1100 Series Camera System User's Manual

P/N 4501

Revision B

TUCSON, ARIZONA

* Notes

The AC-DC power supply operates on incoming mains voltages from 100V to 240V AC at 50/60 Hz, with a maximum fluctuation of plus or minus 10%. The equipment is intended to be used in an installation category II, pollution degree 2 environment.

* Warning

This equipment uses a laser to drive the fiber optic data communications port on the controller. Do not inspect the laser output while it is powered on. Use of controls or adjustments of performance or procedures other than those specified herein may result in hazardous radiation exposure.

Service Requirements

Remove AC power from the unit before performing any maintenance on the equipment

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1 Introduction

The 1100 Series Camera System is a multi-port (from one to four ports) 16-bit camera that is available cooled to cryogenic temperatures (-70ºC to –120ºC) using a re-circulating refrigerant cooler or Thermo-Electrically cooled (–30ºC to –70ºC). It offers high precision, high stability and relatively fast 16-bit readout times from 4-port CCDs. Higher readout rates are available in 14-bit configurations of this camera.

1.1 1100 Series Camera System Overview

The Cryo-cooled 1100 Series camera system consists of two primary modules: the camera head and the camera power/cooling cabinet. The camera head contains the CCD imaging sensor and all of its readout and control electronics. The cabinet contains the power supply and the Cryo-cooler with its attendant return line temperature management hardware. The Cryo-cooler is described in later sections and comes with a separate manual as well.

Thermo-electric cooled versions of the 1100 Series camera consists of three primary modules: the camera head, the power supply chassis and the liquid chiller. The camera head contains the CCD imaging sensor and all of its readout and control electronics.

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 result in the ultimate in stable, high dynamic range digital imaging. Spectral Instruments has invented the term Scientific Imaging CCD, with SICCD as the acronym, which captures this high precision and high quality character of your camera. This label occurs throughout our documentation as a shorthand reminder of those high precision and high quality aspects of your camera system.

1.1.2 CCDs And How They Work

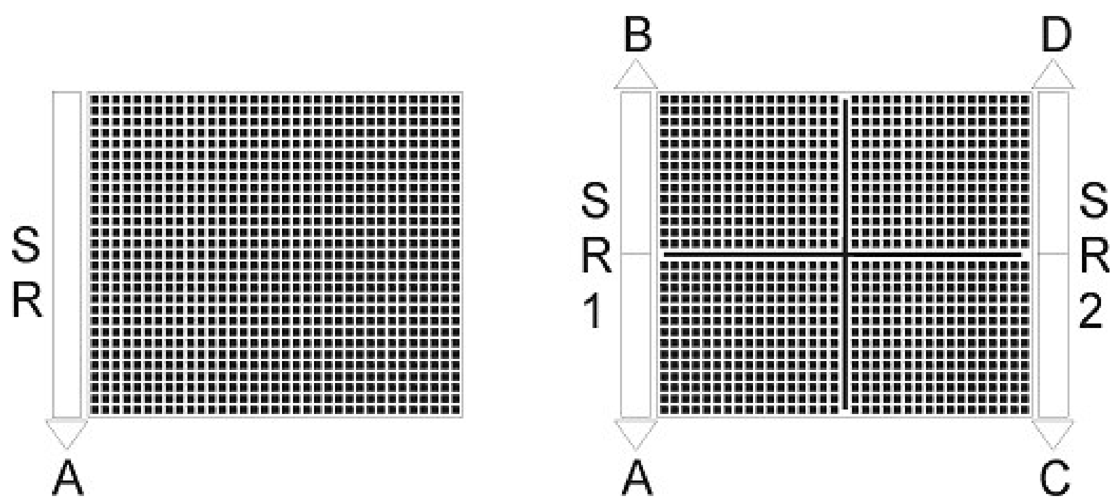
CCDs are used in a large assortment of consumer electronic products. They are available in a variety of sizes and types because of the popularity of this sensor for low-cost digital imaging cameras. Most of these CCDs are not scientific grade. Moreover, they are operated so as to give you a “TV” image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

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

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

Referencing the left-hand portion of Figure 1., the center-checkered region is the imaging area. It is called the parallel register. To read out the CCD, the grid of pixels is moved, one row at a time to the left, along columns, into the serial register, labeled SR. Once a row is moved into the serial register, it is then moved, one pixel at a time to the output node, shown as a triangle and labeled A. A column is a line of pixels consisting of one pixel from each row. The CCD does not 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.



One Port CCD **Four Port CCD**

Figure 1.

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

Referencing now the right-hand side of Figure 1., since the CCD illustrated supports four-port readout there are two serial registers labeled SR1 and SR2. Each serial register is divided into two halves, which is shown figuratively as a black line in the parallel register. The parallel register can also be divided and that is shows as a vertical black line. Neither black line exists 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 sorts them out so they are presented properly. The columns are still horizontal on the figure and rows are vertical in the image.

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

1.1.3 Multi-Port Readout And Sub-Arrays

It is possible to read only a portion of the entire image – a sub-region or sub-array. For a one-port CCD, setting the sub-array to read out is accomplished by sending the camera a new set of readout and format parameters that include serial and parallel offsets to the beginning of the sub-array and the serial and parallel dimensions of the sub-array. The ensuing image readout will only include the selected pixels. This ability to "home in" on a region of interest provides a quick means of aligning or focusing a camera.

Multi-port CCD cameras allow sub-array selection in the same fashion. The difference is that a sub-array is provided for **each** active channel using the submitted parameters as offsets from their respective readout corners. The ensemble of sub-arrays are read out (and displayed in SI Image as a single image) in the same time it would take for just one sub-array because the readout occurs simultaneously for all active ports. So, it may require some imagination, but sub-array readout, even in multiple port cameras, can be quite useful.

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

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

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

Some versions of an 1100 Series camera system employ a refrigerated cooler that is capable of lowering the temperature of the CCD below -110ºC. Spectral Instruments determines the optimum operating temperature for the particular CCD you selected and sets that value as the operating temperature. There is no reason to run warmer, as performance only degrades due to dark signal. There is good reason not to run colder, as the CCD may cease to operate properly. The operating temperature of your camera is a factory selected parameter that can be changed - but shouldn't.

1.1.5 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 saturated any pixels in the CCD, it will affect the camera's 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 1100 Series Camera Head

The camera head back cover is shown in Figures 2A and 2B. It contains 3 indicator lights that are located near the FO connector. A green LED, labeled POWER, indicates that DC power is present; a red LED labeled ALARM, indicates that an out-of-range or other error condition exists.

The third, red, LED, when illuminated, indicates that the fiber optic interface is not properly terminated and that it is not operating. 1100 Series cameras are available with several different options for a data port. AIA parallel copper wire and CameraLink interfaces are currently available. When an alternative data port is active (determined when the camera is built) the fiber optic port is not enabled. When the alternative data port is active the third LED does not illuminate.

The round electrical connector on the camera head back cover is labeled POWER. It connects to the power supply chassis via an 18-pin round connector. The rectangular AIA connector is labeled DATA and is used to connect to an AIA camera interface module. Alternatively, a fiber optic cable can be used to connect a fiber optic camera interface module to the port labeled FO. The SHUTTER connection leads to the shutter at the front of the camera. Not all cameras are equipped with shutters. The TRIGGER port is used to synchronize operation of the camera with external events.

The connector next to the camera power connector, called Vacuum Valve Connector, is used to connect the electrical power to operate the camera vacuum valve. WARNING! It is important never to connect the DC power supply to this connector unless the vacuum port is properly connected to an appropriate, and operating, vacuum system.

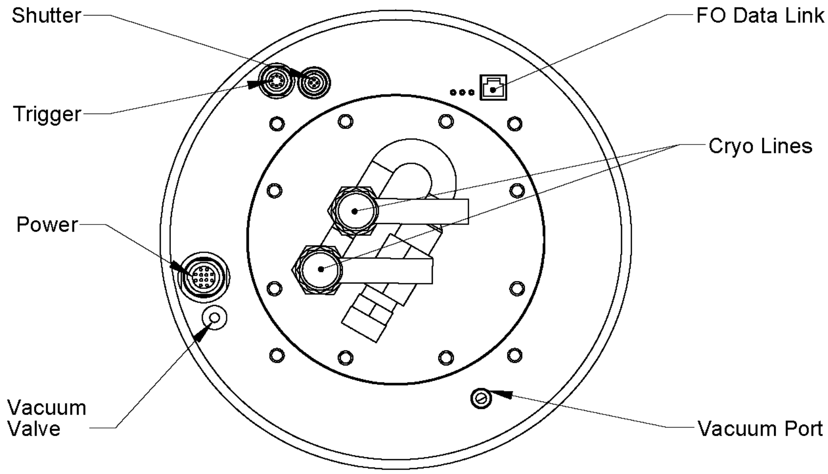


Figure 2A
1100 Series Cryo-cooled Camera Head Connectors

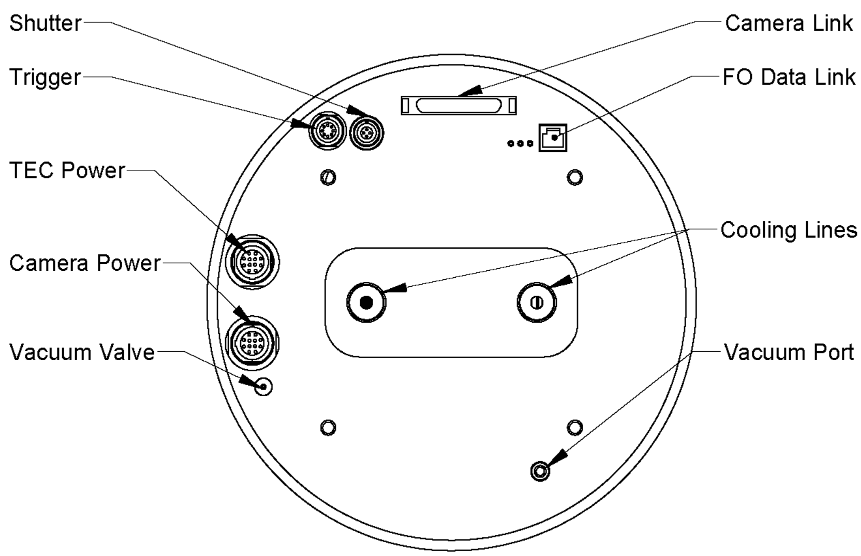


Figure 2B.
1100 Series TE Cooled Camera Head Connectors

1.2.1 The CCD Chamber

As mentioned in Section 1.1.3, the CCD is cooled to reduce dark signal. The CCD is maintained inside a sealed evacuated chamber to insure that moisture does not condense on the CCD or its electronics.

In a lens-based camera, the chamber aperture seal is a fused-silica window. The CCD sensor is typically located 12.2 mm behind the front surface of the window. The window thickness is between 3 and 4 mm depending upon its diameter. Fiber-optic coupled CCD cameras seal the CCD chamber at the fiber optic.

Those models of an 1100 Series camera head cooled by a closed cycle cryogenic refrigerator include a cold end capable of attaining temperatures as low as –190 ºC. The cold end is permanently inside the vacuum chamber through an O-ring seal so the camera body does not get cold – only the CCD. A heater is used to warm the CCD to the operating temperature; typically between –70 ºC and –110 ºC. The cold head has two self-sealing quick-disconnects that allow the camera to be easily unhooked from the compressor lines. A micro-heater around the window prevents the window from frosting due to radiative cooling by the CCD that is immediately behind the window. A TE cooled camera also maintains the CCD inside an evacuated chamber that is very similar to the Cryo-cooled head.

The 1100 Series camera front is shown in Figure 3. In most configurations, two different bolt circles are provided for mounting the camera head to your application. One is a ¼-20 threaded screw hole set aligned with the rows and columns of the CCD. The other is a ¼" clearance hole set aligned at 45º to the rows and columns of the CCD.

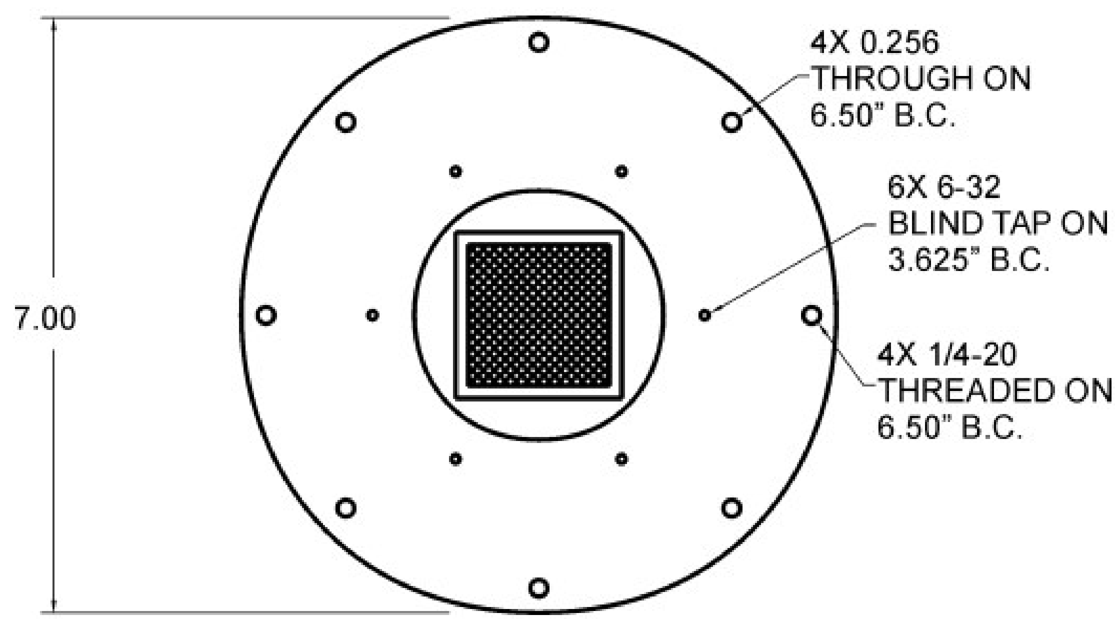


Figure 3.
Front Plate

1.2.2 The Camera Head Module

Within the housing that surrounds the camera head vacuum chamber are the electronics to run the CCD. The camera requires DC power in and provides digital data out, in serial form via a fiber optic cable or in parallel over an AIA or by a "Camera-Link" connection. The connector labels are shown on Figure 2.

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

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

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

1.2.3 Hooking Up Your Camera To Your Equipment

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

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

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

1.2.4 Shutters And Timing Considerations

The camera provides millisecond resolution in timing exposures. 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 while the CCD is 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) upon receipt of the trigger and stares into the application accumulating an image. At some later time the camera is read out. In this “triggered” mode, the camera control electronics operates in microsecond resolution appropriate to streak tube or pulse-triggered imaging.

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

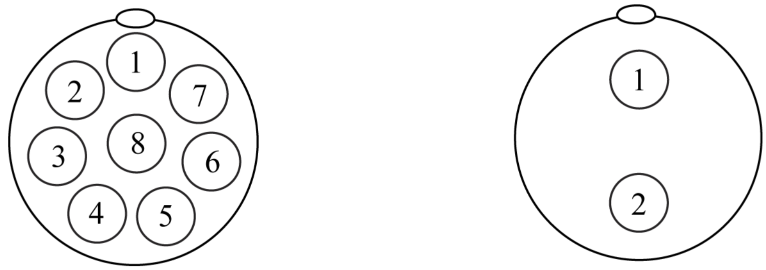
A small twin-blade shutter requires at least 8 milliseconds to open and close. A ten-millisecond exposure with such a shutter means that the integration time is effectively 26 milliseconds for the center of the image and is 10 milliseconds for the edge of the image. The resulting variation in effective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

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

It is important to set the correct delay for allowing the shutter to close before the image readout begins. Failure to make the shutter close delay long enough will cause the image to smear as it starts moving on the CCD while the shutter is not closed. The shutter-close delay is parameter # 11 in the configuration table. It is usually set at SI when the camera is tested.

The shutter is controlled through a current-drive circuit using the two-pin shutter connection. This connection drives either a Vincent Associates or a Mellis Grillot shutter with a 3-volt holding coil.

The shutter signal is available also as a TTL or opto-isolated logic signal on the connector labeled Trigger.



8-Pin Trigger **2-Pin Shutter**

Figure 4.

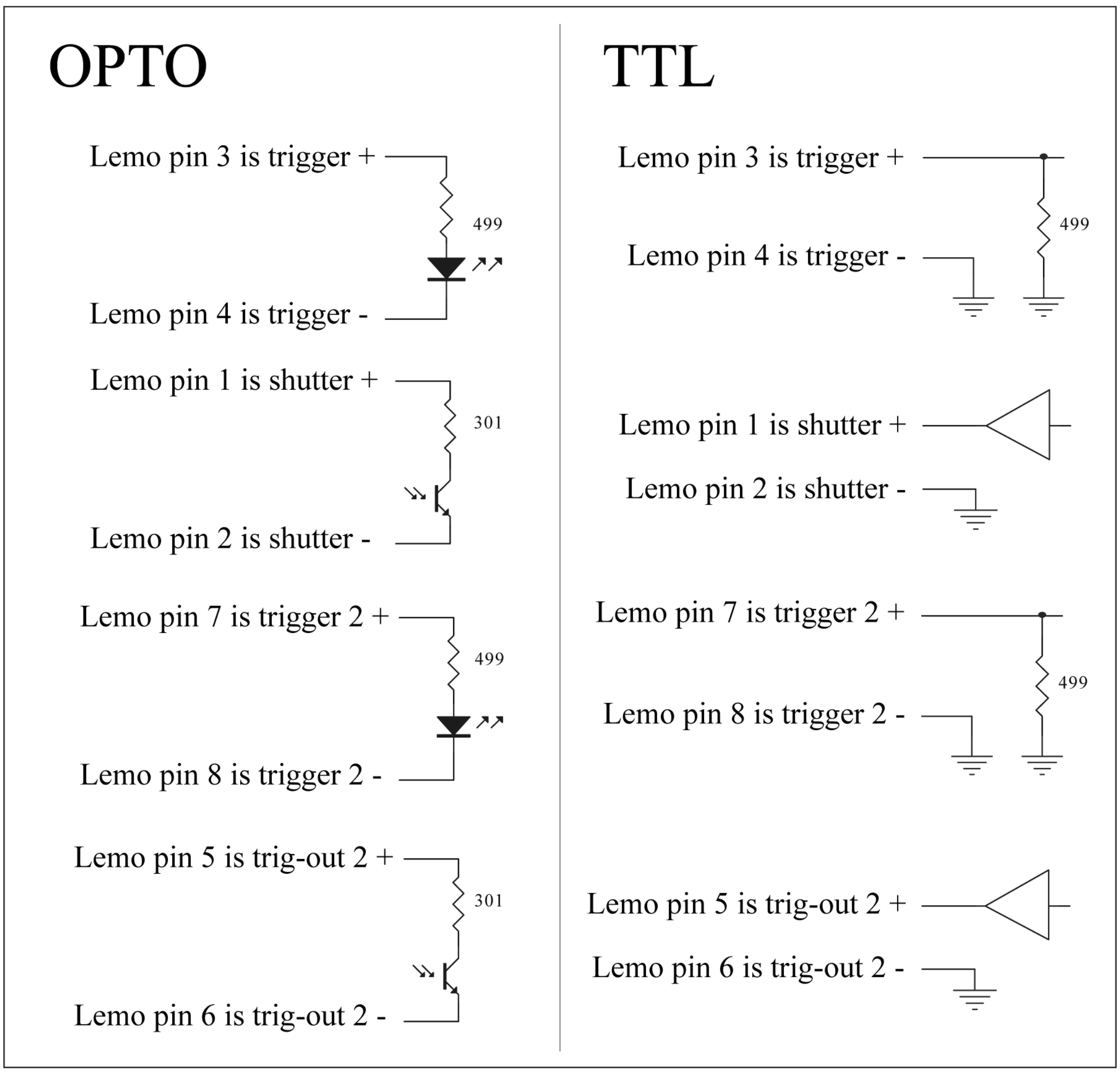


Figure 5.

The circuit for operating the TTL or Opto-isolated shutter is shown in Figure 5, above.

1.2.5 Lenses, Light Paths and Vignetting

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

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

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

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

1.3 The 1100 Series Camera Power Supply Chassis

The power supply is housed in a 3.75" high 19" wide rack-mount chassis. A power-on switch is located on the front panel. All cables enter from the rear of the power supply. Figure 6. shows the rear of the power supply where the connectors attach. The front panel has indicators for all of the DC voltages. It also has indicators for the incoming AC and for the status of a return line heater if one is employed. A service manual is shipped with the power supply.

1.3.1 The Camera DC Supply

The power supply module converts incoming AC mains power into the DC voltages required by the camera.

The power supply provides an AC output that is used to connect a TE liquid circulator or a refrigerated compressor. The AC output is turned on by software. Indicators on the front panel show the power and status of the AC output.

The round 18-pin power connector, CAMERA POWER, connects to the camera head.

The pair of 4-pin connectors labeled HEATER and SENSORS receive the cables to a refrigerated coolant supply line heater if such a return line temperature regime is used.

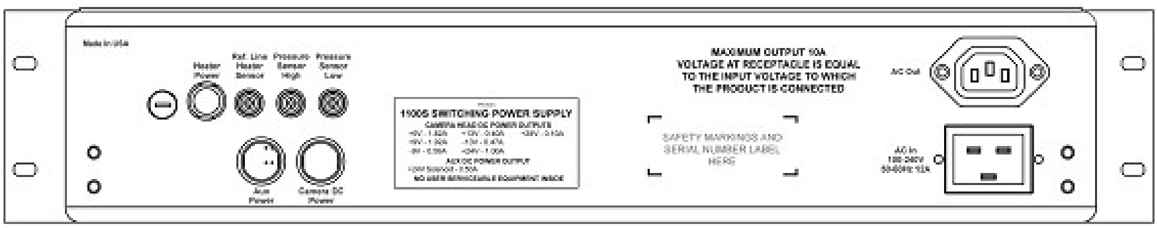


Figure 6.
Camera Power Supply Module – Rear View

The alarm buzzer on the front side indicates any error condition. The front side red LED also turns on when an alarm condition exists. The status lights on the camera head blink three times when the camera is initialized, either after power-on or by external software reset command. If a power supply voltage fails the audio alert is turned on, as is the red "ERROR" LED. In addition, the failing voltage indicator blinks.

1.3.2 Power Requirements

The power supply operates on incoming AC power in the frequency range from 48 to 62 Hz and can run on 100, 120, 230 or 240 volts. The supply auto-voltage detects so there is nothing to change for different AC mains inputs in the 100 to 240 volt 50/60Hz range. The supply has a single 5A fuse at the rear that pertains to the refrigeration line heater if a Cryo-cooler is used.

Manu of the connections to the power supply for a cryo-camera are made internally to the supplied cabinet. Refer to the supplied manual for this cabinet for further detail. If a TEC camera is purchased, the power supply connections, shown in Figure 6, for the 5A fuse, Heater Power, Ref. Line Heater Sensor, Pressure Sensor High and Pressure Sensor Low are not used and are plugged off. Aux Power is used to run the TECs in the camera head.

1.3.3 Thermo Electric Power Supply

Essentially the same power supply is used with Thermo Electrically cooled cameras. The top line of connectors and fuses is not present in the TE version.

1.4 The Cooling System

Two cooling systems are available for the two different camera-cooling mechanisms. One is a Cryo-cooler for use with the –100ºC cameras. The other is a liquid re-circulating chiller for TE cooled cameras.

1.4.1 Refrigerated Cooling System Description

The Cryo-cooler is a single-compressor system that is capable of removing up to 4 watts at an operating temperature of –190ºC. It is a cascaded Joules-Thomson refrigeration system that uses special gas as the refrigerant. It includes pre-charged gas lines in flexible metal-shields. The cables are connected, without leaking, through special connectors. It requires two open-end wrenches (a ⅝" and a ¾") to make or break the connection at either the compressor or the camera head. As mentioned in the manual for the Cryo-cooler, two wrenches must be used so as to avoid applying torque to the connector within the compressor or the camera head.

The 1100 Series cameras includes an A/C relay in the power supply that turns off power to the Cryo-cooler if the temperature becomes too cold, if the DSP ceases running or if the camera power is turned off. An explicit host computer command turns on cooling.

The refrigerated cooler must not turn off and then turn back on immediately. A delay prevents turn-on from happening too quickly after a turn-off. For the 1100 Series cameras, camera cooling is only turned on when the high and low side pressures are within 3 psi. An amber status light on the front panel of the power supply blinks while the delay is counting down. When the amber light is on steadily, the external AC outlet to a cooling unit is enabled.

The refrigerated coolant lines are flexible and designed to bend with a minimum radius of ½ meter. These lines are, however; not designed to flex a lot at the minimum ½-meter radius.

1.4.2 Thermo-electric Cooling System Description

The thermo-electric cooling system typically employs a glycol and water solution that is pumped through the camera head back plate. To maintain the camera cooling at a regulated temperature, the solution is chilled to a regulated temperature at or near to local ambient. A pair of flexible hoses with quick-disconnects attach to the camera head and to the re-circulator.

If the camera head back plate gets too hot, a relay in the power supply turns off the A/C power to the TE cooler power supply. If/when the camera back plate temperature drops below the cut-off (typically 55ºC) the camera cooling can be turned on again. A software command is required to resume cooling.

1.4.3 The Cryo-Cooled Camera Service Cabinet

Cryo-cooled cameras are configured with the camera DC power supply and the cooling compressor mounted in a wheeled cabinet. A manual is provided with the service cabinet. In the instance of the refrigerant being flammable, the service cabinet is shipped without the cooling line filter/drier installed but it is provided in a separate box and must be installed per the accompanying manual.

2. Receiving Your 1100 Series Camera System

The Series 1100 camera system is shipped in containers that are industry standard for electronic equipment. Do not discard them if the equipment is to be transported.

2.1 Shipping Configuration

The number of boxes depends upon the camera. For Cryo-cooled cameras, two crates hold the entire system. A TE cooled camera will only have two cartons unless Spectral supplies the water cooler in which case a third carton is supplied.

The Series 1100 camera head is in a double box with shock absorbing material separating the two boxes. For a TE cooled camera the power supply chassis along with the camera cables, the PDCI computer interface module are in a second box.

The Cryo-cooled camera in a service cabinet configuration includes the camera power supply along with the CryoCooler. If the coolant is flammable then the filter/drier module is shipped separately and the filter/drier is to be installed within the service cabinet when the unit is received.

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 cardboard cartons in such a manner that they can be reused. Once the camera has passed acceptance tests, these cartons can be opened up so they lie flat to minimize storage space. It is important to use these or equivalent packing materials if the camera system is to be transported. Save the foam inserts in the cartons (especially the camera head foam) as this provides the best shipping protection for the camera head if it must be transported.

2.2 Environmental Requirements For 1100 Series Cameras

2.2.1 Temperature - Humidity - Pressure

The camera system operates at temperatures from 6°F (15°C) to 95°F (35°C). The camera system operates at relative humidity from 10% to 50%. The camera is rated to operate from sea level to 10,000 feet.

2.2.2 Electrical Requirements

The camera system runs on regular AC power as long as the frequency is between 48 Hz and 62 Hz and the voltage is 100, 120, 230 or 240 volts ±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 Series 1100 components must be protected from aggressive atmospheric conditions such as are the result of operating in salt laden air or in air that contains corrosive chemical vapors.

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

2.3 Assembly Of The Camera System

Figure 7 shows, for a TEC system, how the 1100 Series camera components connect and how the AC power must be connected. Refer to the camera System Service Manual for a cryo-cooled system.

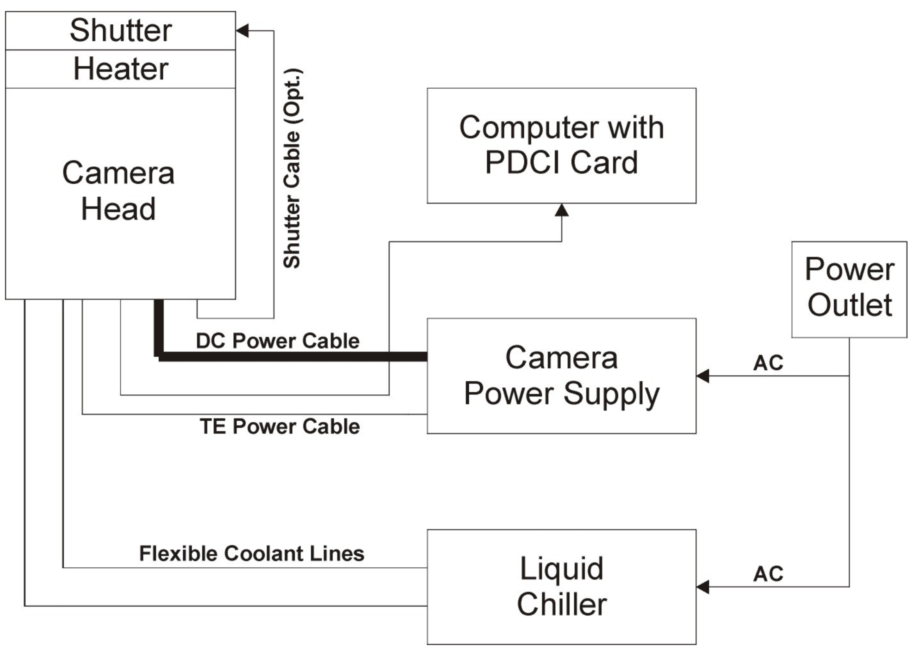


Figure 7
Series 1100 TE-Cooled Interconnect Diagram

2.3.1 Assembly Of The Camera Head

Assembly of the camera head principally involves mounting the head onto a test fixture or onto your equipment. Normal precautions should be taken against handling damage. Note: cameras are shipped with a protective film on the front of the window or fiber optic. This film must be removed before the camera is installed. The Cryo-cooler hoses are not exceedingly flexible and it may be best to connect those hoses before mounting the camera head into the application.

2.3.2 Assembly Of A Cryo-Cooling System

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

The Cryo-cooler is plugged into the AC outlet in the camera power supply. The Cryo-cooler only turns on when the high and low side pressures are within 3 psi.

2.3.2.1 Unpacking The Cryo-cooler

The Cryo-cooler compressor motor is mounted on springs that allow the unit to float during operation. This reduces noise from the unit a lot. To allow the motor to float it is necessary to release the three 10-mm bolts that screw into the motor mounting coil from the bottom of the Cryo-cooler. Do not turn the compressor on its side to release these bolts. Retain the bolts for re-installation if the unit is to be transported.

A Service cabinet configuration has the CryoCooler mechanically bolted to the cabinet. Three wing-nuts in the bottom of the cabinet release a service panel that allows access to the above-mentioned shipping bolts.

The filter/drier unit is shipped separately from the cabinet. It must be installed in the cabinet before the cooling system lines are connected. The Series 1100 Camera System Service Cabinet Service Manual describes the installation process.

Figure 8

2.3.2.2 Connecting The Cryo-cooler

The two Cryo-cooler cooling lines are pre-charged. One is the supply line and the other is the return line. The supply line is marked as such by a SUPPLY label in red ink. The RETURN line is also marked as such but in green ink. The connectors are identical. The return line is end-for-end reversible except that one end terminates in a 90^{o} bend, which may be preferentially located at the compressor or at the camera head depending upon the application. The supply line may come with a line heater attached to the outside of the metal hose.

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

The most important aspect of connecting the cooling lines is to make very certain that the axis of the line connector is parallel to the axis of the plug to which it is being attached. It is necessary to securely hold the line so it remains parallel to the plug with one hand while manually threading the connector on the line onto the plug. The threaded nut of the connector will not turn much by hand but after it is started (and while still maintaining the alignment) use the ¾" wrench to turn the connector until it offers substantial resistance. At this point the alignment can be settled and the 5/8" wrench used to snug the attachment. If there is a slight hiss of escaping gas, continue threading on the connector. Do not hesitate!

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

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

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

The disconnect process is a mirror image of the connect process. Use both sockets to release the tight fit and then hold the line so the connector remains aligned with the socket and use the ¾" wrench to unscrew the threaded end of the connector. Again, if there is a slight hiss of releasing gas, continue disconnecting. Do not hesitate!

2.3.2.3 The Cryo-Cooler Return Line Temperature Control

A camera shipped with a Service cabinet encloses the CryoCooler and filter drier along with the power supply. The cooling hoses to the camera are attached to the cooling line connections on the side of the cabinet. The return line temperature sensor cable attaches to the cabinet near the gauges.

The line heater includes an ambient-temperature-sensor/return-line-temperature sensor. It is important that the ambient temperature sensor be located so as to accurately sense the ambient air temperature at the back of the camera head and not be influenced by local heat sources in the environment of the camera (this is especially important if the camera head is located inside a small enclosed chamber)

1. Install the return line temperature sensor onto the return line at the camera head just below the gas hose fitting. There is a standard dimension collar that the metal temperature sensor clamps onto. Use thermal grease (supplied with the camera) to insure proper connection.

2. Install the ambient air sensor somewhere in the vicinity of the camera head.
3. Plug the 4-pin sensor line into the 4-socket connector on the side of the cabinet.

2.3.2.4 Servicing The Cryo-cooler

If the Cryo-cooler compressor must be serviced, it must be returned to one of the factory service centers. There are no user serviceable components inside the Cryo-cooler. The pressure gauge indicates the pressure of the gas in the unit; 230 (minimum) to 300 PSI for a cold unit. If the pressure becomes too low the Cryo-cooler will not cool the camera. If the pressure is low, the pressure can be raised by field service personnel using a service bottle of the appropriate gas. See the list of field service components in Section 6. for the gas service bottle.

The service cabinet configuration provides two visual pressure gauges. One is for monitoring the standard CryoCooler pressure and the other is used for adding coolant if field recharge is necessary. If necessary, consult Spectral Instruments for information regarding the use of this coolant supply port.

2.3.3 Assembly Of A TE Cooling System

If a re-circulating liquid chilling system is supplied by Spectral Instruments, it will not be charged with liquid. The proper mixture is 50% Glycol and 50% de-ionized water. Do not use a mixture with a higher Glycol ratio as this would result in a reduced cooling capacity. The cooling lines must be attached to the re-circulator and the system charged before it is turned on. The TE power cable is plugged into the 2-pin AUX PWR outlet in the camera power supply. A separate manual with the cooler, if provided, explains how to adjust the temperature of the liquid.

Note: It is important that the coolant not operate at a so low a temperature that water will condense on the cooling lines or the camera head chamber.

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 (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.

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

2.3.5 PDCI Fiber Optic Digital Camera Interface

The fiber optic PDCI interface card is a PCI bus serial data interface card for the Spectral Instruments 1100 series cameras that uses a MT-RJ fiber optic cable. It accepts camera image data at rates up to 64 Mbytes/second and directs it to computer memory by bus-master direct memory access. It also transmits and receives RS422 levels for camera communications.

Turn off your computer and install the PDCI card in any available PCI slot. When the computer is switched back on, a Windows operating system will find that the card has been installed and finish the installation.

2.3.6 Software Operation

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

Once the program screen appears, the pull-down labeled Operate provides a control to initialize the camera. A software users manual, Part # 2523, is provided as a .pdf file on the CDROM that contains the software.

2.4 Startup

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

Four hours must have elapsed since the Cryo-cooler was last transported such that it could have been tilted more than 30^{o} off of upright.

2.4.1 Power-On Condition And Indicators

When the power supply unit is switched on, the POWER indicator on the power supply illuminates and an array of green LEDs indicate the various DC voltages. The power supply contains logic that determines whether the raw DC voltages are present and turns on an alarm LED and audio alarm if a problem is detected. The green LEDs are driven directly from the various raw DC outputs to the camera.

2.4.2 Power-On Self Test

The camera head performs a power-on-self-test (POST) whenever the power is first turned on or when the camera is reset by software command. The housekeeping system runs the diagnostic routines whenever the camera is not reading out an image.

The diagnostic consists of checking the various regulated DC voltages in the camera head to make certain that they are all within proper tolerances. Next, the

DSP checks that the camera head temperature is not below the low temperature limit established for the camera head.

If any error condition prevails, the DSP turns on the alarm LED, which runs continuously thereafter until the camera power supply unit is turned off. If the POST is successful the DSP is ready to receive commands to operate the camera.

The red and green LEDs on the camera head toggle (blink alternately) three times if the DSP succeeds in starting its program. If the POST is successful the red LED is turned off. An error condition results in the red LED remaining on.

2.5 Commanding The Camera

SI Image is supplied with every camera system. It presents a camera control screen after it is started. It looks for a file, with .set as its suffix, which it expects to contain a reasonable camera readout configuration. Such a file is supplied with the camera and is included in the CDROM with the SI Image software. Other similar such files can be created for different imaging applications. SI Image provides an easy mechanism to save the current camera setup as a .set file with its own name that you select. The .set files are ASCII text files and can be edited with a simple text editor such as NOTEPAD©.

If more than one .set file is located, SI Image displays them and asks which one to use. Otherwise, if there is only one such file, SI Image opens it and offers to initialize the camera, which includes sending the readout format and readout speed to the camera.

A manual for SI Image is supplied with the camera. That manual describes how the software works and how to use it to run the camera. In particular, it describes how to obtain light and dark images and how to set the exposure time. Those features are used in the discussion that follows.

2.6 Initial Tests

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

There are several configurations the 1100 Series camera can assume. For some of them it is not possible to “take a light image” without fully integrating the camera into the equipment. This manual uses tests for which a dark environment is sufficient.

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

2.6.1 Types Of Images

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

1) the electrical offset introduced to keep all of the pixel values as positive integers – the bias. Bias is a 0-second exposure dark image.
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 image components.

The bias image is typically a uniform pattern of low-level "noise" superimposed upon on a DC background offset. The value of the offset is different depending upon the way the camera is set up to image (binning, and readout rate.) Bias images also accrue some thermal signal if the readout is slow and the camera is warm. This thermal signal introduces a ramp effect from one side of the bias image to the other since the rows read out last accrued more dark signal that the first rows.

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

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

2.6.2 Default Camera Readout Format

The default image size as contained in the .set file delivered by Spectral Instruments reads out more rows and columns than just the active area. This readout mode calls for "overscan" pixels as well as illuminated pixels. Reading all of the pixels on the CCD instead of just the illuminated pixels provides a means of including diagnostic and calibration information with each image you acquire. If overscan is not wanted it is necessary to change the camera readout format through the appropriate dialog in SI Image.

When overscan readout is employed, the images that result depend upon the design of the CCD sensor itself. An image with overscan will show a black border on at least three sides and for some CCDs, on all sides. Appendix A contains an illustration of overscan readout. Table 8., in Appendix A, shows the settings 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.

The best image for showing all of the components of overscan readout is a dark exposure with a moderately cold camera looking into an application that has a small light leak! For very cold cameras the light leak must be very small as the dark signal will be quite low. This imaging condition results in the light-sensitive pixels being differentiated from the masked pixels (which can accumulate dark signal) and those from the "imaginary" bias pixels that do not exist on the CCD sensor but are obtain by clocking the serial register for more pixels than are extant in the serial register.

In a dark image, the signal from those pixels that are exposed to the same dark signal integration time all have the same brightness. These are the pixels in the parallel register (the image area) and (for readout only) those extra rows that were read out that show up on the right hand side of the image area. These two regions will have dark signal accumulations that are not the same – but each region will have nominally the same signal.

Darker pixels along the top and bottom edges of the image are readout pixels that did not integrate any dark signal - they are the "imaginary" bias pixels that do not exist on the parallel register of the CCD sensor. Adjust the windowing of the software to show low pixel values as gray levels and you will see two distinctly different (in a warm camera) levels along one side of the image. The brighter level corresponds to physical pixels on the sensor, some of which may be masked to incoming light but can still detect dark signal. The other pixels are not physically on the sensor but rather are generated by reading past the physical extent of the edges of the CCD sensor.

2.6.3 Dark Image - Warm Camera

Insure that all external illumination is extinguished and obtain a 0.1 second dark image. The result is a dark image from a warm camera - a gradient in brightness shows up with the brighter pixels on the side of the image away from the serial register. This gradient results from those pixels farther away from the serial register having been exposed to more dark signal because they spent more time accumulating dark charge from the CCD during the readout itself than did those on the other side.

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

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

3. Cooling The Camera

The Cryo-cooled camera requires a stabilization period before measurements can be made. After the Cryo-cooler has sustained a vertical posture for the required four hours, cooling can be turned on. The Cryo-cooled camera head requires one to two hours to achieve the operating temperature range and another ¼ hour to become fully stabilized.

A TE camera cools down in under ten minutes but also requires another ¼ hour to stabilize. Once the camera head has become thermally controlled, it is possible to verify camera performance metrics as described below.

3.1 Image Quality

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

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

Large scale curves (quarter circles typically) or swirls in the 300-second dark are to be expected and show the non-uniform generation of dark signal as a function of position on the wafer at which this CCD was built. Such patterns are normal and completely correctable.

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

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

TE cooled cameras need to use shorter integration times – but the remarks above are appropriate to warmer-temperature images for the most part. For a TE cooled camera use a suitable shorter exposure number where 300 appears as the example exposure time in these notes.

3.2 Performance Metrics

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

3.2.1 Noise

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

This test is sensitive to any structure in the bias. At the factory, the noise is determined by subtracting two bias images to eliminate the structure. The result has twice the noise contribution. To obtain the true noise, divide the rms of the difference image by $\sqrt{2}$.

3.2.2 Dark Signal Generation Rate

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

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

Obtain a 300 second dark image with a freshly cooled camera head and determine the mean signal from a region of the sensor that does not include any hot columns. SI Image provides this mean determination at the current location of the red cursor stats box. 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 read out speed and attenuation used and divided by 300 to yield the dark signal generation rate in electrons per pixel per second. The result will agree with the test report within 10% if proper procedure has been followed.

Note that it may be necessary to bin - combine signal on the CCD sensor before readout - by four rows and four columns in order to increase the accuracy of measuring the dark signal. If this is done, the above dark signal calculation must be changed to divide the result by 16 since 16 physical pixels contributed to each measured “super” pixel. The bias must also be obtained 4 x 4 binned.

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.

3.4 Offset Adjustment

The numeric (DC) signal of the bias can be adjusted. For a single-port readout it is likely that no adjustment of the offset will ever be needed. For multi-port readout, the offset changes somewhat with binning or readout speed. The camera offsets are set at the factory for the primary operational mode. If the binning or readout speed are changed the offset of the different ports will change by slightly different amounts so that the default offset no longer provides half or quarter image sections that have the same appearance.

Parameters 12 through 15 allow setting of offsets for ports one through four. Port nomenclature is not necessarily the same for all multi-port CCDs. However, for two-port CCDs, only offsets one and two are active, offsets three and four are not used.

Pixels from each active output port are transmitted in sequence starting with port 1 and ending with port two or four. In this manual ports are shown as A,B,C and D. This nomenclature is historical but, unless otherwise designated for a particular CCD/camera configuration, the correlation is A:1, B:2, C:3 and D:4. Two port cameras can have ports on the same serial register (as in the typical E2V devices) or they can be on opposing corners (like the Fairchild Imaging 447 sensor). These are both called ports 1 and 2 in the context of port offset.

4. Using The Camera

4.1 Kinds Of Images

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

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

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

4.1.1 Bias Images

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

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

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

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

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

4.1.2 Dark Images

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

To reduce the impact of dark signal, Spectral Instruments 1100 Series cameras utilize a refrigerated cooling system that allows the CCD to be operated at as low a temperature as is consistent with that CCD continuing to operate as a SICCD sensor. The low temperature limit for most CCDs is about -120ºC. At such temperatures, the dark signal may average one electron per pixel every twenty minutes (the actual value varies significantly with pixel size and somewhat among manufacturers).

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

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

4.1.3 Light Images

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

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

4.2 Problems With Images - The Master Image Solution

4.2.1 Bias Images

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

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

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

It is possible to use this master bias with small incremental DC offsets to correct for changes in the DC of the 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 a fraction of a count the master bias can be adjusted to the current bias level of the camera without needing to obtain a new master bias. In this manner, the master bias provides a very accurate image of the bias structure. You adjust the DC level of this structure image to meet the current camera performance. SI Image uses floating point representation of pixel values so fractional count corrections are possible.

Almost every change in the behavior of the camera electronics is revealed in the bias image. The intrinsic conversion factor and the dark signal generation rate are the only parameters that are not essentially revealed in the bias from a 1100 Series camera.

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

Remember that a different master bias is required for each camera readout mode.

4.2.2 Dark Images

For a 1100 Series camera, the dark image is equivalent to the bias image unless a very long (typically greater than five minutes) exposure is obtained. If all of the exposures to be obtained from your 1100 Series camera are going to be the same duration with the camera in the same environment there is no need to obtain separate bias and dark images as master images. Average a large number of identical exposure dark images and you have a master dark+bias image.

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

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

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

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

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

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

4.2.3 Light Images

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

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

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

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

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

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

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

4.3 Correcting Images

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

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

4.3.1 Why

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

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

To inter-compare one region of an image with another you first need to correct for the variation in attenuation over the imaged field of view. It is not necessary to do separate bias and dark; all that is required is a uniform illumination image that has the same exposure time and has not been corrected for bias or dark.

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

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

4.3.2 How

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

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

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

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

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

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

4.3.3 Limitations On The Flat Field Process

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

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

4.3.4 Understanding The Scaling Effects

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

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

Clearly, the value of the multiplier affects the magnitude of the resulting images. For inter-comparison among a number of different sets of images or sequences of images a constant multiplier 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 multiplier assumption is valid.

To determine the base and scale factor to reduce images to an absolute scale requires introduction of known objects into the application “field”. Most measurements are relative. 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 1100 Series camera is warranted for 12 months after shipment. Any failure that occurs within that period, that is not due to mishandling or operating the camera under conditions that void the warranty, is repaired at no charge. Opening either the camera head or the power supply voids the warranty.

5.1 The Warranty Conditions

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

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

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

5.2 Returning A Camera For Service

A 1100 Series 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 either the camera head or the camera power supply unit and it is highly likely that the user could exacerbate a problem by attempting to "open something up." Spectral's cameras are assembled in an anti-static clean room to insure the safety of the CCD and the cleanliness of the camera interior. Only the following diagnostic procedures are authorized. Section 8., troubleshooting, describes in detail how to perform the diagnostic tests that are permitted. The result of such tests is primarily to distinguish between a cable problem (bad connection or broken cable), a camera problem and an application problem.

5.3.1 Fuses

The power supply automatically determines the incoming mains voltage and selects the fuse set that is required to connect the various transformers to the mains AC power. Power indicators on the front of the power supply show incoming AC and the outputs of each of the DC supplies. The user serviceable fuses are located at the back of the power supply module. The proper fuse ratings are listed on the supply.

If the power indicator on the camera head does not come on and the power supply shows proper voltages, the cause is probably a bad or missing power cable connection. The camera head power indicator is operated by the DSP that requires that the +5v dc power be present.

5.3.2 First Checks

When a camera seems to have changed its performance characteristics, it is important to be able to obtain the standard types of images referred to in Section 2.5. One of those images is the bias. The bias image from a properly operating camera will be uniform and have a rms that, when scaled by the digital conversion factor, is about the noise shown on the test report.

5.4 Determining When To Refresh The Vacuum

5.4.1 Measuring The Camera Head Pressure

A Spectral Instruments 1100 Series camera head includes a sensor that measures the pressure inside the camera head. This sensor operates over a pressure range from 10^{-2} torr to about 10 torr. A facility is provided within the 1100 Series camera head status feedback to report the current camera head pressure. Software supplied by Spectral Instruments incorporates this capability into a user status report on the pressure inside of the camera head vessel.

When the camera vacuum has been recently refreshed, the pressure readout from a warm camera head is typically less than 2 torr. As a camera cools, the camera head “cold-pumps”. For a freshly pumped Cryo-cooled camera this results in the pressure indicator being off scale to the low-pressure end of the scale. TE cooled cameras may not peg the pressure indicator to the low end of the scale.

As the camera head pressure degrades due to water molecules passing through the O-rings, the “warm” camera head pressure reading shows the rise in internal pressure. When the “warm camera” internal pressure reaches 2 torr, it is time to refresh the camera head vacuum by pumping the camera head. For a Cryo-cooled camera, if the temperature is below –80ºC, the pressure indicated should be below 0.1 torr or the camera may not cool down the next time the camera is turned off and then on again.

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

5.4.2 Why Pump

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

When the camera head pressure rises so much that the convective heat load overwhelms a Cryo-cooler, the camera does not cool down at all. TE cooled cameras fail to regulate and the back plate temperature may rise so that cooling keeps turning off automatically. At best, the camera will not regulate and the dark signal will not be stable.

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

The second effect is that the camera will not cool.

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

5.5 Refreshing The Camera Vacuum

***WARNING**: A camera must be at room temperature before any attempt is made to refresh the vacuum.*

The Spectral Instruments 1100 Series camera provides an electrically valved port for refreshing the vacuum inside the camera head. It is necessary to refresh the vacuum when the pressure is higher than 2 torr. Failure to service the camera when the pressure has risen above 2 torr risks damage to the CCD sensor inside the camera head.

The camera has a ¼" polished stainless steel tube that extends through the camera head back plate. This tube is threaded internally and is closed with a metric 1.5 Allen set screw. This screw serves to keep debris out of the vacuum port and it also guards against the air inrush that would occur if the vacuum valve were opened without a vacuum pump system attached and running.

5.5.1 Equipment Required

5.5.1.1 Vacuum Pump And Vacuum Hose

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

Figure 9, below, shows the assembled vacuum pump option kit available from Spectral Instruments

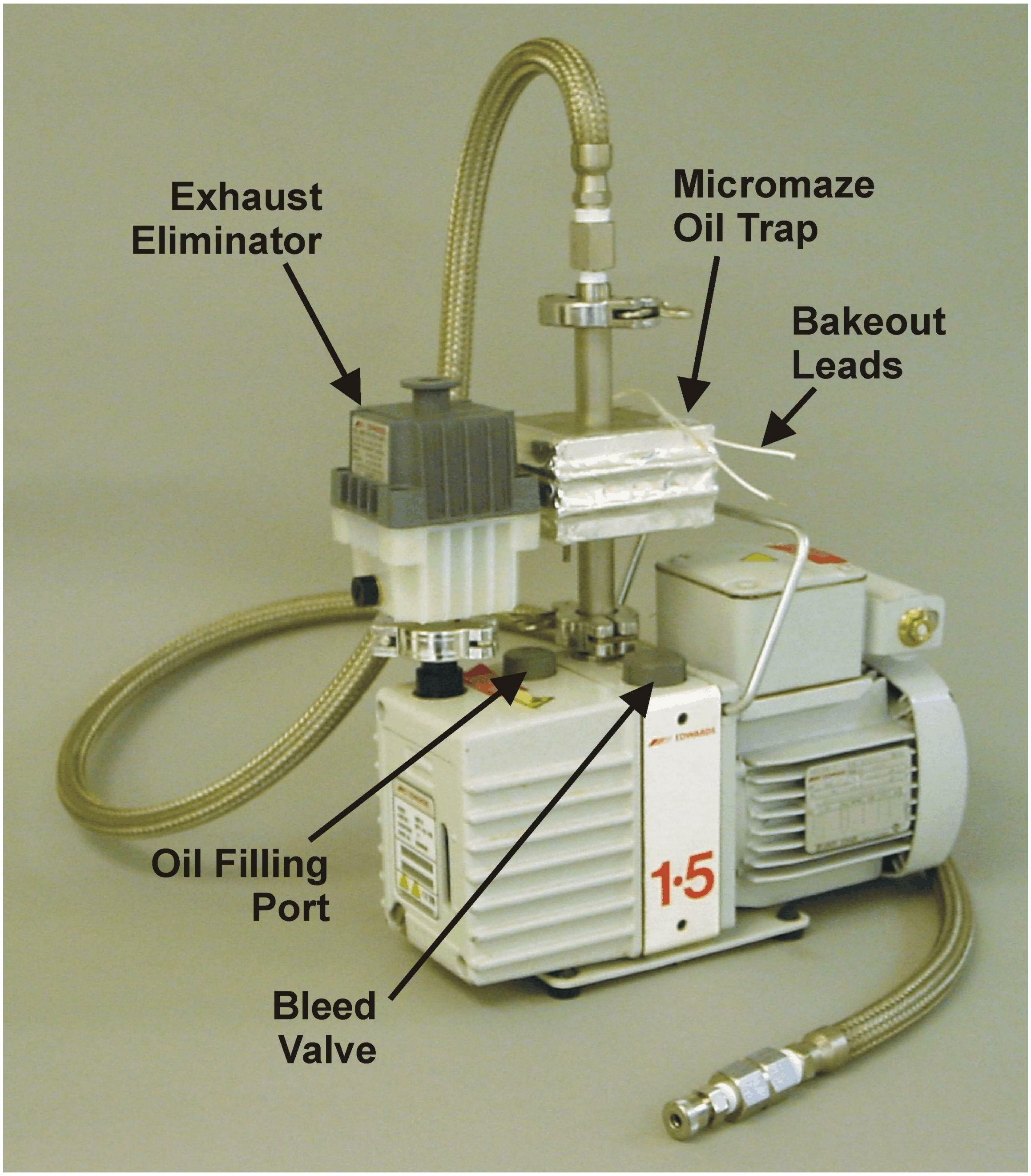


Figure 9
Vacuum Pump

1	ED-A37122919	Kurt J. Lesker	230-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	230-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	QF10-050-SB	Kurt J. Lesker	Blank Flange
1	QF16-075-SB	Kurt J. Lesker	Blank Flange
1	QF16XFNPT4	Kurt J. Lesker	Female Pipe Adapter
1	48805K38	McMaster-Carr	Type 316 SS Instrumentation Threaded Pipe Fitting - Adapter Female-male
1	48805K71	McMaster-Carr	Type 316 SS Instrumentation Threaded Pipe Fitting - Hex coupling
1	54875K13	McMaster-Carr	72” Hi-Pressure Flexible SS Braided Hose Assembly NPT M-M
1	SS-4-UT-1-4	Swagelok	¼” Cajon fitting - ¼” male pipe thread

Table 1.
Parts List For A Vacuum Service Pump

Note that both 110 volt and 230-volt part numbers are listed but only one each pump and foreline trap are required.

The exhaust filter is attached to the exhaust port of the pump using a QF flange adapter. The foreline trap is mounted onto the vacuum inlet port to the pump using an adaptive centering ring and an aluminum clamp. Onto the opposite side of the micromaze filter, another adaptive centering ring and clamp hook up to the female pipe adapter.

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

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

5.5.1.2 Vacuum Hose Fitting

The vacuum port on a 1100 Series cameras is a ¼" metal tube that extends from the vacuum valve. The end of the vacuum hose that connects to the camera head must be equipped with some suitable attachment mechanism for sealing to this ¼" metal tube. A ¼" Swagelok Cajon™ fitting for a ¼" metal tube vacuum port is recommended.

5.5.1.3 The SI Vacuum Valve Actuator

The SI 1100 camera head is equipped with an electronic valve that can be operated through a special DC power supply that is supplied with the camera.

5.5.2 The Refresh Process

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

First turn off the cooler. Allow the camera head to warm up until the temperature of the CCD is approximately 20 ºC (this may take hours for a Cryo-cooled camera).

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. The first step is to make certain that the camera end of the hose is plugged up and then turn on the pump so as to refresh the vacuum in the hose. This guarantees that the hose is clean.

5.5.2.3 Attaching The Vacuum Hose To The Camera

Remove the camera head vacuum tube set screw and set it aside for the duration of the vacuum refresh.

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

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

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

5.5.2.4 Pumping The Camera Head

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

Turn on the camera power and monitor the indicated pressure. With the vacuum pump running and the vacuum hose securely attached to the camera plug in the DC vacuum valve power supply. Immediately unplug the power supply if the pressure rises! Run the pump with the valve open for approximately 3 hours.

Unplug the small DC power supply to close the electrically operated vacuum valve.

Turn off the vacuum pump and remove the vacuum hose from the camera head.

Install the camera head vacuum tube set screw that was set aside for the duration of the vacuum refresh.

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

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

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

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

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

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

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

Install the camera head into the application.

6. Field Replaceable Components

Table 2, below, lists the components of an 1100 Series camera system. The list includes options for both fiber optic data and AIA data coupling as well as options for a Cryo-cooled camera and a TE cooled camera.

Description	Option
Camera Head	
Camera DC Power Supply	TE or Cryo Cooling
PDCI Camera Data Interface Module	FO or AIA
Camera Data Cable	FO or AIA or Camera Link
Camera DC Power Cable	Cryo or TE Cooling
Cryo-cooler Compressor	Cryo Cooling
Cryo-cooler Supply Line	PT 30 or NF Gas
Cryo-cooler Return Line	PT 30 or NF Gas
Re-circulating Liquid Cooler	TE Cooling
Liquid Cooling Lines	TE Cooling
Cooling Line Quick-Disconnects	TE Cooling

Table 2.

6.1 Camera And Power Supply Part Numbers

The various camera part numbers are given in Table 3.

Description	Part Number
Camera Head 1100S TE Cooled CCD486 Custom 4-Channel With Camera Link Interface Camera Head 1100S Cryo-cooled Custom 4-Channel With Fiber Optic Interface	4432 4433
Power Supply 1100S Cryo-cooled camera head	5341
Power Supply 1100S 28-v TE cooled camera head	5173
Power Supply 1100S 15-v TE cooled camera head	5174

Table 3.

6.2 Cables And Lines

Individual cables can be ordered to replace any that fail. It is necessary to submit cable length when ordering a replacement cable.

6.2.1 Camera Data And Power Cables

The various camera cable part numbers are given in Table 4.

Description	Part Number
Cable, FO MT-RJ to MT-RJ, xx Meters Length Cable, External DC Power xx Feet Length	2848-xx 4167-xx
Cable, External DC Power xx Feet Length Cabinet	5492-xx

Table 4.

6.2.2 Cryo-cooler Refrigerant Lines

Description	Part Number
Ref, Gasline, SuperFlex PT30 10’	2267
Ref, Gasline, SuperFlex PT30 25’	2267-1
Ref, Gasline, SuperFlex PT30 50’	2267-2
Ref, Gasline, SuperFlex PT30 15’	2267-3

Table 5.

6.2.3 Power Supply Part Numbers

Description	Part Number
Assy, 1100S Cryo Switching Power Supply Assy, 1100S 15-V Switching Power Supply	5341 5173
Assy, 1100S 28-V Switching Power Supply	5174

Table 6.

6.3 The PDCI Card

The PDCI card comes with both AIA and fiber optic data ports.

Description	Part Number
PCBA/SCH, PCI AIA and FO Gigabit	3097

Table 7.

6.4 The Camera Head

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

6.5 The Cryo-cooler Compressor

The compressor is SI part number 1797. Depending upon the nature of the problem, the camera head and coolant lines may also need to be returned for service if the system lost refrigerant due to a compressor failure.

A service pack of refrigerant gas can be obtained from Spectral Instruments or from a nearby Poly-Cold service center. PT-30 gas is used with most of the camera heads.

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

The Poly-Cold part number for the gas top-off bottle is: 91582530 for PT-30.

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, one AC power cord is provided. No power cords are provided for shipments outside of the U.S.

7.1.3 Power Required

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

7.2 Physical Operating Conditions

7.2.1 Temperature

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

7.2.2 Humidity

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

7.2.3 Altitude

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

7.2.4 Vibration

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

7.2.5 Aggressive Vapors

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

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

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

7.3 Warnings

7.3.1 Cryo-cooling System

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

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

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

7.3.2 Electrical System

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

7.3.3 Camera Power Supply - Camera Head

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

7.3.4 Opening The System

The camera head has no user-serviceable components that are accessible by removing covers.

7.3.5 Refreshing The Vacuum

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

7.3.6 The Camera Window

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

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

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

* Equipment Rating

1. The equipment is intended to be used in an installation category II, pollution degree 2 environment.

* Warnings

1. The return line heater is to be used only when the Spectral Instruments Cryo-cooled camera is also in operation.

2. This equipment must be used as described in this manual. If it is used in a manner not specified by the manufacturer, the protection provided by the equipment may be impaired.

3. This equipment is only intended for indoor use and must be protected from liquid spills.

4. Keep the fan screen and vent areas from collecting dust by wiping down the equipment and cabling with a clean, dry cloth.

* Service Requirements

Remove AC power from the unit before performing any maintenance on the equipment.

Troubleshooting

8.1 Image Issues

The following 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 usually implies that something has "railed" some portion of the video chain. The most frequent cause of an all 0 image is over-saturation of the CCD or the analog processor.

Try short exposures or somehow reduce the light level to relieve the overload. A bias image should not show a 0 image!

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 1-second dark. If it is cold, obtain a 10-minute dark. Either image will exhibit the characteristic pattern of a dark image from a CCD camera if the CCD is working and connected to a power supply unit that is also working. If the image is still very flat without any gradients or bright spots then the CCD is truly not providing image data. This means the camera and power supply 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 module.

8.1.1.3 Fully Saturated Image

A fully saturated image is equivalent to an "all zeros" image - it is difficult to obtain from the analog signal processing system. However; the light from even a darkened room is enough to saturate the CCD. Reduce the light level and image again. In the latter case it is important to make certain that the camera is not exposed to extraneous light that is now "leaking" into the camera head. Attempt to darken the incoming light path and obtain a few-second dark image. If the saturated condition persists it is necessary to remove the camera head from the application and cover it completely with a dark shroud and repeat the dark image. If the saturated condition persists the camera head has failed and must be returned for service.

8.1.2 Streaks In The Image

Streaks occur in numerous forms. The most common source of streaks is a failure of the shutter to close fully and the image starts shifting while the shutter is still closing or remains partially open.

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 would be 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. This sort of pattern is usually only visible in low light level images – particularly bias level images. There are very marked photo-response patterns particularly in back illuminated CCDs. It is important to distinguish between these patterns and noise. The method is to difference two identical illumination images. Pickup noise will not go away. Photo-response pattern will subtract.

The 1100 Series cameras allow selection of the direction of shifting in the serial register. Changing the shift direction is analogous to disconnecting the video signal. This is an easy way to generate a bias image that is not connected to the CCD image area.

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

8.1.3 Noisy Image

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

8.1.3.1 Isolation And Detection

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

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

8.2 The Error Audio Alert

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

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

8.2.1 Camera Head Alarm

A separate house-keeping sub-system runs continuously except when the camera is reading out. This sub-system checks voltages and conditions within the camera head continuously. Any time there is a camera DC power value that moves out of tolerance that fact is reported in the image header for the next image. High or low temperature conditions also are a cause for alarm. Spectral Instruments customer service must be contacted if the camera head alarm is on as there is no simple way to determine the cause of the fault by using SI Image.

8.2.2 CCD Too Cold

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

8.3 The Camera Seems Not To Be Stable

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

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

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

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

8.4 Camera Reports The Proper Temperature But Dark Is High

It should be noted that if the controller 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 Cryo-cooler until the camera reaches a temperature warmer than –40ºC and then turn the Cryo-cooler 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 usually indicates a warm CCD. First set the speed and attenuation to 0 and obtain a five-minute dark image with the CCD in a dark environment. Select a region of interest where there are no hot column defects and record the mean value of the image in the ROI. Next obtain a bias image and record the mean from the same ROI. Refer to the conversion factor for speed and attenuation 0 as recorded in the test report. Subtract the bias mean from the dark mean. Multiply the result by the conversion factor and divide that result by 300. The result is the dark signal in electrons per pixel per second. That value should agree with the test report to within 10%. If the dark signal is too high something is wrong.

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

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

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

8.5 Camera Does Not Cool

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

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

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

8.6 Condensation On The Camera Window

Two possibilities exist: one is that the vacuum needs to be refreshed, the other is that the window heater fuse has opened.

Appendix A

CCD Readout Format

A refresher on row/column terminology. Figure 10. 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 10. 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 8, below, compiles the various image components for each of three different CCDs read out with overscan.

To make overscan work the following two steps are required:

1: Set the parallel readout dimension to be larger than the active imaging pixels - how large depends upon how much you need to see in the overscan image. Table 8 includes a recommended format for each CCD.

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

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

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

A1 Some CCD manufacturers separate the serial register from the parallel register by masked pixels. Data reading out of these rows is not differentiated by the Series 1100 DSP firmware.

A2 These are the imaging rows on the sensor.

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

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

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

B2 The serial register pre-mask pixels are actually physical pixels in the parallel array that 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 Dim.	Parallel Pre-Mask	Parallel Illuminated Pixels	Parallel Over-Scan	Serial Readout Dim.	Serial Pre-ext.	Serial Pre-Mask	Serial Illuminated Pixels	Serial Register Post Mask	Serial register Post Ext.
CCD 485 by quadrant	2048	8	2040	0	2048	9	0	2040	0	0
SI003	1050	0	1024	26	1056	16	0	1024	0	16
KAF 16800	4128	20	4098	10	4145	35	0	4098	0	12
CCD 42-40	2048	0	2048	0	1056	16	0	2048	0	16

Table 8.

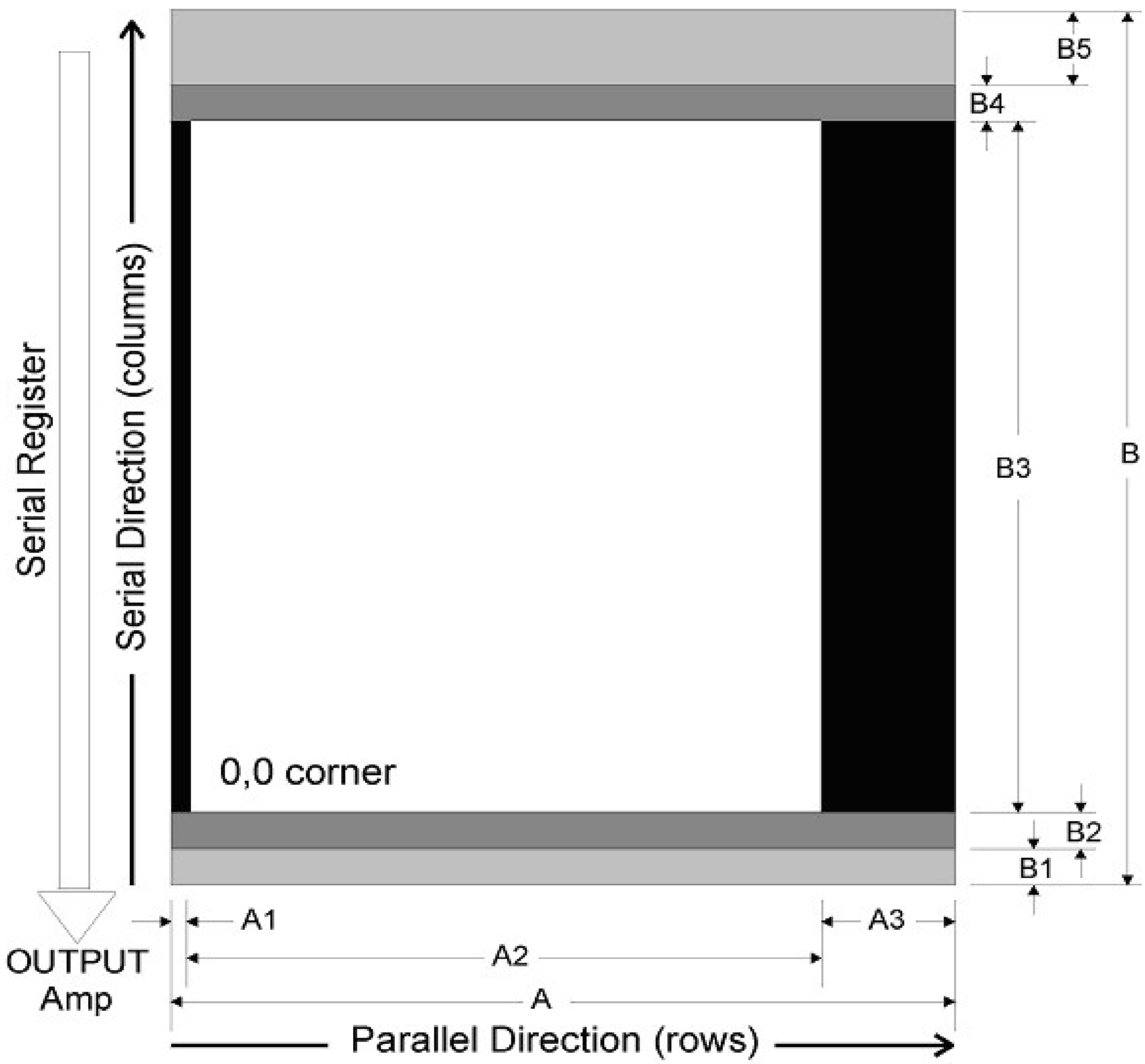


Figure 10.

CCD Readout Format

Appendix B

Multi-Port CCD Readout Parameters

1100 Series cameras support readout through more than one port. This feature only works with those CCDs that are designed to split the readout into more than one output amplifier. It is always possible to read out a multi-port CCD through one single port. The port to be used is controlled by parameters that are sent to the DSP from the host computer. These parameters relate to the "phasing" of the serial and parallel registers and whether the registers are split. Reference Figure 11, below, to visualize multi-port readout. Quadrant 1 is read through the A output, quadrant 2 through the B output. It is possible just to use the B output instead of the A output. Clearly to use the "B" end, the serial register must do something different when pixels are to exit B as opposed to exiting A. The serial phasing parameter selects how pixels shift in the serial register. Again, this election is only an option for the standard one-port readout DSP firmware operating a CCD with more than one good output amplifier. The same circumstance pertains to the way the parallel register behaves. Pixels can be shifted left (to A & B) or right (to D & C) by the phasing parameter.

The Series 1100 cameras all have the ability to readout 1-port, 2-ports or 4-ports. The parameter that governs splitting the serial and parallel registers coupled with the two parameters that control the phasing allow pixels to be routed rather arbitrarily. The exception is that one cannot readout 2-port through the A and D or through the B 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 sub-array is presumed to be symmetric about the center. Similarly, binning can be selected - it occurs the same at all readout ports.

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

Single-Port CCD Image Orientation

Referencing Figure 11. Again, note the arrows in each quadrant. The arrows point diagonally toward the opposite corner denoting the direction in which a readout proceeds. Switching between A and B outputs flips the image vertically. The SI-Image software always places the first pixel at the lower left hand corner of the screen - regardless of the output from which it emerged! Switching from A or B to C or D flips the image right-to left. Re-orienting the image must be handled by your software if the origin of the image and its mapping to the application is important.

Over-Scan in Multi-Port CCD Readout

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

The configuration parameters include several that are related to multi-port operation of the camera. When single port readout is selected, the serial registers shift toward A and D when the serial phasing parameter is set to 0. They shift to B and C when this parameter is set to 1. Similarly, when single port readout is selected the parallel register shifts toward the A-B side, labeled SR1 in 129 below. When the parallel phasing parameter is set to 1 the parallel register reverses shift direction toward SR2.

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

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

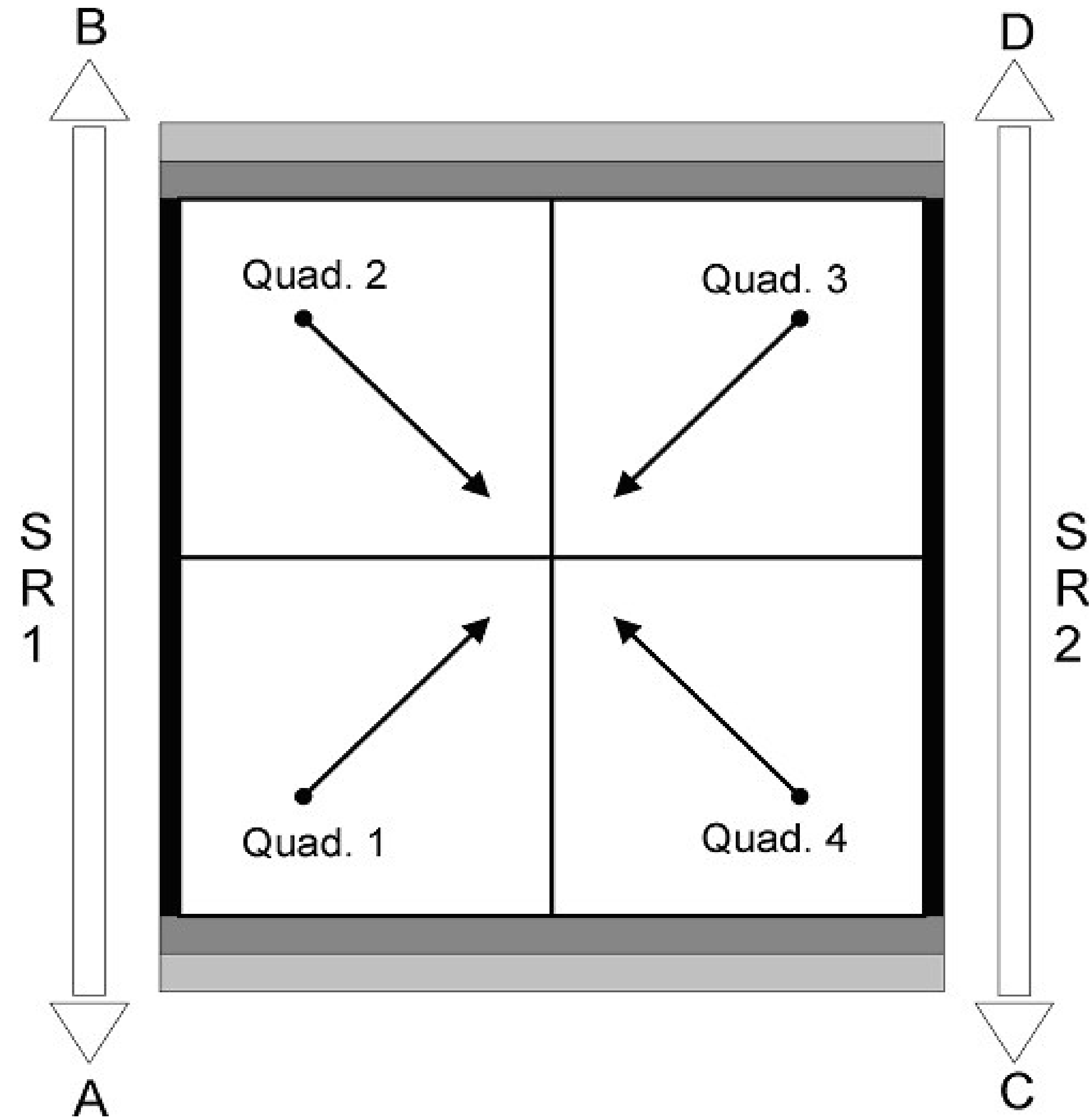


Figure 11.
Multi-Port CCD Readout Format

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 9.

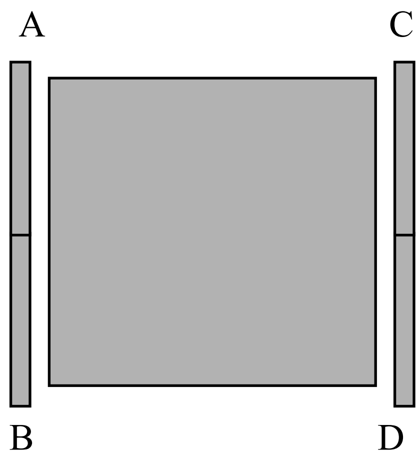


Figure 12.

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 10.

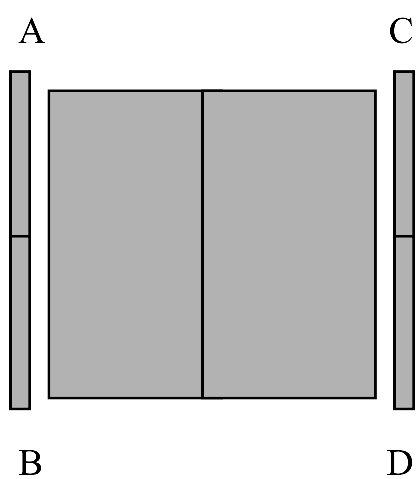


Figure 13.

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. An 1100 Series camera that employs a 16-bit ADC converts the signal of the CCD into numbers that range from 0 to 65535. A 14-bit ADC converts signal of the CCD into numbers that range from 0 to 16385. 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 can range from < 1. to > 20 e^-/ADU. Note that our sensitivity is called gain in classical CCD imaging literature.

In order to quantify images to a highest accuracy, SICCD cameras typically are set up to operate at a sensitivity setting such that the numeric range of the ADC maps to fewer image electrons than a single pixel holds. This means that high signal image areas saturate the electronics but the lower light level regions can be measured more accurately. By this means it is possible to measure the noise floor accurately.

SI cameras provide a user-selectable attenuation. The highest level of attenuation is state 3, the lowest, the default state, is 0. Changing the attenuation from 0 to 3 increases the conversion factor. This permits accurate measurement of high light areas in an image while giving up the ability to measure the noise floor of the camera.

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

The sensitivity of a SICCD camera is determined by two factors: a) the attenuation, which switches among discrete levels, and b) the dual slope integrator setting. The dual slope integrator (DSI) setting determines how long each pixel is sampled (integrated) before it is digitized. The longer the output node voltage (the pixel signal) is integrated, the better the readout because the sample 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 11, below, tabulates a selected set of DSI settings and the effective pixel read time and the equivalent readout rate. This table applies to a 50 kHz analog processing timing scheme and is representative only.

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

Table 11.

Appendix D

Series 1100 Camera Command Set

The Series 1100 cameras utilizes a command protocol that is an extension of the G@ command set used in other SI cameras. The commands are described in full detail in Spectral Instruments document Pt # 5914.

Appendix E.

Series 1100 Acquisition Mode Description

Series 1100 cameras implement a user-selectable acquisition mode that is set by Parameter 17 in the configuration table. The acquisition mode for each of the 4 ports is controlled by 4 bits. This allows 16 modes for each port. Since the modes are controlled independently, the camera can achieve a much larger number of modes. When the acquisition mode is other than 0 the camera only provides the test data of the type selected. These modes are as follows:

0. This mode produces normal output data.
1. This mode produces the simulated bias image (Gaussian distribution 100 +/- 3).
2. This mode produces a 16-bit count that rolls over at 65535 and is clocked by the pixel clock. The value is XORED with the contents of the digital offset register then output on the upper 16 bits of the output bus. Setting the digital offset register to 0x3FFFC causes this to be a count-down from 65535 to zero.
3. This mode produces a count that is cleared to zero by hardware at the end of each serial register (by line strobe going false) and is clocked by the pixel clock. The value is XORED with the contents of the digital offset register then output on the upper 16 bits of the output bus. This allows some useful modes for serial-split cameras. For example:
   - Setting one end of the serial register to this mode with zero in the digital offset register, setting the other end to this mode and loading its digital offset register with 2047 * 4, and sending 1024 pixel clocks would cause the first output to count from 0 to 1023 and the second to count from 2047 down to 1024. This would allow a 2 or 4 port readout to produce a smooth ramp image in the serial direction.
4. This mode produces a 16-bit count that rolls over at 65535 and is clocked by line strobe. The value is XORED with the contents of the digital offset register then output on the upper 16 bits of the output bus. This allows some useful modes for parallel-split cameras. For example:
   - Setting one serial register to this mode with zero in the digital offset register, setting the other serial register to this mode and loading its digital offset register (or registers) with 2047 * 4, and sending 1024 line strobes would cause the first serial register to count from 0 to 1023 and the second to count from 2047 down to 1024. This

would allow a 2 or 4 port readout to produce a smooth ramp image in the parallel direction.

5. This mode produces the value from the digital offset register.

- This allows diagnostics like having each output produce a distinct constant value for debugging de-interlacing routines for our customers who write their own software.

6. This mode produces the average light output.
7. This mode produces the average dark output minus the digital offset register.

- Setting the digital offset register to zero allows collection of the average dark output.

8. Modes 8 and higher provide different test patterns.

Appendix F.

Series 1100 Bias Offset

The Series 1100 cameras utilize two mechanisms to set the offset value. One is the ADC offset and this parameter (for each port) is a factory-only adjustment. A second digital offset value is added to the result of the ADC offset to allow the user to set the effective offset for each port. Parameters 12 through 15 in the readout parameter table allow the offset for each port to be set. It is possible to balance the outputs from a multi-port sensor quite precisely by setting values into the offset register for each port.