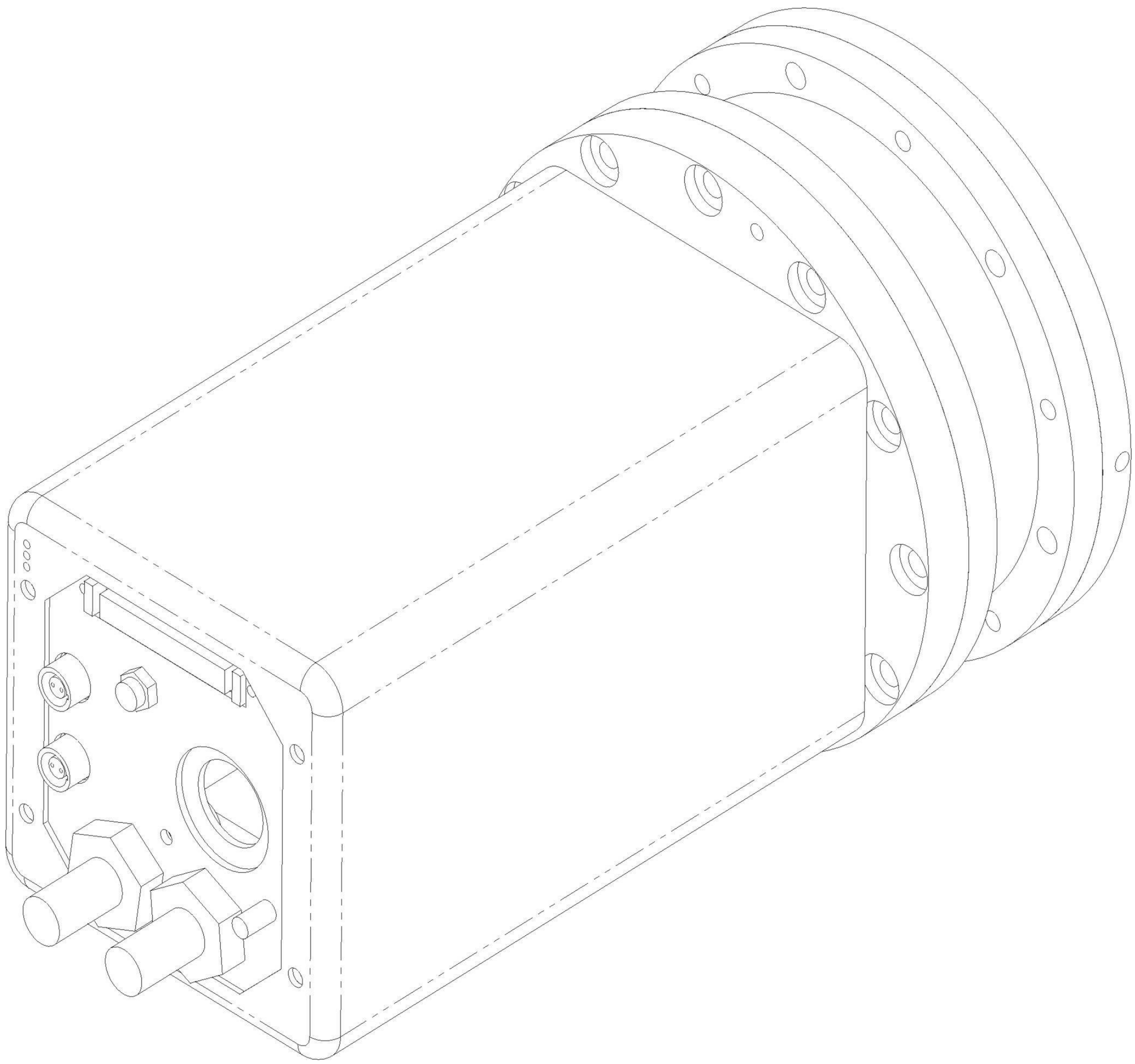

Figure 1.

1.1 S800 Series Camera System Overview

A typical form of the S800 camera is shown in Figure 1. It consists of an evacuated and sealed camera head chamber with the CCD inside and an attached module that contains all of the electronics required to operate the camera. An external camera power supply and a re-circulating water-cooler are also provided. The preamplifier and analog processing circuits as well as the clock drivers, temperature and pressure measurement hardware and digital image output driver circuits are all located inside the electronics module.

The camera system is "self-aware" – that is, the camera knows, and reports to the application software, all the information required to properly operate the camera regardless of the type of CCD or the number of ports.

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 provides 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 symbol 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 type of 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.

CCD cameras that produce high quality digital images are designed to produce a 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 2., below, illustrates a single-port and a four-port CCD.

Referencing the left-hand portion of Figure 2., the checkered center 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 read out 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
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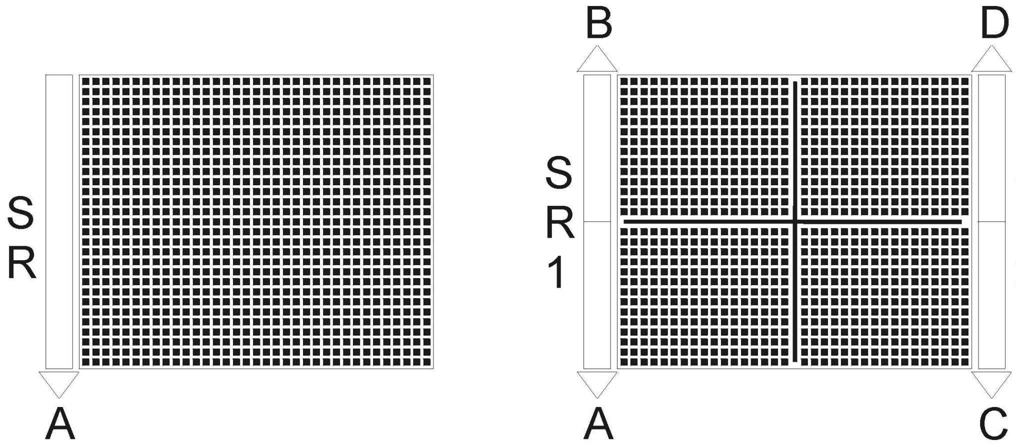


Figure 2.

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 by the binning factors (which may be different for rows and columns).

Referencing now the right-hand side of Figure 2., the CCD illustrated supports four-port readout so there are two serial registers labeled SR1 and SR2. Each serial register is divided into two halves, which is shown figuratively as a black line in the parallel register. The parallel register is also divided and that is shown as a vertical black line. Neither black line exist in the CCD nor in the image that is read out four ports, the divisions are presented as black 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 must sort them out so they are presented properly.

Spectral Instruments' SI-Image software performs this task automatically. The columns are still horizontal and rows are vertical in the final image just as if they came out of a single port. SI-Image software 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

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. 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.

The S800 camera system employs a thermoelectric cooler that is capable of lowering the temperature of a typical CCD to -40°C. The heat from the hot side of the TEC is removed by a liquid heat exchanger that is connected to the camera head. As long as the temperature of the camera is not reduced below the local dew point, it is possible to lower the operating temperature of the CCD by using chilled water in the heat exchanger rather than water at room-air temperature.

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 will affect your 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.

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 S800 Camera

The camera is shown in profile in Figure 3. In this view, the position of the CCD relative to the front flange, or plate, of the camera is shown. Also shown are the overall dimensions of the camera. The camera back-view is shown in Figure 4. Several different connections are required to integrate the camera into your application. The dimensions are all millimeters.

Power is provided through a 14-pin twist-lock connector. The DC voltages to operate the camera are supplied at this connector. The source of power may be a Spectral Instruments S800 rack mount power supply or a DC source in your application (typically through a DC - to - DC converter package supplied by Spectral). In either case, a power sub-system is an integral part of a S800 camera. Connection to the computer is either through a 50-pin sub-miniature D (looks like a SCSI) connector (as shown in Figure 4.) or by a MT-RJ type of fiber optic data and communication connector.

The computer interface module will have a matching connector. Adapters are available that split the twin MT-RJ fiber pair into two ST type of fibers. The dual ST to MT-RJ combining equivalent is also available for use at the data interface card. The data rate is limited to a maximum of 4,000,000 pixels per second. If a multi-output CCD is used, the rate per output port is appropriately lower.

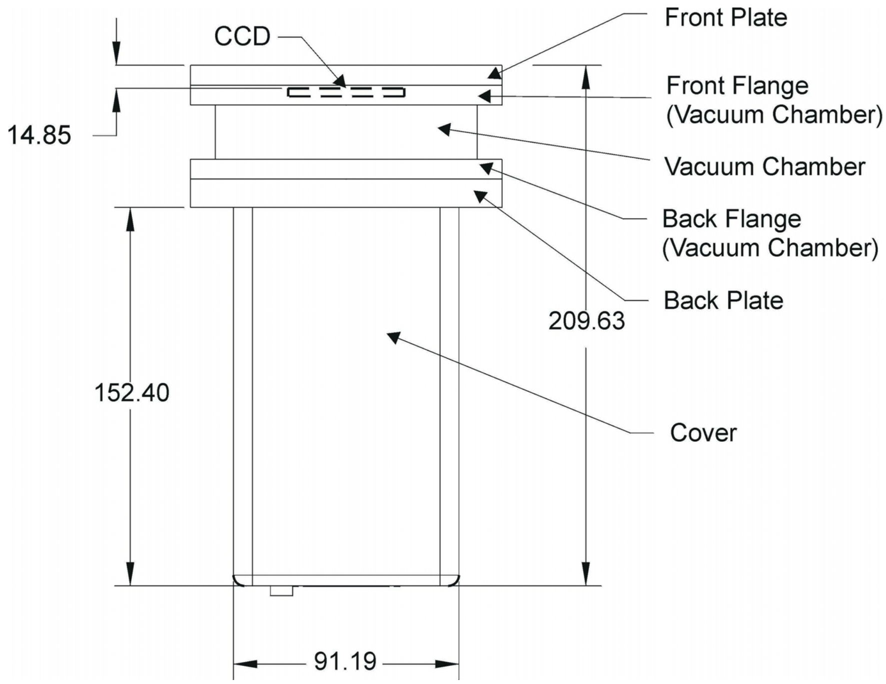


Figure 3

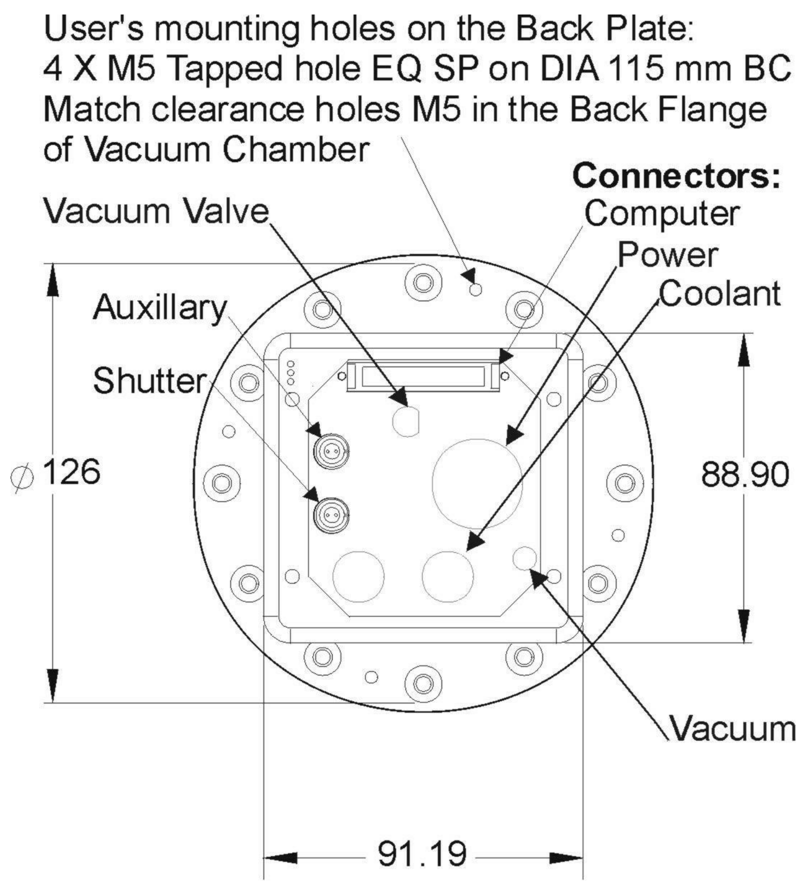


Figure 4

Coolant is supplied to a pair of ¼" Swagelock VCO couplings. The appropriate part numbers for the mating connector is: SS-4-VCO-3-4TA "Tube Gland Adapter" and SS-4-VCO-4 "Female Nut". Other gland forms are available if flexible tube is not your choice for the cooling hose connection. Coolant can be supplied by your application or by a refrigeration unit provided by Spectral Instruments. It is necessary to maintain the back plate of the camera just above the dew point to avoid condensation. It is important to monitor the supply line temperature where chilled liquid is supplied to the camera so that no moisture forms inside the camera electronics chamber.

The camera operates a shutter. Two types of signals for driving a shutter are provided. The two-pin Lemo connector labeled shutter is designed to drive a 6-v shutter from Vincent Associates or from Melles Griot. A suitable shutter can be supplied by Spectral as an option. The 4-pin Lemo connector, labeled AUX, provides a TTL or Opto isolated signal that indicates the shutter status across pins 1 and 2. When the shutter is open the voltage across these pins is +5v. When the shutter is closed the signal is 0 volts. The mating Lemo connector specification is given in Section 1.4.2.

The camera can activate an exposure cycle in conjunction with an external event through the trigger input signal across pins 3 and 4 of the 4-pin Lemo connector labeled AUX. The signal can either be a TTL switch closure or an Opto isolated version of the same switch closure. Details are shown in Appendix E.

Three small LEDs indicate: that the camera is receiving DC power, "**PWR**"; whether the camera head internal vacuum needs to be refreshed, "**VAC**"; and whether the camera temperature regulation is active, "**COOL**", by, respectively, green yellow and green lights. The light comes on when the condition is true.

1.2.1 The Camera Head And Electronics

The camera consists of a camera head chamber and an electronics module that is physically attached to the camera head. All of the electronics required to operate the camera are located in the electronics module.

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 camera head chamber to insure that moisture does not condense on the cold CCD.

In a lens-based camera, the camera head chamber aperture seal is a fused-silica window large enough that the CCD sensor is not shaded from the incoming beam. The CCD sensor is typically located 14.85 mm behind the front surface of the window. The window thickness is typically 3 mm. Other back-distances and window thickness options are available for custom applications.

Fiber-optic based cameras seal the camera head chamber at the fiber optic. The fiber optic protrudes a few millimeters in front of the chamber so the camera can be coupled to other optics.

The S800 camera is cooled by a thermoelectric cooler. That cooler is capable of cooling the CCD below –40°C for small size CCDs that are not connected to a fiber optic. The cold end of the TEC is inside the camera head vacuum chamber. The amount of current flowing to the CCD is regulated to maintain the CCD at the operating temperature, which is typically between –20°C and –40°C.

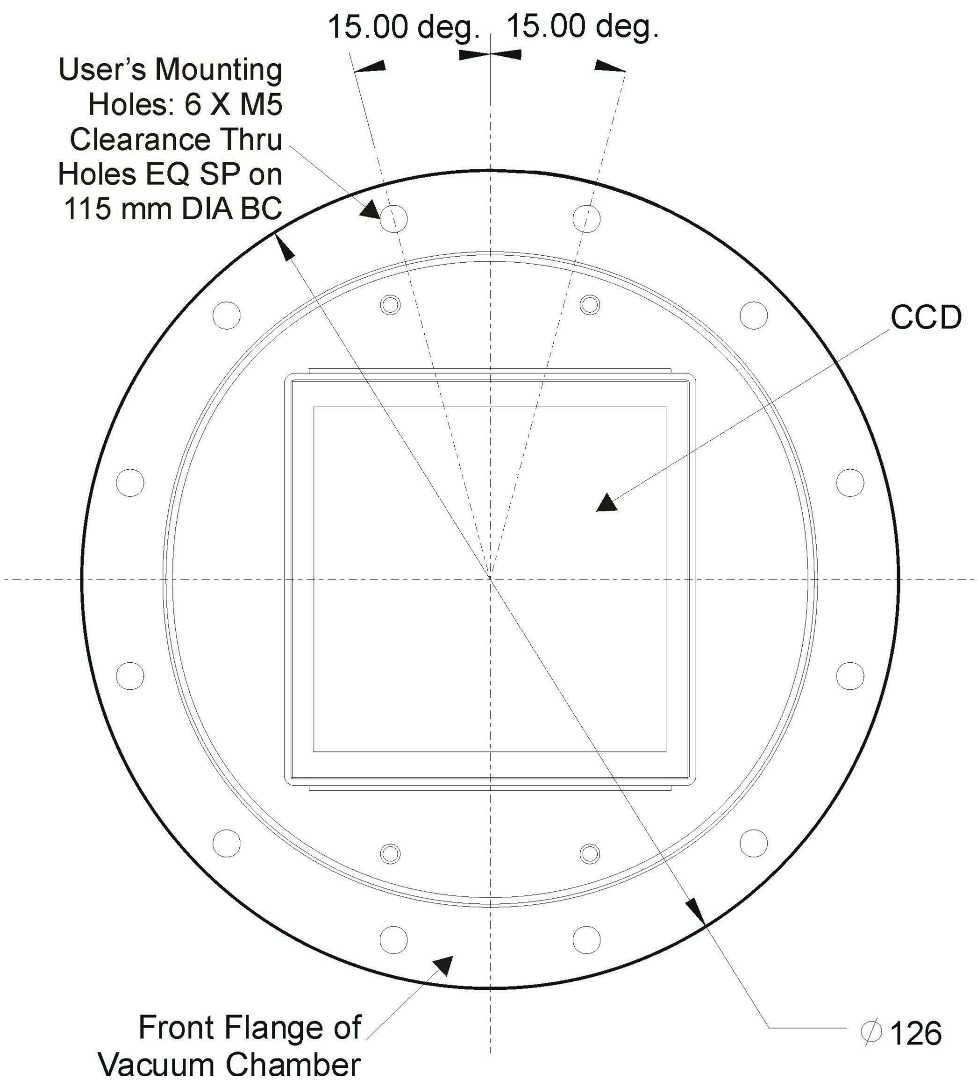


Figure 5.
Front Plate

As shown in Figure 5., a 6X M5 115 mm clearance bolt circle pattern is provided for mounting the camera to your application. As shown in Figure 4., a 4X M5 tapped bolt circle is also available on the back plate if mounting the camera by the back plate is appropriate.

1.2.2 The Camera Power Supply

The DC voltages necessary to operate the camera are provided through a separate power supply module. This module is connected to the camera head by a 14-pin Twist-lock connector. The power supply pin-out is shown in Appendix F.

WARNING*: Turn off the power to the camera power supply before connecting or disconnecting the camera power connector either at the camera head or at the power supply!*

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

WARNING: *The camera system incoming power mains must be filtered against exceedingly strong transients such as that produced by lightning.*

1.2.3 Camera Interface Module

The camera communicates to the host computer either through a proprietary AIA-style communications and data transfer protocol or by a MT-RJ fiber optic link. The two different communication protocols utilize different host interface cards. Both types of connection permit the camera to receive instructions from application software and to read the status of the camera through a serial protocol. The data transfer is different between the two options.

The copper-wire AIA connection transfers image data down the AIA cable as 16-bit parallel pixel values over differentially driven lines. The communication signal is RS422 bi-directional with control characters and parameters transmitted to the camera and status and configuration parameters transmitted back to the host computer.

The optional fiber optic communication and data protocol replaces the AIA drivers and receivers on both ends of the communication with a two-fiber bundle. The communication is still serial but the pixel data is also transferred serially and reconstructed at the fiber optic interface module.

1.2.4 Hooking Up Your Camera To Your Equipment

A detailed description of the system setup and interconnect process is provided in Section 2.3. An important system aspect of connecting the camera to your application is minimizing ground loops. Ground loops result from small voltage differences among grounds of different power sources. They can have a serious effect on images obtained from your SICCD camera. If ground loops are present, various lines, bars, chevrons or wood-grain patterns can occur in the background of low light images (they show up especially well in a bias image). The 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 suitable 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 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.

1.2.5 TDI Operation

Spectral Instruments cameras can image in conjunction with a moving field. In this mode the camera operates either through a timed delay or by synchronizing the shifting of the image on the sensor to an external event. In the latter case, the trigger input provides the synchronization. In TDI mode, a frame is discarded at each end, which is overhead for this imaging mode.

1.2.6 Shutters And Timing Considerations

The camera 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 5 milliseconds depending upon the CCD) upon receipt of the trigger and stares into the application accumulating an image. The camera stares for the currently set integration time and then it reads out.

When a SICCD camera is shuttered by any conventional multi- or twin-blade shutter mechanism, the shutter requires some time to open and to close. These shutter open and close delays must be considered when obtaining short exposures. A user changeable shutter-close delay is programmed into the exposure readout so readout does not start until the shutter is fully closed. However, a good twin-blade shutter requires at least ten milliseconds to open as well as close. A 10-millisecond exposure with such a shutter means that the integration time is effectively 20 milliseconds for the center of the image and is much less for the edge of the image. The resulting variation in effective exposure is 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 image, shutters are electro-mechanical devices that are not very stable so one flat field may not suffice for effective shutter shading correction.

1.2.7 Lenses, Light Paths and Vignetting

Spectral Instruments usually does not provide a lens. This is because most applications that can utilize the precision of a SICCD camera already provide an image plane at which the SICCD camera is positioned. Typically, a lens is only useful for imaging with the camera "straight out of the box" and is usually discarded soon 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 Section 4.

One type of application that is frequently troubled by imaging artifacts is the "long focal ratio". When the camera is exposed to light that is nearly collimated, that beam acts to reveal 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 with 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 using 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.

Although cleaning the outside of the window is not recommended; Section 5.6 describes how to clean the window of your camera if such activity is really necessary.

1.3 The S800 Power Supply

The round 14-pin power connector (POWER) connects to a cable leading to the camera head. This connection provides critical voltages to operate the CCD and must supply completely noise-free DC voltages to the camera.

1.3.1 Power Requirements

The power supply operates on incoming AC power in the 48 to 62 Hz frequency range and can run on 100, 120, 230 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.

1.3.2 Power-On Startup Sequence

When power is applied to the camera head the DSP turns on, reads stored parameters from a local flash RAM and is ready to operate the CCD. The DSP flashes the power LED three times to indicate that it is ready. Static voltages are applied to the CCD. Continuous clearing of the CCD is started. The camera is *not* caused to expose and readout without an application command to do so.

1.3.3 Externally Supplied Power

The camera may be operated from an application-supplied DC power source. In principle, it is possible for the application to provide all of the DC voltages required by the camera. These voltages are detailed in Appendix F.

More likely, your application has a 28-volt or 24-volt DC power source that is preferred for operating the camera instead of sourcing 110- or 230-volt AC power to a Spectral Instruments power supply. Spectral Instruments provides DC - DC converter modules (two modules, one for the camera and the other for the TE cooler) that have two-pin input connectors to receive the incoming DC power. Each module produces all of the camera-specific DC voltages which "wye" into a standard 14-pin output power cable. The length of the cable to the camera head should be short when the DC - DC converter is used in order to minimize line drop. Such converter modules should be located somewhere near the camera head and mounted according to the requirements of the application.

1.4 The S800 Camera Cable Set

1.4.1 Camera To Computer

The camera communicates with the computer either by a copper-wire 50-pin parallel digital connection or by a two-fiber fiber-optic serial connection. In either case, a communication link is included within the cable along with the data lines. The copper-wire cable to the computer connects to the Spectral Instruments proprietary PDCI AIA digital imaging module by a 50- to 68-pin AIA cable.

The fiber optic connection connects to a Spectral Instruments proprietary PDCI FO fiber optic input module. This module presents the identical interface register set and I/O addresses as the PDCI AIA module. The host computer drivers are identical for the two interface modules.

The fiber optic communication configuration provides "fiber active" indicators at each end of the fiber that are turned on if the fiber is not properly connected. Indicators are located at the camera head next to the link and at the computer interface module.

1.4.2 Shutter Connector

If a shutter is supplied, that cable is also included with the camera system. At the back of the camera head, a 2-pin shutter connector port, labeled SHUTTER, is provided for cameras that use a standard 6-volt shutter. The camera head end varies to meet the application requirements and/or physical shutter selected.

The camera shutter connects to a Lemo connector that 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.

1.4.3 The Auxiliary Port

A 4-pin Lemo connector at the camera head provides for external control out of and in to the camera. The current status of the camera shutter is provided as a signal between pins 1 and 2 of the auxiliary port. When the shutter is open the signal is + 5 volts. Otherwise it is 0 volts. A switch closure between pins 3 and 4 on the auxiliary port sends a signal to initiate an exposure when the camera is in the "triggered exposure" mode.

The auxiliary connects to a Lemo connector that 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 thermoelectric cooler that lowers the temperature of the CCD is sized according to the load provided by the camera head configuration. The design load is determined by the size of the CCD, the presence of a fiber optic attachment or the distance between the CCD and the window. The operating load is very much affected by the pressure inside of the camera head chamber.

The watts to be removed from the camera head by an external cooling liquid supply vary according to the size of the TEC. TE coolers run between 30 and 150 watts. Cooling liquid at +20oC flowing at rates between 3 and 10 liters per minute are sufficient for TE coolers at 30 and 150 watts respectively.

It is possible to supply cooling liquid at a controlled temperature by use of a closed cycle refrigeration system. This is necessary in the event that the ambient temperature is high. It is important to avoid bringing the inlet tube to the camera head below the dew point because condensation would result and condensation is always bad.

1.5.2 Hooking Up A Cooler

The camera is fitted with two ¼" Swagelock VCO fittings. Spectral Instruments supplies a closed cycle refrigeration system as a cooling option. The liquid is a 50% ethylene glycol and 50% de-ionized water mixture. It is important that the fluid used be non-corrosive to the metal camera head chamber. As a minimum, a buffered solution must be used. Glycol is not required unless the system is exposed to temperatures that could freeze.

1.5.3 Cooling Cycle

The camera will start to cool immediately when the TE cooler is turned on. It requires a few minutes (for a small CCD camera) to stabilize and it will only stabilize if the temperature requested is at least five degrees warmer than the open-loop temperature.

If the camera is started running with the stabilization temperature requested to be colder than the TEC can provide, the temperature of the CCD will lower to an initial minimum and then rise again to the "open loop" temperature. This small rise in temperature reflects the attainment of a thermal equilibrium throughout the mechanical parts of the camera head.

To disable cooling the camera, set the stabilization temperature above the current ambient temperature. Alternatively, the cooling On/Off configuration parameter can be used to enable or disable power to the TEC.

2. Receiving Your S800 Camera System

The 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

The camera and the computer interface module, with its cable, are shipped in one box. The DC power supply, with its cable, is shipped in a second carton. A cooler, if provided by Spectral, is in another carton. The test report and the SI-Image software are shipped in the box with the camera.

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. It is important to use these or equivalent packing materials if the camera system is to be transported.

2.2 Environment Requirements For S800 Cameras

2.2.1 Temperature - Humidity - Pressure

The camera system operates at temperatures from 60°F (15°C) to 95°F (35°C). The camera system operates at relative humidity from 10% to 60%. 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, 230 or 240 volts. 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 camera 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.

2.3 Assembly Of The Camera System

Camera assembly consists of verifying proper AC line voltage setting, connecting AC line power to the power supply, connecting the power cable between the power supply and camera, and connecting the computer interface cable between the camera and the computer interface card.

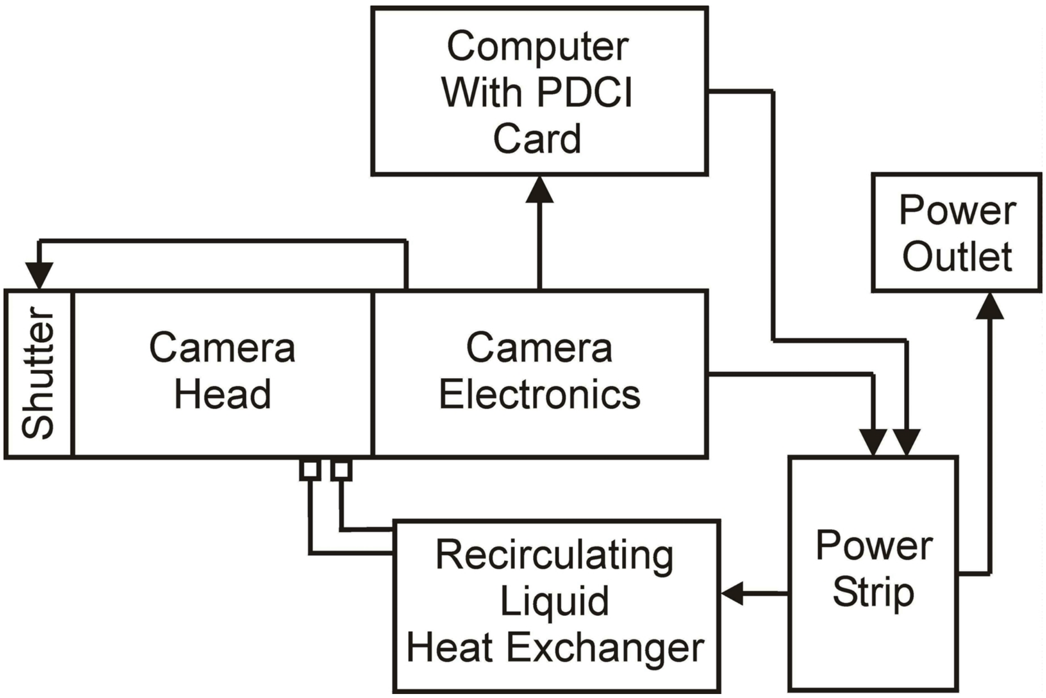


Figure 6.
S800 Interconnect Diagram

Figure 6. shows how the components connect and how the main power must be connected.

2.3.1 Assembly Of The Camera

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

2.3.2 Assembly Of The Camera Power Supply

The AC power setting must be verified or set to the proper configuration before power is applied to the camera. 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 power supply is set to the proper AC power, it must be changed. All of the output fuses must also be changed whenever the incoming power setting is changed from 100/120 to 230/240 volt configurations. The fuse requirements are given below and are labeled on the back of the power supply. Power and fuse changes are accomplished as follows:

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

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 230-240 mains, the fuses must be T1.0 fuses or T1.5 depending upon the TEC power supply installed. For 100-120 mains the fuses must be T2.0 or T3.0 fuses, again depending upon the TEC supply installed. 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 six fuses (labeled F1, F2, F3, F4, F5 and F6) for the DC power must be correct for the incoming line voltage. The first three fuses are identical and are T0.5A for 100/120 volts incoming power. The second set of fuses are also identical and are T1.5A for 100/120 voltage. For 230/240 the two sets are 1.4A and 0.75A respectively.

Once the AC power setting on the electronics unit has been set up for the local AC power, assembly of the camera consists of connecting the power supply cable to the camera.

2.3.3 Digital Camera Interface

Spectral provides two versions of the computer interface module. One is the PDCI-AIA parallel data card that is a PCI bus interface card for the Spectral Instruments 500, 600 and 800 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. The interface card connects to the camera by a 68-pin to 50-pin high-density cable.

The other data interface option is the PDCI-FO, a fiber optic module with the same characteristics insofar as the host computer device driver is concerned. It has a MT-RJ fiber optic connector instead of the 68-pin AIA connector.

To install either module in your computer, first turn off your computer and plug the interface card in any available PCI slot. Insert the Spectral Instruments CDROM into the CDROM reader on the computer.

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, WinNT, Win2K or WinXP) and installs the appropriate driver and camera interface .dll into a directory path that you may redefine as part of the installation.

When the computer is switched back on, a Windows 98 operating system will find that the card has been installed and finish the installation. For Windows NT and Windows 2000, become system administrator and run the setup.exe on the CDROM. Note that installing the software as administrator requires a re-boot cycle to again be able to run the software as a normal user.

2.3.5 Software Operation

The software is typically installed into a sub-directory under the directory containing other Program Files. Two icons are provided, one to run the program and the other to uninstall the application. The SI Image SGL program uses an internal representation of image data as floating point pixel values which means that image data are 32-bits (4-bytes per pixel). The data can be stored under any of several file-storage formats. It is important to select a file storage format that is appropriate to the range of values in the image data! If the image has negative values (as a result of image arithmetic perhaps) those pixels are not represented correctly except as signed 16-bit integers or as 32-bit floating-point values.

Once the program screen appears, the pull-down labeled Operate provides a control to initialize the camera. When this has finished properly, the camera is then ready to operate. A software manual, Part # 2523, is provided as a .pdf file on the CDROM that also contains the software.

2.4 Startup

After the software is installed, the camera has been connected to the power supply and the data cable connected to the PDCI interface, the system is ready to image.

2.4.1 Power-On Condition And Indicators

When the unit is switched on, the "**PWR**" indicator on the camera head flashes three times and then remains illuminated. The amber high-pressure "**VAC**" light will turn on if the camera pressure is above 4 torr. This indicates that vacuum service is required. The green "**COOL**" LED indicator light on the back of the camera housing turns on when DC power is applied to the thermoelectric cooler. The brightness of the light shows the amount of power being applied to the cooler. When the TE cooler is first turned on, maximum cooling power is applied and the light is bright. When the camera has reached the selected operating temperature the "**COOL**" LED glows but not as brightly.

2.5 Commanding The Camera

The camera accepts a 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 and or line feed, are necessary to initiate the command. Only those characters that are part of the command set are valid. The command set is available from Spectral Instruments upon request as part number 1870. 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. Some variations occur in exactly when the various Y responses are transmitted to the host computer depending upon the activity commanded.

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 echo is received. The camera 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 camera waits for the number of bytes that are expected for the command so it is important that every command that requires a parameter be followed by the proper number of bytes. After the parameter(s) is/are received the terminal Y or N response is returned. If a 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, send the information after the command is echoed. These numbers are also 32-bit and are sent with the most significant byte first. After the parameters are sent the Y or N is sent. The camera communications protocol is documented also under SI Part Number 1870.

2.6 Initial Tests

To assure the camera is functional even before it is cooled, it is reasonable to run through initial imaging tests while the camera is cooling down. Final performance metrics cannot be undertaken until the camera has stabilized at its regulating operating temperature.

There are several configurations the camera can assume. For some of them it is not possible to "take an image" without fully integrating the camera into the application apparatus. 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 - the bias,
2) the dark image which includes the bias and shows the sensitivity of the camera to thermal signal and
3) the light image at which the camera was directed. The light image includes the dark and the bias components.

If the exposures are short and of constant duration, then the bias and dark images need not be measured separately - particularly if a dark image is obtained essentially for every light image. Bias images may exhibit a low-level spatial structure that is stable over time. The bias image is different according to the way the camera is set up to image. It changes with readout speed, attenuation and binning. The bias image is a uniform array of very low-level "gray values" superimposed upon on a background DC offset. The value of the offset can be set by software command.

Binning, attenuation (gain) and readout speed all affect the bias image. Some structure may be visible along one edge of the bias image. This stable structure reflects the analog readout electronics responding to the startup transients involved in beginning each row read out. Bias images also incur some thermal signal (dark image) 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 7., the thermal signal is uniform along rows and increases along columns. The plot overlaying the image in Figure 7 shows a horizontal cross section at the red cursor in the image. Colors only show up in the .pdf form of this document.

Dark images are bias images along with the additional thermal signal accrued during the exposure time. Dark accrues more or less uniformly over the entire sensor although some areas of the CCD may contribute thermal image at a higher rate than other areas. This non-uniformity is stable for a given exposure.

Very bright "speckles" will 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 as described in Section 4.

2.6.2 Default Camera Readout Format

The default image readout format, as delivered by Spectral Instruments, reads out more pixels than just the illuminated pixels. This readout mode is called "overscan", reading imaginary 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 A1., in Appendix A, includes the pixel count appropriate to overscan some representative CCDs. The illustration shows you how to relate each of the tabulated parameters to the image read from the camera.

Figure 7, below, shows an image from a warm camera displayed with SI Image and the plot for a column near the center of the image overlaying the image.

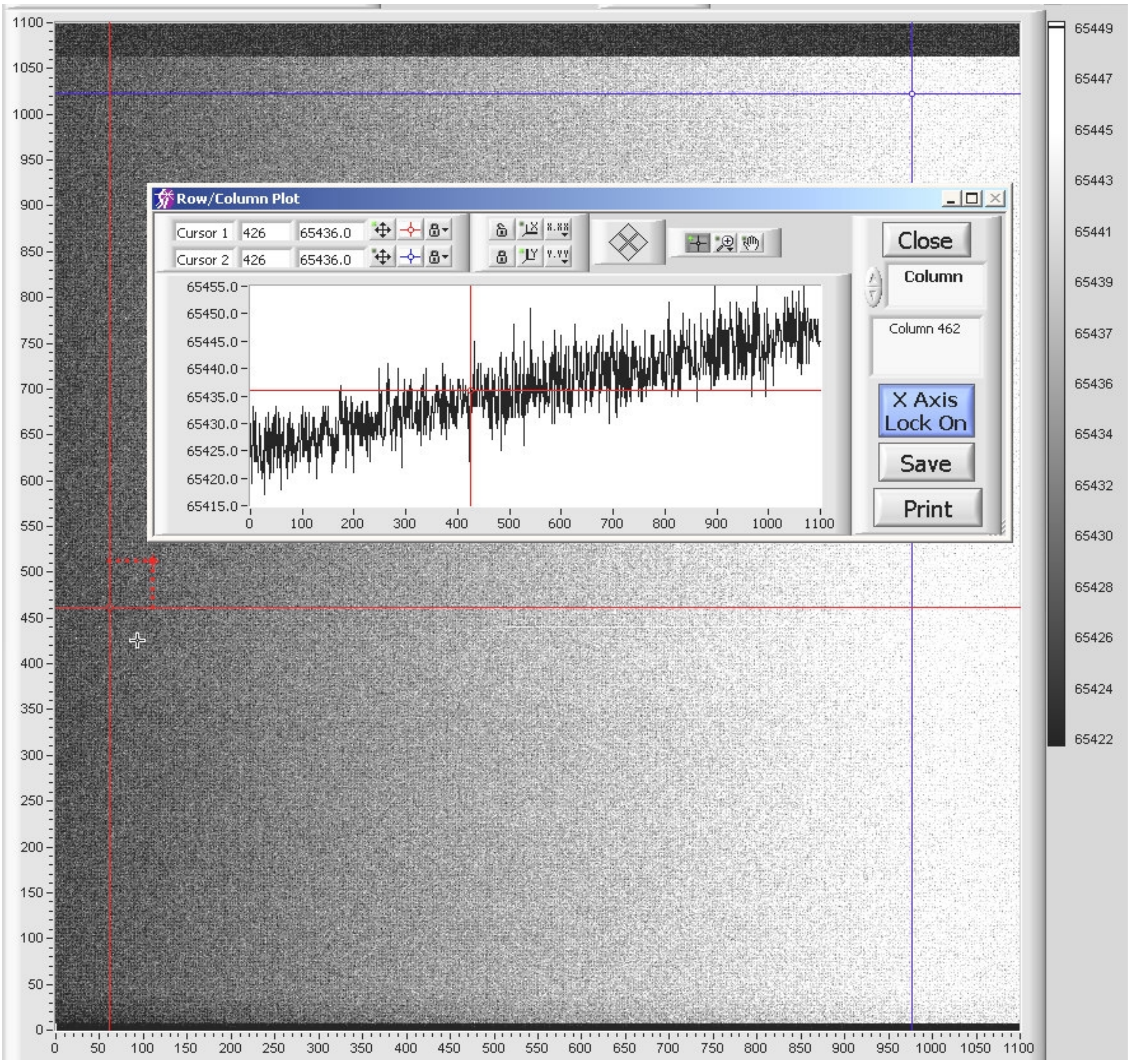


Figure 7.
Camera Image Showing Overscan

The serial register is on the left hand side of the image. The first pixel read is displayed at the lower left hand corner and the readout progresses up rows starting with the first row at the left and progressing to the last row that is displayed on the right hand side of the image. The image is darker on the left and brighter on the right. The column plot shows the "ramp" of increasing dark signal with time. Because of the slow-scan readout, rows on the right hand side of the image were exposed to dark signal longer than those on the left hand side – hence the ramp.

The image shows dark bands at the bottom and top. These bands are from pixels that were digitized but that did not come from the active area of the sensor. The band at the bottom is the 8-pixel prescan extension of the serial register. The wider band at the top is the post scan extension of the serial register. The pre scan and post scan are combined into the general term overscan.

The image shown in Figure 7 includes overscan in the parallel direction as well as in the serial direction. It is not too easy to tell but the last 100 rows in the image have all about the same signal level since all of those rows experienced the same exposure to dark signal during readout. This is because they do not exist on the sensor and are sort of “created” at the far (from the readout) edge and transit the sensor just like the last real row did.

The best image for showing all of the components of overscan readout is a light-exposure from a cold camera. 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.

Dark signal only arises in pixels that exist within the parallel register of the CCD. Note that the parallel overscan, while representing a region that is not on the imaging area of the CCD does show dark signal. This signal is flat because all of the parallel overscan rows are exposed to dark charge for some time (exactly the same time) while passing over the active area during readout (which is when dark signal is experienced.) Reference Figure A1 in Appendix A for an illustration of overscan readout components.

2.6.3 Dark Image

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 for the exposure-time duration - 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 several distinctly different levels along the sides 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 are generated by reading past the physical extent of the edges of the CCD sensor. Depending upon the camera temperature and the amount of the exposure, it may be possible to "see" the difference between masked pixels and illuminated pixels on the parallel register. Finally, the dark signal that accrues during readout is a ramp that starts near the bias level on the side of the serial register and increases to a constant level in the parallel overscan.

Insure that all external illumination is extinguished and obtain a ½ second dark image. The result is a dark image from a moderately cooled camera - a gradient in brightness shows up with the brighter pixels on the side of the image away from the serial register.

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. Any 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. Running The Cooled Camera

Once the camera head has become thermally controlled it is possible to verify some camera performance metrics, as described in subsequent sections.

3.1 Image Quality

Now that the camera head is cold, a bias image is a more uniform array of gray values with a lower-level ramp along columns. The image is otherwise pretty uniform, or else there is a light leak where the camera head joins the application or within the application itself (assuming there is no shutter between the camera and the application). Two bias images taken in succession and subtracted are flat, although you may be able to notice the increase in noise (because of higher dark signal) at the side away from the serial register.

Dark images from moderately cooled cameras exhibit a wide variety of patterns that are typical for different CCDs but may vary in visibility from one CCD of a type to another of the same type. In deeply cooled CCD cameras, you can expect fairly uniform dark images. In moderately cooled CCD cameras, dark non-uniformity is the rule. Many CCDs show wafer-dependent patterns in the dark signal.

With that said, a 100-second dark image shows a structure similar to the bias although the background will be higher (depending upon the CCD and the temperature of the camera). The cold-CCD dark image integrates both internal dark sources and extraneous light (again assuming no shutter) and it shows up light leaks in a way that short exposures typically do not. Light leaks are usually not uniform so they are revealed in dark images. Very low-level light leaks can emulate dark signal – so be wary.

3.2 Performance Metrics

Continue to avoid exposing the CCD to light. It is time to measure some performance parameters. The SICCD camera meets a number of primary performance metrics two of which can be verified without other instrumentation. These are:

3.2.1 Noise

The camera readout noise is determined by the rms of a region from a bias-only section of the CCD. Obtain a overscan bias image and note the rms of the ensemble of pixels in a region of the image that is off of the parallel register. 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 must be divided by $\sqrt{2}$.

3.2.2 Dark Signal Generation Rate

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

It is necessary 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 if the CCD is cold.

Obtain a 100 second dark image from a freshly cooled camera and determine the mean signal from a region on the parallel register 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 divide by 100 to yield the dark signal generation rate in electrons per pixel per second. The result will agree with the test report within 10%.

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 regulated. SICCD cameras on telescopes, where 40^{o}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 starts to be read out. 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 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 the array of active picture elements. Unfortunately, the structure upon which the CCD is formed 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 4 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 noise to make it difficult to measure background-level image signals.

To reduce the impact of dark signal, S800 cameras utilize a thermo-electric cooling system that allows the CCD to be operated at as low a temperature as is consistent with that CCD and the camera configuration.

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 4 electrons and a dark signal of 4 electrons, the combined noise is 5.6 electrons. For a 4-electron camera that is running at one thermal electron per 10 minutes, this means that it is possible to integrate for some tens of 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. 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. The second relates to non-uniform quantum efficiency in the sensor.

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 from 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 Fixing Problems With Images - The Master Image Solution

The SI Image software includes tools to correct images for offset and patterns that are introduced by dark signal and for sensitivity variations that arise in the incoming light signal caused by the entire application optical light path and possibly by camera effects (especially if the CCD is bonded to a fiber optic). The details of operating that software are presented in the software manual. This section of the hardware manual discusses the basic requirements of image calibration.

4.2.1 Master 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 single bias image from any other image - the noise increases by 1.4.

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. Because it is the average of many images, this master bias has virtually no noise and can 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 correct for the current camera offset level. SI Image actually manages images as floating point arrays so numerical processes are not limited to ± ½ count. It is possible to use the bias overscan to measure the short-term DC changes in the bias level.

4.2.2 Master Dark Images

For a S800 camera, the dark image is not equivalent to the bias image unless a very short (typically less than one second) exposure is obtained. However, if all of the exposures to be obtained from your camera are going to be the same duration with the camera in the same readout mode, 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 number 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. Glass products are notorious for thorium decay emissions that are very energetic. Brick buildings can 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. 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.

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. A decision must be made as to what constitutes a pixel so hot that it must be discarded. That determination is strongly a function of the application. 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 absent from the master dark image makes it much easier to scale the display of the master dark image so as to see any dark image structure.

4.2.3 Master Flat Images

The major instrumental 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 is hard to obtain. 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 difficult. Microscopes are the most difficult instrument.

Nevertheless, 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 obtain the flat image.

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 pixels that were determined to be "hot" 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 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 Correct At All?

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.

To inter-compare one region of an image with another you do need to correct for the variation in attenuation over the imaged field of view.

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 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. SI Image uses floating point so fractions are not a problem and neither are negative numbers.

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

You have a master bias, a master dark of some exposure time that has been corrected for hot pixels and a master flat from which you got 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. Again, in SI Image, these tasks are automated for you.

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

Effective flat field correction depends upon stability of 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. There for, 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 very similar (if not identical) illumination beams.

4.3.4 Understanding The Scaling Effects

The example 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 say that the magnitude of the pixel values is now “correct”.

Provided that the master flat image is exposed so that it is about half of the full range of the ADC, a scalor of half the maximum ADC value retains the theoretical maximum pixel dynamic range.

Clearly, the value of the scalor affects the pixel values 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 scale factor to correct 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 S800 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.

5.1 The Warranty Conditions

The camera is guaranteed 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 S800 camera can only be serviced at the factory. You must obtain a Return Material Authorization 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 the camera head or the power supply unit and it is highly likely that the user could exacerbate a problem by attempting to "open something up." Spectral cameras are assembled in an anti-static clean room to insure the safety of the CCD and the cleanliness of the camera interior. 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 No Response

The PDCI card must be correctly seated. It is possible to have the software indicate that the card has been successfully initialized and still have the SI Image application fail to run. Most frequently this is an interrupt conflict or failure to get an interrupt service connection properly set up. Try reseating the PDCI card and maybe move it to an adjoining slot. There has been some indication of an odd vs even slot interrupt assignment that has occasionally caused the SI Image program to fail to run.

5.3.2 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 camera power supply was plugged into mains power with the wrong power setting, a fuse could easily have burned out. This is especially the case running a 230/240-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 power supply fans are not running, the cause is probably a bad AC connection or a blown fuse or fuses. The user serviceable fuses are located on the back of the power supply. 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.

5.4 Determining When To Refresh The Vacuum

5.4.1 Measuring The Camera Head Pressure

A S800 camera head includes a sensor that measures the pressure inside the camera head. This sensor operates over a pressure range from 10^{-4} torr to about 10 torr. A facility is provided within the camera 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 (and temperature) inside of the camera head.

The pressure at which refreshing the vacuum is required is different for different camera applications. At about 4 torr, for cameras where the CCD is not in close proximity to the camera window it is time to pump. If the CCD is quite close to the window the camera may require pumping at 0.5 torr.

5.4.2 Why Pump

The first noticeable condition is that the dark current rises as the heat load on the TEC increases with increased pressure inside the chamber. 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 on the window or elsewhere, or if it has too high a dark signal generation rate the vacuum should be refreshed.

5.5 Refreshing The Camera Vacuum

The camera provides a valved port for refreshing the vacuum inside the camera head. It is necessary to refresh the vacuum when pressure has risen above 10 torr.

5.5.1 Equipment Required

5.5.1.1 Vacuum Pump And Vacuum Hose

For all SI cameras the basic vacuum pumping equipment is identical. A vacuum pump that can pump to 10^{-3} torr is recommended. Pumping to 10^{-2} torr will suffice. The pump must be safeguarded against vacuum oil contamination by an appropriate filter. 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

Although both 110 volt and 220 volt part numbers are included for the pump and the foreline trap only one of each is needed for a pump system.

The exhaust filter is attached to the exhaust port of the pump using a QF flange adapter and an aluminum clamp. The Micromaze 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 hose ensemble.

Connect the female-male adapter to 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. Use Teflon™ tape to ensure proper seals.

It is necessary to bake out the foreline trap by hooking up the wires to an AC voltage source. 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. Note that the controlled leak into the pump must be turned off for highest vacuum. The pump is supplied with a small manual that describes the bake out process and the controlled leak valve that is on the pump.

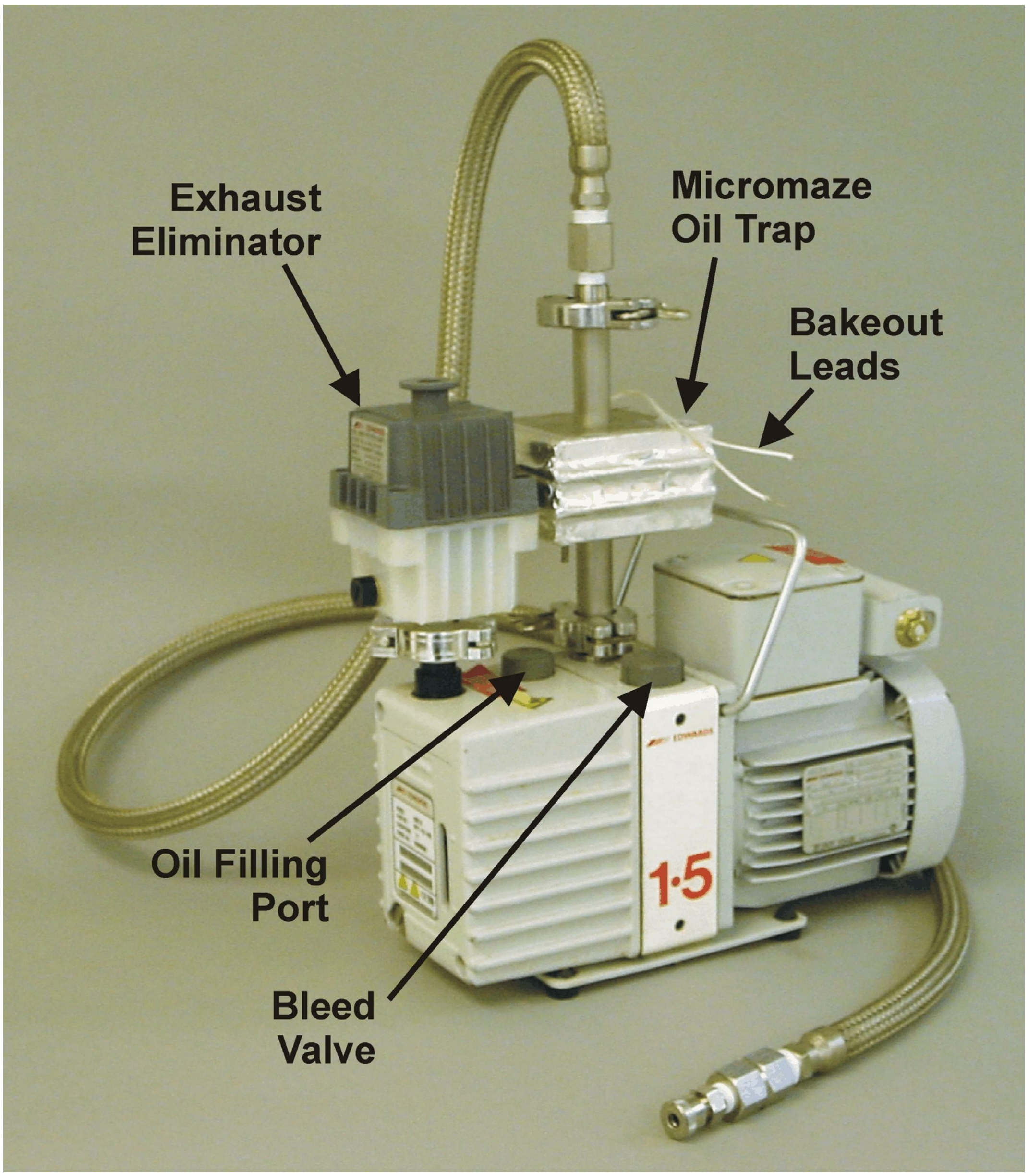


Figure 8.
Vacuum Refresh Kit

5.5.1.2 Vacuum Hose Fitting

The vacuum port on a camera is a ¼" metal tube that extends from the vacuum valve. This tube is "plugged" at the factory with a small Allen set screw which keeps "stuff" out of the vacuum port. This screw must be removed before the camera is pumped. 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. Such a connector is shown at the end of the vacuum hose in Figure 8 above.

5.5.1.3 The SI Vacuum Valve Actuator

The camera head with an externally accessible vacuum port is equipped with a proprietary valve that can be operated through a special valve actuator. The valve is internal to the camera head and is operated electrically. A small DC power supply is supplied with each camera system. Whenever the DC supply is plugged into an AC outlet and into the camera, the vacuum valve is opened!

IT IS IMPERATIVE THAT THE VACUUM PORT BE HOOKED TO AN OPERATING VACUUM PUMP BEFORE THE VACUUM VALVE ACTUATOR IS TURNED ON!

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 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. A built-in internal camera pressure readout is provided by the camera. First turn off the TE cooler. Allow the camera head to warm up until the temperature of the CCD is approximately 20^{o}C (this will take about 1/2 hour).

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. Then turn on the pump so as to refresh the vacuum in the hose. This ensures that the hose is clean.

5.5.2.2 Attaching The Vacuum Hose To The Camera

Remove the port plug set screw. Turn off the vacuum pump and remove the vacuum plug from the end of the hose. Attach the hose to the 1/4" camera head vacuum port fitting and clamp securely. Turn on the vacuum pump and evacuate the line.

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 and hose are operating at a pressure < 10^{-2} torr.

5.5.2.3 Pumping The Camera Head

With the vacuum pump running and the vacuum hose securely attached to the camera, open the valve by plugging in the electrical actuator supplied for your camera. Run the pump with the valve open for 3 hours. Disconnect the vacuum valve actuator to close the valve, turn off the vacuum pump and remove the vacuum hose from the camera head. Install the set-screw into the vacuum port.

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 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 so sensitive to dust on the window.

5.6.1 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

5.6.2 The Process

Set the camera on its side so that the shutter/window is easily accessible.
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 remove 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.

Set up the high-intensity light probe so that a grazing incident beam can be directed at the window. 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 methanol 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 Cables

The only cable that is standard with every S800 camera is the power cable, part number 2748. It comes in a fixed length of 25'. The shutter cable is application specific. The AUX connection is made as described in section 1.4.3. The computer interface cable has part numbers as listed in Table 2 for various cable types and cable lengths.

6.1.2 Camera To PDCI Cable

The camera to PDCI cable part numbers are given in Table 2.

Item	Part #	Description
1	2745	Cable Assy, Computer 50-68pos AIA. Male 25ft
2	2848	Cable Assy, FO MT-RJ to MT-RJ, 10m
3	2848-1	Cable Assy, FO MT-RJ to MT-RJ, 20m
4	2848-2	Cable Assy, FO MT-RJ to MT-RJ, 60m

Table 2.

6.2 The PDCI Card

The PDCI card is Part # 1527 for a copper-wire cable interface module or Part # 2495 for a fiber optic interfaced camera. 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 various headers are not to be used as they provide factory access to downloading the firmware in the module. Don't change any jumpers on this card.

6.3 The Camera

Spectral Instruments maintains a complete service record for every camera system shipped.

The baud rate at which the camera operates is set inside the camera. The standard factory setting is 19,200 baud and no other baud rate is provided. The PDCI interface card must be set to operate at 19,200 baud in order to communicate with the camera. SI Image has a baud rate selection box which must be set at 19,200. When SI Image is operated from a factory supplied .set file the baud rate is preset.

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, 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.

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 60% R.H. The non-operating humidity range for the camera system is 5% to 95%. It is a requirement that the camera not be operated when condensation is forming on any of the camera components. Note that the cameras are frequently supplied with a refrigeration unit that can cool the liquid supplied to the back plate to mitigate the effect of ambient temperature on the minimum regulation temperature for the camera. It is possible to run the cooling liquid so cold that the lines and maybe even the back plate of the camera condense. This is bad because water is condensing inside of the camera housing and may cause electrical failure and possibly a CCD failure.

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 power supply fans must not contain micro-particles that can build up into macro-particles that are electrically conductive because of potential damage to the CCD if the DC voltages fail.

7.3 Warnings

7.3.1 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.

7.3.2 Camera Head

Never disconnect the power cable between the camera head and the camera power supply unit while the latter is powered on. This power cable delivers operating voltages to all of the static and clocked voltages at the CCD.

7.3.3 Opening The System

The camera cover can be removed for access to the jumpers that select TTL or Opto as the operating mode for the AUX connector. Turn off the power and disconnect all of the camera head cables before opening the camera cover. There are 4 M4 Allen screws to remove. Slide the cover very gingerly straight up away from the camera head. Avoid scraping the cover against the components that are quite close to the cover inside the camera head.

When the cover is replaced, again be quite careful to slide the cover down without touching any of the components mounted on the electronics modules.

7.3.4 Refreshing The Vacuum

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

7.3.5 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!

8. Troubleshooting

8.0 Power Problems

8.0.1 Main Power Failure

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

8.0.2 DC Voltage Failure

A camera that was working and suddenly quits has probably lost a DC voltage. There are six fuses for the individual DC power supplies on the S800 power module. See Section 2.3.2 for fuse specifications. Unplug the incoming main power and test the fuses to see if any are open. A fuse can fail without something else having failed, but this is not the normal situation. If replacing a fuse results in another blown fuse, the problem is most likely a power supply failure. Contact Spectral Instruments to see about a replacement.

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 either the offset is wrong or that something has "railed".

The most common cause of a zero data value for the entire image is the offset to the analog processor is set too low. This means changing the value of the offset parameter for the analog channel you are using. There is no one proper value for all cameras. Try changes in each direction by 500-unit increments and see if the bias image appears. If you change by more than 2000 units and no image appears, it is probably not an analog offset problem.

The next most frequent cause of an all 0 image is over saturation of the CCD or the analog processor. Cover up the camera front end. 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 and the CCD is overloaded. Try short exposures or somehow reduce the light level to relieve the overload.

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 was disconnected, check that the camera has been properly reinstalled.

Next, it is necessary to make certain that the problem is in the camera. If the camera is warm obtain a 30-second dark. If it is cold, obtain a 5-minute dark. Either image will exhibit the characteristic pattern of a dark image from a CCD camera if the CCD and the electronics are working. If the image is still very flat without any gradients or bright spots then the CCD is truly not providing image data. This means that the camera must be returned for service.

If a normal 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.

8.1.1.3 Fully Saturated Image

The light from even a darkened room is enough to saturate the CCD. Again, cover the front of the camera and determine whether the saturated condition persists.

Sometimes it is not so easy to darken the incoming signal but it is important to make certain that the camera is not exposed to extraneous light that is “leaking” into the camera head. Attempt to darken the incoming light path and obtain a two-minute 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 the shutter failing to close fully before the image starts shifting. Some streaks result from low-level instabilities in the external electrical environment around the camera.

8.1.2.1 Shutter Problems

Shutters have a finite lifetime and should be considered as a regular service item. One 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 if the problem goes away. Another shutter failure mode is not holding open. This means that every exposure is too short. If the shutter "clicks" open and then closes immediately, the shutter should be replaced.

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.

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. Make certain that the AC electrical connections are to a common power source.

8.1.2.3 Streaking In Triggered Images

Images obtained in response to triggered input usually are obtained from a scintillating source. It is frequently the case that the scintillation persists for some time after the "event" that stimulated the scintillation disappears. It is necessary to wait for this persistent image to reduce to a negligible level before the camera readout is started. Extending the exposure time for the camera is usually the easiest method of delaying the readout. Changing the shutter-close delay may also provide a suitable delay control.

8.1.3 Noisy Image

Noise indicates a signal intrusion into the application environment or a camera failure. It is also usually due to something "running" in the application or to a bad ground connection between the camera and the application.

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 power supply and the refrigeration system 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 Camera Seems Not To Be Stable

Instability can result from a component drifting out of tolerance within the camera system - but it is not likely. 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. 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 operates at low speed, set the attenuation to 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.

8.3 Camera Reports The Proper Temperature But Dark Is High

It should be noted that if the power is turned off while the camera is cold and then turned back on before it warms up, many different sorts of "high dark" syndrome images can be seen. The solution is to turn off the TE cooler until the camera reaches a temperature warmer than -20^{o}C and then turn it back on. This is also the solution to high dark that occurs after the camera is exposed to over saturation.

High dark with the temperature reported at the set point indicates a warm CCD. First set the speed and attenuation to 0 and obtain a two-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 120. 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 possibly 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 conduction. In any event, if the camera pressure is above 2 torr it 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 TE cooler is at margin.

8.4 Camera Does Not Cool

Several possibilities exist. One is that the TE power supply has failed, the other is that the camera vacuum is not high enough. Generally, the back plate of the camera is slightly warm unless a refrigeration unit is in use. If one is, turn it off for a bit and see if the back plate becomes warm to the touch. If the back plate is/becomes warm, the TE power supply is operating. If the back plate is quite warm the water circulation is probably not operating properly. If the camera pressure is high and the dark is high the camera needs to be pumped.

8.5 Condensation On The Camera Window

The most likely scenario is that the vacuum needs to be refreshed.

Appendix A

CCD Readout Format

A refresher on row/column terminology. Figure A1., 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 A1. 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 A1, below, compiles the various image components for several 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 A1 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 read into the DSP as readout parameters.

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. Parallel post extension shows the dark signal quite well.

A1 Some CCD manufacturers separate the serial register from the parallel register by masked pixels.

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 some CCDs are 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 often 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 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 Illumin-ated Pixels	Parallel Over-Scan	Serial Readout Dimension	Serial Pre-ext.	Serial Pre-Mask	Serial Illumin-ated 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 16801	4128	20	4098	10	4145	35	0	4098	0	12
CCD 42-40	2048	0	2048	0	1056	16	0	2048	0	16

Table A1.

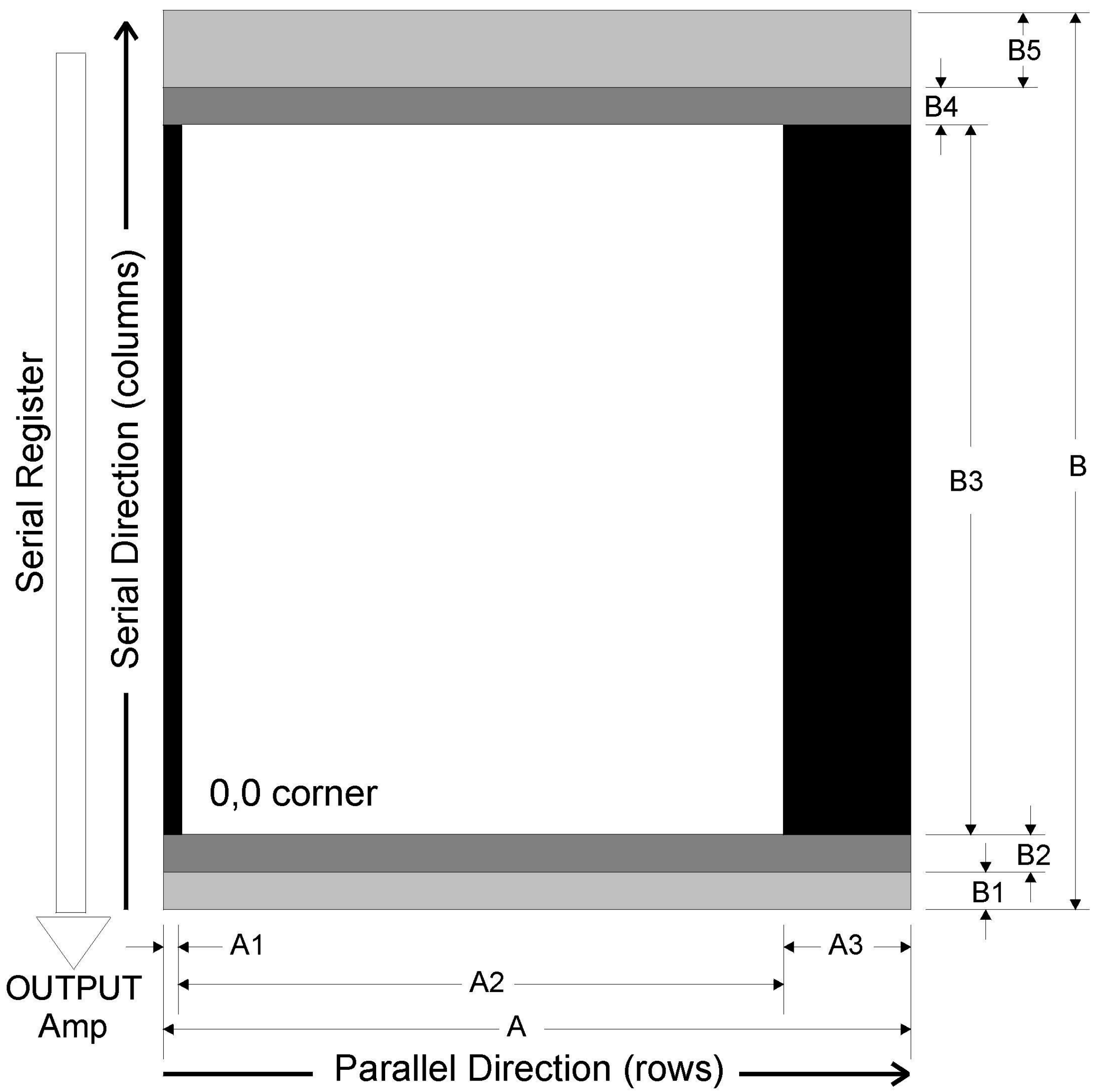


Figure A1.

Appendix B

Multi-Port CCD Readout Parameters

S800 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 B1, 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 multi-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 cameras all have the ability to read out from 1-port, 2-ports or 4-ports. The parameters that govern 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 read out 2-port through the A and D or through the B and 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. Spectral Instruments provides a .dll that can de-interleave a multi-port image.

Single-Port CCD Image Orientation

Referencing Figure B1. 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. Post scan can occur in both directions. 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 read out 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 B1 below. When the parallel phasing parameter is set to 1 the parallel register reverses shift direction toward SR2.

When two-port readout is selected, it is usually the case that the serial register is split. For this situation the serial phasing parameter must be set to 0 and the serial split set to one. If the serial phasing parameter is set to 1 for two-port readout the serial 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.

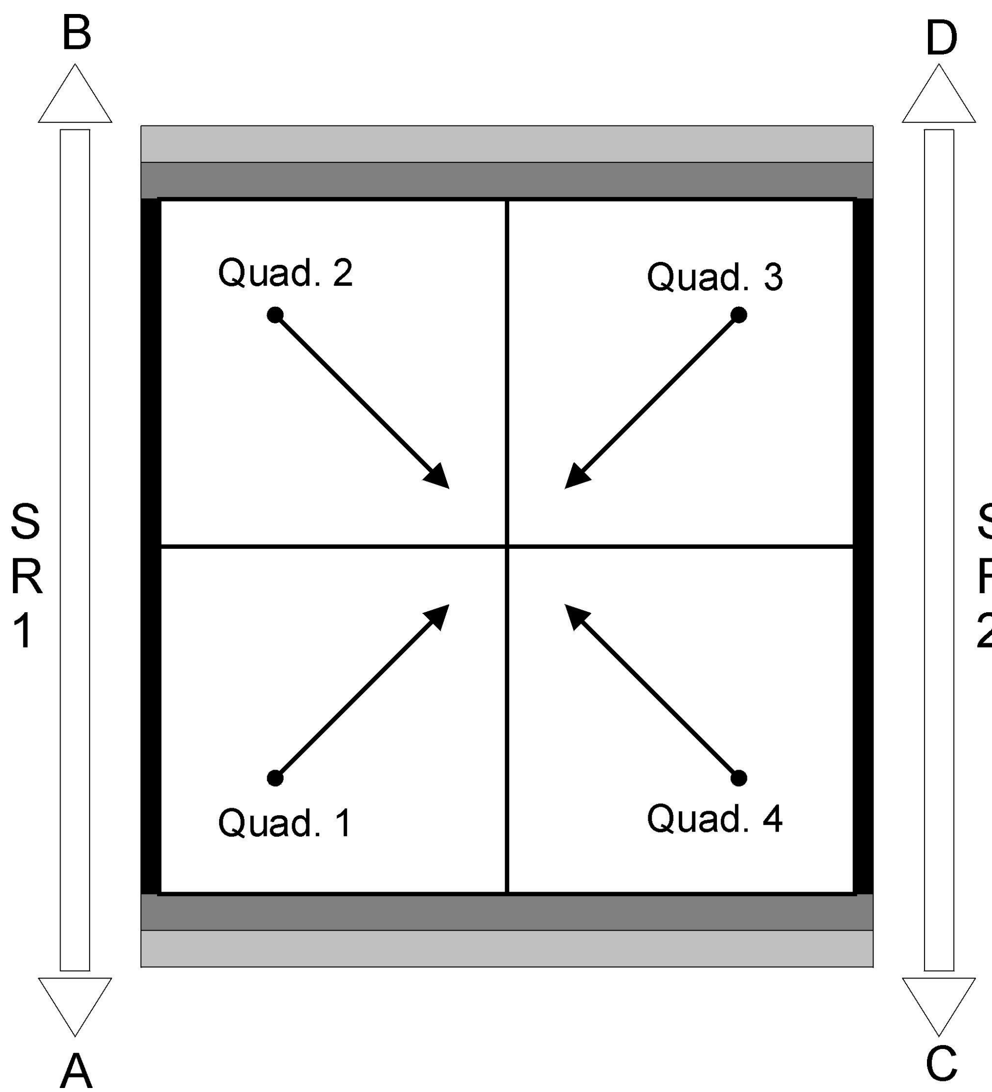


Figure B1.
Multi-Port CCD Readout Format

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 B1.

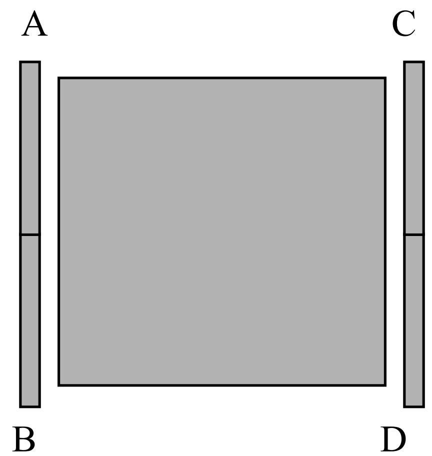


Figure B2.

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 B2.

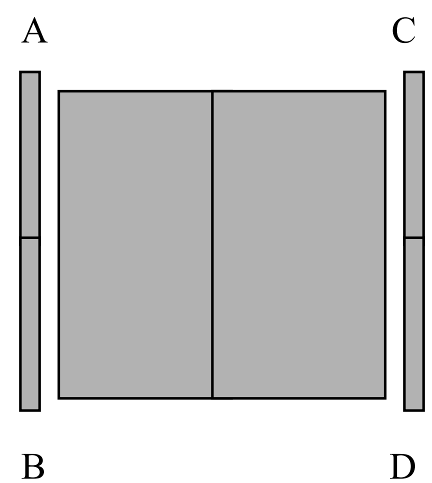


Figure B3.

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 SICCD camera that employs a 16-bit ADC converts the signal from 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. Clearly it is not possible to accurately digitize both full well level signals and very low signals with one camera sensitivity setting. 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 are required that range from less than 1 e^-/ADU, in order to digitize very low level signals, to greater than 50 e^-/ADU to digitize full well level images.

SI cameras that run 15- or 16-bit digitizers are typically set up so that very low level images can be accurately measured. Generally this means setting the system gain so that one digital unit corresponds to about 1/2 electrons of signal or, 0.5 e^-/ADU. In order to also measure high light level images with the same camera, SI cameras offer two software selectable attenuation levels which can be invoked in order to decrease the sensitivity of the camera and thus digitize higher signal level images. The range of sensitivity settings for your camera is provided in the test report that is supplied with the camera.

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 which increases the sensitivity. 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.

Dual Slope Integrator Sensitivity

The sensitivity of a SICCD camera using a dual slope integrator as the analog signal processing system 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 C1., below, tabulates a selected set of DSI settings and the effective pixel read time and the equivalent readout rate for typical S800 SICCD cameras.

DSI Sample Time Parameter	Pixel Read Time In Microseconds	Pixel Readout Rate In Kilohertz
7	1.0	1000
47	2.0	500
87	4.0	250
247	10.0	100

Table C1.

The DSI Sample Time values given above to achieve a particular readout rate are different for different CCDs and for different A/D converters. The above values are only representative of the range of numbers you might expect to see in a .set file for your camera to select different read rates.

Appendix D

Pressure Conversion 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

Appendix E

External Trigger

The S800 camera is capable of acquiring images where the acquisition is synchronized with an external event. When the camera is programmed to acquire an image upon receipt of a trigger, the camera runs continuous clear (unless that activity is specifically disabled) until the trigger line is activated. The camera ceases the continuous clear upon trigger and "stares" at the application target for the time that was last set as the integration time. The image is then readout from the CCD.

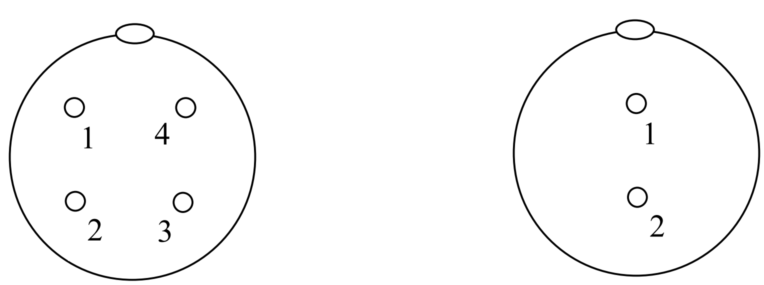
Figure E1, below, shows the character of the trigger signal that is available at the 4-pin Lemo connector on the back of the camera. The two modes available are called TTL and OPTO. The mode is selected independently for the trigger input and the shutter output. Two jumper blocks on the clock card enable either mode to be switched from TTL to OPTO. To set or change the jumper, remove the camera cover and locate the two jumper-pin arrays labeled JP4 and JP5 on the clock card shown in figure E2 below. They are both located near the LEMO connectors. Printed on the PWB next to the JP4 line of pins are the legends:

TTL
OPTO
TTL
OPTO
TTL

Essentially the two lines labeled OPTO are grounds and if the TTL pins are jumpered to ground the camera uses the TTL logic wherein a simple contact closure between pins 3 and 4 causes a trigger. The shutter signal is a TTL output that can be used to synchronize some external equipment with the camera. It is true while the camera is exposing after the trigger. When it goes false, the camera readout has started.

If the pins are not jumpered, then the input and/or output (JP6 is the output, JP5 is the input) are running the OPTO portion of the schematics shown. This mode completely isolates the camera head from any electrical pickup from the external signal whereas the TTL mode is susceptible to external noise.

Pin numbering on the Lemo connectors are shown below for the 4-pin Aux and 2-pin Shutter connectors. The view is looking at the connectors on the camera panel.



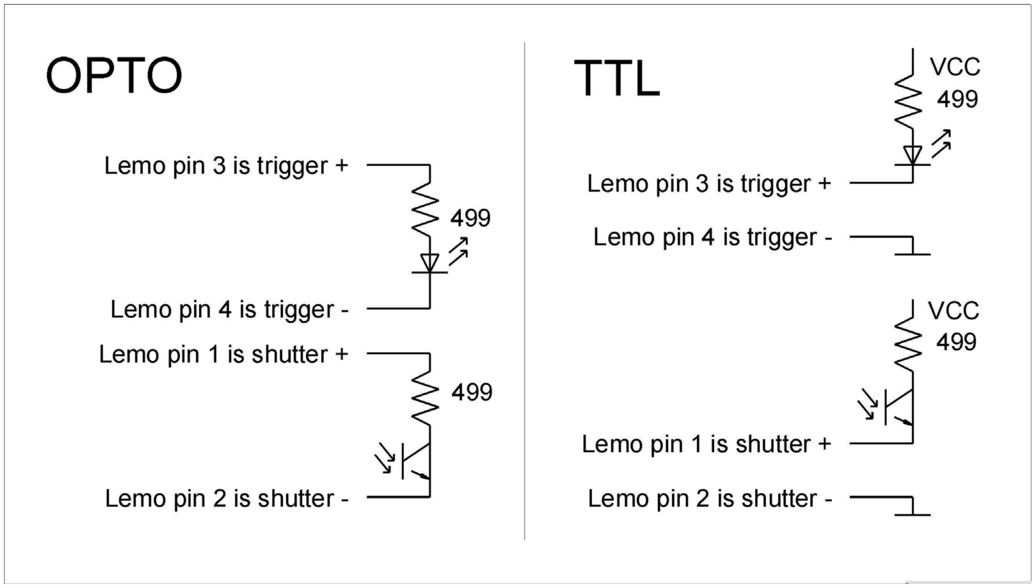


Figure E1

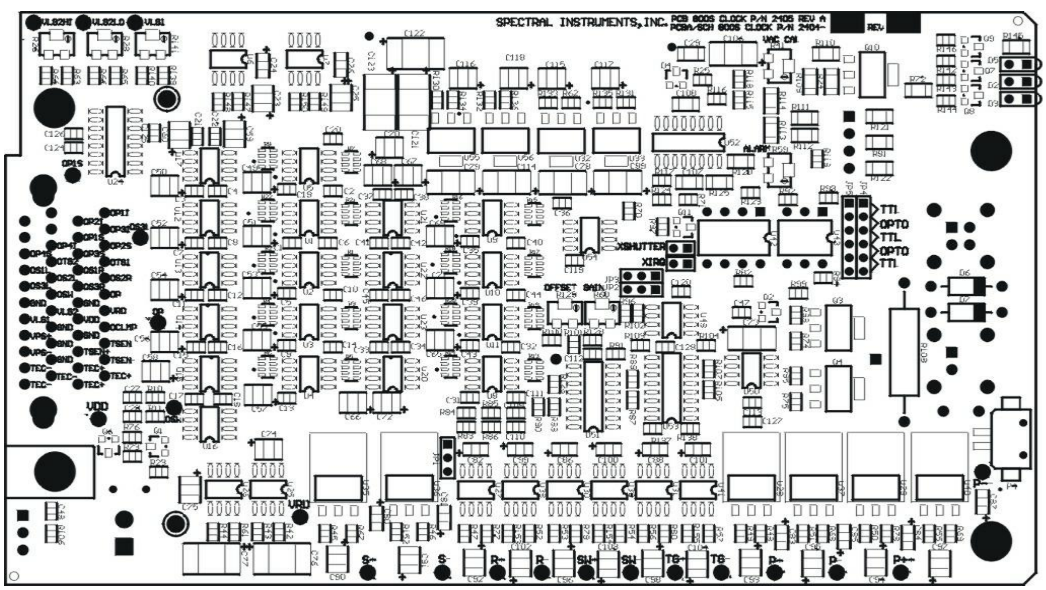


Figure E2

Appendix F

S800 DC Power Specification

The camera uses a 14-pin HiRose TwistLock connector. The table below defines the voltages required. The TEC voltage depends upon the particular TEC installed and that is driven by the load on the CCD. The DC power other than the TEC must be ripple free to 0.01% rms.

Cable Pin Number	Voltage	Amperage
1	+15vdc	0.8
2	-15vdc	0.8
3	+15com	
4	-15com	
5	+30vdc	0.8
6	+30com	
7	+24vdc	1.2
8	+24com	
9	+5vdc	3.0
10	+5com	
11	VAR	TEC+
12	VAR	TEC+
13	VAR	TEC Com
14	VAR	TEC Com

S800 Camera Voltage Pin out