Kuro™ sCMOS Camera System Manual

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Revision History

Issue	Date	List of Changes
Issue 2	March 28, 2019	Issue 2 of this document incorporates the following changes: • Rebranded to Teledyne Princeton Instruments
Issue 1	May 9, 2017	This is the initial release of this document.

Teledyne Princeton Instruments
3660 Quakerbridge Rd
Trenton, NJ 08619
TEL: 800-874-9789 / 609-587-9797
FAX: 609-587-1970

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Chapter 1: About this Manual

Thank you for purchasing a Kuro™ scientific CMOS (sCMOS) camera system from Teledyne Princeton Instruments. For over two decades Teledyne Princeton Instruments has been the legendary name behind the most revolutionary spectroscopy and imaging products for cutting edge research.

Please read the manual carefully before operating the camera. This will help you optimize the many features of this camera to suit your research needs.

If you have any questions about the information contained in this manual, contact the Teledyne Princeton Instruments customer service department. Refer to Contact Information on page 46 for complete contact information.

1.1 Intended Audience

This user manual is intended to be used by scientists and other personnel responsible for the installation, setup, configuration, and acquisition of imaging data collected using a Kuro system.

This document provides all information necessary to safely install, configure, and operate the Kuro, beginning with the system's initial installation.

1.2 Related Documentation

Table 1-1 provides a list of related documentation and user manuals that may be useful when working with the Kuro camera system. To guarantee up-to-date information, always refer to the current release of each document listed.

Table 1-1: Related Documentation

Document Number	Document Title
–	LightField 6 Online Help
–	Kuro Camera System Data Sheet
4410-0047	Quick Start Guide Kuro sCMOS Camera

Teledyne Princeton Instruments maintains updated documentation and user manuals on their FTP site. Visit the Teledyne Princeton Instruments FTP Site to verify that the most recent user manual is available and being referenced:

ftp://ftp.piacton.com/Public/Manuals/Princeton Instruments

ftp://ftp.piacton.com/Public/Manuals/Acton

1.3 Document Organization

This manual includes the following chapters and appendices:

- Chapter 1, About this Manual
  This chapter provides information about the organization of this document, as well as related documents, safety information, and conventions used throughout the manual.
- Chapter 2, Kuro Camera System
  This chapter provides an introduction to, and overview information about, Teledyne Princeton Instruments' Kuro camera system.
- Chapter 3, Install LightField
  This chapter provides information about the installation of Teledyne Princeton Instruments' LightField image acquisition software.
- Chapter 4, System Installation
  This chapter provides information about for connecting the Kuro camera to the host computer using the USB3.0 bus.
- Chapter 5, Theory of Operation
  This chapter provides an overview of sCMOS camera technology as used in the Kuro camera.
- Chapter 6, Operating Features
  This chapter provides information about features and how to optimize them for speed and sensitivity, and how to use the different trigger modes.
- Appendix A, Technical Specifications
  This appendix provides sensor, system, and other basic specifications for a Kuro system.
- Appendix B, Outline Drawings
  This appendix provides outline drawings for the Kuro camera.
- Appendix C, Liquid Cooling Setup
  This appendix provides information about configuring a liquid cooled system.
- Appendix D, Troubleshooting
  This appendix provides recommended troubleshooting information for issues which may be encountered while working with a Kuro system.
- Appendix E, PCI Express (PCIe) Card
  Provides information about the installation and use of a PCI Express (PCIe) card.
- Warranty and Service
  This chapter provides warranty information for the Kuro camera. Contact information is also provided.

1.4 Minimum Host Computer Specifications

The minimum host computer specifications are:

- Windows® 7/8/10 (64-bit)
- 2 GHz or faster Intel processor: either Xeon or Core i7
- 8 GB RAM (or greater)
- CD-ROM drive
- 250+ GB serial ATA (SATA) HDD and/or >512 GB Solid State Drive (SDD) for high-speed imaging and storage
- 512+ MB slot-based ATI/NVIDIA video graphics card (i.e., not an integrated graphics adapter)
- USB3.0 port

1.5 Safety Related Symbols Used in this Manual

CAUTION!

A Caution provides detailed information about actions and/or hazards that may result in damage to the equipment being used, including but not limited to the possible loss of data.

WARNING!

A Warning provides detailed information about actions and/or hazards that may result in personal injury or death to individuals operating the equipment.

WARNING! RISK OF ELECTRIC SHOCK!

The use of this symbol on equipment indicates that one or more nearby items pose an electric shock hazard and should be regarded as potentially dangerous. This same symbol appears in the manual adjacent to the text that discusses the hardware item(s) in question.

1.6 Kuro Safety Information

Before turning on the power supply, the ground prong of the power cord plug must be properly connected to the ground connector of the wall outlet. The wall outlet must have a third prong, or must be properly connected to an adapter that complies with these safety requirements.

WARNINGS!

1. If the Kuro camera system is used in a manner not specified by Teledyne Princeton Instruments, the protection provided by the equipment may be impaired.
2. If the equipment or the wall outlet is damaged, the protective grounding could be disconnected. Do not use damaged equipment until its safety has been verified by authorized personnel. Disconnecting the protective earth terminal, inside or outside the apparatus, or any tampering with its operation is also prohibited.

Inspect the supplied power cord. If it is not compatible with the power socket, replace the cord with one that has suitable connectors on both ends.

WARNING!

Replacement power cords or power plugs must have the same polarity and power rating as that of the original ones to avoid hazard due to electrical shock.

1.7 Precautions

To prevent permanently damaging the Kuro system, observe the following precautions at all times:

- If using high-voltage equipment (such as an arc lamp) with the camera system, turn the camera power on last and when powering down, power the camera off first.
- Never connect or disconnect any cable while the system is powered on.
- The camera's power should be switched off before disconnecting any camera system cables. However it is not necessary to power off the computer to detach the cables.
- Use caution when triggering high-current switching devices (such as an arc lamp) near the system. The image sensor can be permanently damaged by transient voltage spikes. If electrically noisy devices are present, an isolated, conditioned power line or dedicated isolation transformer is highly recommended.
- Always leave one inch of space around the camera's external cooling fins for airflow.
- Do not operate the camera without cooling (air or liquid.)
- Never open the camera. There are no user-serviceable parts inside the Kuro camera. Opening the camera voids the warranty.
- Use only the PCI Express interface card, cables and power supply designated for this camera system. Using non-Kuro cables, PCI Express interface cards, or power supplies may result in permanent damage to the system.
- Do not use a C-mount lens with optics that extend behind the lens flange.

Chapter 2: Kuro Camera System

This chapter provides an introduction to, and overview information about, Teledyne Princeton Instruments' Kuro camera system.

A typical Kuro camera system includes the following items:

- Kuro Camera;
- USB 3.0 data cable;
- External power supply with international power cord set;
- I/O to 8 BNC external trigger cable;
- LightField image acquisition software, including installation disk/hardware key.
- PCI Express (PCIe) Interface Card and data cable.

NOTE:

The PCIe card should only be installed/used under very specific circumstances. Refer to Appendix E, PCI Express (PCIe) Card, on page 39 for complete information.

Kuro system components are connected using USB3.0 data cable and are controlled by the host computer system. All hardware components should be included with the shipment.

2.1 Kuro Camera

Teledyne Princeton Instruments' Kuro™ camera, shown in Figure 2-1, is the world's first scientific CMOS (sCMOS) camera system to implement back-illuminated sensor technology with powerful software. Capable of very low read noise, >95% QE, and >82 fps at full 1200 x 1200 resolution, Kuro is ideal for many challenging lowlight applications.

Figure 2-1: Typical Kuro Camera

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Key features of the Kuro camera system include:

- Reduced Fixed-Pattern Noise

  Kuro uses the latest sCMOS technology along with optimized electronics. As a result, it has a significantly better noise profile than any previous-generation, front-illuminated sCMOS camera.
- High Speed and Low Read Noise

  Kuro offers very high frame rates, up to 41 fps (16 bit) or 82 fps (12 bit) at full 1200 x 1200 resolution with an exceptionally low 1.3 e^- rms (median) read noise. Kuro is capable of delivering hundreds of frames/second with reduced resolution.
- No Microlenses on Pixels

  Unlike front-illuminated sCMOS cameras, which claim ~80% peak QE, the Kuro does not use microlenses to recapture light from the masked area of the pixel. Microlenses significantly degrade QE when light is incident at any angle other than normal to the sensor surface.
- Large Pixels and Wide Dynamic Range

  The 11 μm, 2 pixel pitch of the Kuro sensor captures 2.8 times more photons than previous-generation sCMOS sensors. Each pixel can also handle a large full well of 80,000 electrons, allowing excellent dynamic range (61,500:1 or 95 dB.)
- Flexible Trigger Modes

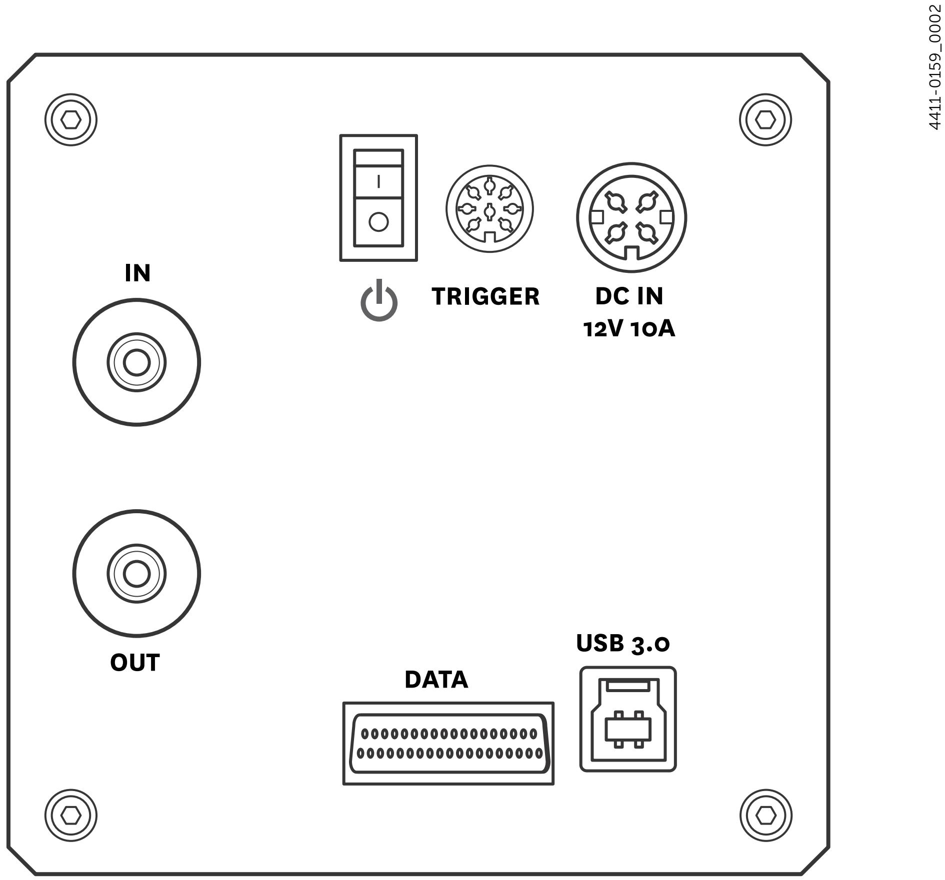
  Kuro provides a full suite of input-output TTL signals making it easy to synchronize camera operation with external events or light sources.
- Optimized for Spectroscopy

  Scientific CMOS sensors typically do not support on-chip binning. However, the Kuro camera's low read noise and support of software binning (off-chip binning) make it ideal for high-speed spectroscopy applications. Furthermore, the pixel pitch of its sensor is a perfect match for optimal use with the award-winning, aberration-free IsoPlane® spectrometer from Teledyne Princeton Instruments.

2.1.1 Connectors and Indicators

Figure 2-2 illustrates the connectors and indicators on a Kuro camera.

Figure 2-2: Kuro Rear Panel Connectors



Refer to Table 2-1 for information about each rear-panel connector.

Table 2-1: Kuro Connectors and Indicators

Label	Description
Initializing	LED blinking indicates the camera is booting up. Once the camera has completed the initialization process, this LED is extinguished.
Power	Turns the camera on and off.
Trigger	External trigger input.
DC IN	Connection to external Power Supply.
In/Out	Liquid Cooling Connections
Data	PCI Express Connection[a]
USB 3.0	Data Connection

a. PCIe should only be used under very specific circumstances. Refer to Appendix E, PCI Express (PCIe) Card, on page 39 for complete information.

2.2 Application Software

Teledyne Princeton Instruments offers a number of data acquisition software packages for use with Kuro camera systems, including:

- LightField®

  The Kuro camera can be operated using LightField, Teledyne Princeton Instruments' 64-bit Windows® compatible software package.

  LightField combines complete control over Teledyne Princeton Instruments' cameras and spectrographs with easy-to-use tools for experimental setup, data acquisition and post-processing. LightField makes data integrity priority #1 via automatic saving to disk, time stamping and retention of both raw and corrected data with full experimental details saved in each file. LightField works seamlessly in multi-user facilities, remembering each user's hardware and software configurations and tailoring options and features accordingly. The optional, patent-pending IntelliCal™ package is the highest-performance wavelength calibration software available, providing up to 10X greater accuracy across the entire focal plane than competing routines.
- PICam™

  The standard 64-bit software interface for cooled CCD cameras from Teledyne Princeton Instruments. PICam is an ANSI C library of camera control and data acquisition functions.

  Refer to the PICam Programmer's Manual for the list of supported operating systems.
- LabView and Matlab (via LightField automation)

  LightField includes automation support with examples about how to acquire data directly into LabView and Matlab. "How To…" videos are available on the Teledyne Princeton Instruments website at www.princetoninstruments.com.

NOTE:

Kuro cameras may also be operated by several other third-party software packages. Please check with the providers of the packages for compatibility and support information.

2.3 Accessories

The Kuro is compatible with many optional accessories. This section provides information about compatibility.

2.3.1 Microscopes, Lenses, and Tripods

The Kuro camera includes a standard threaded video mount and can be mounted to any microscope that accepts a standard C-mount adapter.

The Kuro camera accepts any lens that is compatible with a standard threaded video mount as long as its optics do not extend behind the flange of the lens.

The Kuro camera can be mounted to optical tables, tripods, and copy stands using the eight ¼-20 threaded attachment points located near the camera front and rear on all sides.

2.4 Unpack the System

All required items should be included with the shipment. The Kuro system has been manufactured according to the camera options specified at the time of purchase, including the CCD window and coatings that were ordered.

When unpacking the system, examine the system components for any signs of shipping damage. If there are any, notify Teledyne Princeton Instruments immediately and file a claim with the carrier. Be sure to save the shipping carton for inspection by the carrier. If damage is not apparent but system specifications cannot be achieved, internal damage may have occurred in shipment.

Retain all original packing materials so that the Kuro system can be easily and safely packaged and shipped to another location or returned for service if necessary. If assistance is required at any time, contact Teledyne Princeton Instruments Customer Support. Refer to Contact Information on page 46 for complete information.

2.4.1 Verify Equipment and Parts Inventory

Verify all equipment and parts required to set up the Kuro system have been delivered.

A typical Kuro camera system includes the following items:

- Kuro Camera;
- USB 3.0 data cable;
- External power supply with international power cord set;
- I/O to 8 BNC external trigger cable;
- [optional] LightField Data Acquisition Software, including installation disk/hardware key;
- PCI Express (PCIe) Interface Card and data cable.

NOTE:

The PCIe card should only be installed/used under very specific circumstances. Refer to Appendix E, PCI Express (PCIe) Card, on page 39 for complete information.

2.5 Kuro Camera and System Maintenance

WARNING!

Turn off all power to the equipment and secure all covers before cleaning the unit. Otherwise, damage to the equipment or injury to you could occur.

2.5.1 Camera

Although there is no periodic maintenance that needs to be performed on a Kuro camera, users are advised to wipe it down with a clean, dry, lint-free cloth from time to time. This should only be done on the external surfaces and when all covers are in place and secured.

2.5.2 Optical Surfaces

Optical surfaces are to be cleaned using only a filtered compressed-air source. Hand-held cans are not recommended as they may spray propellant onto the window.

Never touch the window.

2.5.3 Repairs

NOTE:

Do not open the Kuro camera. Opening the camera voids the warranty.

Because the Kuro camera system contains no user-serviceable parts, repairs must be performed by Teledyne Princeton Instruments. Should the system need repair, contact Teledyne Princeton Instruments customer support for instructions. Refer to Contact Information on page 46 for complete information.

Save the original packing materials for use whenever shipping the system or system components.

Chapter 3: Install LightField

This chapter provides the installation procedure for LightField application software.

NOTE:

If LightField has already been successfully installed on the host computer, this chapter may be skipped.

3.1 Prerequisites

Before beginning to install LightField, verify that:

- The host computer satisfies the minimum system requirements as stated in Section 1.4, Minimum Host Computer Specifications, on page 9.
- The host computer includes a USB3 port;

  If it does not support USB3, refer to the host computer manufacturer's instructions for installing a USB3 interface card;
- The installation disk and hardware key are available.

3.2 Installation Procedure

Perform the following procedure to install LightField on the host computer:

1. Insert the LightField Installation CD into the CD drive on the host computer, and follow the on-screen prompts.
2. After the installation has been completed, reboot the host computer.
3. Connect the Kuro system components to the host computer and apply power.
4. Launch LightField, activate it, and begin experiment configuration.

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Chapter 4: System Installation

This chapter provides information about the installation of hardware for a Kuro system.

4.1 Connect Kuro with USB 3.0

Kuro's USB3.0 interface is ubiquitous and easy to use. To use the interface, the PC must have an open USB3.0 port. Kuro is not USB2.0 compatible. USB3.0 ports are usually indicated by the SuperSpeed+ logo and are typically blue in color.

NOTE:

USB devices sharing the same bus as Kuro contend for available bandwidth, potentially causing the camera to drop frame rate. For this reason, Teledyne Princeton Instruments recommends isolating the camera to its own USB3.0 root hub as shown in the Windows Device Manager.

A method for creating an independent root hub in computers with many USB devices is to install a PCI Express based USB3.0 interface card for use with the camera.

It is not recommended to connect Kuro to an external USB3.0 hub.

Figure 4-1 shows a typical USB 3.0 cable.

Figure 4-1: Typical USB 3.0 Cable

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Note that the ends of the USB3.0 cable are different between the camera and PC, and require a specific orientation. The camera has a Type B connector and the computer will have a Type A connector. Do not force insertion when connecting the cable. If significant resistance is encountered stop, re-examine the connection, and if correct, retry.

With the cable connected on both ends, the computer can be powered on:

1. With the camera off, connect the USB3.0 cable between camera and host computer.
2. Power the camera on.
3. Wait 30 seconds before launching the application. An LED on the rear of the camera will stop blinking when the camera is initialized and ready to communicate.

Chapter 5: Theory of Operation

Scientific CMOS, aka sCMOS, is a recent development in image sensor technology. The primary advantage provided by sCMOS sensors is high frame rates, even with very large pixel counts, while still operating with very low electronic noise. This largely eliminates the speed-resolution-noise trade off inherent in CCD sensors.

5.1 CMOS Image Sensor Structure

A major difference between traditional CCD sensors and CMOS sensors is the location where charge-to-voltage conversion of accumulated photoelectrons takes place. CCD sensors transfer the pixels accumulated signal in charge packets in "bucket brigade" fashion across the sensor to a common output node where charge is converted to a voltage. The voltage is then sampled using off-chip Analog-to-Digital Converters (ADC) and transferred to the PC as digital grey values.

While providing excellent quantitative photometry and very high image quality, the large number of transfers and sequential digitization of pixels results in low frame rates. This speed penalty increases with the number of pixels to be digitized.

CMOS sensors leverage many of the same analog signal concepts used in CCDs, but places the output node circuitry inside each pixel. This eliminates the charge transfer process. To read the signal from a given row, the accumulated charge is converted to a voltage inside the pixel, then each pixel in the row is connected to the appropriate column voltage bus, where the on--chip ADCs covert the voltages to an 11-bit or 12- bit grey value. (Thus far, the on-chip ADCs available on CMOS sensors have limited dynamic range.)

The parallel digitization of all pixels in a row provides CMOS devices with a tremendous speed advantage. Imagine a CCD with 1200 x 1200 pixels and each pixel's voltage is measured in 1 μsec. To read a single row, 1200 voltage measurements are performed in serial fashion taking slightly longer than 2 ms, and when repeated for 1200 rows, the entire image takes over four seconds to be digitized.

On a CMOS device, the entire 1200 voltage conversions needed to digitize a row happen in parallel. The sensor in the Kuro sCMOS camera takes parallelism even further by dividing the sensor into two halves, so that two rows of 1200 pixels can be measured at the same time. If the time to digitize a pixel remains at 1 μs, the time to read the entire frame is now approximately 1 ms.

In practice, the time saving is split between faster frame rates and slowing the rate of pixel measurement to reduce electronic noise. For example, if the time to measure a pixel was increased to 10 μsec to lower noise, the image sensor can still be read in 10 ms, for a maximum 100 fps.

Of course, there are many challenges to obtaining the same analog performance from each of the Kuro's 1.4 million pixels, whereas a CCD has a single, common output node resulting in a uniform response. The most common problems are pixel-to-pixel non-uniformity in gain and offset, Random Telegraph Noise (RTN,) and defective pixels with abnormal noise or dark current characteristics (i.e., hot pixels.)

Often solutions to these challenges are found in the digital domain, where Kuro's advanced real time signal processing corrects each pixel for gain and offset variation using calibration at the factory. To address RTN and other pixel defects, real-time digital filters are used.

5.2 Gain Combining

As discussed in Section 5.1, CMOS Image Sensor Structure, the column ADCs present in sCMOS devices have limited dynamic range. This is addressed by making two measurements of the accumulated charge in each pixel:

- The first measurement is made with very high sensitivity but is limited to a maximum signal of approximately 4000 electrons;
- The second measurement is made with reduced sensitivity but is capable of measuring signals up to the pixel's 80,000 electron full-well capacity.

Combining the two measurements into a single 16-bit value is the function of the digital “gain combiner.” This mathematical operation is performed on the camera’s FPGA. The result is a single 1x gain of approximately 0.45e/ADU.

In practice, Kuro's advanced FPGA based signal processing does an excellent job of gain combining as evidenced by the quality of gamma transfer functions (linearity) and photon transfer functions (signal versus noise.) With careful observation and uniform illumination of the sensor, the zone where two measurements overlap can be seen as a slight static vertical pattern in the image. This is inherent on all current generation sCMOS cameras. While impacting image quality, these cannot be addressed without negatively impacting image photometry and wait for further improvements to the on-sensor ADC conversion.

5.3 Rolling and Global Shutter Readout

CMOS image sensors support two shutter readout modes:

- Global Shutter Readout [Not currently supported by Kuro]

  In this mode, a global charge clearing mechanism begins the exposure period for all pixels. Each pixel accumulates signal charge until the exposure period ends. At this point, the accumulated charge is transferred and converted to a voltage in the pixel’s output node, ending the exposure.

  The strength of the Global Shutter approach is that all pixels are exposed at the same instant in time, an important attribute when imaging fast moving objects.

  The downside of this approach is the sensor has two phases, an active image accumulation phase, and a subsequent readout phase. As the phases are not overlapped in time, the maximum achievable frame rate is lower.
- Rolling Shutter Readout

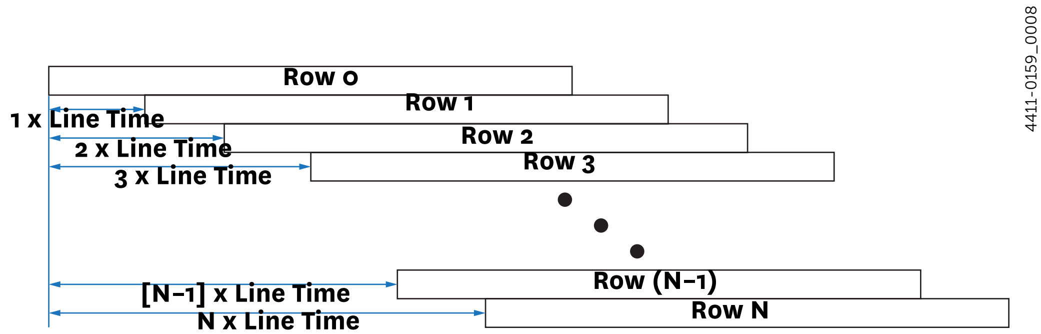
  In this mode, exposure and readout are overlapped. This is accomplished by reading one row while exposing all of the other rows. (The row being digitized “rolls” through the sensor.)

  For Kuro, the time to digitize a single row is 20 μs, and consequently the delay between the start of exposure between two adjacent rows is approximately 9.6 μs. When digitizing 1200 rows of pixels, the time delay from the top to the middle of the sensor is approximately 24 ms. Since readout and exposure are overlapped, the sensor achieves the maximum frame rate of 41 fps.

  In 12-bit mode, because two rows are read out simultaneously, the row time is effectively cut in half to 10 μs, thus increasing the maximum frame rate to 82 fps.

Figure 5-1 illustrates the time delay between each row of pixels in a rolling shutter readout mode with a CMOS camera.

Figure 5-1: Rolling Shutter Exposure Row by Row Exposure Start/End Offset



A disadvantage of Rolling Shutter readout is that any changes in the scene on similar time scales is distorted, as each row samples the image at different times. This is the well-known "rubber band" effect, but can appear in fluorescence microscopy as shaded illumination when rapidly changing wavelengths.

To maintain the benefit of Rolling Shutter readout and eliminate rolling shutter artifacts, external illumination can be gated on when all rows are being simultaneously exposed, and off during the readout phase. This external triggering mode used in combination with high speed light sources (e.g., lasers, LEDs,) achieves a pseudo-global shutter effect. This triggering mode is described in Section 6.3, Device Synchronization (Triggering), on page 27.

Unlike CCDs, there is limited benefit to performing multiple pre-exposure clearing cycles with CMOS, because each pixel is reset as part of the normal readout process, and the charge transfer registers that can hold residual signals are not present.

5.4 Bias Offset

Scientific cameras produce a fixed artificial signal offset known as bias offset. This offset is present even when no light is falling on the sensor and the exposure time is set to zero. This preserves quantization even down to signals of a few electrons per pixel. Typically, the user subtracts this offset before performing quantitative analysis post-acquisition.

The recommended protocol is to capture a new series of bias frames at the start of each experimental run. The series of frames can be averaged to remove noise, then used to remove the bias offset during subsequent image analysis. This can also be used to monitor for light leaks and other systematic effects that can impact experimental results.

NOTE:

The specific Bias Offset value for each Kuro camera is programmed at the factory and is not user-configurable. A typical Bias Offset value is approximately 100 counts.

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Chapter 6: Operating Features

This section explains Kuro's different modes of operation and the best modes to optimize imaging performance.

6.1 Bit Depth and Analog Gain

Kuro supports two Bit Depths

- 12-bit
  12-bit mode provides the highest frame rates which are twice that of the 16-bit mode. To provide imaging flexibility, three analog gain settings are supported:
  - Low
    Provides the maximum full-well capacity with a gain conversion factor of approximately $2e^-$/ADU.
  - Medium
    Provides the best balance between read noise and full-well capacity with a gain conversion factor of approximately $1e^-$/ADU.
  - High
    Provides the highest levels of sensitivity with a gain conversion factor of approximately $0.5e^-$/ADU.
- 16-bit
  16-bit mode provides the best full-well capacity and noise performance. However, it provides lower frame rates than can be achieved with 12-bit mode.

6.2 Region of Interest

Kuro supports the creation of a single Region of Interest (ROI.) An ROI is an image subregion selected by the user to be captured and delivered to the host PC in place of the full image. This can substantially increase frame rates and lower the amount of data that needs to be processed.

Frame rates increase with decreasing numbers of rows contained in an ROI. By reducing the number of rows, frame rates above 1000 fps are achievable with small ROIs. As a result, the sensor architecture, if any pixel in a row is part of the ROI, the entire row is digitized. Reducing the number of columns in the ROI does not improve the frame rate of the camera, but it does reduce the amount of data acquired, saving computer resources and processing time.

NOTE:

Very small ROI's of less than 2000 pixels can result in data transfer problems during high-speed DMA data transfers to host memory. If a small ROI does not return an image, try changing the ROI boundary to make it larger than 2000 pixels, or chose a different starting pixel for the ROI.

This is an excellent technique for reducing the amount of data to the essential in high frame rate experiments. This can also speed up frame rates depending on the number of rows in the bounding envelope that encloses all ROIs.

6.2.1 Mounting Kuro to a Spectrograph

When using Kuro for imaging applications, the orientation of the CCD within the camera body typically does not require any special considerations or configuration by the user.

However, for spectroscopic applications, knowing the orientation of the CCD within the camera's body is critical. When the Kuro is mounted to a spectrograph in its normal orientation (i.e., with the four feet facing down,) the CCD within the camera body is rotated by 90°. LightField automatically compensates for the rotated CCD using its Online Correction ► Orientation feature.

With spectroscopic applications, an ROI is often defined in order to maximize the rate at which data are acquired and read out. This ROI is typically defined so that it spans the entire width of the sensor (i.e., all available columns,) but reduces the number of rows being read out. With Kuro, since the CCD is rotated by 90°, when defining an ROI, it is important to realize that rows and columns are now transposed:

- Rows should be considered columns;
- Columns should be considered rows.

If the definition of an ROI does not compensate for the rotated CCD, no speed advantage is achieved.

6.2.1.1 Rotating Kuro by 90°

When an experiment permits it, one way of compensating for the rotated CCD is to actually rotate the Kuro camera by 90° when mounting it to the spectrograph. Doing so simplifies the definition of an ROI since there is no resulting transposition of rows and columns.

However, when Kuro is rotated 90° when mounted to the spectrograph, LightField will not automatically detect this, and it is important that prior to acquiring data, Online Correction ► Orientation be configured accordingly.

6.3 Device Synchronization (Triggering)

Kuro offers several methods of integrating with external hardware devices. Each camera includes a 10-pin, Hirose HR212-10RC-10SDL(74) connector on the back of the camera for trigger input/output operations. Refer to Table 6-1 for pinout information.

Table 6-1: Trigger Cable Pinout

Signal	Description
Trigger In	Inputs initiate an exposure or sequence
Trigger Ready Out	Status indicating if the camera can accept another trigger
Read Out	Status indicating the camera is currently digitizing
Expose Out 1	Output for controlling illumination source 1
Expose Out 2	Not currently supported.
Expose Out 3	Not currently supported.
Expose Out 4	Not currently supported.

A special BNC breakout cable, illustrated in Figure 6-1, is provided to easily access these signals, and each breakout BNC cable is labeled according to its function.

Figure 6-1: Typical BNC Cable

6.3.1 Trigger Modes

Kuro supports the following three trigger modes:

NOTE:

All triggers are rising edge triggers.

- No Response

  This is the default triggering mode for Kuro.

  When No Response is selected, incoming trigger pulses are ignored. This mode is typically used for experiments incorporating a constant light source (e.g., a CW laser, DC lamp.) Other experiments that can use this mode are high repetition studies where the number of light impulses occurring during a single shutter cycle is so large that the light source appears to be a continuously illuminated source.
- Start on Single Trigger

  Begins the experiment when the trigger is received and the system executes all programmed events.
- Readout Per Trigger

  With Readout Per Trigger, all exposures are synchronized with the rising edge of the incoming trigger pulse.

6.4 Rolling Shutter Readout

NOTE:

All timing diagrams incorporate rising edge triggers.

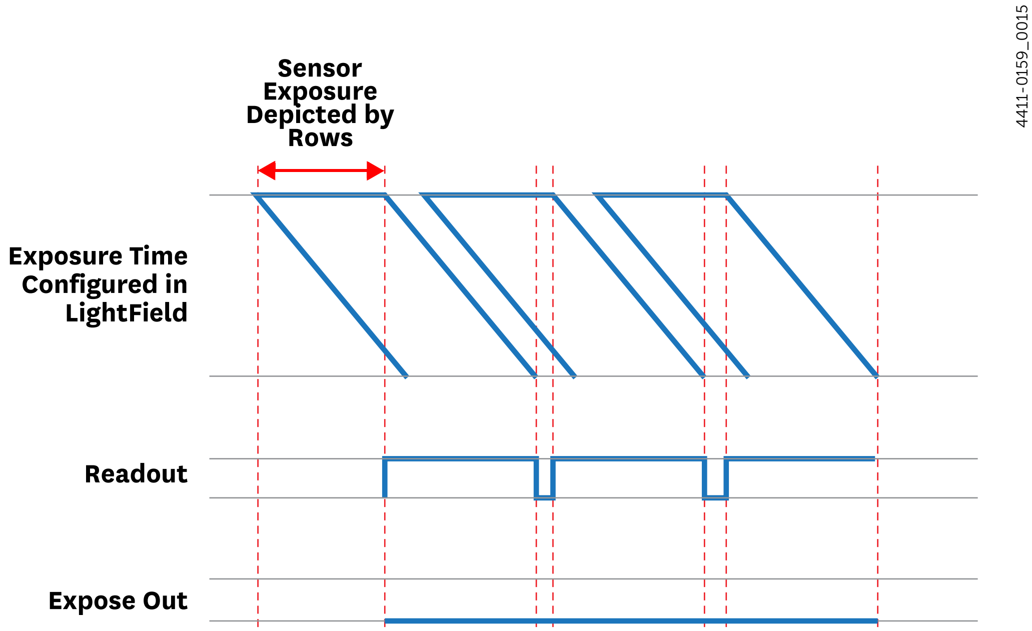
The Expose Out I/O signal goes high only when all rows within a single frame are being exposed simultaneously. The length of the Expose Out signal is equal to the time between the start of the last row's exposure and the end of the first row's exposure. This is also equal to the exposure time configured in LightField provided the exposure time is greater than the readout time.

With Rolling Shutter mode, there are two timing scenarios:

- Exposure Time < Readout Time

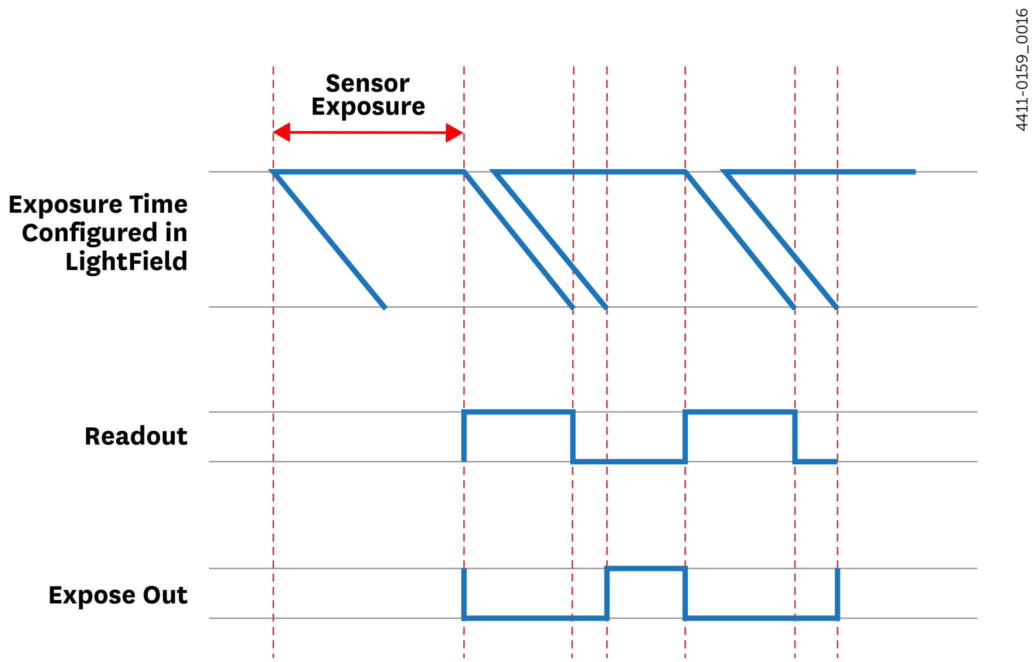
  Figure 6-2 illustrates the timing diagram for this mode.

Figure 6-2: Timing Diagram: Rolling Shutter, Exposure Time < Readout Time



- Exposure Time > Readout Time
  Figure 6-3 illustrates the timing diagram for this mode.

Figure 6-3: Timing Diagram: Rolling Shutter, Exposure Time > Readout Time



6.5 Fan Speed Control and Liquid Cooling

Fans are often used to remove heat from the camera due to their convenience. However, under demanding conditions, fan vibration isolation is insufficient for single molecule localization, high magnification imaging, or use with micro-manipulators.

Kuro solves this problem in two ways. First, a new, innovate fan mounting system has been developed that isolates fan vibration from the rest of the camera. Side-by-side testing with competing products indicate that Kuro outperforms competitors in terms of vibration isolation.

To achieve the ultimate in low vibration performance, Kuro's fan can be completely turned off in software. Kuro provides liquid cooling ports for this purpose.

NOTE:

If the camera is inadvertently left on with the air and liquid cooling disabled, a protection circuit will trip preventing the camera from overheating. This circuit disables current to the sensor cooling system until the camera returns. In this case the camera is unable to cool the sensor. When setting Kuro on a flat surface, be careful not to block the air vents.

Appendix A: Technical Specifications

CAUTION!
All specifications are subject to change.

This appendix provides some technical information and specifications for Kuro cameras. Additional information may be found on data sheets available on the Teledyne Princeton Instruments website (www.princetoninstruments.com).

A.1 Camera Weight

Weight: 3.8 lbs. (1.7 kg)

A.2 Sensor Specifications

Table A-1 provides sensor specifications.

Table A-1: Sensor Specifications

Parameter	Specification
Window	UV grade fused-silica Broadband MgF2 anti-reflective coating on both surfaces
BSI Scientific CMOS Sensor Array	
Sensor	GPixel GSense 144 BSI
Sensor Process	Backside illuminated scientific CMOS
Resolution	1200 x 1200
Pixel Size	11 µm x 11 µm
Sensor Area	13.2 mm x 13.2 mm

A.3 Power Supply Specifications

Table A-2 provides power supply specifications.

Table A-2: Power Supply Specifications (Sheet 1 of 2)

Parameter	Specification
Voltage Input	100-240 V_{AC} @ 50-60 Hz
Current Input	2.5 A (110 V nominal)
Voltage Output	12 V_{DC} @ 8 A
Maximum Power Output	140 W
Power Supply Weight	1.80 lb (0.82 kg)

Table A-2: Power Supply Specifications (Sheet 2 of 2)

Parameter	Specification
Supply Cable Length	4 ft [1.22 m]
Certifications	CE, UL, CUL, FCC, PSE Efficiency level VI

NOTE:
CE certification applies to the Kuro camera only when the camera system operates with a CE-approved power supply.

Figure A-1: Typical Power Supply

4411-0159_0019

A.4 Liquid Circulator Connector Information

- Camera Backplate
  MCD4204 quick-mount couplings terminating in the MC connector
  https://www.cpcworldwide.com/Product-List/Product/459

A.4.1 Hose Set

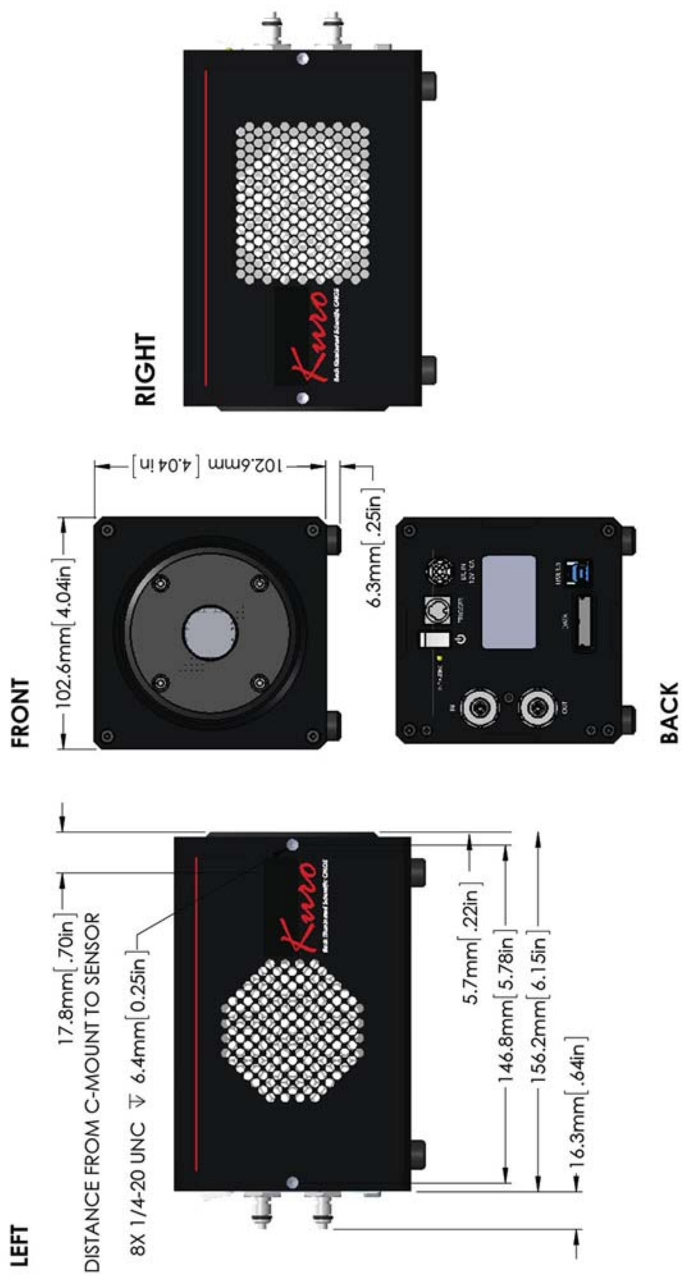
- Hose End 1
  MCD1704 quick-mount couplings to connect to MCD4204 connectors on the camera.
- Hose End 2
  QD2-FS06X10 Koolance Female coupling

Appendix B: Outline Drawings

This appendix provides outline drawings for the Kuro camera.

NOTE:
All measurements are in inches [millimeters].

Figure B-1: Outline Drawing: Kuro Front View



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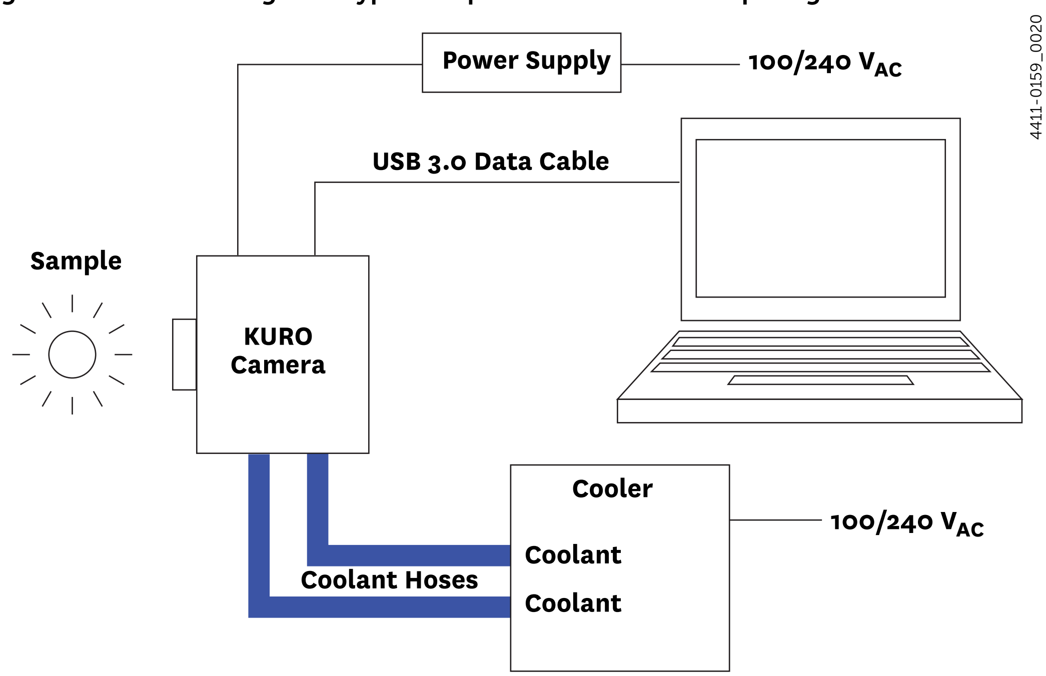
Appendix C: Liquid Cooling Setup

> **WARNING!**
> Use of equipment not originally provided by Teledyne Princeton Instruments for use with liquid cooled cameras will void any and all warranty coverage of the product.

Figure C-1 illustrates the typical hardware configuration for a liquid cooled Kuro system.

Figure C-1: Block Diagram: Typical Liquid Cooled Kuro Setup Diagram



Perform the following procedure to configure the Kuro system for liquid cooling:

1. Unpack the cooler and hose assembly.
2. Confirm the cooler and hoses are pre-filled with blue-colored coolant.
3. Press one hose connector into its mate on the cooler.
4. Repeat with the second hose connector.
5. Press each hose connector on to its mating connector on the camera as follows:
   - Circulator Out > Camera In
   - Camera Out > Circulator In

   Listen for the click.
6. Pull each connector to ensure they are locked.
7. Inspect the set-up to insure the hose connectors are secure at the cooler and camera.
8. Set both the pump speed and fan speed to level 10 on the front display on the Circulator.

9. Plug-in the cooler and turn it on.
10. Look through the clear cover on the coolant reservoir to observe the liquid level and confirm circulation.

NOTE:

The liquid surface will appear agitated with normal circulation.

11. Turn on the camera power and continue the setup per Quick Start Guide.
12. Use Software to set the camera fan speed to OFF. DO NOT turn off the camera fan without liquid circulating.

NOTE:

There is no temperature adjustment on the unit.

Appendix D: Troubleshooting

For difficulty in troubleshooting or if the symptoms are not listed here, contact Teledyne Princeton Instruments Customer Service.

D.1 New Hardware Found Dialog Box Does Not Appear

If the New Hardware Found dialog box does not appear after installing a new interface card to the computer and booting Windows 7:

1. Make sure the new interface card is inserted in an expansion slot according to the computer manufacturer's instructions.
2. Ensure Kuro is connected and powered on at least 10 seconds before starting the computer when using the PCIe interface.
3. When using the USB3.0 interface, wait for the LED on the rear of the camera to stop blinking before checking for “New Hardware Found” and opening the application.

It is possible that there is a conflict between the new interface card and a previously installed expansion card. With the computer's power turned off, remove any previously installed expansion cards that the system does not need to function (If you are unsure which cards can be safely removed, call Teledyne Princeton Instruments Customer Service.) Then turn the computer back on.

If the New Hardware Found dialog box still does not appear, contact Teledyne Princeton Instruments Customer Service. Refer to Contact Information on page 46 for complete information.

D.2 Images Not Displayed

If no images appear:

1. Confirm the camera switch is set to on.
2. Confirm that the Kuro sCMOS camera is selected in the imaging software application.
3. Power off the camera and the host computer and check all system connections (particularly the DATA and power cables,) then restart.
4. Confirm the camera is operational by taking an image with a standard C-mount lens attached to the camera. Using normal room lighting, place the camera on a table about three meters away from an object and acquire an image.

If the problem persists, contact Teledyne Princeton Instruments Customer Service. Refer to Contact Information on page 46 for complete information.

D.3 Camera Running Too Warm

It is normal for the camera to be slightly warm to the touch while in operation. However, if it is more than slightly warm to the touch (and at least one inch of space has been left around the external cooling fins for airflow,) switch off the camera immediately and contact Teledyne Princeton Instruments Customer Service. Refer to Contact Information on page 46 for complete information.

D.4 Lengthy Pauses During Imaging

If you notice lengthy pauses marked by a lot of disk activity while imaging:

- Close any other programs that may be running.
- Install more physical memory (RAM) in your computer system.

Appendix E: PCI Express (PCIe) Card

Under normal operation, the PCI Express (PCIe) card is not required and should never be used. The only time the PCIe interface will be required is in the unlikely event that the Kuro camera's firmware needs to be reloaded/upgraded.

E.1 Install the PCI Express (PCIe) Card

Figure E-1 illustrates a typical PCIe interface card.

> **NOTE:**
> The specific PCIe card shipped with the Kuro may vary from that illustrated.

Figure E-1: Typical PCI Express Interface Card

4411-0159_0003

Perform the following procedure to install a PCIe card into the host computer:

1. Shut down the host computer and unplug it from the wall receptacle.
2. Remove the side of the host computer to access the PCI and PCIe slots. See Figure E-2.

Figure E-2: Typical Host Computer (Internal View)

4411-0159_0004

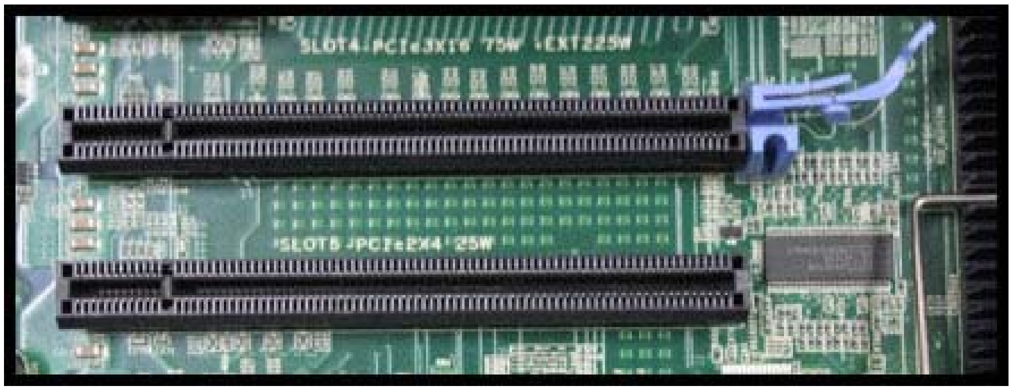
3. Locate an available 4-channel or higher PCIe slot (marked x4.) Refer to the PC's documentation to locate a suitable slot.

NOTE:

The PC may have motherboard slot information on the side cover.

See Figure E-3.

Figure E-3: Typical Motherboard PCIe Slots



4411-0159_0005

4. Holding the Kuro PCIe card and being careful not to touch the board's components or PCIe bridge pins insert it with the proper orientation into the open slot. The card should slide into place with minimal resistance and snap when fully inserted.
5. Replace the cover on the host computer.
6. Boot the host computer.

E.2 Connect Kuro to the PCIe Bus

The Kuro sCMOS camera data cable, shown in Figure E-4, is a quick insertion, quick release cable that works with the interface card and camera. Either end of the cable can be plugged into either device, and in any order.

Figure E-4: Typical Kuro PCIe Data Cable

4411-0159_0006

The connector can only be inserted with the correct orientation, do not force the connector. If the connector does not insert, simply turn the connector over and retry.

NOTE:

With the camera oriented so the labels on the camera are upright, the green “quick release” pull tab on the cable will be facing down.

With the cable connected on both ends of the camera, it is ready to power on the computer.

1. Verify that the power switch on the side of the camera is in the off position.
2. Connect the power supply to the Power connector on the rear of the camera.
3. Plug the power cord into the power supply and then into a suitable wall outlet.
4. Switch on the camera (power switch on the side of camera.)
5. Wait 10 seconds before powering on the PC.

NOTE:

The power supply and connector used by the Kuro sCMOS camera is a common type. However, Teledyne Princeton Instruments carefully selects power supplies for optimum noise performance, EMI compliance and stability. Do not swap power supplies with other lab equipment even though they may meet the connector, voltage and ampere requirements of the Kuro.

E.3 Troubleshooting

This section provides information about troubleshooting issues that may arise that are PCIe specific.

E.3.1 System Does Not Boot Normally

If the operating system does not boot normally after the interface card is installed, try reseating the PCIe card. If this is unsuccessful, try installing the new card in another open PCIe 4x or higher slot. If this does not work:

1. Turn off the computer and remove the newly installed interface card.
2. Turn the computer on. If the system boots normally, there is probably an interrupt conflict between a previously installed device.

If you need assistance resolving the interrupt conflict, contact Teledyne Princeton Instruments Customer Service. Refer to Contact Information on page 46 for complete information.

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Warranty and Service

Limited Warranty

Teledyne Princeton Instruments ("us," "we," "our,") makes the following limited warranties. These limited warranties extend to the original purchaser ("You," "you,") only and no other purchaser or transferee. We have complete control over all warranties and may alter or terminate any or all warranties at any time we deem necessary.

Basic Limited One (1) Year Warranty

Teledyne Princeton Instruments warrants this product against substantial defects in materials and/or workmanship for a period of up to one (1) year after shipment. During this period, Teledyne Princeton Instruments will repair the product or, at its sole option, repair or replace any defective part without charge to you. You must deliver the entire product to the Teledyne Princeton Instruments factory or, at our option, to a factory-authorized service center. You are responsible for the shipping costs to return the product. International customers should contact their local Teledyne Princeton Instruments authorized representative/distributor for repair information and assistance, or visit our technical support page at www.princetoninstruments.com.

Limited One (1) Year Warranty on Refurbished or Discontinued Products

Teledyne Princeton Instruments warrants, with the exception of the CCD imaging device (which carries NO WARRANTIES EXPRESS OR IMPLIED,) this product against defects in materials or workmanship for a period of up to one (1) year after shipment. During this period, Teledyne Princeton Instruments will repair or replace, at its sole option, any defective parts, without charge to you. You must deliver the entire product to the Teledyne Princeton Instruments factory or, at our option, a factory-authorized service center. You are responsible for the shipping costs to return the product to Teledyne Princeton Instruments. International customers should contact their local Teledyne Princeton Instruments representative/distributor for repair information and assistance or visit our technical support page at www.princetoninstruments.com.

XP Vacuum Chamber Limited Lifetime Warranty

Teledyne Princeton Instruments warrants that the cooling performance of the system will meet our specifications over the lifetime of an XP style detector (has all metal seals) or Teledyne Princeton Instruments will, at its sole option, repair or replace any vacuum chamber components necessary to restore the cooling performance back to the original specifications at no cost to the original purchaser. *Any failure to "cool to spec" beyond our Basic (1) year limited warranty from date of shipment, due to a non-vacuum-related component failure (e.g., any components that are electrical/electronic) is NOT covered and carries NO WARRANTIES EXPRESSED OR IMPLIED.* Responsibility for shipping charges is as described above under our Basic Limited One (1) Year Warranty.

Sealed Chamber Integrity Limited 12 Month Warranty

Teledyne Princeton Instruments warrants the sealed chamber integrity of all our products for a period of twelve (12) months after shipment. If, at anytime within twelve (12) months from the date of delivery, the detector should experience a sealed chamber failure, all parts and labor needed to restore the chamber seal will be covered by us. *Open chamber products carry NO WARRANTY TO THE CCD IMAGING DEVICE, EXPRESSED OR IMPLIED.* Responsibility for shipping charges is as described above under our Basic Limited One (1) Year Warranty.

Vacuum Integrity Limited 12 Month Warranty

Teledyne Princeton Instruments warrants the vacuum integrity of "Non-XP" style detectors (do not have all metal seals) for a period of up to twelve (12) months from the date of shipment. We warrant that the detector head will maintain the factory-set operating temperature without the requirement for customer pumping. Should the detector experience a Vacuum Integrity failure at anytime within twelve (12) months from the date of delivery all parts and labor needed to restore the vacuum integrity will be covered by us. Responsibility for shipping charges is as described above under our Basic Limited One (1) Year Warranty.

Image Intensifier Detector Limited One Year Warranty

All image intensifier products are inherently susceptible to Phosphor and/or Photocathode burn (physical damage) when exposed to high intensity light. Teledyne Princeton Instruments warrants, with the exception of image intensifier products that are found to have Phosphor and/or Photocathode burn damage (which carry NO WARRANTIES EXPRESSED OR IMPLIED,) all image intensifier products for a period of one (1) year after shipment. *Refer to additional Limited One (1) year Warranty terms and conditions above, which apply to this warranty.* Responsibility for shipping charges is as described above under our Basic Limited One (1) Year Warranty.

X-Ray Detector Limited One Year Warranty

Teledyne Princeton Instruments warrants, with the exception of CCD imaging device and fiber optic assembly damage due to X-rays (which carry NO WARRANTIES EXPRESSED OR IMPLIED,) all X-ray products for one (1) year after shipment. *Refer to additional Basic Limited One (1) year Warranty terms and conditions above, which apply to this warranty.* Responsibility for shipping charges is as described above under our Basic Limited One (1) Year Warranty.

Software Limited Warranty

Teledyne Princeton Instruments warrants all of our manufactured software discs to be free from substantial defects in materials and/or workmanship under normal use for a period of one (1) year from shipment. Teledyne Princeton Instruments does not warrant that the function of the software will meet your requirements or that operation will be uninterrupted or error free. You assume responsibility for selecting the software to achieve your intended results and for the use and results obtained from the software. In addition, during the one (1) year limited warranty. The original purchaser is entitled to receive free version upgrades. Version upgrades supplied free of charge will be in the form of a download from the Internet. Those customers who do not have access to the Internet may obtain the version upgrades on a CDROM from our factory for an incidental shipping and handling charge. *Refer to Item 12 in Your Responsibility of this warranty for more information.*

Owner's Manual and Troubleshooting

You should read the owner's manual thoroughly before operating this product. In the unlikely event that you should encounter difficulty operating this product, the owner's manual should be consulted before contacting the Teledyne Princeton Instruments technical support staff or authorized service representative for assistance. If you have consulted the owner's manual and the problem still persists, please contact the Teledyne Princeton Instruments technical support staff or our authorized service representative. *Refer to Item 12 in Your Responsibility of this warranty for more information.*

Your Responsibility

The above Limited Warranties are subject to the following terms and conditions:

1. You must retain your bill of sale (invoice) and present it upon request for service and repairs or provide other proof of purchase satisfactory to Teledyne Princeton Instruments.
2. You must notify the Teledyne Princeton Instruments factory service center within (30) days after you have taken delivery of a product or part that you believe to be defective. With the exception of customers who claim a "technical issue" with the operation of the product or part, all invoices must be paid in full in accordance with the terms of sale. Failure to pay invoices when due may result in the interruption and/or cancellation of your one (1) year limited warranty and/or any other warranty, expressed or implied.
3. All warranty service must be made by the Teledyne Princeton Instruments factory or, at our option, an authorized service center.
4. Before products or parts can be returned for service you must contact the Teledyne Princeton Instruments factory and receive a return authorization number (RMA.) Products or parts returned for service without a return authorization evidenced by an RMA will be sent back freight collect.
5. These warranties are effective only if purchased from the Teledyne Princeton Instruments factory or one of our authorized manufacturer's representatives or distributors.
6. Unless specified in the original purchase agreement, Teledyne Princeton Instruments is not responsible for installation, setup, or disassembly at the customer's location.
7. Warranties extend only to defects in materials or workmanship as limited above and do not extend to any product or part which:
   - has been lost or discarded by you;
   - has been damaged as a result of misuse, improper installation, faulty or inadequate maintenance, or failure to follow instructions furnished by us;
   - has had serial numbers removed, altered, defaced, or rendered illegible;
   - has been subjected to improper or unauthorized repair;
   - has been damaged due to fire, flood, radiation, or other "acts of God," or other contingencies beyond the control of Teledyne Princeton Instruments; or
   - is a shutter which is a normal wear item and as such carries a onetime only replacement due to a failure within the original 1 year Manufacturer warranty.
8. After the warranty period has expired, you may contact the Teledyne Princeton Instruments factory or a Teledyne Princeton Instruments-authorized representative for repair information and/or extended warranty plans.
9. Physically damaged units or units that have been modified are not acceptable for repair in or out of warranty and will be returned as received.

10. All warranties implied by state law or non-U.S. laws, including the implied warranties of merchantability and fitness for a particular purpose, are expressly limited to the duration of the limited warranties set forth above. With the exception of any warranties implied by state law or non-U.S. laws, as hereby limited, the forgoing warranty is exclusive and in lieu of all other warranties, guarantees, agreements, and similar obligations of manufacturer or seller with respect to the repair or replacement of any parts. In no event shall Teledyne Princeton Instruments' liability exceed the cost of the repair or replacement of the defective product or part.
11. This limited warranty gives you specific legal rights and you may also have other rights that may vary from state to state and from country to country. Some states and countries do not allow limitations on how long an implied warranty lasts, when an action may be brought, or the exclusion or limitation of incidental or consequential damages, so the above provisions may not apply to you.
12. When contacting us for technical support or service assistance, please refer to the Teledyne Princeton Instruments factory of purchase, contact your authorized Teledyne Princeton Instruments representative or reseller, or visit our technical support page at www.princetoninstruments.com.

Contact Information

Teledyne Princeton Instruments' manufacturing facility for this product is located at the following address:

Teledyne Princeton Instruments
3660 Quakerbridge Road
Trenton, NJ 08619 (USA)

Tel: 1-800-874-9789 / 1-609-587-9797
Fax: 1-609-587-1970

Customer Support E-mail: techsupport@princetoninstruments.com

Refer to http://www.princetoninstruments.com/support for complete support and contact information, including:

- Up-to-date addresses and telephone numbers;
- Software downloads;
- Product manuals;
- Support topics for Teledyne Princeton Instruments' product lines.

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www.princetoninstruments.com

TELEDYNE PRINCETON INSTRUMENTS
Everywhereyoulook™

Part of the Teledyne Imaging Group

info@princetoninstruments.com
USA +1 877-474-2286 | **France** +33 (1) 60 86 03 65 | **Germany** +49 (0) 89 660 7793 | **UK & Ireland** +44 (0) 1628 472 346
Singapore +65 6408 6240 | **China** +86 10 659 16460 | **Japan** +81 (3) 5639 2741