



## **PI-MAX<sup>®</sup>3 System**

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# Attention!

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## WARNING

Intensified CCD detectors, such as the PI-MAX<sup>®</sup>3, when biased ON, can be irreparably damaged if continuously exposed to light levels higher than twice the A/D saturation level. Thus it is **critical** that you **not** establish conditions that could result in damage to the intensifier. Although intensified detectors are less prone to damage from *background light* when operated gated, they are at **significant risk** to damage from high-intensity light sources like a laser. High intensity sources can damage the intensifier before the protection circuits have time to respond, or even cause spot damage without the protection circuits acting at all. If a sustained alarm indication occurs when the controller is turned on, either completely cover the intensifier to reduce the light to halt the overload condition, or reduce the laboratory illumination still further until safe operating conditions are established.

## Alarm

To reduce the risk of detector damage, the PI-MAX3 detector is equipped with an audible alarm in the detector head, activated when the intensity of light falling on the image intensifier exceeds a preset threshold. While the alarm is sounding, the photocathode is disabled. Immediately switch the **I.I.T.** switch (on the back of the PI-MAX3) to the **OFF** position. Cover the detector window and only switch the **I.I.T.** switch to **ON** after the illumination level has been lowered. If the alarm sounds continuously even when the illumination level is adequately low, shut the system down and contact the factory for guidance.

**Note:** It is normal for the alarm to sound briefly when the system is turned on.

## Caution

Discontinue operation and contact the factory at once if sporadic or continuous unwarranted alarms occur. They may indicate intensifier damage or another situation that requires immediate attention.

## Unigen<sup>™</sup> II Coating

For greater sensitivity, the PI-MAX3 camera with Unigen II coating comes without a protective window over the intensifier. Do not scratch the image intensifier's coated surface. To remove any lint or dust, use very clean dry nitrogen with < 5 PSI pressure. If you have any questions please contact your sales contact or the factory.

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## Introduction

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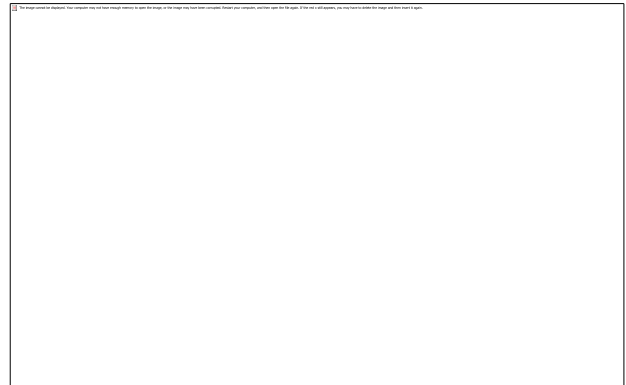
The Princeton Instruments PI-MAX<sup>®</sup>3 Intensified CCD camera is designed for general macro-imaging and microscopy imaging applications. It is ideal for applications involving ultra low light measurements, or measurements of transient effects. PI-MAX3 uses a proximity-focused microchannel plate (MCP) image intensifier (Gen II and Filmless Gen III intensifiers available) fiber-optically coupled to a CCD array. The fastest intensifiers can be gated in as little as 3 ns or less with an exceptionally high on/off light-transmission ratio. The CCD array provides a low noise, high dynamic range readout device that can be scanned at a variety of pixel rates. A number of different arrays are available to match the PI-MAX3 to the widest possible range of experimental requirements. In operation, data acquired by the camera is routed to the computer for processing and display. The computer controls both the system configuration and data acquisition via software, of which Princeton Instruments LightField<sup>®</sup> and WinView/32 are examples.

### PI-MAX3 System Components

All PI-MAX3 systems consist of standard hardware and software as well as the appropriate interface hardware for your computer system.

#### **Camera**

The PI-MAX3 camera houses the CCD and intensifier and it supplies all of the high voltages needed to operate the intensifier (see Chapter 3 for more information).



*Figure 1. Typical PI-MAX3 System Components*

Cooling within the camera is performed by a cooling fan and a multi-stage Peltier cooler that is thermally coupled to the CCD (liquid coolant circulation can also be used for the PI-MAX3 camera). Photocathode cooling to reduce equivalent background illumination (EBI) can be achieved via a dry nitrogen source. C-, F-, and spectroscopy mount adapters are supplied (one of which is factory-installed).

The camera can be operated in one of the following two modes: Safe mode and Gate mode. In Safe mode, the photocathode is gated off. In Gate mode, the photocathode is biased on only during the time each gate pulse is applied.

The PI-MAX3 contains the analog and digital electronics, scan control and exposure timing hardware, and controller I/O connectors. Readout modes supported include full resolution, simultaneous multiple subimages, and nonuniform binning. Single or multiple software-defined regions of interest can also be tested without having to digitize all the pixels of the array. Flexible exposure, set through software, is also fully supported.

The PI-MAX3 contains two High Speed analog-to-digital converters. The effective digitization rate is software-selectable. After the data is converted, it is transferred directly from the camera to the host computer memory via the high speed interface cable.

### **Cable**

AUX I/O Cable: 6050-0660, female DB26 to 5 BNC.

### **Computer Interface:**

- Standard Ethernet Cable: 6050-0621, 5 meter. Other lengths up to 100 m are available.
- User-provided GigE interface card. (Intel Pro1000 recommended)

### **Tubing**

Clear PVC tubing, 3', 5/32" OD, 1/32" wall (McMaster-Carr 5006K42) for dry nitrogen cooling of photocathode.

### **Manuals**

PI-MAX3 System manual and optional application software manual.

### **Optional Application Software**

Princeton Instruments' WinView/32 or WinSpec/32.

Princeton Instruments' LightField

## **Summary of PI-MAX3 Data Acquisition**

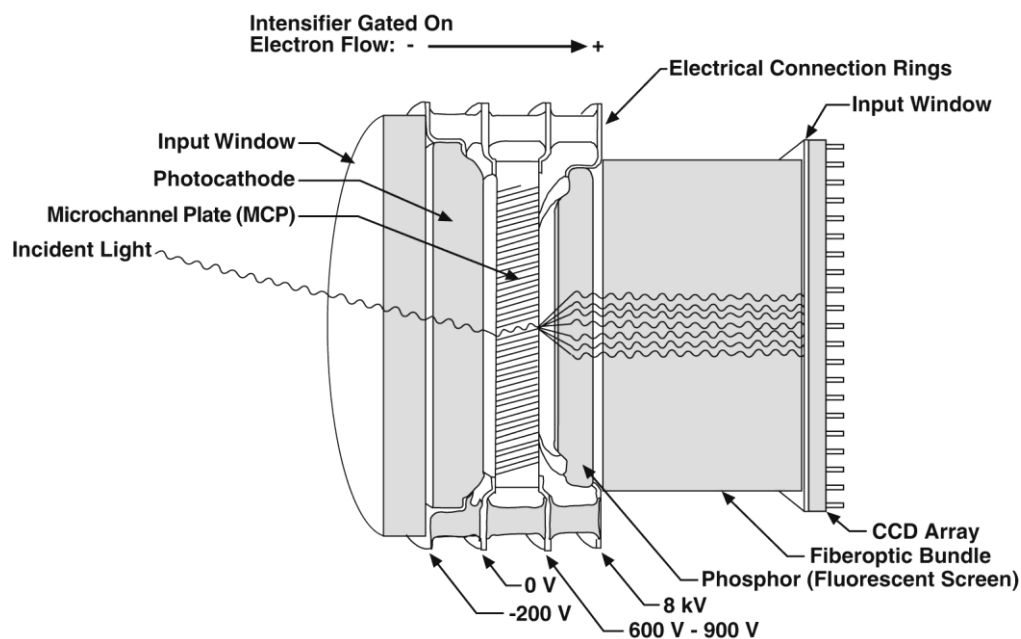


Figure 2. Major Components of the Intensifier-CCD

In the PI-MAX3 camera, the input image is focused onto the photocathode of an image intensifier tube. The tube electronically amplifies the image and outputs it, much brighter, as gray-scaled green light. That light is then coupled to the CCD using a fused fiber-optic bundle from the output of the image intensifier to the front side of the CCD. The image at



the output of the image intensifier is translated to the input of the CCD at the same size.\* After being detected by the CCD, the image is read out to the internal controller, where it is digitized, and then transferred to the computer for processing via a high-speed data link.

The sequence below steps through the process by which photons are converted to data that can be displayed on a computer monitor. For the sake of simplicity, triggers and gate pulses are not mentioned and it is assumed that a high speed (GigE) serial interface card is installed in the host computer. When reading through the sequence, keep in mind that electrons are attracted to more positively charged surfaces and are repelled by more negatively charged surfaces. This principal is used to control electron flow through the intensifier tube: changing the photocathode voltage with respect to the voltage at the MCP input is used to switch (gate) the intensifier on and off.

1. Incident photons pass through the intensifier input window, strike the photocathode, and release electrons. (*see Figure 2*)
2. Assuming that the intensifier is gated ON (the photocathode is more negative than the MCP input), these electrons will be attracted to the MCP input. *Gating acts like a shutter in that gating the intensifier on allows the CCD to "see" light and gating the intensifier off prevents the CCD from seeing light.*
3. Since the voltage at the MCP output is much more positive, most of the electrons accelerate into the MCP channels and, if they hit the channel walls, will generate additional electrons, resulting in electron gain. *The amount of gain is adjusted by increasing or decreasing the voltage at the MCP output.*
4. When the electrons exit the channels they are further accelerated by a constant high voltage (5-6 kV) and strike the phosphor coating on the fluorescent screen causing it to release photons. *Because of the MCP gain, there are now many photons for each photon that struck the photocathode surface.*
5. The photons released by the coating are transferred to the surface of the CCD (via fiberoptic or lens) and produce charge at the pixels they strike. Note that fiberoptic coupling is not only the most efficient coupling possible, but lens-coupling effects such as vignetting are eliminated.
6. Charge accumulates in the pixel wells until the intensifier is gated off (the photocathode is more positive than the MCP input).
7. At that point, the accumulated charge is shifted to the serial register where it is read out to an on-chip amplifier that converts the charge to an analog voltage.
8. This voltage is input to the selected analog-to-digital (A/D) converter(s) where it is digitally encoded. The conversion speed and the quality of the data are dependent on the effective ADC rate.
9. The digitized information is transmitted from the camera through the Ethernet cable to the interface card in the host computer where it is stored in RAM.
10. The application software retrieves the information from RAM, processes it, displays it, and/or stores it to a file according to user-defined settings.

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\* Units having a tapered fiber optic bundle may also be available. Contact the factory for information.

## Safety Information

### *Safety Related Symbols Used in This Manual*



**Caution!** The use of this symbol on equipment indicates that one or more nearby items should not be operated without first consulting the manual. The same symbol appears in the manual adjacent to the text that discusses the hardware item(s) in question.



**Caution! 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.

### *Grounding and Safety*

The PI-MAX3 and power supply are of Class I category as defined in IEC Publication 348 (Safety Requirements for Electronic Measuring Apparatus). They are designed for indoor operation only. 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.

#### **WARNING!**

If the equipment 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.



The PI-MAX3 has internal power supplies that generate hazardous (and potentially lethal) voltages. It contains no user-serviceable parts. Do not attempt to operate it with the covers removed.

#### **WARNING!**

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

### *Intensifier Modes and Safety*

**WinX Applications:** The Experiment Setup **Main** screen in WinX applications allows you to select one of two intensifier modes: **Gate Mode** or **Safe Mode**. In **Gate Mode**, the photocathode is biased on only for the time that each gate pulse is applied. As a result, the tolerance to room light is higher in gated operation, but the risk of damaging overload from intense light sources such as lasers remains. In fact, intense light sources in gated experiments can cause spot damage that would be undetected by the alarm circuit. In **Safe Mode**, the photocathode is continuously biased OFF and the intensifier is as safe as it can be.

**LightField:** In LightField, you can enable or disable the intensifier on the **Common Acquisition Settings** expander. When the intensifier is enabled, the camera can be gated; when disabled, the photocathode is continuously biased OFF and the intensifier is as safe as it can be.

**Note:** In order for gating to occur, the I.I.T. switch on the back of the PI-MAX3 must also be in the **ON** position.

### **Audible Alarm**

**Note:** It is normal for the alarm to sound briefly when the system is turned on.

To reduce the risk of camera damage, the PI-MAX3 camera is equipped with an audible alarm in the camera, activated when the intensity of light falling on the image intensifier exceeds a preset threshold. While the alarm is sounding, the photocathode is disabled. Immediately switch the **I.I.T.** switch on the back of the PI-MAX3 to the **OFF** position. Cover the detector window and only switch the **I.I.T.** switch to **ON** after the illumination level has been lowered. If the alarm sounds continuously even when the illumination level is adequately low, shut the system down and contact the factory for guidance.

### **Caution**

Discontinue operation and contact the factory at once if sporadic or continuous unwarranted alarms occur. They may indicate intensifier damage or another situation that requires immediate attention.

### **High Intensity Light Damage**

### **WARNING!**

Intensified CCD cameras such as the PI-MAX3, when biased ON, can be irreparably damaged if continuously exposed to light levels higher than twice the A/D saturation level. Thus it is **critical** that you **not** establish conditions that could result in damage to the intensifier. Although intensified cameras are less prone to damage from *background light* when operated gated, they are at **significant risk** to damage from high-intensity light sources like a laser. High intensity sources can damage the intensifier before the protection circuits have time to respond, or even cause spot damage without the protection circuits acting at all. If a sustained alarm indication occurs when the camera is turned on, immediately switch the **I.I.T.** switch on the back of the PI-MAX3 to the **OFF** position. Cover the detector window and only switch the **I.I.T.** switch to **ON** after the illumination level has been lowered.

If the alarm sounds continuously even when the illumination level is adequately low, shut the system down and contact the factory for guidance.

## **Precautions**

To prevent permanently damaging the system, please observe the following precautions:

- Always switch off and unplug the PI-MAX3 power supply before changing your system configuration in any way.
- Whenever you turn the PI-MAX3 power supply, be sure to leave it OFF for at least 30 seconds before switching it back ON. If you switch it ON too soon, a fault logic state is established that causes the overload alarm to sound continuously.
- The CCD array is very sensitive to static electricity. Touching the CCD can destroy it. Operations requiring contact with the device can only be performed at the factory.

- Never operate the camera cooled without proper evacuation or backfill. This could damage the CCD! Do not open the purge valve.
- Never connect or disconnect any cable while the PI-MAX3 system is powered on. Reconnecting a charged cable may damage the CCD.
- Never prevent the free flow of air through the equipment by blocking the air vents.

## Cleaning and Maintenance

### ***Cleaning the Camera***

Although there is no periodic maintenance that *must* be performed on the PI-MAX3 camera, users are advised to wipe it down with a clean dust collecting cloth from time to time.

### ***Cleaning Optical Surfaces – Unigen™ II Coating***

For greater sensitivity, the PI-MAX3 camera with Unigen II coating comes without a protective window over the intensifier. Do not scratch the image intensifier's coated surface. To remove any lint or dust, use very clean dry nitrogen with < 5 PSI pressure. If you have any questions please contact your sales contact or the factory.

### ***Cleaning Optical Surfaces – Protective Window***

Optical surfaces may need to be cleaned due to the accumulation of atmospheric dust. We advise that the *drag-wipe* technique be used. This involves dipping a clean cellulose lens tissue into clean anhydrous methanol, and then dragging the dampened tissue over the optical surface to be cleaned. Do not allow any other material to touch the optical surfaces.

### ***Flushing and Refilling the CCD Chamber***

#### **WARNING!**

Under normal conditions the CCD chamber is sealed and backfilled so there is no danger of damage due to condensation.

#### **WARNING!**

Operating a PI-MAX3 that is no longer backfilled with dry air or dry nitrogen may result in condensation on the array that could cause irreversible damage. Such damage would not be covered by the Warranty.

Before a PI-MAX3 camera leaves the factory, its CCD chamber is backfilled with clean dry air or dry nitrogen. For proper operation it is essential that the integrity of the front enclosure be maintained.

In normal operation, the CCD chamber should remain sealed for the life of the detector and should require no maintenance to assure integrity. If it should ever happen that the CCD chamber becomes unsealed, contact the factory and arrange to return the detector to the factory where it can be properly flushed, backfilled and resealed again. *See page 205 for contact information.*

## Repairs

Save the original packing materials. Because the PI-MAX3 system contains no user-serviceable parts, repairs must be done by Princeton Instruments. Should your system need repair, contact Princeton Instruments customer support for instructions (telephone, e-mail, and address information are provided on page 205 of this manual).

Use the original packing materials whenever shipping the system or system components.

## About this Manual

### **Manual Organization**

This manual provides the user with all the information needed to install a PI-MAX3 Intensified CCD camera and place it in operation. Topics covered include a detailed description of the camera, installation and setup, first time data acquisition, tips and tricks, microscopy applications, temperature control and more. A brief description of each of the chapters and appendices follows.

### **Notes:**

1. “WinX” is a generic term for WinView/32, WinSpec/32, and WinXTest application software.
2. In many instances, WinX and LightField use different terms for the same functions or parameters. Unless the topic is specifically for WinX or LightField, curly brackets { } are used to denote a LightField term or location. When the topic applies to both application programs, the WinX term will be followed by the {LightField term}: for example, when **Continuous Cleans** is used, it will be followed by **{Clean Until Trigger}**. This convention is also used when a location for setting a parameter is mentioned: for example, Exposure Time is set on the **Experiment Setup|Main** tab **{Common Acquisition Settings** expander}.

**Chapter 1, Introduction** provides an overview of the PI-MAX3 camera. Topics include a description, theory of operation, and specifications.

**Chapter 2, Installation Overview** cross-references system setup actions with the relevant manuals and/or manual pages. It also contains system layout diagrams.

**Chapter 3, System Setup** provides detailed directions for installing and setting up the PI-MAX3 for both spectroscopy and imaging.

**Chapter 4, First Light** provides abbreviated directions for getting your PI-MAX3 into operation as soon as possible.

**Chapter 5, General Operation Factors** provides information about experiment setup, temperature control, background subtraction, array readout, binning, and digitization.

**Chapter 6, WinX and Gated Operation** discusses issues specific using WinX and operating the PI-MAX3 system in gate mode.

**Chapter 7, LightField and Gated Operation** discusses issues specific using LightField and operating the PI-MAX3 system in gate mode.

**Chapter 8, Timing Generator Pulses and Sequences** discusses and illustrates the trigger modes available when operating the system in gate mode.

- Chapter 9, WinX and Dual Image Feature (DIF)** discusses using WinX with the mode specifically designed for capturing a pair of gated images in rapid succession.
- Chapter 10, LightField and Dual Image Feature (DIF)** discusses using LightField with the mode specifically designed for capturing a pair of gated images in rapid succession.
- Chapter 11, MCP Gating Option** discusses how to set up a PI-MAX3 that has an installed MCP Gating board.
- Chapter 12, Sub-Nanosecond Option** discusses how to set up a PI-MAX3 that has an installed Sub-Nanosecond board.
- Chapter 13, Tips and Tricks** discusses a number of issues that can have a bearing on getting good experimental results.
- Chapter 14, System Component Descriptions** describes the PI-MAX3 camera and other system components. Includes descriptions of connectors and other front and rear panel features.
- Chapter 15, Troubleshooting** provides information regarding possible system problems.
- Appendix A, Specifications** provides general specifications as well as operating environment and internal pulser specifications.
- Appendix B, Outline Drawings** includes outline drawings for the PI-MAX3 camera, the PI-MAX3 power supply, and the CoolCUBE<sub>II</sub> coolant circulator.
- Appendix C, Cross-Referencing of WinX and LightField Terms** includes two alphabetically sorted tables (WinX to LightField and LightField to WinX) that cross reference terms used in the two applications.
- Appendix D, Extender Bracket Kit** explains how to use this kit to mount the PI-MAX3 to any laboratory table with either 25 mm or 1 inch hole spacing.
- Appendix E, Mounting and Focusing C-Mount and F-Mount Lenses** discusses focusing of an F-mount adapter and focusing of F-mount and C-mount lenses.
- Appendix F, C-, F-, and Spectroscopy-Mount Adapters** describes how to change the adapter on the front of the PI-MAX3 to another type if you have multiple adapters.
- Appendix G, Spectrograph Adapters** provides mounting instructions for the spectroscopy-mount adapter and for the spectrograph adapters available for PI-MAX3 cameras with spectroscopy-mounts.
- Appendix H Glossary** provides definitions of commonly used words and terms related to intensified camera characteristics and usage.
- Declarations of Conformity** contains the Declarations of Conformity for PI-MAX3 systems.
- Warranty & Service** details the warranties for Princeton Instruments equipment and software.

## Chapter 2

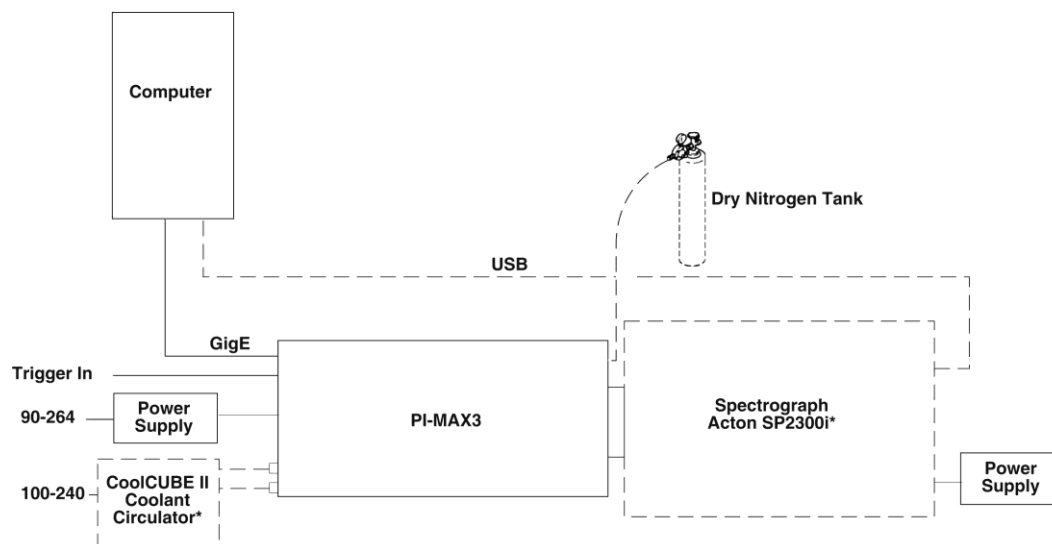
# Installation Overview

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The list and diagrams below briefly describe the sequence of actions required to install your system and prepare to gather data. Refer to the indicated references for detailed information.

Action	Reference
1. If the system components have not already been unpacked, unpack them and inspect their carton(s) and the system components for in-transit damage.	Chapter 3: System Setup, page 25
2. Verify that all system components have been received.	Chapter 3: System Setup, page 25
3. If the camera will be used on a spectrograph, mount it to the equipment using the required adapter(s).	Appendix G, page 186
4. If the appropriate interface card is not already installed in the host computer, install it and its drivers.	Chapter 3: System Setup, page 29
5. If the application software is not already installed in the host computer, install it.	Application manual.
6. With the PI-MAX3 power supply and computer power turned OFF, connect the Ethernet cable (GigE) to the PI-MAX3 and the interface card in the host computer.	
7. <b>Air-Cooled System:</b> Plug the power supply into the rear of the camera and plug the power supply into the power source. <b>Liquid-Cooled System:</b> Make the hose and power connections to the camera and plug the circulator into the power source. Add coolant if necessary. Turn on the circulator.	Chapter 3: System Setup, page 29
8. If the photocathode will be cooled, connect the supplied PVC tubing to the hose barb on the front of the camera and to a dry nitrogen source.	Chapter 3; System Setup, page 31
9. Turn the PI-MAX3 power supply ON.	

Action	Reference
<p>10. Turn on the computer and begin running the WinX or LightField application. When the computer boots, you may be asked for the location of the interface drivers.</p> <p><b>WinX:</b> If this is the first time you have used a WinX application, the Camera Detection wizard will automatically run. This wizard retrieves information from the camera and enters this information as the default parameters for your system.</p> <p><b>LightField:</b> When LightField boots, it will detect the camera and automatically place its icon in the <b>Available Devices</b> area. When you move that icon to the <b>Experiment Devices</b> area, the default parameters will automatically be loaded into the expanders.</p>	<p>Chapter 3: System Setup, page 31</p> <p>WinView/32 or WinSpec/32 manual</p> <p>LightField manual (PDF) (Located in the Documents subdirectory of the location where LightField was installed.)</p>
<p>11. Verify the hardware setup information or change the parameters, as appropriate. Enter the pulser information. Enter the experiment setup parameters. If using a spectrograph, enter or edit that setup information.</p>	<p>WinView/32 or WinSpec/32 manual</p> <p>LightField manual</p>
<p>12. Set the target array temperature. The typical target temperature is <math>-25^{\circ}\text{C}</math>.</p>	<p>Setting the Temperature, page 48</p>
<p>13. When the system reaches temperature lock, begin acquiring data in focus mode.</p>	<p>Initial Data Acquisition, page 37</p>
<p>14. Adjust the focus for the best image or spectral lines. If you are using WinSpec/32, you may want to use the Focus Helper function for this purpose. If you are using LightField, you may want to use the Align Spectrometer function.</p>	<p>Appendix E: Mounting and Focusing C-Mount and F-Mount Lenses, page 180</p> <p>Appendix G: Spectroscopy-Mount and Spectrograph Adapters, page 186</p>



\* Spectrograph, coolant circulator, and dry nitrogen tank connections are optional.

Figure 3. PI-MAX3 System Diagram



## System Setup

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### Introduction

This chapter includes general instructions for setting up a PI-MAX3 system for operation in both imaging and spectroscopic applications.

### Dangers and Warnings

#### DANGER

Voltages inside the PI-MAX3 may exceed 6,000 volts. To avoid possible hazard to personnel, use the instrument only according to the directions in this manual and only for the purposes for which it is designed. Never attempt to operate the PI-MAX3 with its covers removed.

#### WARNING

Image intensified detectors can be *destroyed* if exposed to excessive light levels. Princeton Instruments cannot take responsibility for PI-MAX3 detector damage due to misuse. Intensified cameras are particularly susceptible to overload damage when operated in conjunction with high-intensity light sources such as lasers. Spot damage can occur without the overload condition being detected.

The PI-MAX3 has an audible alarm and shutdown circuit to bias the photocathode OFF if excessive photocathode current is detected. The circuit automatically resets and biases the photocathode back on after about 0.5 seconds. The short-term protection provided will not prevent intensifier damage if excessive light is allowed to continuously fall on the intensifier. It is also possible for excessively bright spots to damage the intensifier tube without triggering the alarm.

### Unpacking the System

During unpacking, check the system components for possible signs of shipping damage. If there are any, notify Princeton Instruments 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. Please save the original packing materials so you can safely ship the camera system to another location or return it to Princeton Instruments for repairs if necessary.

### Checking the Equipment and Parts Inventory

Confirm that you have all of the equipment and parts required to set up the PI-MAX3 system. A typical system consists of:

- PI-MAX3 camera (Gen II or Filmless Gen III).
- PI-MAX3 power supply.
- Timing Generator: Integrated into the PI-MAX3

- Accessory Kit: Contains light table mount extender, AUX I/O cable, PVC tubing, double-ended screwdriver with magnet top, and two adapter mounts (C-mount, F-mount, and spectroscopy mounts are supplied, one of which has been factory installed).
- Computer Interface: GigE
- Computer: Provided by user.
- WinView/WinSpec or LightField CD-ROM
- User Manuals
- Interface Dependent Components:
  - Computer Interface GigE cable: Standard Ethernet Cable: 6050-0621, 5 meter. Other lengths up to 100 m are available.
  - Interface Card: User-provided GigE interface card. (Intel Pro1000 recommended).
- System Dependent Components
  - CoolCube<sub>II</sub> Coolant Circulator and Coolant Tubing

If there are any problems, contact the Princeton Instruments Customer Support department (see page 205 for contact information).

## System Requirements

### ***Environmental***

Storage temperature  $\leq 55^{\circ}\text{C}$

Operating environment temperature:  $30^{\circ}\text{C} > T > -25^{\circ}\text{C}$

Relative humidity  $< 80\%$  noncondensing

### ***Ventilation***

**Camera:** Allow at least one-inch clearance for side and rear air vents. There are internal fans located behind an intake opening in the rear panel. Their purpose is simply to cool the camera and TE-cooler. The fans run continuously whenever the camera is powered. Air enters the through the openings in the rear panel and is exhausted through ventilation openings on the side panels. It is important that there be an adequate airflow for proper functioning. As long as both the camera's intake ventilation openings and the fan exhaust opening aren't obstructed, the camera will remain quite cool.

**Power Supply:** There is an internal fan located at the rear panel behind an exhaust opening. Its purpose is simply to cool the power supply electronics. This fan runs continuously whenever the power supply is powered. Air enters the through ventilation openings in the side panels, flows past the warm electronics, and is drawn out the rear by the fan. It is important that there be an adequate airflow for proper functioning. As long as both the intake ventilation openings and the fan exhaust opening are not obstructed, the power supply will remain quite cool.

## Power

**Camera:** The PI-MAX3 camera receives its power from the self-switching power supply which in turn plugs into a source of AC power.

**Power Supply:** 90-264 VAC, 400W (Max.), 47-63 Hz, auto-switching. The plug on the power cord supplied with the system should be compatible with the line-voltage outlets in common use in the region to which the system is shipped. If the power cord plug is incompatible, a compatible plug should be installed, taking care to maintain the proper polarity to protect the equipment and assure user safety.

### Caution

Whenever you turn the PI-MAX3 power supply OFF, be sure to leave it OFF for at least 30 seconds before switching it back ON. If you switch it ON too soon, a fault logic state is established that causes the overload alarm to sound continuously.

## Host Computer

**Note:** Computers and operating systems all undergo frequent revision. The following information is only intended to give an approximate indication of the computer requirements. Please contact the factory to determine your specific needs.

- Operating System:
  - WinView/32 and WinSpec/32: Windows® XP (32-bit with SP3 or later), Windows Vista® (32-bit) or Windows 7® (32-bit)
  - LightField: Windows Vista (64-bit) or Windows 7 (64-bit)
- 2 GHz Pentium® 4 (or greater)
- 1 GB RAM (or greater)
- CD-ROM drive
- At least one unused PCI card slot (32-bit) (PCI 2.3 compliant 32-bit 33/66 MHz bus)
- Super VGA monitor and graphics card supporting at least 65535 colors with at least 128 Mbyte of memory. Memory requirement is dependent on desired display resolution.
- Hard disk with a minimum of 1 Gbyte available. A complete installation of the program files takes about 50 Mbytes and the remainder is required for data storage, depending on the number and size of images/spectra collected. Disk level compression programs are not recommended. Drive speed of 10,000 RPM recommended.
- Mouse or other pointing device.

**Note:** The above requirements are the minimum for operating a PI-MAX3 camera. A faster computer with 2GB or larger memory (RAM) and a fast hard drive (10,000 rpm) will greatly enhance the software performance during live mode operations.

## Mounting the PI-MAX3

### ***Imaging Applications***

The PI-MAX3 is supplied with the lens mount specified when the system was ordered, normally either a screw-type C-mount lens or a bayonet type F-mount lens, allowing a lens of the corresponding type to be mounted quickly and easily. The installed mount is secured by four (4) Phillips head screws which must be removed to change mounts. Refer to ***Appendix E: Mounting and Focusing C-Mount and F-Mount Lenses, Appendix F: C-, F-, and Spectroscopy-Mount Adapters***, and ***Appendix G: Spectrograph Adapters*** for more information for changing mounts and focusing.

The PI-MAX3 can be mounted at any attitude or angle but additional camera support may be required. The camera can rest on any secure surface. Take care not to block the ventilation openings.

### **WARNING**

In the case of cameras equipped with F-mount, do not mount the camera in the *nose-up* operation where the lens mount would be required to hold the camera's weight. The F-mount is not designed to sustain the weight of the camera in this orientation and the camera could pull free. *You must provide additional support for the camera.*

Should the camera be mounted in the nose-up position beneath a table, take care to protect the mounting components from lateral stresses, such as might occur should someone accidentally bump the camera with a knee while working at the table. One solution to this problem would be to install a barrier between the camera and operator to prevent any accidental contact.

There are no special constraints on nose-down operation. Again, however, good operating practice might make it advisable to take steps to prevent accidental contact from unduly stressing the mounting components. Be sure liquid connections do not leak in this orientation.

### **WARNING**

Always begin with the lens stopped all the way down (largest f/ stop number) to minimize the risk of overloading the intensifier.

### ***Spectroscopy Applications***

The PI-MAX3 detector must be properly mounted to the spectrograph to achieve the highest resolution. In the correct orientation, the text on the back of the detector should be right side up. Take care not to block the ventilation openings. Refer to the ***“Quick Start: Mounting a PI-MAX3 (3.60 3-hole Slotted) to an Acton Series Spectrograph”*** instructions supplied with your system and also provided in Appendix G.

## Software Installation

### WinX

#### Notes:

1. Install the GigE Adapter card BEFORE installing the WinView/32 or WinSpec/32 application software.
2. Leave the interface cable disconnected from the camera until you have installed WinView/32 or WinSpec/32 (Ver. 2.5.25 or higher).

The following installation is performed via the WinView/32 or WinSpec/32 software installation CD.

1. On the **Select Installation Type** dialog (see Figure 4), click on **Typical** radio button to install the required drivers and the most commonly installed program files. Select the **Custom** radio button if you would like to choose among the available program files or do not want to install the drivers. **Complete** installs all of the application features.
2. Make sure the camera is connected to the host computer and that the camera power supply is turned on.
3. Reboot the computer.
4. At bootup, Windows will detect the GigE card. Refer to “**WinX First Light Instructions**” on page 34.

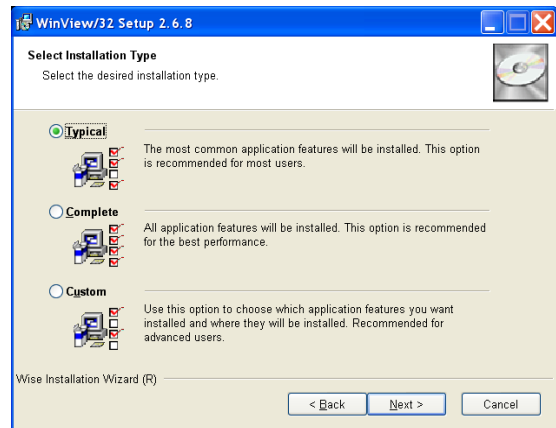


Figure 4. WinView Installation: Select Installation Type dialog

### LightField

**Note:** Install the GigE Adapter card BEFORE installing the LightField application software.

The following installation is performed via the LightField software installation CD.

1. Before starting the installation:
  - Verify that the computer operating system is Windows Vista (64-bit) or Windows 7 (64-bit).
  - Confirm that a GigE adapter card has been installed.
  - Verify that your computer is connected to the Internet. Internet connection is required for product activation.
2. Insert the CD and follow the installation wizard prompts.



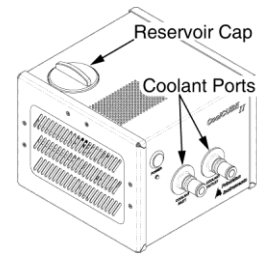
Figure 5. LightField Installation Wizard dialog

3. After the installation finishes, reboot the computer.
4. Connect the PI-MAX3 system components to your computer and power them on.
5. Start LightField, activate it, and begin setting up your experiment. Refer to “*LightField First Light Instructions*” on page 38

## Making the Camera-Circulator Connections

For liquid-cooled cameras, the CoolCUBE<sub>II</sub> circulator provides a vibration-free method of heat removal.

1. Make sure the camera and the circulator power switches are turned off.
2. Make sure the circulator is 6 inches (150 mm) or more below the camera. The vertical distance should not exceed 10 feet (3 m). Typically, the camera is at table height and the circulator is on the floor.
3. Make the coolant connections between the circulator and the camera. It does not matter which hose from the circulator is plugged into a coolant port on the camera.
4. It is recommended that hoses be secured to the camera hose barbs with the clamp supplied.



### Notes:

1. Make sure that there are no kinks in the hoses that impede the coolant flow. Lack of sufficient flow can seriously harm the detector and any resulting damage is not covered under warranty.
2. Damage caused by water leaking into the PI-MAX3 voids the warranty.
5. Unscrew the reservoir cap (on top of the CoolCUBE II) and make sure that the coolant reservoir contains coolant. If additional coolant is required, fill with a 50:50 mixture of water and ethylene glycol.
6. Screw the reservoir cap back in.
7. Plug the circulator into a 100-240 VAC, 47-63 Hz power source.
8. Turn the circulator on. Make sure there are no leaks or air bubbles in the hoses.

**Note:** Small air bubbles (about the size of bubbles in soda) are common in the CoolCUBE<sub>II</sub> especially at start up and do not prevent proper operation

- If there are no problems, continue to Step 9.
  - If there are leaks or air bubbles, turn the circulator off and correct the problem(s) by securing the hoses or adding more coolant to the reservoir. Turn the circulator back on. Recheck and if there are no problems, continue to Step 9.
9. Turn the camera on.
  10. Start the application software.

## Making the Camera to Dry Nitrogen Source Connections

Equivalent Background Illumination (EBI) can impose limitations on ultra-low-light or photon-counting applications. Reduction of EBI can be achieved by directly cooling the photocathode via a dry nitrogen source.

1. Remove the 3 foot (approximately 1 meter) clear PVC tubing from the accessories kit.
2. Slip one end of the tubing on the plastic hose barb on the front of the PI-MAX3.
3. Connect the other end to a source of dry nitrogen.

## Entering the Default Camera System Parameters

### **WinX (Versions 2.5.25.X or higher)**

1. Make sure the PI-MAX3 is connected to the host computer and that its power supply is turned ON.
2. Run the WinX application. The **Camera Detection wizard** will automatically run if this is the first time you have installed a Princeton Instruments WinX application (WinView/32, WinSpec/32, or WinXTest/32) and a supported camera. Otherwise, if you installing a new camera type, click on the **Launch Camera Detection Wizard...** button on the **Controller/CCD** tab to start the wizard.
3. On the **Welcome** dialog (Figure 6), leave the checkbox unselected and click on **Next**.

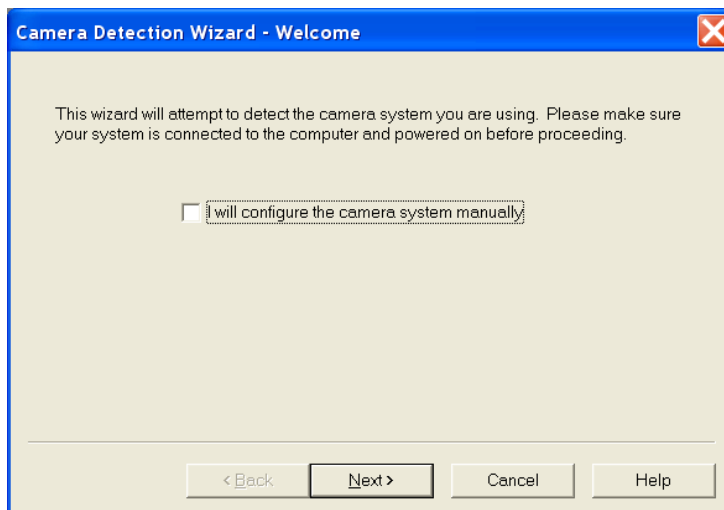


Figure 6. Camera Detection Wizard - Welcome dialog

4. Follow the instructions on the dialogs to perform the initial hardware setup: this wizard enters default parameters on the Hardware Setup dialog tabs and gives you an opportunity to acquire a test image to confirm the system is working.

**Note:** For a step-by-step procedure on basic system operation, refer to the “*WinX First Light Instructions*” section (page 34).

### **LightField**

1. Make sure the PI-MAX3 (and spectrograph, if this is a spectroscopy system) is connected to the host computer and that the camera (and spectrograph) power supply is turned on.
2. Start LightField.
3. While LightField is starting up, it will detect the available device(s) and load the appropriate icons into the **Available Devices** area in the **Experiment** workspace.
4. When you drag an icon into the **Experiment Devices** area, the appropriate expanders will be loaded into the **Experiment Settings** stack on the lefthand side of the window.

**Note:** For a step-by-step procedure on basic system operation, refer to the “*LightField First Light Instructions*” section (page 38).



## First Light

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### Introduction

This chapter contains two procedures (one for WinX and one for LightField) that can be used to verify PI-MAX3 system operation. To reduce setup complexity, these procedures are run in **Imaging Mode** and SuperSYNCHRO™ **Internal Trigger Mode**. All of the setup can be performed under normal lighting. Since these first light procedures do not require a spectrograph, instructions for cabling and mounting of a spectrograph are not included.

**Note:** Issues that could be of importance in some applications are omitted in this chapter for the sake of brevity. General application issues are addressed in Chapter 5 and those that are specific to Gate Mode are addressed in the appropriate chapters.

### Required Equipment and Cables

The equipment and cables listed below are required to set up and run the PI-MAX3 camera system in accordance with the procedure in this chapter.

- Princeton Instruments PI-MAX3 camera with C-mount adapter.
- User-supplied C-mount lens (with smallest aperture of f/16 or f/22).
- PI-MAX3 power supply.
- Computer equipped with a GigE Ethernet interface card.
- Standard Ethernet cable.
- Application software (WinX/32 or LightField)

### Cable Connections

**WARNING! All of the system components must be turned off before connecting or disconnecting cables.**

The following cabling configuration is used when operating in Gating Mode with an internal trigger.

1. Connect the PI-MAX3 power supply to the rear of the camera and to the AC power source.
2. Connect the **GigE** cable (6050-0621) from the PI-MAX3 **GigE** connector to the computer's **GigE** Interface card connector.

## Before Turning on the System

1. Set the PI-MAX3 I.I.T. On/Off switch to OFF.
2. Confirm that only room light will be present.
3. If a C-mount adapter is not on the camera, refer to “*Appendix F C-, F-, and Spectroscopy-Mount Adapters*”, page 182, for changeover instructions.
4. After making the changeover, screw in the lens. Set the lens to its smallest aperture (f/16 or f/22).
5. Place a suitable target (non-light source) approximately 9 inches in front of the camera.

## Turning on the System

### WARNING

Always begin with the lens stopped all the way down (largest f/ stop number) to minimize the risk of overloading the intensifier.

1. Turn on the PI-MAX3 power supply.

**Note:** The PI-MAX3 overload alarm may sound briefly and then stop. This is normal and is not a cause for concern. However, if the alarm sounds continuously, even with no light entering the camera (or spectrograph, something is wrong. Turn off the power and contact the factory for guidance.

2. Turn on the computer power.
3. Start the software application (WinView/32, WinSpec/32, or LightField as appropriate).
4. Follow the appropriate first light instructions.

## WinX First Light Instructions

### *Introduction*

This section provides step-by-step instructions for acquiring an imaging measurement in WinX for the first time. The intent of this procedure is to help you gain basic familiarity with the operation of your system and to show that it is functioning properly. Once basic familiarity has been established, then operation with other operating configurations, ones with more complex timing modes, can be performed.

### *Assumptions*

The following procedure assumes that

1. You have already set up your system in accordance with the instructions in the previous chapters.
2. You have read the previous sections of this chapter.
3. You are familiar with the application software.
4. The system is being operated in imaging mode.
5. The target is a sharp image, text, or a drawing that can be used to verify that the camera is “seeing” and can be used to maximize focus.

### *Getting Started*

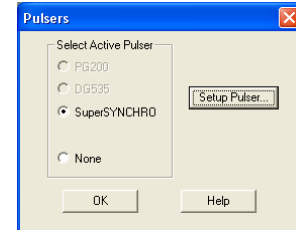
1. Verify that you have a test target approximately 9 inches in front of the camera.
2. Power ON the camera (the power switch is on the back of the power supply).

3. Turn on the computer power.
4. Start the application software.

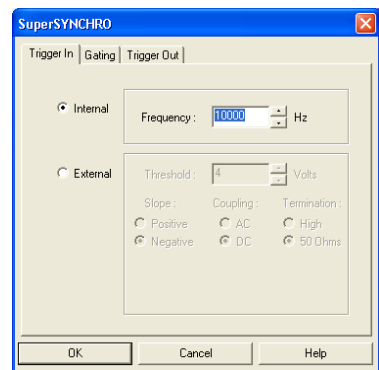
### Configuring the Software

#### Setup menu

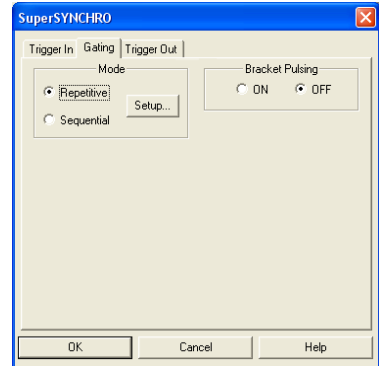
1. From the **Setup** menu, select **Pulsers**.
2. On the **Pulsers** dialog, select **SuperSYNCHRO** and then click on the **Setup Pulser...** button.



3. On the **Trigger In** tab, confirm that **Internal** is selected and that the **Frequency** is 10000 Hz.



4. On the **Gating** tab, select **Repetitive** and then click on the **Setup...** button.



5. On the **Repetitive Gating Setup** dialog, enter the following settings:

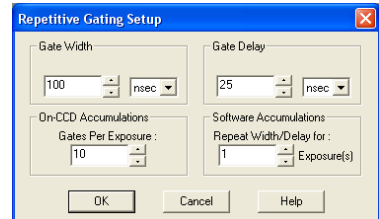
**Gate Width:** 50 ms

**Gate Delay:** 10 ns

**Gates per Exposure:** 1

**Repeat Width/Delay:** 1.

6. Click on **OK**.

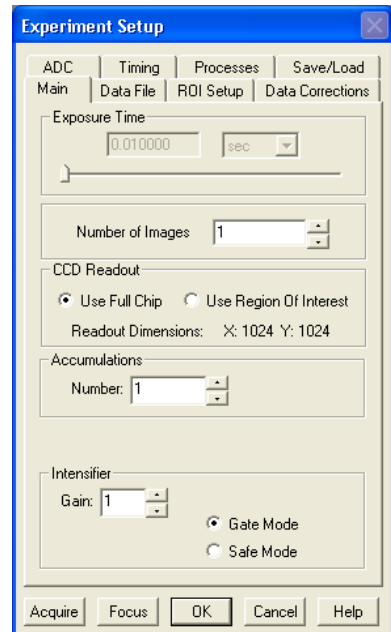


**Acquisition menu**

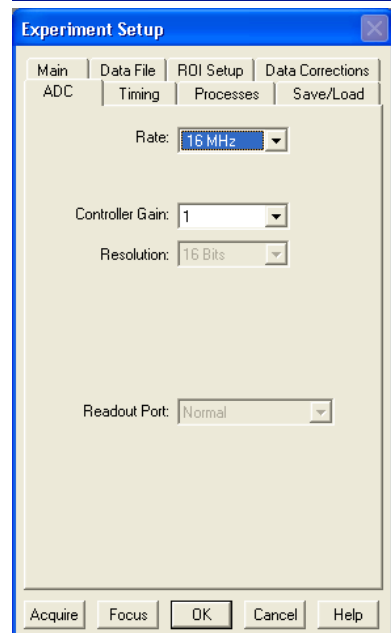
1. From the **Acquisition** menu, select **Experiment Setup**.

2. On the **Main** tab, make the following settings.

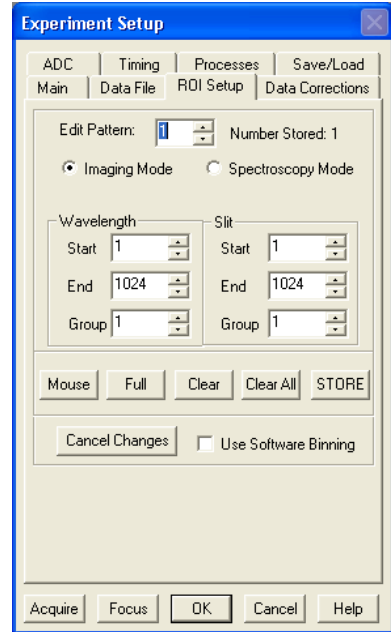
**CCD Readout:** Use Full Chip  
**Intensifier**  
**Gain:** 1  
**Gate Mode:** selected



3. On the **ADC** tab, select the appropriate **Rate** (16 MHz for Kodak 1024x1024, 1 MHz for CCD30-11).



- If you are running WinSpec, select **Imaging Mode** on the **ROI Setup** tab.




- Click on **OK** to execute the selections and close the dialog.

### **Initial Data Acquisition**

- Verify that room or ambient lighting is subdued.
- Set the PI-MAX3 I.I.T switch to **ON**.

**Note:** The PI-MAX3 overload alarm may sound briefly and then stop. This is normal and is not a cause for concern. However, if the alarm sounds repetitively, even with no light entering the lens, something is wrong. Turn off the power and contact the factory for guidance.

- At the computer, click on the **ACQ** button  or select **Acquire** mode (WinX **Acquisition** menu). Data acquisition will begin and an acquired image will be displayed on the computer monitor. If one is not displayed, check the software settings.



- If an image is displayed, you have confirmed that the PI-MAX3 can acquire an image. If the image is out of focus, you could reposition the target and/or rotate the lens and click on **Acquire** to confirm that the degree of focus has changed.
- If the image is upside down (acquired with an older PI-MAX3:1024x256 camera as in the image above), you can either physically invert the camera or you can change the

image orientation via the **Setup|Hardware|Hardware Setup|Display** tab. After **Reverse** and **Flip** were selected and a new image was acquired, the text was right-reading.



6. Now that you have confirmed that the PI-MAX3 can acquire an image, set the PI-MAX3 I.I.T. switch to **OFF**.
7. Close the WinX application.
8. If you do not want to use the PI-MAX3 with the lens, replace the C-mount lens with the screw-in dust cover provided with the C-mount adapter.
9. If you will be using a different adapter, you can switch adapters at this point. Be sure to use the adapter's dust cover whenever the PI-MAX3 is not being used.

### ***Focusing***

Instructions for focusing C-mount and F-mount lenses are provided in Appendix E. Instructions for focusing the detector on a spectrograph are provided in Appendix G.

## **LightField First Light Instructions**

### ***Introduction***

This section provides step-by-step instructions for acquiring an imaging measurement in LightField for the first time. The intent of this procedure is to help you gain basic familiarity with the operation of your system and to show that it is functioning properly. Once basic familiarity has been established, then operation with other operating configurations, ones with more complex timing modes, can be performed.

### ***Assumptions***

The following procedure assumes that

1. You have already set up your system in accordance with the instructions in the previous chapters.
2. You have read the previous sections of this chapter.
3. You are familiar with the application software.
4. The system is being operated in imaging mode.
5. The target is a sharp image, text, or a drawing that can be used to verify that the camera is “seeing” and can be used to maximize focus.

### ***Getting Started***

1. Verify that you have a test target approximately 9 inches in front of the camera.

2. Power ON the camera (the power switch is on the back of the power supply).
3. Turn on the computer power.
4. Start the application software.

### Setting the Parameters

**Note:** The following procedure is based on LightField. Basic familiarity with the LightField software is assumed. If this is not the case, you may want to review the software manual or have it available while performing this procedure.

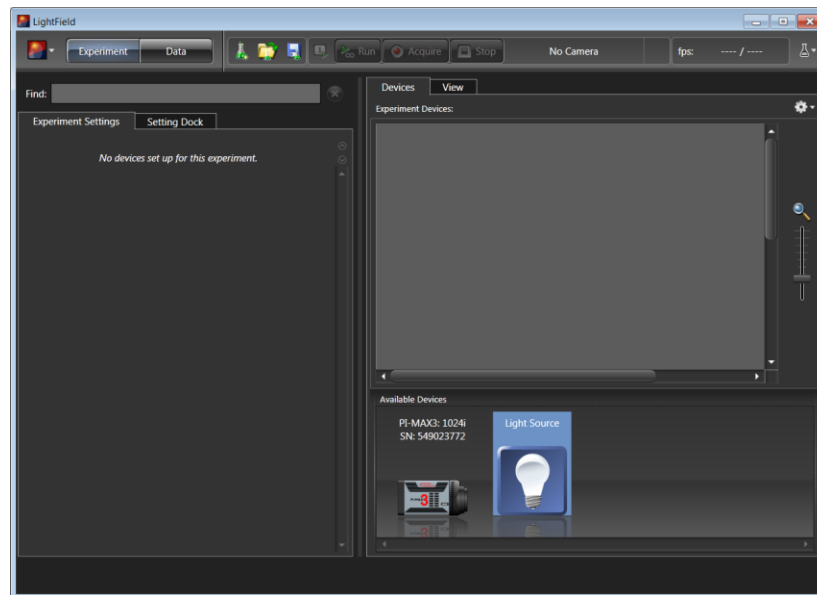


Figure 7. Available Devices Area

1. After LightField opens, you should see an icon representing your camera in the **Available Devices** area. In the figure above, the camera is a PI-MAX3:1024x256.
2. Drag the icon into the **Experiment Devices** area.

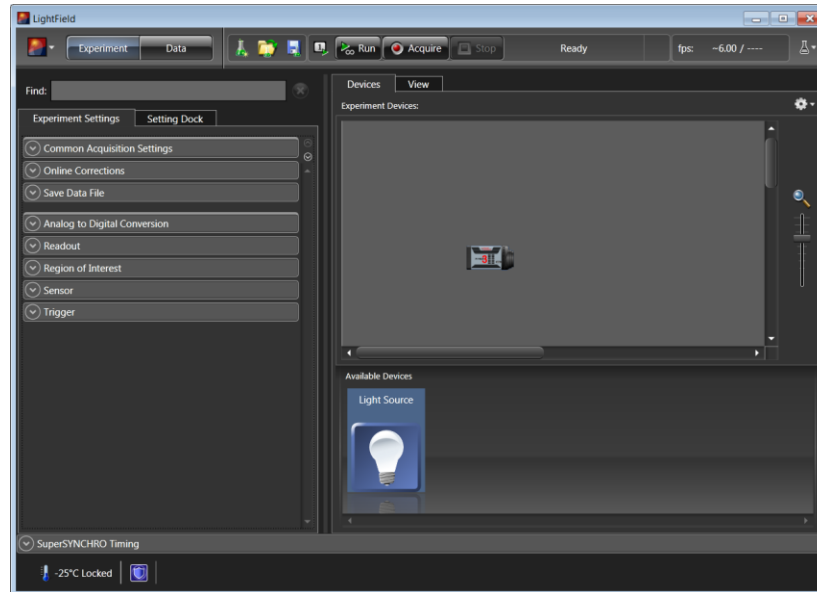


Figure 8. Experiment Devices Area

3. Note that the **Experiment Settings** stack on the left now displays several expanders, including the **SuperSYNCHRO Timing** expander just above the **Status** bar (at the bottom of the window). Because this is a new experiment, the default settings for the camera will be active. The **Status** bar displays an icon for temperature and intensifier status.

Temperature status reports the current temperature and whether the set temperature has been reached. Intensifier status reports whether or not the **I.I.T. Power switch** (on the rear of the camera) is turned on and whether the **Enable Intensifier** check box is checked. Clicking on an icon opens a panel where you can view more information about the status and/or click on a hyperlink to access the expander where status affecting changes can be made.

4. **PI-MAX3:1024x256 Camera:** If the camera was built before January 2012, these additional steps are required for the 1024x256 camera.
  - a. Open the **Online Corrections** expander.
  - b. Click on the bottom button on the Orientation image.
  - c. The icon will rotate 180° (see image below). Unless you subsequently change the orientation or create a new experiment, data will be displayed correctly.

**Note:** A new experiment resets all of the camera parameters to their default settings. Therefore, the orientation for a PI-MAX3:1024x256 camera must be corrected whenever a new experiment is created.



### Acquiring Data

1. Verify that the **I.I.T. Power switch** on the rear of the camera is in the **ON** position
2. Verify that **Enable Intensifier** is selected on the **Common Acquisition Settings** expander.



3. Click on the **View** tab, just above **Experiment Devices**, to change to the display area.

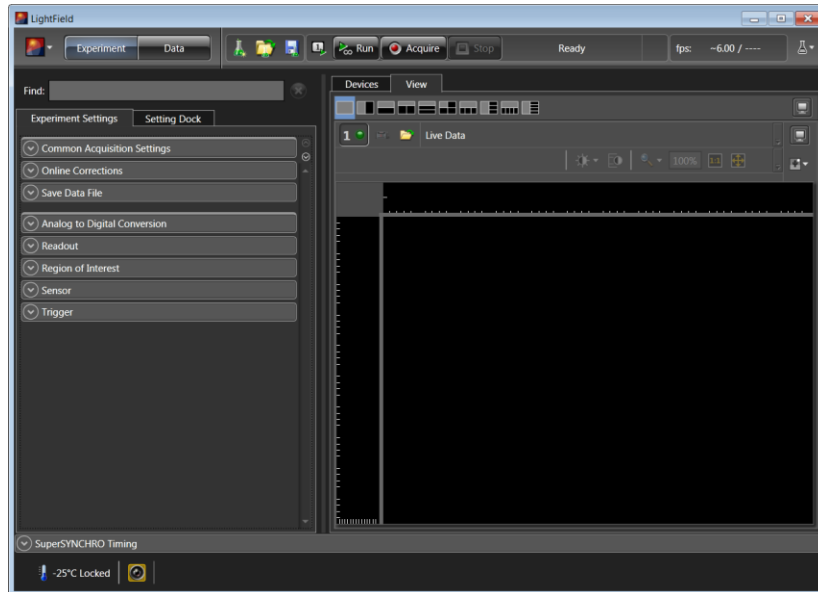


Figure 9. View Area


4. Click on the **Acquire** button  to start **Acquire** mode.
  - If an image is displayed, you have confirmed that the PI-MAX3 can acquire an image.
  - If the image is out of focus, you could reposition the target and/or rotate the lens and click on **Acquire** to confirm that the degree of focus has changed.
  - If the image is upside down, you need to change the orientation via the **Online Corrections** expander.



Figure 10. View Area Displaying an Image

***Focusing***

Instructions for focusing C-mount and F-mount lenses are provided in Appendix E.  
Instructions for focusing the detector on a spectrograph are provided in Appendix G.

**Final Comments**

This completes the *First Light* directions. If you have followed the instructions, you should have verified the basic operation of your system. Subsequent chapters provide general and specific information about operating a PI-MAX3 system.

## General Operation Factors

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### Introduction

The purpose of the First Light chapter was to help you get your system up and running so you could verify that it worked. The step-by-step procedures provided the appropriate settings but did not explain why those settings were selected. The information in this chapter covers general operation factors that apply to **Gate Mode** operation of the PI-MAX3 system. These factors play a part before, during, and after the exposure and readout of the CCD array: dark charge, clean cycles, continuous cleans, exposure modes, readout, digitization, software binning, and background subtraction. Factors that are specific to a particular intensifier mode and pulser are included in the appropriate chapter.

### Data Acquisition Sequence

When data is acquired, the CCD array is exposed to an incoming signal, which integrates on the array. At the end of the exposure (may include multiple gates), the charge from the array pixels must be read out, digitized, and transferred to the computer before the image from the array appears on the computer screen. This sequence is shown in the block diagram below (Figure 11).

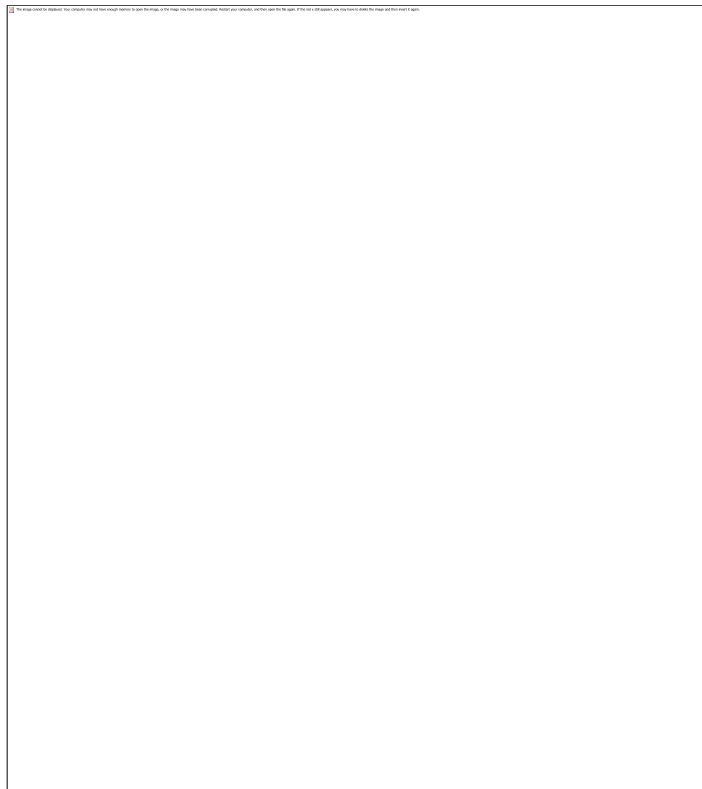


Figure 11. Block Diagram of Signal Path in Standard PI-MAX3 System

## WinX System On/Off Sequences

The following on/off sequences are specific to WinX and the Ethernet interface:

1. The PI-MAX3 power supply must be turned on before the WinX application software (WinView/32 or WinSpec/32) is opened to ensure communication between the controller and the computer. If the WinX application is opened and the PI-MAX3 power supply is off, many of the functions will be disabled and you will only be able to retrieve and examine previously acquired and stored data. You must close the WinX application software, turn on the power supply, and reopen the WinX application software before you can set up experiments and acquire new data.
2. The WinX application software must be closed before turning off the power supply. If you turn off the power supply before closing the WinX application software, the communication link with the PI-MAX3 will be broken. You can operate the program in a playback mode (i.e., examine previously acquired data) but will be unable to acquire new data until you have closed the WinX application software, turned on the power supply, and then re-opened the WinX application software.

## Pre-Exposure Removal of Accumulated Charge

### *Introduction*

The purpose of the CCD array is to acquire a signal of interest that can then be digitized and transmitted to the host computer for storage, display, and post-processing. It will acquire signal whenever the camera has power, whether or not the intensifier is being gated to take an exposure. If the intensifier is off, dark charge will be the main source of signal accumulation on the array. To counteract this, clean cycles and continuous clean cycles are used to remove the dark charge while the camera is waiting to acquire the signal of interest. Dark charge, clean cycles, and continuous clean cycles are described in the paragraphs that follow.

### *Dark Charge*

As soon as the PI-MAX3 camera is powered on, thermally-induced charge will begin integrating on the CCD array even if the photocathode is biased off. Because dark charge is thermally-induced, reducing the array temperature significantly reduces the rate at which this charge accumulates in the pixel wells. Even so, enough dark charge could accumulate in the pixels between data acquisitions to affect dynamic range at the beginning of an exposure. To prevent this from happening, clean cycles repeatedly shift and discard any signal that has integrated on the array PI-MAX3 is waiting for a Start Acquisition command from the host computer.

After the Start Acquisition command is received, a final clean cycle occurs and exposure begins. During the exposure, both the signal of interest and dark charge integrate on the array. The longer the exposure and the warmer the camera, the larger and less uniform the dark charge will appear. To minimize the dark charge contribution to the acquired signal, you should operate with the lowest temperature possible for your camera. Reducing the gate width may also be helpful.

To further reduce the dark charge contribution to an acquired signal, you may be able to perform background subtraction, which subtracts a dark charge background from raw data acquired using the same experiment conditions (see *“Background Subtraction”*, page 50).

**Note:** Do not be concerned about either the DC level of this background noise or its shape unless it is very high, i.e., > 1000 counts with 16-bit A/D. What you see is not noise. It is a fully subtractable readout pattern. Refer to *“Background Subtraction”*, page 50, for more information.

## WARNING!

If you observe a sudden change in the baseline signal you may have excessive humidity in the camera's CCD enclosure. **Immediately** turn off the controller. *Then, contact Princeton Instruments Customer Support for further instructions. See page 205 for contact information.*

## Cleaning

The basic cleaning function is implemented by clean cycles. These cycles start when you turn the camera on and a clean pattern is programmed into the camera. Their purpose is to remove charge that accumulates on the array while the camera not acquiring data (i.e., exposing and reading out the array). The timing diagram below is for an experiment set up to acquire three (3) images using Internal trigger mode selected on **SuperSYNCHRO Trigger In** tab { **Trigger** expander } and Gate Mode selected on **Experiment Setup Main** tab { In LightField, the equivalent of Gate Mode is active when **Enable Intensifier** is checked on the **Common Acquisition Settings** expander }. In this diagram, clean cycles occur before the first exposure and after the last readout period. They do not need to occur between exposures since each readout cleans the array before the next exposure starts.

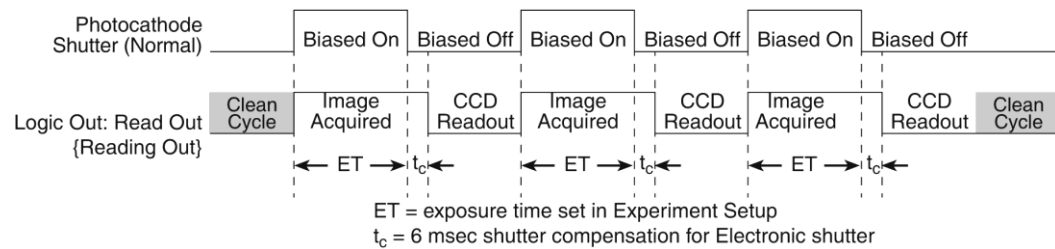


Figure 12. Clean Cycles in Internal Trigger Mode of Operation

The configuration of clean cycles is performed on the **Hardware Setup|Cleans/Skips** tab { via the **Sensor Cleaning** pane accessed on the **Sensor** expander }. When you set up the camera for the first time, default values are automatically inserted into these fields. These will give the best results for most applications. Even so it is a good idea to know what these entries mean with regard to cleaning.

- **Number of Cleans** { **Number of Clean Cycles** } value is usually set to one (1). These are additional clean cycles that can be required after a start exposure signal is received and the current clean cycle has finished. The maximum value for this entry depends on the camera.
- **Number of Strips per Clean** { **Clean Cycle Height** } sets the number of rows that will be shifted and discarded per clean cycle. While a large number such as the number of rows in the array may result in the best cleaning of the array, the tradeoff is that there may be a significant delay between the receipt of a start exposure signal and the beginning of the actual exposure. This delay occurs because the current clean cycle must be completed before a start exposure signal received during the cycle will be implemented. Typically, the default setting is much smaller and in time critical experiments, the setting should be 1 or 2.

- **Clean Before Exposure** { **Clean Before Exposure** } is only provided for cameras that have a Frame Transfer CCD and is only available for selection when in Full Frame mode is active. Normally, cleaning occurs until the acquisition starts. When **Clean Before Exposure** is active, cleaning occurs up until acquisition starts and the entire CCD will be cleaned once right after the readout occurs. It is a clean operation for the next exposure and it matters only when multiple images are taken with a short exposure time.

**Note:** **Clean Before Exposure** is **NOT** relevant when you are in a triggered mode.

- **Continuous Cleans** { **Clean Until Trigger** } is available when the start of exposure is tied to an external trigger. In WinX, this cleaning becomes active when **External Sync** timing mode is selected. In LightField, it becomes active when **Trigger Response** is set to **Readout Per Trigger** or **Shift Per Trigger**.
- **Skip Serial Register Clean** (deselected) { **Clean Serial Register** } The Top margin inactive parallel strips on a CCD are made up of the dark pixels that come before the active strips on a sensor as they exit to the serial register. When these are available (i.e., Pre Dummies {Top Margin} > 0), they serve the purpose of cleaning the serial register before readout of the active strips. In LightField, if there are no inactive parallel strips (i.e., {Top Margin} = 0), selecting **Clean Serial Register** forces a clean of the serial register before readout of the active strips.

**Note:** The start of the exposure is signaled by the **Read Out** { **Reading Out** } output of the **LOGIC OUT** connector going low but will not occur until the current clean cycle and the additional user-defined number of cleans (typically 0) have finished. “Number of Cleans” is defined on the **Setup|Hardware|Cleans/Skips** tab { **Sensor Cleaning** flyout pane on **Sensor** expander }. If you enter a value other than “0”, you will further delay the start of the exposure by that number of clean cycles.

## Phosphor Decay Delay

The WinX and LightField applications allow you to enter a delay between the end of the exposure time and the beginning of the array readout. This time is inserted to allow the phosphor to decay to 1% before readout occurs and will vary depending on the phosphor type. This delay has no effect on the actual time it takes for the phosphor to decay.

**Note:** In the case of an experiment using a PI-MAX3:1024i and a very short exposure time, artifacts will appear in the first frame unless the phosphor decay delay is set to 3 ms. This amount of delay will ensure that the vertical registers (under the mask) are cleared before the acquired signal is shifted under the mask.

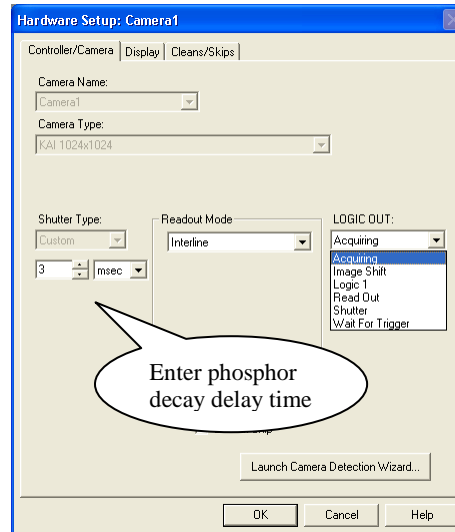
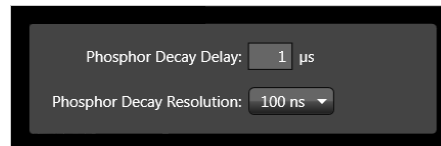


Figure 13. WinX: Phosphor Decay Delay



LightField: Phosphor Decay Delay (Common Acquisition Settings/Advanced)

## Temperature Control

### WARNING

Under normal conditions, the front end of the camera is sealed and backfilled so there is no danger of damage due to condensation.

### Cooling Method

Cooling the CCD array reduces the amount of dark charge, thereby acting to improve the signal-to-noise ratio. An internal Peltier device directly cools the cold finger on which the CCD is mounted. The heat produced by the Peltier device is then removed by the air drawn into the camera by the internal fans and exhausted through the side-panel grill. The fans are always running and cooling the CCD and the internal electronics. Additional heat removal can be performed by circulating coolant through an internal heat block.

**Air-cooling:** With air-cooling alone, at an ambient temperature of 25°C, temperature lock at -25° should typically take ten to twenty minutes. Cooling performance is affected by the CCD array being used (i.e., larger arrays may take longer to cool than

smaller arrays). Also, if the lab is particularly warm, achieving temperature lock might take longer or not be obtainable at all.

**Supplemental Circulating Coolant:** Allows temperature lock to be achieved more rapidly than would be required to lock at the same temperature with air-cooling alone. In addition, it will be possible to achieve temperature lock at lower temperatures, typically three or four degrees lower than would be possible with air-cooling alone. Use the Princeton Instruments CoolCUBE<sub>II</sub> coolant circulator. It is a closed circulation system that depends on ambient air-cooling of the circulating coolant. Unless the laboratory has high humidity, the ambient temperature coolant should prevent condensation inside the PI-MAX3. See “*Making the Camera-Circulator Connections*”, page 29 for CoolCUBE<sub>II</sub> setup instructions.

## WARNING

Cooling performance can be enhanced by circulating water with a temperature below laboratory ambient but *this approach will increase the risk of condensation inside the PI-MAX3*. This condensation can cause *catastrophic failure* of the camera electronics. Any resulting damage would be considered to have resulted from improper operation and will *not* be covered by the Warranty. *Even ordinary tap water is too cold to be used without risk!* For safety, the water should be no colder than the laboratory ambient temperature. Closed circulation systems that depend on ambient air-cooling of the circulating water will generally give good results. If you feel that you must use water colder than the laboratory ambient temperature, it is absolutely essential that the PI-MAX3 be operated where the humidity is low enough to prevent internal condensation. If the coolant is below the freezing temperature of water, we advise using a mixture of 50% water and 50% ethylene glycol as the coolant.

The easiest and most practical way to achieve the required low humidity is to put the PI-MAX3 inside a closed container and to then purge the container with a continuous flow of dry nitrogen. On completion of the experiment, be sure to continue the purge until the PI-MAX3's internal cold surfaces have had time to warm to the ambient laboratory temperature. Contact the factory if you require additional information.

### **Setting the Temperature**

Regardless of the type of cooling, the CCD array temperature is set via the application software. When WinX is the controlling software, temperature control is done via **Setup | Detector Temperature** menu choice. When Light Field is being used, temperature control is done on the **Sensor** expander.

Once the target (desired) array temperature {Temperature Setpoint} has been set, the software controls the camera's cooling circuits to reach set array temperature. On reaching that temperature, the control loop locks to that temperature for stable and reproducible performance. When the Target Temperature {Temperature Setpoint} has been reached, the current temperature is **Locked**. The on-screen indication allows easy verification of temperature lock.

Temperature lock to a set temperature in the operating range will typically occur within ten minutes. Another five minutes will be required for maximum temperature stability to be achieved.

**Note:** The WinX **Detector Temperature** dialog will not display temperature information while you are acquiring data.



## Exposure

### **Introduction**

Data acquisition has two parts: exposure and readout. Exposure refers to the integration of a signal of interest on the CCD array and readout is the transfer of the integrated signal from the array pixels to a shift register and from there to a preamplifier. During exposure, each pixel in the two-dimensional grid of individual pixels senses the intensity of light falling on its collection area and stores a proportional amount of charge in its associated well. Once charge accumulates for the exposure time (via gating sequences defined in the application software), the pixels are read out serially.

Because CCD arrays are always sensitive to light, light must not be allowed to fall on the array during readout (with a few exceptions). Intensified cameras such as the PI-MAX3 rely on gating the intensifier off, to prevent light from reaching the array. During each data acquisition, the intensifier is gated on and off (this may happen a number of times if there are multiple gates per exposure) to allow the pixels to register light during the “on” period. It is gated off for the readout period.

### **Exposure with an Image Intensifier**

PI-MAX3 cameras use an image intensifier both to gate light on and off and to greatly increase the brightness of the image. In these cameras the image intensifier detects and amplifies the light, and the CCD is used for readout. The exposure programmed by software in this case refers to duration of gating of the intensifier.

The MCP (microchannel plate) of the intensifier is composed of more than  $10^6$  individual miniature electron multipliers with an excellent input to output spatial geometric accuracy. Intensifier gain is varied by adjusting the voltage across the MCP or the voltage across the MCP output and the phosphor. This second parameter is a factory adjustment, as it affects both the gain and the resolution of the intensifier.

Detection of extremely weak Continuous Wave (CW) signals, e.g., luminescence and Raman scattering from solid state samples, is typically limited by the dark current of the intensifier's photocathode, usually referred to as the equivalent background illumination (EBI).

### **Saturation**

When signal levels in some part of the image are very high, charge generated in one pixel may exceed the “well capacity” of the pixel, spilling over into adjacent pixels in a process called “blooming.” If this is the case, you could reduce the intensifier gain or read out more frequently, with signal averaging to enhance S/N (Signal-to-Noise ratio) accomplished through the software.

### **Caution**

Signals large enough to bloom may damage the intensifier.
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For signal levels low enough to be readout-noise limited, longer exposures, and therefore longer signal accumulation in the CCD, will improve the S/N ratio approximately linearly with the length of exposure time. There is, however, a maximum time limit for on-chip averaging, determined by either the saturation of the CCD pixels by the signal or the loss of dynamic range due to the buildup of dark charge in the pixels.

## Background Subtraction

Each CCD has its own dark charge pattern or background that can be subtracted from the total acquired signal. By subtracting this background, you can eliminate the dark charge, which might otherwise hide low-intensity signal.

When setting up for background subtraction, set up the experiment conditions for acquiring the actual image (camera temperature, gating sequences, region of interest, timing mode, etc.) and then, while blocking the incoming signal from the array, acquire a dark charge “background image” under those conditions. Once the background image is acquired, save it to disk.

After storing the background data to disk, you have two choices for background subtraction: automatic or post-processing.

- **Automatic:** In WinX, this approach requires that you activate “Background” and specify the background filename on the **Acquisition|Experiment Setup...|Data Corrections** tab before acquiring an image. In LightField, you must check the **Apply Background Subtraction** box on the **Online Corrections** expander and select the appropriate background file or acquire a new background. When you acquire an image, the specified background will be subtracted automatically from the raw image data before the corrected data is displayed and is available for storage to disk.
- **Post-Processing:** If you prefer to acquire and preserve the raw image data, make sure that “Background” is not active on the **Acquisition|Experiment Setup...|Data Corrections** tab { **Apply Background Subtraction** box is not checked }. Then, acquire the image, save the raw image data to disk. In WinX you would then use the Image (or Spectra) Math function (accessed from the **Process** menu) to subtract a background data file from the raw image data: the resulting data can then be saved to disk in a separate file. In LightField you would open the data in the **Data Workspace**, select **Background...** from the **Processes** dropdown list, choose the appropriate background file, click on **Preview**, and then click on **OK**: you can now click on the **Save** button, edit the filename if desired, and save the data to disk.

## Readout of the Array

At the end of the exposure, the charge from the pixels is shifted to the shift register, amplified, and digitized. Depending on the experiment design, binning may also occur as part of the readout operation.

- For the PI-MAX3:1024i camera and WinX, dual port readout mode is selected whenever full image readout is selected or when the region of interest (ROI) is defined to be horizontally symmetrical and centered. Single port readout is activated when the ROI is not horizontally symmetrical and centered. The same rules apply whether or not binning is utilized. Readout in single port mode may be slower than dual port mode readout. The port used for single port mode is dictated by the CCD design.
- For the PI-MAX3:1024i camera and LightField, when 2 port readout is selected, you can acquire either a full image or a region of interest (ROI) defined to be horizontally symmetrical and centered. If the ROI is not horizontally symmetrical and centered, single port readout must be selected. The same rules apply whether or not binning is utilized. Readout in single port mode may be slower than dual port mode readout. The port used for single port mode is dictated by the CCD design.
- For the PI-MAX:1024x256, signal is read out of a single port.

### Interline CCD Readout

In this section, a simple  $6 \times 3$  pixel interline CCD is used to demonstrate how charge is shifted and digitized using a single port. As described below, two different types of readout, overlapped and non-overlapped can occur. In overlapped operation, each exposure begins while the readout of the previous one is still in progress. In non-overlapped operation (selected automatically if the exposure is shorter than the readout time) each readout goes to completion before the next exposure begins.

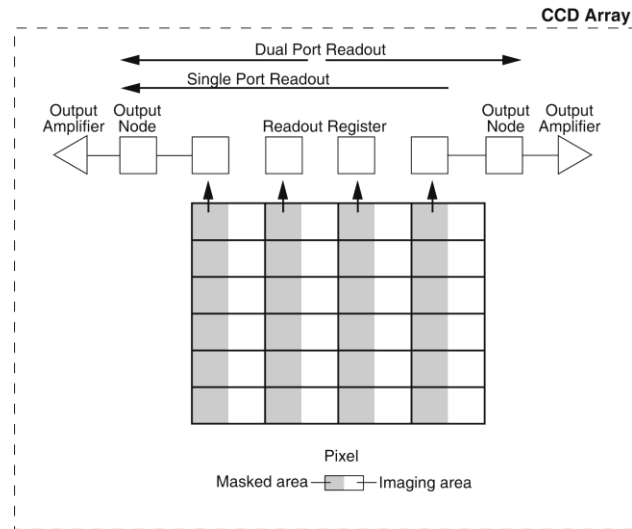


Figure 14. Interline CCD Readout

### Non-Overlapped Operation Exposure and Readout

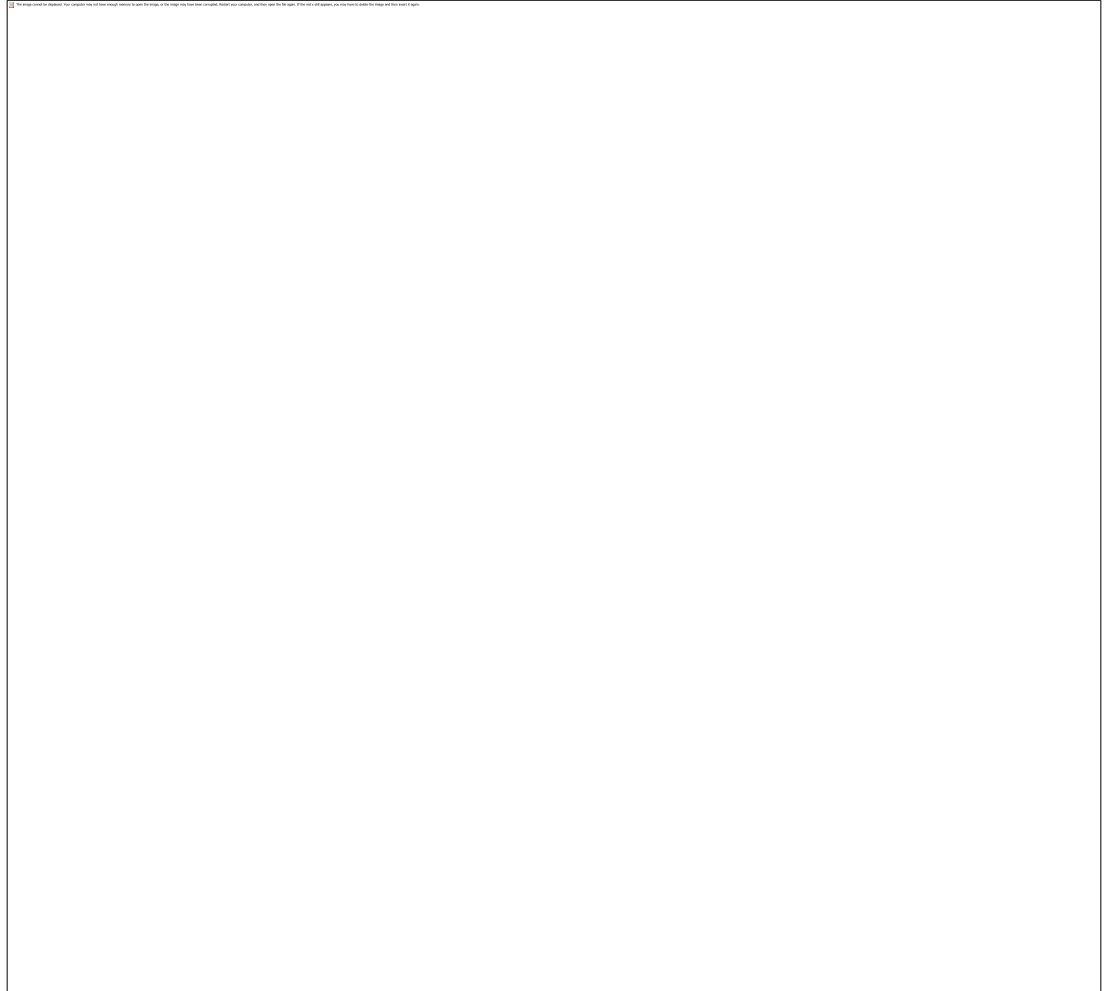
Figure 15 illustrates exposure and readout when operating in the non-overlapped mode. Non-overlapped operation occurs automatically any time the exposure is shorter than the readout time. Figure 15 contains four parts, each depicting a later stage in the exposure-readout cycle.

Part 1 of the figure shows the array early in the exposure. The imaging areas contain charge proportional to the amount of light integrated on each of them. The masked (storage) areas are empty because no charge has been transferred to them. The arrows between adjacent imaging and masked areas indicate the direction the charge will be shifted when the transfer occurs.

Part 2 of Figure 15 shows the situation early in the readout cycle. The charge in the imaging areas has been transferred to the adjacent masked areas and up-shifting to the readout register has started. Note that a second exposure does not begin while the readout is in progress because the intensifier is not gated on at this time.

Part 3 of Figure 15 shows the transfer to the output node. The lowermost pixel in each column is shown empty. Each row of charges is moved in turn into the readout register, and from there to the output node and off of the array for further processing. The process continues until all charges have been completely transferred out of the array. The image intensifier is off during this time so no signal charge is accumulated, but dark current does accumulate. Because this scheme is less time efficient than that used in the overlapped mode, the frame rate may be lower in non-overlapped operation than it is in overlapped operation with the some gating setups.

Part 4 of Figure 15 illustrates the situation at the end of the readout. Both the imaging and storage areas are empty. When the intensifier is gated on again, signal charge will again be accumulated.



*Figure 15. Non-Overlapped Mode Exposure and Readout*

A subsection of the CCD can be read out at full resolution, sometimes increasing the readout rate while retaining the highest resolution in the region of interest (ROI).

### Readout Rate for Interline

Below are the equations that determine the rate at which the CCD is read out. Tables of values for CCDs supported at the time of the printing of this manual also appear below.

Assuming the shutter selection is **None**, the time needed to take an entire frame at full resolution in non-overlapped timing mode is:

$$t_R + t_{\text{exp}} \quad (1)$$

where

$t_R$  is the CCD readout time,  
 $t_{\text{exp}}$  is the exposure time.

The readout time is approximately given by:

$$t_R = [N_x \cdot N_y \cdot (t_{\text{sr}} + t_v)] + (N_x \cdot t_i) \quad (2)$$

where

$N_x$  is the smaller dimension of the CCD  
 $N_y$  is the larger dimension of the CCD.  
 $t_{\text{sr}}$  is the time needed to shift one pixel out of the shift register  
 $t_v$  is the time needed to digitize a pixel  
 $t_i$  is the time needed to shift one line into the shift register

The readout rate in frames per second for the PI-MAX3:1003 Kodak  $1024 \times 1024$  interline array running at 16 MHz is shown in Table 1.

Binning	Region of Interest Size		
	1024 × 1024	400 × 400	200 × 200
1x1	25.8	36.2	42.5
2x2	56.3	49.5	50
4x4	94.5	58.7	54.6*

\*ROI increased to 202x200 to accommodate GigE rules.

Table 1. Readout Rates for Kodak  $1024 \times 1024$  Array at 16 MHz Dual Port

A subsection of the CCD can be read out at full resolution, sometimes increasing the readout rate while retaining the highest resolution in the region of interest (ROI).

### Full Frame CCD Readout

The PI-MAX3:1024x256 camera uses a full frame CCD for data acquisition. The upper left drawing in Figure 16 represents a CCD after exposure but before the beginning of readout. The capital letters represent different amounts of charge, including both signal and dark charge. This section explains readout at full resolution, where every pixel is digitized separately.

Readout of the CCD begins with the simultaneous shifting of all pixels one row toward the “shift register,” in this case the row on the bottom. The shift register is a single line of pixels along the edge of the CCD, not sensitive to light and used for readout only. Typically the shift register pixels hold twice as much charge as the pixels in the imaging area of the CCD.

After the first row is moved into the shift register, the charge now in the shift register is shifted toward the output node, located at one end of the shift register. As each value is “emptied” into this node it is digitized. Only after all pixels in the first row are digitized is the second row moved into the shift register. The order of shifting in our example is therefore A1, B1, C1, D1, A2, B2, C2, D2, A3....

After charge is shifted out of each pixel the remaining charge is zero, meaning that the array is immediately ready for the next exposure.

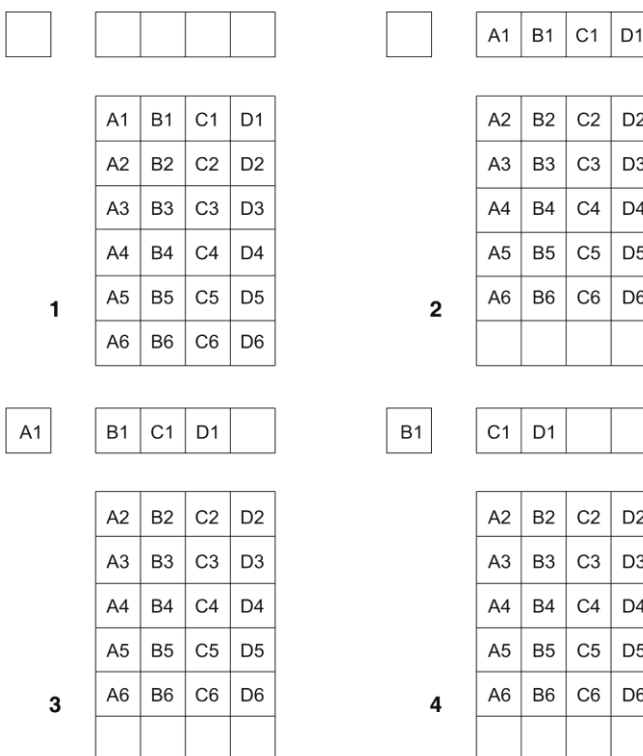


Figure 16. Full Frame CCD Readout

Below are the equations that determine the rate at which the CCD is read out.

The time needed to take a full frame at full resolution is:

$$t_R + t_{\text{exp}} + t_c \quad (1)$$

where

$t_R$  is the CCD readout time,

$t_{\text{exp}}$  is the exposure time, and

$t_c$  is the phosphor decay time.

The readout time is approximately given by:

$$t_R = \left[ N_x \cdot N_y (t_{sr} + t_v) \right] + (N_x \cdot t_i) \quad (2)$$

where

$N_x$  is the smaller dimension of the CCD

$N_y$  is the larger dimension of the CCD

$t_{sr}$  is the time needed to shift one pixel out of the shift register

$t_v$  is the time needed to digitize a pixel

$t_i$  is the time needed to shift one line into the shift register

A subsection of the CCD (number of horizontal pixels must be divisible by 4) can be read out at full resolution, sometimes dramatically increasing the readout rate while retaining the highest resolution in the region of interest (ROI). To approximate the readout rate of an ROI, in Equation 2 substitute the x and y dimensions of the ROI in place of the dimensions of the full CCD. Some overhead time, however, is required to read out and discard the unwanted pixels.

The readout rate in frames per second for the PI-MAX3:e2v CCD30-11 1024 × 256 full frame array running at 2 MHz is shown in Table 2.

Binning	Region of Interest Size		
	1024 x 256	1024 x 10*	1024 x 1*
1 x 1	6.67		
1 x 256	270		
1 x 10		1567	
1 x 1			1831

\* CCD format using Custom Chip mode

Table 2. Spectral Rates for e2v CCD30-11 Array at 2 MHz

## ***Binned Readout (Hardware Binning)***

### **Introduction**

Binning is the process of adding the charge from adjacent pixels together to form a single pixel (sometimes called a super-pixel), and it can be accomplished in either hardware or software. Rectangular groups of pixels of any size may be binned together, subject to some hardware and software limitations.

Hardware binning reduces readout time and the burden on computer memory by summing charge *before* the preamplifier reads out the signal. For signal levels that are readout noise limited this method improves S/N ratio linearly with the number of pixels grouped together. For signals large enough to render the camera photon shot noise limited, the S/N ratio improvement is roughly proportional to the square-root of the number of pixels binned. In the WinX application, hardware binning is set up on the **Acquisition|Experiment Setup...|ROI Setup** tab by entering a value in the **Group** fields: for example, a “2” in each of the Group fields will set up 2 x 2 hardware binning. In LightField, hardware binning is set up via the **Region of Interest** expander: first by verifying that hardware binning is selected on the **Advanced** flyout pane, then selecting **Full Sensor Binned**, and entering a “2” in fields or by clicking on the **Edit ROIs...** button and creating a custom ROI with **Bin W** and the **Bin H** values of “2”.

Limitations of hardware binning include:

- Lowered resolution because charge from adjacent pixels is summed into a super pixel.
- Increased possibility to blooming. Because shift register pixels typically hold only twice as much charge as image pixels, the binning of large sections may result in saturation and spilling of charge back into the image area
- Possible data loss if the total charge binned together exceeds the capacity of the shift register or output node.
- For dual port operation, there are symmetry requirements that limit the choice of patterns. Regions of interest (ROIs) must be symmetrical about the center line (horizontal).
- The number of pixels in the serial (horizontal) direction must be evenly divisible by 4, even after binning.

The possibility of blooming or data loss strongly limits the number of pixels that may be binned in cases where there is a small signal superimposed on a large background, such as signals with a large fluorescence. Ideally, one would like to bin many pixels to increase the S/N ratio of the weak peaks but this cannot be done because the fluorescence would quickly saturate the CCD. The solution is to perform the binning in software. Limited hardware binning may be used when reading out the CCD. Additional post-processing binning is accomplished in software, producing a result that represents many more photons than was possible using hardware binning.



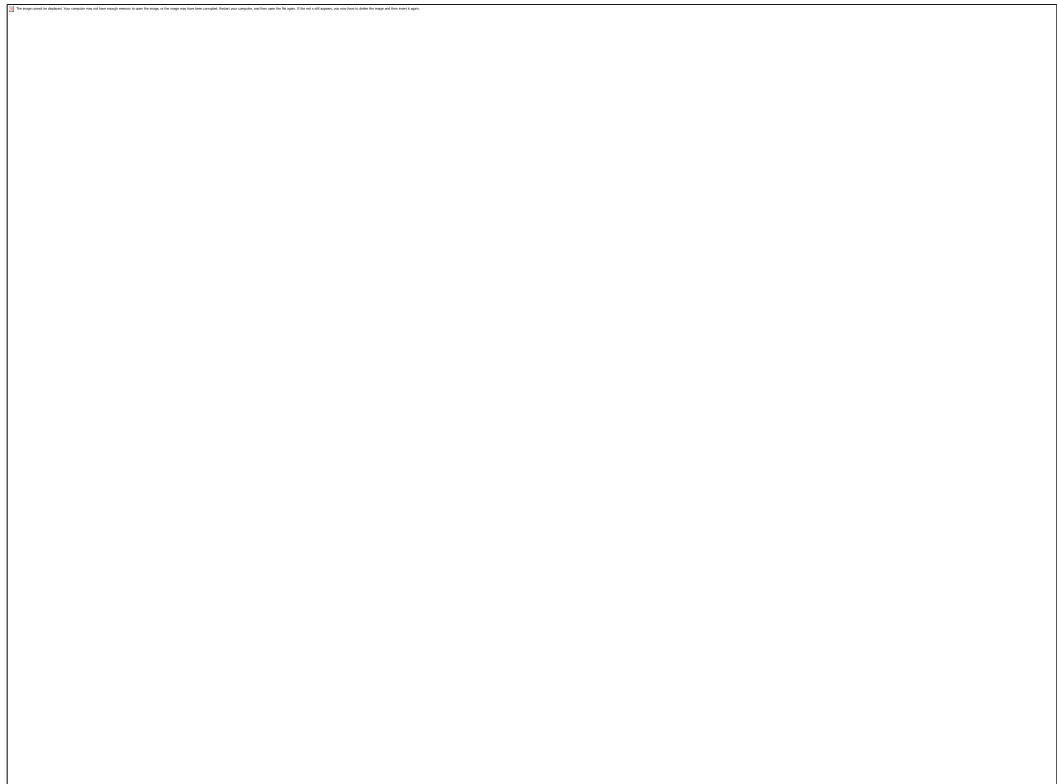
### CCD Type and Readout Port(s)

The PI-MAX3 will either have a full frame or an interline CCD. Full frame CCDs such as the 1024x256 device have a single port for readout. The 1024x1024 interline CCD is designed for either dual or single port readout. When single port readout is active, the port used has been set at the factory.

Dual port readout is about two times faster than single port readout and occurs whenever the full frame is being read out or when an ROI is symmetrical about the horizontal center of the CCD. In WinX, a single port readout will automatically occur when an ROI is not symmetrical about the horizontal center of the CCD; in LightField, you can either change the ROI location/size or select single port readout (via the **Advanced** flyout pane on the **Region of Interest** expander).

### Full Frame Binning

Figure 17 shows an example of  $2 \times 2$  binning with dual port operation for an interline array: each pixel of the image displayed by the software represents 4 pixels of the array. Figure 18 shows the LightField **Region of Interest** expander setup for full sensor  $2 \times 2$  binning. Figure 19 shows an example of single port operation for a full frame array.



*Figure 17. Dual Port Readout:  $2 \times 2$  Binning of Interline CCD*

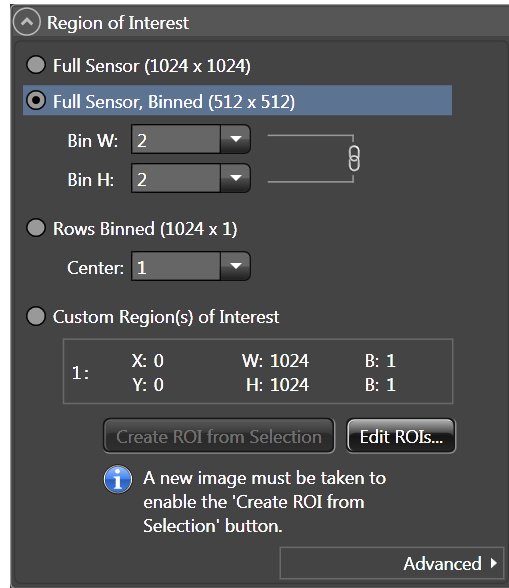


Figure 18. Dual Port Readout: LightField Settings for 2 × 2 Binning of Interline CCD

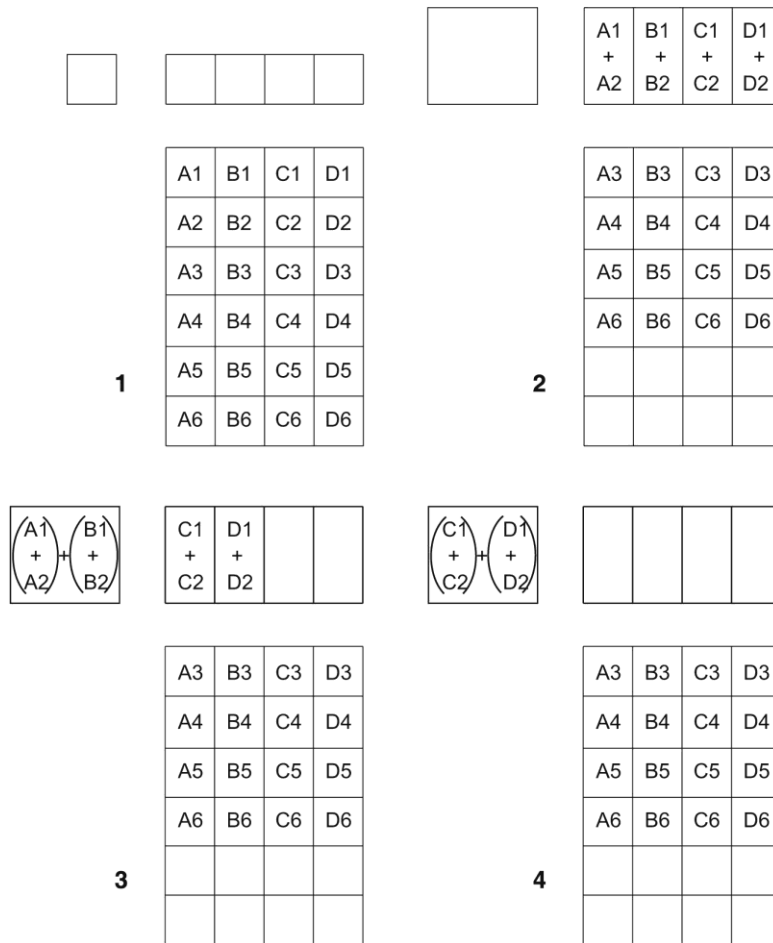


Figure 19. Single Port Readout: 2 × 2 Binning of Full Frame CCD

### WinX and Partial Frame ROI Binning

When setting up a partial frame ROI (regardless of the array type – full frame or interline), keep in mind that for the PI-MAX3 the following constraint applies: **the number of pixels in the serial (horizontal) direction must be evenly divisible by 4, even after binning.** The software may refer to the horizontal as X or Wavelength depending on the application.

**Examples:** These examples include partial frame ROIs with and without binning. The terminology is based on the ROI Setup tab shown to the right.

**X Start to End** = 200 pixels, no grouping (binning). Since  $200/4=50$ , this is a valid ROI setup.



**X Start to End** = 200 pixels and grouping (binning) is by 8. The resulting number of super pixels is 25. Since  $25/4=6.25$ , this is not a valid ROI setting for the horizontal direction.

**X Start to End** = 240 pixels, no grouping (binning). Since  $240/4=60$  this is a valid ROI setup.

**X Start to End** = 240 pixels and grouping (binning) is by 3. The resulting number of super pixels is 80. Since  $80/4=20$ , this is a valid ROI setup.

**X Start to End** = 240 pixels and grouping (binning) is by 16. The resulting number of super pixels is 15. Since  $15/4=3.75$ , this is not a valid ROI setting for the horizontal direction.

### LightField and Partial Frame ROI Binning

Partial Frame ROI binning can be defined via the Region of Interest expander's **Custom Region(s) of Interest** function and the **Edit Regions of Interest** window (Figure 21). The ROI shown in the image has been created for a PI-MAX3:1024i using dual port readout. Because the ROI is not centered horizontally, an **Experiment Conflict** is shown. If you click on the **Experiment Conflict** icon , a pop up window will report the nature of the conflict. In this case, the ROI needs to be centered horizontally: you would click on the middle **Center** button  to reposition the ROI correctly.

**Note:** Only one ROI can be created when dual port readout is selected. When single port readout is active (the CCD is a 1024x256 or single port is selected for the 1024x1024 interline), multiple ROIs can be created and the horizontal centering is not required.

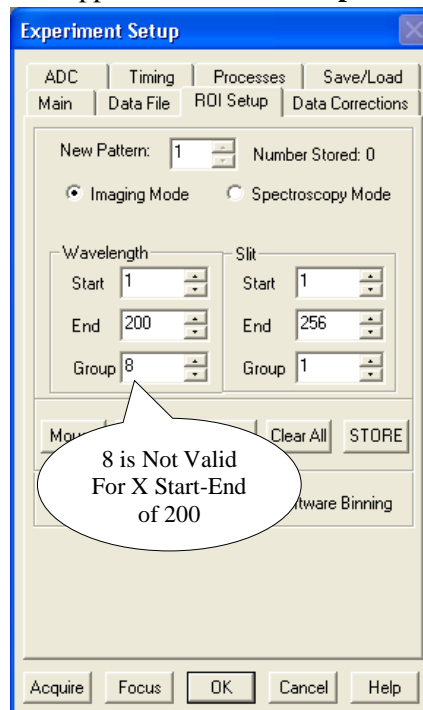


Figure 20. Experiment Setup|ROI

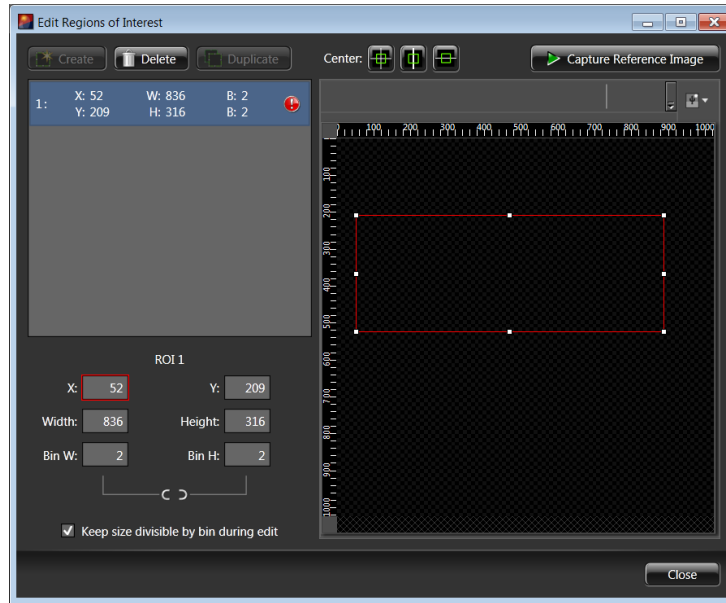


Figure 21. Edit Regions of Interest window

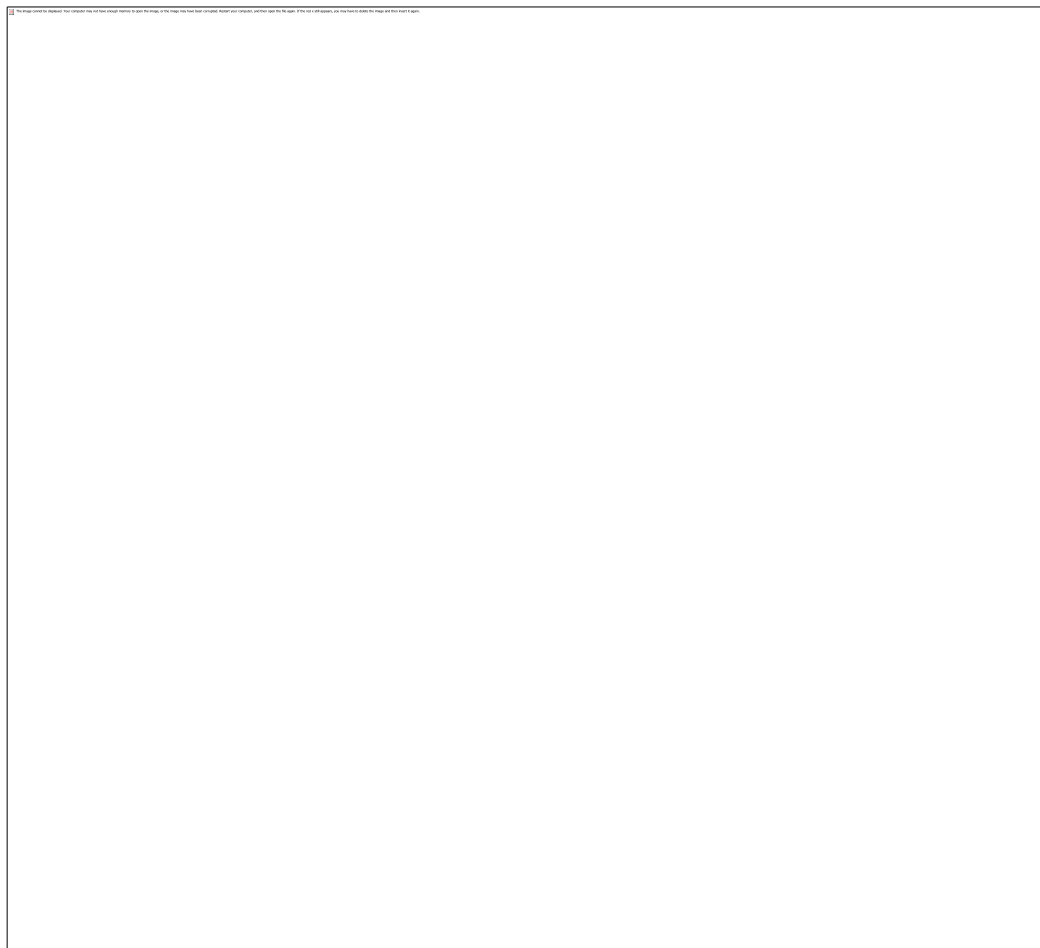


Figure 22. Partial Frame  $2 \times 2$  Binning for Interline CCD - Single Port Readout (ROI does not have to be centered horizontally)

Figure 23 shows the LightField **Region of Interest** expander and  $5 \times 3$  binning setup for an interline with dual port readout selected. Both the **Full Sensor Binned** and the **Custom Region(s) of Interest** results of using the 5 and 3 bin values are reported.

**Note:** On LightField's **Region of Interest** expander, you can select **Full Sensor, Binned** and enter Bin W and Bin H values that would not be allowed if you selected **Custom Region(s) of Interest** and entered them in the **Edit Regions of Interest** window. For example a Bin W=5 and a Bin H=3 would not be allowed via the **Edit Regions of Interest** window until you created a horizontally centered ROI whose dimensions would permit even division by those values. If you use the **Full Sensor, Binned** function, LightField creates the appropriately sized ROI and reports the resulting image size. The **Custom Region(s) of Interest** panel shows the non-binned ROI size and the bin values that will be applied to it.

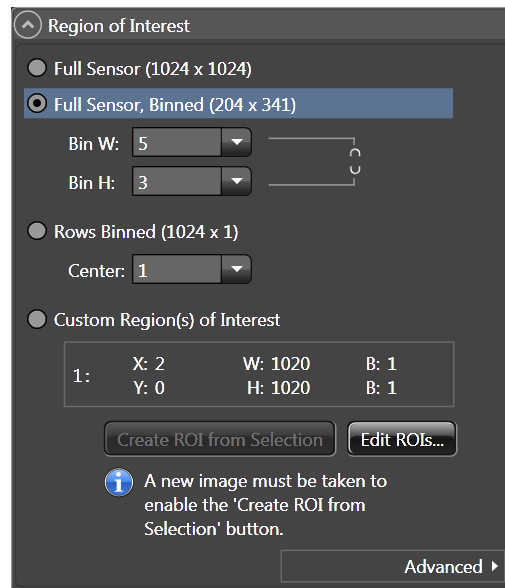


Figure 23. Dual Port Readout: LightField Settings for  $5 \times 3$  Binning for Interline CCD

## Software Binning

Software binning is a software-averaging post-acquisition process that can be performed on either unbinned or hardware-binned data. This type of binning can improve the S/N ratio by as much as the square root of the number of binned pixels. Unfortunately, with a high number of scans (i.e., above 100), camera 1/f noise may reduce the actual S/N ratio to slightly below this theoretical value. Also, if the light source used is photon flicker (1/f noise) limited rather than photon shot-noise limited, this theoretical signal improvement cannot be fully realized. Again, background subtraction from the raw data is necessary.

Software binning is also useful in high light level experiments, where the camera is again photon shot-noise limited. Summing multiple pixels in software corresponds to collecting more photons, and results in a better S/N ratio in the measurement.

In WinX and LightField software, software binning can either be set up to occur automatically or as a manual post-processing operation.

- **WinX:** Automatic software binning is set up by entering **Group** parameters on the **Acquisition|Experiment Setup...|ROI Setup** tab card and then selecting the **Use Software Binning** checkbox. The drawback to automatic binning is that the raw data is lost. Alternatively, you can acquire raw data and then use the post-processing binning function (located on the **Process|Binning and Skipping...** dialog) to select the input data, enter the binning parameters, and save the result to an appropriately named file.
- **LightField:** Automatic software binning is set up by entering the **Bin W** and **Bin H** parameters directly on the **Region of Interest** expander or when creating a Custom ROI via the **Edit Regions of Interest** window. Alternatively you can acquire raw data, load the file in the Data Workspace, select **Software Binning** from the **Processes** menu, enter the binning parameters, preview the resulting data, **OK** the process, and then use the Data Workspace **Save** function to save the result to an appropriately named file.

## Controller Gain {Analog Gain}

Controller gain (a function of the preamplifier) is software-selectable and is used to change the relationship between the number of electrons acquired on the CCD and the Analog-to-Digital Units (ADUs or counts) generated. Selecting the amount of gain is done on the **Acquisition|Experiment Setup...|ADC** tab {**Analog to Digital Conversion** expander}. The choices are **1 {Low}** and **2 {High}**.

Three factors should be considered when making the selection: the intensity of the incoming signal, binning, and CCD saturation.

- 1 {Low}:** Users who measure high-level signals may wish to select **1 {Low}** for digitization of larger signals: more electrons are required per ADU. Since binning combines the signal from two or more pixels, the user may also want to select **1 {Low}** if binning is being applied. In both instances, the goal is to prevent CCD saturation and maximize signal acquisition.
- 2 {High}:** Users who consistently measure low-level signals may wish to select **2 {High}**, which requires fewer electrons to generate an ADU and reduces some sources of noise. If saturation occurs at this setting, **1 {Low}** should be selected.

## Digitization

During readout, an analog signal representing the charge of each pixel (or binned group of pixels) is digitized. The number of bits per pixel is 16.

Some PI-MAX3 cameras have two complete analog channels including separate A/D converters. Because the readout noise of CCD arrays increases with the readout rate, it is sometimes necessary to trade off readout speed for high dynamic range. The two analog converters, both high speed, are optimized for slower read rates by digitally processing the signal in the camera before transferring it to the host.

## Logic Out Control

The TTL-compatible logic level output (0 to +3.3 V) from the **LOGIC OUT** connector on the rear panel can be used to monitor camera status and control external devices. By default, the logic output level is high while the action is occurring. The timing of the level changes depends on the output type selected on the

**Setup|Hardware|Controller/Camera** tab {**Trigger** expander}:

- Acquiring{Acquiring}**: After a start acquisition command, this output changes state on completion of the array cleaning cycles that precede the first exposure. Initially low, it goes high to mark the beginning of the first exposure. In Focus mode operation it remains high until the system is halted. If a specific number of frames have been programmed, it remains high until all have been taken and then returns low. Figure 25 assumes 3 frames have been programmed.
- Image Shift {Shifting Under Mask}**: This level is at a logic high while the image is being shifted under the mask.
- Logic 1 {Always High}**: The level at the connector is high.
- Read Out {Reading Out}**: It is at a logic high when CCD is being read; otherwise low.
- Shutter {Shutter Open}**: This level is at a logic high when the photocathode is gated on (signal is accumulating on the CCD) and can be used to drive an external electro-mechanical shutter. Contact the factory for more information.
- Wait for Trigger {Waiting For Trigger}**: This level is at a logic high when the camera is ready to acquire and is waiting for an external trigger (through the EXT SYNC connector) before exposing the CCD. The level goes low when a trigger is detected: exposure begins. The Wait for Trigger (WFT) signal goes high immediately after readout or after preopen (if it is active). If continuous cleans is enabled, the camera will check for a trigger at the EXT SYNC connector before

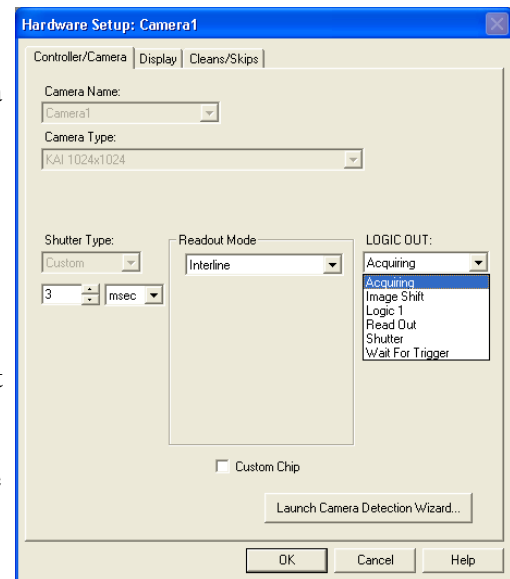


Figure 24. PI-MAX3 Setup/  
Hardware/Controller/Camera tab

entering a continuous clean cycle. If none has occurred, a cleaning cycle is initiated and completed. Before the next cycle begins, the EXT SYNC connector is checked again, and exposure will start if a trigger has occurred.

When the **Invert LOGIC {Invert Output Signal}** check box is checked, the output is at a logic low when the action is occurring.

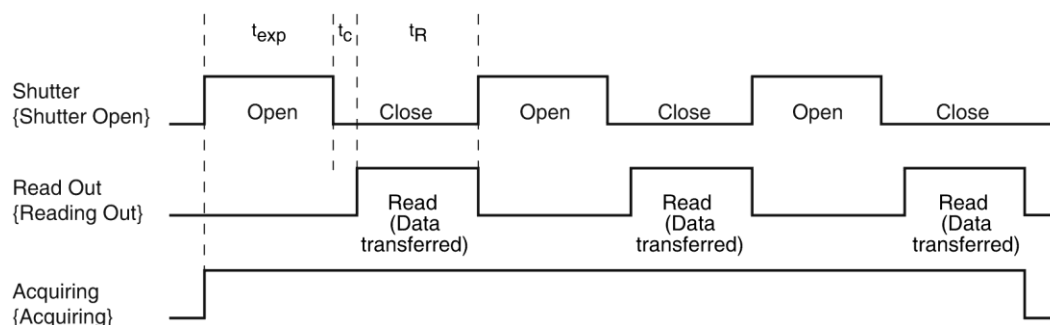


Figure 25. Comparison of Shutter {Shutter Open}, Read Out {Reading Out}, and Acquiring {Acquiring} Levels

## WinX Experiment Setup

### Main tab

In WinX, the first experiment setup parameters are typically selected/entered on the **Experiment Setup|Main** tab. These parameters determine such things as the number of separate frames (denoted as images or spectra) that will be acquired, how much of the CCD will be used to acquired data, the intensifier gain, and the intensifier mode. The Main parameters are described briefly below.

### Number of Images/Spectra and Accumulations

This is the number of sequential frames the software will collect and store in a single file. Each frame will be digitized and stored, but all of the frames will be in a single file. A frame may contain data from more than one region of interest as defined via the **ROI Setup** tab.

If the **Accumulations** > 1, each stored frame will contain summed data sets from two or more exposures. The number of separate frames stored will the same as it would be for Accumulations =1, but the total number of exposures required would be the product of the **Number of Images/Spectra** parameter times the **Accumulations** value.

### CCD Readout

This parameter selection determines whether the entire CCD array will be used to acquire a frame or if only a rectangular portion (or portions) of the array will be used. When **Use Region of Interest** is selected, data will be collected from the region(s) defined on **ROI Setup** tab. The full chip size or the sum of the active region(s) as defined on the ROI tab is displayed.

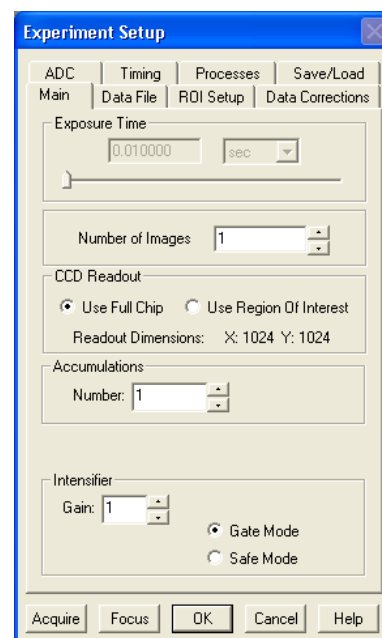


Figure 26. Experiment Setup|Main tab



### Intensifier Gain

The Intensifier gain setting provides continuous adjustment over a range of 1 to 100. Gain is approximately proportional to the number entered. 100 is maximum gain or 100%; 1 is approximately 1% of maximum gain. The default setting will give good results in many applications. Gain can only be changed when acquisition is NOT occurring: you must stop acquisition, change the gain, and then restart acquisition. We suggest beginning with a low setting and then increasing it until optimum results are obtained.

**Note:** The intensifier gain also affects the Equivalent Background Illumination (EBI) of the intensifier. One result of this is that, to properly perform background subtraction, a new background must be taken whenever the intensifier gain is changed.

### Intensifier Mode

The Intensifier Mode selection determines whether the intensifier will be biased on or off by the defined pulser gate timing (Gate Mode) or it will be continuously biased off until Gate mode is selected (Safe Mode).

### Timing tab

Experiment setup requires the selection of a variety of experiment timing parameters. The parameters described in this section are those that appear on the **Experiment Setup|Timing** tab (Figure 27). With the exception of Fast Mode/Safe Mode, which is described in full, the following paragraphs briefly describe these timing parameters. The settings appropriate to the intensifier mode and selected pulser are discussed in *Chapter 7: WinX and Gated Operation*.

### Timing Mode

The timing mode parameter refers to the PI-MAX3's synchronization of data acquisition with an external TTL signal applied to the **TRIGGER IN** connector on the back of the camera or an internal trigger generated by the internal timing generator. The modes available depend on the selected intensifier mode (**Safe** or **Gate**) and the selected pulser (**SuperSYNCHRO**).

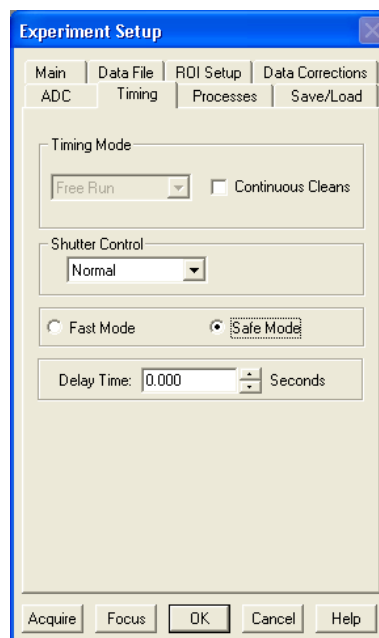


Figure 27. Experiment Setup/Timing dialog

### Fast Mode or Safe Mode

In WinX, the Fast Mode or Safe Mode selection determines whether the PI-MAX3 will run the experiment according to the experiment timing, with no interruptions from the computer, or the computer will interrupt the acquisition flow to process each frame as it is received. Figure 28 compares the two modes.

**Note:** The Safe Mode on the **Timing** tab is not the same as the **Intensifier** Safe Mode on the **Main** tab.

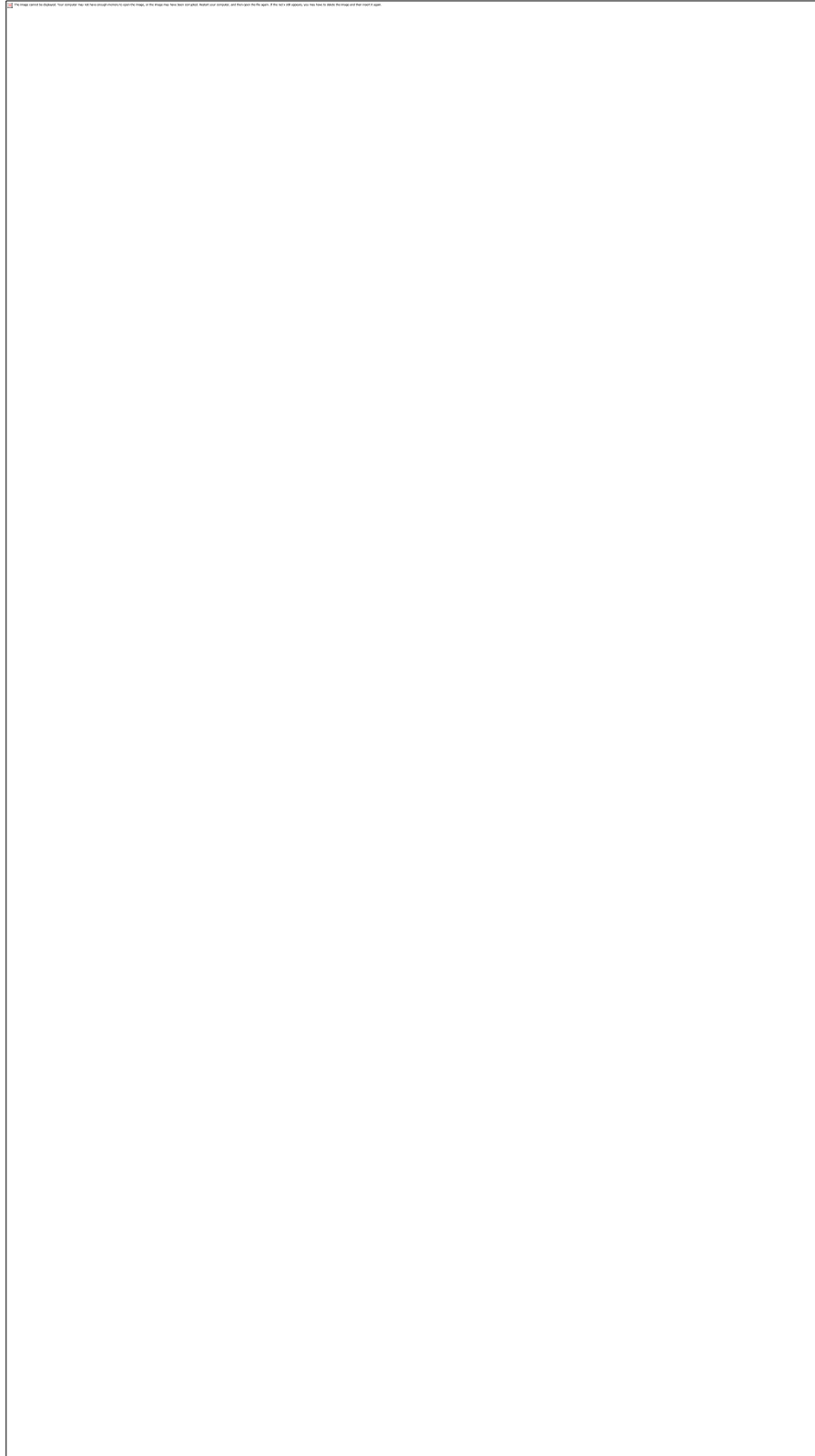
Fast Mode operation is primarily for collecting “real-time” sequences of experimental data, where timing is critical and events cannot be missed. Once the PI-MAX3 is sent the Start Acquisition command by the computer, all frames are collected without further intervention from the computer. The advantage of this timing mode is that timing is controlled completely through hardware. A drawback to this mode is that the computer will only display frames when it is not performing other tasks. Image display has a lower priority, so the image on the screen may lag several images behind. A second drawback is that a data overrun may occur if the number of images collected exceeds the amount of allocated RAM or if the computer cannot keep up with the data rate.

Safe Mode operation is primarily useful for experiment setup, including alignment and focusing, when it is necessary to have the most current image displayed on the screen. It is also useful when data collection must be coordinated with external devices such as external shutters and filter wheels. As seen in Figure 28, in Safe Mode operation, the computer controls when each frame is taken. After each frame is received, the detector sends the Stop Acquisition command to the detector, instructing it to stop acquisition. Once that frame is completely processed and displayed, another Start Acquisition command is sent from the computer to the detector, allowing it to take the next frame. Display is therefore, at most, only one frame behind the actual data collection.

One disadvantage of the Safe mode is that events may be missed during the experiment, since the PI-MAX3 is disabled for a short time after each frame.

### Delay Time

Allows a delay to be inserted between successive frame acquisitions. This parameter is only active in Safe Mode operation, in which each frame must be completely processed before the next one can be taken. The Delay Time inserts an additional delay after the computer has finished processing the previous frame before the next one can be acquired.



*Figure 28. Safe Mode and Fast Mode Operation*

## LightField Experiment Setup

### Introduction

Initial experiment setup for LightField is an easy process. If your PI-MAX3 is powered on when you start LightField, the camera will be detected and its icon will be placed in the **Available Devices** area. When you drag the icon into the **Experiment Devices** area, the appropriate expanders will be loaded in the Experiment Settings stack. If this is the first time you have started LightField with this camera, the default settings for the camera will have been loaded into the expanders. The following paragraphs provide brief descriptions of several of the **Experiment Settings** expanders. For detailed descriptions of all of the expanders, refer to the LightField User's Manual and LightField's online help.

### Common Acquisition Settings expander

This expander includes the **Number of Frames**, **On-CCD Accumulations**, and **Exposures per Frame** settings that determine how many images will be acquired, whether multiple frames will be used to create a single frame, and whether multiple exposures will occur while a frame is being acquired. In addition, this expander is where the intensifier is enabled and the amount of intensifier gain can be set. The **Advanced** flyout allows you to enter a **Phosphor Decay Delay Time** and choose its resolution. Finally, you can specify time stamping information to be stored and displayed with the data.

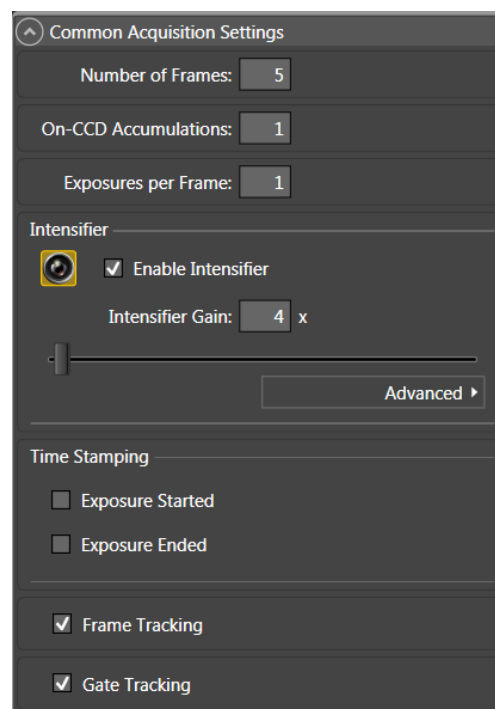


Figure 29. Common Acquisition Settings expander

### Region of Interest expander

The **Region of Interest** expander allows you to specify how much of the total sensor image area will be used to acquire the data (full sensor or one or more regions of interest). This is also where you can set up and select either hardware or software binning.

The **Advanced** button opens a flyout pane where you the type of binning (hardware or software) to be used if you have entered bin values other than 1.

The **Edit ROIs** button opens the **Edit Regions of Interest** window where you can capture a reference image to help you define which area or areas on the sensor are to be included when data acquisition is started. You can draw a selection box to define an area or you can key values into the ROI fields.

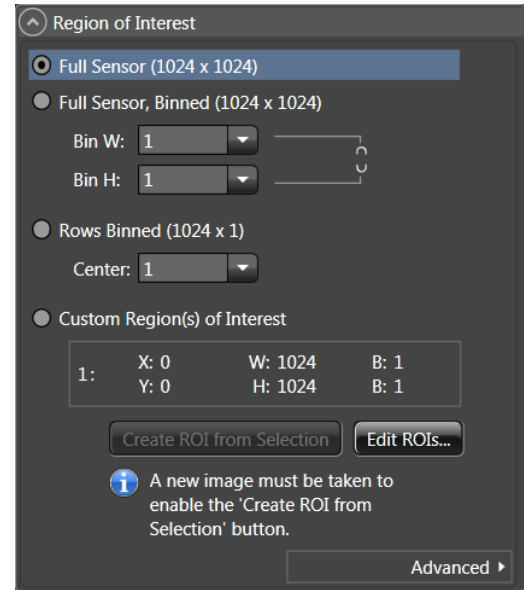


Figure 30. Region of Interest expander

### Trigger expander

The **Trigger** expander is where you specify the trigger source (**Internal** or **External**) to be used to trigger gating. Internal trigger uses the user-selected **Internal Trigger Frequency** (selected on the **SuperSYNCHRO Timing** expander). External requires that you define the external trigger so LightField will be able to recognize it when it occurs at the **TRIGGER IN** BNC on the rear of the PI-MAX3. This is also where you can choose the logic level output of the **LOGIC OUT** BNC.

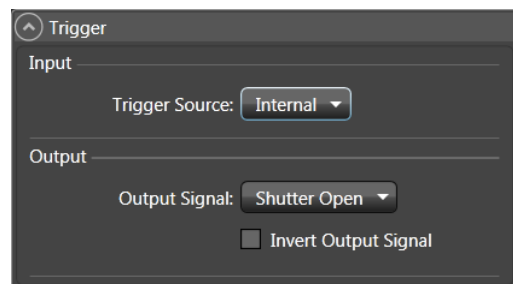


Figure 31. Trigger expander: Internal

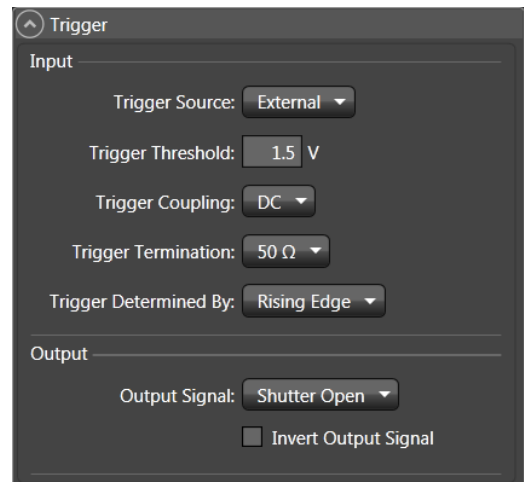


Figure 32. Trigger expander: External

### SuperSYNCHRO Timing expander

The **Super SYNCHRO Timing** expander is located at the bottom of the LightField desktop. This is where you select the type of gating (for example, Repetitive, Sequential, or DIF) and enter the gate delay and width information. This is also where you can enter gate width and delay information for the **AUX OUT BNC**. When **Internal Trigger** is the selected Trigger Source or **SyncMASTER** is turned on, you can also enter the **Internal Trigger Frequency**. The hyperlinks open the appropriate expanders so you can check or make changes to the current settings for the intensifier, trigger, phosphor decay delay, number of frames, on-CCD accumulations, and readout mode. Note that you can grab and drag the top of the **SuperSYNCHRO Timing** expander up to show more of the panel or drag the top down so you can see more of the **Experiment Settings** stack or the **Device/View** panel.

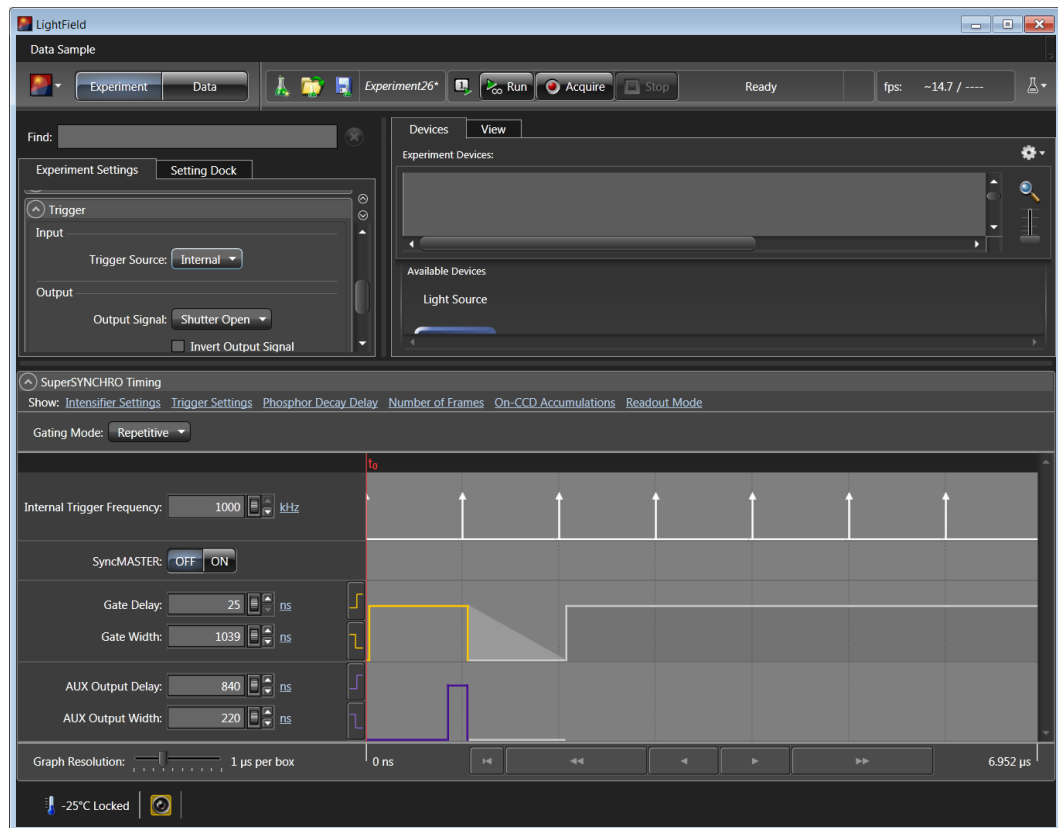


Figure 33. SuperSYNCHRO Timing expander

## WinX and Gated Operation

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### Introduction

This chapter discusses gated operation with the SuperSYNCHRO™ timing generator and aspects of operation of the PI-MAX3 not covered in Chapter 4, *First Light*. We additionally suggest that you review Chapter 13, *Tips and Tricks*, which contains information that should prove helpful in getting good results in more complex measurements.

Gating provides electronic shutter action by controlling the photocathode bias, allowing the detection of low light level signals in the presence of interfering light sources of much greater energy. For instance, in combustion research, a pulsed laser probe is used to investigate the chemistry within a flame. Since the flame itself emits broadband light continuously, the integrated flame emission is much greater than the integrated signal resulting shortly after the laser probe (such as laser-induced fluorescence or Raman). Fortunately, since the laser pulse is very short and the time at which it occurs is known, it is possible to gate for a few nanoseconds during the laser pulse, thus reducing the flame emission interference by approximately the measurement duty factor ratio.

Exposure time is the 'time space' from which charge integrating on the CCD will get summed into the reported data. Gate width is the time during which light will be detected by the intensifier, intensified, and applied to the CCD. Basically, the intensifier controls what the chip 'sees' during the exposure time.

For signal to be detected, it must fall in a valid gate width during a valid exposure. Many gate pulses can be placed into one exposure at repetitive or sequential intervals because there is no temporal measure inside a given exposure (all incident signals get summed (integrated) into one value per pixel/superpixel inside a given exposure).

Using presently available image intensifiers and gate pulse generators, optical gate times  $\leq 4$  ns FWHM (full width at half maximum) are possible. Since the control is electronic, the gate width can be made virtually as long as desired, allowing a wide range of experiment requirements to be satisfied in one instrument setup. Further, in UV measurements, where the On:Off ratio is only  $10^4:1$ , the PI-MAX3's MCP bracketing feature can be used to extend the On:Off ratio to  $10^6:1$ .

## Precautionary Measures

### WARNING

Intensified CCD detectors, such as the PI-MAX3, when biased ON, can be irreparably damaged if continuously exposed to light levels higher than twice the A/D saturation level. Thus it is **critical** that you **not** establish conditions that could result in damage to the intensifier. Although intensified detectors are less prone to damage from *background light* when operated gated, they are at **significant risk** of damage from high-intensity light sources such as lasers. High intensity sources can damage the intensifier before the protection circuits have time to respond, or even cause spot damage without the protection circuits acting at all. If a sustained alarm indication occurs when the controller is turned on, immediately switch the **I.I.T.** switch on the back of the PI-MAX3 to the **OFF** position. Cover the detector window and only switch the **I.I.T.** switch to **ON** after the illumination level has been lowered to safe operating conditions.

### **Intensifier Modes and Safety**

The Experiment Setup **Main** screen in WinX applications allows you to select one of two intensifier modes: **Gate Mode** or **Safe Mode**. In **Gate Mode**, the photocathode is biased on only for the time that each gate pulse is applied. As a result, the tolerance to room light is higher in gated operation, but the risk of damaging overload from intense light sources such as lasers remains. In fact, intense light sources in gated experiments can cause spot damage that would be undetected by the alarm circuit. In **Safe Mode**, the photocathode is continuously biased OFF and the intensifier is as safe as it can be.

**Note:** In order for gating to occur, the I.I.T. switch on the back of the PI-MAX3 must also be in the **ON** position.

### **Alarm**

**Note:** It is normal for the alarm to sound briefly when the system is turned on.

To reduce the risk of detector damage, the PI-MAX3 detector is equipped with an audible alarm in the detector head, activated when the intensity of light falling on the image intensifier exceeds a preset threshold. While the alarm is sounding, the photocathode is disabled. Immediately toggle the **I.I.T.** switch (on the back of the PI-MAX) to the **OFF** position. Cover the detector window and only switch the **I.I.T.** switch to **ON** after the illumination level has been lowered. If the alarm sounds continuously even when the illumination level is adequately low, shut the system down and contact the factory for guidance.

### Caution

Discontinue operation and contact the factory at once if sporadic or continuous unwarranted alarms occur. They may indicate intensifier damage or another situation that requires immediate attention.



## Timing Mode

When you are in **Gate Mode**, the internal timing generator will only operate using **Internal Sync** timing. This timing mode initiates a readout cycle after each internal timing generated pulse ensemble.\* The handshakes that prevent a readout from occurring while the timing generator is busy and that prevent the timing generator from pulsing the photocathode ON while a readout cycle is in progress are performed within the camera. For this mode, the following parameters are automatically set by the application software and cannot be changed: **Exposure Time** is set to 0, **Continuous Cleans** is disabled, and **Disabled Opened** is selected for Shutter Control.

Timing Mode	“Shutter” Control	Ext Trigger Input
Controlled by Internal Timing Generator	Controlled by Internal Timing Generator	Trigger In BNC

Table 3. Timing Mode, Shutter Control, and Ext. Trigger Input when using the Internal Timing Generator

### Notes:

1. These automatically set parameters may not be visible in some versions of the software.
2. The **Accumulations** and **Images** (or **Spectra**) parameters (WinView/32 or WinSpec/32 Acquisition Setup **Main** tab) govern how the data will be processed. Integrating multiple events on the CCD really brings the power of the PI-MAX3 to bear on low-light gate-mode experiments. If the experiment allows, many pulses can be summed on the CCD with no pulse artifacts in the readout. The signal increases nearly linearly with the number of pulses (within limits imposed by the CCD).

## MCP Bracket Pulsing

### Introduction

The principal utility of gating is that it allows temporal discrimination against background light. By allowing the photocathode to “see” only during the event of interest, very high background illumination levels can be tolerated without materially degrading experiment results. The limit on this technique is set by the light leakage of the intensifier, which, although it is very good, is not without limit. In the visible, the on/off ratio of a typical Gen II Intensifier with just the photocathode gated is excellent, typically between  $10^6$  and  $10^7$ . In most measurements, this ratio is sufficient to assure that the signal reaching the CCD during the intensifier Off times will be too small to affect the data.

Below 350 nm, however, a second leakage mechanism occurs, optical leakage through the photocathode to the UV-sensitive MCP, which reduces the On:Off ratio to about  $2 \times 10^4$  at 200 nm. This is the dominant response of a Gen II image intensifier to UV photons when the photocathode is electrically off. At an On:Off ratio of 20,000, the ability of a camera with conventional photocathode (only) gating to perform certain kinds of measurements in the UV is adversely affected.

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\* An internal timing generator pulse ensemble consists of a Gate Start pulse, a Gate Stop pulse, and one or more Auxiliary pulses.

MCP bracket pulsing\*\* keeps the MCP biased OFF except for an interval that brackets the timing of the photocathode gate as shown in Figure 34. For emitted photoelectrons to be accelerated in the MCP, the MCP must be biased ON. In conventional intensified cameras, the MCP is biased ON continuously. In the PI-MAX3, however, when bracket pulsing is ON, the MCP is biased OFF until just before the photocathode is gated ON and is biased OFF shortly after the photocathode is biased OFF.

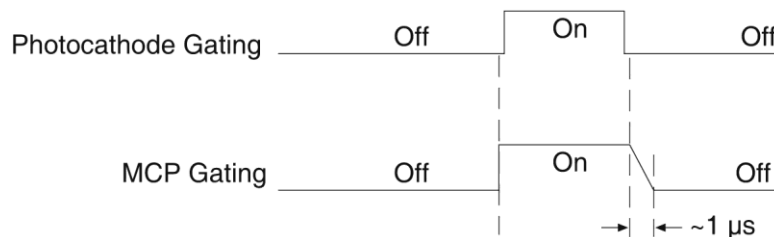


Figure 34. Timing: Bracket Pulsing

By bracket pulsing the MCP off (in addition to photocathode gating), the on/off ratio of the Gen II PI-MAX3 in UV is improved by 2-3 orders of magnitude. The resulting UV ratio exceeds even the high levels normally achieved in the visible. Applications that benefit from this new approach include LIF and nanosecond pump-probe experiments.

**Note:** Bracket pulsing does not help in the visible region. Under extremely low duty-factor conditions, the only remedy is to install an external shutter ahead of the camera.

### **Bracket Pulsing in LIF Measurements**

Most experiments using laser-induced fluorescence to probe combustion flows are performed with UV probe/lasers. Atomic emission from flames also has significant UV content. If the flame is continuous, the UV background will also be continuous. Even where a flame is transient (e.g. internal combustion engine), its lifetime can be many milliseconds, compared to the nanosecond time scale of the laser used. This background can be a million times as long. If the background is bright, then a UV on/off ratio of 20,000:1 will be overwhelmed by the duty cycle and will not be adequate for extracting a signal of  $10^{-5}$ . In high dynamic range quantitative measurements, backgrounds must be kept to an absolute minimum. MCP bracket pulse gating dramatically improves the rejection of CW and even millisecond time-scale background.

An alternative to suppressing background for imaging has been the use of very narrow spectral bandpass filters. In the UV, these filters are expensive and they can have low transmission at their central wavelength. An additional filter is required for each wavelength to be imaged. The use of electronic temporal rejection of CW or quasi-CW background may make it unnecessary to use these filters, thus increasing the optical throughput, sensitivity, and quantitative precision of the measurement.

### **Bracket Pulsing in Nanosecond Pump Probe Experiments**

Some nanosecond pump-probe experiments combine a nanosecond or faster pump with a flashlamp probe. The duration of the probe flash can be 10-50  $\mu$ s and a gate is used to select the specific nanosecond-scale time slice to be observed within the much longer probe flash. In these absorbance experiments, accurate measurement of absorbance values depends critically on the lack of stray light contamination, particularly at moderate

\*\* Bracket pulsing is not available for cameras having a filmless Gen III Intensifier. Gen III Intensifiers do not respond in the UV.

to high optical density levels. Selecting a 5 ns time window out of a 10  $\mu$ s pulse is already one part in 2,000. If UV leakage gives an on/off ratio of only 20,000:1, contamination could be 10% or higher. This would limit the optical density to 1.0, and it could make linear quantitation difficult beyond 0.1 OD.

MCP bracket pulse gating can substantially improve the on/off ratio in such an experiment. Even with a 1  $\mu$ s MCP pulse, the rejection of flash-lamp leakage can add more than an order of magnitude of range, to 2.0 OD.

### ***Limitations of Bracket Pulse Gating***

MCP bracket pulse gating is most useful in rejecting background that lasts microseconds up to CW. Fast transient backgrounds can be in the form of stray laser light scattering (Rayleigh, MIE, Raman) or unwanted fast fluorescence. Because these usually fall below the MCP bracket pulsing 35 ns delay restriction, these measurements cannot be improved much by MCP bracket pulsing in the PI-MAX3.

Electrically, gating the MCP will only reduce leakage at wavelengths where the MCP has photoelectric response (primarily in the UV). Thus, for visible and NIR wavelengths where leakage is primarily optical, the improvement will be minimal (although the on/off ratio is already very good in these regions). Note that in some spectroscopic applications, visible leakage may appear to be reduced by MCP pulsing. This is because the second order UV spectrum overlays the first order visible spectrum in a grating spectrograph. MCP pulsing can eliminate unwanted sensitivity to CW or quasi-CW second order UV, causing the apparent improvement.

Also, keep in mind that MCP bracket pulsing adds 10 ns delay to the photocathode gating. Even though the bracket timing is controlled automatically by the software, in an experiment where it is necessary to delay the arrival of the laser pulse at the sample, this will mean inserting an additional delay of 10 ns (min gate delay = 25 ns, with bracket = 35 ns) to accomplish coincidence at the detector. MCP bracketing should only be used in experiments where it is going to make a difference.

Also, MCP bracket gating limits the repetition rate to 6.25 kHz, without it the gate repetition rate can be up to 1 MHz (more with option boards). This is not a significant limitation in most cases. Note that with a 10 ns gate at 6.25 kHz, the on/off ratio = 16,000, close to the non-bracket value.

Note that background light need not be the limiting factor in measurements where MCP bracket pulsing is unable to provide the required degree of rejection. In such measurements, the option remains of installing an external shutter ahead of the PI-MAX3.

### ***Impact of Bracket Pulsing on Delay***

*If operating in the UV* when bracket pulsing is activated (Gen II Intensifier only), the MCP gate automatically brackets the photocathode gate pulse to further enhance the on/off ratio. There is, however, a limitation of bracket pulsing that can complicate the coincidence of the signal and gate at the camera. Because MCP bracket gating is slower than photocathode gating (35 ns is required to gate the MCP on and another 1  $\mu$ s to gate the MCP off at the end of the photocathode gate). As a result, MCP bracket pulsing should not be used in experiments where the delay between the trigger and the photocathode gate is less than 35 ns.

## Setup

MCP Bracket pulse implementation is accomplished by selecting **Bracket Pulsing ON** from the host software. Figure 35, is a timing diagram for bracket pulsing. Insertion delay between trigger and T0 is  $\sim 12$  ns. Insertion delay to photocathode gate is 35 ns (i.e., the minimum delay in bracket mode is 35 ns); this delay allows the MCP to be up to “full gain” before the photocathode is gated on.

**Note:** Because *Gen III* Intensifiers do not respond in the UV, bracket pulsing is not available for these intensifiers.

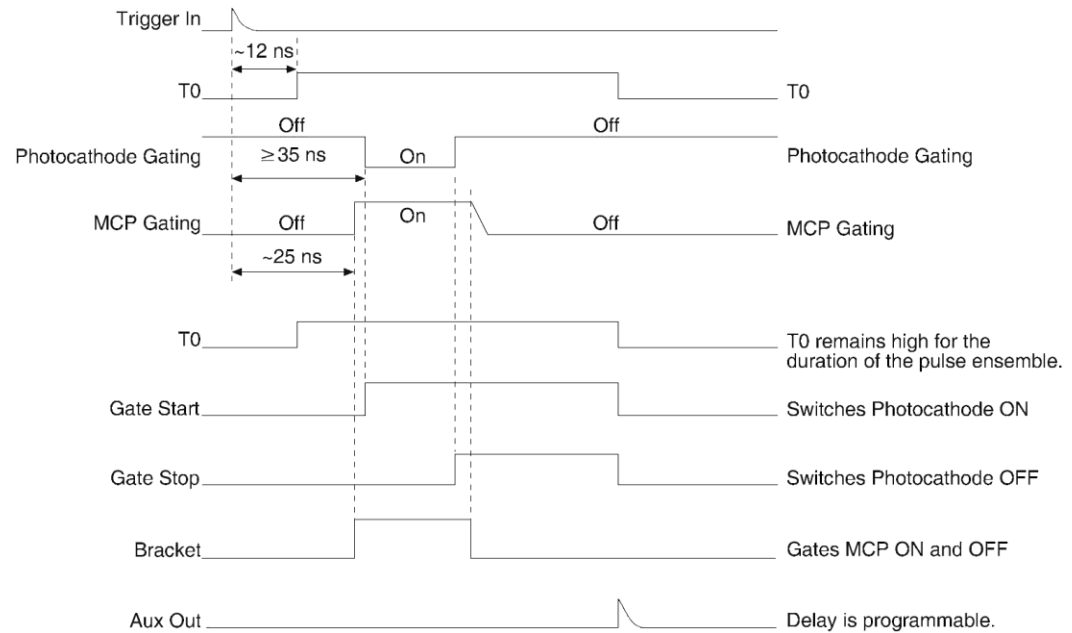


Figure 35. PI-MAX3 Timing for MCP Bracket Pulsing

## Additional Experiments

### Introduction

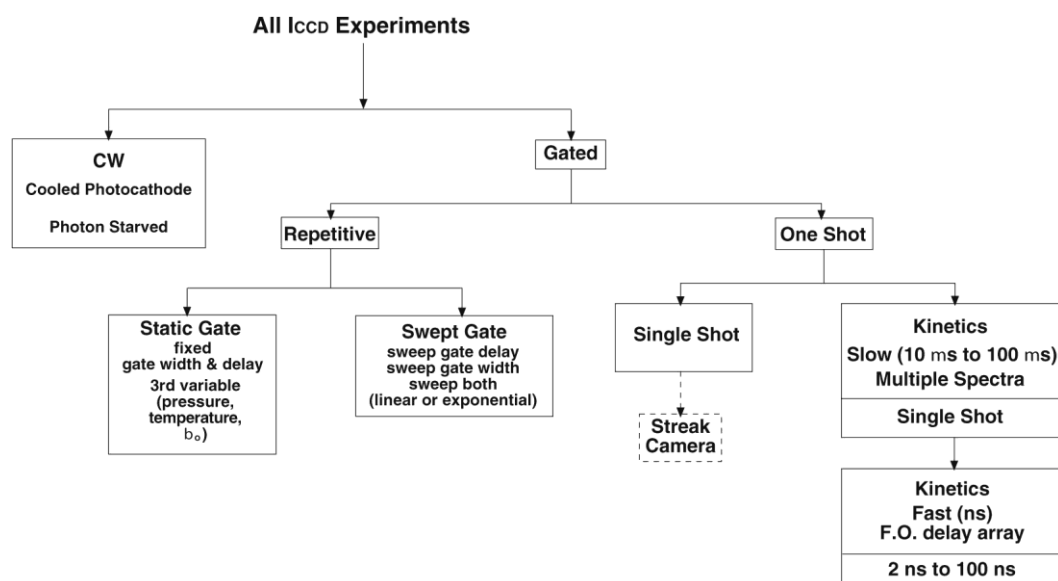


Figure 36. Experiments with the PI-MAX3

Figure 36 illustrates the kinds of experiments that can be performed with a PI-MAX3 detector. Of the many gated measurements that can be performed with a PI-MAX3, most will fall in one of the following categories:

- **Static Gate:** This type of experiment may also be referred to as “Repetitive-Continuous”. There is a repetitive trigger, and the Gate Width and Gate Delay are fixed. Some variable in the experiment such as pressure, concentration, wavelength or temperature is varied.
- **Swept Gate:** In this type of experiment, Gate Width, Gate Delay, or both may be varied.

**Repetitive-Sequential 1:** The Trigger is repetitive, Gate Width is fixed, and Delay is varied over the course of the measurement. The result of the experiment is a plot of intensity vs. time, such as might be obtained with a sampling oscilloscope. This technique is used to measure lifetime decays.

**Repetitive-Sequential 2:** The Trigger is repetitive and Gate Width and Delay are varied over the course of the measurement. Gate Width and Delay can be incremented in a linear fashion or in an exponential fashion. Increasing the Gate Width is useful for trying to find fine detail in a weak decaying signal. If you choose linear, you have to take a lot more points. Exponential lets you take data points closer together where the signal is changing rapidly and further apart where the signal is changing slowly.

- **Single Shot:** A single shot experiment is one where you have only one chance to catch the data. Any experiment that can't be repeated more often than once a minute, such as high power lasers and explosives, is considered a single shot. You have to catch the trigger when it comes. Prior to the event, the CCD runs in continuous cleans mode. You don't have the luxury of having the CCD just sitting there doing nothing because the

CCD will be accumulating dark current. When the trigger arrives, the intensifier gates, the continuous cleans stop, and the array is read out with a minimum of dark current. Pre-Trigger can be helpful if available.

The next section provides step-by-step instructions, along with diagrams and screen shots, for setting up and performing a Swept Gate experiment with fixed Gate Width and variable Gate Delay (type Repetitive-Sequential 1).

### **Procedure for Setting up and Performing a Swept Gate Experiment (Fixed Width, Variable Delay)**

This experiment is an attempt to time-resolve a Xenon light flash from a commercially available strobe light. Since the strobe does not have a “pretrigger” out, an electrical trigger is generated by using a photodiode. Output from the photodiode is connected to the **Trigger In** BNC of the PI-MAX3 (Figure 37). Then perform the steps that follow.

#### **Experiment is Master Clock**

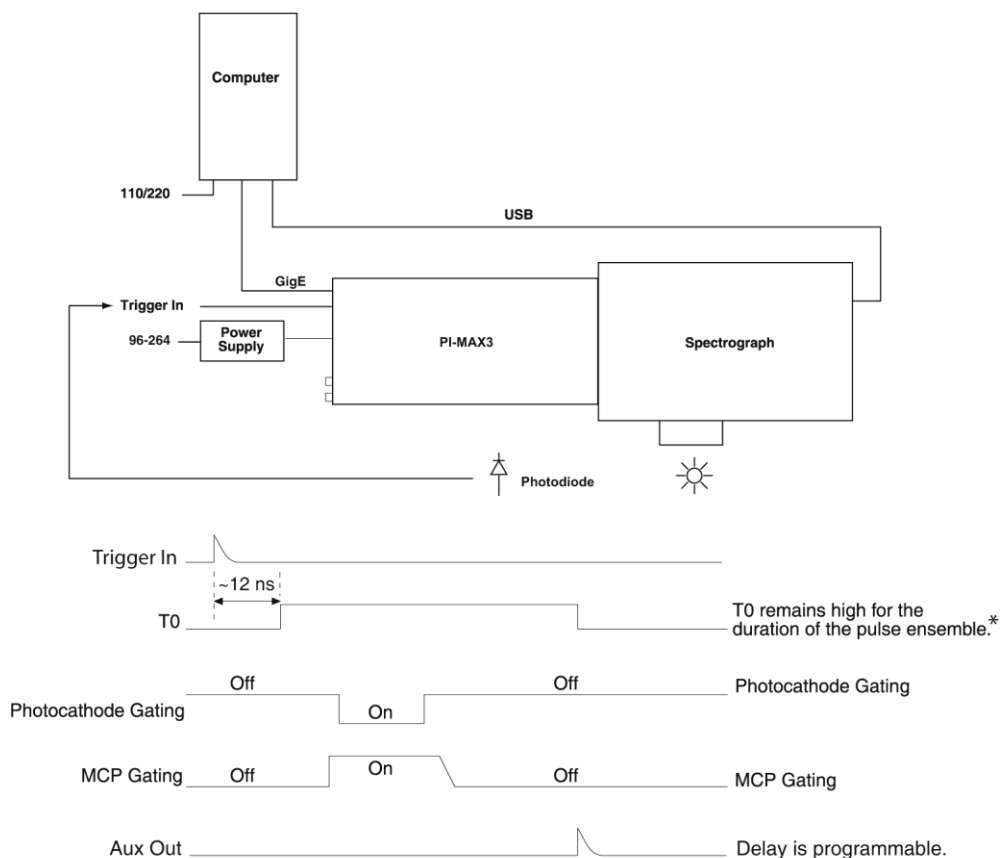


Figure 37. Experiment is Master Clock: Hardware Setup and Timing Diagram

### Experiment as Master Clock

The following procedure uses the experiment as the master clock and therefore refers to connections as shown in Figure 37.

1. Switch on the equipment and start the WinX application software (Ver. 2.5.25 or higher).
2. Open the **Setup|Hardware|Hardware Setup** dialog. The screen should resemble Figure 38, which shows the setup for a KAI 1024x1024 interline camera.

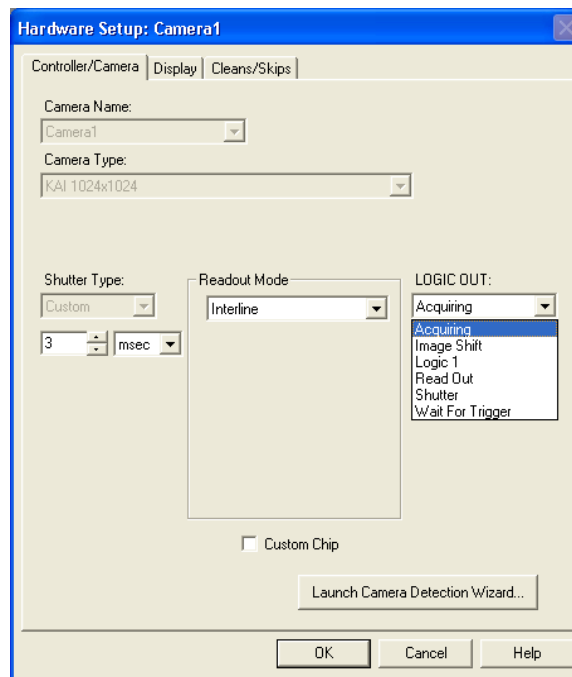


Figure 38. Hardware Setup: Controller/ Camera tab

- a. Click on “Load Default Values” on the Cleans/Skips tab.
  - b. Set the detector temperature by selecting “Detector Temperature” on the Setup menu, entering the Target Temperature information, clicking on “Set Temp” and then clicking on “OK”. You may want to refer to the WinView/32 or WinSpec/32 manual, as appropriate.
3. If you have a spectrograph, set the spectrograph properties by using the menu items on the “Spectrograph” menu (WinSpec/32 only). If the spectrograph you will be using has not been installed, first click on “Install/Remove Spectrograph” and do so before setting the properties. Figure 39 shows the WinSpec/32 sequence for an Action 300I spectrograph.

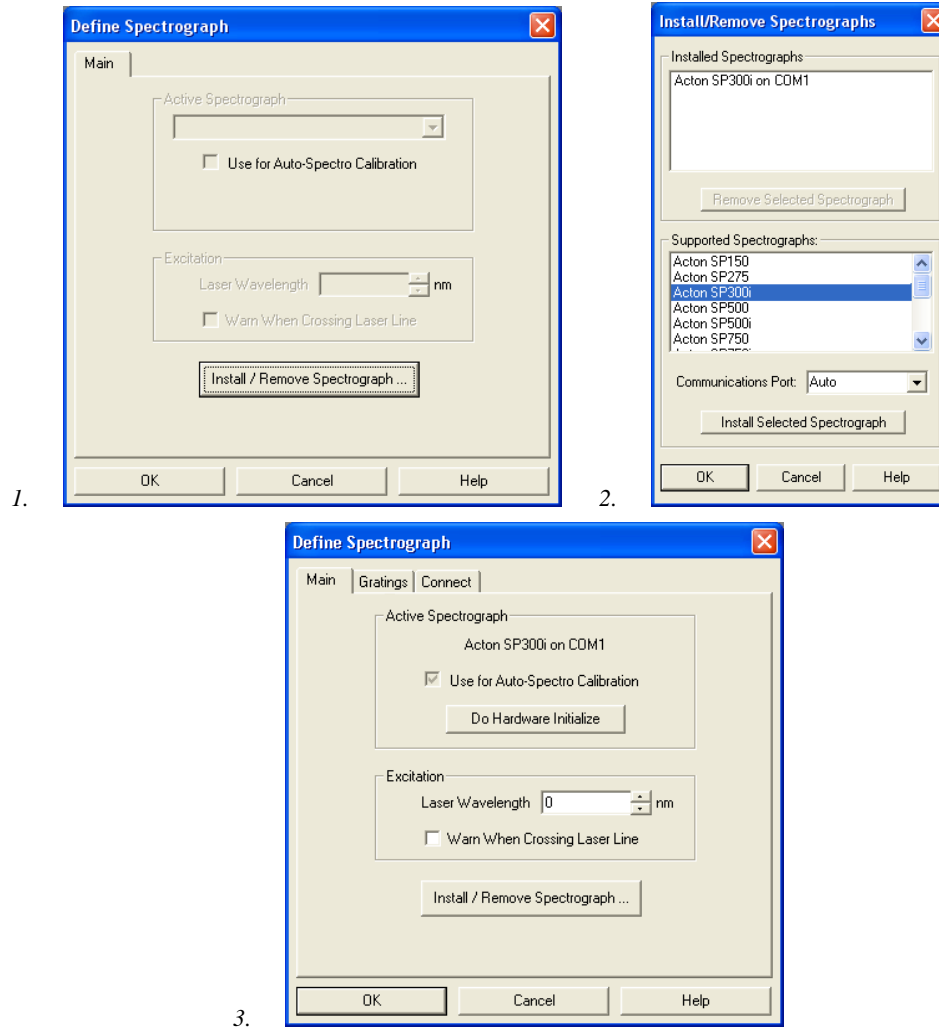


Figure 39. Define Spectrograph and Install/Remove Spectrographs dialogs

4. After you have installed and defined the spectrograph, move the grating to the desired wavelength.

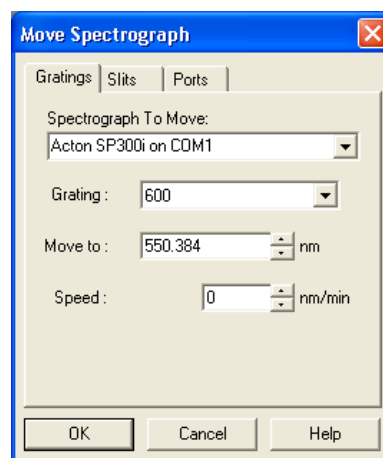


Figure 40. Move Spectrograph dialog



5. At this point, it is a good practice to make sure that the camera is focused by running it in “Internal Trigger” mode. This requires that you set the experiment parameters on the Experiment Setup tabs (refer to Figure 41 and Figure 42) and on the SuperSYNCHRO Trigger tab (Figure 43).
  - a. On the **Experiment Setup|Main** tab, choose **Gate Mode**, and set a value between 0 and 100 for MCP gain.
  - b. On the **Timing** tab, select **Fast Mode**.
  - c. On the **ADC** tab, select the appropriate rate.
  - d. On the **ROI Setup** tab, select the appropriate ROI.
  - e. On the **SuperSYNCHRO Trigger In** tab, select **Internal**.

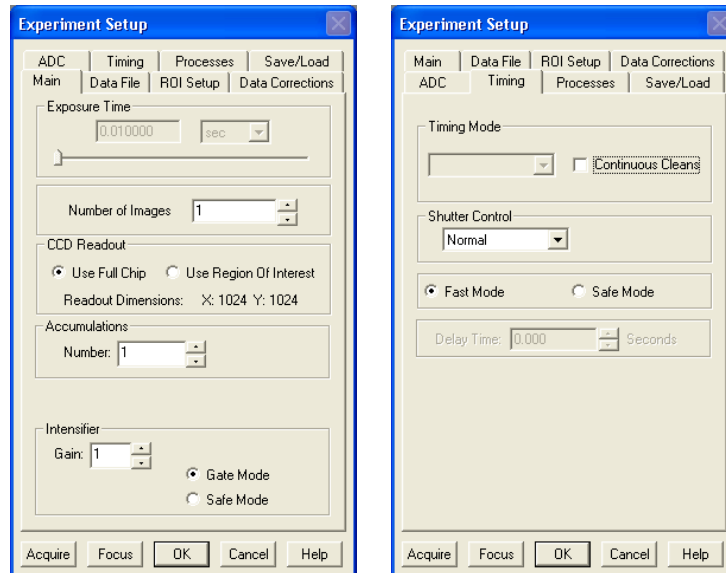


Figure 41. Experiment Setup: Main and Timing tabs

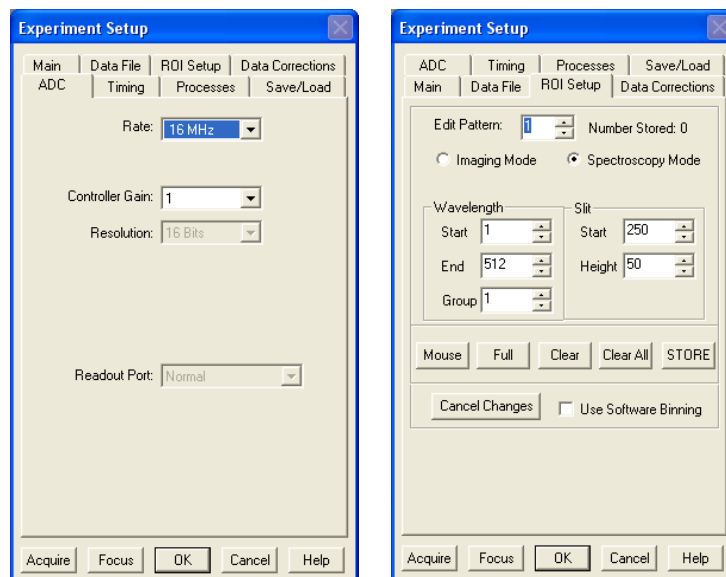


Figure 42. Experiment Setup: ADC and ROI Setup tabs

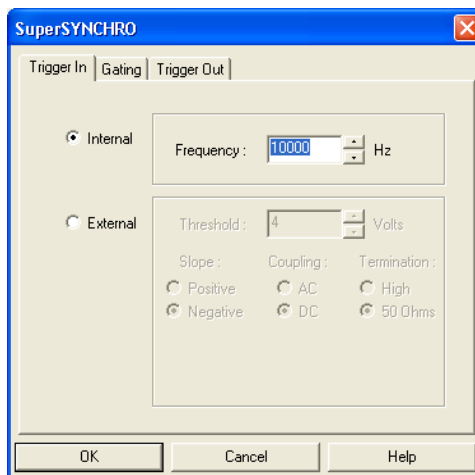


Figure 43. SuperSYNCHRO: Trigger tab

6. After setting the parameters and making sure the ambient light level is low, click on **Focus**.
7. If the readout mode is currently set to “Use Region of Interest” on the Main tab, the camera will start acquiring data immediately. If the readout mode is currently set to “Use Full Chip” you will be asked if you want to change the setting to “Use Region of Interest” before focus mode is activated. Click on “Yes” and the camera will begin acquiring data.
8. After you make sure that the camera is seeing, stop data acquisition.
9. Set up the pulser (SuperSYNCHRO). The following figures show typical examples of the screens you would use to set up the SuperSYNCHRO.
  - a. After selecting the SuperSYNCHRO as the active pulser, click on “Setup Pulser...”. Define the external trigger on the **Trigger In** tab. See Figure 44.
  - b. On the **Gating** tab, select **Sequential** as the Active Mode and then click on “Setup...”. If you have a Gen II intensifier, set Bracket Pulsing to OFF for this experiment. See Figure 44.

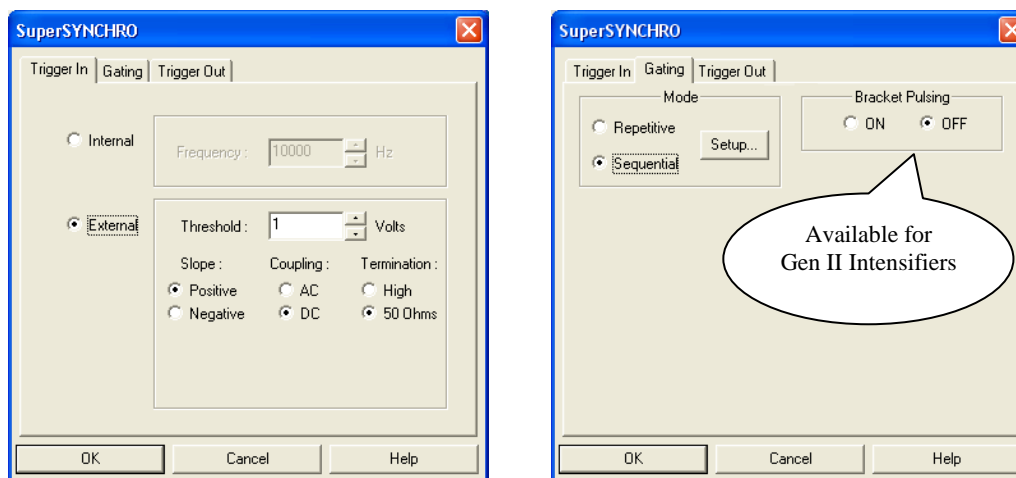


Figure 44. SuperSYNCHRO: Trigger In and Gating tabs

- c. Click on “Setup...” and define the pulse sequence on the Sequential Gating Setup dialog. See Figure 45.
- Enter the number of spectra to be acquired (in this case, 41).
  - Select “Fixed Increment”.
  - Enter the start and end times for the gate width. (Since this experiment requires a fixed gate width these values will be the same.)
  - Enter the start and end durations for the gate delay. (For this experiment, the start delay is 1  $\mu$ s and the end delay is 201  $\mu$ s.)
  - Then select the number of gates per exposure (in this case, 1).
  - To check the gate delay for each of the 41 spectra, click on “View Width/Delay Sequence.”

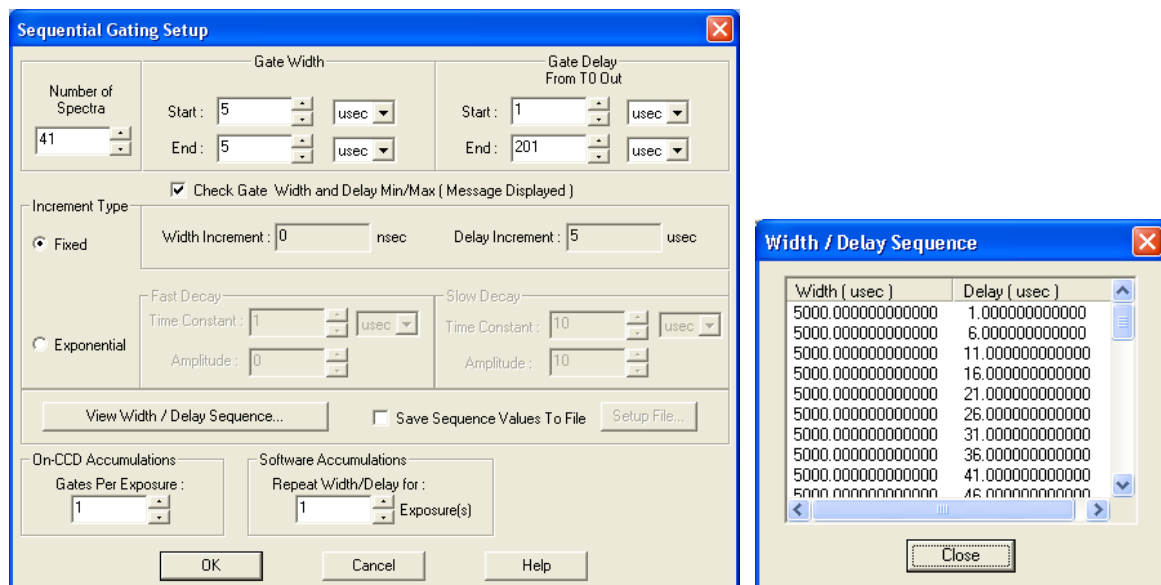


Figure 45. Sequential Gating Setup and Width/Delay Sequence dialogs

- d. The functions on the **Trigger Out** tab allow you to enable the SyncMASTER™ trigger output from the SyncMASTER1 and SyncMASTER2 connectors on the **AUX I/O** cable and set up the Aux. Out signal at the **AUX OUT** connector on the rear of the PI-MAX3.
- When you enable **SyncMASTER 1**, the output of the SyncMASTER1 connector will be at the frequency entered on the **Trigger In** tab.
  - The output of the **SyncMASTER2** connector will be at the same frequency as that of SyncMASTER1. However, you can enter a delay so the edges of that signal will occur after the edges of SyncMASTER1.
  - If you are using the **Aux. Out** signal from the SuperSYNCHRO to trigger a piece of equipment, then enter the Auxiliary pulse delay time on the **Trigger Out** tab (Figure 46). The delay is based on T0 (in effect it is a delay from SyncMASTER1 which also starts at T0). Enter the pulse width needed to trigger the equipment.

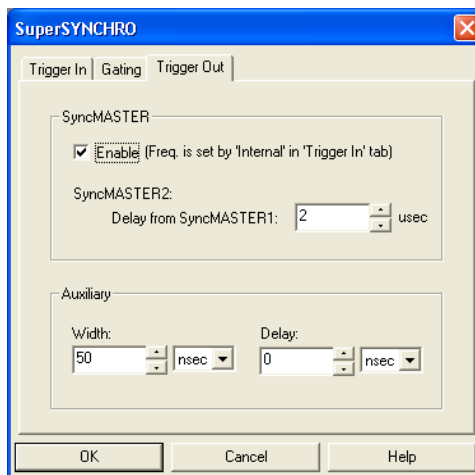


Figure 46. Trigger Out tab

- e. Click on **OK** to program the SuperSYNCHRO.
10. Set up the experiment parameters from the Experiment Setup dialog.
    - a. On the **Timing** tab, change the timing as shown in Figure 47.
    - b. On the **Main** tab, enter the **Gain** value and switch to **Gate Mode**. The number of spectra will be automatically set depending on the number entered on the Sequential Gating Setup dialog (Figure 45).

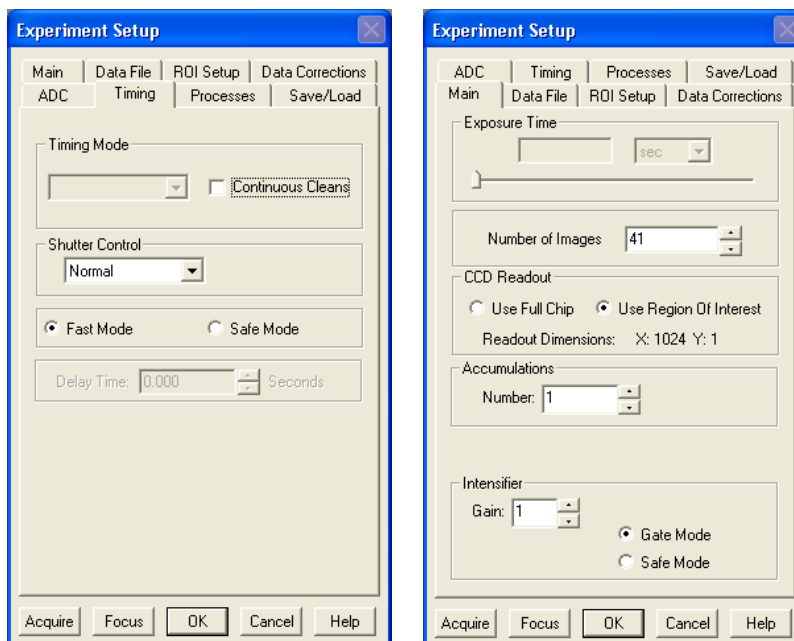


Figure 47. Experiment Setup: Timing and Main tabs

**Note:** In **Gate Mode**, the photocathode is biased on only for the time that each gate pulse is applied. This limits the risk of damage resulting from room light. However, there is a risk of damaging overload from intense light sources such as lasers.

11. After verifying all connections and equipment readiness, click on **Acquire** to begin acquiring the spectra (or images).
12. Figure 48 displays the 3-D graph for a “Sequential-Repetitive” experiment with Fixed Width and Variable Delay (as set in Figure 44 and Figure 45).

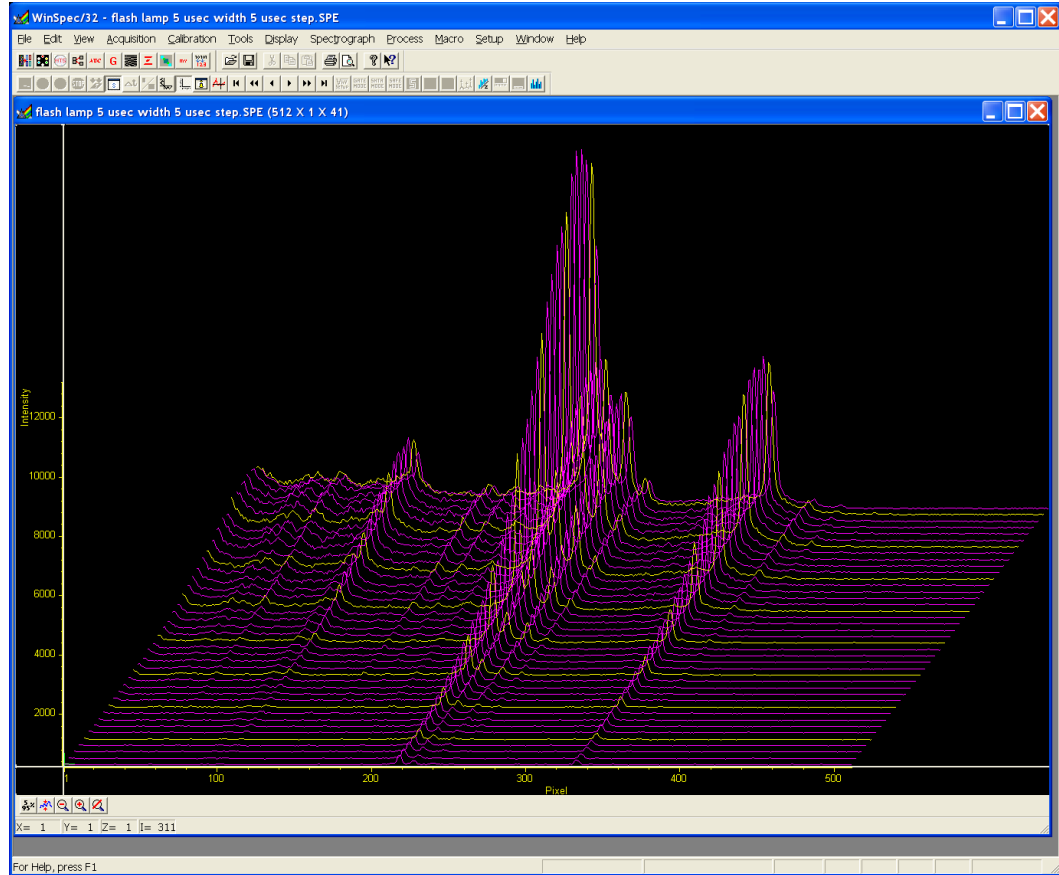


Figure 48. Experiment Results in 3-D

### SyncMASTER1 as Master Clock

If you have a light source that has a “Trigger In”, the PI-MAX3 SyncMASTER function can be used as the Master clock (cable connections shown in Figure 49). The setup procedure is much the same as that given for the “Experiment as Master Clock”. The differences are that Internal Trigger is selected, SyncMASTER is enabled, and a cable is connected between the PI-MAX3’s AUX I/O cable’s SyncMASTER1 BNC and the light source (experiment) for triggering the event.

#### PI-MAX3 SyncMASTER1 is Master Clock

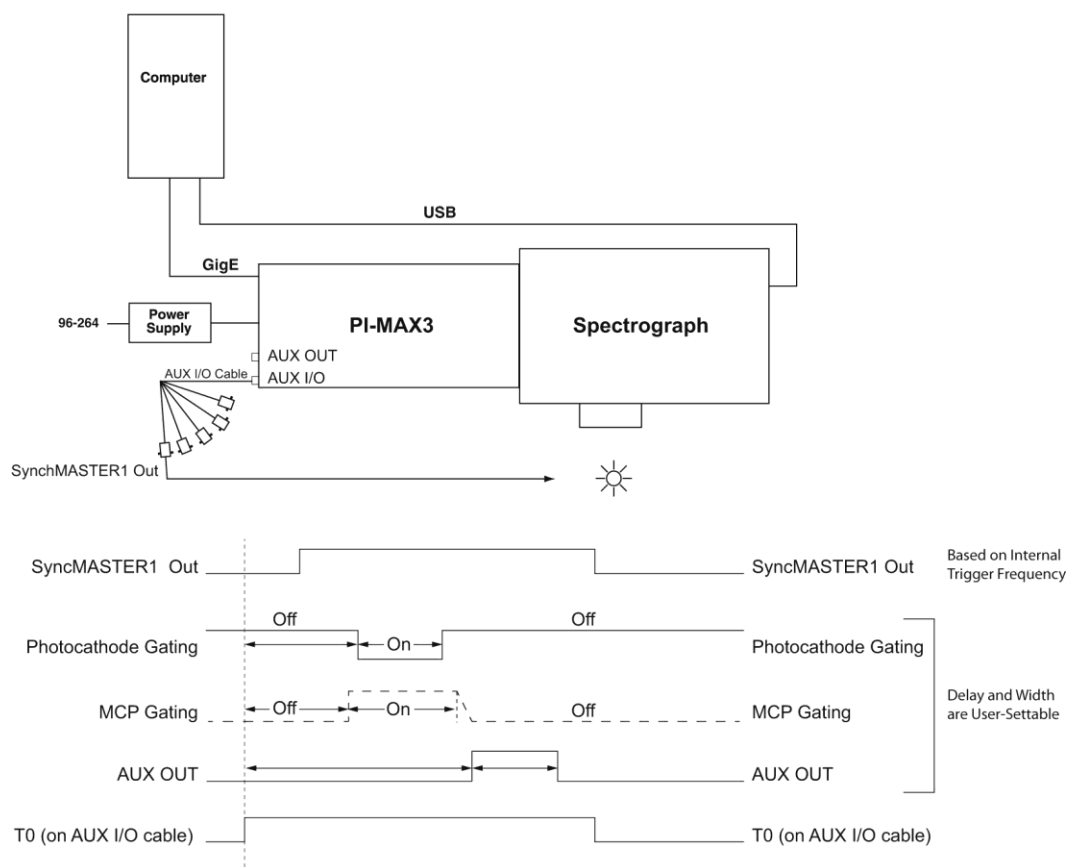


Figure 49. PI-MAX3 SyncMASTER is Master Clock: Hardware Setup and Timing Diagram

### Procedure for Setting up and Performing a Single Shot Experiment

A single shot experiment offers only one chance to capture an event. As in any gated experiment, the “time budget” of the experiment is crucial. If there is no pre-trigger from the experiment, a photodiode can be used to generate an electrical trigger from the laser light. In this situation, light has to be delayed by optical means (fiber-optic cable or mirror reflections) to allow sufficient time for the electronics to be activated after receiving the trigger. Another important thing to note in single shot experiments is that the CCD is set in “Continuous Cleans” mode so that there is no dark charge accumulation while it is waiting for the trigger.

The following experiment is an attempt to capture a 60 ns fluorescence generated by a single shot laser. The time budget of the experiment is shown in Table 4. This information is important in order to choose the correct length fiber-optic cable.

Delay Source	Delay (ns)	Total Delay (ns)	Fiber-Optic Cable Length
Photodiode (light -> TTL pulse)	2	30	A minimum of 21 ft of fiber-optic cable is required.
Photodiode -> PI-MAX3 (2 ft BNC cable)	3		
PI-MAX3	25		

Table 4. Single Shot Experiment Time Budget

In this experiment, the cables are kept as short as possible to minimize the length of the fiber-optic cable required.

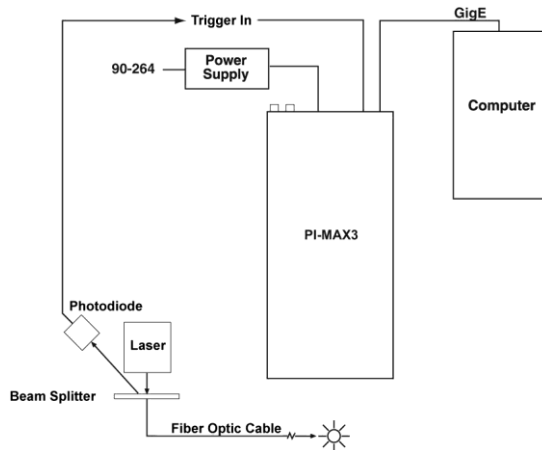


Figure 50. Single Shot: Hardware Setup

After setting up the appropriate hardware, as shown in Figure 50, default values for “Cleans and Skips” are loaded (Figure 51). If the CCD has to wait more than a few seconds for the external trigger, it is advisable to increase the number of cleans.

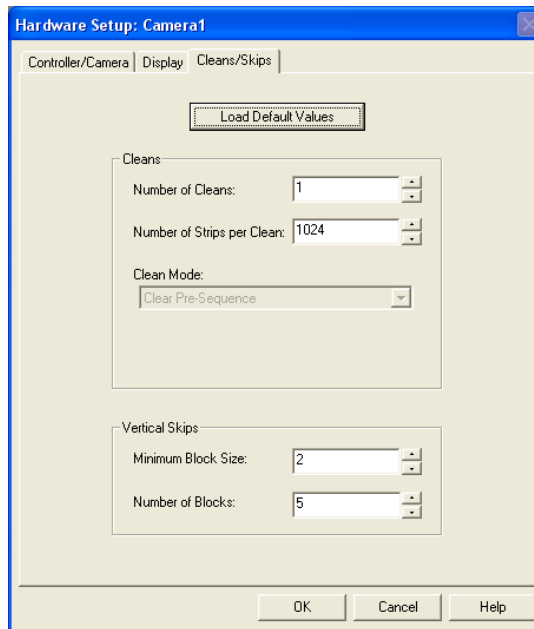


Figure 51. Cleans and Skips: Default Values Loaded

The sequence of operations is similar to the “Sequential” experiments. After focusing the camera on the fluorescing sample, the camera is set in “Gate” mode and the appropriate Gain is selected (Figure 52).

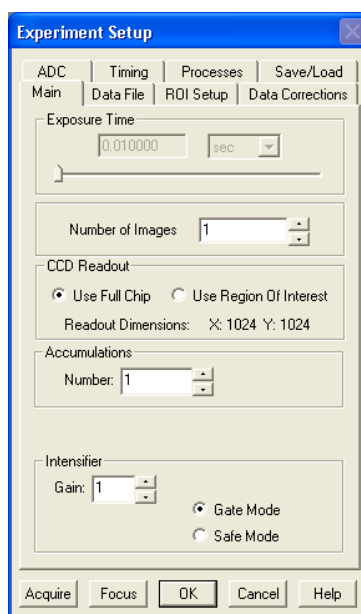


Figure 52. Experiment Setup: Gain Selected

Gate width and gate delay are set in such a way that the intensifier is gated ON during the entire event (in this case the event is a 60 ns fluorescence).

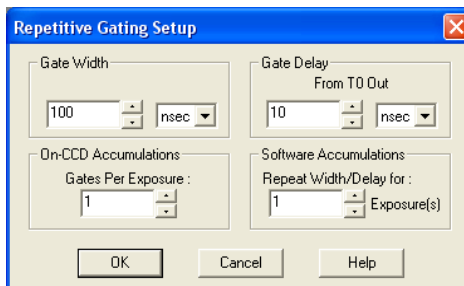


Figure 53. Repetitive Gating Setup: 100 ns Width, 10 ns Delay

Figure 54 shows the result of the experiment. Figure 55 shows the peak obtained by binning, in the vertical direction, the entire region around the fluorescence spot.



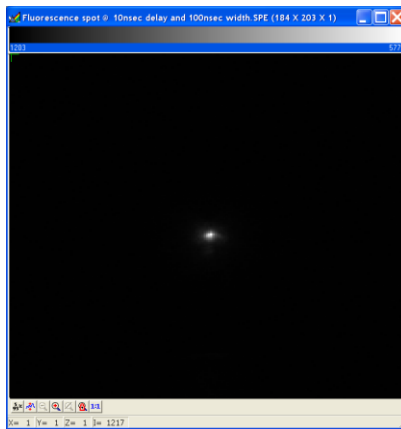


Figure 54. Single Shot Result: Fluorescence Spot, 100 ns Width, 10 ns Delay

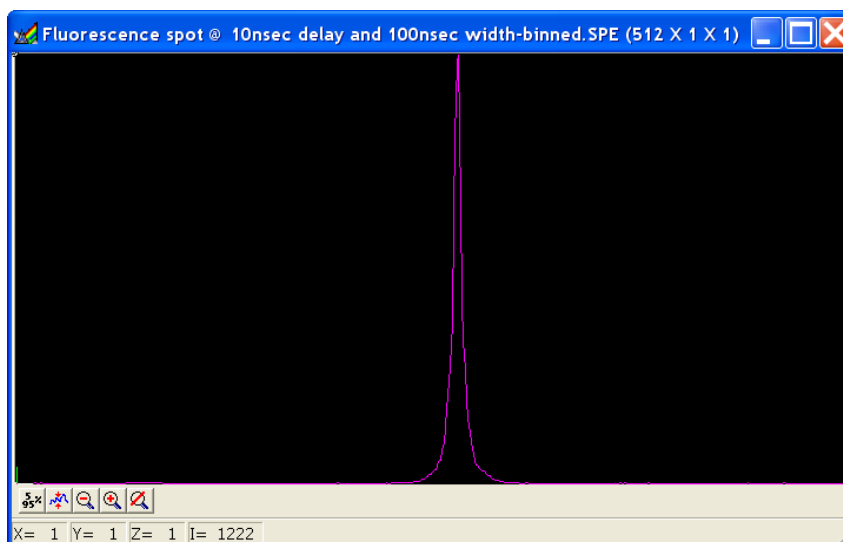


Figure 55. Single Shot Result: Fluorescence Spot, 100 ns Width, 10 ns Delay, Binned Vertically

### **Procedure for Setting up and Performing a Swept Gate Experiment (Variable Width, Variable Delay)**

The sequence of steps for a Swept Gate experiment with variable width and delay is similar to the Swept Gate experiment with fixed width and variable delay but with the following exception:

- In addition to entering differing start and end values for the Gate Delay, you would also enter differing start and end values for the Gate Width.

### ***Procedure for Setting up and Performing a Static Gate Experiment (Fixed Width, Fixed Delay)***

The sequence of steps for a Static Gate experiment is similar to the Swept Gate experiment but with the following exceptions:

- The Gate Mode would be **Repetitive**.
- The Gate Width and Gate Delay values would be entered in the dialog shown in Figure 56.

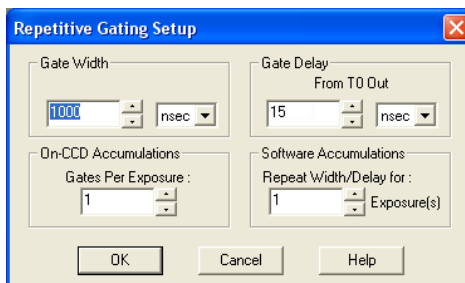


Figure 56. Repetitive Gating Setup dialog

# Chapter 7

## LightField and Gated Operation

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### Introduction

This chapter discusses gated operation with the SuperSYNCHRO™ timing generator and aspects of operation of the PI-MAX3 not covered in Chapter 4, *First Light*. We additionally suggest that you review Chapter 13, *Tips and Tricks*, which contains information that should prove helpful in getting good results in more complex measurements.

Gating provides electronic shutter action by controlling the photocathode bias, allowing the detection of low light level signals in the presence of interfering light sources of much greater energy. For instance, in combustion research, a pulsed laser probe is used to investigate the chemistry within a flame. Since the flame itself emits broadband light continuously, the integrated flame emission is much greater than the integrated signal resulting shortly after the laser probe (such as laser-induced fluorescence or Raman). Fortunately, since the laser pulse is very short and the time at which it occurs is known, it is possible to gate for a few nanoseconds during the laser pulse, thus reducing the flame emission interference by approximately the measurement duty factor ratio.

Exposure time is the 'time space' from which charge integrating on the CCD will get summed into the reported data. Gate width is the time during which light will be detected by the intensifier, intensified, and applied to the CCD. Basically, the intensifier controls what the chip 'sees' during the exposure time.

For signal to be detected, it must fall in a valid gate width during a valid exposure. Many gate pulses can be placed into one exposure at repetitive or sequential intervals because there is no temporal measure inside a given exposure (all incident signals get summed (integrated) into one value per pixel/superpixel inside a given exposure).

Using presently available image intensifiers and gate pulse generators, optical gate times  $\leq 4$  ns FWHM (full width at half maximum) are possible. Since the control is electronic, the gate width can be made virtually as long as desired, allowing a wide range of experiment requirements to be satisfied in one instrument setup. Further, in UV measurements, where the On:Off ratio is only  $10^4:1$ , the PI-MAX3's MCP bracketing feature can be used to extend the On:Off ratio to  $10^6:1$ .

## Precautionary Measures

### WARNING

Intensified CCD detectors, such as the PI-MAX3, when biased ON, can be irreparably damaged if continuously exposed to light levels higher than twice the A/D saturation level. Thus it is **critical** that you **not** establish conditions that could result in damage to the intensifier. Although intensified detectors are less prone to damage from *background light* when operated gated, they are at **significant risk** of damage from high-intensity light sources such as lasers. High intensity sources can damage the intensifier before the protection circuits have time to respond, or even cause spot damage without the protection circuits acting at all. If a sustained alarm indication occurs when the controller is turned on, immediately switch the **I.I.T.** switch on the back of the PI-MAX3 to the **OFF** position. Cover the detector window and only switch the **I.I.T.** switch to **ON** after the illumination level has been lowered to safe operating conditions.

### **Intensifier Modes and Safety**

In LightField, you can enable or disable the intensifier on the **Common Acquisition Settings** expander. When the intensifier is enabled, the camera can be gated; when disabled, the photocathode is continuously biased OFF and the intensifier is as safe as it can be.

**Note:** In order for gating to occur, the I.I.T. switch on the back of the PI-MAX3 must also be in the **ON** position.

### **Alarm**

**Note:** It is normal for the alarm to sound briefly when the system is turned on.

To reduce the risk of detector damage, the PI-MAX3 detector is equipped with an audible alarm in the detector head, activated when the intensity of light falling on the image intensifier exceeds a preset threshold. While the alarm is sounding, the photocathode is disabled. Immediately toggle the **I.I.T.** switch (on the back of the PI-MAX) to the **OFF** position. Cover the detector window and only switch the **I.I.T.** switch to **ON** after the illumination level has been lowered. If the alarm sounds continuously even when the illumination level is adequately low, shut the system down and contact the factory for guidance.

### Caution

Discontinue operation and contact the factory at once if sporadic or continuous unwarranted alarms occur. They may indicate intensifier damage or another situation that requires immediate attention.

## Timing Mode

When you are in **Gate Mode**, the internal timing generator will only operate using **Internal Sync** timing. This timing mode initiates a readout cycle after each internal timing generated pulse ensemble.\* The handshakes that prevent a readout from occurring while the timing generator is busy and that prevent the timing generator from pulsing the photocathode ON while a readout cycle is in progress are performed within the camera. For this mode, the following parameters are automatically set by the application software and cannot be changed: **Exposure Time** is set to 0, **Continuous Cleans** is disabled, and **Disabled Opened** is selected for Shutter Control.

Timing Mode	“Shutter” Control	Ext Trigger Input
Controlled by Internal Timing Generator	Controlled by Internal Timing Generator	Trigger In BNC

Table 5. Timing Mode, Shutter Control, and Ext. Trigger Input when using the Internal Timing Generator

### Notes:

1. These automatically set parameters may not be visible in some versions of the software.
2. The **Accumulations** and **Images** (or **Spectra**) parameters (WinView/32 or WinSpec/32 Acquisition Setup **Main** tab) govern how the data will be processed. Integrating multiple events on the CCD really brings the power of the PI-MAX3 to bear on low-light gate-mode experiments. If the experiment allows, many pulses can be summed on the CCD with no pulse artifacts in the readout. The signal increases nearly linearly with the number of pulses (within limits imposed by the CCD).

## MCP Bracket Pulsing

### Introduction

The principal utility of gating is that it allows temporal discrimination against background light. By allowing the photocathode to “see” only during the event of interest, very high background illumination levels can be tolerated without materially degrading experiment results. The limit on this technique is set by the light leakage of the intensifier, which, although it is very good, is not without limit. In the visible, the on/off ratio of a typical Gen II Intensifier with just the photocathode gated is excellent, typically between  $10^6$  and  $10^7$ . In most measurements, this ratio is sufficient to assure that the signal reaching the CCD during the intensifier Off times will be too small to affect the data.

Below 350 nm, however, a second leakage mechanism occurs, optical leakage through the photocathode to the UV-sensitive MCP, which reduces the On:Off ratio to about  $2 \times 10^4$  at 200 nm. This is the dominant response of a Gen II image intensifier to UV photons when the photocathode is electrically off. At an On:Off ratio of 20,000, the ability of a camera with conventional photocathode (only) gating to perform certain kinds of measurements in the UV is adversely affected.

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\* An internal timing generator pulse ensemble consists of a Gate Start pulse, a Gate Stop pulse, and one or more Auxiliary pulses.

MCP bracket pulsing\*\* keeps the MCP biased OFF except for an interval that brackets the timing of the photocathode gate as shown in Figure 34. For emitted photoelectrons to be accelerated in the MCP, the MCP must be biased ON. In conventional intensified cameras, the MCP is biased ON continuously. In the PI-MAX3, however, when bracket pulsing is ON, the MCP is biased OFF until just before the photocathode is gated ON and is biased OFF shortly after the photocathode is biased OFF.

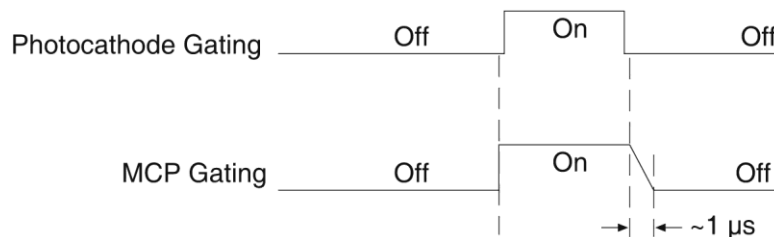


Figure 57. Timing: Bracket Pulsing

By bracket pulsing the MCP off (in addition to photocathode gating), the on/off ratio of the Gen II PI-MAX3 in UV is improved by 2-3 orders of magnitude. The resulting UV ratio exceeds even the high levels normally achieved in the visible. Applications that benefit from this new approach include LIF and nanosecond pump-probe experiments.

**Note:** Bracket pulsing does not help in the visible region. Under extremely low duty-factor conditions, the only remedy is to install an external shutter ahead of the camera.

### **Bracket Pulsing in LIF Measurements**

Most experiments using laser-induced fluorescence to probe combustion flows are performed with UV probe/lasers. Atomic emission from flames also has significant UV content. If the flame is continuous, the UV background will also be continuous. Even where a flame is transient (e.g. internal combustion engine), its lifetime can be many milliseconds, compared to the nanosecond time scale of the laser used. This background can be a million times as long. If the background is bright, then a UV on/off ratio of 20,000:1 will be overwhelmed by the duty cycle and will not be adequate for extracting a signal of  $10^{-5}$ . In high dynamic range quantitative measurements, backgrounds must be kept to an absolute minimum. MCP bracket pulse gating dramatically improves the rejection of CW and even millisecond time-scale background.

An alternative to suppressing background for imaging has been the use of very narrow spectral bandpass filters. In the UV, these filters are expensive and they can have low transmission at their central wavelength. An additional filter is required for each wavelength to be imaged. The use of electronic temporal rejection of CW or quasi-CW background may make it unnecessary to use these filters, thus increasing the optical throughput, sensitivity, and quantitative precision of the measurement.

### **Bracket Pulsing in Nanosecond Pump Probe Experiments**

Some nanosecond pump-probe experiments combine a nanosecond or faster pump with a flashlamp probe. The duration of the probe flash can be 10-50 μs and a gate is used to select the specific nanosecond-scale time slice to be observed within the much longer probe flash. In these absorbance experiments, accurate measurement of absorbance values depends critically on the lack of stray light contamination, particularly at moderate

\*\* Bracket pulsing is not available for cameras having a filmless Gen III Intensifier. Gen III Intensifiers do not respond in the UV.

to high optical density levels. Selecting a 5 ns time window out of a 10  $\mu$ s pulse is already one part in 2,000. If UV leakage gives an on/off ratio of only 20,000:1, contamination could be 10% or higher. This would limit the optical density to 1.0, and it could make linear quantitation difficult beyond 0.1 OD.

MCP bracket pulse gating can substantially improve the on/off ratio in such an experiment. Even with a 1  $\mu$ s MCP pulse, the rejection of flash-lamp leakage can add more than an order of magnitude of range, to 2.0 OD.

### ***Limitations of Bracket Pulse Gating***

MCP bracket pulse gating is most useful in rejecting background that lasts microseconds up to CW. Fast transient backgrounds can be in the form of stray laser light scattering (Rayleigh, MIE, Raman) or unwanted fast fluorescence. Because these usually fall below the MCP bracket pulsing 35 ns delay restriction, these measurements cannot be improved much by MCP bracket pulsing in the PI-MAX3.

Electrically, gating the MCP will only reduce leakage at wavelengths where the MCP has photoelectric response (primarily in the UV). Thus, for visible and NIR wavelengths where leakage is primarily optical, the improvement will be minimal (although the on/off ratio is already very good in these regions). Note that in some spectroscopic applications, visible leakage may appear to be reduced by MCP pulsing. This is because the second order UV spectrum overlays the first order visible spectrum in a grating spectrograph. MCP pulsing can eliminate unwanted sensitivity to CW or quasi-CW second order UV, causing the apparent improvement.

Also, keep in mind that MCP bracket pulsing adds 10 ns, delay to the photocathode gating. Even though the bracket timing is controlled automatically by the software, in an experiment where it is necessary to delay the arrival of the laser pulse at the sample, this will mean inserting an additional delay of 10 ns (min gate delay = 25 ns, with bracket = 35 ns) to accomplish coincidence at the detector. MCP bracketing should only be used in experiments where it is going to make a difference.

Also, MCP bracket gating limits the repetition rate to 6.25 kHz, without it the gate repetition rate can be up to 1 MHz (more with option boards). This is not a significant limitation in most cases. Note that with a 10 ns gate at 6.25 kHz, the on/off ratio = 16,000, close to the non-bracket value.

Note that background light need not be the limiting factor in measurements where MCP bracket pulsing is unable to provide the required degree of rejection. In such measurements, the option remains of installing an external shutter ahead of the PI-MAX3.

### ***Impact of Bracket Pulsing on Delay***

*If operating in the UV* when bracket pulsing is activated (Gen II Intensifier only), the MCP gate automatically brackets the photocathode gate pulse to further enhance the on/off ratio. There is, however, a limitation of bracket pulsing that can complicate the coincidence of the signal and gate at the camera. Because MCP bracket gating is slower than photocathode gating (35 ns is required to gate the MCP on and another 1  $\mu$ s to gate the MCP off at the end of the photocathode gate). As a result, MCP bracket pulsing should not be used in experiments where the delay between the trigger and the photocathode gate is less than 35 ns.

## Setup

MCP Bracket pulse implementation is accomplished by selecting **Bracket Pulsing ON** from the host software. Figure 35, is a timing diagram for bracket pulsing. Insertion delay between trigger and T0 is  $\sim 12$  ns. Insertion delay to photocathode gate is 35 ns (i.e., the minimum delay in bracket mode is 35 ns): this delay allows the MCP to be up to “full gain” before the photocathode is gated on.

**Note:** Because *Gen III* Intensifiers do not respond in the UV, bracket pulsing is not available for these intensifiers.

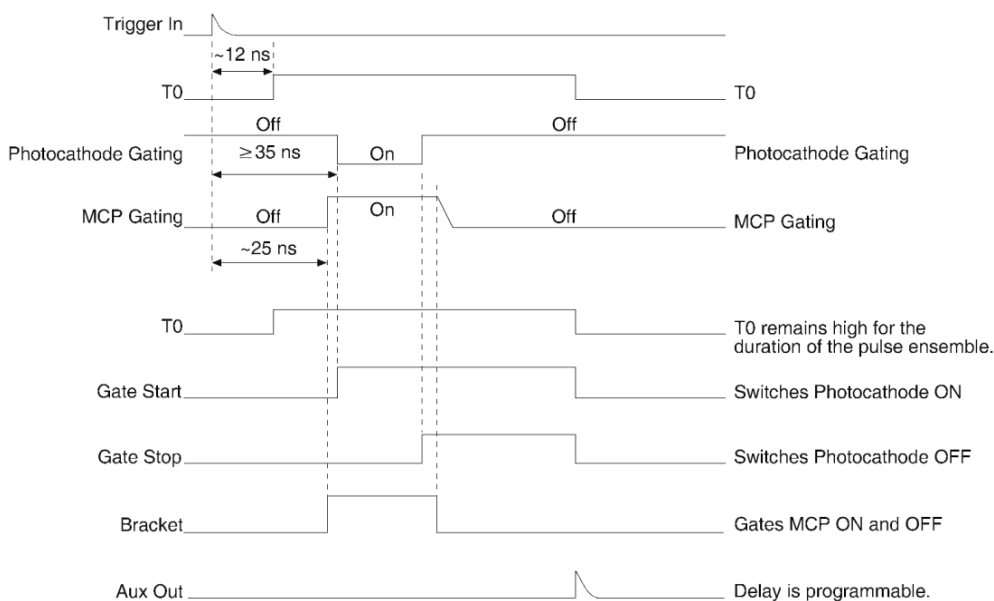


Figure 58. PI-MAX3 Timing for MCP Bracket Pulsing

## Additional Experiments

### Introduction

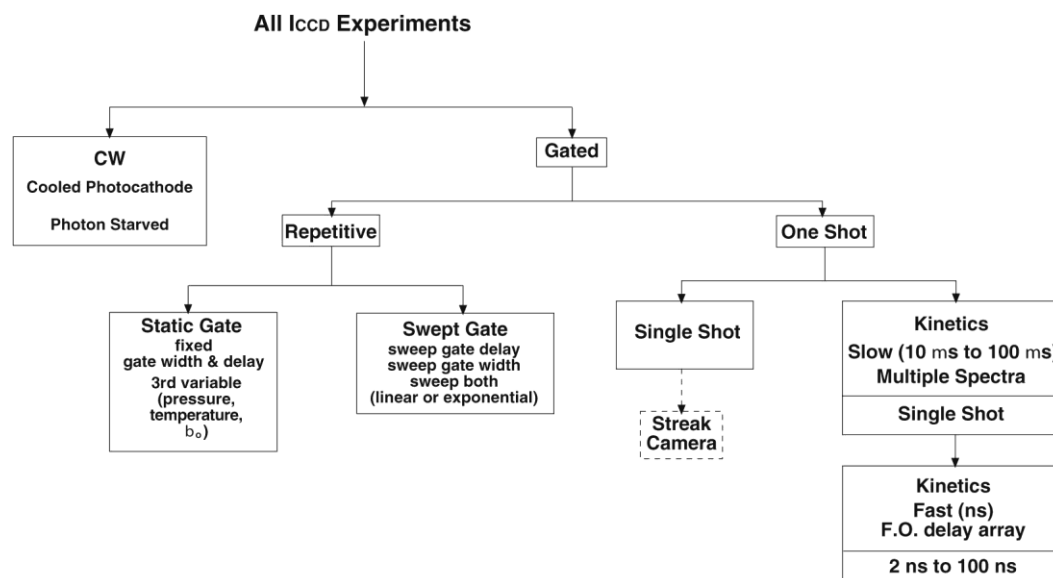


Figure 59. Experiments with the PI-MAX3



Figure 36 illustrates the kinds of experiments that can be performed with a PI-MAX3 detector. Of the many gated measurements that can be performed with a PI-MAX3, most will fall in one of the following categories:

- **Static Gate:** This type of experiment may also be referred to as “Repetitive-Continuous”. There is a repetitive trigger, and the Gate Width and Gate Delay are fixed. Some variable in the experiment such as pressure, concentration, wavelength or temperature is varied.
- **Swept Gate:** In this type of experiment, Gate Width, Gate Delay, or both may be varied.

**Repetitive-Sequential 1:** The Trigger is repetitive, Gate Width is fixed, and Delay is varied over the course of the measurement. The result of the experiment is a plot of intensity vs. time, such as might be obtained with a sampling oscilloscope. This technique is used to measure lifetime decays.

**Repetitive-Sequential 2:** The Trigger is repetitive and Gate Width and Delay are varied over the course of the measurement. Gate Width and Delay can be incremented in a linear fashion. Increasing the Gate Width is useful for trying to find fine detail in a weak decaying signal. If you choose linear, you have to take a lot more points.

- **Single Shot:** A single shot experiment is one where you have only one chance to catch the data. Any experiment that cannot be repeated more often than once a minute, such as high power lasers and explosives, is considered a single shot. You have to catch the trigger when it comes. Prior to the event, the sensor runs in Clean Until Trigger mode. You need to have this active, otherwise dark current would accumulate on the sensor. When the trigger arrives, the cleans stop, the intensifier gates, and the array is read out with a minimum of dark current.

The next section provides step-by-step instructions, along with diagrams and screen shots, for setting up and performing a Swept Gate experiment with fixed Gate Width and variable Gate Delay (type Repetitive-Sequential 1).

### ***Procedure for Setting up and Performing a Swept Gate Experiment (Fixed Width, Variable Delay)***

This experiment is an attempt to time-resolve a Xenon light flash from a commercially available strobe light. Since the strobe does not have a “pretrigger” out, an electrical trigger is generated by using a photodiode. Output from the photodiode is connected to the **Trigger In** BNC of the PI-MAX3 (Figure 37). Then perform the steps that follow.

### Experiment is Master Clock

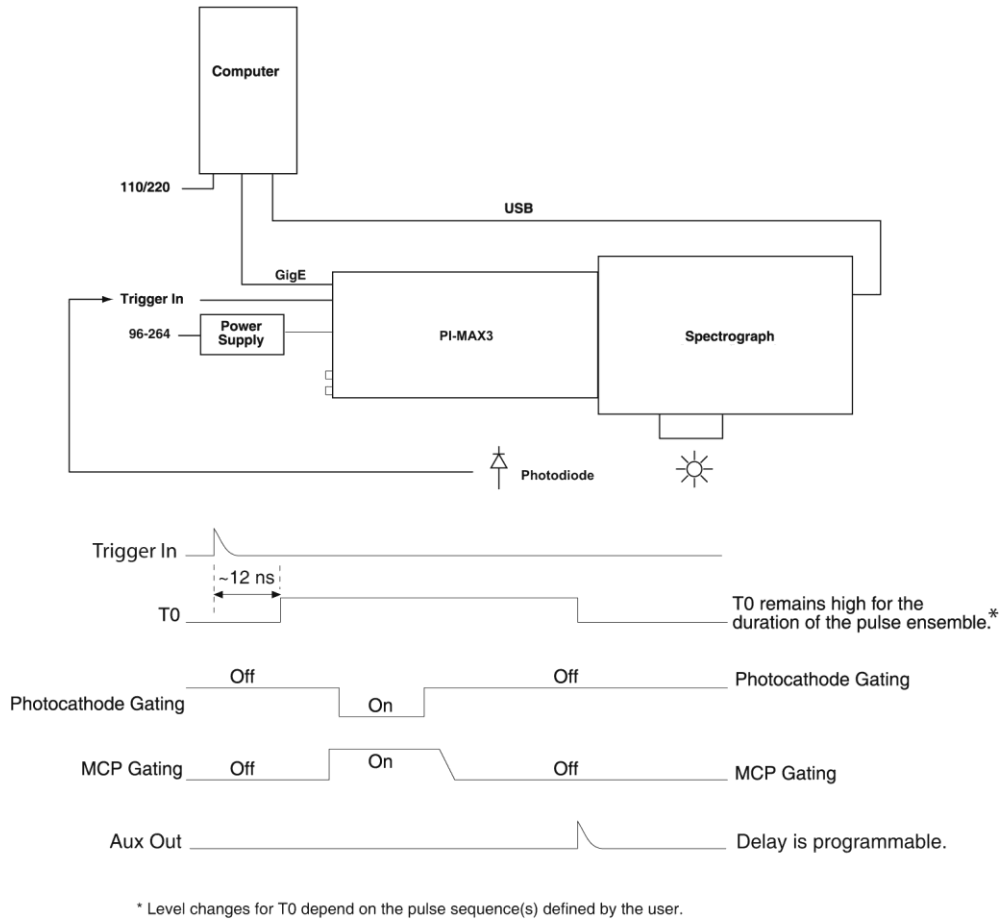


Figure 60. Experiment is Master Clock: Hardware Setup and Timing Diagram

### Experiment as Master Clock

The following procedure uses the experiment as the master clock and therefore refers to connections as shown in Figure 60.

1. Switch on the equipment and start the LightField software.
2. Open the **Sensor** expander and click on the **Sensor Cleaning** button. The screen should resemble Figure 61, which shows the setup for the PI-MAX3:1024i camera.

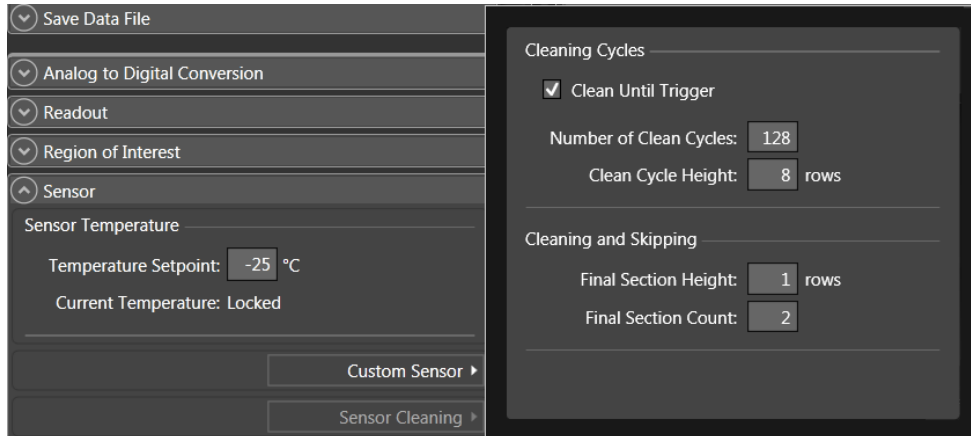
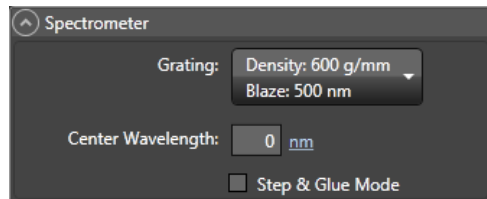
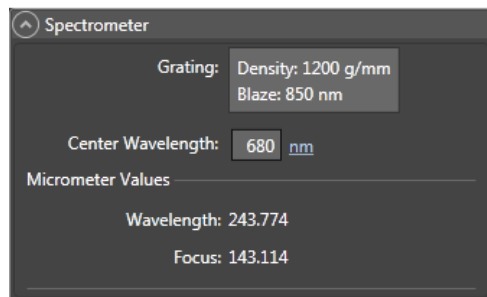


Figure 61. Sensor Cleaning flyout pane

- a. If one or more orange reset buttons are shown on the flyout pane, click on them to reset to the default values.
  - b. Set the detector temperature by entering the Target Setpoint information.
3. If you have an Acton Series spectrograph, make sure it was turned on when LightField was started. If you have an LS-785, its icon should be in the Available Devices area. When the spectrograph icon is dragged into the Experiment Devices area, the **Spectrometer** expander will be added to the Experiment Settings stack. Set the spectrograph properties by using the items on the **Spectrometer** expander.



Acton Series Spectrometer



LS 785 Spectrometer

Figure 62. Spectrometer expander

4. Move the grating to the desired wavelength.
5. On the **Region of Interest** expander, select **Full Sensor**.

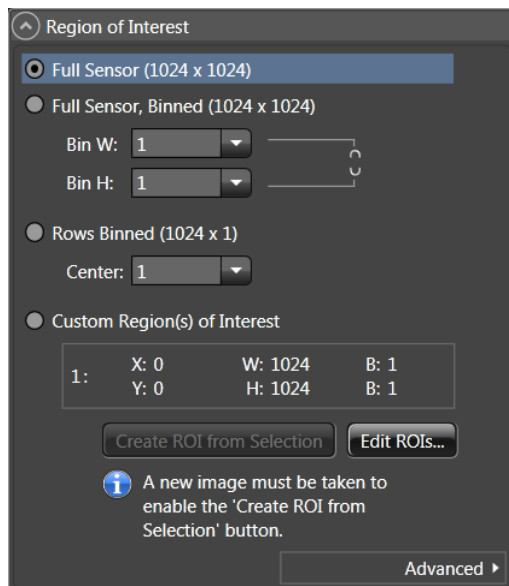


Figure 63. Region of Interest expander: Full Sensor

6. At this point, it is a good practice to make sure that the camera is focused by running it in “Internal Trigger” mode. This requires that you set the experiment parameters on the **Experiment Settings** expanders, including the **SuperSYNCHRO Timing** expander.
  - a. On the **Common Acquisition Settings** expander, check in the **Enable Intensifier** box and set a value between 1 and 100 for the **Intensifier Gain**.

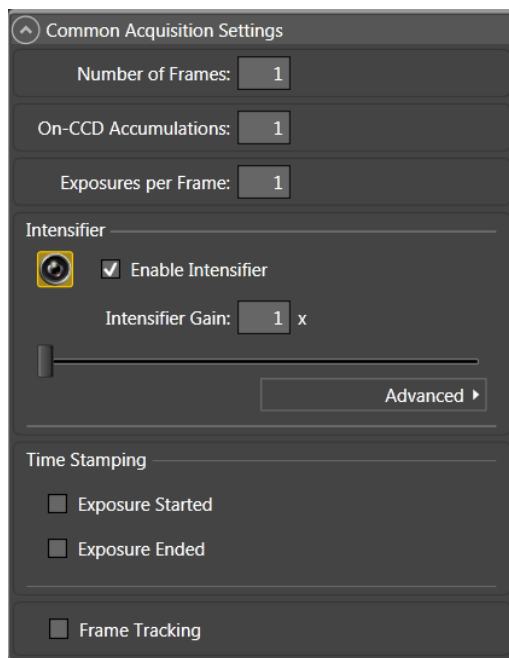


Figure 64. Common Acquisition Settings expander

- b. On the **Analog to Digital Conversion** expander, select the speed and gain.

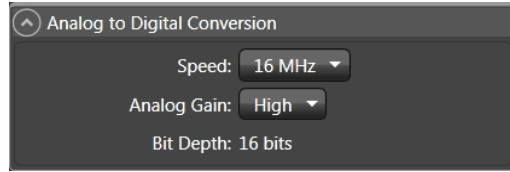


Figure 65. Analog to Digital Conversion expander

- c. On the **Trigger** expander, select **Internal**.

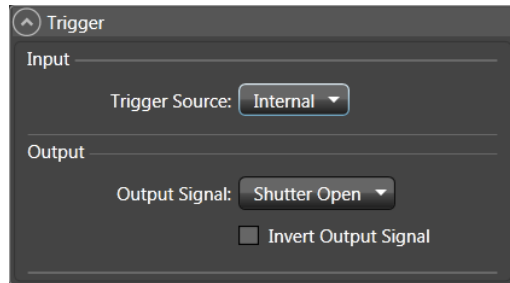


Figure 66. Trigger expander: Internal Trigger Source

7. After setting the parameters and making sure the ambient light level is low, click on the **View** tab to bring it to the front and then click on the **Run** button.
8. The camera will begin acquiring data. This data will not be saved.
9. After you make sure that the camera is seeing, stop data acquisition.
10. On the **Region of Interest** expander, select **Full Sensor, Binned** and enter 1024 in the **Bin H** field.

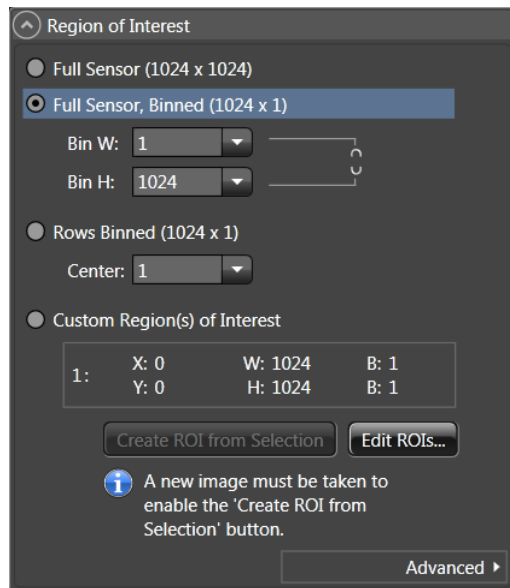


Figure 67. Region of Interest expander: Full Sensor Binned

11. On the **Trigger** expander, change the **Trigger Source** to **External** and define the external trigger.

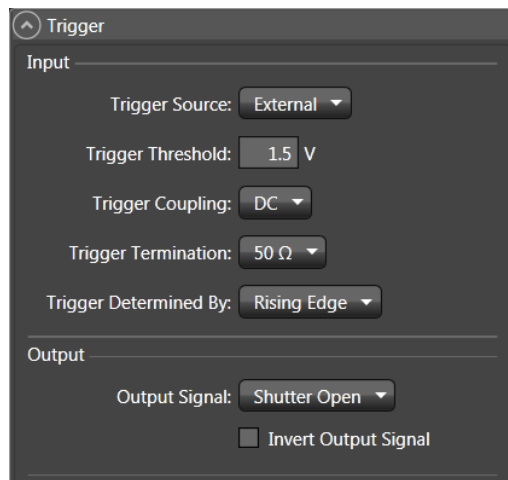


Figure 68. Trigger expander: External Trigger Source

12. Open the **SuperSYNCHRO Timing** expander (above the Status bar) and begin setting up the gate timing.
  - a. Select **Sequential** as the Active Mode. If you have a Gen II intensifier, set Bracket Pulsing to OFF for this experiment.
  - b. Define the pulse sequence.
    - Click on the **Number of Frames** hyperlink and enter the number of frames to be acquired (in this case, 41).
    - Enter the start and end times for the gate width. (Since this experiment requires a fixed gate width, these values will be the same.)
    - Enter the start and end durations for the gate delay. (For this experiment, the start delay is 1  $\mu$ s and the end delay is 201  $\mu$ s.)
    - Click on the **On-CCD Accumulations** hyperlink and enter the number of **On-CCD Accumulations** per frame (in this case, 1).
  - c. The **SyncMASTER ON** button allows you to enable the SyncMASTER™ trigger output from the SyncMASTER1 and SyncMASTER2 connectors on the **AUX I/O** cable and select the frequency for the SyncMASTER outputs. You can also set up the AUX Output signal at the **AUX OUT** connector on the rear of the PI-MAX3.
    - When you enable **SyncMASTER**, the output of the SyncMASTER1 connector will be at the frequency entered on the **Internal Trigger Frequency** field.
    - The output of the **SyncMASTER2** connector will be at the same frequency as that of SyncMASTER1. However, you can enter a delay so the edges of that signal will occur after the edges of SyncMASTER1.
    - If you are using the **AUX Output** signal from the SuperSYNCHRO to trigger a piece of equipment, then enter the Auxiliary pulse delay time. Enter the pulse width needed to trigger the equipment.

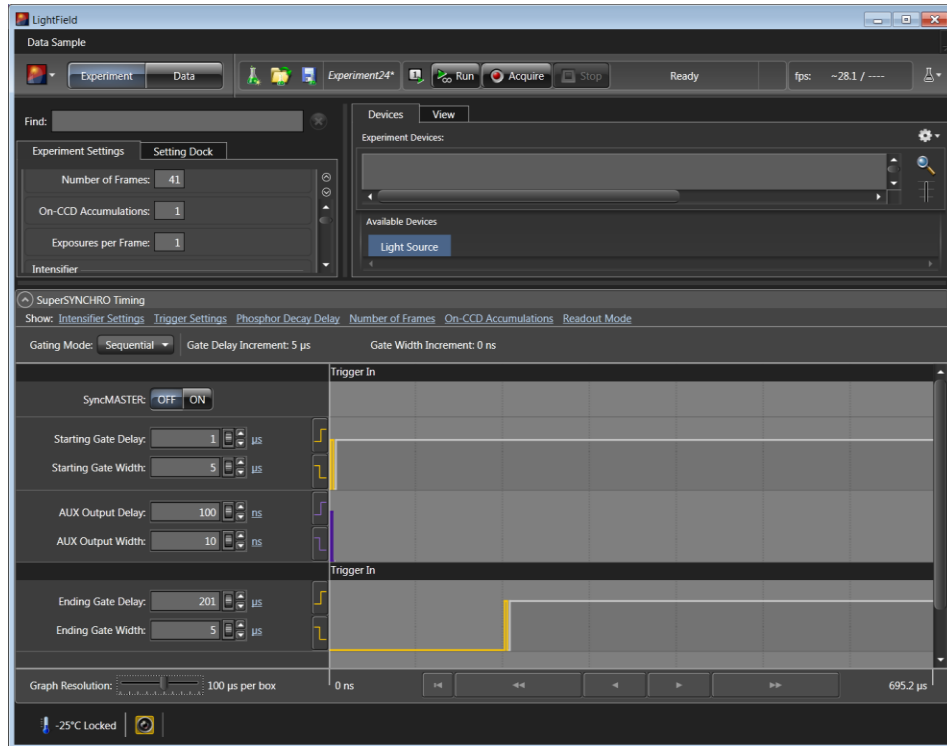


Figure 69. SuperSYNCHRO Timing expander

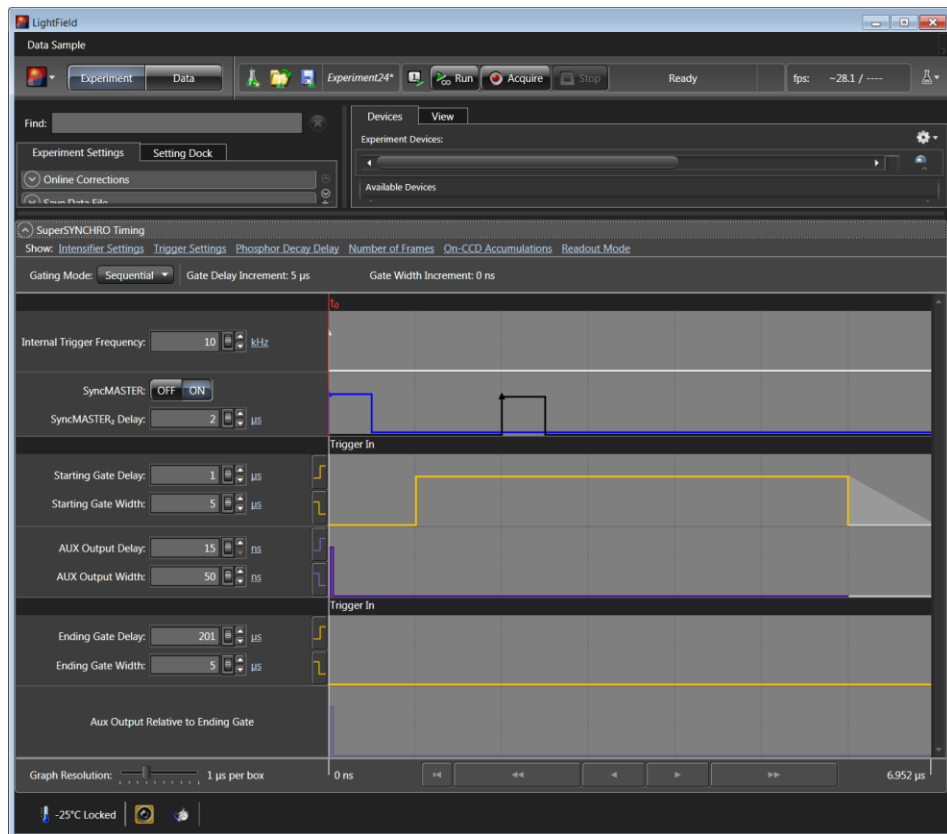


Figure 70. SuperSYNCHRO Timing with SyncMASTER On

13. After verifying all connections and equipment readiness, contract the **SuperSYNCHRO Timing** expander, click on the **View** tab (if it is not in the front), and click on **Acquire** to begin acquiring the spectra (or images).

**Note:** The photocathode is biased on only for the time that each gate pulse is applied. This limits the risk of damage resulting from room light. However, there is a risk of damaging overload from intense light sources such as lasers.

14. Figure 48 displays the graph for a “Sequential-Repetitive” experiment with fixed width and variable delay. **Show Frame Cross Section** has been selected. The intensity of the selected point was at its maximum in Frame 23.



Figure 71. Experiment Results with Frame Cross Section



### SyncMASTER1 as Master Clock

If you have a light source that has a “Trigger In”, the PI-MAX3 SyncMASTER function can be used as the Master clock (cable connections shown in Figure 72). The setup procedure is much the same as that given for the “Experiment as Master Clock”. The differences are that Internal Trigger is selected, SyncMASTER is enabled, and a cable is connected between the PI-MAX3’s AUX I/O cable’s SyncMASTER1 BNC and the light source (experiment) for triggering the event.

#### PI-MAX3 SyncMASTER1 is Master Clock

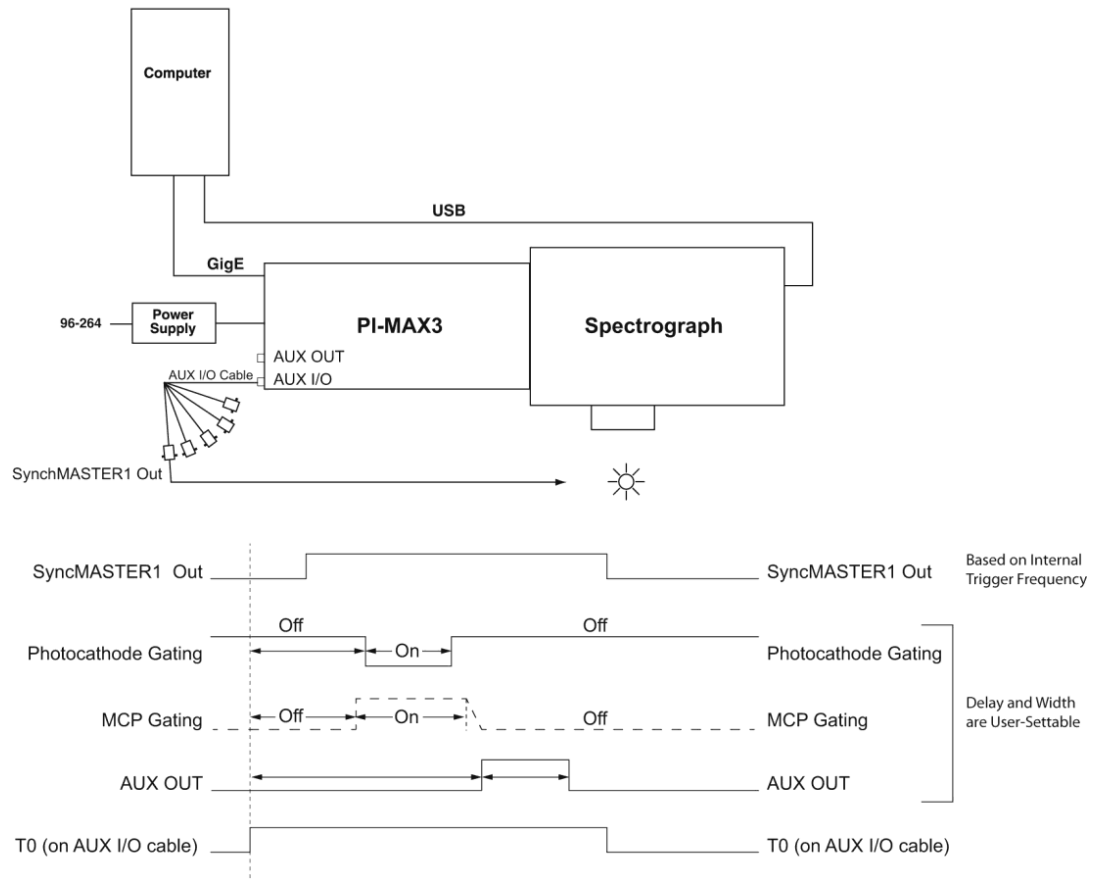


Figure 72. PI-MAX3 SyncMASTER1 is Master Clock: Hardware Setup and Timing Diagram

### Procedure for Setting up and Performing a Single Shot Experiment

A single shot experiment offers only one chance to capture an event. As in any gated experiment, the “time budget” of the experiment is crucial. If there is no pre-trigger from the experiment, a photodiode can be used to generate an electrical trigger from the laser light. In this situation, light has to be delayed by optical means (fiber-optic cable or mirror reflections) to allow sufficient time for the electronics to be activated after receiving the trigger. Another important thing to note in single shot experiments is that **Sensor Cleaning** is set to **Clean Until Trigger** so there is no dark charge accumulation while waiting for the trigger.

The following experiment is an attempt to capture a 60 ns fluorescence generated by a single shot laser. The time budget of the experiment is shown in Table 6. This information is important in order to choose the correct length fiber-optic cable.

Delay Source	Delay (ns)	Total Delay (ns)	Fiber-Optic Cable Length
Photodiode (light -> TTL pulse)	2	30	A minimum of 21 ft of fiber-optic cable is required.
Photodiode -> PI-MAX3 (2 ft BNC cable)	3		
PI-MAX3	25		

Table 6. Single Shot Experiment Time Budget

In this experiment, the cables are kept as short as possible to minimize the length of the fiber-optic cable required.

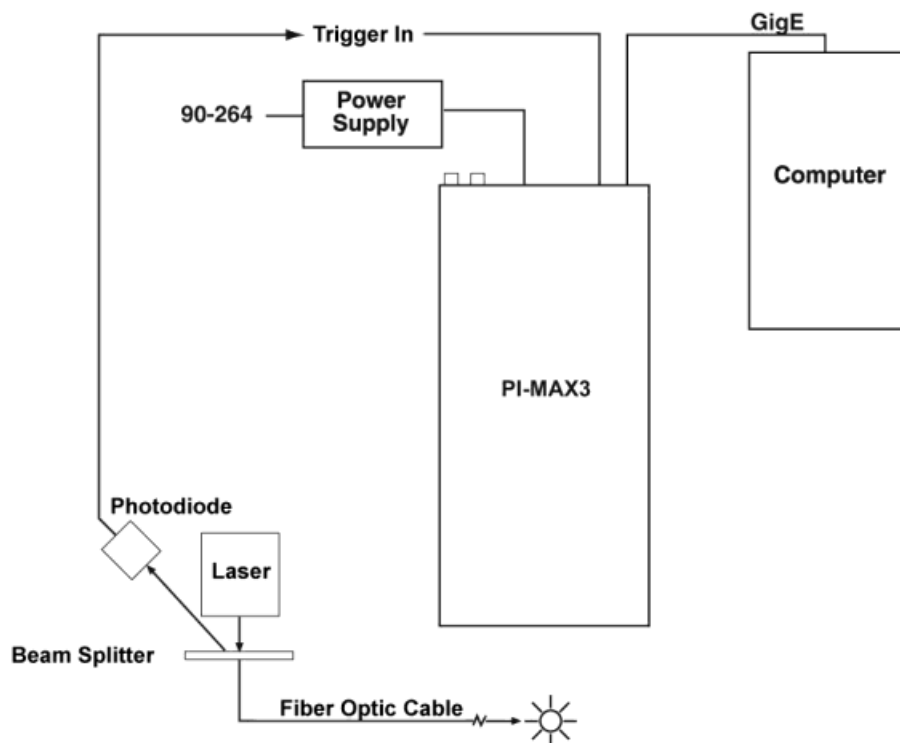


Figure 73. Single Shot: Hardware Setup

After setting up the appropriate hardware, as shown in Figure 50, default values for “Cleaning and Skipping” are loaded (Figure 51). If the PI-MAX3 has to wait more than a few seconds for the external trigger, it is advisable to increase the number of cleans.

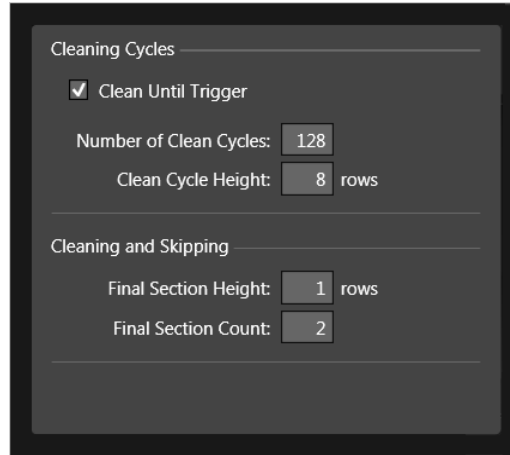


Figure 74. Cleans and Skips: Default Values Loaded

The sequence of operations is similar to the “Sequential” experiments. After focusing the camera on the fluorescing sample, the appropriate Gain is selected (Figure 52).

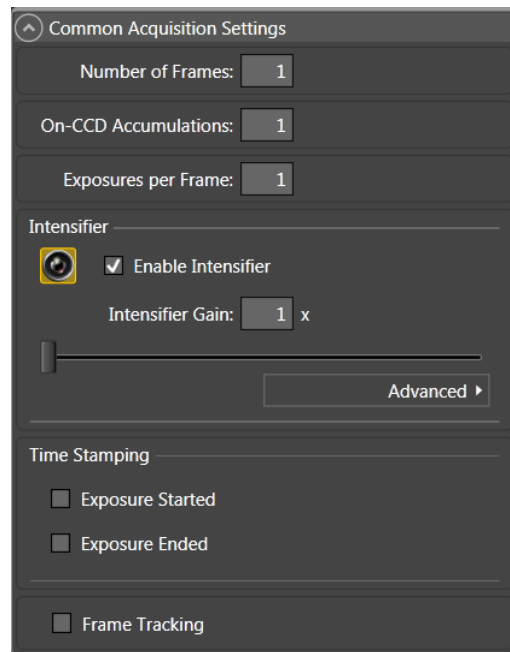


Figure 75. Experiment Setup: Gain Selected

Gate width and gate delay are set in such a way that the intensifier is gated ON during the entire event (in this case the event is a 60 ns fluorescence).

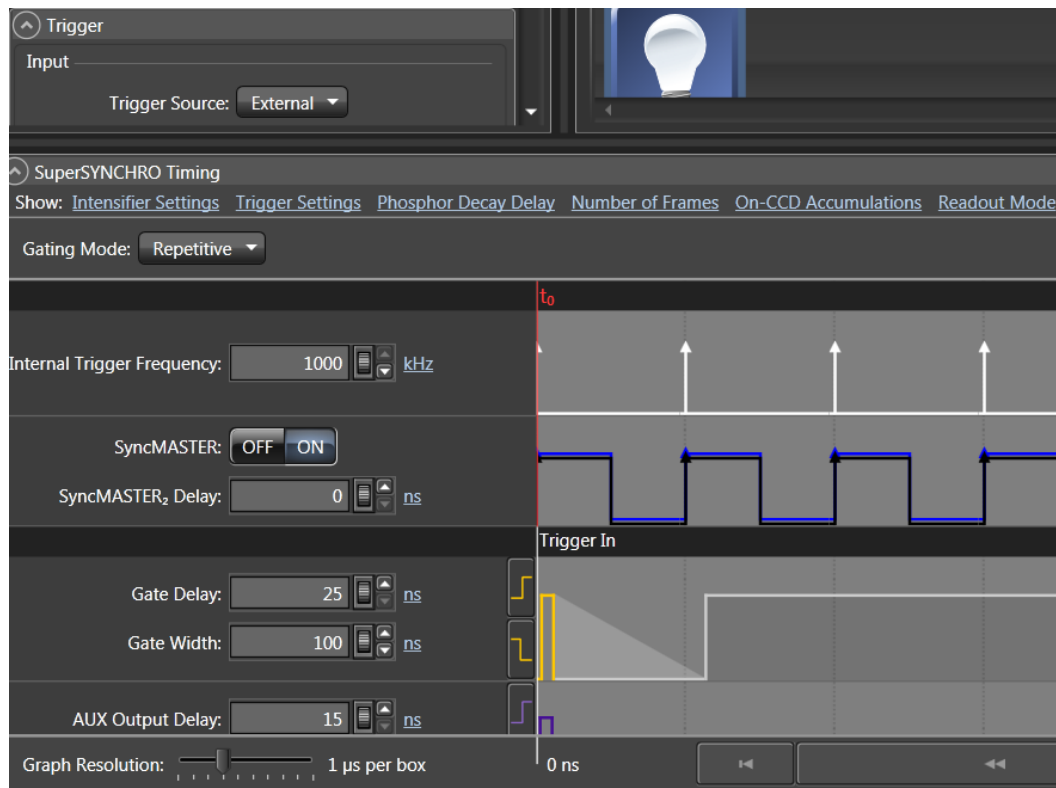


Figure 76. Repetitive Gating Setup: 100 ns Width, 25 ns Delay

Figure 54 shows the result of the experiment. Figure 55 shows the peak obtained by binning, in the vertical direction, the entire region around the fluorescence spot.

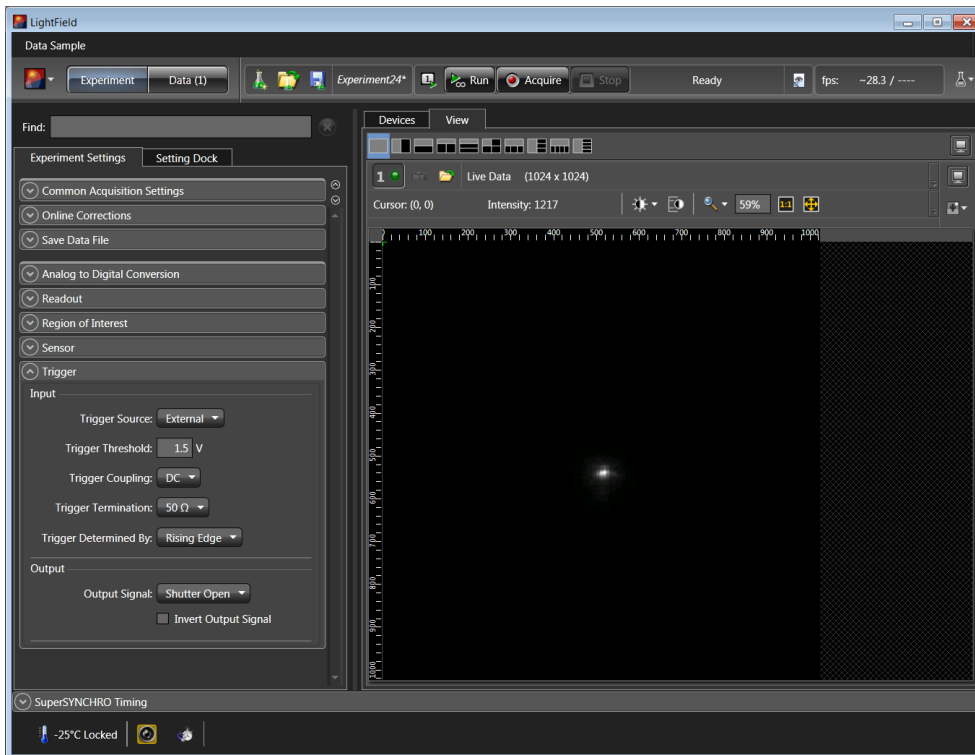


Figure 77. Single Shot Result: Fluorescence Spot, 100 ns Width, 25 ns Delay

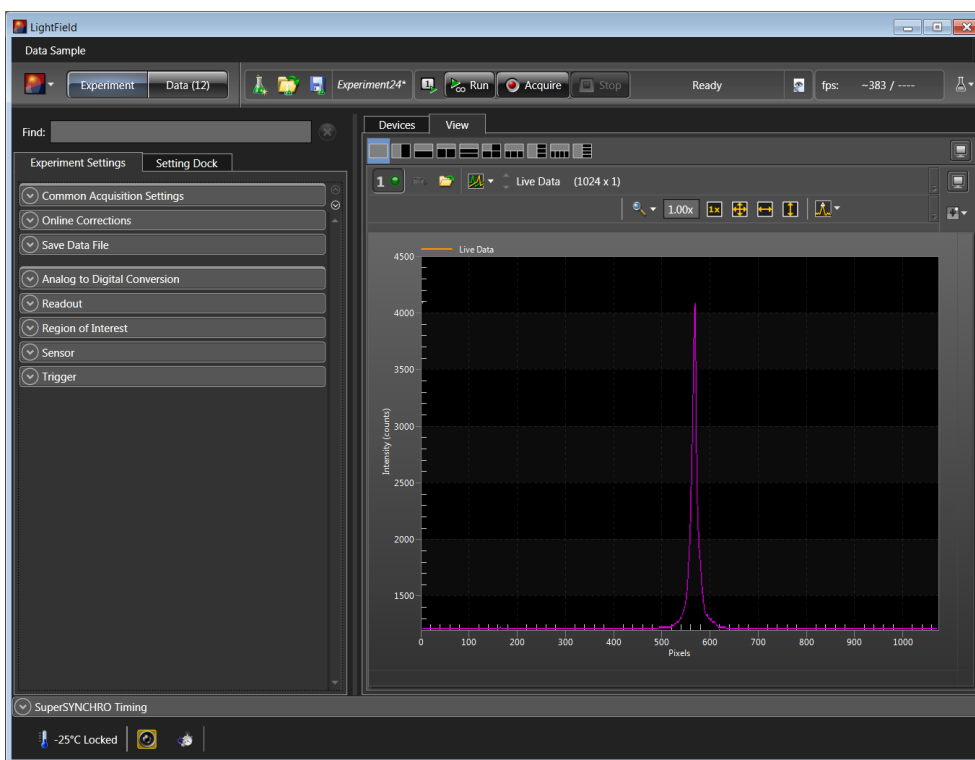


Figure 78. Single Shot Result: Fluorescence Spot, 100 ns Width, 25 ns Delay, Binned Vertically

### ***Procedure for Setting up and Performing a Swept Gate Experiment (Variable Width, Variable Delay)***

The sequence of steps for a Swept Gate experiment with variable width and delay is similar to the Swept Gate experiment with fixed width and variable delay but with the following exception:

- In addition to entering differing start and end values for the Gate Delay, you would also enter differing start and end values for the Gate Width.

### ***Procedure for Setting up and Performing a Static Gate Experiment (Fixed Width, Fixed Delay)***

The sequence of steps for a Static Gate experiment is similar to the Swept Gate experiment but with the following exceptions:

- The Gate Mode would be **Repetitive**.
- The Gate Width and Gate Delay values would be entered in the **SuperSYNCHRO Timing** expander (Figure 79).

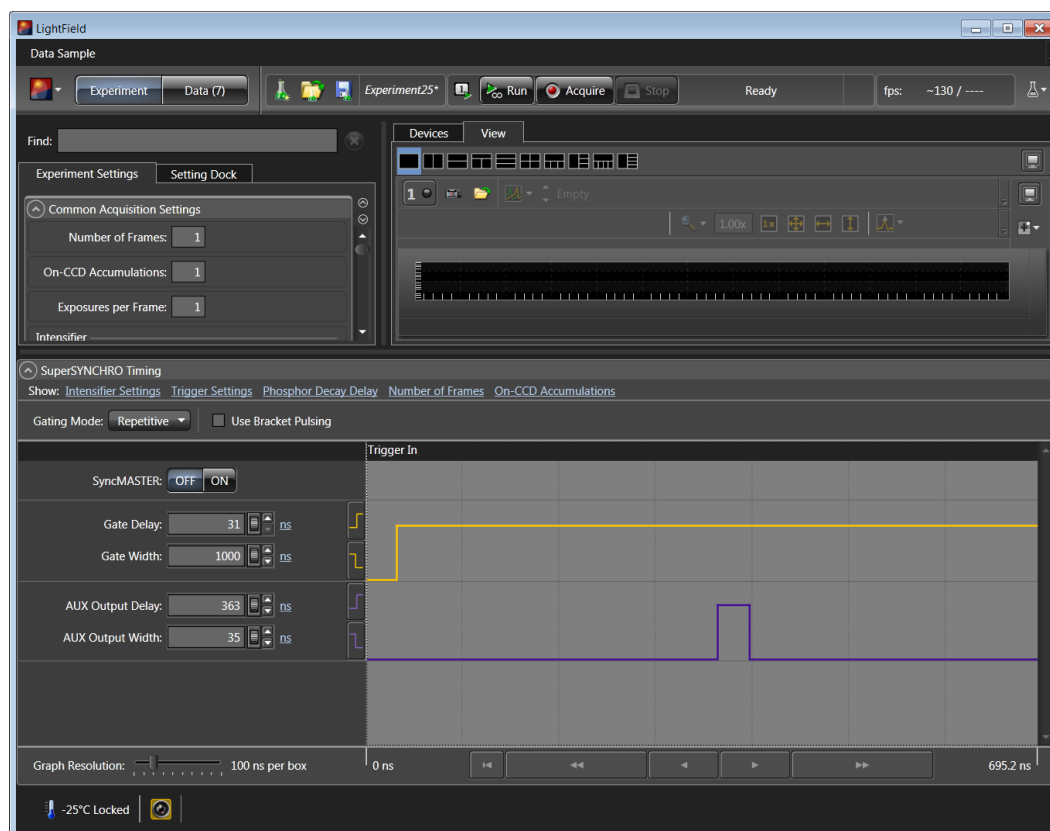


Figure 79. SuperSYNCHRO Timing expander: Repetitive Gating Setup

# Chapter 8

## Timing Generator Pulses and Sequences

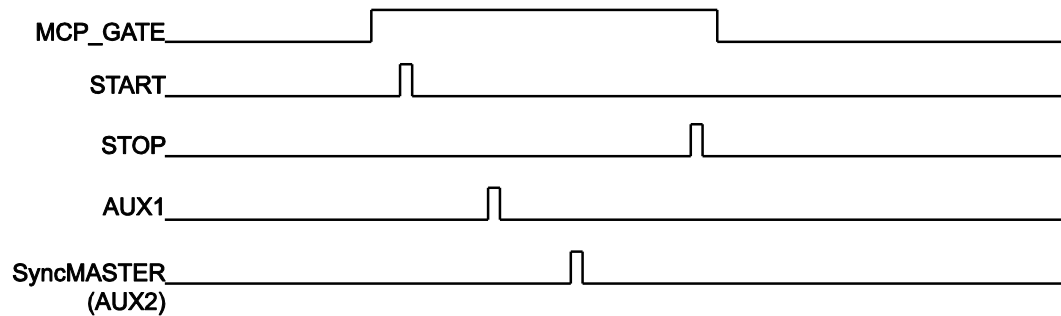
---

### Pulse Set

#### **Description**

A pulse set includes the following signals: MCP\_GATE, START, STOP, AUX1, and SyncMASTER. START and STOP define the photocathode gate pulse. *See Figure 80.*

**Note:** MCP GATE, START, and STOP are not visible to the user and are included for information purposes only.



*Figure 80. Pulse Set*

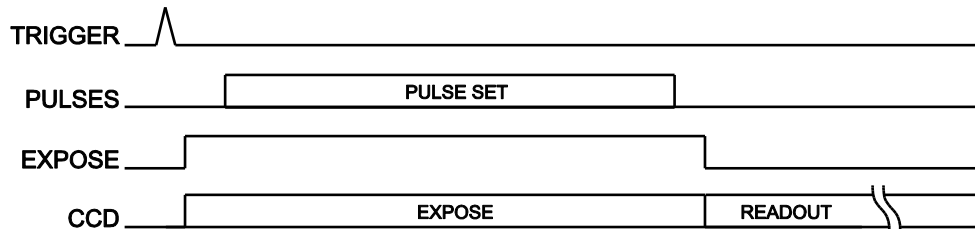
The EXPOSE signal remains high for the duration of the pulse set and goes low upon approximately 15 ns after pulse completion.

#### **Supported Timing Generator Trigger Modes:**

**Trigger per Pulse:** The pulse set is initiated by its own trigger (either internal or external). *See Figure 81.*

#### **Supported Trigger Sources are:**

- **Source 1: Timing Generator internal trigger.** A pulse set is initiated by the timing generator's internal trigger.
- **Source 2: External Trigger (on TRIGGER IN BNC).** A pulse set is initiated by an external trigger.



*Figure 81. Trigger per Pulse*

## Single Sequence

A sequence is the repetition of one pulse set “X” number of times. Figure 82 shows a sequence with the pulse set repeated three (3) times.

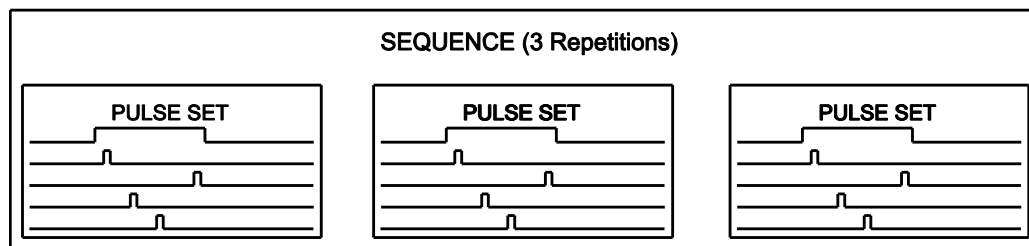


Figure 82. Sequence with 3 Repetitions

The EXPOSE signal remains high for the duration of the sequence and goes low approximately 15 ns after sequence completion.

### Supported Timing Generator Trigger Modes:

**Trigger per Pulse:** Each pulse of the single sequence is initiated by its own trigger (all triggers must be from the same source and all must be either internal or external). See Figure 83.

#### Supported Trigger Sources:

- **Source 1: Timing Generator internal trigger.** Each pulse set of the sequence is initiated by the timing generator’s internal trigger.
- **Source 2: External Trigger (on TRIGGER IN BNC).** Each pulse set is initiated by an external trigger.

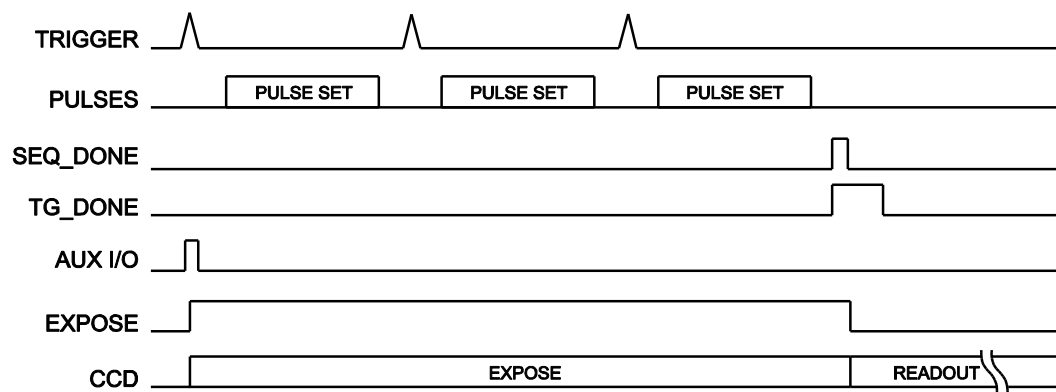


Figure 83. Timing Diagram: Sequence with 3 Repetitions and Trigger per Pulse



## Time Stamping

Time Stamping provides the ability to include the following timing data with each frame of acquired data:

- Exposure Started;

This time stamp indicates the time control is passed from the camera FPGA to the timing generator, not the actual image intensifier gate time.

Once control is passed to the timing generator, the timing generator waits for a trigger or triggers (internal or external, as configured by the user.) The timing generator then executes the timing the user has selected.

When the timing generator completes its task(s), control is then returned to the camera FPGA.

- Exposure Ended.

This time stamp indicates the time when the timing generator returns control to the camera FPGA.

The resolution for PI-MAX3 time stamps is 1  $\mu$ S.

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# Chapter 9

## WinX and Dual Image Feature (DIF)

---

### Introduction

The purpose of PI-MAX3 DIF is to acquire a pair of gated images in rapid succession. The time between frames can be as short as 2  $\mu$ s (limit imposed by P46 phosphor decay time) with exposure times as short as 5 ns. The DIF capability is ideally suited to capturing rapidly evolving events. These experiments will fall into one of two broadly applicable categories: single trigger and dual trigger experiments. Single trigger experiments involve a single impulse event that evolves over time such as a laser-induced plasma or luminescence decay. Dual trigger experiments involve two impulses separated in time such as double laser pulse velocimetry measurements.

### Requirements

The PI-MAX3 must use an interline CCD. In addition, it is recommended that the intensifier have a fast decay phosphor (P46). Since DIF operation involves acquiring images in rapid succession, phosphor persistence can become the limiting factor in the rate of image acquisition.

WinView or WinSpec software (version 2.5.26 or higher) can control the DIF functionality of the PI-MAX3 and provide full access to the two DIF timing modes: single trigger and dual trigger.

### Interline CCD Operation

An interline CCD consists of alternating columns of light sensitive pixels and storage pixels. The light sensitive columns are referred to as the active area and acquire the image. The storage pixels are called the masked area and store the image in the dark while it is read out. With this architecture, the CCD can acquire a second image while the first image is being read out, unlike a standard CCD, which must read out the first image before the second acquisition can begin. The ability of the interline CCD to quickly transfer an image under the masked columns and hold it there makes DIF possible. As soon as the first image is acquired, it is shifted under the masked area and held. The second exposure begins and is held in the active area until the first image is read out.

## Timing Modes

The following two DIF timing/readout modes are available in WinX:

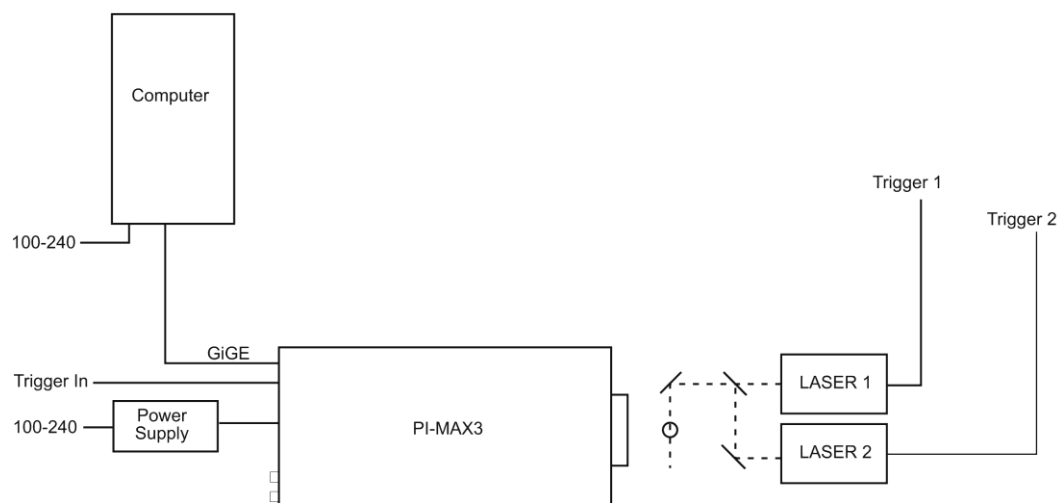
**Single Trig. Mode:** two shot, one trigger for both shots.

**Dual Trig. Mode:** two shot, each shot requires a trigger.

The trigger(s) can be generated by an external source connected to the PI-MAX3 or the PI-MAX3 can generate the trigger(s) internally. In WinX, DIF readout is selected on the **Hardware Setup|Controller/Camera** tab. The timing mode (single or dual trigger) is selected on the **Acquisition|Experiment Setup...|Timing** tab.

## Setting Up a Single Trigger DIF Experiment

### Hardware



\* Spectrograph, coolant circulator, and dry nitrogen tank connections are optional.

Figure 84. System Diagram: DIF Operation

### Software

For the purposes of this setup, it is assumed that you are using either WinView or WinSpec to control the system.

### Operation

The operation of the PI-MAX3 in DIF mode is similar to the standard operation of a PI-MAX3 with SuperSYNCHRO. There are only a few differences due to the special timing modes of DIF, and they will be outlined here.

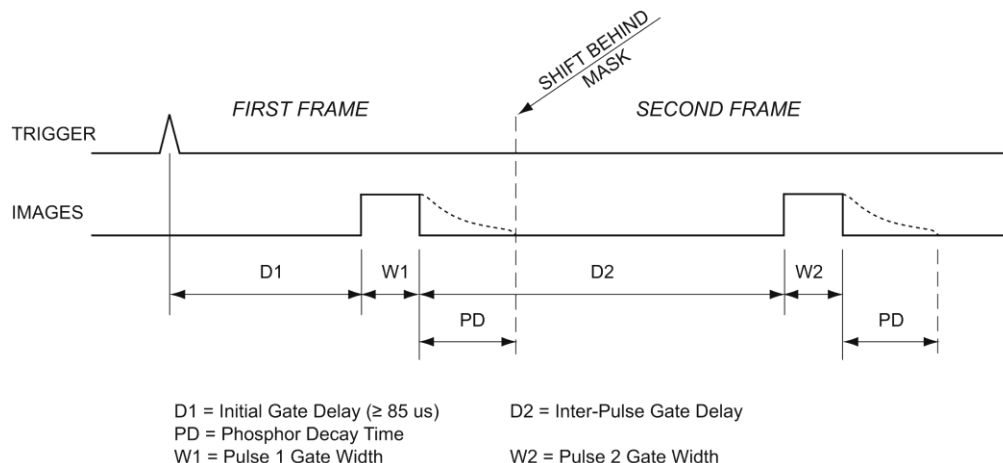


Figure 85. DIF Operation: Single Trigger Timing Diagram

- The first requirement is that the PI-MAX3 camera be aligned and focused on the area of interest in the experiment. This is best accomplished while the PI-MAX3 is operating in Interline mode (i.e., before switching to DIF mode). Verify that the **Phosphor Decay Time** is appropriate to the phosphor used by your camera: (this field is located on the **Setup|Hardware Setup|Controller/Camera** tab). The procedure for initial focus is outlined in Chapter 4.
- After the alignment and focus, the PI-MAX3 system needs to be put into DIF mode. On the **Setup|Hardware Setup|Controller/Camera** tab, select **Dual Image Feature** as the **Readout Mode**, and then click **OK**.
- The PI-MAX3 must be set to Gate Mode for the intensifier to operate properly. Either click on the **Gate mode** button on the Custom Toolbar or select **Gate Mode** on the **Acquisition|Experiment Setup...|Main** tab.
- On the **Acquisition|Experiment Setup...|Timing** tab, verify that **Single Trig. Mode** is the selected timing mode. **Continuous Cleans** is recommended for DIF.
- Select **Pulsers** from the **Setup** menu, select **SuperSYNCHRO**,

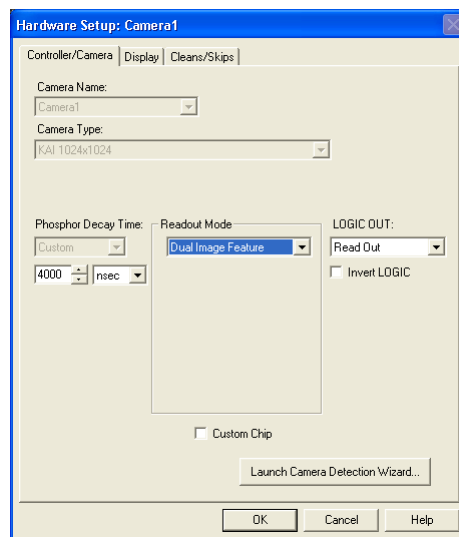


Figure 86. Hardware Setup|Controller/Camera tab

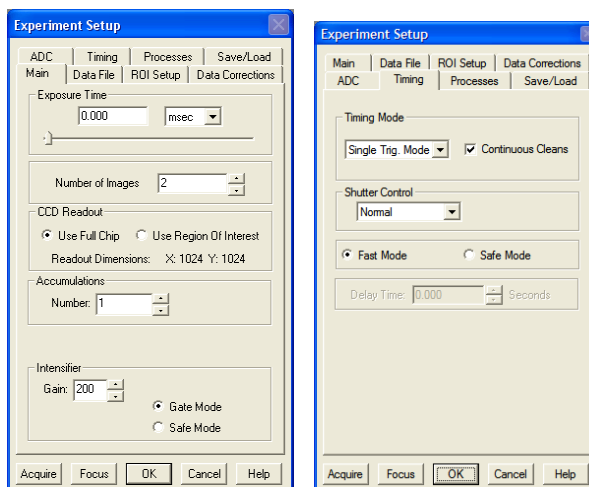


Figure 87. Experiment Setup|Main and Timing tab

and click on the **Setup Pulser** button.

- a. On the **Gating** tab of the **SuperSYNCHRO** dialog, select **DIF Gating** and click on the **Setup** button.
- b. On the **DIF Gating Setup** dialog, enter the gate width and delay times.

- When entering the **Initial Gate Delay** time, make sure that it is  $\geq 75 \mu\text{s}$ .
- When entering the **Inter-Pulse Gate Delay** time, make sure that the delay is  $\geq$  Phosphor Decay Time (as entered on the **Setup|Hardware Setup|Controller/Camera** tab).

- c. On the **Trigger In** tab, select **Internal** or **External** triggering. If you will be using **External** triggering, make sure the trigger characteristics match the active trigger edge, etc. of the trigger pulse that will be used.

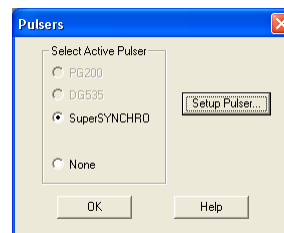


Figure 88. Pulsers dialog



Figure 89. Gating tab

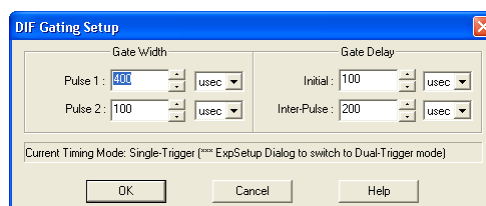


Figure 90. DIF Gating Setup dialog – Single Trigger

- d. If required, on the **Trigger Out** tab, set up output triggers.
- e. At the bottom of the **SuperSYNCHRO** dialog, click **OK** to download the gating sequence to the SuperSYNCHRO.

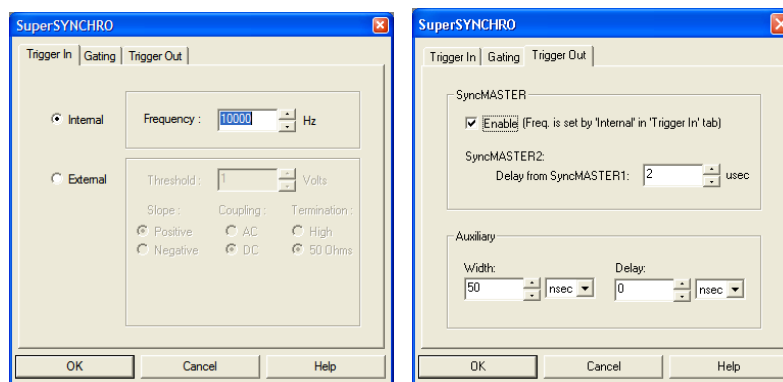
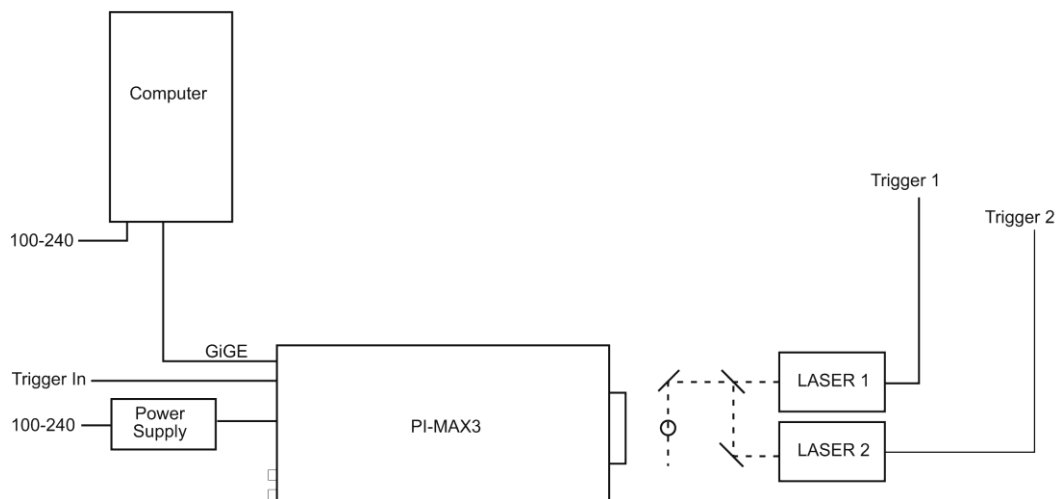


Figure 91. Trigger In and Trigger Out tabs

6. When the experiment is ready, click on the **ACQ** button or select **Acquire** on the **Acquisition** menu to start the image acquisition.

## Setting Up a Dual Trigger DIF Experiment

### Hardware



\* Spectrograph, coolant circulator, and dry nitrogen tank connections are optional.

Figure 92. System Diagram: DIF Operation

### Software

For the purposes of this setup, it is assumed that you are using either WinView or WinSpec to control the system.

### Operation

The operation of the PI-MAX3 in DIF mode is similar to the standard operation of a PI-MAX3 with SuperSYNCHRO. There are only a few differences due to the special timing modes of DIF, and they will be outlined here.

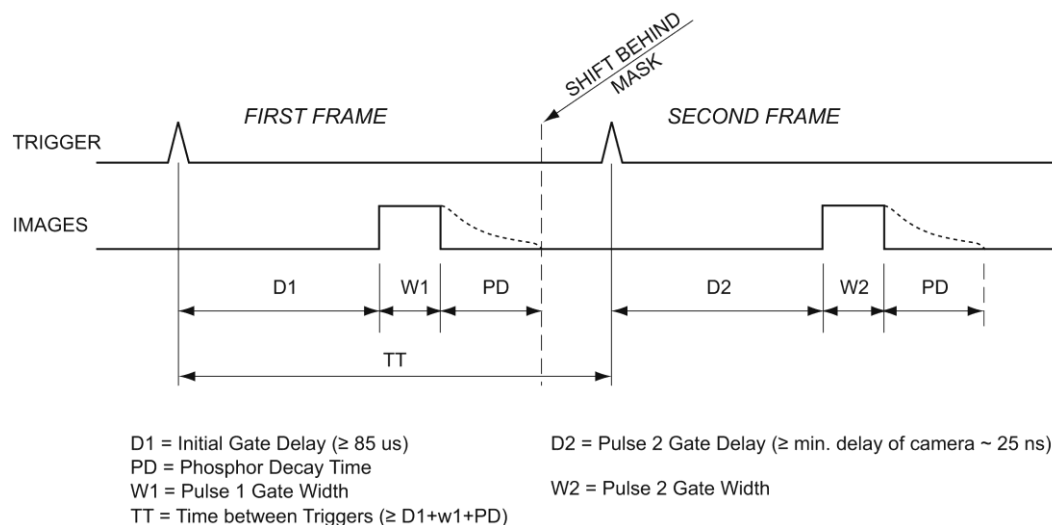


Figure 93. DIF Operation: Dual Trigger Timing Diagram

1. The first requirement is that the PI-MAX3 camera be aligned and focused on the area of interest in the experiment. This is best accomplished while the PI-MAX3 is operating in Interline mode (i.e., before switching to DIF mode). Verify that the **Phosphor Decay Time** is appropriate to the phosphor used by your camera: (this field is located on the **Setup|Hardware Setup|Controller/ Camera** tab). The procedure for initial focus is outlined in Chapter 4.
2. After the alignment and focus, the PI-MAX3 system needs to be put into DIF mode. On the **Setup|Hardware Setup|Controller/Camera** tab, select **Dual Image Feature** as the **Readout Mode**, and then click **OK**.

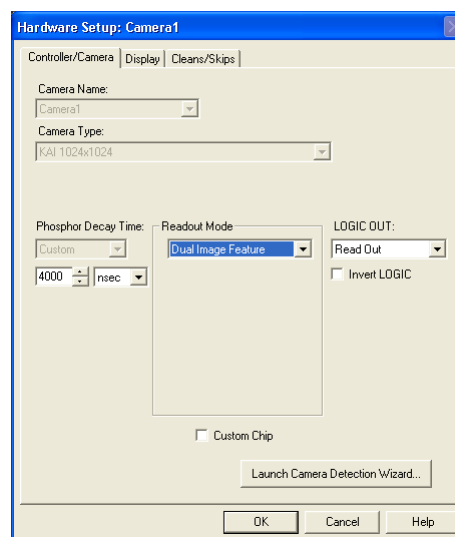


Figure 94. Hardware Setup|Controller/Camera tab



3. The PI-MAX3 must be set to Gate Mode for the intensifier to operate properly. Either click on the **Gate** mode button on the Custom Toolbar or select **Gate Mode** on the **Acquisition|Experiment Setup...|Main** tab.
4. On the **Acquisition|Experiment Setup...|Timing** tab, verify that **Dual Trig. Mode** is the selected timing mode. **Continuous Cleans** is recommended for DIF.
5. Select Pulsers from the **Setup** menu, select **SuperSYNCHRO**, and click on the **Setup Pulser** button.
  - a. On the Gating tab of the SuperSYNCHRO dialog, select DIF Gating and click on the Setup button.
  - b. On the **DIF Gating Setup** dialog, enter the gate width and delay times. When entering the **Pulse 1 Gate Delay** time, make sure that it is  $\geq 75 \mu\text{s}$ .
  - c. On the **Trigger In** tab, select **Internal** or **External** triggering. If you will be using **External** triggering, make sure the trigger characteristics match the active trigger edge, etc. of the trigger pulse that will be used.
  - d. If required, on the **Trigger Out** tab, set up output triggers.
  - e. At the bottom of the **SuperSYNCHRO** dialog, click **OK** to download the gating sequence to the SuperSYNCHRO.

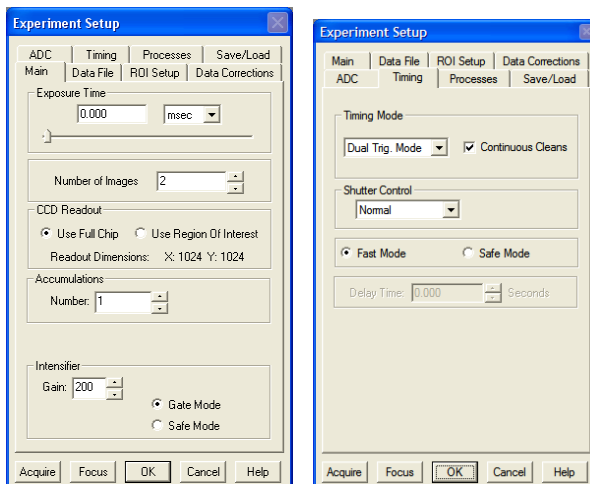


Figure 95. Experiment Setup|Main and Timing tabs

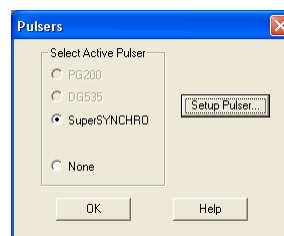


Figure 96. Pulsers dialog

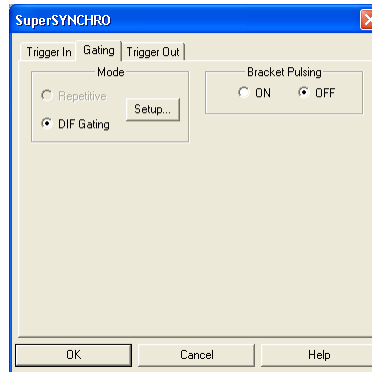


Figure 97. Gating tab

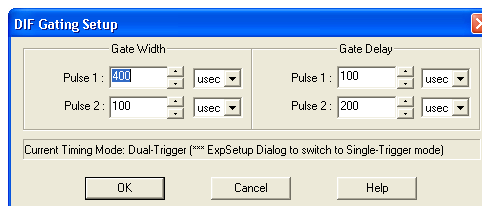


Figure 98. DIF Gating Setup dialog – Dual Trigger

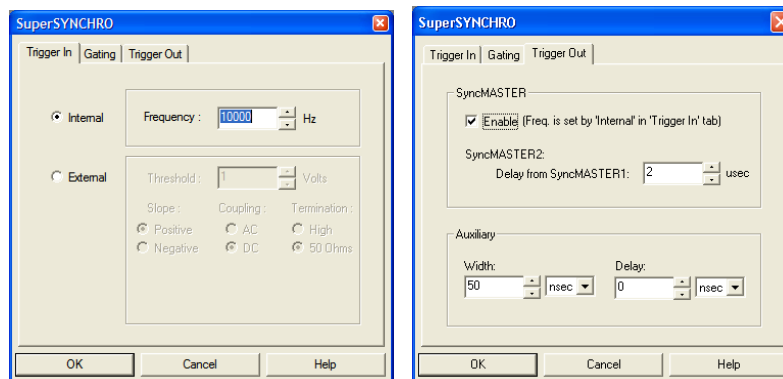


Figure 99. Trigger In and Trigger Out tabs

- When the experiment is ready, click on the **ACQ** button or select **Acquire** on the **Acquisition** menu to start the image acquisition.

## Tips and Tricks

Experiments using the DIF feature of the PI-MAX3 can be complex, and timing of the events is usually rather exacting. Here are several points to consider that may make the experiment setup or troubleshooting much smoother and easier.

- The most important piece of equipment in a DIF experiment is an oscilloscope. The PI-MAX3 has a **MONITOR** BNC on the back of the camera which is very useful for seeing when the two image exposures occur during the course of the experiment. The use of the **MONITOR** BNC and an oscilloscope is discussed in more detail in *Chapter 13: General Tips and Tricks*.
- The short time between the two images in DIF requires an intensifier with a fast phosphor. P46 phosphor has a decay time of  $\sim 2 \mu\text{s}$  which means it takes  $2 \mu\text{s}$  for the phosphor emission to drop to 10% of its peak value. The decay is not a simple single exponential; even after  $100 \mu\text{s}$  there may be 1% or more of the first image on the phosphor screen. It is usually possible to subtract a percentage of the first image from the second image to remove the residual image. If this is not possible, there are intensifiers with P47 phosphor, which is an order of magnitude faster than P46.
- The software uses the Phosphor Decay Time to determine how long to wait after the gate pulse to shift the image. This value can be adjusted in the Hardware Setup dialog. If there is some residual image from the first frame in the second frame, simply increase the Phosphor Decay Time to allow the phosphor more time to decay before shifting the image. If residual image is not an issue, then Phosphor Decay Time can be shortened to decrease the time between the two DIF images.

# Chapter 10

## LightField and Dual Image Feature (DIF)

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### Introduction

The purpose of PI-MAX3 DIF is to acquire a pair of gated images in rapid succession. The time between frames can be as short as 450 ns; the second image will have some remnants from the first image due to the longer persistence of the P46 phosphor. Exposure times can be as short as 2.5 ns. The DIF capability is ideally suited to capturing rapidly evolving events. These experiments will fall into one of two broadly applicable categories: single trigger and dual trigger experiments. Single trigger experiments involve a single impulse event that evolves over time such as a laser-induced plasma or luminescence decay. Dual trigger experiments involve two impulses separated in time such as double laser pulse velocimetry measurements.

### Requirements

For DIF operation, the PI-MAX3 must use an interline CCD and DIF must be the selected Readout Mode (Readout expander, see Figure 100). The number of frames must be a multiple of 2 and is set via the **Common Acquisitions Settings** expander (Figure 101). In addition, it is recommended that the intensifier have a fast decay phosphor (P46). Since DIF operation involves acquiring images in rapid succession, phosphor persistence can become the limiting factor in the rate of image acquisition.

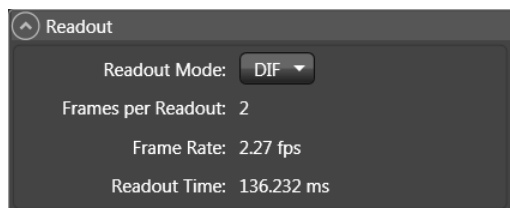


Figure 100. Readout expander

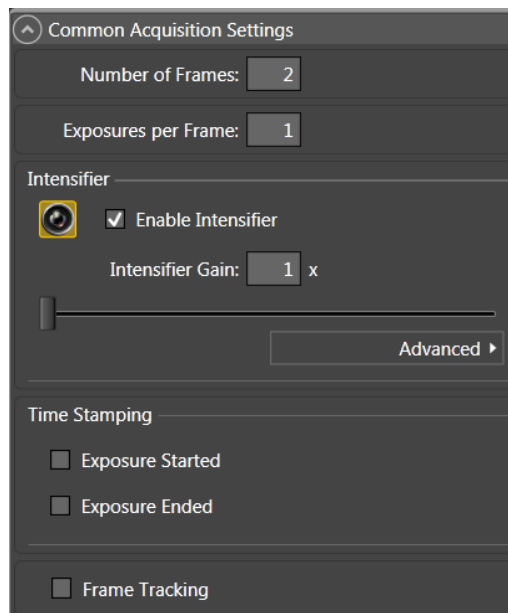


Figure 101. Common Acquisition Settings expander

**Note:** The PI-MAX3:1024i is currently the only PI-MAX3 that can operate in DIF mode.

## Interline CCD Operation

An interline CCD consists of alternating columns of light sensitive pixels and storage pixels. The light sensitive columns are referred to as the active area and acquire the image. The storage pixels are called the masked area and store the image in the dark while it is read out. With this architecture, the CCD can acquire a second image while the first image is being read out, unlike a standard CCD, which must read out the first image before the second acquisition can begin. The ability of the interline CCD to quickly transfer an image under the masked columns and hold it there makes DIF possible. As soon as the first image is acquired, it is shifted under the masked area and held. The second exposure begins and is held in the active area until the first image is read out.

## Trigger Setup

### **Introduction**

Triggering for DIF operation is set up on the Trigger and the SuperSYNCHRO expanders. Trigger setup consists of selecting the trigger response and the trigger source.

### **Trigger Response**

The selected Trigger Response (Readout Per Trigger or Shift Per Trigger) determines whether one or two triggers will be required for the acquisition. The trigger(s) can either be internally generated by the PI-MAX3 or can be generated by an external source connected to the **TRIGGER IN** connector on the rear of the camera.

### **Trigger Responses:**

- **Readout Per Trigger:** Two shot, one trigger for both shots.
- **Shift Per Trigger:** Two shot, each shot requires a trigger.

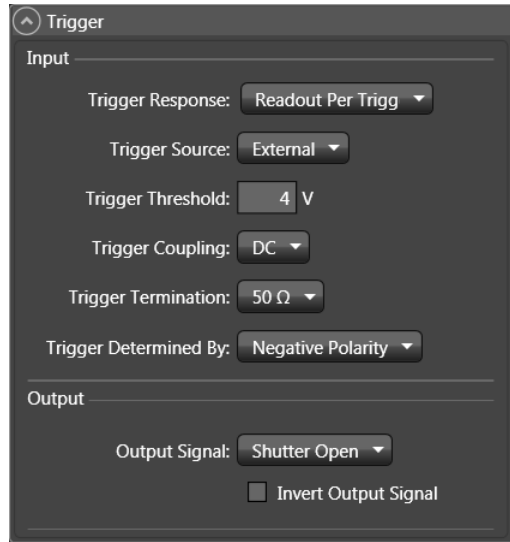


Figure 102. Trigger expander

### Trigger Source

The trigger source is selectable via the Trigger Source drop-down list. The trigger source can either be internal or external and is selected/configured on the Trigger expander (Figure 102). In addition, trigger frequency (if internal is selected) is set via the SuperSYNCHRO expander (Figure 103).

- Internal:** Trigger pulses will be generated by the PI-MAX3 based on the Internal Trigger Frequency setting (entered on the SuperSYNCHRO Timing expander). The range of settings is 2 Hz to 1MHz, in 1 Hz increments. Note that the Internal Trigger Frequency setting also determines the frequency of SyncMASTER1 and SyncMASTER2 outputs.

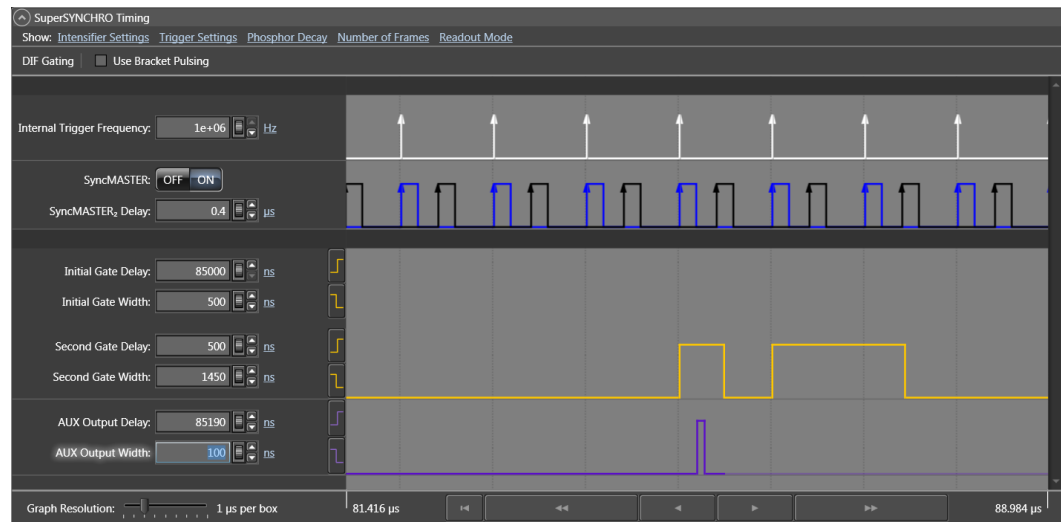
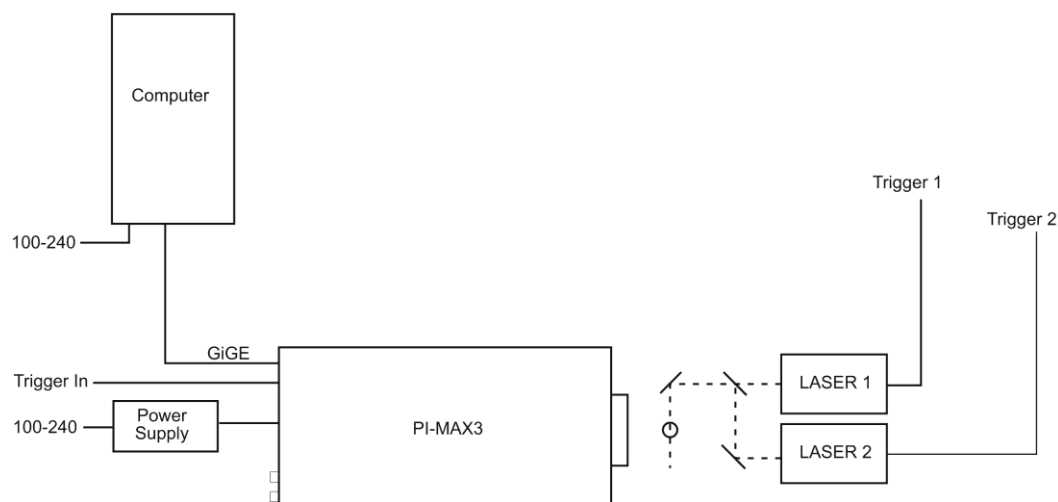


Figure 103. SuperSYNCHRO Timing expander: DIF

- External:** In order for the PI-MAX3 to recognize triggers from an external source, you will need to enter the characteristics of the triggers to be used in triggering DIF acquisition. These characteristics include trigger threshold, coupling, termination, and polarity and are entered on the Trigger expander.

## Setting Up a Single Trigger DIF Experiment

### Hardware Setup



\* Spectrograph, coolant circulator, and dry nitrogen tank connections are optional.

Figure 104. DIF Hardware Connection diagram

### Software Setup and Operation

The operation of the PI-MAX3 in DIF mode is similar to the standard operation of a PI-MAX3 with SuperSYNCHRO. There are only a few differences due to the special timing modes of DIF, and they will be outlined here.

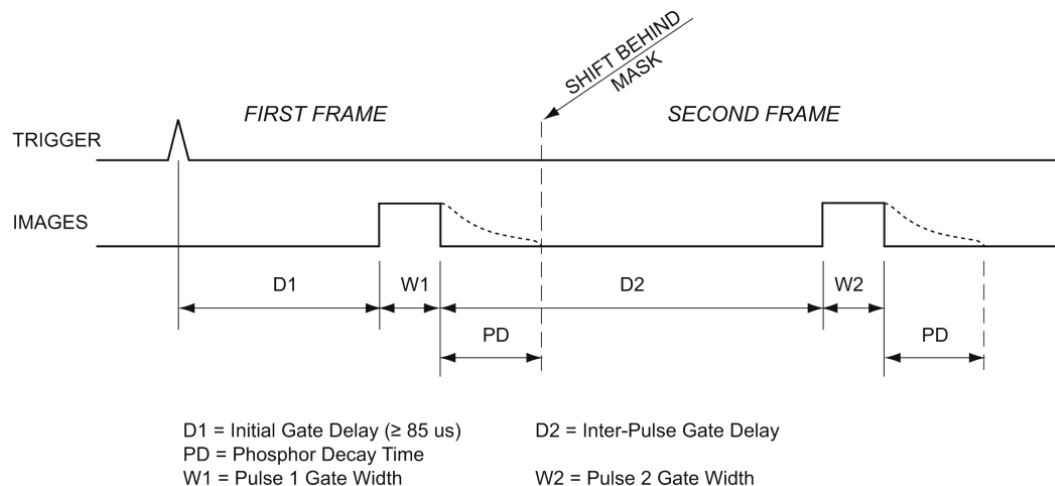


Figure 105. DIF Single Trigger Mode Timing diagram

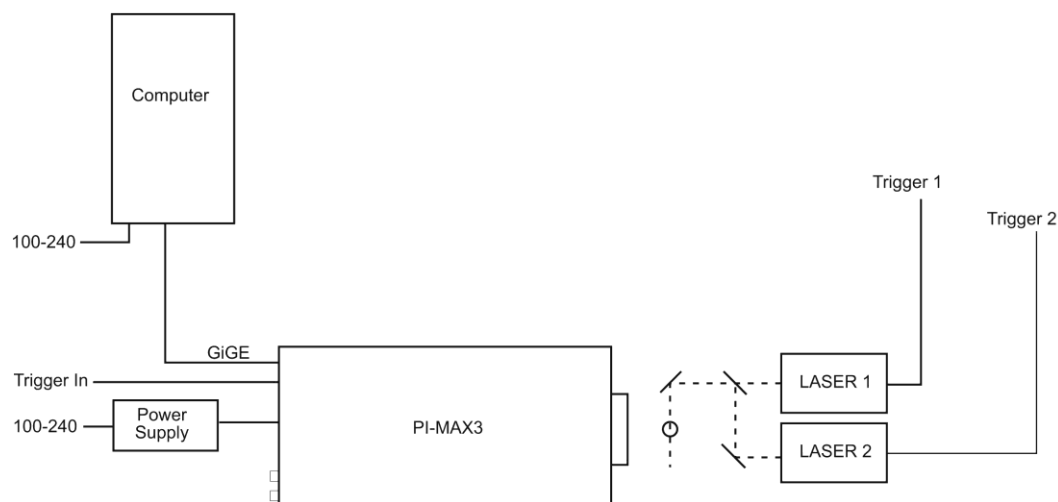
1. The first requirement is that the PI-MAX3 camera be aligned and focused on the area of interest in the experiment. This is best accomplished while the PI-MAX3 is operating in Full Frame readout mode (i.e., before switching to **DIF** mode on the **Readout** expander). Verify that the **Phosphor Decay Delay** is appropriate to the phosphor used by your camera: the phosphor decay delay time entered in LightField can be viewed or changed after clicking on the **Advanced** button on the **Common Acquisition Settings** expander.

**Note:** The Phosphor Decay Delay setting is used to tell LightField how long to wait after the gate pulse to shift the image. If there is some residual image from the first frame in the second frame, simply increase the Phosphor Decay Delay setting to allow more time for the phosphor emission to decay before shifting the image. If residual image is not an issue, then the Phosphor Decay Delay setting can be decreased to reduce the time between the two DIF images.

2. After the alignment and focus, the PI-MAX3 system needs to be put into DIF mode.
  - On the **Readout** expander, select **DIF** as the **Readout Mode**.
  - On the **Common Acquisition Settings** expander, set the **Number of Frames** to a multiple of 2 (for example 2, 4, 6).
3. On the **Trigger** expander, verify that **Readout Per Trigger** is the trigger response.
4. On the **Trigger** expander, select **Internal** or **External** triggering.
  - For External triggering, make sure the trigger characteristics on the Trigger expander match the active trigger edge, etc. of the trigger pulse that will be used.
  - For Internal triggering, set the Internal Trigger Frequency on the **SuperSYNCHRO Timing** expander
5. Open the **SuperSYNCHRO Timing** expander (at the bottom of the window) and begin entering the internal trigger frequency, gate width, gate delay, Aux output delay, Aux output width, and the SyncMASTER state (On or OFF).
  - a. Use the hyperlinks at the top of the expanded panel to make any changes to the intensifier settings, trigger settings, phosphor decay delay time, number of frames (a multiple of 2), and readout mode (DIF or Full Frame).
  - b. If you are using PI-MAX3 generated internal triggers for DIF acquisition, enter the internal trigger frequency.
  - c. Enter the gate width and delay times for the first and second image.
    - The Initial Gate Delay time will be  $\geq 85 \mu\text{s}$ .
    - The Second Gate Delay time will be  $\geq .441 \mu\text{s}$ .
  - d. If required, set up AUX Output trigger.
  - e. If you want to have trigger output from the SyncMASTER1 and SyncMASTER2 connectors on the AUX I/O cable, click on the SyncMASTER ON button. When you enable SyncMASTER, the output of the SyncMASTER1 connector will be at the Internal Trigger Frequency. The SyncMASTER2 output will be at the same frequency but can be delayed (range for delay is from 0 to 999700 ns, in increments of 100 ns).
6. Verify that the I.I.T. Power switch on the rear of the PI-MAX3 is turned ON and that **Enable Intensifier** has been checked on the **Common Acquisition Settings** expander.
7. When the experiment is ready, click on the **Acquire** button.

## Setting Up a Dual Trigger DIF Experiment

### Hardware Setup



\* Spectrograph, coolant circulator, and dry nitrogen tank connections are optional.

Figure 106. DIF Hardware Connection diagram

### Software Setup and Operation

The operation of the PI-MAX3 in DIF mode is similar to the standard operation of a PI-MAX3 with SuperSYNCHRO. There are only a few differences due to the special timing modes of DIF, and they will be outlined here.

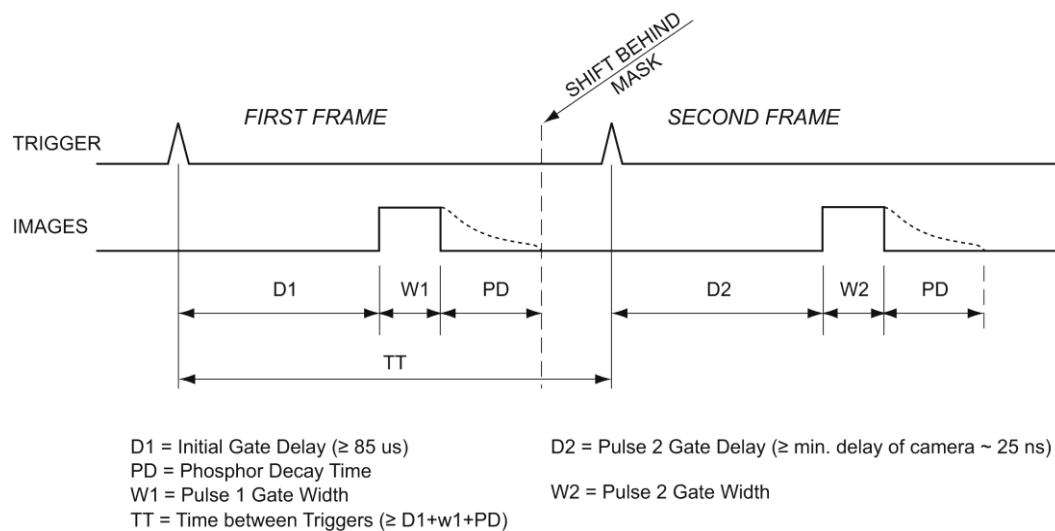


Figure 107. DIF Dual Trigger Mode Timing diagram

1. The first requirement is that the PI-MAX3 camera be aligned and focused on the area of interest in the experiment. This is best accomplished while the PI-MAX3 is operating in Full Frame readout mode (i.e., before switching to DIF mode). Verify that the Phosphor Decay Delay is appropriate to the phosphor used by your camera: the phosphor decay delay time entered in LightField can be viewed or changed after clicking on the **Advanced** button on the **Common Acquisition Settings** expander.



**Note:** The Phosphor Decay Delay setting is used to tell LightField how long to wait after the gate pulse to shift the image. If there is some residual image from the first frame in the second frame, simply increase the Phosphor Decay Delay setting to allow more time for the phosphor emission to decay before shifting the image. If residual image is not an issue, then the Phosphor Decay Delay setting can be decreased to reduce the time between the two DIF images.

2. After the alignment and focus, the PI-MAX3 system needs to be put into DIF mode.
  - On the **Readout** expander, select **DIF** as the **Readout Mode**.
  - On the **Common Acquisition Settings** expander, set the **Number of Frames** to a multiple of 2 (for example 2, 4, 6).
3. On the **Trigger** expander, verify that **Shift Per Trigger** is the trigger response.
4. On the **Trigger** expander, select **Internal** or **External** triggering.
  - For External triggering, make sure the trigger characteristics on the Trigger expander match the active trigger edge, etc. of the trigger pulse that will be used.
  - For Internal triggering, set the Internal Trigger Frequency on the **SuperSYNCHRO** expander.
5. Open the **SuperSYNCHRO Timing** expander (at the bottom of the window) and begin entering the internal trigger frequency, gate width, gate delay, Aux output delay, Aux output width, and the SyncMASTER state (On or OFF).
6. Use the hyperlinks at the top of the expanded panel to make changes to the intensifier settings, trigger settings, phosphor decay delay time, number of frames (a multiple of 2), and readout mode (DIF or Full Frame).
7. If you are using PI-MAX3 generated internal triggers for DIF acquisition, enter the internal trigger frequency.
8. Enter the gate width and delay times for the first and second image.
  - The Initial Gate Delay time will be  $\geq 85 \mu\text{s}$ .
  - The Second Gate Delay time will be  $\geq .441 \mu\text{s}$ .
  - If required, set up AUX Output trigger.
  - If you want to have trigger output from the SyncMASTER1 and SyncMASTER2 connectors on the AUX I/O cable, click on the SyncMASTER ON button. When you enable SyncMASTER, the output of the SyncMASTER1 connector will be at the Internal Trigger Frequency. The SyncMASTER2 output will be at the same frequency but can be delayed (range for delay is from 0 to 999700 ns, in increments of 100 ns).
9. Verify that the I.I.T. Power switch on the rear of the PI-MAX3 is turned ON and that **Enable Intensifier** has been checked on the **Common Acquisition Settings** expander.
10. When the experiment is ready, click on the **Acquire** button.

## Tips and Tricks

Experiments using the DIF feature of the PI-MAX3 can be complex, and timing of the events is usually rather exacting. Here are several points to consider that may make the experiment setup or troubleshooting much smoother and easier.

- The most important piece of equipment in a DIF experiment is an oscilloscope. The PI-MAX3 has a **MONITOR** BNC on the back of the camera which is very useful for seeing when the two image exposures occur during the course of the experiment. The use of the **MONITOR** BNC and an oscilloscope is discussed in more detail in *Chapter 13 - General Tips and Tricks*.
- The short time between the two images in DIF requires an intensifier with a fast phosphor. P46 phosphor has a decay time of  $\sim 2 \mu\text{s}$  which means it takes  $2 \mu\text{s}$  for the phosphor emission to drop to 10% of its peak value. The decay is not a simple single exponential; even after  $100 \mu\text{s}$  there may be 1% or more of the first image on the phosphor screen. It is usually possible to subtract a percentage of the first image from the second image to remove the residual image. If this is not possible, there are intensifiers with P47 phosphor, which is an order of magnitude faster than P46.
- The software uses the **Phosphor Decay Delay** setting to determine how long to wait after the gate pulse to shift the image. This value can be adjusted in **Advanced** flyout pane on the **Common Acquisition Settings** expander. If there is some residual image from the first frame in the second frame, simply increase the Phosphor Decay Delay setting to allow more time for the phosphor emission to decay before shifting the image. If residual image is not an issue, then the Phosphor Decay Delay setting can be decreased to reduce the time between the two DIF images. This setting has no effect on the actual phosphor decay time; it is just used to adjust timing.

## MCP Gating Option

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### Introduction

MCP gating (not to be confused with MCP bracket pulsing) provides you with a unique combination of nanosecond-scale gating speed and high ultraviolet QE. Normally, such high UV QE is only available in so-called slow gate intensifiers (i.e., those without a nickel underlay). The PI-MAX3 applies the primary gating pulse to the MCP portion of the tube and applies the bracket pulse to the photocathode. Consequently, it provides the full benefit of bracket pulsing along with enhanced QE.

The main limitations with this option are that there is a somewhat larger propagation delay and larger optical FWHM than a standard fast gate PI-MAX3. Insertion delay between trigger and T0 is ~12 ns. Insertion delay to the photocathode gate is  $\geq 30$  ns. Insertion delay to MCP gate is 75-225 ns (dependent on the individual intensifier): this delay allows the photocathode to be fully on before the MCP is gated. Pulse repetition rate is limited to 10 kHz.

### Setup and Operation

The PI-MAX3 must have an installed MCP Gating board.

1. Make all of the required cable connections for your experiment.
2. Switch on the equipment and start the application software.
3. Set up the gating parameters. You may want to start with a relatively long gate to acquire the phenomenon of interest.
4. Begin running the experiment.
5. Finally, narrow down the gate to the desired operation.

**Note:** Pulse repetition rate is limited to 10 kHz.

### Gain Variation

MCP gain approximately doubles for each 50 V increase in voltage. Therefore, small ripples in the MCP voltage as a result of the gating waveform will cause gain changes that vary with time after the rising edge of the gate pulse. A gain overshoot of 20 to 30% during the first 20 ns of a gate pulse is typical, with smaller variations later in time if a wider gate pulse is used. For a given gain setting and pulse width, these variations are reasonably repeatable, and may be calibrated.

## Fluorescence Experiment

A typical laser-induced fluorescence experiment might incorporate a pulsed laser that excites a sample with the laser beam and that additionally provides a trigger to the PI-MAX3. When the laser pulse hits the sample, some atoms are raised to a higher energy state and then spontaneously relax to the ground state, emitting photons as they do to generate the fluorescence signal. This signal can be applied to a spectrograph that spreads the fluorescence spectrum across the photocathode of the PI-MAX3. The spectrum would then be intensified and applied to the PI-MAX3's CCD array.

## Cabling for MCP Gated Operation

Figure 108 illustrates the cabling for an MCP gated experiment using SuperSYNCHRO™. The laser trigger output is applied to the PI-MAX3's **TRIGGER IN** connector to initiate the timing sequence. SuperSYNCHRO outputs gate the MCP on and off. To prevent artifacts from the laser from degrading the data, it is essential that SuperSYNCHRO be inhibited during each readout.

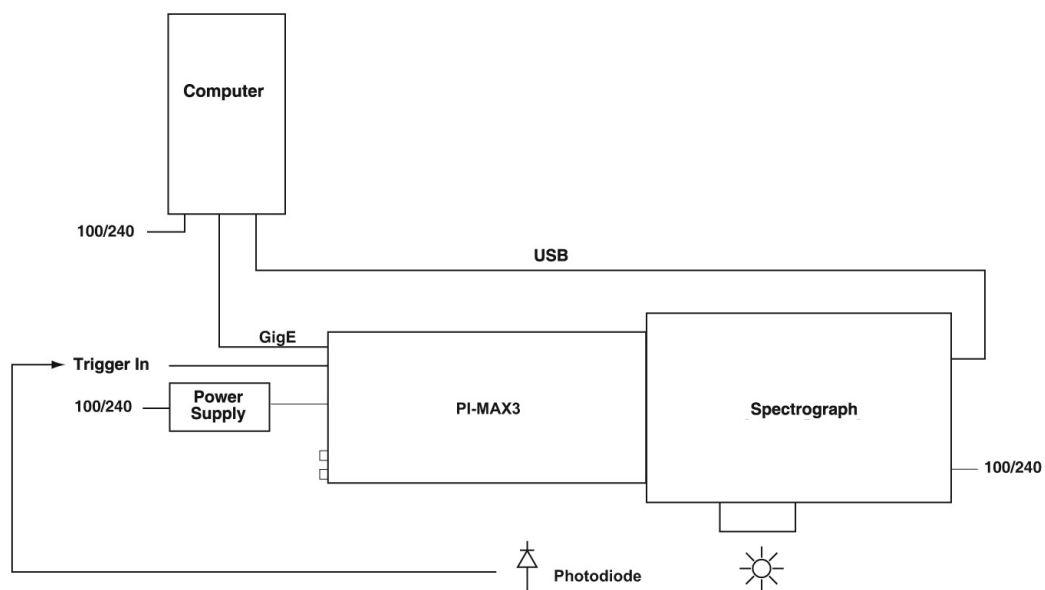
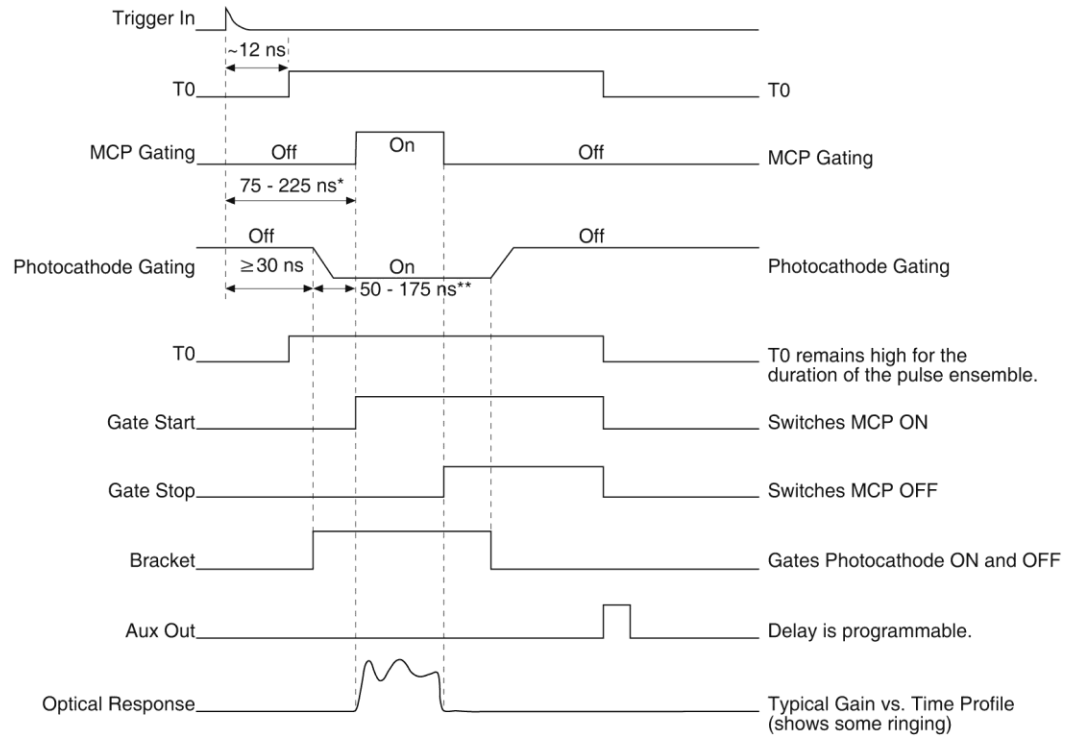


Figure 108. MCP Gated Operation Cabling

Figure 109 is a timing diagram for MCP gating of the photocathode.



\*  $T_d + T_{pk}$  typical. Depends on individual image intensifier

\*\* Depends on individual image intensifier

Figure 109. PI-MAX3 Timing in MCP Gated Operation

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## Picosecond Option

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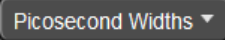
### Introduction

The picosecond gating option for the PI-MAX3 allows optical gates down to less than 500 ps (or to the lowest gate width the intensifier will support, whichever is greater). It consists of a picosecond gating board installed in the PI-MAX3 and some other modifications to support the board. The picosecond option can operate up to 100 kHz repetition rate\* (the main gate generator goes to 1 MHz) and has a few nanoseconds larger insertion delay than the main gate generator. The **MONITOR** BNC output operates differently in picosecond operation.

\* Refer to “*Repetition Rate Issues*“, on page 136, for detailed information about achievable repetition rates.

### Activating Picosecond Operation

**WinX:** Automatically selects the picosecond gating board whenever the gate width is set below 3 ns.

**LightField:** The **Picosecond Widths** button  will be added to the **SuperSYNCHRO Timing** expander when a PI-MAX3 containing the picosecond gating board is detected and loaded as an experiment device.

### Gain and Gate Width

The apparent gain of the intensifier falls off as the gate width is reduced. Typically, at the lower limit, the gain is less than 10% of the value observed at 50 ns.

**WinX:** The software automatically selects the appropriate gate pulse generator to use when the user selects a gate width: the standard switch-over width is 3 ns.

**LightField:** The user selects one of the available gate widths from the **Picosecond Widths** drop down list and that width will be automatically entered in the **Gate Width** field(s).

**Note:** When Sequential Gating is active, the starting and ending gate widths are the same: there are **NO** gate width sequences. However, differing starting and ending gate delays (swept delay) can be used with a constant gate width.

### MONITOR Operation

The **MONITOR** output (at the BNC on the rear panel) is calibrated to provide a rising edge at the time the optical gate is opening (+/- 500 ps). The **MONITOR** width is **NOT** indicative of the optical gate width. It does **NOT** change width when the gate width is changed in the picosecond mode. This is because at these speeds, the electrical pulse width is not directly translated into optical gate width. In addition, many users do not have oscilloscopes available that will reliably capture picosecond pulse widths. Therefore, it was decided to use a pulse width of ~6 ns, regardless of the selected gate width. The true optical gate width is shown in the application software and this is calibrated at the factory using a fast pulsed laser.

## Repetition Rate Issues

The picosecond gate generator operates at high peak power levels and therefore has a lower repetition rate capability than the main gate generator. The normal peak repetition rate for the picosecond gate generator is 100 kHz. However, it will allow 2 gates to be generated at up to 1 MHz to allow for DIF operation. In addition, the 100 kHz repetition rate cannot be sustained continuously. Practically, it must be interrupted periodically to read the CCD so this is not as great a problem as it may seem. The picosecond gate generator includes a digital average duty factor limiting circuit that will lock out gating (and light the red LED on the rear panel) to limit the average heat buildup in the gating circuit. This allows continuous operation at 10 kHz, and varying numbers of gates per frame at higher rates, depending on the read out time. Acquisitions of a few frames can usually be done with more gates per frame without hitting the limit and red light. Some typical numbers for sustained operation with a PI-MAX3:1024i are shown in Table 7.

Repetition Rate (kHz)	ADC Rate (MHz)	Binning & ROI	Readout Time (ms)	Gates/Frame
90	16	Full frame	~40	450
75	16	Full frame	~40	461
50	16	Full frame	~40	500
50	16	1Hx100V ROI	~3.4	145
25	16	Full frame	~40	666
10	any	any		No limit

Table 7. Typical Picosecond Rates, Readout Times, and Gates/Frame for PI-MAX3:1024i

## Timing

When using optical gate widths from a few nanoseconds to a fraction of a nanosecond, timing is obviously critical. The PI-MAX3 is calibrated with respect to the optical input plane (front mounting plane) and the rear panel. All other propagation paths must be accounted for by the user. These are significant, considering a 1 meter coaxial cable represents typically 4.5 ns delay or 9 times the gate width, assuming the gate width is set to 500 ps. To get the best representation of the **MONITOR** output, the user should use a high bandwidth oscilloscope set at 50Ω input impedance. The rise time of the **MONITOR** pulse is typically less than 500 ps when terminated in 50Ω.

## Methods for Finding a Short Optical Pulse

1. The “textbook” method is to calculate all the delays in the optical and trigger paths and set the PI-MAX3 delay accordingly. If one does all the arithmetic correctly and has accurate numbers for all of the delays involved, this method will work. In practice it seldom works because either some of the delays are not accurately known or something gets overlooked. The sum of the optical delays must be greater than the trigger delay (including the PI-MAX3 minimum delay). Doing the sums after the fact is still a valuable check on the system, even if the timing is achieved by the second method (see below).
2. A more direct and usually more convenient method is to start with a gate pulse much wider than the optical pulse and set the PI-MAX3 so the optical gate is wide enough to be sure it encompasses the optical pulse. This method works well if the pulse is conveniently repetitive, such as one derived from a repetitive laser. Once the pulse is found, it is an easy matter to reduce the pulse width and adjust the delay until the




precise timing needed is achieved. The PI-MAX3 repetitive and sequential gating can be used to good advantage in this method.

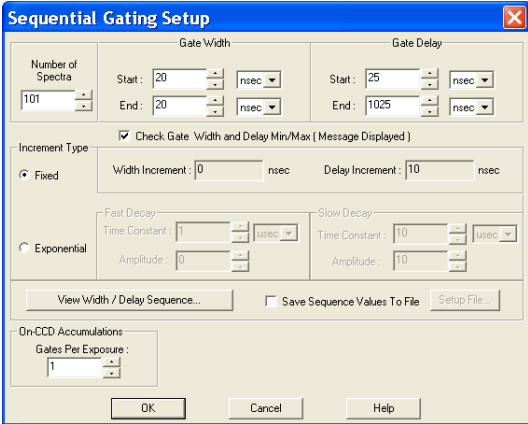
### Example:

This example is simplified in that it does not address all of the possible settings for Gate mode setup. It is intended to a sense of how to locate the signal of interest by successively decreasing gate pulse parameters.

- a. Suppose we start with a 1  $\mu$ s gate and delay set to the minimum value for the PI-MAX3 (approximately 25 ns), and we see the pulse. We then know the pulse is arriving between 25 ns and 1.025  $\mu$ s.

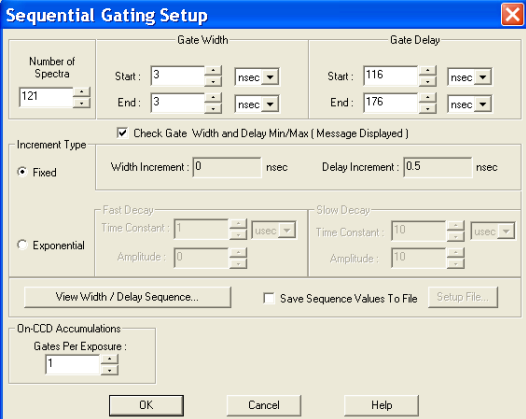
WinX	LightField
	<b>Gate Mode:</b> Repetitive
	<b>Number of Frames:</b> 1
	<b>Gate Delay:</b> 25 ns
	<b>Gate Width:</b> 1 $\mu$ s
<b>Number of Images/Spectra:</b> 1	

- b. We now set the sequential gating parameters for 20 ns gate width and 101 images/spectra {frames} at 10 ns per image/spectra {frames}: this spans the 1  $\mu$ s. We set the starting gate delay of 25 ns, ending gate delay of 1025, and take the sequence. We can then quickly look through the images or spectra (in WinX or LightField) and see to the nearest 10 ns when the optical pulse arrived.

WinX	LightField
	<b>Gate Mode:</b> Sequential
	<b>Number of Frames:</b> 101
	<b>Starting Gate Delay:</b> 25 ns
	<b>Starting Gate Width:</b> 20 ns
	<b>Ending Gate Delay:</b> 1025 ns
	<b>Ending Gate Width:</b> 20 ns
	<b>Reported Gate Delay Increment:</b> 10 ns
<b>Number of Images/Spectra:</b> 101	

- c. Assuming we found the signal in the 12<sup>th</sup> frame, we now set a narrower gate (say 3 ns) and sweep about this value in 500 ps steps with a span of 60 ns to find the time within 500 ps. Adjust the experiment for best signal strength and/or signal to noise ratio, then jump down to the final gate width (if width < 500 ps is desired) and again do a sweep to find the exact timing that maximizes the result.

This method has the advantage of assuring that the camera is seeing the pulse with the most favorable set-up before narrowing the gate width down.

WinX	LightField
	<p><b>Gate Mode:</b> Sequential</p> <p><b>Number of Frames:</b> 121</p> <p><b>Starting Gate Delay:</b> 116</p> <p><b>Starting Gate Width:</b> 3 ns</p> <p><b>Ending Gate Delay:</b> 176</p> <p><b>Ending Gate Width:</b> 3 ns</p> <p><b>Reported Gate Delay Increment:</b> .5 ns</p>
<p><b>Number of Images/Spectra:</b> 121</p>	

## General Tips and Tricks

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### Introduction

In Chapters 4, 6, and 7, the objective was to show how to take an image or spectrum with a minimal operating configuration and following a simple procedure. In this chapter, we consider factors that affect more complex measurements.

### Overexposure Protection

#### WARNING

Image intensified detectors such as the PI-MAX3 can be *destroyed* if exposed to excessive light levels. Princeton Instruments cannot take responsibility for damage due to misuse.

Intensified detectors must not be continuously exposed to high-level radiation ( $\geq 10^{-4}$  foot candles). When the illumination level is not quantitatively known, toggle the **I.I.T.** switch (on the back of the PI-MAX3) to the OFF position while you are adjusting the incoming light level. After making adjustments, toggle the switch to the **ON** position. If the alarm sounds repetitively, toggle the switch back to **OFF** and readjust the lighting conditions.

If the experimental conditions dictate that only a small portion of the photocathode is illuminated over relatively long periods of time, change the illuminated region of the photocathode periodically to avoid long term localized photocathode or MCP damage.

If you can do so, it is a good idea to avoid intense light on the intensifier even when it is off. High light levels increase EBI, often for hours, even when the intensifier is off. Image burn-in can occur with some photocathode types.

**Note:** The audible alarm and protection circuits are not fail-safe protection, particularly when working with high intensity sources such as lasers. For additional information, see the “*Alarm*” discussion on page 72.

### Signal Delay

#### *Introduction*

For the detector to see a transient signal, it is essential that it be gated on when the signal arrives at the detector. If this requirement isn't given careful consideration, it is possible to set up an experiment in which the signal will come and go *before* the detector is gated on. If this happens, no proper data can be taken. Depending on the nature of the experiment and the specific equipment involved, a number of different factors may need to be considered to be assured that the detector gates at the right time.

#### *Time Budgets*

A time budget is a listing of all the delays in the system that affect coincidence of the signal and gate at the camera. Given a system that, in addition to the PI-MAX3 and an internal timing generator, contained a low-jitter pulsed laser triggered from an external

timer and an external trigger source that is also triggering the pulse generator, a time budget for this system might appear as follows.

### PI-MAX3 Internal Timing Generator

#### Signal Delay

- **Cable Delay from External Timer to Laser:** 10 ns (6 ft cable is assumed)
  - **Delay (at laser); Trigger to Laser Pulse:** 10 ns
  - **Delay; Laser Pulse to Sample:** 10 ns
  - **Delay; Fluorescence Signal to Detector:** 5 ns
- Total Signal Delay:** 35 ns

#### Gate On Delay

- **Cable Delay from External Timer to PI-MAX3:** 15 ns (10 ft cable is assumed)
  - **PI-MAX3 Insertion Delay; Trigger to Start of Gate Open Pulse:** 25 ns
- Total Gate On Delay:** 40 ns

In this example, although the Signal Delay and the Gate On Delay are close, if the signal is a pulse lasting only a few nanoseconds, it will have come and gone before the Gate opens, and no valid experimental data could be taken. Obviously, this sample time budget is unlikely to match any actual system and the values for both the Signal Delay and the Gate On Delay could be very different from those indicated here. Nevertheless, it illustrates the importance of making a record of the delays that will be encountered in any system to determine their possible impact on experimental results.

### Measuring Coincidence

In addition to preparing a Time Budget, it is advantageous if you can directly measure the timing of the critical signals. A fast oscilloscope can be used for this purpose. Without an oscilloscope to monitor the signals, it will be difficult to determine the timing with sufficient accuracy.

**Tips:** If you have a set of matching probes, use them. Major brand oscilloscope probes of the same model are usually matched to better than 1 ns. If you choose to use coaxial cables, measure the delay of each and use that information in the calculations.

The PI-MAX3 **Monitor** BNC connector provides a pulse coincident with respect to the actual intensifier photocathode gating by  $\pm 5$  ns. Note that this output is not designed for good fidelity but rather for accurate timing. The amplitude is typically more than a volt and we suggest that you monitor the pulse with a high impedance probe (you can also use 50  $\Omega$  coaxial cable to a 50  $\Omega$  oscilloscope and you will get a lower amplitude pulse).

The signal timing will probably be more difficult to measure. Typically, you might divert a small portion of the laser beam using a pellicle mirror located near the sample position. By directing the beam to a PIN diode module, you could obtain an electrical signal that could be monitored with the oscilloscope to accurately indicate the arrival of the laser beam at the sample position. Note that the indicated time would have to be corrected for the insertion delay of the path from the pellicle mirror to the oscilloscope, including the insertion time of the PIN diode, which might be on the order of the 10 ns. This correction would have to be compared with the delays that would normally exist between the sample

position and the detector to determine the actual time the signal would arrive at the detector. Also, the oscilloscope will have its own insertion delay, perhaps 20 ns, and an uncertainty of nominally 1% of the time base.

Another consideration is how to trigger the oscilloscope. If there is a common trigger source for the sample position signal and for the gating, that trigger could also be used to trigger the oscilloscope, allowing both signals to be observed simultaneously. Another possibility is to trigger the oscilloscope from the PIN diode signal to observe the Monitor signal, or to trigger the oscilloscope from the Monitor signal to observe the PIN diode signal. The signal that occurs first would have to be used as the oscilloscope trigger. *This is not necessarily always the case. Digital oscilloscopes can display signals that occur before the trigger.*

### **Adjusting the Signal Delay**

The PI-MAX3 internal timing generator gives the user wide latitude with respect to adjusting the delay between the time the timing generator is triggered and the time the Gate On and Off edges are generated. This being the case, as long as the light signal applied to the detector occurs *after* the minimum delay time of the timing generator (25 ns), there will be no problem establishing the necessary coincidence.

On the other hand, if the light signal applied to the detector occurs *before* the minimum delay time of the timing generator, then no amount of adjusting the delay at the timing generator can rectify the problem. The light signal itself will have to be delayed.

If a common source is triggering both the timing generator and the laser, a very convenient solution is to insert electrical delay (long cable) between the trigger source and the laser. This is generally preferable to establishing the necessary delay optically via mirrors or fiber optic cable.

Alternatively, pass the laser output through a length of optical fiber cable. By using different lengths of fiber, almost any desired signal delay can be achieved. Yet another solution would be to set up two separated parallel mirrors with a small angle between them. Typically, it will be easily possible to bounce the laser beam back and forth between the mirrors half a dozen times to obtain the necessary delay. In any case, once the light signal is arriving at the detector *after* the minimum gate time, the timing generator delay adjustments can be used to bring them into coincidence. Keep in mind that using optical cable or mirrors to delay the signal will carry some intensity penalty, which might have an adverse affect on measurement results in some experiments.

### **Optimizing the Gate Width and Delay**

When the basic delay questions have been answered, the next consideration is optimization of the Gate Width and Delay. The goal is to have the gate just bracket the signal event. One effective approach is to:

1. Begin with minimum delay and a gate width far wider than the optical signal pulse to be measured.
2. While observing the data signal at the computer monitor, gradually increase the delay until the event vanishes. This will mark the point at which the gate is opening just *after* the signal, causing the signal to be lost.
3. Reduce the delay until the signal reappears.
4. Then begin reducing the gate width (not the delay). As the gate is narrowed, the amount of EBI generated will decrease so the signal-to-noise ratio should improve.

When the point is reached where the gate becomes narrower than the signal being measured, the observed signal data will degrade. You may have to adjust the delay to keep the signal in view.

5. From there increase the width slightly for maximum signal and optimum signal-to-noise.

## Lasers

Pulsed lasers are used in many experiments where a gated intensified detector might be used to recover the signal. For example, in combustion measurements, a laser pulse might be applied to a flame and the resulting fluorescence studied as the signal to be analyzed. Because this short-term signal is much weaker than the integrated light emitted by the flame, an intensified gated detector should be used to do the measurement.

Because available lasers differ so widely with respect to their characteristics and features, there is no way to discuss specifically how to incorporate your particular laser into a measurement system. It is necessary that users be familiar with the features, operation, and limitations of their equipment. Nevertheless, the following observations might prove helpful.

### ***Free Running Lasers***

These lasers behave essentially as oscillators. They typically exhibit little jitter from pulse to pulse and are very easy to synchronize with the experiment. If the laser has a Pretrigger Output, it can be used to trigger the timing generator. If the interval between the Pretrigger and the laser output is long enough, the timing generator delay can then be adjusted to catch the laser pulse following each pretrigger. If the interval between the Pretrigger and the laser output isn't long enough to accommodate all the insertion delays, the timing generator delay can be adjusted to catch the *next* laser pulse. *As long as the laser's jitter relative to the period is small*, this is a perfectly valid way to operate. If the laser doesn't have a Pretrigger Output, one option is to use a pellicle mirror and a PIN diode to obtain the timing generator trigger. Again, the timing generator delay could be adjusted to catch the *next* laser pulse to achieve the necessary synchronization between the optical signal and the photocathode gate at the detector, although this would cause at least every other laser pulse to be lost.

### ***Triggered Lasers***

**Timing Generator as Trigger Source:** Using the PI-MAX3's **SyncMASTER1** signal to trigger the laser allows you to get rid of the propagation delay for the External Trigger (25 ns) and to set up all timing relative to **T0**. You will still need to consider the delays from the cable to the laser (1.5 ns/ft), internal delay from trigger to firing (laser dependent, 50 ns for example), the PI-MAX3's internal minimum allowable gate delay (25 ns).

**External Source Triggers Both Timing Generator and Laser:** This is the more complex case because it contains many sources of delay that would have to be considered. A carefully prepared Time Budget could prove invaluable in determining what steps need to be taken to bring the gate and signal into coincidence at the detector. In addition, actually measuring delays with a fast oscilloscope as previously described could be very helpful. If the laser provides a **Pre-Trigger** output that can be used to trigger the Timing Generator, it may not be necessary to use mirrors or fiber-optic cable to delay the laser pulse. If there is no **Pre-Trigger**, then taking steps to delay the arrival of the laser pulse at the sample would likely be necessary. The easiest solution would be to insert electrical delay between the external trigger source and the laser.

### ***Jitter***

Jitter, uncertainty in the timing of the laser output, is a critical laser performance parameter in gated experiments. If the jitter is significant relative to the duration of the signal pulse, the gate width will have to be wide enough to accommodate it, and the temporal discrimination against unwanted signal will be reduced. Some types of high power laser pulse have considerable jitter, even using a pretrigger. Where this is the case, there is no choice but to trigger from the actual laser pulse. One way of doing that is to use a pellicle mirror and PIN diode as previously described and then to delay the light (usually by multiple reflections between mirrors or in an optical fiber) until the gate “opens.”

## **Inhibiting the Pulser during Readout**

In Gate mode operation, if gating pulses are applied to the detector during a readout, it will cause undesirable artifacts in the data. In experiments where the time between cycles is longer than the readout time, there is no possibility of this happening and it is not a matter of concern. If the experiment is such that it is possible for a new gate to be applied before the readout of the previously gathered data set is complete, preventive action will be required. With a PI-MAX3, the timing generator is inhibited internally.

## **Lens Performance**

Imaging applications require that a lens be mounted to the detector. Because the lens characteristics affect system performance, it may be helpful to review some basic lens concepts. Basically, light from an object enters the front of the lens and is focused to a sharp image on the photocathode of the intensifier. The ability of the lens to do this well depends on a number of factors, as follows.

### ***Throughput***

The throughput of a lens is determined by its aperture, which can ordinarily be set to a number of different values or  $f/$  stops. The higher the number after the slash, the smaller the aperture and the lower the throughput. Depth of field considerations make the focus adjustment most sensitive at maximum aperture (smallest  $f/$ ).

### ***Depth of Field***

Depth of field is a measure of how the sharpness of a lens varies with respect to the distance of an object from the lens. For any given aperture, there is a depth of field, usually marked on the barrel of the lens. Objects within the zone will be sharply imaged. Objects closer or further than the depth of field will not be as sharp. The further an object is from the point of sharpest focus, the less sharp its image on the CCD will be. *The point of maximum sharpness is located 1/3 of the way into the depth of field zone.* For example, if the indicated depth of field for the selected aperture extended from 3 ft to 6 ft, the point of maximum sharpness will be at 4 ft.

For good focusing sensitivity, the depth of field should be small (large aperture). If the aperture is small, the depth of field will be deep, making it difficult to establish the point of sharpest focus. For example, with a 50 mm lens, at  $f/4$  the depth of field will extend from 8 ft to infinity. By focusing at full aperture, the depth of field will be as shallow as possible. As a result, the effects of even very small focusing adjustments will be readily observed, allowing the focus to be set with precision. Once the optimum focus setting has been achieved, the aperture can be reduced to the point of maximum sharpness. In some experiments, you may wish to adjust the aperture for optimum signal level. However, the

experiment setup parameters established with the applications software can also be used to adjust the signal level, allowing the lens aperture and focus to be optimized.

## Baseline Signal

With the detector completely blocked, the CCD will collect a dark charge pattern, dependent on the exposure time, detector temperature, and intensifier gain setting. The longer the exposure time and the warmer the detector the larger and less uniform this background will appear.

After temperature lock has been established, wait about 5 minutes for the detector temperature to completely stabilize. Then try taking a few dark charge readings with the detector operated with the I.I.T. switch set to OFF.

**Note:** Do not be concerned about either the baseline level of this background or its shape, unless it is very high, i.e., > 1000 counts (or > 3000 counts at Gain=2 for some cameras). What you see is not noise. It is a fully subtractable readout pattern. Each CCD has its own dark charge pattern, unique to that particular device. In addition, a small offset is built in to prevent noise or pattern from going below zero. Every device has been thoroughly tested to ensure its compliance with Princeton Instruments' demanding specifications.

## Temperature Lock

If the PI-MAX3 Detector loses temperature lock, the internal temperature of the camera has gotten too high, such as might occur if the operating environment is particularly warm or if you are attempting to operate at a too cold temperature. If this happens, an internal thermo-protection switch will disable the cooler circuits to protect them. Although the thermo-protection switch will protect the camera, users are advised to power down and correct the operating conditions that caused the thermal-overload to occur. Note that the cooling performance of the detector can be enhanced by circulating water coolant. See *“Temperature Control”*, page 47.

Turn the controller off for fifteen or twenty minutes. Then turn it back on and set a warmer temperature from the software **Detector Temperature** dialog. Temperature lock should be re-established within a few minutes.

## Intensifier Alarm

### Caution

Contact the factory at once if sporadic or continuous unwarranted alarms occur. They may indicate intensifier damage or another situation that requires immediate attention.

To reduce the risk of detector damage, PI-MAX3 detectors are equipped with an audible alarm in the detector head, activated when the intensity of light falling on the image intensifier exceeds a preset threshold. While the alarm is sounding, the photocathode is temporarily disabled. Toggle the **I.I.T.** switch on the back of the PI-MAX3 to the **OFF** position. Cover the detector window and only switch the **I.I.T.** switch to **ON** after the illumination level has been lowered. If the alarm sounds repetitively even when the illumination level is adequately low, select **Safe Mode** in the WinX application or shut the system down and contact the factory for guidance.



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# Chapter 14

## System Component Descriptions

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### Introduction

PI-MAX3 is an advanced intensified CCD (ICCD) camera system used for low light and time resolved applications. It consists of an imaging (square) or spectroscopy (rectangular) format CCD coupled to Gen II (PI-MAX3 RB, SB, UV) or Filmless Gen III (PI-MAX3 HQ) intensifiers. The operation of the camera system is under complete control of WinView/32 (Imaging) or WinSpec/32 (Imaging and Spectroscopy) or LightField software packages. In pulsed/gated experiments, where the camera needs to be synchronized to a light source such as laser, the internal timing generator is used.

### PI-MAX3 Camera



#### Mount Adapters

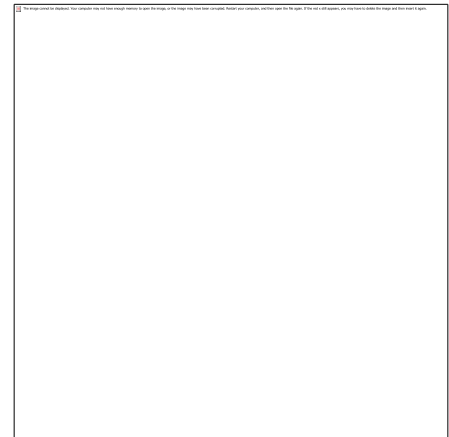
The nose at the front end of the PI-MAX3 camera is designed to accept three types of mount adapters: C-mount, F-mount, and Spectroscopy-mount. The mount adapter specified when the system was ordered was installed on PI-MAX3 at the factory (the other two mounts are supplied in the PI-MAX3 accessory kit). For more information about these mount adapters, refer to Appendix E for C- and F-mount adapters and refer to Appendix G for spectroscopy-mount adapters and spectrograph adapters.

#### Switches, Connectors and Indicators

**Power connector:** 7-pin D specialty connector; connects to the PI-MAX3 power supply. See *Figure 110*.

**AUX OUT:** DC-coupled variable delay trigger output for synchronizing other system components with the PI-MAX3 internal timing generator. The host software sets the Delay Time of this output with respect to the internal timing generator trigger time. The source impedance is approximately  $100\ \Omega$  and it will provide  $> 1\ \text{V}$  into  $50\ \Omega$ .

**Monitor:** BNC port for TTL logic 1 pulse delayed  $\pm 3\ \text{ns}$  with respect to photocathode gating. *Cable delay,  $\sim 1.5\ \text{ns/ft}$ , will be in addition to the delay at the connector.*



*Figure 110. PI-MAX3 Rear Panel*

**I.I.T. PWR On/Off switch:** This switch biases the image intensifier photocathode ON or OFF. When the I.I.T. switch is set to **ON**, the photocathode can be gated ON.

*Exception: Selecting **SAFE** on the Experiment Setup Main screen overrides control and will prevent the photocathode from being biased on regardless of the I.I.T. switch setting.*

When the I.I.T. switch is set to **OFF**, then the photocathode cannot be turned on from software.

**Caution**

It is advisable to set the I.I.T. switch to **OFF** as a fail-safe measure if the PI-MAX3 is left ON but unused for a period of time.

**Error:** Red LED lights to warn of excessive repetition rate. Must be off for proper operation.

**Note:** Excess Rep Rate LED is also activated by MCP bracket pulsing; MCP bracket repetition rate limit is 6.25 kHz.

**Trigger In:** When external triggering is selected in the software, the internal timing generator will be triggered by an externally derived trigger pulse (range of  $\pm 5.5$  V) applied to this input. The threshold, slope, coupling mode (AC or DC), and input impedance (High or  $50\ \Omega$ ) are selectable in software. The associated Green LED flashes each time PI-MAX3 is triggered (glows steadily at high repetition rates).

**Note:** In gated operation, the green LED indicator flashes each time the PI-MAX3 is triggered. The actual triggering can also be readily determined by observing the signal at the PI-MAX3 **Monitor** output with a fast oscilloscope.

**Coolant ports:** Two standard  $\frac{1}{4}$ " size barbed brass fittings for circulating coolant are located on the back panel. Either port may be used as the inlet. ***The coolant cannot be chilled.*** Use the Princeton Instruments CoolCUBE<sub>II</sub> coolant circulator. See *"Making the Camera-Circulator Connections,"* page 30 and *"Temperature Control,"* page 47 for additional information.

**Note:** Although circulating water will extend the PI-MAX3's cooling capabilities, it is not necessary. Most of the PI-MAX3 cooling is provided by the fan.

**Ready Out:** Level at this BNC is initially LOW. It changes state on completion of cleaning cycles before the first exposure.

**AUX I/O:** 26-pin male DB connector. Provides the following five I/O signals (that can be used to input a trigger to initiate data acquisition, to monitor frame readout status, and to control an external shutter): T0 Out, Pre-Trigger In, SyncMASTER1, General Purpose Input 0, and SyncMASTER2. Refer to *"AUX I/O Connector Pinout"*, page 161, for more information.

**Logic Out:** 0 to +3.3V logic level output (TTL-compatible). WinView/WinSpec32 (Ver. 2.5.25 or higher) software-selectable Acquiring, Image Shift, Logic 1, Read Out, Shutter, and Wait for Trigger signal. When the **Invert LOGIC** check box is checked, the output is at a logic low when the action is occurring.

**Fan:** Ventilation fan that runs continuously to remove heat generated by the thermoelectric cooler and the electronics. Air is drawn into the camera through the rear grill, picks up the heat from the electronics and the cooler, and is then exhausted through the side ventilation slots.

**Thermoelectric Cooler:** The thermoelectric (TE) cooler is mounted to the heat removal block. With air-cooling alone, at an ambient temperature of 25°C, temperature lock at -25° will generally occur within ten to fifteen minutes. Note that the exact cooling performance is a function of the CCD array installed. Also, if the lab is particularly warm, achieving temperature lock might take longer or not occur at all.

### WARNING!

Always turn the power off at the power supply before connecting or disconnecting any cable that interconnects the camera and the computer or serious damage to the CCD may result. This damage is **NOT** covered by the manufacturer's warranty.

## Interface Card



**GigE Ethernet Card:** This card must be installed in the host computer to control the PI-MAX3 camera and to receive data from the camera.

## Extender Bracket Kit

Each PI-MAX3 camera is shipped with an Extender Bracket kit that when mounted to the rear of the camera, allows the PI-MAX3 to be secured to a laboratory table with tapped mounting hole arrays with ¼-20 on 1" spacing or M6 on 25 mm spacing.

## CoolCUBE<sub>II</sub> Coolant Circulator (Option)



Liquid-cooled PI-MAX3 cameras can cool to a lower temperature (typically -35° C) than air cooling. Instead of using a fan to remove heat, these cameras incorporate a closed loop system of circulating fluid. The CoolCUBE<sub>II</sub> circulator unit continuously pumps the 50:50 mixture of room temperature (23°C) water and ethylene glycol. To prevent voiding the warranty, use only the circulator and hoses shipped with your system.

## Spectrograph (Option)

The system may also include a spectrograph. If so, the camera must be properly mounted to it as described in the manual supplied with the spectrograph. If the spectrograph will be computer-controlled, a suitable interface cable will additionally be required. For mounting instructions, see Appendix G, *Spectrograph Adapters*, beginning on page 186.

## Cables

The cables listed below may be supplied with the PI-MAX3 system.



**Ethernet Cable:** This standard 5 meter (16.4') cable is a Cat 5e/6 Ethernet cable (6050-0621) for interconnecting the camera and the host computer. The distance between the camera and the computer can be over 50 meters. Please contact the factory for longer cables.



**AUX I/O Cable:** The I/O cable (6050-0660) has a female, DB26, high-density connector that connects to the **AUX I/O** connector. The five (5) BNCs at other end of the cable provide access to the following five I/O signals (that can be used to input a trigger to initiate data acquisition, to monitor frame readout status, and to control an external shutter): **T0 Out**, **Pre-Trigger In**, **SyncMASTER1**, **General Purpose**

**Input 0**, and **SyncMASTER2**. Refer to “*AUX I/O Connector Pinout*”, page 161, for more information.

### Other Cables

Other cables may also be required depending on the system requirements.

## Tubing



Clear PVC tubing (3', 5/32" OD, 1/32" wall McMaster-Carr 5006K42) is supplied with the PI-MAX3. This tubing is for connecting the PI-MAX3 to a dry nitrogen source for cooling the photocathode.

## Application Software



**WinX:** The PI-MAX3 camera can be operated by using either WinView/32 or WinSpec/32, Princeton Instrument's 32-bit Windows® software packages designed specifically for high-end imaging and spectroscopy, respectively. The Princeton Instruments' software provides comprehensive image/spectral capture and display functions. The package also facilitates snap-ins to permit advanced operation. Using the optional built-in macro record function, you can also create and edit your own macros to automate a variety of operations.

**PVCAM:** The standard software interface for cooled CCD cameras from Roper Scientific. It is a library of functions that can be used to control and acquire data from the camera when a custom application is being written. For example, in the case of Windows, PVCAM is a dynamic link library (DLL). Also, it should be understood that PVCAM is solely for camera control and image acquisition, not for image processing. PVCAM places acquired images into a buffer, where they can then be manipulated using either custom written code or by extensions to other commercially available image processing packages.

**Scientific Imaging ToolKit™:** SITK™ is a collection of LabVIEW® VIs for scientific cameras and spectrographs. This third party software can be purchased from Princeton Instruments.



**LightField®:** The PI-MAX3 can be operated using LightField, Princeton Instrument's 64-bit Windows Vista® and Windows® 7 compatible software package. LightField combines complete control over Princeton Instruments' cameras and spectrometers 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 Princeton Instruments. PICam is an ANSI C library of camera control and data acquisition functions. Currently, the interface supports Windows Vista and Windows 7.

## User Manuals



**PI-MAX3 System User Manual:** This manual describes how to install and use the PI-MAX3 system components. The most up-to-date version of this manual and other Princeton Instruments manuals can be found and downloaded from [ftp://ftp.princetoninstruments.com/public/Manuals/Princeton Instruments/](ftp://ftp.princetoninstruments.com/public/Manuals/Princeton%20Instruments/)

**WinView/32 or WinSpec/32 User Manual:** This manual describes how to install and use the application program. A PDF version of this manual is provided on the installation CD. Additional information is available in the program's on-line help.



**LightField<sup>®</sup> User Manual:** This manual describes how to install and use the LightField application program (for 64-bit Windows Vista<sup>®</sup> and Windows<sup>®</sup> 7 operating systems). The manual is provided in PDF version on the installation CD and will be installed in the Princeton Instruments/LightField/Documents subdirectory. Acrobat 7.0 or higher is required. Additional information is available in the program's on-line help.

**Note:** You can download current versions of Princeton Instruments manuals at [ftp://ftp.princetoninstruments.com/Public/Manuals/Princeton Instruments/](ftp://ftp.princetoninstruments.com/Public/Manuals/Princeton%20Instruments/). Versions of Acton manuals are located at <ftp://ftp.princetoninstruments.com/Public/Manuals/Acton/>.

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# Chapter 15

## Troubleshooting

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**CAUTION!** If you observe a sudden change in the baseline signal you may have excessive humidity in the CCD enclosure of the camera. Contact the factory for information on having the camera checked or repaired.

**WARNING!** Do not attach or remove any cables while the camera system is powered on.

### Introduction

The following issues have corresponding troubleshooting sections in this chapter.

Alarm Sounds Repetitively	Page 153
Alarm Sounds Sporadically	Page 153
Baseline Signal Suddenly Changes	Page 153
Camera Is Not Responding	Page 153
Camera Stops Working	Page 154
Cooling Troubleshooting	Page 154
Data Loss or Serial Violation	Page 155
Error Occurs at Computer Powerup	Page 155
Ethernet Network is not accessible	Page 155
Excessive Readout Noise	Page 157



## Alarm Sounds Repetitively

Immediately reduce the light entering the camera. This can be done by switching **I.I.T.** switch on the back of the PI-MAX3 to “**OFF**” until you lower the source illumination, by decreasing the lens aperture, or by completely blocking the light into the camera window with a lens cap or equivalent until the light level has been lowered.

If the alarm sounds repetitively even when the illumination level is adequately low, switch the **I.I.T.** to “**OFF**” and turn off the PI-MAX3 power supply. Then contact the factory: this may indicate intensifier damage or another situation that requires immediate attention.

## Alarm Sounds Sporadically

It is normal for the alarm to sound briefly when the high-voltage supply is first turned on. However, if the alarm sounds sporadically, contact the factory at once. This may indicate intensifier damage or another situation that requires immediate attention.

## Baseline Signal Suddenly Changes by > 1000 ADU

There are two possible reasons for this change:

- The temperature setting has been changed. In this case, a change in baseline signal is normal.
- There may be excessive *humidity* in the CCD enclosure of the camera. If the temperature setting has not been changed and you observe a baseline signal change, turn off the system immediately. An excess humidity condition should be corrected promptly or permanent damage not covered by the Warranty could occur. Have the unit serviced by Princeton Instruments or an authorized service facility of Princeton Instruments.

## Camera Is Not Responding

If this message pops up when you click on **OK** after selecting the Interface Type during **Hardware Setup** (under the WinX **Setup** menu), the system has not been able to communicate with the camera. Check to see if the Controller has been turned ON and if the interface card, its driver, and the interface cable have been installed.

- If the Camera is ON, the problem may be with the interface card, its driver, interrupt or address conflicts, or the cable connections.
- If the interface card is not installed, close the application software and turn the PI-MAX3 power supply OFF. Follow the interface card manufacturer’s installation instructions and cable the interface card to the “GIG-E” port on the rear of the camera. Then do a “Custom” installation of WinSpec/32 or WinView/32 with the appropriate interface component selected. Be sure to deselect the interface component that does not apply to your system.
- If the interface card is installed in the computer and is cabled to the “GIG-E” port on the rear of the camera, close the application program and turn the camera OFF. Check the cable connections and secure the cables if connections are loose.
- If the interface card was installed after the WinX application software has been installed, close the application program and do a “Custom” installation of WinSpec/32 or WinView/32 with the GigE interface component selected. Be sure to deselect the interface component that does not apply to your system.

## Camera Stops Working

Problems with the host computer system or software may have side effects that appear to be hardware problems. If you are sure the problem is in the camera system hardware, begin with these simple checks:

1. Turn off all AC power.
2. Verify that all cables are securely fastened and that all locking screws are in place and all slide latches are in the latched position.
3. Correct any apparent problems and turn the system on.
4. If the system still does not respond, contact Customer Support.

## Cooling Troubleshooting

### ***Temperature Lock Cannot be Achieved or Maintained.***

Possible causes for not being able to achieve or maintain lock could include:

- Ambient temperature greater than +20°C. This condition affects TE-cooled cameras. If ambient is greater than +20°C, you will need to cool the camera environment or raise the set temperature.
- Airflow through the camera and/or circulator is obstructed. The camera needs to have approximately two (2) inches (50 mm) clearance around the vented covers. If there is an enclosure involved, the enclosure needs to have unrestricted flow to an open environment. The camera vents its heat out the side vents near the nose. The air intake is at the rear of the camera.
- A hose is kinked. Unkink the hose.
- Coolant level is low. Add 50:50 mix of ethylene glycol and water. Refer to manufacturer's instructions for adding coolant.
- There may be air in the hoses. Remove air and add 50:50 mix of ethylene glycol and water. Refer to manufacturer's instructions for removing excess air and adding coolant.
- Circulator pump is not working. If you do not hear the pump running when the circulator is powered on, turn off the circulator and contact the manufacturer's Customer Support.
- CoolCUBE<sub>II</sub>: The circulator is higher than the camera. Reposition the circulator so that it is 6 inches (150 mm) or more below the camera. The vertical distance should not exceed 10 feet (3 m). Typically, the camera is at table height and the circulator is on the floor.
- The target array temperature is not appropriate for your particular camera and CCD array.
- The camera's internal temperature may be too high, such as might occur if the operating environment is particularly warm, if you are attempting to operate at a temperature colder than the specified limit, or if you have turned off the fan and are not circulating coolant through the camera. TE cameras are equipped with a thermal-protection switch that shuts the cooler circuits down if the internal temperature exceeds a preset limit. Typically, camera operation is restored automatically in about ten minutes. Although the thermo-protection switch will protect the camera, you are nevertheless advised to power down and correct the operating conditions that caused the thermal-overload to occur.

### ***Gradual Deterioration of Cooling Capability***

While unlikely with the PI-MA3 camera (guaranteed permanent vacuum for the life of the camera), if you see a gradual deterioration of the cooling capability, it might be due to damaged camera vacuum. This can affect temperature performance such that it may be impossible to achieve temperature lock at the lowest temperatures. In the kind of applications for which cooled CCD cameras are so well suited, it is highly desirable to maintain the system's lowest temperature performance because lower temperatures result in lower thermal noise and better the signal-to-noise ratio. Contact the factory to make arrangements for returning the camera to the support facility.

## **Data Loss or Serial Violation**

You may experience either or both of these conditions if the host computer has been set up with Power Saving features enabled. This is particularly true for power saving with regard to the hard drive. Make sure that Power Saving features are disabled while you are running WinView/32 or WinSpec/32.

## **Error Occurs at Computer Powerup**

If an error occurs at boot up, either the Interface is not installed properly or there is an address or interrupt conflict. Turn off the computer, try a new address or interrupt and reinstall the card. Be sure the Interface is firmly mounted in the slot.

### **Caution**

Since interrupts and DMA channels cannot be shared, make sure no other boards in your computer use this interrupt or these DMA channels.

one and reports the address and interrupt assignments for that one as well. In a few

## **Ethernet Network is not accessible**

When the Princeton Instruments software is installed, all Intel Pro/1000 interface card drivers found on the host computer are updated with the Intel Pro/1000 Grabber Adapter (Vision High-Performance IP Device) driver provided by Pleora Technologies, Inc. If this computer is connected to an Ethernet network via an Intel Pro/1000 card that does not use the Pleora driver, the network connection will be broken. The tool used to restore the network connection depends on whether you are using WinX (32-bit) or LightField (64-bit).

### ***For WinX:***

1. Locate the EbDriverTool32.exe file.
  - Download the **EbDriverTool32.exe** file to your computer from <ftp://ftp.princetoninstruments.com/public/Software/Official/WinX32/GigE/>
  - Or open the default Pleora directory. Typically it is located at **C:\Program Files\Common Files\Pleora**. The **EbDriverTool32.exe** (or EbDriverTool.exe) file may be in a subdirectory.
2. Run the file.
3. When this program executes, select the appropriate Ethernet card and under the **Action** category, choose “**Install Manufacturer Driver**” from the pulldown menu.

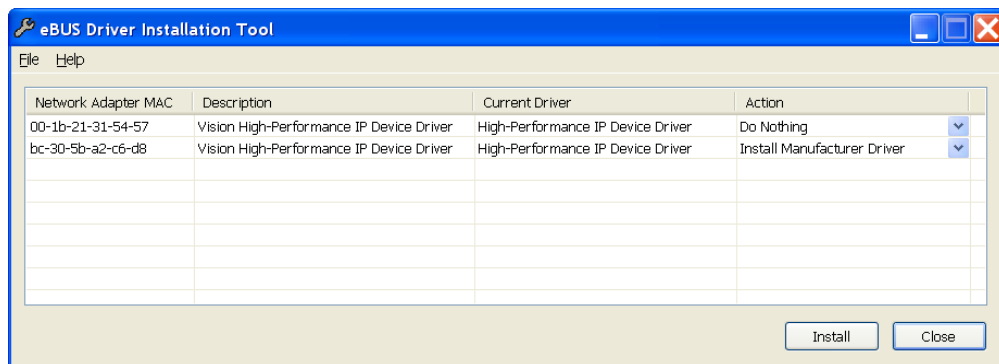


Figure 111. Ebus Driver Installation Tool dialog

4. After making the selection, click on **Install**.
5. After the installation you may be asked to reboot the computer. If you are asked to reboot, you can
  - Click on “**Yes**” to initiate the reboot.
  - Click on “**No**” to wait before rebooting. If you select “**No**,” you may be required to close the **eBUS Driver Installation Tool** dialog. Reboot the computer at your convenience.
6. Verify that the network connection has been re-established. If a reboot was required, wait until the reboot has occurred before verifying the connection.

#### **For LightField:**

1. Locate the EbDriverTool64.exe file. Typically it is located at **C:\Program Files\Common Files\Pleora**. The **EbDriverTool64.exe** file may be in a subdirectory.
2. Run the file.
3. When this program executes, select the appropriate Ethernet card and under the **Action** category, choose “**Install Manufacturer Driver**” from the pulldown menu.

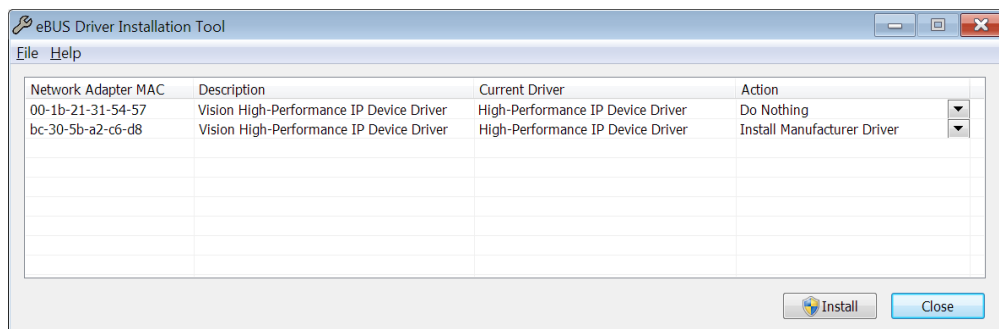


Figure 112. Ebus Driver Installation Tool dialog

4. After making the selection, click on **Install**.
5. After the installation you may be asked to reboot the computer. If you are asked to reboot, you can
  - Click on “**Yes**” to initiate the reboot.

- Click on “**No**” to wait before rebooting. If you select “**No**,” you may be required to close the **eBUS Driver Installation Tool** dialog. Reboot the computer at your convenience.
6. Verify that the network connection has been re-established. If a reboot was required, wait until the reboot has occurred before verifying the connection.

## Excessive Readout Noise

Excessive readout noise with the intensifier off indicates possible moisture accumulation in the CCD. This should be corrected promptly or permanent damage not covered by the Warranty could occur.

Normal camera noise is a function of the gain setting and temperature as well as CCD type, but is typically in the range of 1-50 ADU rms (6 -300 ADU pk-pk). This is on top of offset that typically is about 600 counts. Moisture accumulation produces a coarser noise with many spikes  $\geq 300$  ADU. If these types of spikes occur, especially after the camera has been in use for an extended period, turn off the system immediately. Have the unit serviced by Princeton Instruments or an authorized service facility of Princeton Instruments.

# Appendix A

## Specifications

### ATTENTION

The following specifications are *subject to change*. Contact the factory or go to [www.princetoninstruments.com](http://www.princetoninstruments.com) for the latest information on performance, options, and accessories.

### PI-MAX3

	1024i	1024x256
<b>CCD type</b>	Kodak KAI:1003 (interline)	e2v CCD30-11 (full frame)
<b>CCD format</b>	1024x1024	1024x256
<b>CCD pixel size</b>	12.8 $\mu\text{m}$ x 12.8 $\mu\text{m}$	26 $\mu\text{m}$ x 26 $\mu\text{m}$
<b>Imaging area</b>	13.1 mm x 13.1 mm (18mm dia.)	18 mm x 6.7 mm or 25 mm x 6.7 mm
<b>Intensifier size</b>	18 mm	18 mm or 25 mm
<b>Intensifier type</b>	Gen II, Gen III filmless, or UNIGEN II	Gen II, Gen III filmless, or UNIGEN II
<b>Phosphor type</b>	P43, *P46 (optional)	P43, P46 (optional)
<b>Pixel Full Well (min.)</b>	130 k e <sup>-</sup>	450 k e <sup>-</sup>
<b>Read Noise (typ.)</b>	16 e <sup>-</sup> rms @ 4 MHz digitization 30 e <sup>-</sup> rms @ 16 MHz digitization 35 e <sup>-</sup> rms @ 32 MHz digitization	14 e <sup>-</sup> rms @ 500 kHz digitization 15 e <sup>-</sup> rms @ 1 MHz digitization 22 e <sup>-</sup> rms @ 2 MHz digitization

\*Contact Princeton Instruments for P46 and P47 phosphor availability.

Table 8. CCD Specifications

#### Gating:

**Jitter:** ~35 ps RMS

**Minimum delay from trigger:** ~25 ns (without bracket pulse), ~35ns with bracket pulse

**Delay, width granularity:** 10 ps.

**Repetition Rate:** 1 MHz (“full voltage” pulse), not burst length limit

#### Maximum Repetition Rate (photocathode)

**Sustained:** 1 MHz in variable mode; 6.25 kHz with bracket

**Digital Conversion:** 16 bits

**Image Intensifier:** 18 mm or 25 mm

**Method of Coupling:** fiber optic

**Mounts:** Three different interchangeable mounts/adapters are available so that C-mount lenses, F-mount lenses, and spectrograph can all be readily accommodated. Changeover from one mounting system to another can be accomplished in moments with no adjustments required. Any one of the three mount types is simply secured by four screws, which require a small Phillips screwdriver. Available mounts include:

**Spectroscopy Adapter:** Three 120° slots in concentric configuration with 3.6" bolt circles.

**F-Mount Adapter:**\* Accepts standard F-mount latching mechanism.

**C-Mount Adapter:** Accepts standard C-mount threaded lenses.

**Focal Depth (distance from adapter flat to photocathode surface)**

**Spectroscopy:** Mounting face to image plane is factory preset to an optical distance of 0.894"  $\pm$ 0.010" [22.71 mm  $\pm$ 0.25 mm].

**F-Mount:** Mounting face to image plane is factory preset to an optical distance of 1.831"  $\pm$ 0.010" [46.50 mm  $\pm$ 0.25 mm].

**C-Mount:** Mounting face to image plane is factory preset to an optical distance of 0.690"  $\pm$ 0.010" [17.53 mm  $\pm$ 0.25 mm].

**Vignetting:** With fiber optic coupling there is no vignetting. With a 1024  $\times$  256 array, which has a width of 26 mm, pixels that fall beyond the 18 mm or 25 mm width (depending on intensifier width) of the intensifier will not be illuminated.

**Gen II Spatial Resolution**

**1:1 coupling:** typically 70  $\mu$ m spot size FWHM

**Gen II High Res Spatial Resolution**

**1:1 coupling:** typically 45  $\mu$ m spot size FWHM

**Filmless Gen III Spatial Resolution**

**1:1 coupling:** typically 42  $\mu$ m spot size FWHM

**Geometric Distortion:** typically < 1 pixel

**Sensitivity:** Variable intensifier gain adjustment (via software) allows sensitivities from 1-80 counts/photoelectron for Gen II and 1-200 counts/photoelectron for Gen III. Some phosphor choices may result in lower values. Gain adjustment range is 1-100.

**Gating ON/OFF Ratio**

**Visible (550 nm):** 5  $\times$  10<sup>6</sup>:1 typical

**UV (250 nm):** 10<sup>4</sup>:1 with photocathode gating only; 10<sup>6</sup>:1 with supplemental MCP bracket pulsing typical.

**Response Linearity:** Linearity is difficult to predict in ICCD systems, especially at high frame rates. Most intensifiers cannot generate sufficient light in a single gate to achieve full scale illumination, or even approach it. Generally, it takes a few milliseconds for an intensifier to recover from a single gate event (if the charge output is significant). Good linearity is observed when the light intensity is low and the signal is built up over a large number of exposures or over a long exposure. Poor linearity is observed when one attempts to get large signal amplitude from a single short exposure. This is a general property of MCP image intensifiers, not just of PI ICCDs.

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\* Similar mount for Canon lenses may also be available. Contact factory for information.

**Photocathode Dark Charge (EBI):** Red-blue enhanced, < 5 counts/pixel-second;  
Red-enhanced, < 15 counts/pixel-second

**Phosphor Decay:** 3 ms P43 standard, 2  $\mu$ s  
P46 phosphor is optional

### Phosphor Emission Spectra

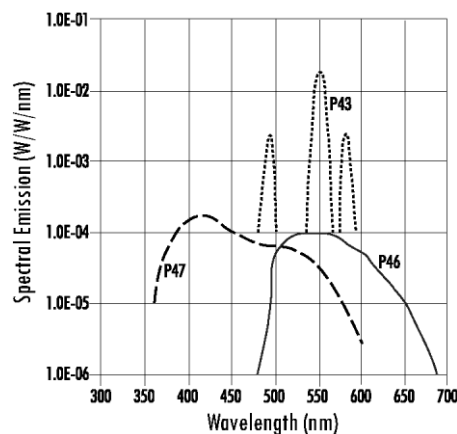
P43 = Gd<sub>2</sub>O<sub>2</sub>S:Tb

P46 = Y<sub>3</sub>Al<sub>5</sub>O<sub>12</sub>:Ce

### Spectral Range

**Gen II:** Red-blue enhanced, 180-900 nm; Red enhanced, 360-920 nm

**Filmless Gen III:** HQ, 450-900 nm  
(HQ (Blue), 375-900 nm)



**Nonuniformity:** Typically 12% pk-pk for Gen II 18 mm intensifiers, 16% pk-pk for Gen II 25 mm intensifiers

**CCD Cooling:** Down to -25°C air cooled; supplementary cooling with circulating room-temperature water will enhance cooling performance. Temperatures to -35°C are achievable with supplemental circulating coolant via a CoolCUBE<sub>II</sub> circulator. Chilled coolant can achieve even lower temperatures but must be used with extreme caution.

**Note:** See warning in “*Temperature Control*,” page 47 before initiating supplemental water cooling.

**Readout Noise:** 1-1.5 counts RMS in gated operation (100 kHz).

### A/D Converters

**Standard:** 16-bit, 80 MHz readout rate. One or two converters depending on the CCD

**Linearity:** better than 1%.

**Readout noise:** Depends on the pixel rate and CCD type.

### Input:

**TRIGGER IN:** Rear Panel BNC. It is the main trigger input to timing generator. Used for triggering by an external source. When external triggering is selected in the software, the internal timing generator will be triggered by an externally derived trigger pulse (range of  $\pm 5.5$  V) applied to this input. The threshold, slope, coupling mode (AC or DC), and input impedance (High or 50  $\Omega$ ) are selectable in software. The associated Green LED flashes each time PI-MAX3 is triggered (glows steadily at high repetition rates). The actual triggering can also be readily determined by observing the signal at the **Monitor** output with a fast oscilloscope.

### Outputs:

**READY:** TTL signal. Represents camera status. It changes state when ready just before the exposure.

**Gig-E:** Gigabit Ethernet connector.



**LOGIC OUT:** 0 to +3.3V programmable logic level output (TTL-compatible). The output can be programmed via software as ACQUIRING, IMAGE SHIFT, LOGIC 1, READ OUT, SHUTTER, or WAIT FOR TRIGGER signal. For detailed definition of each output, please see “Logic Out Control” (page 63). The output can also be inverted through software.

**AUX Out:** DC-coupled programmable delay (delay from T0: 0.01ns - 1 sec) trigger output to synchronize external devices with PI-MAX3.

**Monitor:** TTL signal to monitor actual gate timing

**AUX I/O:** The AUX I/O connector and cable (6050-0660) give you access to the T0 Output, Pre-Trigger Input, SyncMASTER1 Output, General Purpose Input 0, and SyncMASTER2 Output I/O signals of the AUX I/O connector. The leads on the five (5) BNC tipped leads are color coded as shown in the table below. Refer to “*AUX I/O Connector Pinout*” for additional information on these and other available I/O signals.



Name	Color	Pin Center	Pin Return
T0 OUT	Red	Pin 1	Pin 3
PRE-TRIG IN	Green	Pin 2	Pin 6
SyncMASTER1	Blue	Pin 7	Pin 18
GP INPUT 0	Gray	Pin 8	Pin 20
SyncMASTER2	Black	Pin 23	Pin 25

Table 9. AUX I/O Cable Leads

### AUX I/O Connector Pinout

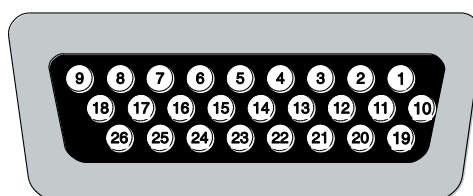


Figure 113. AUX I/O Connector Pinout

The AUX I/O (Input/Output Status) connector provides information about trigger function, DAC, and TTL signals. Inputs must be at least 2.4 V for a TTL high and less than 0.9 V for a low.

The numbers on the I/O connector diagram correspond to the numbers given to the definition of each of the pins. The I/O connector is a female, DB26, high-density connector. The I/O cable (6050-0660) to access T0 Output (Pin 1), Pre-Trigger Input (Pin 2), SyncMASTER1 Output (Pin 7), General Purpose Input 0 (Pin 8), and SyncMASTER2 Output (Pin 23) is provided with the PI-MAX3 camera.

PORT #	PIN #	SIGNAL Description
--------	-------	--------------------

<b>PORT #</b>	<b>PIN #</b>	<b>SIGNAL Description</b>
	<b>1</b>	<b>T0 Output:</b> LVCMOS FPGA output with limited ESD protection, goes high at T0. Indicates a trigger has been received.
	<b>2</b>	<b>Pre-Trigger Input:</b> LVCMOS ESD-protected input. Pre-Trigger is an optional signal that may be used to terminate the continuous cleans instruction operation. In ordinary operation there is a one clean cycle jitter between the trigger and the finish of cleaning (i.e., the clean cycle in process must be completed). A rising edge will cause a pre-trigger. <b>Note:</b> The camera must already be in Acquire mode before the pre-trigger is sent to the input.
	<b>3</b>	<b>GND:</b> System chassis ground. Any external circuitry intended to interface with the trigger control signals must reference this ground connection.
	<b>4</b>	<b>Lockout Output:</b> LOW indicates I.I.T. is locked off.
	<b>5</b>	(NOT USED)
	<b>6</b>	<b>GND:</b> System chassis ground. Any external circuitry intended to interface with the trigger control signals must reference this ground connection.
	<b>7</b>	<b>SyncMASTER1 Output:</b> LVCMOS Active high. User-configurable output. SyncMASTER1 can be user-configured to provide a user-specified continuous frequency output (not just when the camera is taking data) until halted by the user. In this configuration, the output could be used to synchronize a laser, shutter, AOTF... with the camera.
	<b>8</b>	<b>General Purpose Input 0:</b> Reserved for future use as general LVCMOS input limited ESD protection.
	<b>9</b>	<b>L_Shutter (via 1kOhm):</b> Do Not Use.
	<b>10</b>	<b>Source Comp:</b> Future Use. Analog Input.
	<b>11</b>	<b>Logic GND:</b> Do Not Use.
	<b>12</b>	+5.9 V thru 100 Ohms
	<b>13</b>	(NOT USED)
	<b>14</b>	<b>General Purpose Output 3 (via 1 kOhm):</b> Reserved
	<b>15</b>	<b>General Purpose Output 2 (via 1 kOhm):</b> Reserved
	<b>16</b>	<b>General Purpose Output 1 (via 1 kOhm):</b> Reserved
	<b>17</b>	<b>SyncMASTER2 Output (via 1 kOhm)</b>
	<b>18</b>	<b>GND:</b> System chassis ground. Any external circuitry intended to interface with the trigger control signals must reference this ground connection.

Table 10. AUX I/O Connector Pinout and Signal Description

<b>PORT #</b>	<b>PIN #</b>	<b>SIGNAL Description</b>
	<b>19</b>	(NOT USED)
	<b>20</b>	<b>GND:</b> System chassis ground. Any external circuitry intended to interface with the trigger control signals must reference this ground connection.
	<b>21</b>	<b>General Purpose Input 2 (via 1 kOhm):</b> Reserved
	<b>22</b>	<b>General Purpose Input 1 (via 1 kOhm):</b> Reserved
	<b>23</b>	<b>SyncMASTER2 (via 10 Ohm):</b> Programmable continuous frequency output (100 ns - 6.55 ms delay from SyncMASTER1) synchronize external devices with PI-MAX3, e.g. Q-switch.
	<b>24</b>	(NOT USED)
	<b>25</b>	<b>GND:</b> System chassis ground. Any external circuitry intended to interface with the trigger control signals must reference this ground connection.
	<b>26</b>	<b>General Purpose Input 3 (via 1 kOhm):</b> Reserved

Table 7. AUX I/O Connector Pinout and Signal Description (cont.)

### Miscellaneous

**Dimensions:** See Appendix B.

**Power Requirements:** Nominally 100, 120, 220 or 240 VAC. Refer to Fuse/Voltage label on rear of power supply for details. Required DC voltages are generated in the PI-MAX3 power supply and are supplied via the power cable to the rear of the camera.

### Environmental Requirements:

Storage temperature: -20° C to 55° C

Operating temperature: 5°C to +30°C

Relative humidity: <50% noncondensing

**TTL Requirements:** Rise time  $\leq$  40 ns, Duration  $\geq$  100 ns.

## Internal Pulser

The PI-MAX3 incorporates an internal gate pulse generator and high voltage power supply controlled by the internal timing generator

### Gating Speed

#### Fast Gate Intensifier

**Gen II 18 mm:** <5 ns FWHM

**Gen II 25 mm:** <7 ns FWHM

**Filmless Gen III 18 mm:** < 5 ns FWHM

**Slow Gate 18 mm:** ~50 ns FWHM. Contact factory or Princeton Instruments representative.

**Slow Gate 25 mm:** ~100 ns FWHM. Contact factory or Princeton Instruments representative.

**Propagation Delay:** ≤ 25 ns (35 ns with bracket).

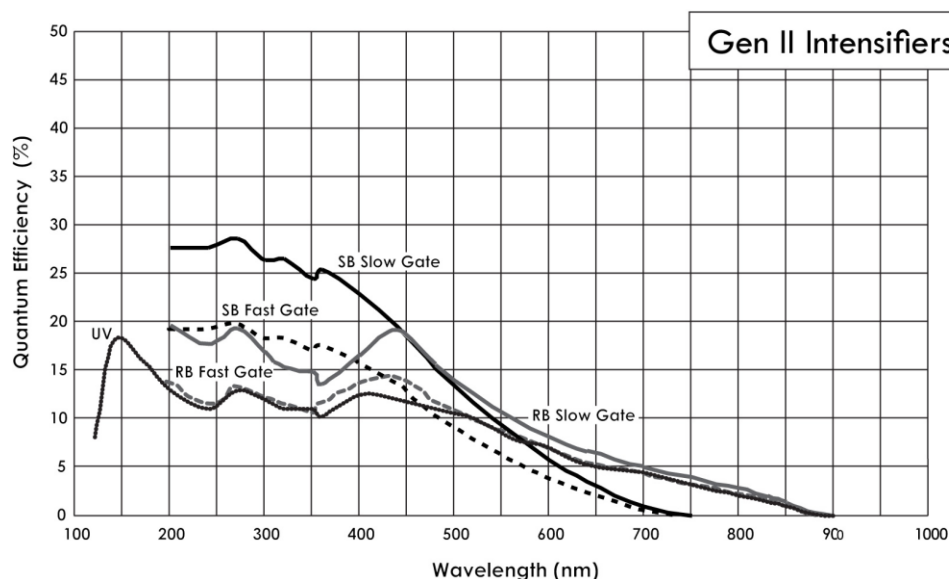
**Maximum Repetition Rate (MCP bracket pulsing):** 6.25 kHz

**MCP Bracket Pulsing:** MCP requires 35 ns to gate On and ~1 μs to gate Off.

**Note:** Bracket pulsing only applies to units having a Gen II Image Intensifier. In the case of units having a Filmless Gen III Image Intensifier, bracket pulsing does not apply.

## Intensifier Quantum Efficiency

Quantum Efficiency (QE) curves for selected Gen II and Gen III filmless intensifiers:



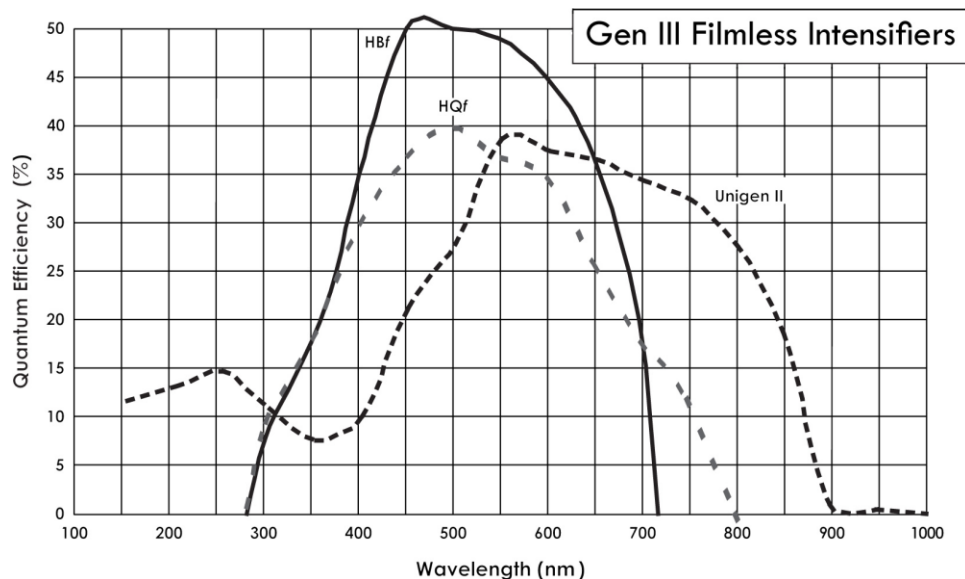


Figure 114. Intensifier QE Curves

## CoolCUBE<sub>II</sub> Circulator

### Closed loop system

**Hoses:** Two 3 meter (10') hoses may be supplied with the PI-MAX3 camera. These hoses are made up of a .3 meter (2') piece of 1/4" ID hose joined by a reducer to a 2.4 meter (8') piece of 3/8" ID hose. Refer to your coolant circulator's specifications regarding circulator-compatible hose fittings. If a Princeton Instruments CoolCUBE<sub>II</sub> circulator is ordered with the camera, hoses are supplied with appropriate CoolCUBE<sub>II</sub> connectors.

**Note:** Part numbers for the hose, reducer fitting, and CoolCUBE<sub>II</sub> fitting are McMaster MCM # 5624K11 (1/4 ID) and #5624K12 (3/8 ID); McMaster # MCM 91355K32 (3/8-1/4 Reducer); and CPC # NS6D17006 (3/8" Quick Disconnect), respectively.

**Coolant:** 50:50 ethylene glycol and water at 23°C

**Dimensions:** Refer to *Appendix B, "Outline Drawings"*, page 172

**Circulator Weight (Filled):** 6.0 lbs (2.7 kg)

**Hose Weight (Filled):** 3.0 lbs (1.4 kg) per hose

## Computer

The GigE Ethernet communications interface is used for communication between the PI-MAX3 camera and the host computer. The minimum computer requirements for the system are as listed below:

- Operating System
  - WinX: Windows® XP (32-bit with SP3 or later), Vista (32-bit), or Windows 7 (32-bit)
  - LightField: Vista (64-bit), or Windows 7 (64-bit)
- 2 GHz Pentium® 4 (or greater)

- 1 GB RAM (or greater)
- CD-ROM drive
- At least one unused PCI card slot (32-bit) (PCI 2.3 compliant 32-bit 33/66 MHz bus)
- Super VGA monitor and graphics card supporting at least 65535 colors with at least 128 Mbyte of memory. Memory requirement is dependent on desired display resolution.
- Hard disk with a minimum of 1 Gbyte available. A complete installation of the program files takes about 50 Mbytes and the remainder is required for data storage, depending on the number and size of images/spectra collected. Disk level compression programs are not recommended. Drive speed of 10,000 RPM recommended.
- Mouse or other pointing device.

## Operating Environment

**Storage Temperature:** < 55°C

**Lab Temperature:** 30°C > T > -25°C

**Supplemental Cooling Water Flow Rate:** 1-3 liters per minute

**Note:** Circulating water will enhance cooling performance but is not required.

**Lab Humidity:** < 80%; non-condensing.

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# Appendix B

## Outline Drawings

**Note:** Dimensions are in inches and [mm] unless otherwise noted.

### PI-MAX3

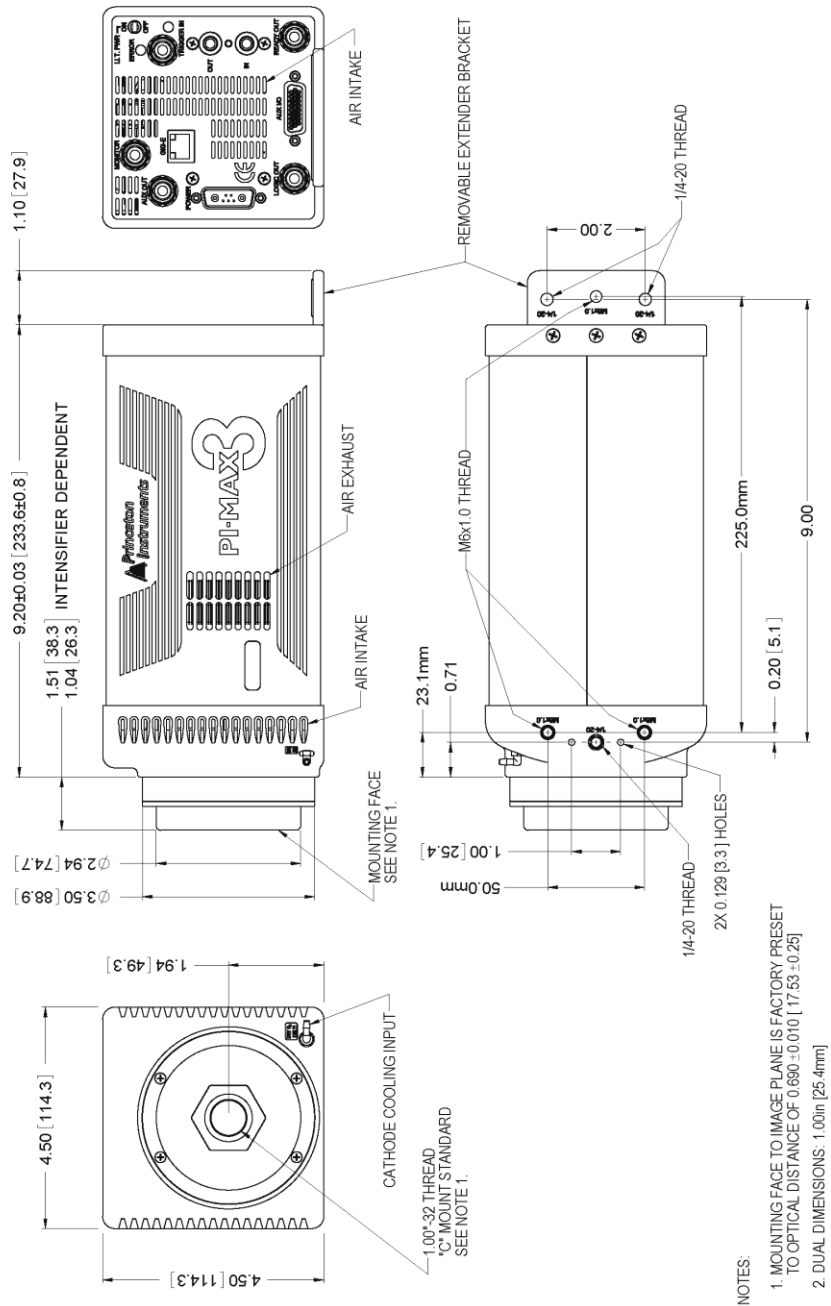


Figure 115. Outline Drawing: PI-MAX3 with C-mount Adapter



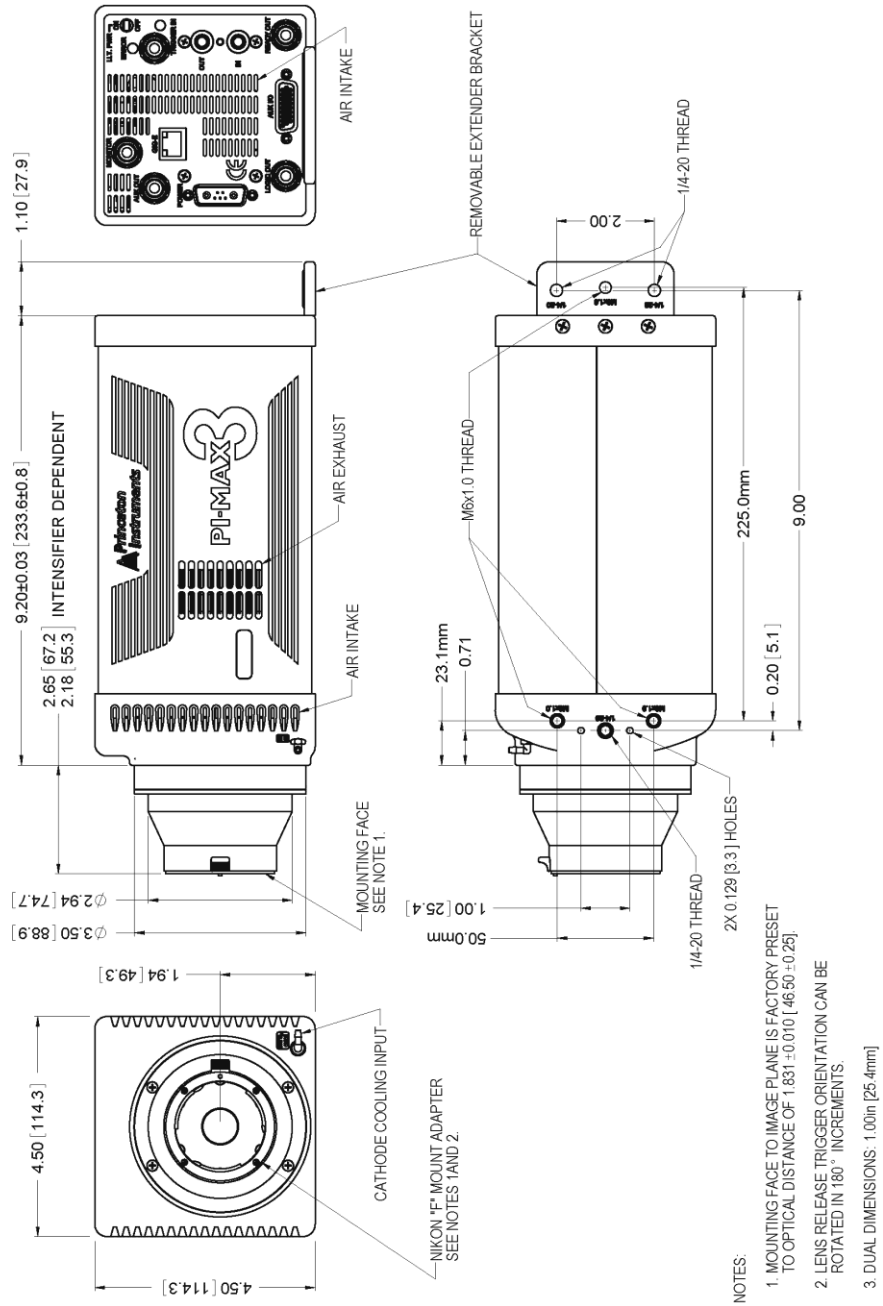
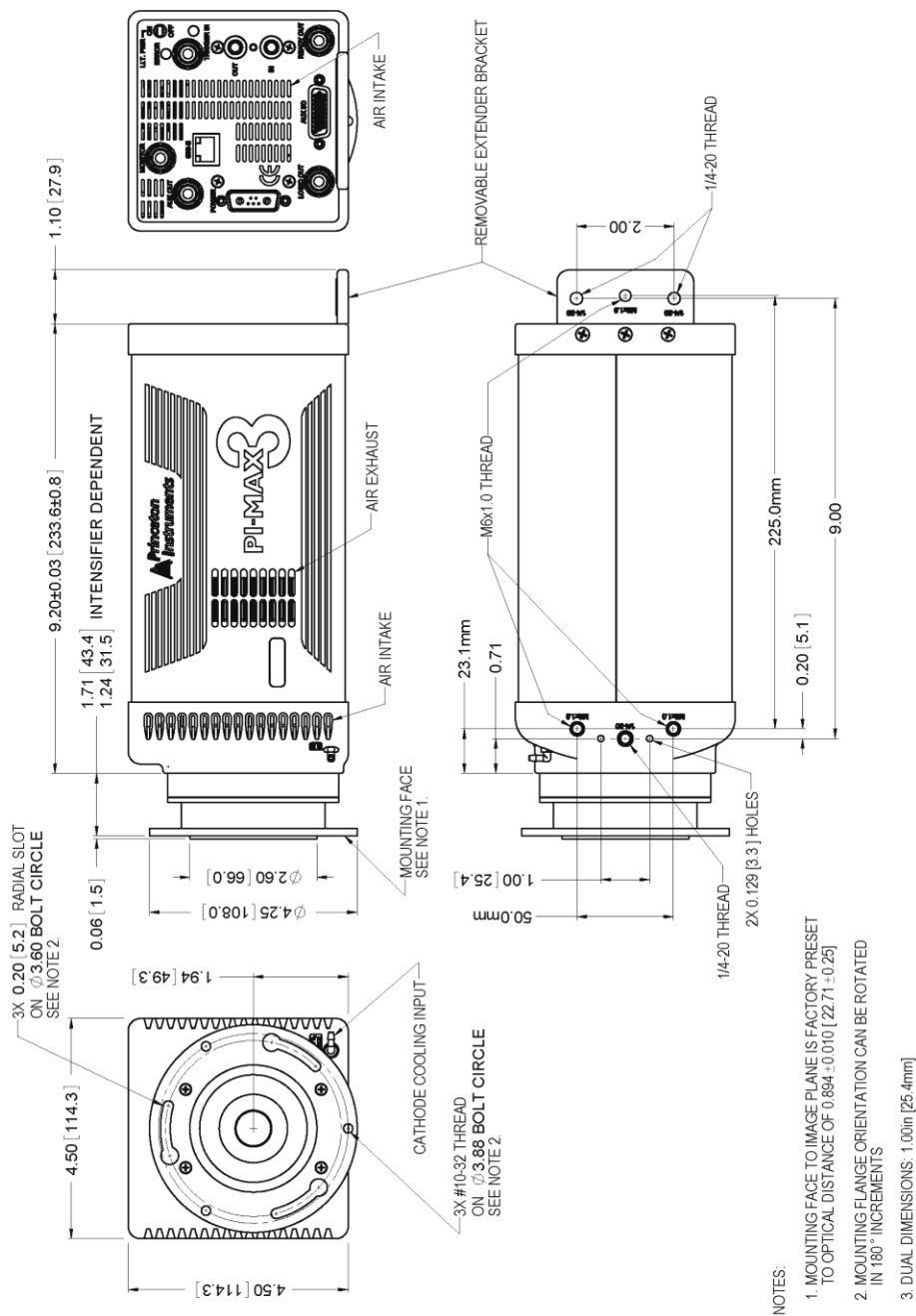


Figure 116. Outline Drawing: PI-MAX3 with F-mount Adapter



- NOTES:
1. MOUNTING FACE TO IMAGE PLANE IS FACTORY PRESET TO OPTICAL DISTANCE OF 0.894 ±0.010 [22.71 ±0.25]
  2. MOUNTING FLANGE ORIENTATION CAN BE ROTATED IN 180° INCREMENTS
  3. DUAL DIMENSIONS: 1.00in [25.4mm]

Figure 117. Outline Drawing: PI-MAX3 with Spectroscopy-mount Adapter

# PI-MAX3 Power Supply

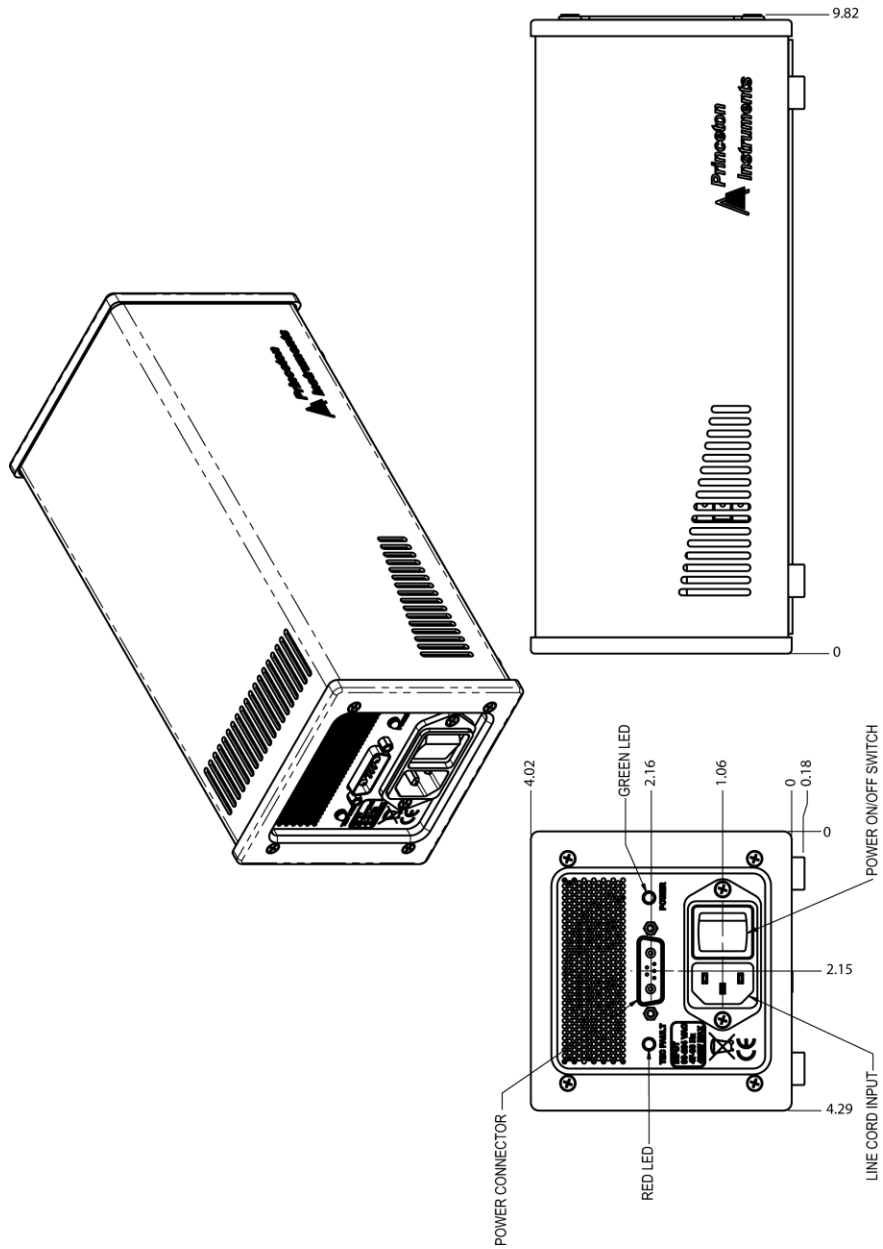


Figure 118. Outline Drawing: PI-MAX3 Power Supply

# CoolCUBE<sub>II</sub> Circulator

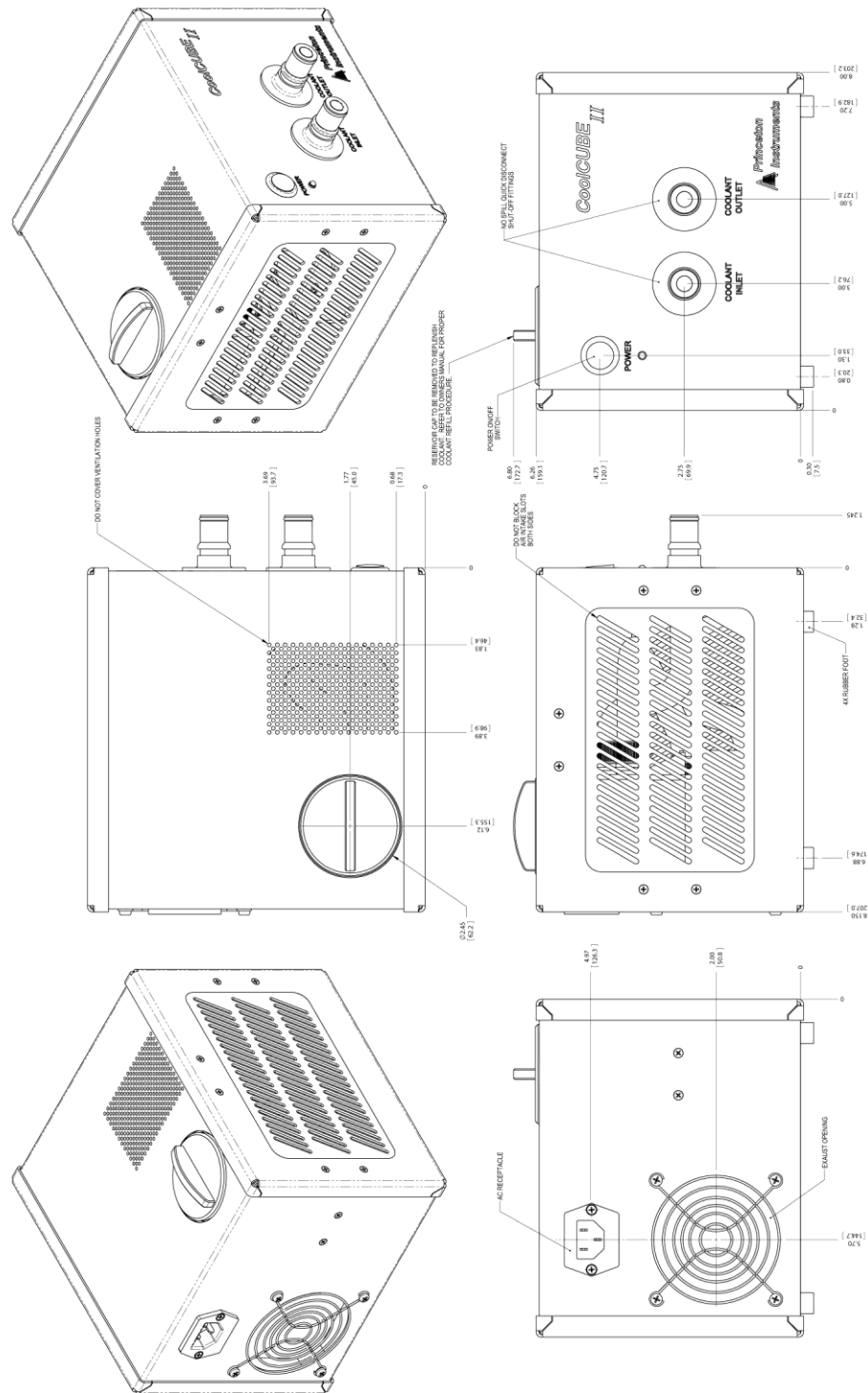


Figure 119. Outline Drawing: CoolCUBE<sub>II</sub> Circulator

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## Appendix C

# Cross-Referencing of WinX and LightField Terms

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### WinX-to-LightField

WinX	LightField
Active Rows Parallel to Shift Register	Active Height
Active Shift Register Columns	Active Width
ADC Rate	Speed
ADC Resolution	Bit Depth
Continuous Cleans	Clean Until Trigger
Controller Gain	Analog Gain
Custom Chip	Custom Sensor
Custom Timing	Custom Timing
Disabled Closed (Shutter)	Always Closed (Shutter)
Disabled Open (Shutter)	Always Open (Shutter)
Dual Trigger Mode	Shift Per Trigger
Easy Bin	Sensor Readout Region expander functions
Edge Trigger	Trigger Determined By
External Sync	Readout Per Trigger
F.T. Dummies or Frame Transfer Dummies	Active Area: Top Margin
Focus	Preview or Run
Free Run	No Response
Logic Out	Output Signal
Logic Out: Logic 0	Output Signal: Always Low
Logic Out: Logic 1	Output Signal: Always High
Logic Out: Not Ready	Output Signal: Busy
Logic Out: Not Scan	Output Signal: Not Reading Out
Logic Out: Shutter	Output Signal: Shutter Open
Minimum Block Size	Final Section Height
Normal Shutter	Normal (Shutter)

<b>WinX</b>	<b>LightField</b>
Number of Blocks	Final Section Count
Number of Cleans	Number of Clean Cycles
Number of Strips per Clean	Clean Cycle Height
Post-Dummy Rows Parallel to Shift Register	Active Area: Bottom Margin
Post-Dummy Shift Register Columns	Active Area: Right Margin
Pre-Dummy Rows Parallel to Shift Register	Active Area: Top Margin
Pre-Dummy Shift Register Columns	Active Area: Left Margin
PreOpen (Shutter)	Open Before Trigger (Shutter)
Readout Port	Quality
Shutter Close Compensation Time	Closing Delay
Shutter Control	Shutter Mode
Shutter Open Compensation Time	Opening Delay
Single Trigger Mode (DIF)	Readout Per Trigger
Skip Serial Register Clean (deselected)	Clean Serial Register
Target Temperature	Temperature Setpoint
Timing Mode	Trigger Response

## LightField-to-WinX

LightField	WinX
Active Area: Bottom Margin	Post-Dummy Rows Parallel to Shift Register
Active Area: Left Margin	Pre-Dummy Shift Register Columns
Active Area: Right Margin	Post-Dummy Shift Register Columns
Active Area: Top Margin	F.T. Dummies or Frame Transfer Dummies
Active Area: Top Margin	Pre-Dummy Rows Parallel to Shift Register
Active Height	Active Rows Parallel to Shift Register
Active Width	Active Shift Register Columns
Always Closed (Shutter)	Disabled Closed (Shutter)
Always Open (Shutter)	Disabled Open (Shutter)
Analog Gain	Controller Gain
Bit Depth	ADC Resolution
Clean Cycle Height	Number of Strips per Clean
Clean Serial Register	Skip Serial Register Clean (deselected)
Clean Until Trigger	Continuous Cleans
Closing Delay	Shutter Close Compensation Time
Custom Sensor	Custom Chip
Custom Timing	Custom Timing
Final Section Count	Number of Blocks
Final Section Height	Minimum Block Size
No Response	Free Run
Normal (Shutter)	Normal Shutter
Number of Clean Cycles	Number of Cleans
Open Before Trigger (Shutter)	PreOpen (Shutter)
Opening Delay	Shutter Open Compensation Time
Output Signal	Logic Out
Output Signal: Always High	Logic Out: Logic 1
Output Signal: Always Low	Logic Out: Logic 0
Output Signal: Busy	Logic Out: Not Ready
Output Signal: Not Reading Out	Logic Out: Not Scan
Output Signal: Shutter Open	Logic Out: Shutter
Preview	Focus



<b>LightField</b>	<b>WinX</b>
Quality	Readout Port
Readout Per Trigger	External Sync
Readout Per Trigger (DIF)	Single Trigger (DIF)
Sensor Readout Region expander functions	Easy Bin
Shift Per Trigger (DIF)	Dual Trigger Mode (DIF)
Shutter Mode	Shutter Control
Speed	ADC Rate
Temperature Setpoint	Target Temperature
Trigger Determined By	Edge Trigger
Trigger Response	Timing Mode

# Appendix D

## Extender Bracket Kit

An Extender Bracket kit is shipped with each PI-MAX3. After securing the bracket at the rear of the PI-MAX3, you can mount the PI-MAX3 to any laboratory table with either 25 mm or 1 inch hole spacing.

### *To secure the plate to the camera:*

1. Remove the extender bracket and the three (3) 6-32x1/4" flathead screws from the bag.
2. Turn the camera upside down.
3. With the rear of the camera facing you, place the tongue of the bracket into the cutout under the now topmost edge. The text on the bracket should be visible.
4. Secure the plate with the three screws.
5. Turn the camera right side up and secure it to the laboratory table. If you will be using one or more mounting holes at the bottom front of the camera, tighten the fastener(s) there before tightening down the fastener(s) at the extender bracket.

**Note:** The table mounting holes in the plate are elongated to allow for tolerance variations.

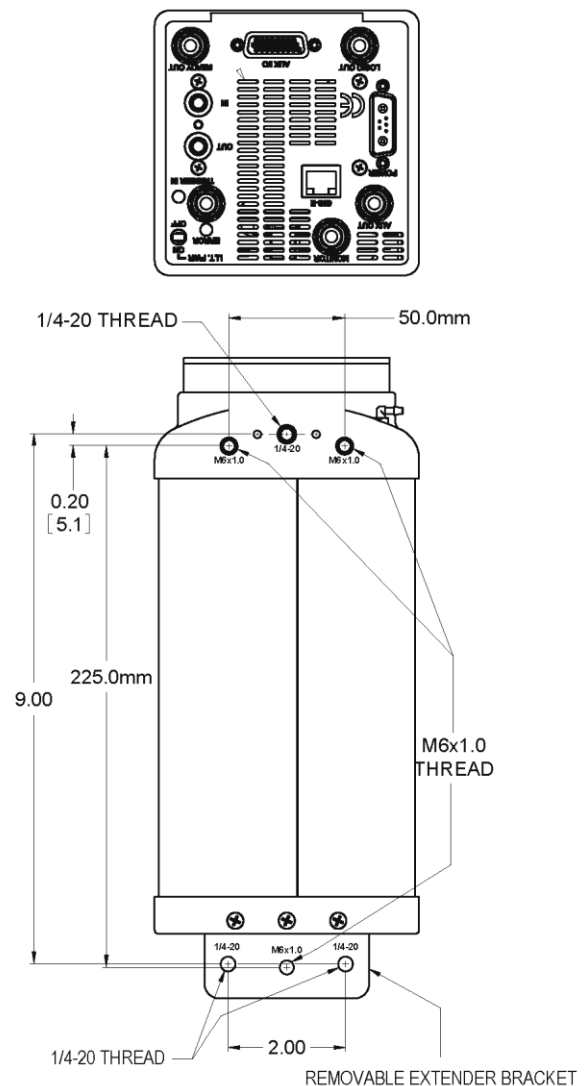


Figure 120. Extender Bracket Kit mounted to PI-MAX3

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## Appendix E

# Mounting and Focusing C-Mount and F-Mount Lenses

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### Mounting the Lens

C-mount lenses simply screw clockwise into the threaded lens mount at the front of the camera. In mounting a C-mount lens, tighten it securely by hand (*no tools*).

To mount an F-mount lens on the camera (Figure 121), locate the large indicator dot on the side of the lens. There is a corresponding dot on the front side of the camera lens mount. Line up the dots and slide the lens into the mount. Then turn the lens counterclockwise until a click is heard. The click means that the lens is now locked in place.

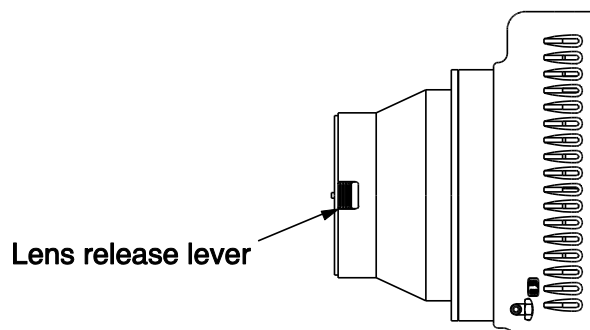


Figure 121. F-mount (Nikon) Lens Adapter

Removing either type lens is equally simple. In the case of a C-mount lens, rotate the lens counterclockwise until it is free of the mount. In the case of an F-mount lens, press the locking lever on the mount while rotating the lens clockwise until it comes free and can be pulled straight out.

Both types of lenses typically have provisions for focusing and aperture adjustment, with the details varying according the make and model of the lens.

#### WARNING

Always begin with the lens stopped all the way down (largest f/ stop number) to minimize the risk of overloading the intensifier.

### Mounting Orientation

The PI-MAX3 can be mounted at any attitude or angle. The camera can rest on any secure surface. Take care not to block the ventilation openings.

#### WARNING

In the case of cameras equipped with F-mount, do not mount the camera in the *nose-up* operation where the lens mount would be required to hold the camera's weight. The F-mount is not designed to sustain the weight of the camera in this orientation and the camera could pull free. *You must provide additional support for the camera.*

Should the camera be mounted in the nose-up position beneath a table, take care to protect the mounting components from lateral stresses, such as might occur should someone accidentally bump the camera with a knee while working at the table. One solution to this problem would be to install a barrier between the camera and operator to prevent any accidental contact.

There are no special constraints on nose-down operation. Again, however, good operating practice might make it advisable to take steps to prevent accidental contact from unduly stressing the mounting components.

**WARNING**

Always begin with the lens stopped all the way down (largest f/ stop number) to minimize the risk of overloading the intensifier.

**Focusing**

There is no difference between focusing considerations for an F-mount lens and a C-mount lens. Simply rotate the lens-focusing ring for the sharpest observed image. The lens will show maximum focus sensitivity at full aperture (lowest f-stop setting). Once the point of optimum focus is obtained, you may wish to adjust the lens aperture to  $f/8$  or  $f/11$ , that is, somewhere near mid-range aperture, where the lens will probably be sharper than it is with the lens aperture completely open. Some readjustment of the Exposure Time may be required to achieve the most pleasing image.

# Appendix F

## C-, F-, and Spectroscopy-Mount Adapters

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### Accessory Kits

#### ***PI-MAX3 18 mm Tube***

Among the items in the accessory kit shipped with an 18 mm PI-MAX3 are three adapter kits (C-mount, F-mount, and spectroscopy-mount adapters are supplied, one of which has been factory-installed on the camera), a double-ended screwdriver with magnet top, and a PI-MAX3 (with spectroscopy-mount adapter) to Acton spectrograph quick start sheet.

#### ***PI-MAX3 25 mm Tube***

Among the items in the accessory kit shipped with a 25 mm PI-MAX3 are two adapter kits (F-mount and spectroscopy-mount adapters are supplied, one of which has been factory-installed on the camera), a double-ended screwdriver with magnet top, and a PI-MAX3 (with spectroscopy-mount adapter) to Acton spectrograph quick start sheet.

### Adapter Kits

The table below lists the part numbers for the individual adapter kits that may be shipped in the accessory kit.

Kit	Part Number	Contents
C-Mount Adapter	7389-0031	Adapter, 4-40x 7/16 flat head Phillips screws, dust cover
F-Mount Adapter	7389-0033	Adapter, 4-40x 7/16 flat head Phillips screws, dust cover
Spectroscopy-Mount Adapter	7389-0032	Adapter, 4-40x7/16 flat head Phillips screws, dust cover
NVUV Spectroscopy-Mount Adapter	7389-0039	Adapter, 4-40x7/16 flat head Phillips screws, o-ring (2.739" I.D.), o-ring (2.614" I.D.), dust cover



*Figure 122. Screwdriver with Reversible Flat and Phillips tips.*

## PI-MAX3 to Acton Spectrograph Quick Start Guides

Because each PI-MAX3 system is shipped with a spectroscopy-mount adapter kit, a quick start guide for mounting a PI-MAX3 with spectroscopy-mount adapter to an Acton spectrograph is included. Typically, the guide assumes that there is a spectroscopy-mount adapter mounted to the face of the PI-MAX3 camera.

### Standard C-, F-, and Spectroscopy-Mount Adapters

To change from one adapter to another:

1. Using the supplied screwdriver, remove the four (4) Phillips head screws that secure the adapter to the front of the PI-MAX3.

**Note:** If the Phillips end of the screwdriver is not available, pull the driver shaft out of the handle, flip the shaft, and insert the flat end into the handle.

2. Remove the existing adapter and store it in a safe place.
3. Using the same screws, mount the new adapter to the front of the PI-MAX3.

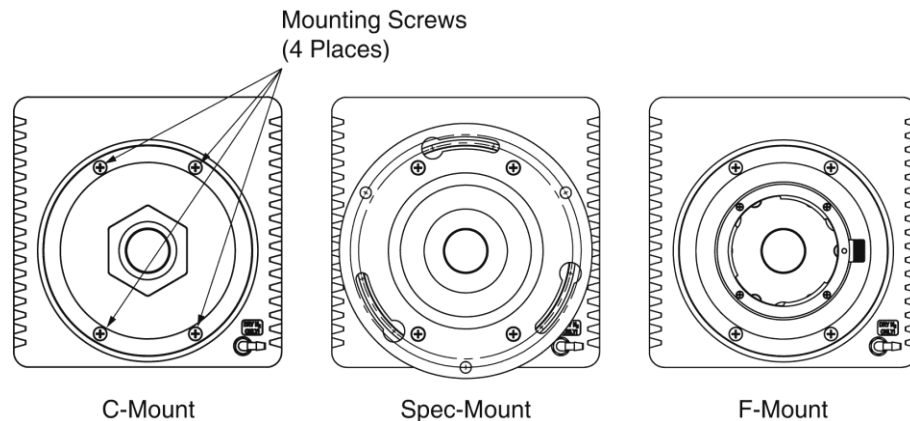


Figure 123. PI-MAX3 Mount Adapters

### Spectroscopy-Mount for NVUV Cameras

In addition to the spectroscopy adapter, NVUV cameras require two o-rings, each with a different inner diameter (I.D). Typically, the camera would be shipped with the adapter mounted to the face of the camera and the 2.739" ID o-ring (lightly coated with vacuum grease) would already be in the groove between the face of the camera and the spectrograph adapter. The 2.614" ID o-ring (lightly coated with vacuum grease) is installed in the groove on the face of the spectrograph adapter. Figure 124 shows where the two different o-rings are installed.

To mount an NVUV spectroscopy-mount adapter:

1. Using the supplied screwdriver, remove the four (4) Phillips head screws that secure the current adapter to the front of the PI-MAX3.

**Note:** If the Phillips end of the screwdriver is not available, pull the driver shaft out of the handle, flip the shaft, and insert the flat end into the handle.

2. Remove the existing adapter and store it in a safe place.
3. After lightly applying vacuum grease to the o-rings, position the larger diameter

ring in the groove on the face of the camera.

4. Using the same screws, mount the spectroscopy-mount adapter to the front of the PI-MAX3.
5. Position the small diameter ring in the groove on the face of the adapter.

A spare set of o-rings may be supplied. If you need to use one of these spares, be sure to lightly coat it with vacuum grease before putting it in place. Lightly coating the o-rings with vacuum grease helps to insure air-tight seals between the camera and adapter and between the adapter and the spectrograph sliding tube.



Figure 124. O-ring Positions for PI-MAX3 NVUV Cameras

## Optical Distance from Mounting Face to Image Plane

Each adapter has a preset optical distance from the mounting face to the image plane. The distance varies from one adapter type to another and is explained on the PI-MAX3 outline drawings. For quick reference, the distances are given below.

**C-Mount:** Mounting face to image plane is factory preset to an optical distance of  $0.690'' \pm 0.010''$  [17.53 mm  $\pm$  0.25 mm].

**Spectroscopy:** Mounting face to image plane is factory preset to an optical distance of  $0.894'' \pm 0.010''$  [22.71 mm  $\pm$  0.25 mm].

**F-Mount:** Mounting face to image plane is factory preset to an optical distance of  $1.831'' \pm 0.010''$  [46.50 mm  $\pm$  0.25 mm].



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## Spectrograph Adapters

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### Introduction

A PI-MAX3 with the spectroscopy-mount adapter can be readily mounted to an Acton Series spectrograph or to an IsoPlane SCT-320 spectrograph. Mounting the camera to an Acton Series spectrograph requires a male sliding tube that slides into the spectrograph for setting the focus. Mounting a PI-MAX3 to an IsoPlane is a matter of bolting it directly to the mounting plant on the IsoPlane.

#### Notes:

1. When mounted to a spectrograph, the text on the back of the PI-MAX3 should be right side up.
2. A C-mount adapter plate and nut are available for mounting a camera with a C-mount adapter to an Acton Series spectrograph. See “*Acton (C-Mount Adapter)*” on page 192 for mounting instructions.

### Spectrograph-Detector Focusing

The detector mounting hardware provides two degrees of freedom: **focus** and **rotation**. In this context, focus means to physically move the detector back and forth through the focal plane of the spectrograph. The approach taken is to slowly move the detector in and out of focus and adjusting for optimum while watching a live display on the monitor, followed by rotating the detector and again adjusting for optimum. The following procedure, which describes the focusing operation with an Acton SP-2300i spectrograph, can be easily adapted to other spectrographs. For IsoPlane SCT-320 related focusing information, see “*IsoPlane SCT-320 Spectrograph*” on page 188.

#### Tips:

1. Use a USB-powered or a DC-powered light source. The 60 Hz of an AC-powered light source may make it more difficult to achieve focus.
2. If you must use an AC light source, set the SuperSYNCHRO Internal frequency to around 10 Hz.

#### **Acton Series Spectrograph**

1. Mount a light source such as a mercury pen-ray type in front of the entrance slit of the spectrograph. Any light source with line output can be used. *Standard fluorescent overhead lamps have good calibration lines as well.* If there are no “line” sources available, it is possible to use a broad band source such as tungsten for the alignment. If this is the case, use a wavelength setting of 0.0nm for alignment purposes.
2. With the spectrograph properly connected to the computer, turn the power on, wait for the spectrograph to initialize.
3. With the PI-MAX3 mounted to the spectrograph and connected to the computer, turn on the power and wait for the detector to initialize.

4. Boot the application software. If you are using WinSpec you will need to define the spectrograph. If you are using LightField, you will need to drag the icons for the PI-MAX3 and the spectrograph into the **Experiment Devices** area.
5. Set the spectrograph to 435.8 nm if using a mercury source or to 0.0 nm if using a broadband source.

**Hint:** Overhead fluorescent lights produce a mercury spectrum. Use a white card tilted at 45 degrees in front of the entrance slit to reflect overhead light into the spectrograph. Select 435.833 as the spectral line.

6. Set the slit to 25  $\mu\text{m}$ . If necessary, readjust the SuperSYNCHRO frequency to maintain optimum (near full-scale) signal intensity.
7. Begin running in **Focus** or **Preview** mode.
8. Slowly move the detector in and out of focus. You should see the spectral line go from broad to narrow and back to broad. Leave the detector set for the narrowest achievable line.

Note that the way focusing is accomplished depends on the spectrograph, as follows.

- **Long focal-length spectrographs such as the Acton SP-2300i:** The mounting adapter includes a tube that slides inside another tube to move the detector in or out as required to achieve optimum focus.
  - **Short focal-length spectrographs:** there is generally a focusing mechanism on the spectrograph itself which, when adjusted, will move the optics as required to achieve proper focus.
  - **No focusing adjustment:** If there is no focusing adjustment, either provided by the spectrograph or by the mounting hardware, then the only recourse will be to adjust the spectrograph's focusing mirror or to shim the detector.
9. Next adjust the rotation. You can do this by rotating the detector while watching a live display of the line. The line will go from broad to narrow and back to broad. Leave the detector rotation set for the narrowest achievable line.

**Note:** With LightField, you can use the **Align Spectrometer** function.

10. Alternatively, take an image, display the horizontal and vertical cursor bars, and compare the vertical bar to the line shape on the screen. Rotate the detector until the line shape on the screen is parallel with the vertical bar.

**Note:** When aligning other accessories, such as fibers, lenses, optical fiber adapters, first align the spectrograph to the slit. Then align the accessory without disturbing the detector position. The procedure is identical to that used to focus the spectrograph (i.e., do the focus and alignment operations while watching a live image).

### ***IsoPlane SCT-320 Spectrograph***

Because the PI-MAX3 is mounted directly to the mounting plate on the IsoPlane focusing and alignment is different from the way that focusing and alignment are performed for an Acton Series spectrograph. The following information assumes that you are familiar with the locations of the mounting plate, Micrometer Compartment, and the locking set screw. If not, refer to the IsoPlane manual supplied with the spectrograph.

#### **Notes:**

1. When adjusting focus for IsoPlane for the first time with a PI-MAX3, it is likely that the IsoPlane focus mirror will need to be adjusted. If the IsoPlane was previously used with a PIXIS or other Princeton Instruments camera with a back focus distance of approximately 0.6 inches, the focus setting will need to be changed to a much lower micrometer reading when focusing using a PI-MAX3 since the PI-MAX3 has a back focus distance of approximately 0.9 inches.
2. If the PI-MAX3 has a 25mm intensifier, some vignetting of the sides of the focal plane is normal. Vignetting is much less likely to occur if the PI-MAX3 has an 18 mm diameter intensifier.
3. If the IsoPlane was ordered with a shutter at the entrance slit and a PI-MAX3 is to be used with this IsoPlane, the shutter must either be removed from the IsoPlane or controlled by an Acton SHC-EXT external shutter control box if one is available. See the IsoPlane manual for shutter removal instructions.
1. Mount an Acton light source such as the dual HG/NeAr source in front of the entrance slit of the spectrograph.
2. With the spectrograph properly connected to the computer, turn the power on, wait for the spectrograph to initialize.
3. With the PI-MAX3 mounted to the spectrograph and connected to the computer, turn on the power and wait for the detector to initialize.
4. Boot the application software. If you are using WinSpec you will need to define the spectrograph. If you are using LightField, you will need to drag the icons for the PI-MAX3 and the spectrograph into the **Experiment Devices** area.
5. Set the spectrograph to 435.8 nm if using a mercury source or to 0.0 nm if using a broadband source.
6. Remove the cover from the Micrometer Compartment.
7. Using a 3/32" hex wrench, loosen the locking set screw.
8. While continuously acquiring data, adjust the micrometer until you maximize the intensity level of a selected peak or peaks.
9. Tighten down the locking set screw.
10. Place the Micrometer Cover on the spectrograph. Replace and tighten all of the cover screws.
11. Next adjust the rotation. First, use a 9/64" hex wrench to loosen the four screws at the corners of the detector mounting plate. While watching a live display of the line, rotate the detector (up to 4 degrees of rotation are possible). The line will go from broad to narrow and back to broad. Leave the detector rotation set for the narrowest achievable line.

**Note:** With LightField, you can use the **Align Spectrometer** function.

12. Alternatively, take an image, display the horizontal and vertical cursor bars, and compare the vertical bar to the line shape on the screen. Rotate the detector until the line shape on the screen is parallel with the vertical bar.
13. After completing the rotational alignment, re-tighten the four screws.

## Mounting a PI-MAX3 (3.60 3-hole Slotted Flange) to an Acton Series Spectrograph

### Tools

5/32" Hex wrench

3/32" Hex wrench

5/16" Open end wrench (provided in Spectrometer Kit bag)

(3) 10-32x 1/2" hex head stainless steel screws (provided in Spectrometer Kit bag)

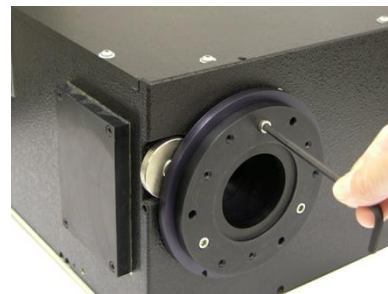


### Procedure

1. Remove shipping plate and store.



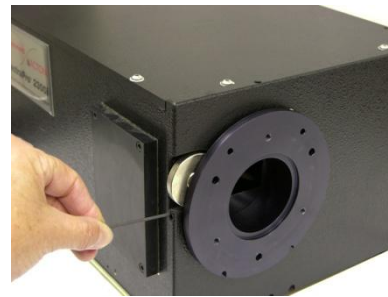
2. Remove spacer and store.



3. Loosen setscrew with 3/32" hex wrench.



4. Loosen setscrew.



5. Gently rotate and pull.



6. Finger tighten hex head screws. Leave about 1/4" thread exposed.



7. Mount tube to camera, align baffle with bottom/top of camera, and tighten mounting screws.



8. Gently rotate while inserting.



9. Tighten setscrew.

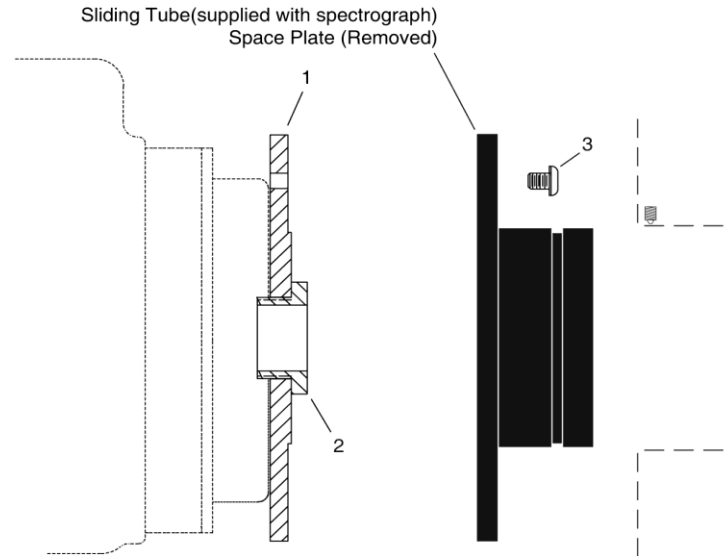


10. Tighten setscrew.



**Note:** Adapter parts are machined to provide a tight fit. It may be necessary to rotate the detector back and forth when inserting the sliding tube into the spectrograph. Forcing the tube into the spectrometer could permanently damage the tube and the spectrometer opening.

## Acton (C-Mount Adapter)



Qty	P/N	Description
1	8401-071-01	Adapter Plate
1	8401-071-02	Threaded C-Mount Adapter
3	2826-0127	Screw, 10-32 × 1/4, Button Head Allen Hex, Stainless Steel

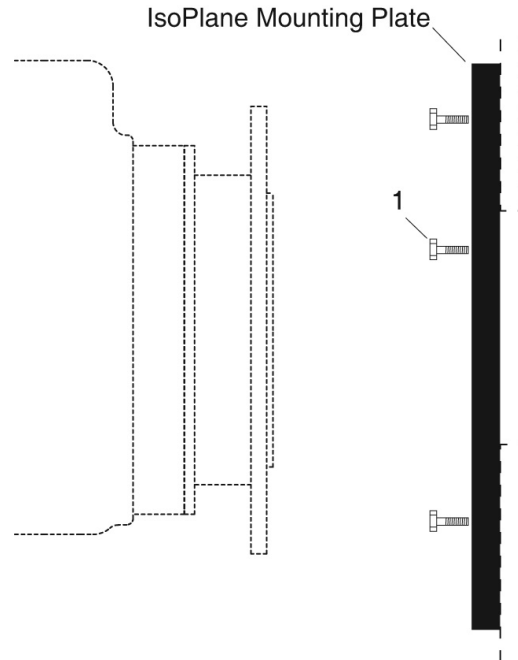
### Assembly Instructions

1. Make sure that the shipping cover has been removed from the detector port on the spectrograph.
2. Loosen the setscrews holding the sliding tube in the spectrograph and remove the tube. If there is a spacer plate installed on the sliding tube, remove it.
3. Place the flat side of the adapter plate against the face of the detector.
4. Insert the threaded C-mount adapter through the center hole in the plate and screw the adapter into the detector's C-mount.
5. Using three (3) 1/4" long button head screws, secure the sliding tube to the adapter plate.
6. Gently insert the sliding tube into the spectrograph and secure it with the setscrews.

**Note:** Spectrometer parts are machined to provide a tight fit. It is necessary to rotate the detector back and forth when inserting the sliding tube into the spectrometer. Forcing the tube into the spectrometer could permanently damage the tube and the spectrometer opening.



## Mounting a PI-MAX3 to an IsoPlane SCT-320



Qty	P/N	Description
3	2826-0120	Screw, 10-32 × 1/2, Hex Head, Stainless Steel

### Assembly Instructions

1. Make sure that the shipping cover has been removed from the detector mounting plate on the IsoPlane.
2. Leaving 1/4" of thread exposed, screw the three (3) hex head screws into the mounting plate.
3. Mount the detector to the mounting plate: the text should be right-reading on the back of the detector.
4. Tighten the three screws with a 5/16" open end wrench.

### Notes:

1. Rotational alignment of the detector to the spectrograph optics is done by loosening and subsequently retightening the screws at the mounting plate corners. The holes are slotted to allow about 4° of rotation.
2. If the IsoPlane was ordered with an internal shutter, an external shutter control box will be required to control the shutter or the shutter will need to be removed. See the IsoPlane SCT 320 manual for shutter removal instructions.

## Glossary

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**Binning:** A process that may occur in the readout register and the output node (on-chip or hardware binning) or is performed as a post-process (software binning). Binning combines charge from rectangular groups of adjacent pixels into super pixels. When done on-chip, this process reduces readout time and the burden on computer memory; the drawbacks are lowered resolution and the possibility of saturation and blooming. Software binning avoids the problem of saturation and blooming.

**Blooming:** The spillover of excess charge into adjacent pixels.

**Bracket Pulsing:** See *MCP Bracket Pulsing*.

**Burst Mode:** PTG term. Used when a short burst of very rapid gate pulses is needed to synchronize data acquisition with a high frequency signal of interest. Occurring during the CCD array exposure time, a burst has a maximum repetition rate of 500 kHz, generating a high voltage pulse every 2  $\mu$ s. The burst can be driven from an external trigger or from the internal oscillator.

**CCD Array Dimensions and Pixel Size:** Arrays that are square or nearly square are typically used for imaging applications, while rectangular arrays are typically used in spectroscopy applications. The smaller the pixel size, the better the resolution, but the pixel full-well capacity smaller. Conversely, the larger the pixel size, the poorer the resolution, and the greater the pixel full-well capacity.

**CCD Array Dynamic Range:** The dynamic range of a CCD is the maximum achievable signal divided by the camera noise, where the signal strength is determined by the full-well capacity and noise is the sum of dark and read noises. The greater the dynamic range, the better the CCD is able to detect differences between the dimmest and brightest intensities in an image. The readout speed affects the dynamic range of a pixel: the faster the speed, the higher the noise, and the smaller the dynamic range.

**CCD Spectral Sensitivity:** Coatings applied to the CCD input window can enhance sensitivity in the UV regions. Deep-depletion enhances sensitivity in the NIR.

**Dark Charge or Dark Current:** The thermally induced buildup of charge in the CCD over time. Dark charge values vary widely from one CCD array to another and are exponentially temperature dependent. In the case of cameras that have MPP type arrays, the average dark charge is extremely small. However, the dark-charge distribution is such that a significant number of pixels may exhibit a much higher dark charge, limiting the maximum practical exposure. To minimize the collection of dark charge, operate the camera at the lowest CCD temperature possible.

Since each CCD has its own dark charge pattern, unique to that particular device, acquiring and saving a dark charge “background image” under conditions identical to those used to acquire the “actual” image and then subtracting that image from the actual image will significantly reduce dark-charge effects.

**EBI:** Equivalent Background Illumination. EBI comes from thermally-generated electrons that cannot be distinguished from those generated by light photons. EBI can

be reduced by cooling the intensifier (or environment) and is usually negligible in gated applications.

**Exposure Time:** The period during which the camera allows incoming signal to integrate on the CCD array. For signal to be detected and integrated on the CCD array, it must both fall in a valid gate width and in a valid exposure time. In **Gate Mode**, the exposure time is determined by an internal pulse ensemble defined by the internal timing generator gating setup.

**External Sync:** Readout synchronization mode where the CCD array is synchronized to an external source, i.e., the array is scanned upon arrival of an external trigger pulse.

**External Trigger mode:** Trigger mode where gate pulses are delayed from external input trigger pulses. Also a detector readout synchronization mode where the detector is scanned continuously but data storage does not begin until the arrival of an external trigger pulse.

**Frame:** The area of the CCD array that is readout after an exposure time ends. For a 1024x1024 array, a full frame would consist of the entire 1024X1024 pixel area. In the WinX/32 software, the number of frames to be acquired during a data acquisition is determined by the Number of Images (or Number of Spectra) parameter on the **Experiment Setup|Main** tab. If the parameter value is greater than 1, multiple frames of data will be acquired and stored in a single data file.

**Frame Rate (fps):** The number of frames that can be readout per second. The effective frame rate can be increased by defining a Region of Interest (ROI) that is smaller than the full-frame size. This means that a selected portion of the image can be displayed and the remainder of the accumulated charge discarded. The frame rate generally increases with reduction in the size of the detected area. For example, a CCD with a sensor size of 1000 x 1000 and an output rate of ten frames/second can produce 100 frames/second if the read-out region is reduced to 100 x 100 pixels.

**Full-Well Capacity:** The number of electrons that can be stored in a pixel. The smaller the pixel, the fewer electrons can be stored; therefore, either the exposure times need to be shorter or the signal intensity must be lower. Note that binning relies on the full-well capacity of the pixels in the serial shift register and of the output node. Typically, a serial shift register pixel has a full-well capacity that is 2 times greater than that of an image pixel and the output node has a full-well capacity that is about 1.5-2 times greater than that of a serial register pixel.

**FWHM:** Full width half-maximum. Time period from the mid-point of the leading edge to the mid-point of the trailing edge of the gate pulse. Used to describe pulse width.

**Gate Delay:** The time between the beginning of the trigger pulse (either internal or external) and the beginning of the photocathode gate pulse.

**Gate Mode:** PI-MAX3 intensifier mode in which the photocathode is biased on only for the time that each gate pulse is applied. In this way, the array can be exposed to multiple images during a single exposure time. As a result, the tolerance to room light is higher in gated operation, but the risk of damaging overload from intense light sources such as lasers remains. In fact, intense light sources in gated experiments can cause spot damage that would be undetected by the alarm circuit.

**Gate Width:** The time during which light will be detected by the intensifier, intensified, and applied to the CCD. Basically, the intensifier controls what the chip 'sees' during

the exposure time. For signal to be detected, it must both fall in a valid gate width and in a valid exposure time.

**Input Windows:** The intensifier and the CCD array both have input windows.

**MgF<sub>2</sub>:** High vacuum UV transmission (between 100 nm and 200 nm).

**Quartz:** Excellent transmission over 190 nm - 1100 nm.

**Clear glass (BK7):** Visible (400 nm -700 nm) and NIR (700 nm - 2500 nm).

Anti-Reflection (A/R) coatings may be added to input windows to reduce signal loss and glare caused by reflection.

**Intensifier-CCD Coupling:** Transmission of the emitted photons is either through a fiberoptic bundle or with a lens. The drawback to lens coupling is lower throughput (5%-10%) and increased stray light in the camera system. The advantages are that the intensifier can be removed and the camera can be used as a standard CCD imager conversely an intensifier can be added to an existing camera.

Fiberoptic coupling results in a throughput of >60%, are capable of sensitivities approaching single-photoelectron detection, and have a much better signal-to-noise ratio (SNR) than lens-coupled devices. Disadvantages are that the fiberoptic bundle is permanently attached to the CCD array and that the camera must be operated in a dry, non-vacuum inert environment.

**Intensifier Gating Speed:** Temporal resolution in a PI-MAX3 is made possible by switching the intensifier on and off (gating) very rapidly. Typical fast-gate intensifiers have minimum gate widths (FWHM=full width at half-maximum gate pulse) of approximately 2 ns. For slow-gated devices the FWHM is about 50 ns.

Fast-gating is achieved by adding a nickel (Ni) underlayer to photocathode. However, this layer may produce an effective QE reduction of as much as 40%. Slow-gate intensifiers have neither the Ni layer nor its effects on QE.

**Intensifier On/Off Ratio:** The ratio of light output when the intensifier is gated on and off: The higher the ratio, the better the gating. A high on/off ratio is necessary to eliminate the background and to faithfully reproduce transient events. In the visible region on/off ratios exceeding 10<sup>6</sup>:1 is typically achieved. In the UV region, the on/off ratio is typically much poorer (10<sup>4</sup>:1) though with MCP Bracket Pulsing (see page 73) ratios in the UV region can be improved dramatically (10<sup>7</sup>:1).

**Intensifier Size:** 18 mm dia. and 25 mm dia. Generally speaking, the larger diameter gives a larger field of view at the surface of the CCD array. The coupling of the intensifier to the CCD array is also a factor in determining the field view. A fiberoptic reducing taper of 1.27:1 will increase the field of view, while a taper of 1:1 will have no effect.

#### **Intensifier Types:**

**Gen I: Obsolete.** Developed in the early 1960's. Used electrostatic focusing and electron acceleration to achieve signal gains up to 150. These intensifiers could detect images under ambient light intensity as low as .01 lux. Problems included image distortion, short-lived components, and large size.

**GenII:** Introduced in the late 1960's and early 1970's. Incorporated MCPs with resulting signal gain improvement (up to 20,000). Not as efficient as Gen I intensifiers however have high resolution, no image distortion, and are small. Can detect images under ambient light intensity as low as .001 lux.

**Super Gen II:** Gen II devices that employ novel photocathodes with extended spectral range or high QE in a particular wavelength.

**Gen III:** Gen II technology with GaAs added as the photocathode coating. Highly sensitive in the NIR region above 800 nm but relatively insensitive in the blue/green region. Utilizes high-resolution MCPs (6  $\mu\text{m}$  diameter channels) and ion-barrier films. 2-3 orders of magnitude more sensitive to light than Gen II devices. Can detect images under ambient light intensify as low as .0001 lux.

**Filmless Gen III:** Filmless Gen III devices use GaAsP photocathodes which have no ion barrier film (MCP). The Gen III *filmless* intensifiers offer ultra-fast gating as well as >50% QE for the best combination of sensitivity in the visible region (<780nm) and gate speed.

**Gen IV:** Introduced in 1999. No ion barrier film and exhibit enhanced QE, SNR, dynamic range, and high-light-level resolution.

**lp/mm:** line pairs per millimeter. A measure of resolution based on the ability of the imaging system to differentiate between two parallel lines. The higher the value, the finer the resolution.

**MCP:** MicroChannel Plate. Composed of cylindrical channels through which electrons from the photocathode travel and generate additional electrons, resulting in electron gain. At the output of the MCP is a phosphor-coated fluorescent screen that converts the electrons to photons that subsequently strike the CCD array and generate charge in the array pixels.

**MCP Bracket Pulsing:** Available for PI-MAX3 cameras with Gen II intensifiers. This technique enhances the intensifier's on/off ratio in UV measurements by automatically adjusting the on/off switching of the MCP to bracket the photocathode gate pulse. By switching off the MCP, unwanted UV signal that strikes the photocathode (even though gated off) is prevented from passing through the MCP to integrate on the CCD array.

**MCP Gating:** Available for PI-MAX<sub>MG</sub> cameras. Applies the primary gating pulse to the MCP portion of the tube and, if chosen by the user, applies the bracket pulse to the photocathode.

**MCP Resolution:** The MCP is a slightly conductive glass substrate with millions of parallel traversing channels containing a secondary electron emitter on their inner walls. The smaller the diameter and more tightly grouped the channels, the higher the resolution.

**Phosphor Decay Time:** A delay between the end of the exposure time and the beginning of the array readout. This time is inserted to allow the phosphor to decay to 1% before readout occurs and will vary depending on the phosphor type.

**Phosphor Type:** A phosphor is a chemical substance that fluoresces when excited by x-rays, an electron beam, or ultraviolet radiation. Phosphors usually emit green light with decay times ranging from hundreds of nanoseconds to a few milliseconds. P43 offers high resolution (~ 3 ms decay) while P46 offers fast decay for high-repetition rate spectroscopy (~ 2  $\mu\text{s}$  decay). The P47 offers even faster decay (0.4  $\mu\text{s}$ ). The phosphor decay time (see above), inserted between the end of the exposure time and the beginning of the array readout, allows for the decay time.

**Photocathode Coatings:** Coatings on the photocathode convert a portion of the incident photons into electrons. Any photons that are not captured by the photocathode are lost from the final signal produced by the intensifier. Therefore, the kind of coating and the resulting QE of the photocathode is very important. The choice of coating determines the most effective spectral range for the intensifier. For example GaAs (gallium arsenide) has high QE in the VIS and NIR regions. Multi-alkali coatings have fair photoconversion in the visible (VIS) and ultraviolet (UV) but have relatively limited response in the near IR (NIR).

**Pulse Ensemble:** PTG term. Consists of a Gate Start pulse, a Gate Stop pulse, and an Auxiliary pulse. At the end of the ensemble, the photocathode is gated off, phosphor decay time elapses to allow for phosphor decay, and then the CCD array is readout.

**QE:** Quantum Efficiency. The percentage of incident photons converted to electronic charge. The throughput of the input windows, the spectral sensitivity of the photocathode and the CCD array, the illuminated surface (front or back) of the CCD array, the intensifier on/off ratio, the MCP resolution, the MCP gain, and the intensifier-CCD coupling all contribute to the total system QE.

**RAM:** Random Access Memory used to store data such as experiment parameters.

**Region of Interest (ROI):** A square or rectangular set of contiguous pixels on the CCD array that is usually smaller than the full frame. Using an ROI to acquire data results in a faster readout of the array since data from pixels outside of that ROI is discarded.

**Safe Mode:** PI-MAX3 intensifier mode in which the photocathode is continuously biased off.

**Saturation:** Caused when a pixel well is completely filled with charge. Once a pixel is saturated, additional charge will spillover (bloom) into adjacent pixels. Ways to deal with saturation include lowering the array temperature (to reduce the dark charge component), shortening the exposure time (to reduce the signal component), and decreasing the gain (also to reduce the signal component).

**Scan or Scanning:** The process of reading out the contents of a CCD array.

**Vertical Shift Time ( $\mu$ s):** Reports the speed (in microseconds) at which a single row will be shifted vertically. This information is based on the value in the Vertical Shift box. The higher the value in that box, the longer the vertical shift time. This information appears for the Frame Transfer.

**Vertical Shift:** Determines the speed of the image transfer from the exposed area of an array to the masked area. Setting a lower value increases the shift speed. A higher value gives a slower shift. If the shift is too fast, not all of the charge will be transferred. If too slow, image smearing will be increased due to the exposure that takes place while the transfer is in progress. The default value gives good results in most measurements.

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# Declaration of Conformity

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This section of the PI-MAX3 system manual contains the declaration of conformity for PI-MAX3 systems. A system includes the PI-MAX3 with a Gen II or Filmless Gen III intensifier and a PI-MAX3 power supply.



# DECLARATION OF CONFORMITY

We, the undersigned

**Manufacturer: Roper Scientific (Princeton Instruments)**  
**Address, City: 3660 Quakerbridge Road, Trenton, NJ 08619**  
**Country: USA**

**Authorized Representative in Europe: Roper Scientific, GmbH**  
**Address, City: Rosenheimer Landstr. 87, D-85521, Ottobrunn**  
**Country: Germany**

Certify and declare under our sole responsibility that the following apparatus:

**PI-MAX3 Camera with Power Supply,**

Conforms to the emissions requirements of EN61326-1:2006; Clause 7.2:

<b>CISPR 11 Edition 4: 2003</b>	<b>Conducted Emissions, Class A</b>
<b>CISPR 11 Edition 4: 2003</b>	<b>Radiated Emissions, Class A</b>
<b>IEC 61000-3.2: 2000</b>	<b>Harmonics</b>
<b>IEC 61000-3-3: 2002</b>	<b>Flicker</b>

Conforms to the immunity requirements of EN61326-1:2006; Table 1:

<b>IEC 61000-4-2: 2001</b>	<b>Electrostatic Discharge</b>
<b>IEC 61000-4-3: 2002</b>	<b>Radiated Immunity</b>
<b>IEC 61000-4-4: 2004</b>	<b>EFT/Burst and Power Leads</b>
<b>IEC 61000-4-5: 2001</b>	<b>Surge Immunity</b>
<b>IEC 61000-4-6: 2003</b>	<b>Conducted Immunity and Power Leads</b>
<b>IEC 61000-4-11: 2004</b>	<b>Voltage Dips and Interrupts</b>

And follows the provisions of Low Voltage Directive and Safety:

**CE Low Voltage Directive 2006/95/EC**  
**Product Safety Regulations and Standards IEC 60950-1:2005**  
**EMC Directive 2004/108/EC**

The technical documentation is kept at the following address:

**Company: Princeton Instruments**  
**Address, City, State: 3600 Quakerbridge Rd, Trenton, NJ 08619**  
**Country: USA**  
**Telephone Number: +1 800.874.9789/+1 609.587.9797**  
**Fax Number: +1 609.587.1970**

Name and Position of Person Binding the Manufacturer or his Authorized Representative:

**William Asher**

**Vice President of New Product Development**

Signature: 

Date: June 2, 2009

# Warranty & Service

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## Limited Warranty

Princeton Instruments, a division of Roper Scientific, Inc. (“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***

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, 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 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 Princeton Instruments authorized representative/distributor for repair information and assistance, or visit our technical support page at [www.princetoninstruments.com](http://www.princetoninstruments.com).

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

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, 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 Princeton Instruments factory or, at our option, a factory-authorized service center. You are responsible for the shipping costs to return the product to Princeton Instruments. International customers should contact their local Princeton Instruments representative/distributor for repair information and assistance or visit our technical support page at [www.princetoninstruments.com](http://www.princetoninstruments.com).

### ***XP Vacuum Chamber Limited Lifetime Warranty***

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 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***

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***

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. 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. *See 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***

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. *See 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***

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. 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 CD-ROM from our factory for an incidental shipping and handling charge. *See Item 12 in the following section of this warranty (“Your Responsibility”) 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 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 Princeton Instruments technical support staff or our authorized service representative. *See Item 12 in the following section of this warranty (“Your Responsibility”) 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 Princeton Instruments.
2. You must notify the 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 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 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 Princeton Instruments factory or one of our authorized manufacturer's representatives or distributors.
6. Unless specified in the original purchase agreement, 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 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 Princeton Instruments factory or a 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 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 Princeton Instruments factory of purchase, contact your authorized Princeton Instruments representative or reseller, or visit our technical support page at [www.princetoninstruments.com](http://www.princetoninstruments.com).

## Contact Information

Roper Scientific's manufacturing facility for this product is located at the following address:

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](mailto:techsupport@princetoninstruments.com)

For immediate support in your area, please call the following locations directly:

<b>North America</b>	800 899 1144 (toll free) or 609 587 9797
<b>France</b>	+33 (1) 60 86 03 65
<b>Germany</b>	+49 (0) 89 660 7793
<b>Japan</b>	+81 (3) 5639 2741
<b>UK &amp; Ireland</b>	+44 (0) 1628 472 346
<b>Singapore</b>	+65 6408 6240
<b>China</b>	+86 10 659 16460

Otherwise, see our Support web page at [www.princetoninstruments.com](http://www.princetoninstruments.com).

An up-to-date list of addresses and telephone numbers is posted on the [www.princetoninstruments.com/Support](http://www.princetoninstruments.com/Support) page. In addition, links on this page to support topics allow you to send e-mail based requests to the Customer Support group.

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