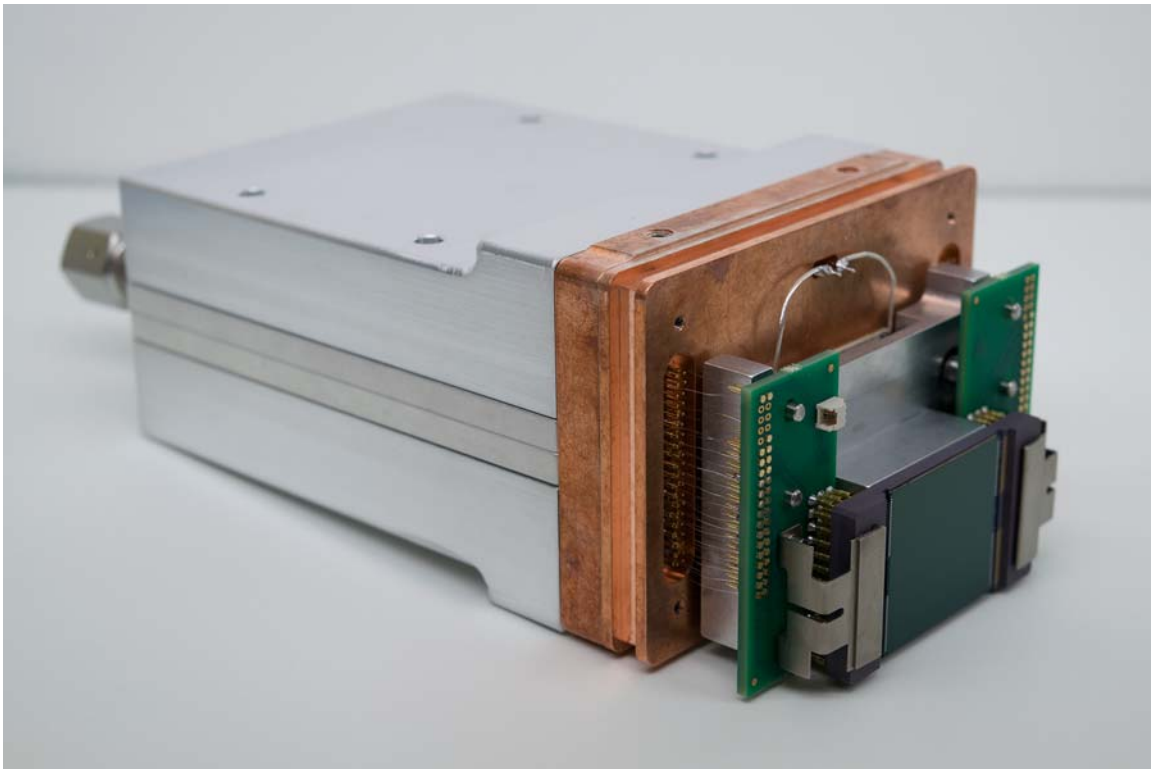


PI-MTE3 System Manual



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Issue 1
March 27, 2019

Revision History

Issue	Date	List of Changes
Issue 1	March 27, 2019	This is the initial release of this document.

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Chapter 1: About this Manual

Thank you for purchasing a PI-MTE3 camera system from Teledyne Princeton Instruments. Since it was founded in 1981, Teledyne Princeton Instruments has been the legendary name behind the most revolutionary spectroscopy and imaging products for cutting edge research.

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

If you have any questions about the information contained in this manual, contact the Teledyne Princeton Instruments customer service department. Refer to [Contact Information](#) on page 126 for complete contact information.

1.1 Intended Audience

This user manual is intended to be used by scientists and other personnel responsible for the installation, setup, configuration, and acquisition of imaging data collected using a PI-MTE3 system.

This document provides all information necessary to safely install, configure, and operate the PI-MTE3, beginning with the system's initial installation.

1.2 Related Documentation

[Table 1-1](#) provides a list of related documentation and user manuals that may be useful when working with the PI-MTE3 camera system. To guarantee up-to-date information, always refer to the current release of each document listed.

Table 1-1: Related Documentation

Document Number	Document Title
–	LightField 6 Online Help
–	PI-MTE3 Camera System Data Sheet

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

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

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

1.3 Document Organization

This manual includes the following chapters and appendices:

- [Chapter 1, About this Manual](#)
This chapter provides information about the organization of this document, as well as related documents, safety information, and conventions used throughout the manual.
- [Chapter 2, PI-MTE3 Camera System](#)
This chapter provides information about the components included with a standard PI-MTE3 camera system, as well as options that are available for purchase from Teledyne Princeton Instruments.
- [Chapter 3, Install LightField](#)
This chapter provides information about the installation of Teledyne Princeton Instruments' LightField image acquisition software.
- [Chapter 4, System Block Diagrams](#)
This chapter provides high-level block diagrams of typical system configurations.
- [Chapter 5, Hardware Configuration](#)
This chapter provides information about the installation and configuration of system hardware.
- [Chapter 6, LightField First Light](#)
- This chapter provides a step-by-step procedure for placing a PI-MTE3 camera system in operation for the first time when using Teledyne Princeton Instruments' LightField 64-bit data acquisition software.
- [Chapter 7, Acquired Image Quality](#)
This chapter provides information about factors that affect the signal acquired on the array, including array architecture, exposure time, temperature, and saturation.
- [Chapter 8, Analog to Digital Conversion](#)
This chapter provides information about the configuration of Analog-to-Digital Conversion parameters.
- [Chapter 9, Full Frame Readout](#)
This chapter provides information about Full Frame Readout operation and related parameter configuration.
- [Chapter 10, Kinetics Readout](#)
This chapter provides information about Kinetics operation and related parameter configuration.
- [Chapter 11, Binning](#)
This chapter provides information about the configuration of Hardware and Software binning.
- [Chapter 12, Shutter Configuration and Control](#)
This chapter provides information about the configuration of shutter control parameters.
- [Appendix A, Technical Specifications](#)
This appendix provides CCD, system, and other basic specifications for a PI-MTE3 system.
- [Appendix B, Outline Drawings](#)
This appendix provides outline drawings of the PI-MTE3 camera and controller. This appendix provides information about VCR fittings used.

- [Appendix C, Troubleshooting](#)
This appendix provides recommended troubleshooting information for issues which may be encountered while working with a PI-MTE3 camera system.
- [Warranty and Service](#)
This section provides warranty information for the PI-MTE3. Contact information is also provided.

1.4 Safety Related Symbols Used in this Manual



CAUTION!

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



WARNING!

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



WARNING! RISK OF ELECTRIC SHOCK!

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

1.5 PI-MTE3 Safety Information

The MTE-3 Controller that controls the PI-MTE3 camera is of Class I category as defined in IEC Publication 348, *Safety Requirements for Electronic Measuring Apparatus*. It is 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 be properly connected to an adapter that complies with these safety requirements.



WARNINGS!

1. If the PI-MTE3 camera system is used in a manner not specified by Teledyne Princeton Instruments, the protection provided by the equipment may be impaired.
 2. Always position the MTE-3 Controller such that the power cord is easily accessible and can be disconnected from the power source in the event of an emergency.
 3. If the equipment or the wall outlet is damaged, the protective grounding could be disconnected. Do not use damaged equipment until its safety has been verified by authorized personnel. Disconnecting the protective earth terminal, inside or outside the apparatus, or any tampering with its operation is also prohibited.
-

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



WARNING!

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

1.6 Precautions



CAUTION!

NEVER place the PI-MTE3 detector nose-down on any surface. The placement of the CCD within the unit is such that it extends slightly beyond the housing. Placing the detector nose-down on any surface will damage the CCD, and will not be covered under the warranty.



CAUTION!

Never attempt to cool the CCD when the camera head is not in a vacuum. Operating the built-in TEC or passing cold coolant through the camera while in air may cause condensation on the CCD. CCDs damaged by condensation are not covered by the warranty.



NOTE:

Materials wetted by the coolant are copper, nickel, stainless steel, and polymers.

It is best not to mix and match MTE-3 Controllers and cameras. The controller shipped with the camera has been adjusted to operate with the camera included in the PI-MTE3 system that has been ordered. The System ID number on the camera and the controller serial labels should be the same. Although operation with a non-matched controller is permissible, but performance may be degraded.

To prevent permanently damaging the PI-MTE3 system, observe the following precautions at all times.

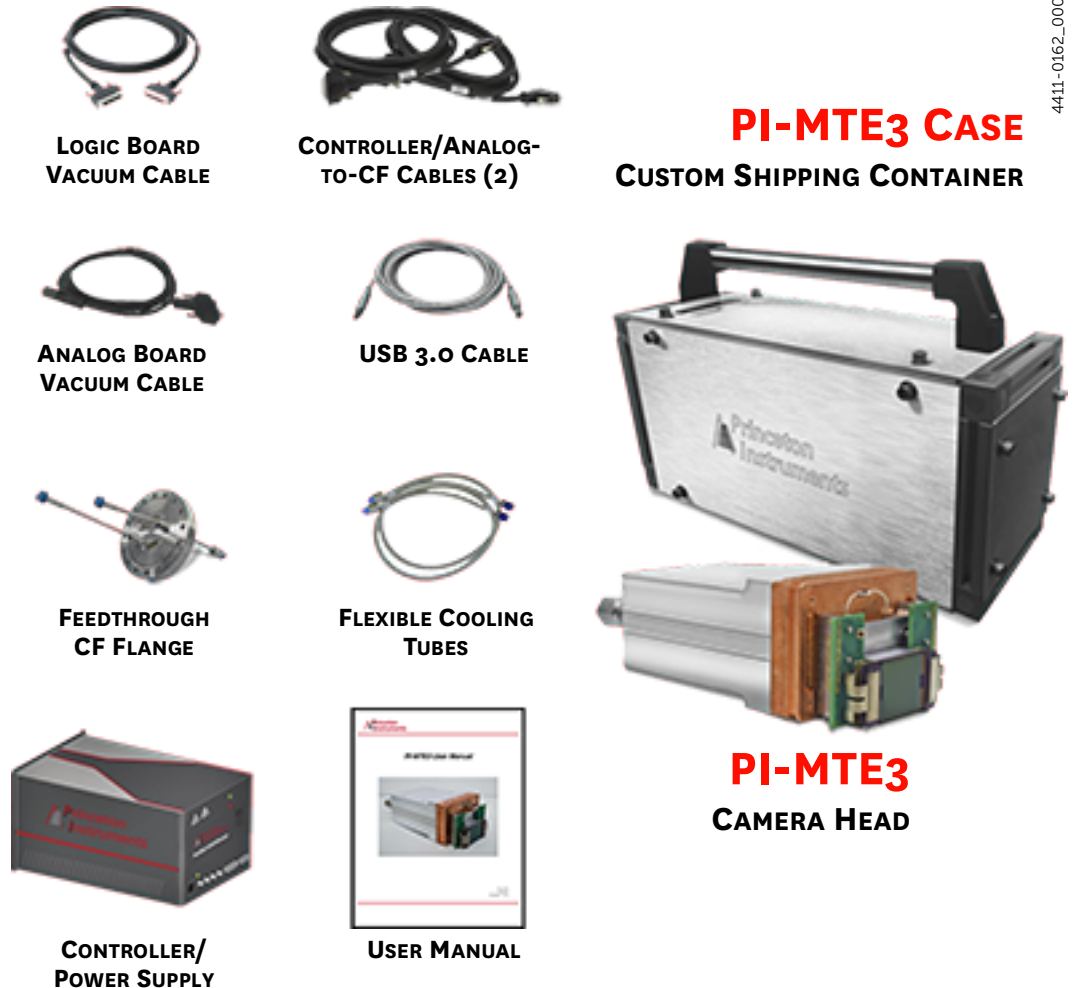
- Always turn off and unplug the MTE-3 Controller before changing the system configuration in any way.
- The CCD array is very sensitive to static electricity. Touching the CCD can destroy it. Operations requiring contact with the CCD can only be performed at the factory.
- When using high-voltage equipment (e.g., an arc lamp,) with the camera system, be sure to turn the controller power ON LAST and OFF FIRST.
- Use caution when triggering high-current switching devices (e.g., an arc lamp,) near the system. The CCD can be permanently damaged by transient voltage spikes. If electrically noisy devices are present, an isolated, conditioned power line or dedicated isolation transformer is strongly recommended.
- Never connect or disconnect any cable while the system is powered on. Connecting an energized cable may damage the CCD.
- Never restrict air flow through the MTE-3 Controller by blocking the air vents.
- Never operate a liquid-cooled PI-MTE3 camera with coolant that is at a temperature below that specified for the camera. Refer to [Table A-3, Default Operating Temperature](#), on page 108 for complete information.

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Chapter 2: PI-MTE3 Camera System

This chapter provides an introduction to, and overview information about, Teledyne Princeton Instruments' PI-MTE3 camera system. Figure 2-1 shows those items that are typically included as part of a standard PI-MTE3 Camera system.

Figure 2-1: Typical PI-MTE3 System Components



Standard items for a typical liquid-cooled system¹ include:

- PI-MTE3 Camera;
- MTE-3 Controller
- Power Cable;
- USB 3.0 Interface Cable;
- Coolant Hoses;
- In-Vacuum Cable Set;
- Flange-to-Controller Cable Set;
- Certificate of Performance;
- Data Acquisition Software.

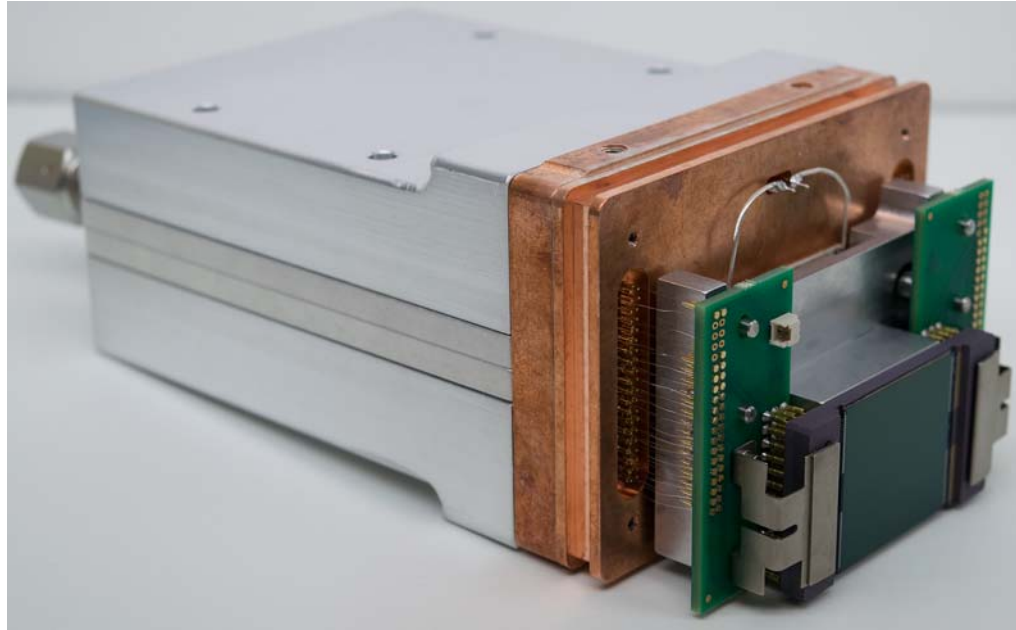
1. For conduction cooled systems, contact Teledyne Princeton Instruments for information.

2.1 PI-MTE3 Camera

PI-MTE3 cameras are designed to operate inside a vacuum chamber. State-of-the-art CCD arrays are available for the PI-MTE3 camera that enable outstanding performance in a wide range of X-ray Imaging and Spectroscopy applications. The PI-MTE3 camera is also suitable for medium-low light applications that require small size.

The PI-MTE3 is a complete camera system. The camera, illustrated in [Figure 2-2](#), contains all of the electronics necessary to read out and control the CCD device. The precision analog-to-digital converters (ADCs) as well as a USB 3.0 port to interface with the host computer are housed in the controller.

Figure 2-2: Typical PI-MTE3 Camera



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NOTE:

Wetted materials are copper, nickel, stainless steel, and polymers.

PI-MTE3 camera systems offer all basic CCD camera functions, such as Region of Interest (ROI) selection and binning, all under software control. It also provides advanced triggered operation as well as programmable TTL output.

This chapter provides an overview of the components included with a PI-MTE3 system.

2.1.1 Handling a PI-MTE3 Detector



CAUTION!

Never touch the CCD itself. Dust or other contaminants can block the light sensitivity of any pixel on which it lands. Dust usually cannot be successfully removed using canned dust removal products, and they can cause damage to the surface and/or bond wires. Teledyne Princeton Instruments recommends keeping the protective nose on the camera until it is ready to be installed in the vacuum chamber. At that time the cover can be removed and the camera installed.

When handling the PI-MTE3 detector with its protective shipping cover removed, exercise extreme caution to avoid damaging the detector. **NEVER** place an exposed PI-MTE3 detector on a flat surface with its CCD edge facing the surface as illustrated in [Figure 2-3](#). Because of the CCD positioning, placing PI-MTE3 detector on a surface as illustrated risks permanently damaging the CCD.



NOTE:

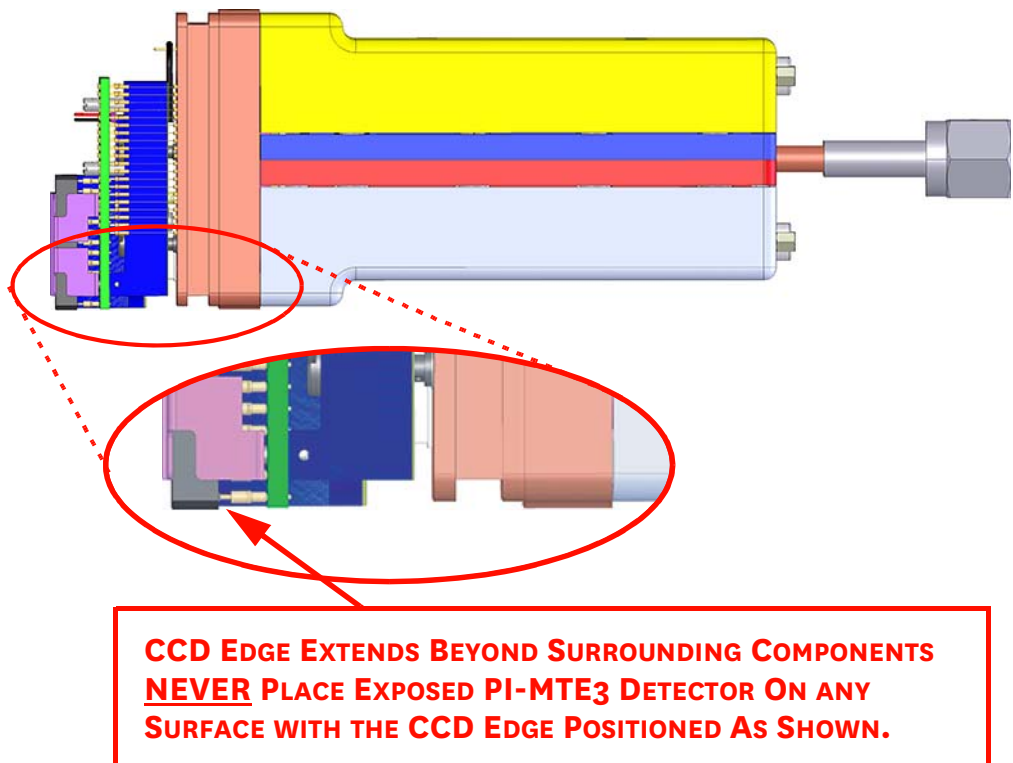
Damage due to mishandling of the PI-MTE3 detector is not covered under warranty.



CAUTION!

NEVER PLACE A PI-MTE3 DETECTOR ON A FLAT SURFACE ORIENTED AS ILLUSTRATED IN [Figure 2-3](#).

Figure 2-3: Incorrect PI-MTE3 Orientation when Placed on a Flat Surface



2.1.2 CCD Array

The PI-MTE3 camera system incorporates a back-illuminated, scientific-grade CCD to ensure the highest image fidelity, resolution, and acquisition flexibility required for scientific imaging. Large full wells, square pixels, and 100% fill factors provide high dynamic range and excellent spatial resolution. Your choice of CCD is already installed in the camera that you received and has been individually tested.

For complete specifications and information about the CCD used in PI-MTE3 cameras, refer to [Appendix A, Technical Specifications](#), on page 107.

2.1.3 Cooling

Dark current is significantly reduced in PI-MTE3 camera systems through liquid-assisted Thermoelectric (TE) cooling of the CCD array.

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 conduction to the internal heatsink. Heat is transferred out of the camera by the flow of coolant through the heatsink.

2.1.3.1 External Cooling Circulator

PI-MTE3 cameras can be cooled by circulating coolant providing a low vibration system for data acquisition. The PI-MTE3 camera is equipped with two 1/4" coolant ports located on the rear of the camera.

**NOTE:**

The coolant circulator can be any commercially available circulator capable of meeting or exceeding the technical specifications listed in [Section A.5, External Coolant Circulator Specifications](#), on page 110.

Coolant temperature should not be below the dew point of the ambient air in the unlikely event the PI-MTE3 is operated outside of the vacuum chamber. Since the PI-MTE3 is normally operated within a vacuum, condensation will occur outside the vacuum chamber, which may be an issue for the user. Internal condensation caused by operation below the dew point may damage the PI-MTE3 camera and will void the warranty.

2.1.4 Controller Connector

Power, control signals, and data are exchanged between the MTE-3 Controller and the PI-MTE3 camera via a 25-pin D-connector and a 15-pin D-connector located on the rear of the camera.

**CAUTION!**

Controller power must be OFF before connecting to or disconnecting from either this connector or the equivalent connector on a vacuum flange.

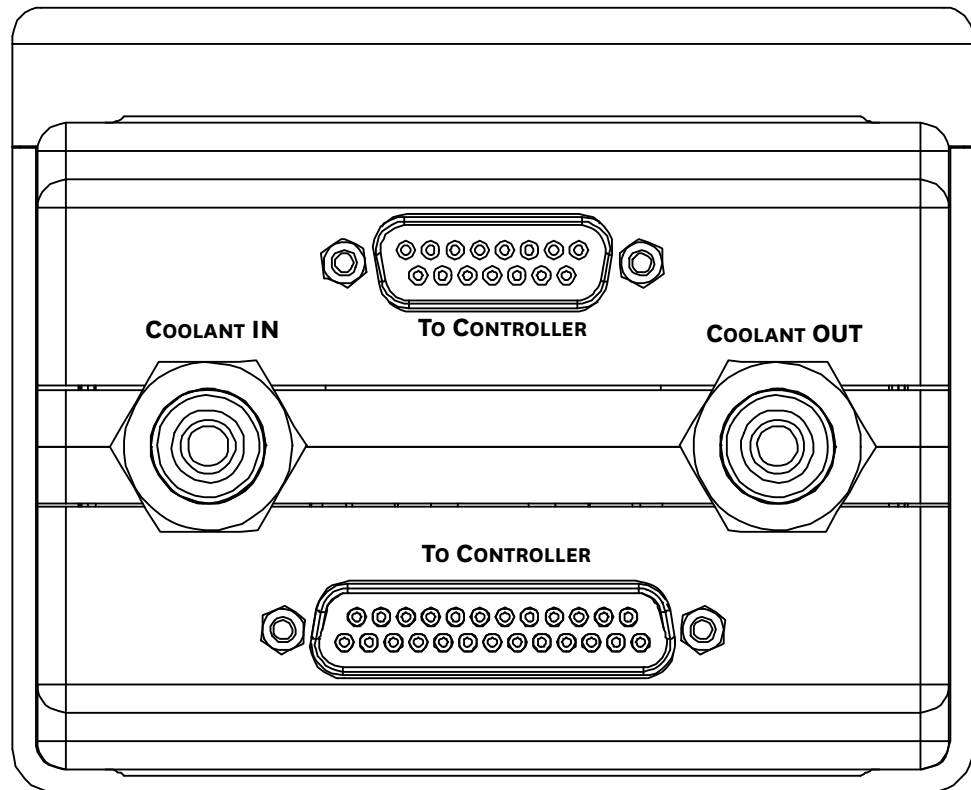
**NOTE:**

Although both ends of the DB-25 controller cable has male connectors, it is not symmetric. The cable must be connected with its **A** end going to the camera.

2.1.5 Rear-Panel Connectors

Figure 2-4 illustrates the typical rear-panel connectors found on a PI-MTE3 camera.

Figure 2-4: Typical PI-MTE3 Camera Rear-Panel Connectors



4411-0162_0007

Refer to [Table 2-1](#) for information about each rear-panel connector and indicator.

Table 2-1: PI-MTE3 Camera Rear Panel Connectors

Label	Description
To Controller	DB-15 Analog Cable.
To Controller	DB-25 Power/Control Cable. A end of cable connects to camera.
Coolant IN	Coolant In Port. Connects to chiller OUT port.
Coolant OUT	Coolant Out Port. Connects to chiller IN port.

2.2 MTE-3 Controller

The MTE-3 Controller is a compact, high performance CCD Detector Controller for operation with Teledyne Princeton Instruments detectors. [Figure 2-5](#) illustrates a typical controller.

Figure 2-5: Typical MTE-3 Controller



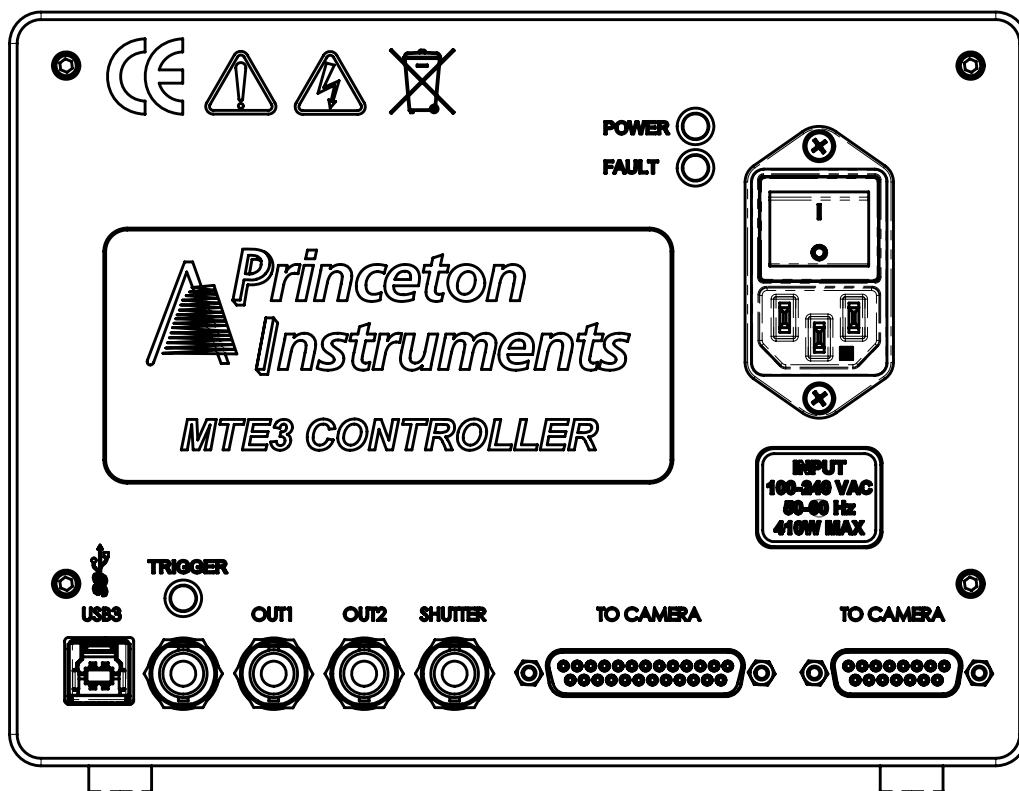
Designed for high speed and high performance image acquisition, the MTE-3 Controller offers data transfer at speeds up to 4 x 4 Mpixels/second output. A variety of A/D converters are available to satisfy different speed and resolution requirements.

In addition to containing the power supply, the controller contains the analog and digital electronics, scan control and exposure timing hardware, and controller I/O connectors.

2.2.1 Connectors and Indicators

Figure 2-6 illustrates the connectors and indicators found on an MTE-3 Controller.

Figure 2-6: Typical MTE-3 Controller Rear-Panel Connectors and Indicators



Refer to [Table 2-2](#) for information about each rear-panel connector and indicator.

Table 2-2: MTE-3 Controller Rear Panel Connectors and Indicators (Sheet 1 of 2)

Label	Description
Fault LED	This Red LED is normally extinguished. When illuminated or flashing, this LED indicates a fault within the system has been detected. Refer to Appendix C, Troubleshooting , on page 115 for additional information.
Power LED	When illuminated, this Green LED indicates that the power supply is turned on. When extinguished, the power supply is turned off. NOTE: If the Power On/Off switch is in the ON position, but the Power LED is not illuminated, refer to Section C.1.1, MTE-3 Controller Switch in On Position, But Power LED Extinguished , on page 116 for recommended troubleshooting procedures.
USB3	Connects the MTE-3 Controller to the Host Computer.
Trigger	Logic-level input for external trigger operation.

Table 2-2: MTE-3 Controller Rear Panel Connectors and Indicators (Sheet 2 of 2)

Label	Description
Out1	0 to +5.0 V programmable TTL-compatible logic level output capable of driving logic levels into 50 Ω . This output can be programmed and inverted via the application software.
Out2	0 to +5.0 V programmable TTL-compatible logic level output capable of driving logic levels into 50 Ω . This output can be programmed and inverted via the application software.
Shutter	0 to +5.0 V programmable TTL-compatible logic level output to drive a TTL-compatible external shutter driver.
To Camera	DB-25 cable for power and control signals. B end of cable connects to controller.
To Camera	DB-15 cable for video and power signals.

2.3 Cables

[Table 2-3](#) describes the cables included with a standard PI-MTE3 camera system.

Table 2-3: Standard PI-MTE3 Camera System Cables (Sheet 1 of 2)




Cable	Part Number	Description/Purpose	Length
Vacuum		Kapton® Braided Cables to connect the PI-MTE3 camera to a compatible vacuum flange. See Figure 2-6 on page 21 for additional information.	
	6050-0781	DB-25 to DB-25 cable.	custom
	6050-0782	DB-15 to DB-15 cable.	custom
			

Table 2-3: Standard PI-MTE3 Camera System Cables (Sheet 2 of 2)

Cable	Part Number	Description/Purpose	Length
Controller	6050-0788	Logic Controller Cable; Controller to ConFlat	9.8 ft [3 m]
	6050-0789	Analog Controller Cable Controller to ConFlat.	9.8 ft [3 m]
		 4411-0162_0007	
USB 3.0	6050-0738	<p>Connect the USB 3.0 connector on the rear of the MTE-3 Controller to a USB 3.0 card that has been installed in the host computer. This cable is equipped with standard USB 3.0 connectors.</p> <p>See Figure 2-6 on page 21 for additional information.</p>	6.0 ft [1.8 m]
		 4411-0162_0009	

2.4 Optional Vacuum Accessories

[Table 2-4](#) provides information about optional vacuum accessories that are available from Teledyne Princeton Instruments for use with the PI-MTE3 camera system.

Table 2-4: Optional PI-MTE3 Camera System Vacuum Accessories (Sheet 1 of 2)


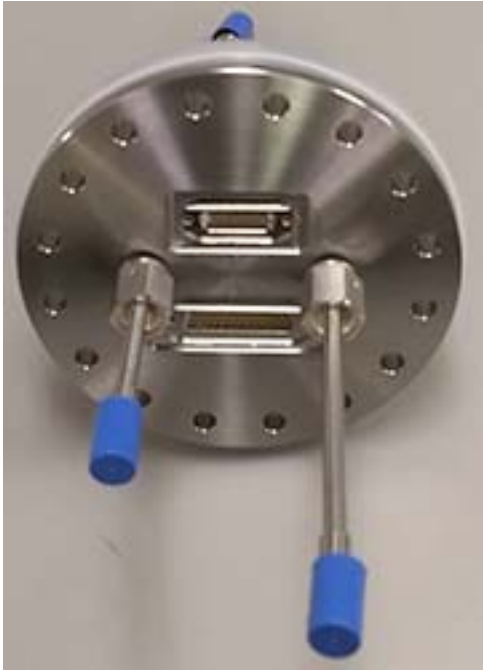
Item	Part Number	Description/Purpose
Flexible Tubing	2825-0449	<p>Stainless-steel, vacuum-compatible flexible tubing that connects the PI-MTE3 camera's water tubing and the vacuum feed through the customer-ordered ConFlat Flange.</p> <p>Tubing specifications are:</p> <ul style="list-style-type: none"> Outer Diameter: 0.25" Length: 36"
		 4411-0162_0010

Table 2-4: Optional PI-MTE3 Camera System Vacuum Accessories (Sheet 2 of 2)

Item	Part Number	Description/Purpose
ConFlat Flange	2550-0921	<p>6.0" ConFlat Flange equipped with:</p> <ul style="list-style-type: none"> • 25-pin D-sub connector; • 15-pin D-sub connector; • Coolant Feed-throughs. 

2.5 Certificate of Performance

Each PI-MTE3 camera is shipped with a Certificate of Performance which states that the camera system has been assembled and tested according to approved Teledyne Princeton Instruments procedures. It documents the camera's performance data as measured during the testing of the PI-MTE3 and includes the Camera Serial Number(s).

This information is useful when contacting Teledyne Princeton Instruments Customer Support.

2.6 Application Software

Teledyne Princeton Instruments offers a number of data acquisition software packages for use with PI-MTE3 camera systems, including:

- **LightField®**
The PI-MTE3 camera can be operated using LightField, Teledyne Princeton Instruments' 64-bit Windows® compatible software package.
LightField combines complete control over Teledyne Princeton Instruments' cameras and spectrographs with easy-to-use tools for experimental setup, data acquisition and post-processing. LightField makes data integrity priority #1 via automatic saving to disk, time stamping and retention of both raw and corrected data with full experimental details saved in each file. LightField works seamlessly in multi-user facilities, remembering each user's hardware and software configurations and tailoring options and features accordingly. The optional, patent-pending IntelliCal™ package is the highest-performance wavelength calibration software available, providing up to 10X greater accuracy across the entire focal plane than competing routines.
- **PICam™**
The standard 64-bit software interface for cooled CCD cameras from Teledyne Princeton Instruments. PICam is an ANSI C library of camera control and data acquisition functions.
Refer to the PICam Programmer's Manual for the list of supported operating systems.
- **Scientific Imaging ToolKit™ (SITK™)**
A collection of LabVIEW® VIs for scientific detectors and spectrographs. This third party software can be purchased from Teledyne Princeton Instruments.



NOTE:

PI-MTE3 cameras may also be operated by several other third-party software packages. Please check with the providers of the packages for compatibility and support information.

2.7 Accessories

Teledyne Princeton Instruments offers a number of optional accessories that are compatible with PI-MTE3. For complete ordering information, contact Teledyne Princeton Instruments.

2.7.1 External Shutters

The PI-MTE3 controller does not drive any external shutter directly. It does, however, provide a logic signal that can be used to drive an external shutter by means of an external shutter driver unit typically available directly from the shutter manufacturer.

Contact Teledyne Princeton Instruments for information about ordering an external shutter for use with PI-MTE3. Refer to [Contact Information](#) on page 126 for complete information.

2.8 Unpack the System

All required items should be included with the shipment. The PI-MTE3 system has been manufactured according to the camera options specified at the time of purchase, including the CCD window and coatings that were ordered.

When unpacking the system, examine the system components for any signs of shipping damage. If there are any, notify Teledyne Princeton Instruments immediately and file a claim with the carrier. 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.



CAUTION!

The PI-MTE3 camera is shipped with a protective cover over the CCD. Do not remove the cover except within a clean-room environment (or equivalent.)

When the cover is removed, the CCD will be exposed and can be damaged easily. Never touch the CCD itself. Any dust or oils will cause defects in the image.

Retain all original packing materials so that the PI-MTE3 system can be easily and safely packaged and shipped to another location or returned for service if necessary. If assistance is required at any time, contact Teledyne Princeton Instruments Customer Support. Refer to [Contact Information](#) on page 126 for complete information.

2.8.1 Verify Equipment and Parts Inventory

Verify all equipment and parts required to set up the PI-MTE3 system have been delivered.

A typical system consists of:

- PI-MTE3 Camera;
- MTE-3 Controller;



NOTE:

For optimal system performance, do not substitute any other controller for the controller supplied with your system. The controller that has been shipped with your system has been calibrated to the camera at the factory.

- Camera-to-Vacuum Flange cable set:
 - Vacuum-compatible DB-25 to DB-25, custom length;
 - Vacuum-compatible DB-15 to DB-15, custom length;
- Vacuum Flange to Controller Cable Set (6050-0783 and 6050-0784, 5 m each,) or custom lengths;
- Power Cable;
- USB 3.0 Interface Cable;
- Vacuum Flange(s), custom per order;
- Flexible Hoses
Two 30" stainless steel flexible hoses to connect camera coolant ports to vacuum flange. Hoses for more recent systems may have female VCR fittings or as ordered.
- Certificate of Performance;
- Data Acquisition Software, including:
 - Installation disk;
 - Hardware Key

Accessories that may have been purchased include:

- Swagelok Fittings;
- Coolant hoses (for liquid-cooled system).

2.9 PI-MTE3 Camera and System Maintenance



WARNING!

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



CAUTION!

NEVER place the PI-MTE3 detector nose-down on any surface. The placement of the CCD within the unit is such that it extends slightly beyond the housing. Placing the detector nose-down on any surface will damage the CCD, and will not be covered under the warranty.

2.9.1 Camera

Normally, PI-MTE3 cameras operated in vacuum remain clean by virtue of the vacuum. Therefore, it should remain within the vacuum system at all times.



NOTE:

Some discoloration of the copper portions of the camera may occur. This is normal and has no effect on operation.

2.9.2 Repairs

Save all original packing materials. Because the PI-MTE3 camera system contains no user-serviceable parts, repairs must be done by Teledyne Princeton Instruments. Use the original packing materials whenever shipping the system or any system component.

If the system requires repair, contact Teledyne Princeton Instruments Customer Support for instructions. Refer to [Contact Information](#) on page 126 for complete information.



CAUTION!

Be sure to install the shipping cover over the CCD before shipping. The cover should be installed as soon as the PI-MTE3 has been removed from the vacuum chamber.

Chapter 3: Install LightField

This chapter provides the installation procedure for LightField application software.



NOTE:

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

3.1 Prerequisites

Before beginning to install LightField, verify that:

- The operating system on the desired host computer is Windows® 7/8/10 (64-bit);
- The host computer supports USB3;
If it does not support USB3, refer to the host computer manufacturer's instructions for installing a USB3 interface card;
- The installation disk and hardware key are available.

3.2 Installation Procedure

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

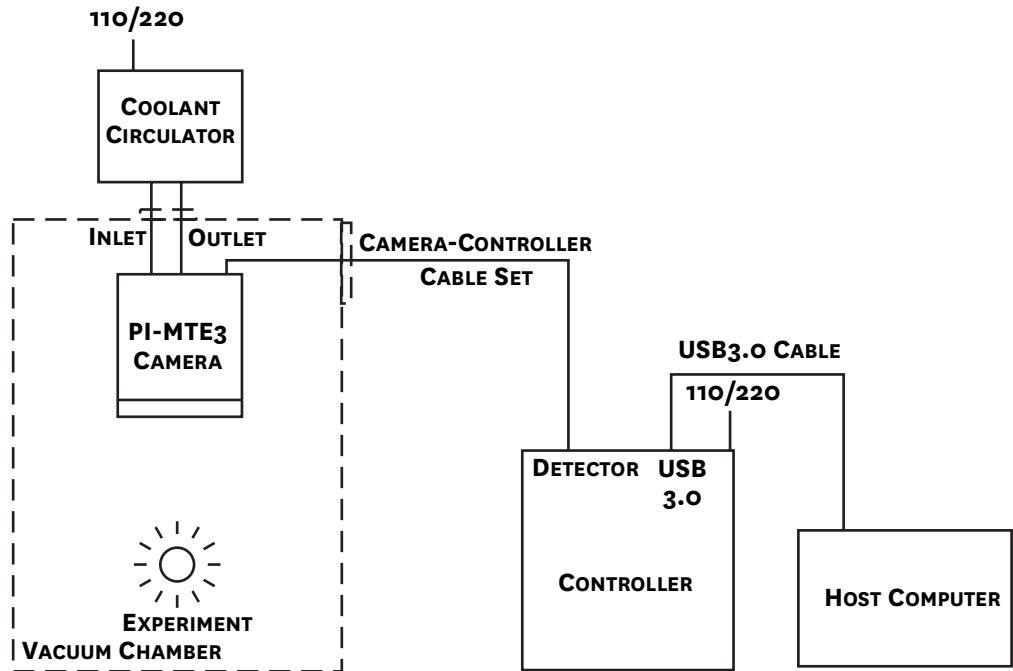
1. Insert the LightField Installation CD into the CD drive on the host computer, and follow the on-screen prompts.
2. After the installation has been completed, reboot the host computer.
3. Connect the PI-MTE3 system components to the host computer and apply power.
4. Launch LightField, activate it, and begin experiment configuration.

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Chapter 4: System Block Diagrams

This section provides block diagrams of typical system configurations.

Figure 4-1: Block Diagram: Typical PI-MTE3 Block Diagram



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Chapter 5: Hardware Configuration

This chapter provides information about the installation of hardware for a PI-MTE3 camera.

5.1 Critical Setup and Configuration Information



CAUTION!

To prevent permanently damaging the PI-MTE3 camera and controller, it is imperative that all information within this section be read, understood, and followed. Failure to do so will void the warranty.

It is very important not to impose a difference in electrical potential between the PI-MTE3 camera head and the MTE-3 Controller. Even small differences in potential (particularly when they have low source impedance,) can cause excessive current to flow between the camera head and the controller, resulting in permanent damage to the camera, controller, or both. Such damage is considered user abuse and is not covered by the warranty. Often (depending on the user's installation,) the PI-MTE3 camera head is electrically connected to the user's vacuum chamber (e.g., bolted to the vacuum chamber, or bolted to some structure in the chamber.) If the vacuum chamber is grounded to a different ground from the ground used for the controller's power cable, it is possible to have a sizable potential difference between the chamber and the controller. This is particularly true in cases in which equipment with high electrical power (or high peak power) are used in the chamber. Some examples are Xenon lamps, arc lamps, high power pumps, etc. If the user cannot assure equal potential between the camera head mounting and the controller, the user should insulate the camera head from the vacuum chamber structure and rely on the camera's cables to ground the camera to the controller.



NOTE:

An insulated camera head could be vulnerable to static charge build up, especially if the head is left disconnected from the controller or the controller is left disconnected from ground. In this case, a 1 M Ω connection from the camera to chamber ground is a good work-around.

It is also important to prevent any electro-static discharge (ESD) to the camera head. While the camera head is protected from low level ESD events, high-level ESD events can overcome the built-in protections and cause extensive damage, up to and including destruction of the CCD.

5.2 Chiller Configuration

For liquid-cooled PI-MTE3 systems, the liquid circulator provides a vibration-free method of heat removal. Perform the following procedure to connect a circulator to a liquid-cooled PI-MTE3 camera:



NOTE:

For specific configuration information, refer to the manufacturer-supplied documentation included with the circulator.

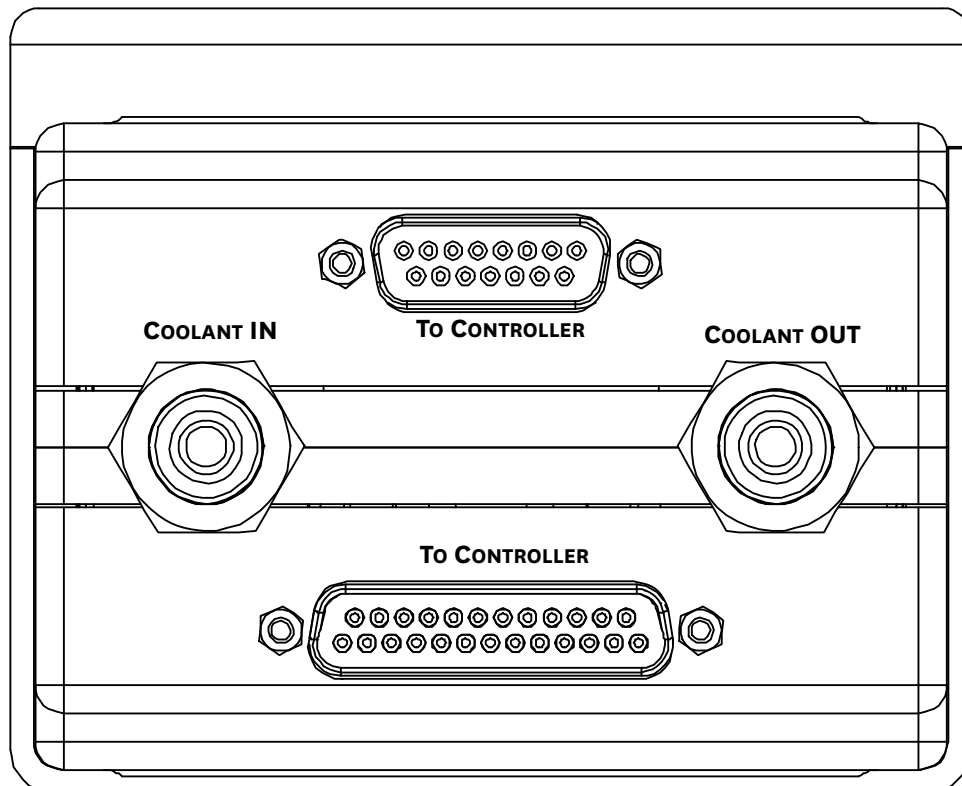
1. Verify the camera and the circulator power switches are turned off.
2. Verify the circulator is positioned a minimum of 6 inches (150 mm) below the PI-MTE3 camera. The vertical distance should not exceed 10 feet (3 m). Typically, the camera is at table height and the circulator is on the floor.
3. Using the supplied stainless steel, flexible hoses, connect the two coolant ports on the PI-MTE3 to the vacuum flange.



NOTE:

See [Figure 5-1](#) for Coolant IN and Coolant OUT port identification. These ports are **NOT INTERCHANGEABLE**.

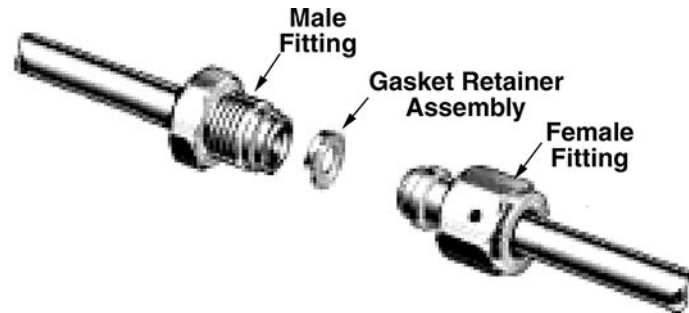
Figure 5-1: PI-MTE3 Coolant Ports



4411-0162_0007

The stainless steel hoses are equipped with female VCR fittings to make these connections. These VCR fittings are completely assembled and are ready to be connected. Fittings on the PI-MTE3 coolant pipes are VCR size ¼" male glands with gasket retainer assemblies containing copper gaskets. The flex tubing has female fittings on both ends and the ConFlat has male fittings on both ends. See [Figure 5-2](#).

Figure 5-2: Typical VCR Fittings



4411-0162_0012

4. Using hoses that are as short as possible, connect the two coolant ports on the circulator to the two coolant ports on the vacuum flange.



CAUTION!

Verify there are no kinks in hoses that may impede coolant flow. Lack of sufficient flow can seriously harm the detector. Any resulting damage is not covered under warranty.



NOTE:

Damage caused by water leaking into the PI-MTE3 voids the warranty.

5. On the circulator, verify that the reservoir contains coolant. If additional coolant is required, use a 50:50 mixture of water and ethylene glycol to add sufficient coolant.
6. Replace the reservoir cap.
7. Plug the circulator into a compatible power source as specified by the circulator's manufacturer.
8. Turn the circulator on.



CAUTION!

When configuring a circulator, adhere to the following:

- Coolant flow-rate should never exceed 0.8 gal/minute.
- Coolant pressure should never exceed 20psi.
- Never set the circulator temperature below the dew point.

9. Verify there are no leaks or air bubbles in the hoses.

**NOTE:**

Small air bubbles (approximately the size of bubbles in soda) are common in the circulator, particularly immediately following start up. These bubbles do not prevent proper operation.

- If no problems are observed, proceed to step 10.
 - 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, proceed to step 10.
10. Turn on the PI-MTE3 camera's controller and allow it to boot up.
 11. Launch LightField.

5.3 Connect Controller to Host Computer

Perform the following procedure to connect the USB 3.0 cable between the MTE-3 Controller and the host computer:

1. Verify power to both the MTE-3 Controller and the host computer are off before connecting or disconnecting the Controller-Computer cable.
2. Connect one end of the USB 3.0 cable into the USB 3.0 port on the host computer.
3. Connect the other end of the USB 3.0 cable to the USB 3.0 port on the rear of the MTE-3 Controller.

5.4 Remove Protective Shipping Cover

Before mounting the PI-MTE3 detector where required, the protective shipping cover must first be removed. This section provides information necessary to remove the cover.

The following tools are required when removing the shipping cover:

- #1 Phillips head screwdriver.

Perform the following procedure to remove the protective shipping cover from the PI-MTE3 detector:



CAUTION!

Refer to [Section 2.1.1, Handling a PI-MTE3 Detector](#), on page 17, before proceeding with this procedure.

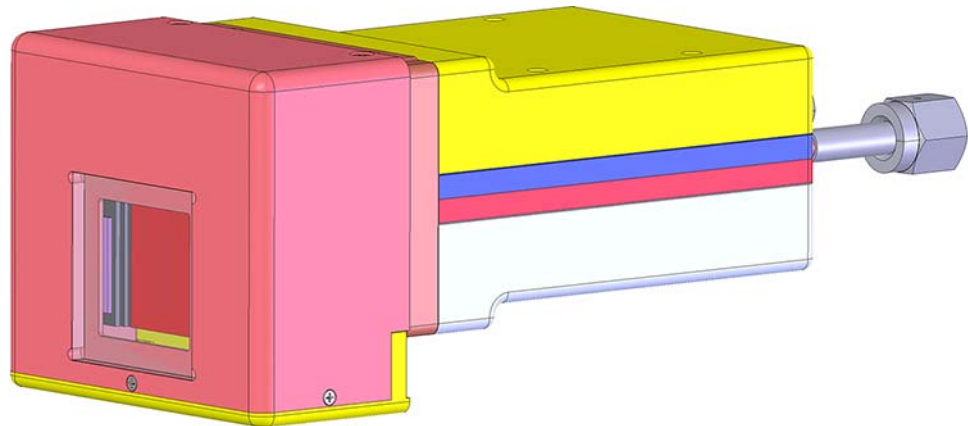
1. Place the PI-MTE3 detector on a clean, level, and sturdy work surface. [Figure 5-3](#) illustrates a typical PI-MTE3 detector.



NOTE:

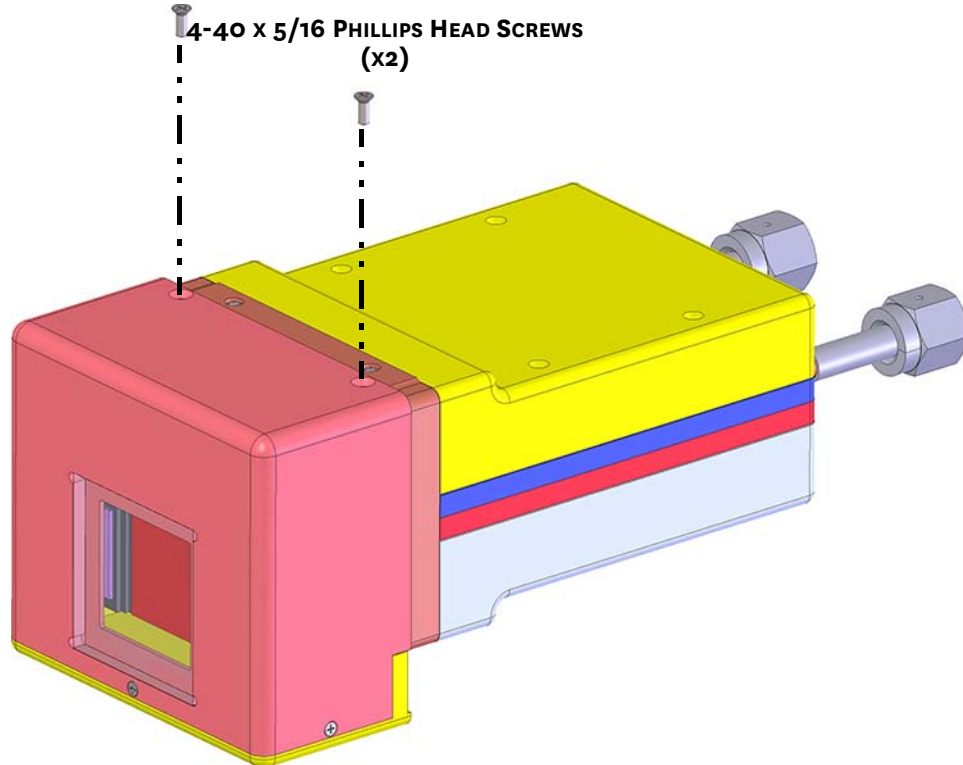
Colors shown in [Figure 5-3](#) and subsequent figures are for ease of identification and clarity only. Actual parts are natural finish.

Figure 5-3: Typical PI-MTE3 Detector: Protective Cover Installed



- Use a #1 Phillips head screwdriver to remove two (2) 4-40 x 5/16 Phillips head screws. See [Figure 5-4](#).

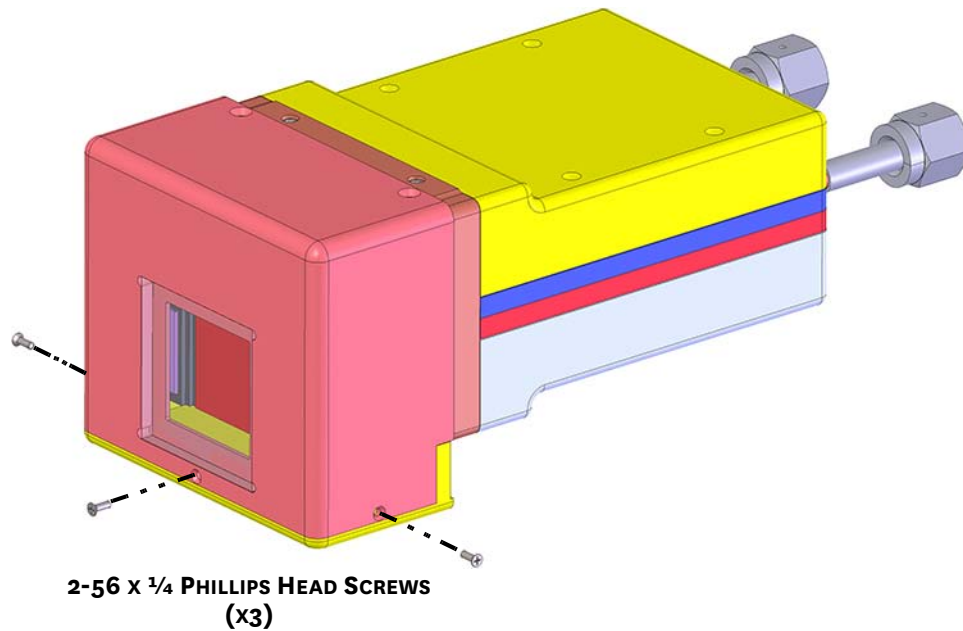
Figure 5-4: Remove Two (2) 4-40 x 5/16 Phillips Head Screws



4411-0162_0029

- Use a #1 Phillips head screwdriver to remove three (3) 2-56 x 1/4 Phillips head screws. See [Figure 5-5](#).

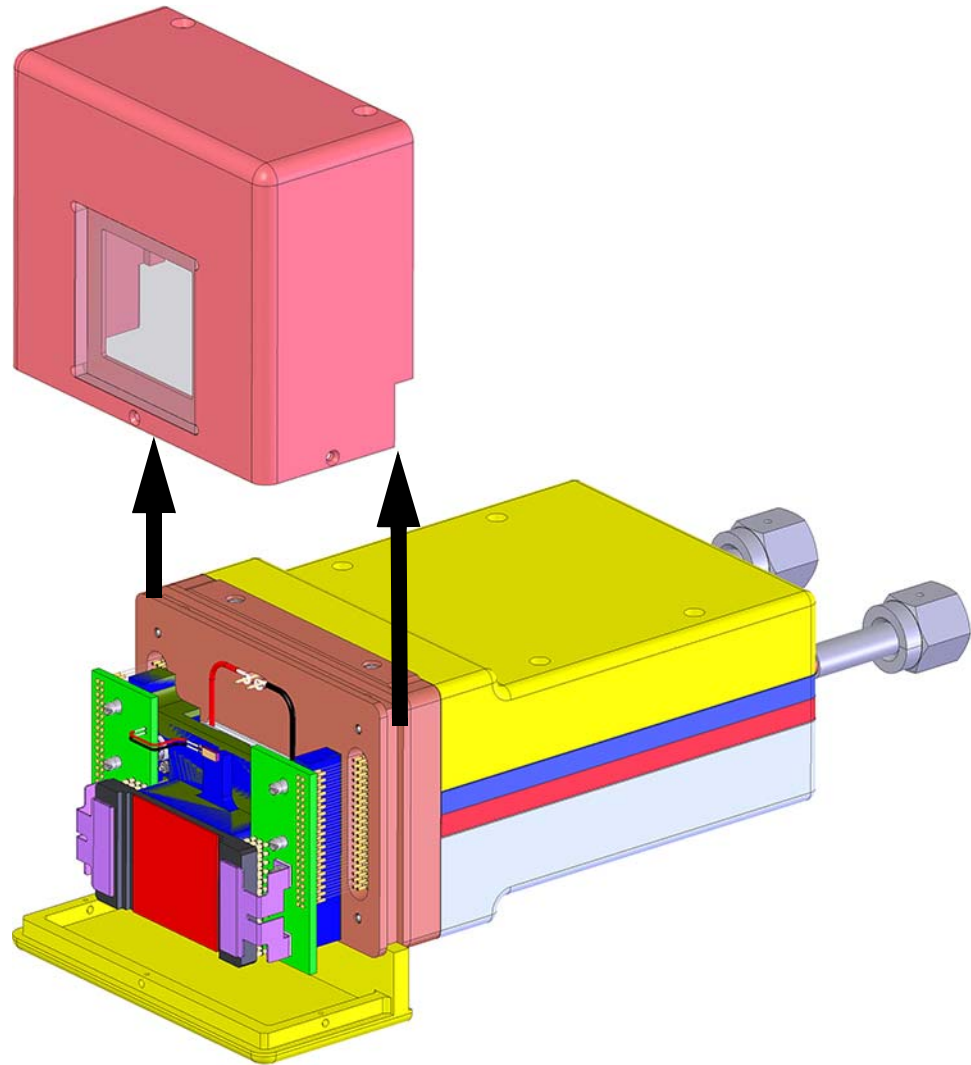
Figure 5-5: Remove Three (3) 2-56 x 1/4 Phillips Head Screws



4411-0162_0030

4. Carefully slide the front cover up and off of the detector chassis. See [Figure 5-6](#).

Figure 5-6: Remove Front Cover



4411-0162_0031

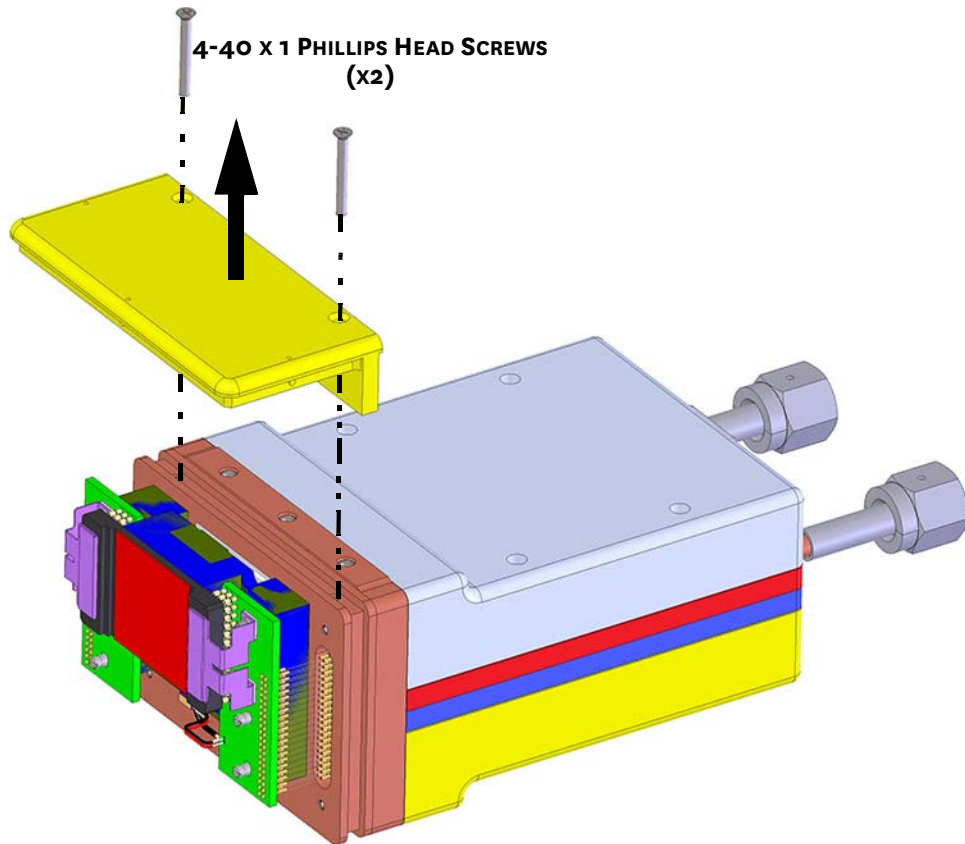
5. Carefully turn the camera over.

- Use a #1 Phillips head screwdriver to remove two (2) 4-40 x 1 Phillips head screws. Carefully lift the bottom cover off the detector chassis.

**CAUTION!**

Now that the camera has been unpacked and no longer is in its protective case, extreme caution must be exercised in order to protect the CCD when placing it on a flat surface.

Figure 5-7: Remove Two (2) 4-40 x 1 Phillips Head Screws and Bottom Cover



4411-0162_0032

- The PI-MTE3 detector is now ready to be mounted.

5.5 Mount the PI-MTE3 Detector



CAUTION!

Refer to [Section 2.1.1, Handling a PI-MTE3 Detector](#), on page 17, before proceeding with this procedure.

Perform the following procedure to mount the PI-MTE3 detector as required:

1. [Figure 5-8](#) shows the locations of the two sets of 8-32 mounting holes provided on opposite sides of the PI-MTE3.



CAUTION!

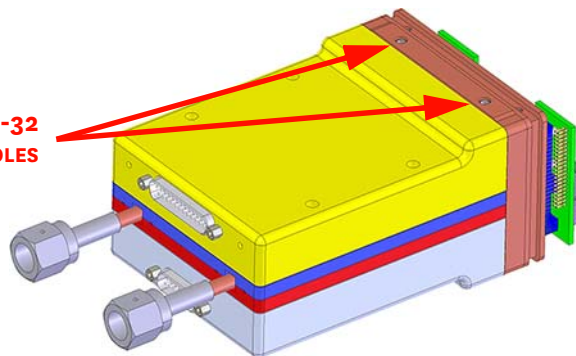
To avoid damaging the PI-MTE3, never mount the unit using both sets of holes simultaneously. Either use the set of two holes, OR use the set of three holes.

NEVER USE ALL FIVE HOLES AT THE SAME TIME!

Figure 5-8: Mounting Hole Locations on PI-MTE3

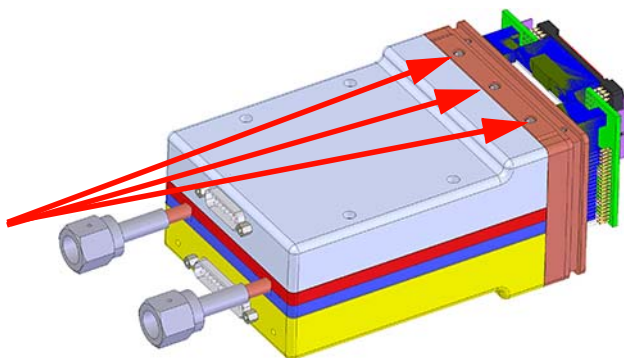
MOUNT THE UNIT USING EITHER:

• THESE TWO 8-32 MOUNTING HOLES



— OR —

• THESE THREE 8-32 MOUNTING HOLES



2. Use two/three #8-32 screws to mount the PI-MTE3 as required.

5.6 Connect the PI-MTE3 to the MTE-3 Controller

When using the PI-MTE3 in a vacuum chamber, the shipping cover installed on the camera prior to its being shipped must be removed.

Additionally, two cables sets are required for this procedure:

- One set is required for inside the vacuum chamber;
- One set is required for connection to the MTE-3 Controller outside of the chamber.



CAUTION!

The vacuum-compatible cable is very fragile and should be handled very carefully to prevent wire breakage at the connector ends. Never pull on the cable wires when connecting or disconnecting it from the cable connectors on the vacuum flange or the PI-MTE3.

Perform the following procedure to connect the PI-MTE3 to the MTE-3 Controller for vacuum applications:

1. Verify that power to the MTE-3 Controller is turned off.
2. Connect male ends of the Detector-Controller cable set to the ports on the rear of the MTE-3 Controller labeled To Camera.
3. Secure the cables using the integrated locking screws on the cable.
4. Connect the female end of the cable to the vacuum flange.
5. Screw the connector locking screws in place.
6. Use a 3/32" hex driver to carefully secure the 3 foot long vacuum-compatible cable to the inside of the vacuum flange.



CAUTION!

The in-vacuum cables are NOT SYMMETRIC. For proper operation and performance, it is required that:

- The **A** ends of each cable be connected to the PI-MTE3 **CAMERA**;
- The **B** ends of each cable be connected to the **FLANGE FEED-THROUGH CONNECTORS**.

7. Connect the other end of the cable to the back of the PI-MTE3 and secure the cable using the integrated locking screws.

5.7 Experiment Shutdown

Following the completion of a liquid-cooled experiment, perform the following procedure:

1. Turn off the PI-MTE3 camera's power supply.
2. Turn off the circulator according to all manufacturer-supplied documentation and procedures.
3. If desired, carefully disconnect the coolant hoses from the PI-MTE3 camera.

Chapter 6: LightField First Light

Once the PI-MTE3 camera has been configured as described in [Chapter 5, Hardware Configuration](#), on page 33 acquiring data using LightField is straightforward. For most applications simply:

- Establish optimum performance using Preview mode;
- Set a target camera temperature;



CAUTION!

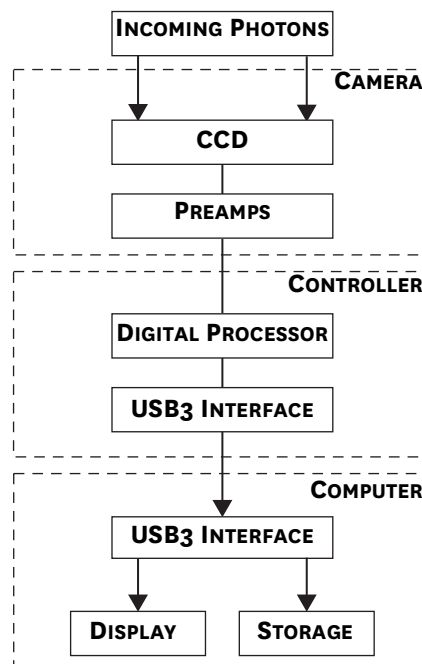
The PI-MTE3 must be in-vacuum when using cooling. Attempting to cool the CCD in a non-vacuum environment is likely to cause permanent damage to the CCD. Do not set the system temperature below +25°C when not in a vacuum.

- Wait until the system's temperature has stabilized;
- Acquire live data in Acquire mode.

Additional considerations regarding experiment setup and equipment configuration are addressed in the LightField Online Help.

During data acquisition, the CCD array is exposed to a source and charge accumulates in the pixels. After the defined exposure time, the accumulated signal is readout of the array, digitized, and then transferred to the host computer. Upon data transfer, the data are displayed and/or stored via the application software. This sequence is illustrated by the block diagram shown in [Figure 6-1](#).

Figure 6-1: Light Path Block Diagram for PI-MTE3 Systems



4411-0162_0018

Whether data are displayed and/or stored depends on the data collection operation that has been selected in the application software:

- Preview

**NOTE:**

In LightField, this button is labeled Run and includes a green arrow.

Data collection operations use the experiment setup parameters to establish the exposure time (the period when signal of interest is allowed to accumulate on the CCD). Preview is typically used when setting up the system.

In Preview mode, the number of frames is ignored. A single frame is acquired and displayed, another frame is acquired which overwrites the currently displayed data, and so on, until Stop is selected.

**NOTE:**

The last frame acquired before Stop is selected cannot be stored.

However, the last frame of data can be saved by configuring the Number of Frames to 1, and clicking Acquire rather than Stop.

Preview mode is particularly convenient for familiarization and configuration. For ease in focusing, the screen refresh rate should be as quick as possible, achieved by operating with axes and cross-sections off, and with Zoom 1:1 selected.

- Acquire

Acquire mode is typically used for the collection and storage of data. In Acquire mode, every frame of data collected can be automatically stored, so the completed dataset may include multiple frames with one or more accumulations. This mode is typically selected during actual data collection.

One limitation of Acquire mode operation is that if data acquisition continues at too fast a rate for it to be stored, data overflow may occur.

6.1 Set Up and Configuration

This section provides step-by-step instructions for acquiring an image in LightField for the first time. The intent of this procedure is to gain familiarity with the operation of the system and to show that it is functioning properly. Once basic familiarity has been established, additional, more complex configurations can be implemented.

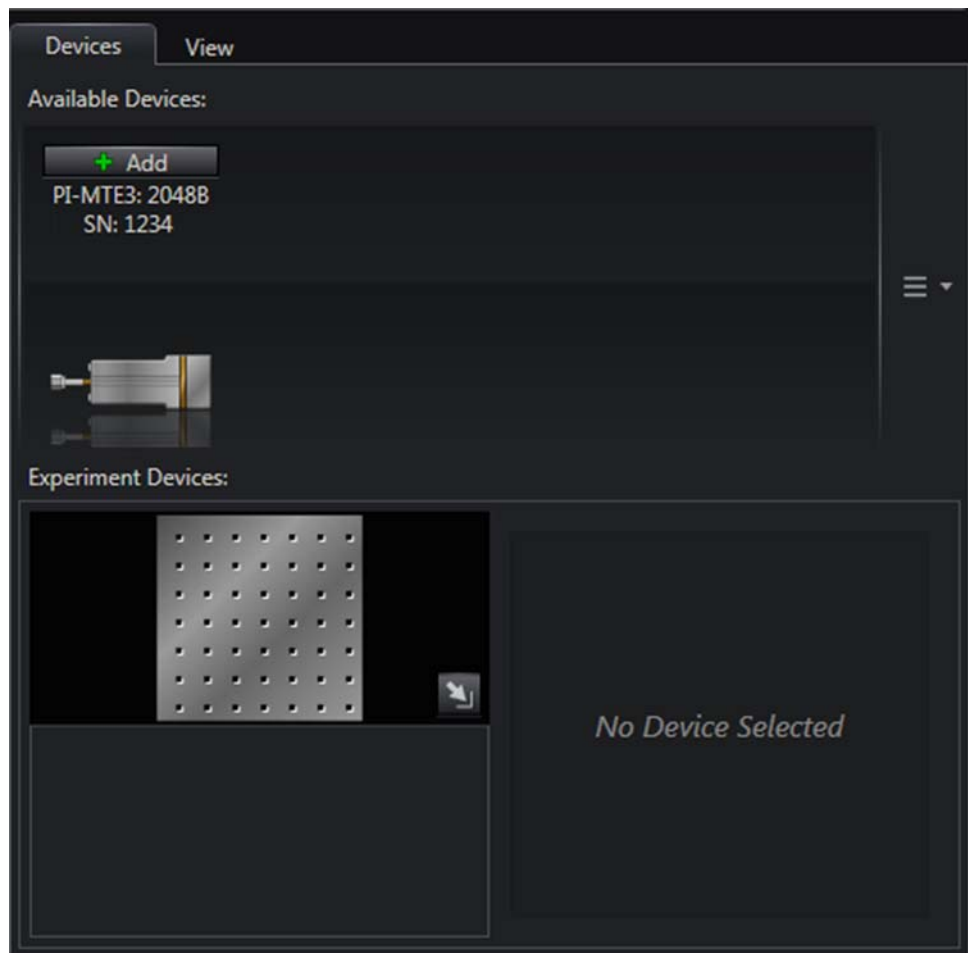
The following procedure assumes:

- The system has been set up in accordance with the instructions in previous chapters;
- Familiarity with LightField.
If this is not the case, refer to the online help while performing this procedure.
- The system is liquid cooled.
- The target is a sharp image, text, or a drawing that can be used to verify that the camera is seeing. Because the PI-MTE3 camera has no lens/lens holder, nor are there any focus adjustments, the target must be projected directly onto the CCD. Either an attenuated laser pointer (with an ND4 filter) or an LED with an external lens can be used.

Perform the following procedure to set up and configure the system to acquire an image:

1. Verify the [chiller] has been properly installed and configured as described in [Section 5.2, Chiller Configuration](#), on page 34.
2. Project a test target onto the camera.
3. Turn on the PI-MTE3.
4. Turn on the host computer.
5. Launch LightField.
6. Once LightField has launched, a PI-MTE3 camera icon will be shown in the Devices area. See [Figure 6-2](#).

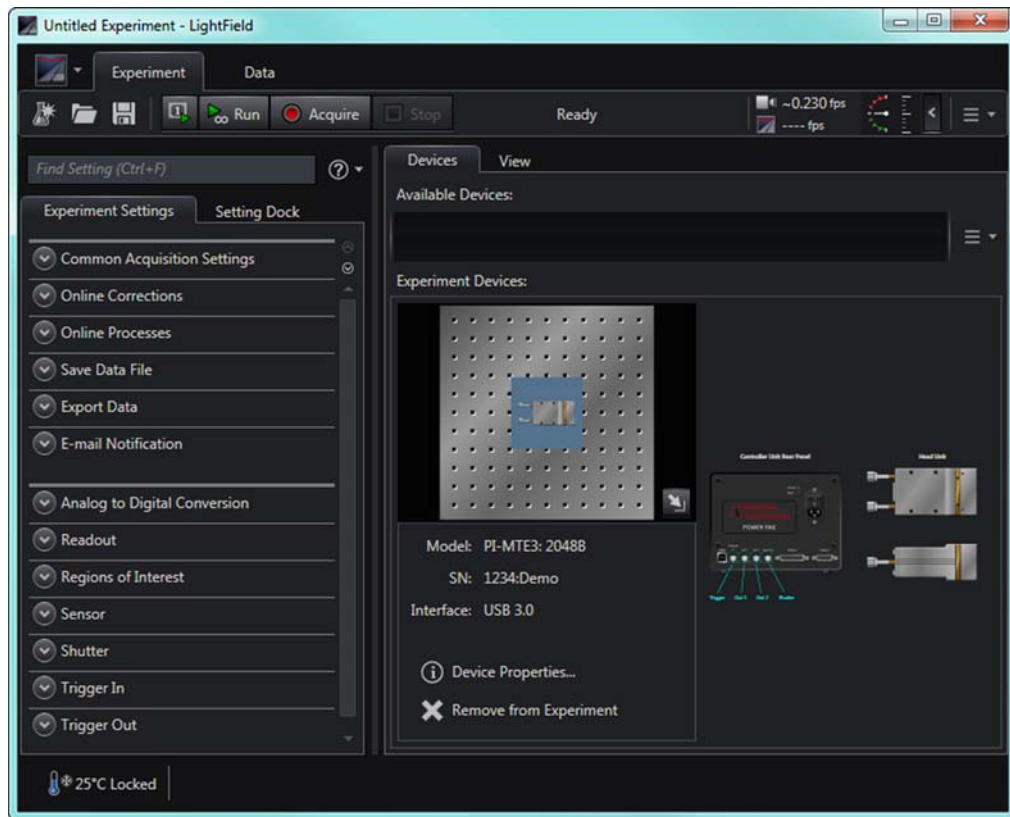
Figure 6-2: Available Devices Area



7. Drag the PI-MTE3 icon into the Experiment Devices area.

8. The Experiment Settings stack on the left includes several expanders. Since this is a new experiment, the default configuration settings for the camera are preconfigured. See [Figure 6-3](#).

Figure 6-3: Experiment Devices Area



4411-0162_0022

The Status bar across the bottom of the window includes an icon for temperature status. Temperature Status reports the current system temperature and whether the set temperature has been reached. Clicking on the icon opens the Sensor expander in which the desired temperature can be configured.



NOTE:

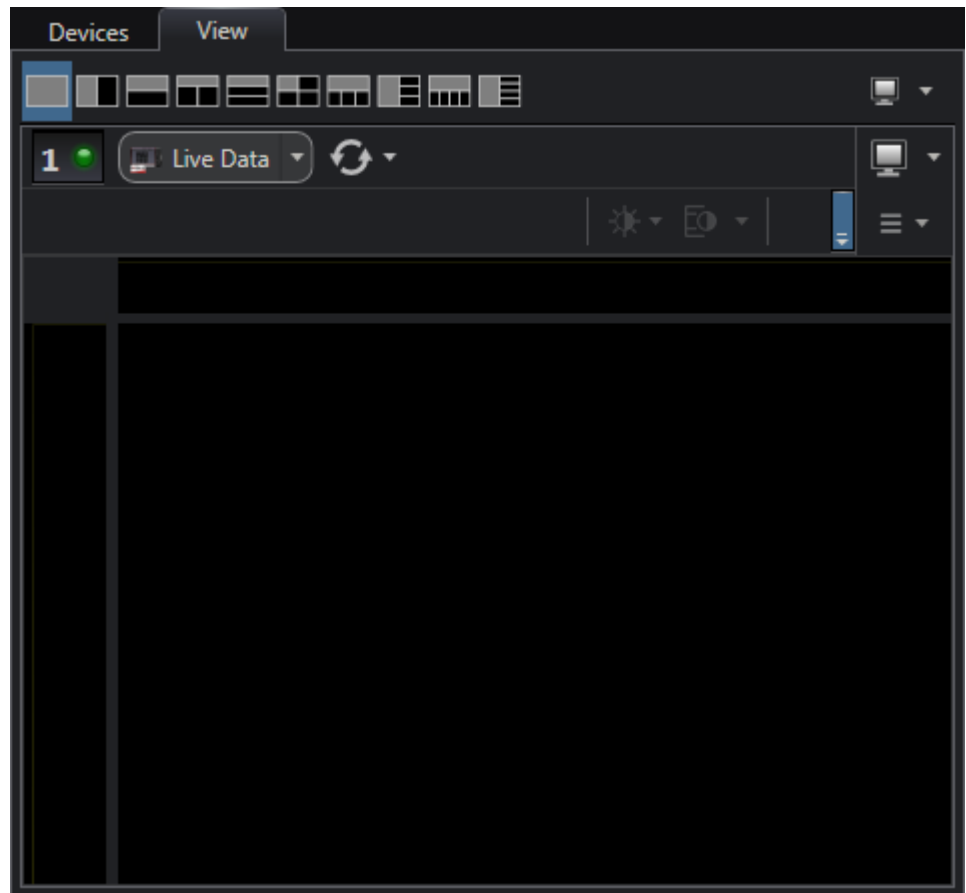
Each PI-MTE3 camera is carefully calibrated at the factory for optimum performance at low CCD temperatures. If operated at warmer temperatures, such as during system cool down or if the temperature set point is set warmer than the factory-calibrated temperature, the camera might not image properly. Artifacts in the image, fixed value pixels, or lack of imaging in one or more quadrants may occur.

6.1.1 Data Acquisition

Perform the following procedure to acquire live data:

1. Click on the View tab located above Available Devices to change focus to the View area. See [Figure 6-4](#).

Figure 6-4: View Area




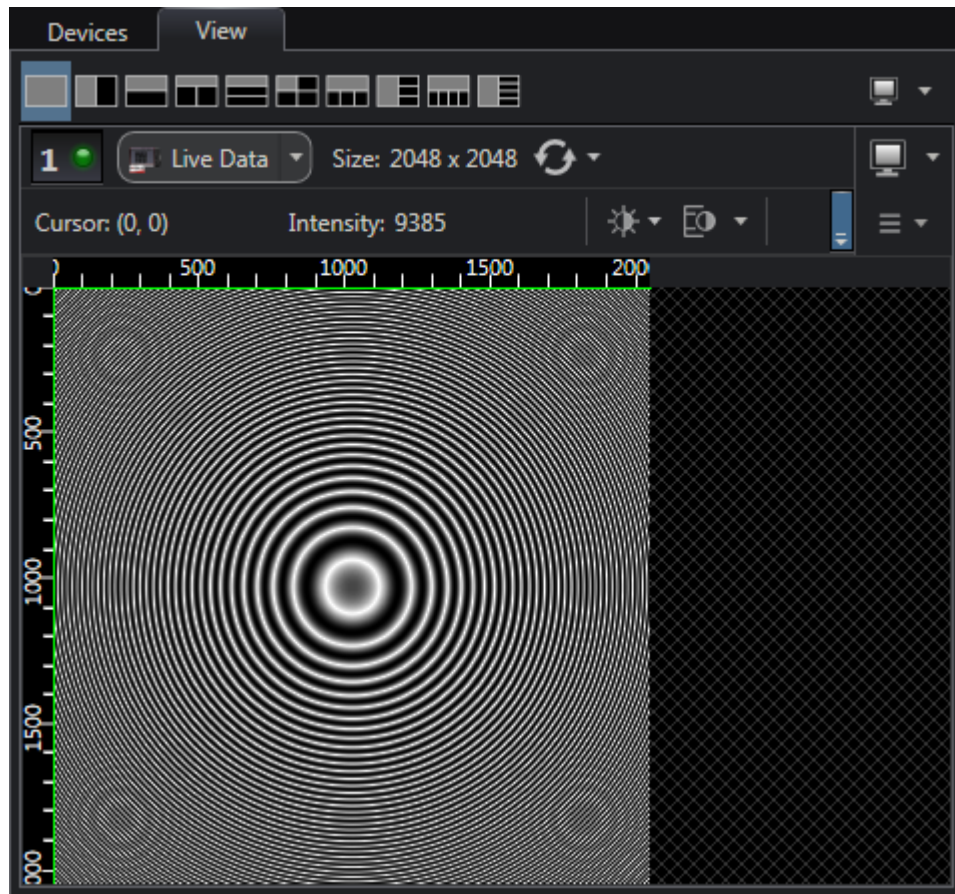
2. Click Run  to initiate Preview mode.
In this mode, images are continuously acquired and displayed. See [Figure 6-5](#).

Figure 6-5: View Area Displaying an Image



3. After the camera has been successfully focused, either:
 - Exit/stop Preview mode;
 - Continue Preview mode;
 - Begin Acquire mode.

6.2 System Shutdown

Perform the following procedure to shutdown the PI-MTE3 system:

1. Set the camera temperature to +25°C and allow the CCD to warm up.
2. Once the camera has warmed to +25°C, exit LightField.
3. Turn off the light source.
4. Turn off the camera power by moving the power supply switch from the 1 position to the 0 (ZERO) position.

Chapter 7: Acquired Image Quality

This chapter discusses factors that may affect the quality of the signal acquired on the CCD array, such as:

- Exposure Time;
- CCD Temperature;
- Dark Charge;
- Saturation.

7.1 Exposure Time

Exposure Time is the time during which the CCD gathers light. LightField starts to acquire data when Run or Acquire is clicked, and continues to acquire data until it Stop is clicked. As a result, the acquisition of multiple frames of data spanning multiple exposure times is possible.

When an external trigger response other than No Response is selected on the Trigger expander, the external trigger controls when the continuous cleaning of the CCD stops and when the accumulated signal is readout. Continuous cleaning prevents the buildup of Dark Current and unwanted signal prior to an x-ray pulse. At the end of the Exposure Time, the CCD is readout and cleaning starts again.

Because PI-MTE3 cameras are not equipped with an internal shutter, some signal may accumulate on the CCD array while data are being readout. This continuous exposure of the array during readout may result in some image smearing. However, exposures that are significantly longer than the Readout Time can be achieved without a shutter because the level of smearing will be low.

If smearing or other factors require a shutter, the SHUTTER signal on the MTE-3 Controller's SHUTTER output can be used to control a customer-provided external x-ray shutter. By using one of these signals to synchronize the shutter operation with exposure, the CCD can be read out in darkness. Alternatively, the x-ray source can be interrupted elsewhere in the system while readout is taking place.

7.2 CCD Temperature

Lowering the temperature of the CCD will generally enhance the quality of the acquired signal. Temperature control is done on the Sensor expander.

Once a Temperature Setpoint has been programmed on the Sensor Expander, the software controls the camera's cooling circuits to reach the programmed array temperature.

When the camera's temperature has cooled to within $\pm 0.5^\circ\text{C}$ of the programmed setpoint, Locked is displayed to the right of the target temperature in LightField's status bar. At this point, PI-MTE3's control loop will continue to reduce the thermal error, typically holding the temperature to within $\pm 0.05^\circ\text{C}$ of the programmed setpoint.

The time required to achieve lock may vary considerably depending on factors such as the camera type, CCD array type, ambient temperature, etc. Ultimate system stability is achieved approximately 20 minutes after thermal loop locks. However, as long as PI-MTE3's CCD has cooled sufficiently to image, focusing of the system can begin. Typically, quantitative data may be acquired as soon as thermal lock is relatively stable. If, however, an experiment requires exposure times in the 10 to 30 minutes range or more, it is recommended that PI-MTE3 be permitted to cool for a longer period of time before acquiring live data.

**NOTE:**

It will be obvious if PI-MTE3 has not yet cooled sufficiently by the presence of high dark current. Simply wait for the camera to cool before beginning to focus the system.

The deepest operating temperature for a system depends on the CCD array. Refer to [Table A-3, Default Operating Temperature](#), on page 108 for typical deepest cooling temperatures.

7.3 Dark Charge

Dark charge (or dark current) is the thermally induced buildup of charge in the CCD over time. The statistical noise associated with this charge is known as dark charge noise. Dark charge values vary widely from one CCD array to another and are exponentially temperature dependent. In the case of cameras with 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. Dark charge effect is more pronounced in the case of cameras having a non-MPP array (such as deep-depletion devices.)

With the light into the camera completely blocked, the CCD will collect a dark charge pattern, dependent on the exposure time and CCD temperature. The longer the exposure time and the warmer the camera, the larger and less uniform this background will appear. Thus, to minimize dark-charge effects, you should operate with the lowest CCD temperature possible.

**CAUTION!**

If a sudden change in the baseline signal is observed, there may be excessive humidity in the camera vacuum enclosure. Turn off the camera and contact Teledyne Princeton Instruments Customer Support. Refer to [Contact Information](#) on page 126 for complete contact information.

Do not be concerned about the DC level of this background. This is not noise but rather a subtractable bias pattern. By acquiring/saving a dark charge background image under conditions identical to those that will be used to acquire live data, this background image can then be subtracted from the acquired image, thus reducing dark-charge effects.

Although the dark charge pattern will be subtracted from the acquired image, both the dark charge pattern and the acquired image include system readout noise, N_R , which is additive. Therefore, when acquiring a dark charge pattern, it is strongly recommended that multiple frames of dark data be acquired and averaged since the cumulative noise within the dark background is reduced by the square root of the number of frames that have been averaged. The cumulative readout noise, which is the sum of the acquired image readout noise plus the dark data readout noise, is calculated as follows:

$$N_{RT} = \sqrt{N_R^2 + \frac{N_R^2}{F}}$$

where:

- N_{RT} = Total Readout Noise;
- N_R = Readout Noise;
- F = Number of Dark Pattern Frames Acquired.

For example, when acquiring one frame of dark data to generate the subtractable pattern, the dark pattern readout noise will be $\sim 1.414\sqrt{N_R}$, which is an increase of $\sim 41\%$ over the baseline readout noise. This value is calculated as follows:

$$\begin{aligned} V_{RT} &= \sqrt{N_R^2 + \frac{N_R^2}{F}} \\ &= \sqrt{N_R^2 + \frac{N_R^2}{1}} \\ &= \sqrt{N_R^2 + \frac{N_R^2}{1}} \\ &= \sqrt{2N_R^2} \\ &= 1.414N_R \end{aligned}$$

Refer to [Table 7-1](#) for typical noise penalty figures as a percentage of readout noise, N_R .

Table 7-1: Readout Noise Penalty vs Number of Acquired Frames

Number of Acquired Frames (F)	Noise Penalty ^a
1	41%
4	12%
8	6%
16	3%

a. Expressed as a percentage of N_R

7.3.1 Clean Until Trigger

When using an external trigger to initiate data readout, PI-MTE3 supports Clean Until Trigger (CUT,) an additional level of cleaning/removing accumulated dark charge that continues until the moment the incoming trigger pulse is received.



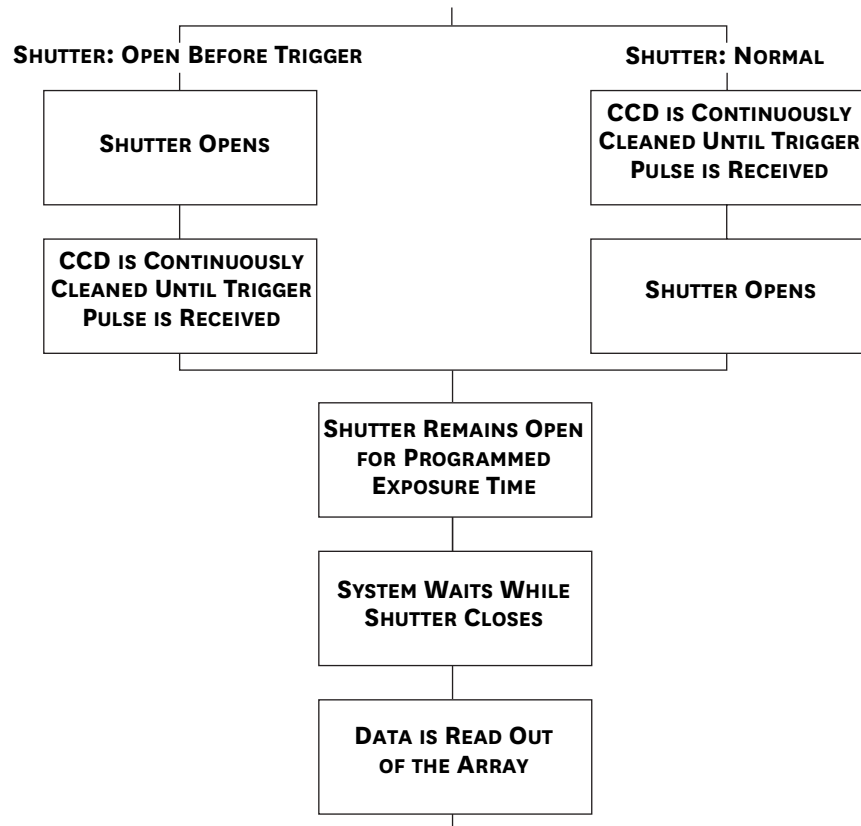
REFERENCES:

For information about the use and configuration of external triggers, refer to:

- [Section 9.2, Experiment Timing](#), on page 66, for Full Frame Mode;
- [Section 10.2, Experiment Timing](#), on page 83, for Kinetic Mode.

[Figure 7-1](#) illustrates a flowchart of this mode.

Figure 7-1: Flowchart: Clean Until Trigger

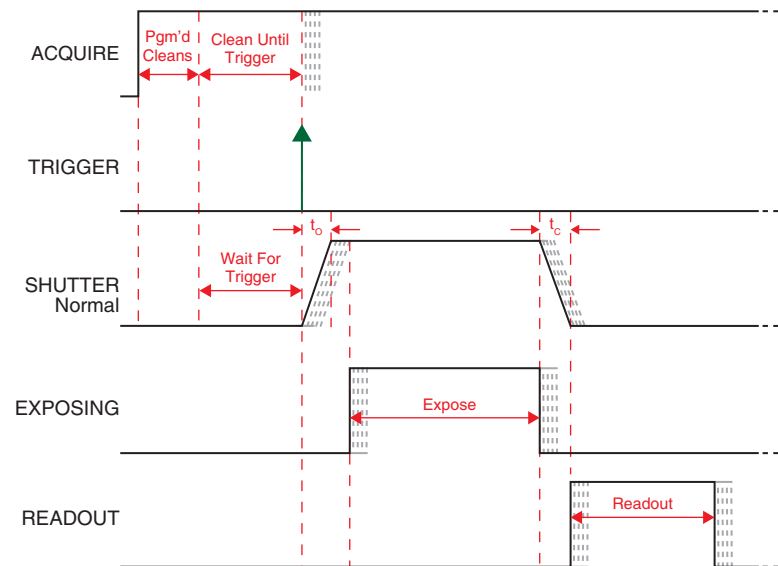


7.3.1.1 Normal Shutter Mode

When an incoming Trigger pulse has been received, cleaning of the array stops as soon as the current cleaning pattern has been completed and shifted. Because the incoming trigger is not synchronous with the cleaning cycle, there is an inherent jitter of up to one cleaning cycle in the system's response to an incoming trigger. After this, the shutter remains open for the programmed exposure time, and frame collection can begin.

Figure 7-2 illustrates the timing diagram for Clean Until Trigger, Normal shutter mode. In this figure, system jitter is shown as light gray dashed lines.

Figure 7-2: Timing Diagram: Clean Until Trigger, Normal Shutter Mode

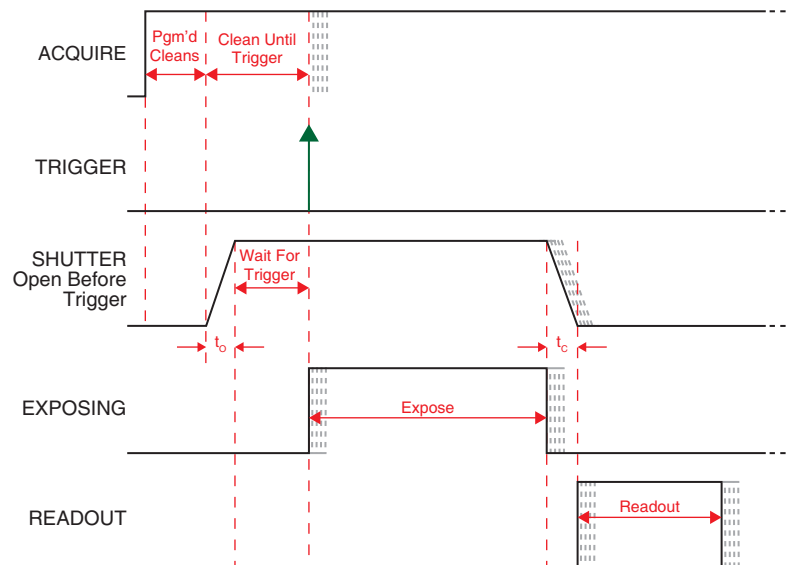


7.3.1.2 Open Before Trigger Mode

With Open Before Trigger shutter mode, the shutter is opened at the beginning of Clean Until Trigger. As with Normal mode, once the incoming Trigger pulse has been received, cleaning of the array stops as soon as the current cleaning pattern has been completed and shifted. Because the incoming trigger is not synchronous with the cleaning cycle, there is an inherent jitter of up to one cleaning cycle in the system's response to an incoming trigger. After this, the shutter remains open for the programmed exposure time, and frame collection can begin.

Figure 7-3 illustrates the timing diagram for Clean Until Trigger, Open Before Trigger shutter mode. In this figure, system jitter is shown as light gray dashed lines.

Figure 7-3: Timing Diagram: Clean Until Trigger, Open Before Trigger



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If the vertical rows are shifted midway when the Trigger pulse arrives, the pulse is saved until the row shifting is completed, to prevent the CCD from getting out of step. As expected, the response latency is on the order of one vertical shift time, from 1-30 μ s depending on the array. This latency does not prevent the incoming signal from being detected, since photo generated electrons are still collected over the entire active area. However, if the signal arrival is coincident with the vertical shifting, image smearing of up to one pixel is possible. The amount of smearing is a function of the signal duration compared to the single vertical shift time.

7.4 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. In this case a shorter exposure is advisable, with signal averaging to enhance S/N (Signal-to-Noise ratio) accomplished through the software.

For signal levels low enough to be readout-noise limited, longer exposure times, and therefore longer signal accumulation in the CCD, will improve the S/N ratio approximately linearly with the length of exposure time. However, due to cosmic ray strikes, the maximum practical exposure time is in the range of 15 to 30 minutes. Be aware that some deep depletion CCDs have a higher dark charge rate and may also be dark current limited.

Chapter 8: Analog to Digital Conversion

After the programmed exposure time has elapsed, accumulated charge stored in the CCD array must be:

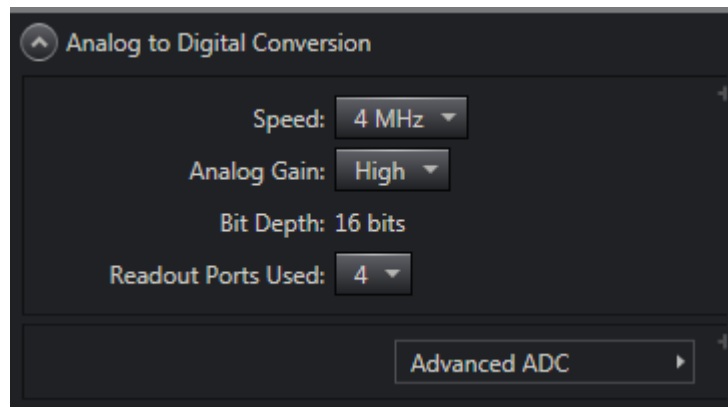
- Read out;
- Converted to a digital format;
- Transferred to the application software where it can be displayed and/or stored.

The number of ports used to read out data and other Analog-to Digital conversion factors are configured within LightField on the Analog to Digital Conversion expander using the following parameters:

- Readout Ports Used;
- Analog Gain;
- Speed.

See [Figure 8-1](#).

Figure 8-1: Typical Analog to Digital Conversion Expander

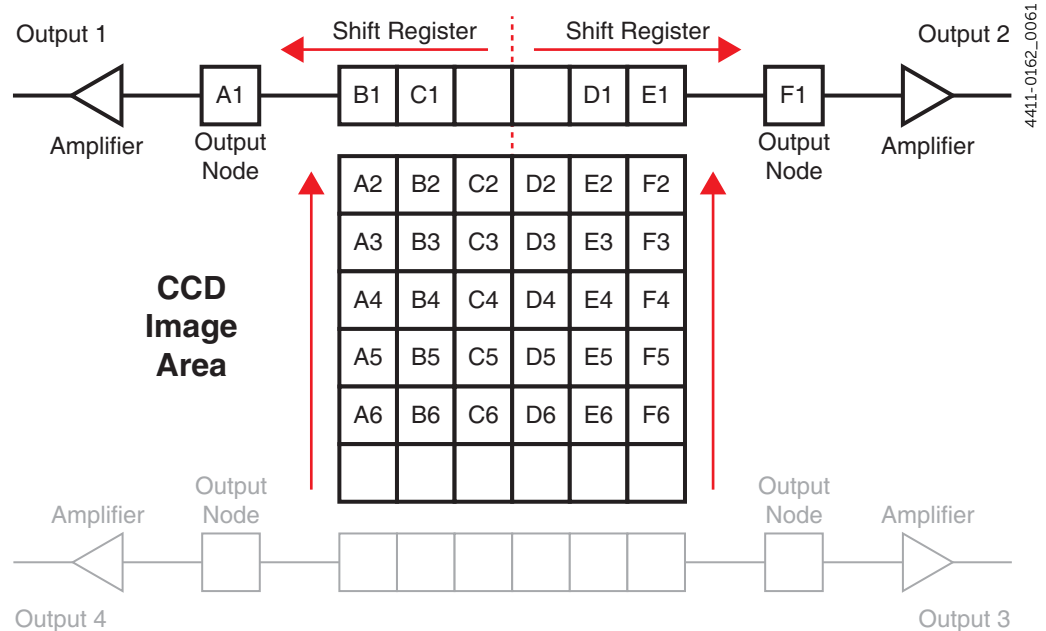


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The following sections describe the impact each of these parameters has on acquired image data.

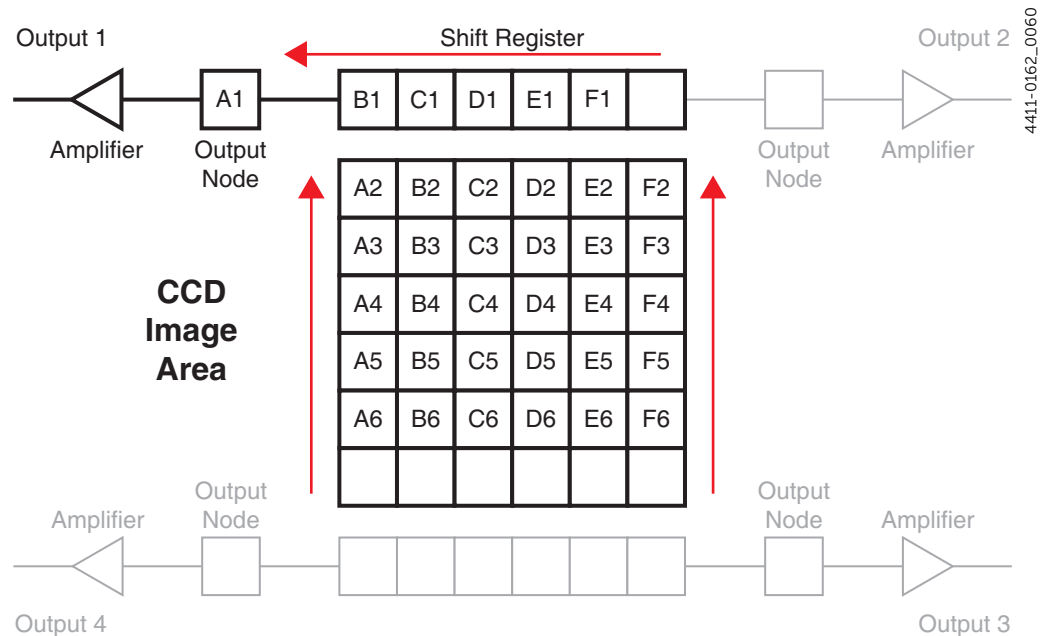
- 2 amplifiers/output ports;
Figure 8-3 illustrates the charge being shifted and read out using two PI-MTE3 output ports.

Figure 8-3: Data Readout Using Two Output Ports



- 1 amplifier/output port.
Figure 8-4 illustrates the charge being shifted and read out using one PI-MTE3 output port.

Figure 8-4: Data Readout Using One Output Port



Charge that has been stored in Shift Register pixels is shifted into the appropriate Output Node(s) and finally to the Output Amplifier where electrons are grouped as electrons/count.

8.1.1 Output Amplifier

Each Output Amplifier that has been configured for use amplifies the collected charge from the output node and transfers it to the ADC. The amount of Gain that is applied by each Output Amplifier is user configurable. Refer to [Section 8.3, Analog Gain](#), on page 60 for additional information.

8.2 Digitization

After gain has been applied to the signal, the Analog-to-Digital Converter (ADC) converts analog information (continuous amplitudes) into digital data (quantified, discrete steps,) that can be read, displayed, and stored by the application software.

**NOTE:**

The number of bits per pixel is 16.

Factors associated with digitization include:

- Speed
This is software configurable within LightField, and specifies the rate at which data are digitized.
- Baseline Offset.
This is not a user-configurable value; it is set at the factory at the time of manufacture.

These factors are discussed in the following paragraphs.

8.2.1 Speed

Because the readout noise for a CCD array increases with readout rate, it may be necessary at times to trade off readout speed for high dynamic range. PI-MTE3 provides users flexibility regarding how quickly the data are digitized by supporting three user-configurable digitization rates:

- 100 kHz;
This should be used when the reduction of readout noise is critical to an experiment's success.
- 1 MHz;
- 4 MHz.
Provides the fastest possible data collection.

Switching between digitization speed can be completely controlled by software for total experiment automation.

8.2.2 ADC Offset (Bias)

With the camera's light path completely blocked, the CCD accumulates a dark charge pattern, dependent on the exposure time and camera temperature. The longer the exposure time and the warmer the camera, the larger this background will appear. To minimize the amount of this signal that gets digitized, the baseline has been offset by adding a voltage to the signal to bring the A/D output to a non-zero value, typically 550-600 counts. This offset value ensures that all the true variation in the signal can really be seen and not lost below the A/D "0" value. Since the offset is added to the signal, these counts only minimally reduce the range of the signal from 65535 (16-bit A/D) to a value in the range of 500-600 counts lower.



WARNING!

If a sudden change in the baseline signal is observed, there may be excessive humidity in the camera vacuum enclosure. Turn off the camera and contact Teledyne Princeton Instruments Customer Support. Refer to [Contact Information](#) on page 126 for complete information.



NOTES:

1. It is important to note that the bias level is not noise. It is a fully subtractable readout pattern. Every device has been thoroughly tested to ensure its compliance with Teledyne Princeton Instruments' demanding specifications.
2. The ADC Offset is pre-set at the factory and is not user-changeable.

8.2.2.1 Correct Pixel Bias

By default, Pixel Bias Correction is ENABLED in LightField. Correct Pixel Bias automatically corrects any pixel bias drift that may be introduced.

This setting can be disabled by clicking  on the Analog to Digital Conversion expander, and deselecting the Correct Pixel Bias option.

8.3 Analog Gain

Controller gain, a configurable function of the preamplifier, changes the relationship between the number of electrons acquired on the CCD and the Analog-to-Digital Units (ADUs) generated. The level of gain is configured by the Analog Gain parameter on the Analog to Digital Conversion expander.

Supported Analog Gain options are:

- **Low**
This gain setting is best suited for binning applications, particularly when high-level signals are being digitized. Although this setting may be used with non-binned modes, the CCD single pixel well typically will not reach ADC saturation when applying Low gain.
- **Medium**
This gain setting is typically selected for experiments within the mid-level intensity range.
- **High.**
Applications that consistently measure low-level signals should select this gain setting since it requires fewer electrons to generate each ADU. Additionally, this setting can reduce some sources of noise.

[Table 8-1](#) provides typical electron counts required to generate an ADU for each supported Analog Gain setting.



NOTE:

The Certificate of Performance included with PI-MTE3 specifies the measured gain values for various Analog Gain settings.

Actual electron counts required are also dependent upon the configured readout rate.

Table 8-1: Typical Electron Counts vs. Analog Gain Setting

Low	Medium	High
5 e ⁻ /count	1.7 e ⁻ /count	0.7 e ⁻ /count

8.3.1 Example

In this example, it is assumed the incoming light level is identical in all three instances. The electron counts listed in [Table 8-1](#) are used to illustrate the relative effects of changing controller gain settings and may not reflect actual performance. Achievable gain depends on the CCD being used as well as the readout rate that has been configured.

- **Low**
Requires 5 electrons to generate one ADU.
In low gain, non-binned operation, the CCD will usually saturate before the ADC. So on-scale CCD saturation effects may be seen in the image.
Strong signals can be acquired without over-ranging the ADC array. If the gain is set to Low and the images or spectra appear weak, selecting Medium or High may improve results.
- **Medium**
Requires 1.7 electrons to generate one ADU.
When analog gain is set to Medium and images or spectra do not appear to utilize the full dynamic range of the ADC array, it may be worthwhile changing the gain setting to High.
However, if the ADC appears to be saturated, changing the gain setting to Low is advised.
- **High**
Requires 0.7 electron to generate one ADU.
Some noise sources are reduced. Because fewer electrons are needed to generate an ADU, weaker signals can be more readily detected. Lower noise further enhances the ability to acquire weak signals.
If the ADC array appears to be saturated, changing the gain setting to Medium or Low is advised.

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Chapter 9: Full Frame Readout

When operating in Full Frame mode, PI-MTE3 reads and processes a complete frame of data at a time via 1, 2, or 4 output ports. Every pixel of information is digitized individually.



REFERENCES:

Refer to [Section 8.1, Readout Ports Used](#), on page 56 for complete information about selecting the number of ports used.



NOTE:

For simplicity, this chapter describes a PI-MTE3 system that has been configured to read out data using a single output port. Similar processes are employed when using 2 or 4 ports.

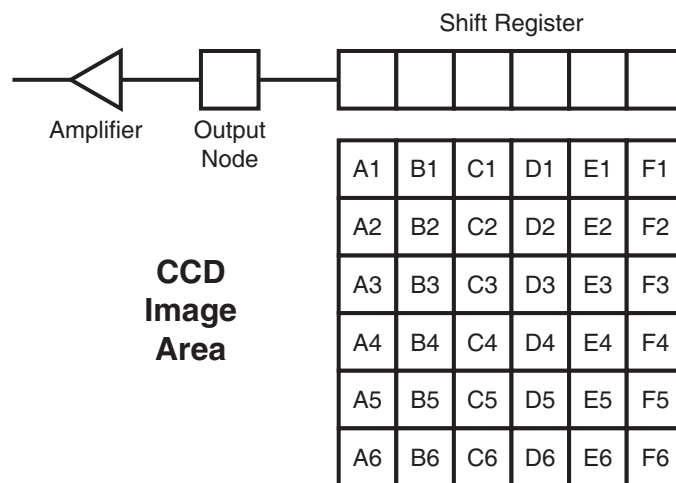
[Figure 9-1](#) illustrates a CCD array following exposure but prior to the beginning of readout.



NOTE:

Capital letters represent different amounts of accumulated charge, both desired signal and dark charge.

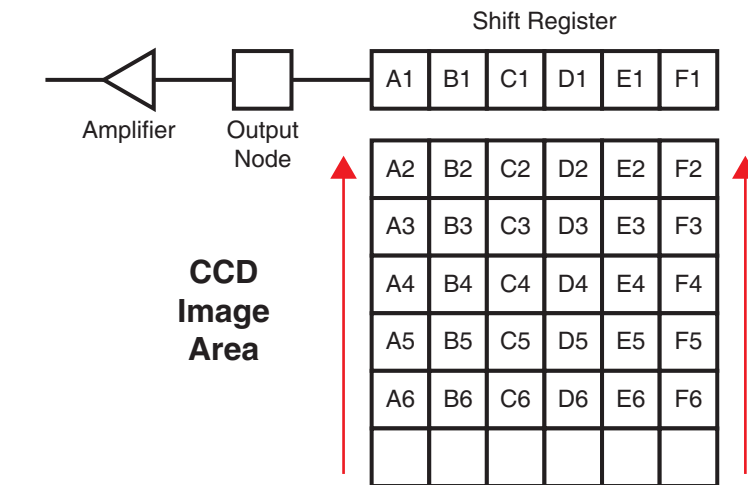
Figure 9-1: Full Frame Readout: Unshifted CCD Charge



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Readout of the CCD begins with the simultaneous shifting of all pixels one row toward the Shift Register which is a single row of pixels along the edge of the CCD. The Shift Register is not sensitive to light and is only used to store charge during readout. See [Figure 9-2](#).

Figure 9-2: Full Frame Readout: One Row of Charge Shifted into Shift Register



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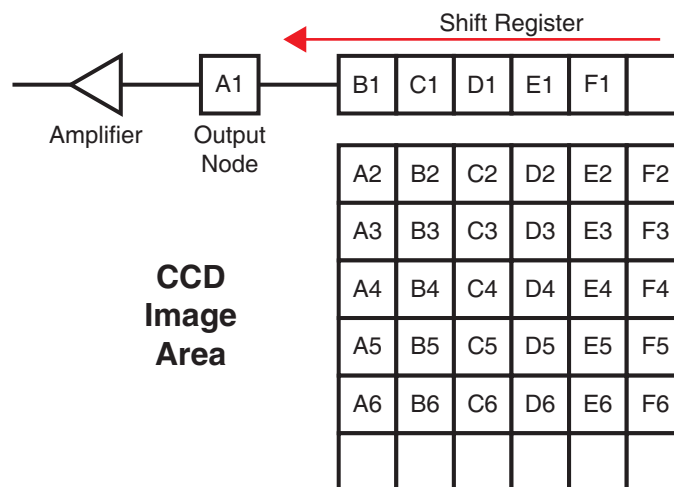


NOTE:

Typically, each pixel within the Shift Register can store up to twice as much charge as pixels within the CCD imaging area.

Once one row of charge has been shifted into the Shift Register, the charge is then shifted by one pixel toward the corresponding Output Node where it is then digitized. See [Figure 9-3](#).

Figure 9-3: Full Frame Readout: One Pixel of Charge Shifted to Output Node



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Once the charge within all of the Shift Register's pixels has been shifted out and digitized, the next row of charge is shifted vertically into the shift register where it is then shifted, pixel by pixel into the Output Node and digitized. This process continues until all accumulated charge in the CCD has been shifted out and digitized. The result is zero charge stored within each CCD pixel and the array is immediately ready for the next exposure.

9.1 Calculating Image Acquisition/Readout Time

The total time required to acquire and readout a full frame of data at full resolution is calculated as follows:

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

where:

- t_R is the CCD readout time;
Refer to [Section 9.1.1, CCD Readout Time](#), for additional information.
- t_{exp} is the exposure time;
This is a user-defined value, and is configured in LightField on the Common Acquisition Setting expander.
- t_c is the sum of the shutter opening and closing compensation times.

9.1.1 CCD Readout Time

LightField automatically calculates the readout time, including Region of Interest (ROI) operations and an approximation of overhead times.



NOTE:

When PI-MTE3 is configured for either 2- or 4-port readout, LightField accounts for very specific symmetry rules regarding ROI dimensions and placement.

CCD readout time is approximately calculated as follows:

$$(2) \quad t_R = (N_y \times t_i) + (N_y \times N_x \times t_{pix})$$

where:

- t_R is the readout time;
- N_y is the number of rows within the CCD;
When PI-MTE3 is configured for 4-port readout:
 $N_y = \frac{1}{2}$ [total number of CCD rows]
For example, if a CCD is 2048 rows high, $N_y = 1024$.
- N_x is the number of columns within the CCD;
When PI-MTE3 is configured for 2-port or 4-port readout:
 $N_x = \frac{1}{2}$ [total number of CCD columns]
For example, if a CCD is 2048 columns wide, $N_x = 1024$.

- t_i is the time needed to shift one line into the shift register.
- t_{pix} is the time needed to process one pixel.

**NOTE:**

Equation 2 above does not include certain overhead times. A more accurate calculation of CCD Readout Time is provided by LightField.

A subsection of the CCD 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.

9.2 Experiment Timing

For many experiments, the acquisition of quality/useful data is dependent on precise synchronization with external experiment events. Using the SYNC input on the rear of PI-MTE3, externally-generated trigger pulses can be used to control:

- Shutter operation;

**NOTE:**

The PI-MTE3 does not include an integrated shutter. All shutter actions illustrated in this section assume the use of an external shutter and shutter driver.

**REFERENCES:**

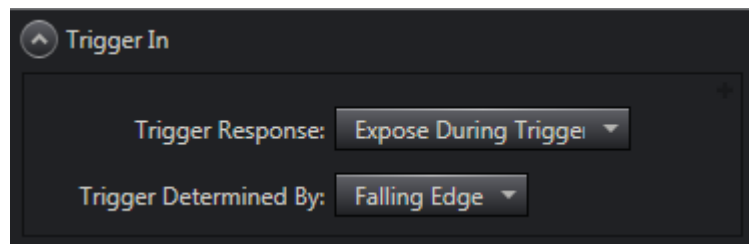
Refer to [Chapter 12, Shutter Configuration and Control](#), on page 105 for information about available shutter modes.

- Data readout.

This section describes how to configure PI-MTE3 to use incoming trigger pulses to precisely control experiment synchronization in Full Frame mode.

[Figure 9-4](#) illustrates a typical Trigger In expander.

Figure 9-4: Trigger In Expander



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Depending on the specific experiment, two parameters are used to configure PI-MTE3's response to an incoming trigger pulse:

- [Trigger Response](#);
- [Trigger Determined By](#).

Information about the configuration and use of each of these parameters is described in the following sections.

9.2.1 Trigger Response

The Trigger Response parameter defines how, upon receipt of an incoming trigger pulse, PI-MTE3 reads out data that have been acquired.

Supported Trigger Response modes are:

- [No Response](#);
- [Start on Single Trigger](#);
- [Readout Per Trigger](#);
- [Expose During Trigger Pulse](#).

The following sections describe each of these options and how experiment synchronization is impacted. Within the following sections, the following symbols may be used:

- t_{exp} = exposure time;
- t_{O} = shutter opening delay;
- t_{C} = shutter closing delay;
- t_{R} = data readout time.

9.2.1.1 No Response

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

Supported Shutter modes are:

- [Normal](#);
- [Always Closed](#);
- [Always Open](#).

The following sections describe how each of these modes impacts experiment timing.



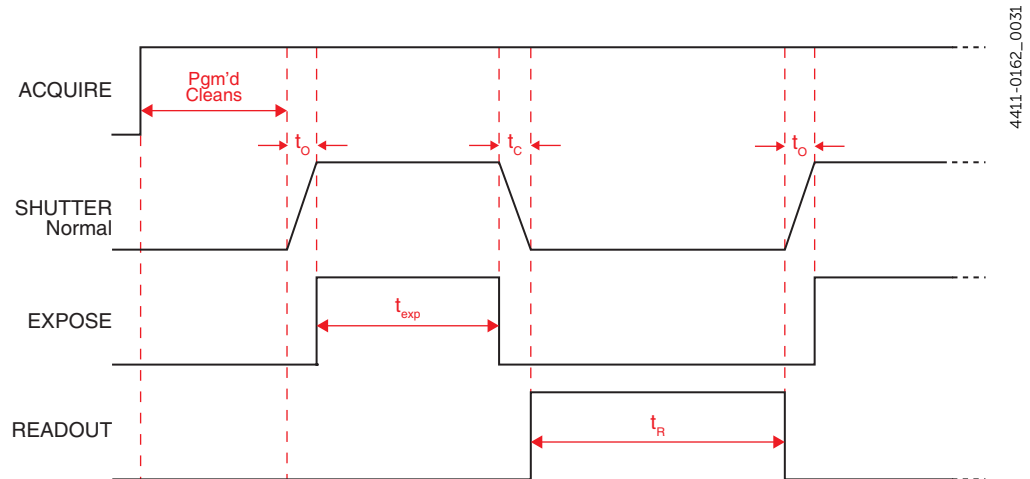
NOTE:

In all timing diagrams, Trigger Determined By Rising Edge is illustrated.

9.2.1.1.1 Normal

Figure 9-5 illustrates the timing diagram for No Response mode combined with Normal shutter mode.

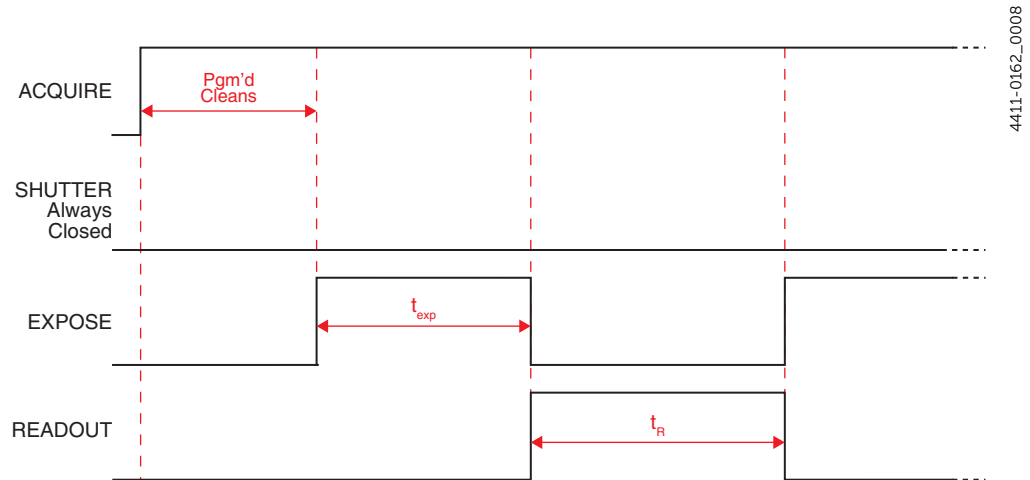
Figure 9-5: Full Frame Timing Diagram: No Response, Normal



9.2.1.1.2 Always Closed

Figure 9-6 illustrates the timing diagram for No Response mode combined with Always Closed shutter mode.

Figure 9-6: Full Frame Timing Diagram: No Response, Always Closed

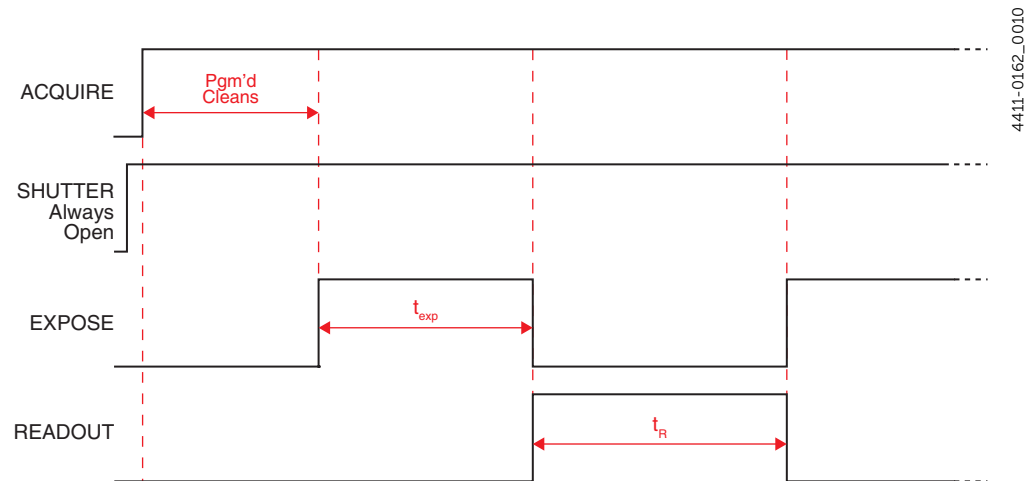


This mode is primarily used when acquiring a dark reference file. However, PI-MTE3 typically runs at such a low temperature that a dark reference file is often unnecessary.

9.2.1.1.3 Always Open

Figure 9-7 illustrates the timing diagram for No Response mode combined with Always Open shutter mode.

Figure 9-7: Full Frame Timing Diagram: No Response, Always Open



This mode is typically used when an experiment does not support waiting for the shutter to open. Ideally, the only light generated by the experiment is the signal of interest (e.g., a dark chamber with a spark discharge.)

9.2.1.2 Start on Single Trigger

Begins the experiment when the trigger is received and the system executes all programmed events.

Supported Shutter modes are:

- Normal;
- Always Closed;
- Always Open;
- Open Before Trigger.

The following sections describe how each of these modes impacts experiment timing.



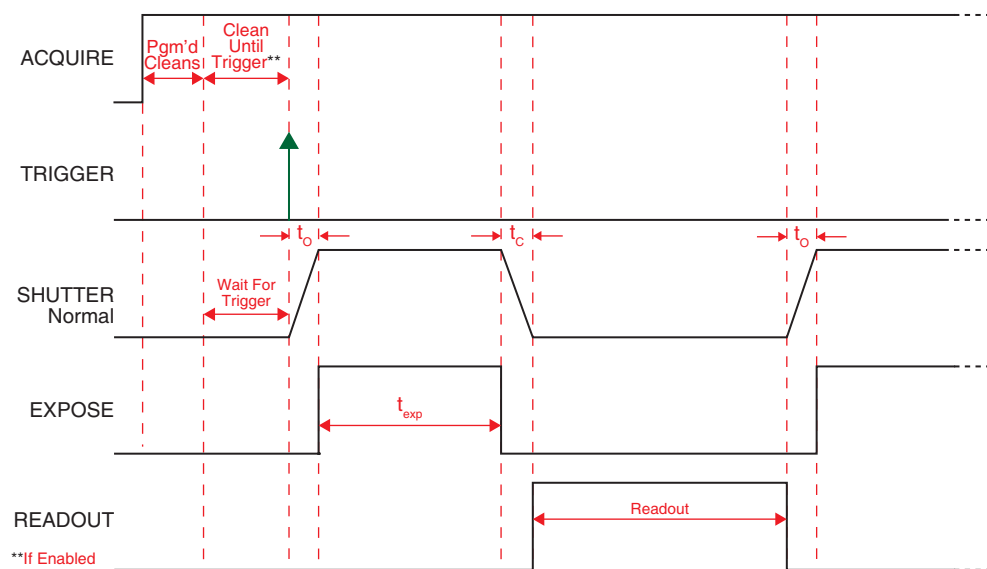
NOTES:

1. When Clean Until Trigger is enabled, an inherent jitter is introduced into the system Refer to [Section 7.3.1, Clean Until Trigger](#), on page 52 for additional information.
2. In all timing diagrams, Trigger Determined By Rising Edge is illustrated.

9.2.1.2.1 Normal

[Figure 9-8](#) illustrates the timing diagram for Start on Single Trigger mode combined with Normal shutter mode.

Figure 9-8: Full Frame Timing Diagram: Start on Single Trigger, Normal

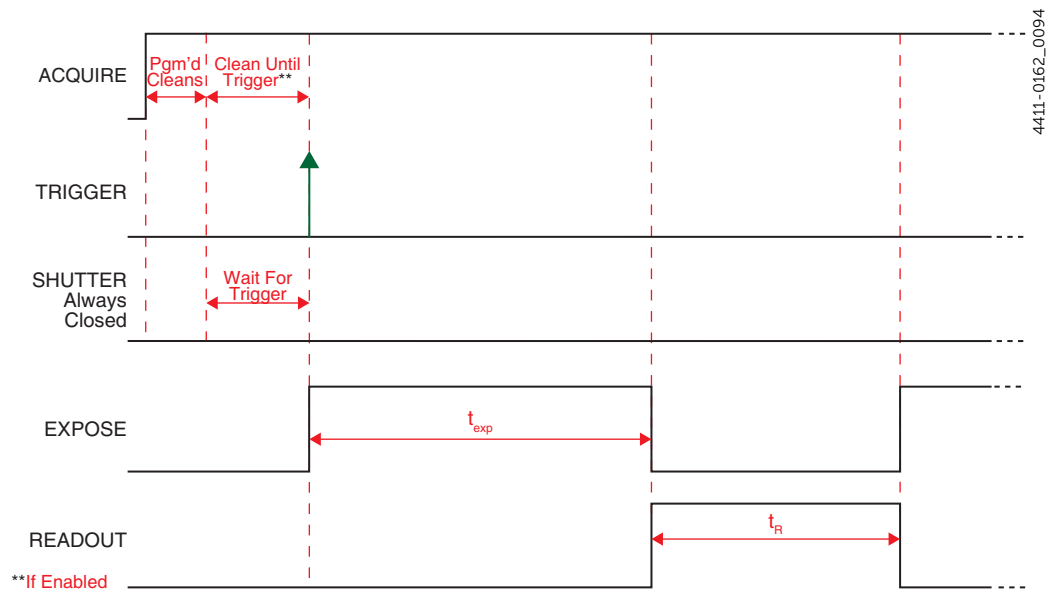


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9.2.1.2.2 Always Closed

Figure 9-9 illustrates the timing diagram for Start on Single Trigger mode combined with Always Closed shutter mode.

Figure 9-9: Full Frame Timing Diagram: Start on Single Trigger, Always Closed

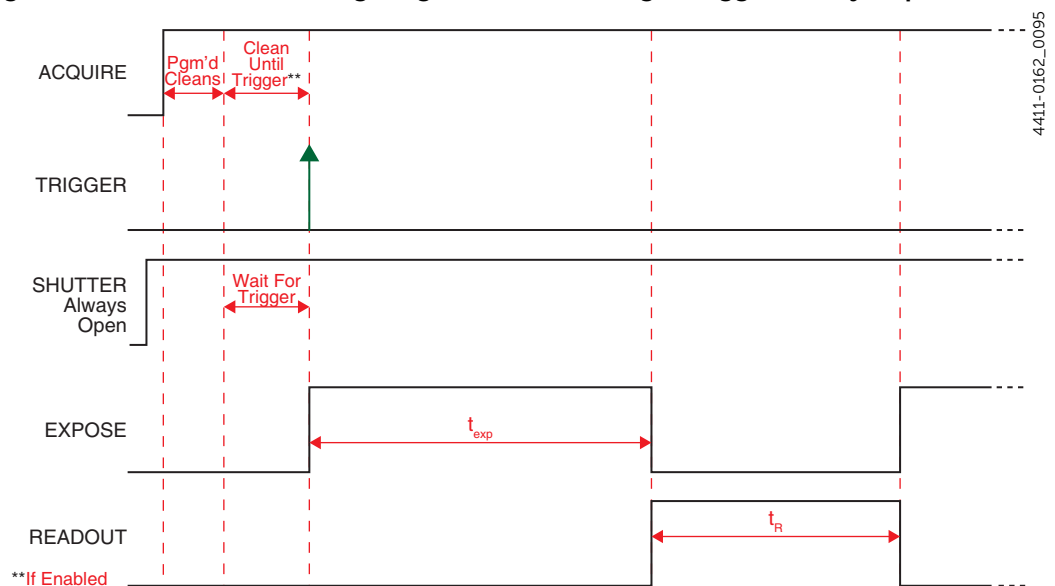


This mode is primarily used when acquiring a dark reference file. However, PI-MTE3 typically runs at such a low temperature that a dark reference file is often unnecessary.

9.2.1.2.3 Always Open

Figure 9-10 illustrates the timing diagram for Start on Single Trigger mode combined with Always Open shutter mode.

Figure 9-10: Full Frame Timing Diagram: Start on Single Trigger, Always Open

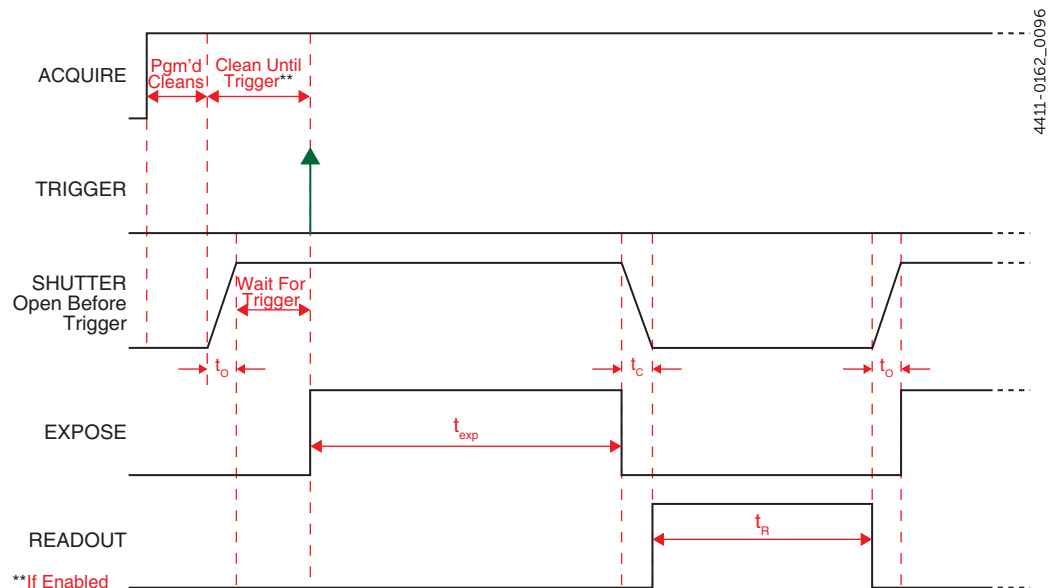


This mode is typically used when an experiment does not support waiting for the shutter to open. Ideally, the only light generated by the experiment is the signal of interest (e.g., a dark chamber with a spark discharge.)

9.2.1.2.4 Open Before Trigger

Figure 9-11 illustrates the timing diagram for Start On Single Trigger mode combined with Open Before Trigger shutter mode.

Figure 9-11: Full Frame Timing Diagram: Start on Single Trigger, Open Before Trigger



9.2.1.3 Readout Per Trigger

With Readout Per Trigger, all exposures are synchronized with an incoming trigger pulse. Synchronization occurs on either the Rising Edge or Falling Edge of the trigger pulse which is configured using the Trigger Determined By parameter on the Trigger In expander. Refer to [Section 9.2.2, Trigger Determined By](#), on page 79 for complete information.

Supported Shutter modes are:

- [Normal](#);
- [Always Closed](#);
- [Always Open](#);
- [Open Before Trigger](#).

The effect each of these shutter modes has on experiment synchronization is described in the following sections.



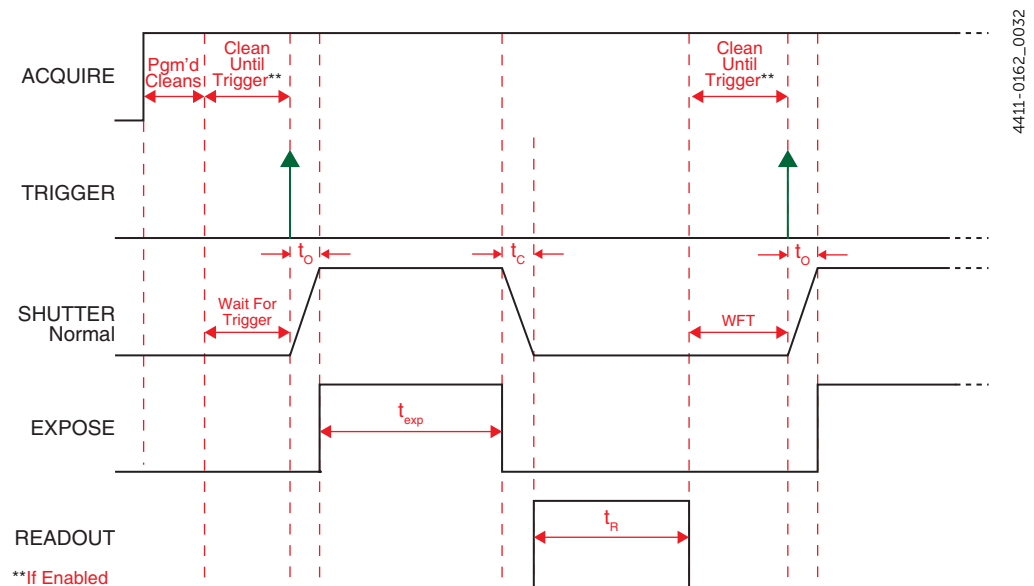
NOTES:

1. When Clean Until Trigger is enabled, an inherent jitter is introduced into the system Refer to [Section 7.3.1, Clean Until Trigger](#), on page 52 for additional information.
2. In all timing diagrams, Trigger Determined By Rising Edge is illustrated.

9.2.1.3.1 Normal

Figure 9-12 illustrates the timing diagram for Readout Per Trigger mode combined with Normal shutter mode.

Figure 9-12: Full Frame Timing Diagram: Readout Per Trigger, Normal



4411-0162_0032

When a trigger pulse has been received, PI-MTE3 opens the active shutter for the programmed exposure time, t_{exp} .

Once the exposure is complete, the shutter is closed, and the CCD array is read out.

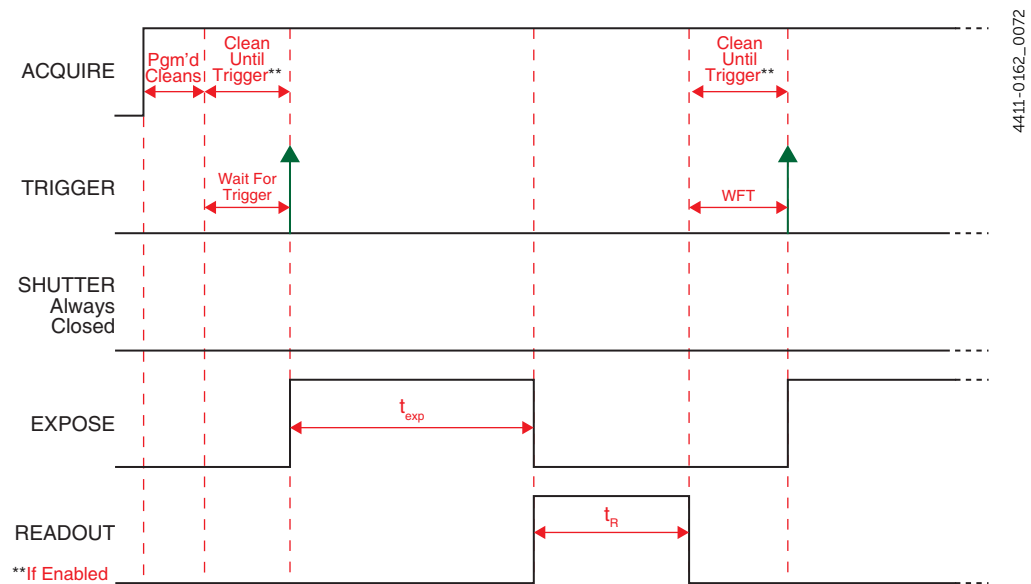
Because a shutter requires a finite length of time to fully open, the trigger pulse from the experiment must precede the start of data acquisition by at least this length of time. If it does not, the shutter may not be completely open throughout the duration of the desired data acquisition, and data acquisition may even be missed completely.

Since the amount of time from initialization of the experiment to the first trigger pulse is not fixed, an accurate background subtraction may also not be possible for the first readout. In multiple-shot experiments this is easily overcome by simply discarding the first frame.

9.2.1.3.2 Always Closed

Figure 9-13 illustrates the timing diagram for Readout Per Trigger mode combined with Always Closed shutter mode.

Figure 9-13: Full Frame Timing Diagram: Readout Per Trigger, Always Closed



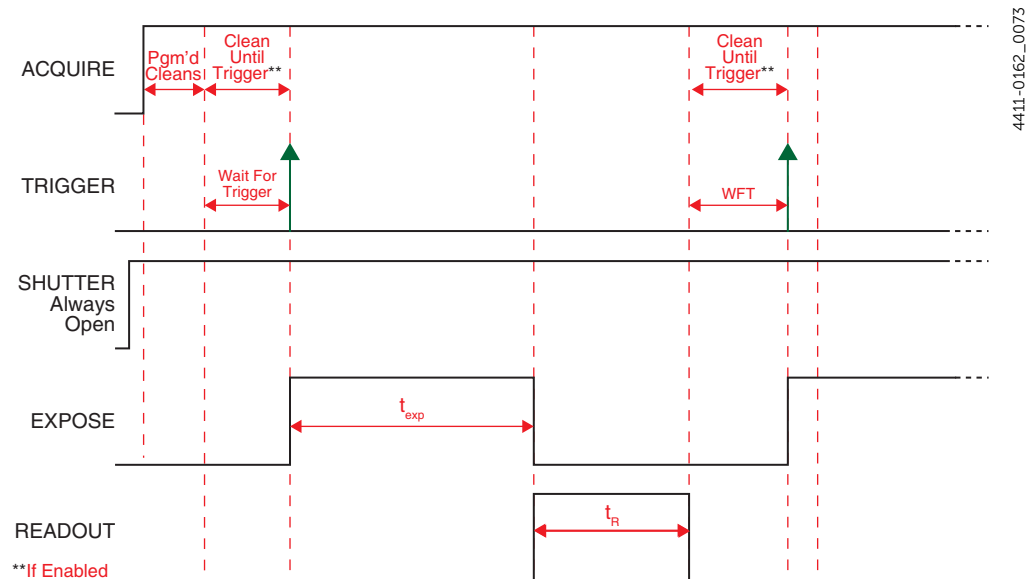
4411-0162_0072

This mode is primarily used when acquiring a dark reference file. However, PI-MTE3 typically runs at such a low temperature that the dark reference file is typically unnecessary.

9.2.1.3.3 Always Open

Figure 9-14 illustrates the timing diagram for Readout Per Trigger mode combined with Always Open shutter mode.

Figure 9-14: Full Frame Timing Diagram: Readout Per Trigger, Always Open



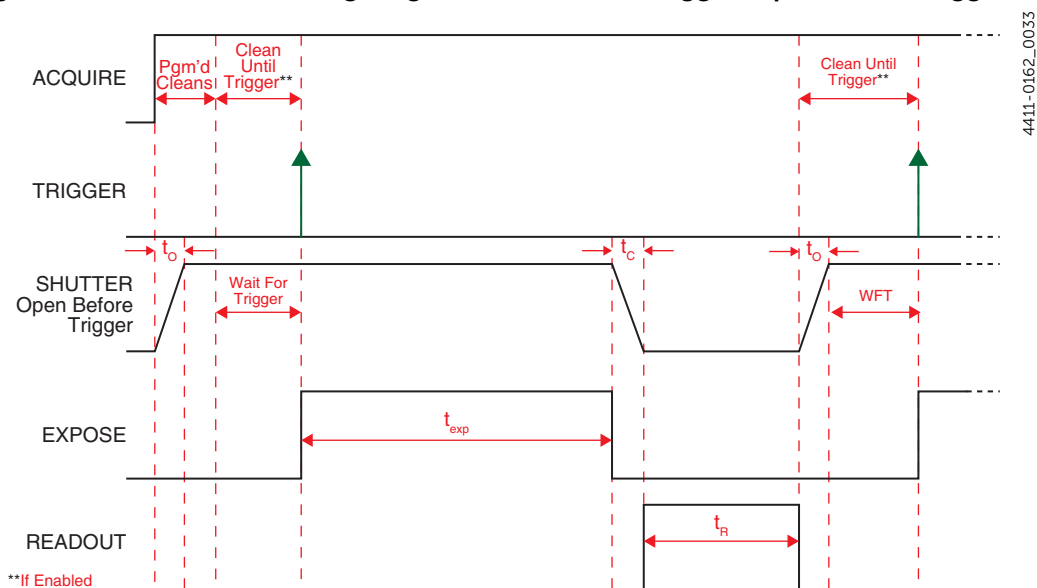
4411-0162_0073

This mode is typically used when an experiment does not support waiting for the shutter to open. Ideally, the only light generated by the experiment is the signal of interest (e.g., a dark chamber with a spark discharge.) [Open Before Trigger](#) is closely related.

9.2.1.3.4 Open Before Trigger

Figure 9-15 illustrates the timing diagram for Readout Per Trigger mode combined with Open Before Trigger shutter mode.

Figure 9-15: Full Frame Timing Diagram: Readout Per Trigger, Open Before Trigger



When Open Before Trigger is selected, the active shutter is partially synchronized with the experiment.

Upon arrival of the first trigger pulse at the SYNC connector, the shutter:

- Remains open for the configured exposure period;
- Closes;
- The CCD is read out.

Once data readout is complete, the active shutter reopens and waits for the next frame.

Open Before Trigger is most useful when the time between the trigger pulse and the desired incoming signal is not sufficiently long enough to allow the active shutter to completely open.

Unfortunately, this mode exposes the CCD to ambient light while the shutter is open between frames. If the ambient light is constant, triggers occur at regular intervals, and continuous cleaning is enabled, then, depending on the specific cleaning pattern used, most of the average background light can be removed, except for noise attributed to jitter (refer to [Section 7.3.1, Clean Until Trigger](#), on page 52.) If a short cleaning pattern is used, not all ambient light will be removed since only a portion of the CCD will be cleaned on each pattern, and the result is a blurry residual.

Additionally, shot noise of the background cannot be subtracted which may be significant. Consider applications using High gain (i.e., $1e^-/ADU$), and ambient equals 10% of full scale (i.e., $6500 e^-$.) The shot noise is then approximately 80 ADU, which is significantly greater than the camera's read noise.

As with Normal shutter mode, accurate background subtraction may not be possible for the first frame.

In addition to signal from ambient light, dark charge accumulates during the wait time. Any variation in the external sync frequency also affects the amount of dark charge, even if light is not falling on the CCD during this time.

9.2.1.4 Expose During Trigger Pulse

Controls when exposure begins and ends.

Supported Shutter modes are:

- Normal;
- Always Closed;
- Always Open;
- Open Before Trigger.

The effect each of these shutter modes has on experiment synchronization is described in the following sections. In all timing diagrams, Trigger Determined By Rising Edge is illustrated.



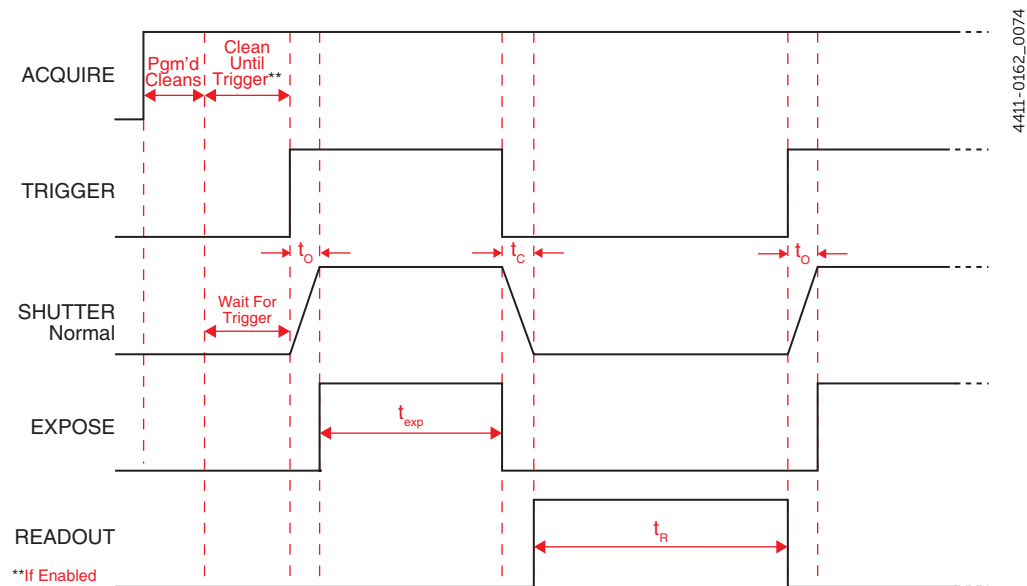
NOTES:

1. When Clean Until Trigger is enabled, an inherent jitter is introduced into the system Refer to [Section 7.3.1, Clean Until Trigger](#), on page 52 for additional information.
2. In all timing diagrams, Trigger Determined By Rising Edge is illustrated.

9.2.1.4.1 Normal

[Figure 9-16](#) illustrates the timing diagram for Expose During Trigger mode combined with Normal shutter mode.

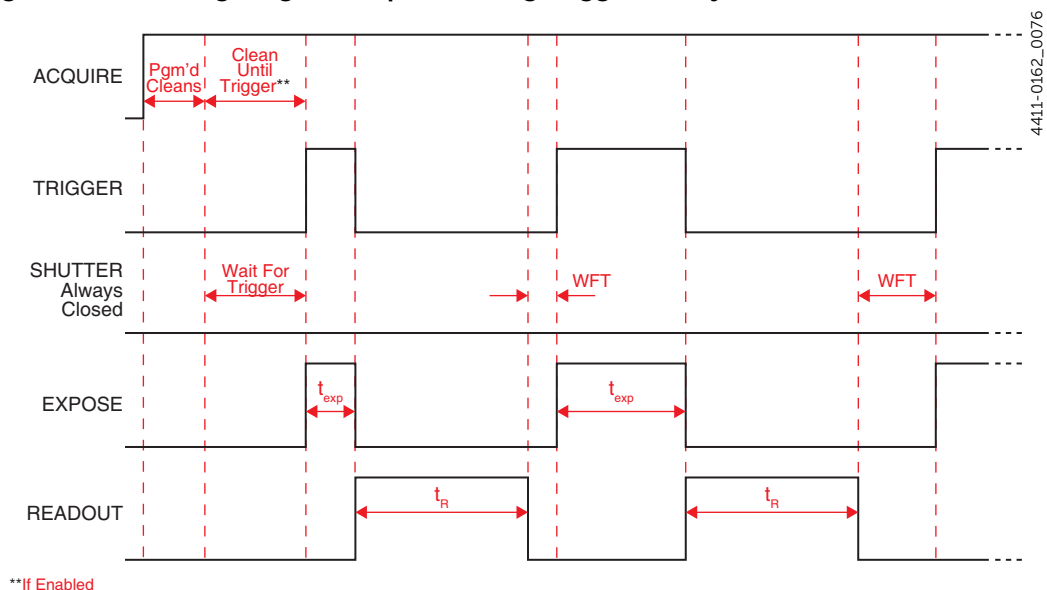
Figure 9-16: Full Frame Timing Diagram: Expose During Trigger, Normal



9.2.1.4.2 Always Closed

Figure 9-17 illustrates the timing diagram for Expose During Trigger Pulse mode combined with Always Closed shutter mode.

Figure 9-17: Timing Diagram: Expose During Trigger, Always Closed

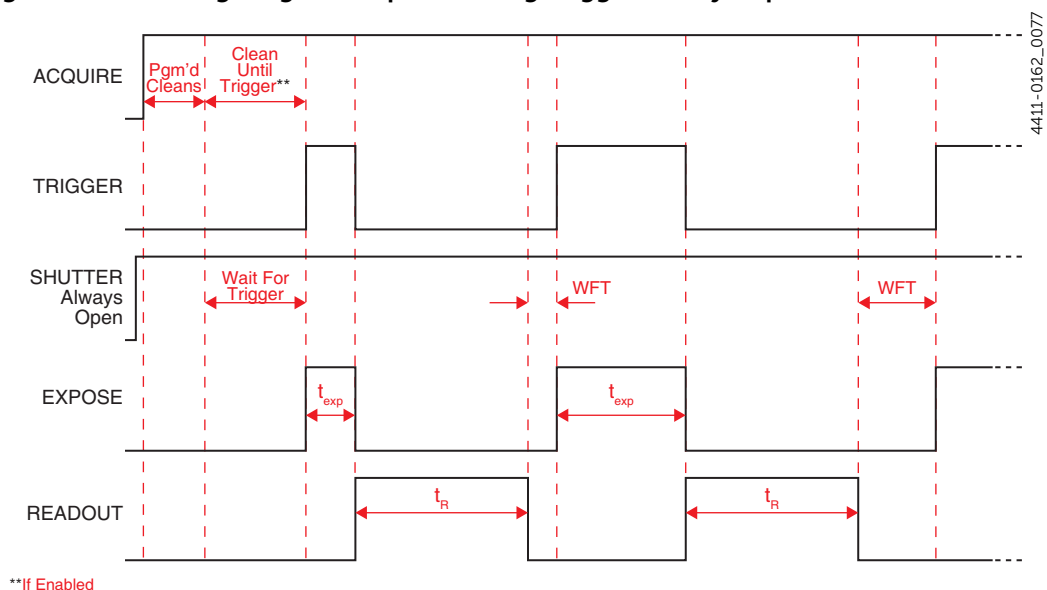


This mode is primarily used when acquiring a dark reference file.

9.2.1.4.3 Always Open

Figure 9-18 illustrates the timing diagram for Expose During Trigger Pulse mode combined with Always Open shutter mode.

Figure 9-18: Timing Diagram: Expose During Trigger, Always Open

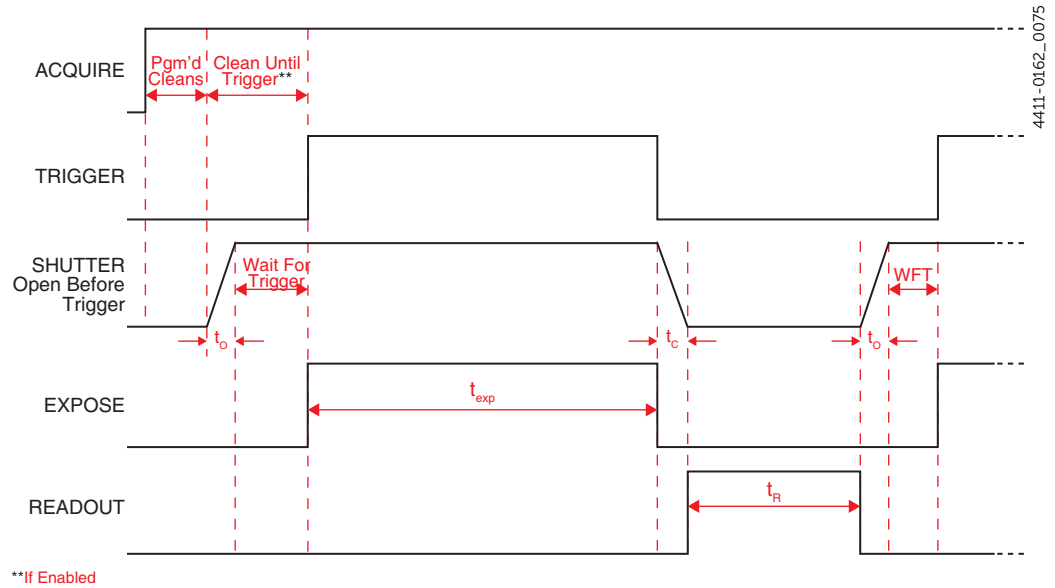


This mode is typically used when an experiment does not support waiting for the shutter to open. Ideally, the only light generated by the experiment is the signal of interest (e.g., a dark chamber with a spark discharge.) [Open Before Trigger](#) is closely related.

9.2.1.4.4 Open Before Trigger

Figure 9-19 illustrates the timing diagram for Expose During Trigger Pulse mode combined with Open Before Trigger shutter mode.

Figure 9-19: Timing Diagram: Expose During Trigger, Open Before Trigger



9.2.2 Trigger Determined By

When using an external trigger to initiate a readout, PI-MTE3 can be configured to respond to:

- The rising edge of the incoming trigger pulse;
- The falling edge of the incoming trigger pulse.

The Trigger Determined By parameter configures this behavior. Valid values are:

- Rising Edge;

PI-MTE3 responds to the rising edge of incoming trigger pulses. Depending on the specific system configuration, one or more subsequent trigger pulses may be required (or ignored) by the system. Refer to [Section 9.2.1, Trigger Response](#), on page 67 for complete information about configuring incoming trigger responses.

When using [Expose During Trigger Pulse](#) mode:

- Exposure begins on the Rising Edge of each incoming trigger pulse;
- Exposure ends on the Falling Edge of the respective trigger pulse.

The timing diagrams in [Section 9.2.1.4, Expose During Trigger Pulse](#), on page 76 illustrate this.



NOTE:

If PI-MTE3 is busy when a subsequent trigger pulse is received, the trigger is ignored.

- Falling Edge

PI-MTE3 responds to the falling edge of incoming trigger pulses. Depending on the specific system configuration, one or more subsequent trigger pulses may be required (or ignored) by the system. Refer to [Section 9.2.1, Trigger Response](#), on page 67 for complete information about configuring incoming trigger responses.

When using [Expose During Trigger Pulse](#) mode:

- Exposure begins on the Falling Edge of each incoming trigger pulse;
- Exposure ends on the Rising Edge of the respective trigger pulse.



NOTE:

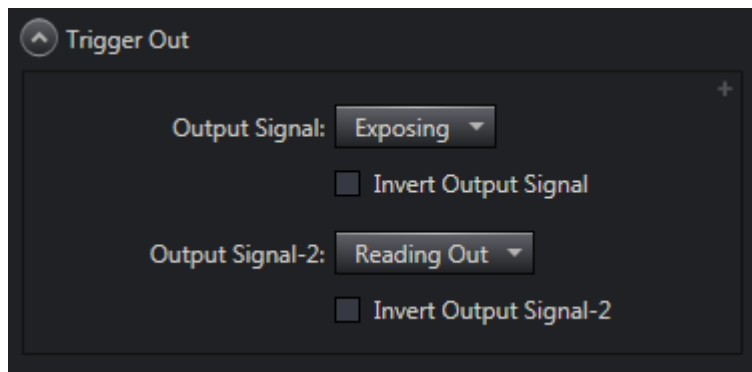
If PI-MTE3 is busy when a subsequent trigger pulse is received, the trigger is ignored.

9.3 Trigger Out

In addition to being able to synchronize PI-MTE3 with an experiment, additional equipment can be synchronized using the Trigger Out connector on the rear of PI-MTE3.

Two trigger out pulses are configured on the Trigger Out expander, shown in [Figure 9-20](#).

Figure 9-20: Typical Trigger Out Expander



4411-0162_0034

The following options are available for each of the two output signals:

- Acquiring;
The associated output signal is high when PI-MTE3 is acquiring or ready to receive the first trigger.
- Always High;
The associated output signal is always high.
- Exposing;
The associated output signal is high when the sensor is exposed as configured within LightField.
- Reading Out;
The associated output signal when data are being read out of the sensor.
- Shifting Under Mask;
This option is not currently supported by PI-MTE3 cameras.
When using Kinetics Readout (refer to [Chapter 10, Kinetics Readout](#), on page 81,) this output indicates when Kinetics shifts are occurring.
- Shutter Open;
The associated output signal is high when the shutter is open.
- Waiting for Trigger.
The associated output signal when PI-MTE3 is waiting for an incoming trigger.

Each of these options can also be inverted to create active low signals using the Invert Output Signal option.

Chapter 10: Kinetics Readout

Kinetics mode uses the CCD to expose and store a limited number of images in rapid succession. The time it takes to shift each line (or row) on a CCD is typically within the range of a few hundred nanoseconds to few microseconds, depending on the CCD. For PI-MTE3, this shift can be achieved in as little as 24 μ s. Kinetics mode allows full frame CCDs to take time-resolved images. Optical or mechanical masking of the array is required.

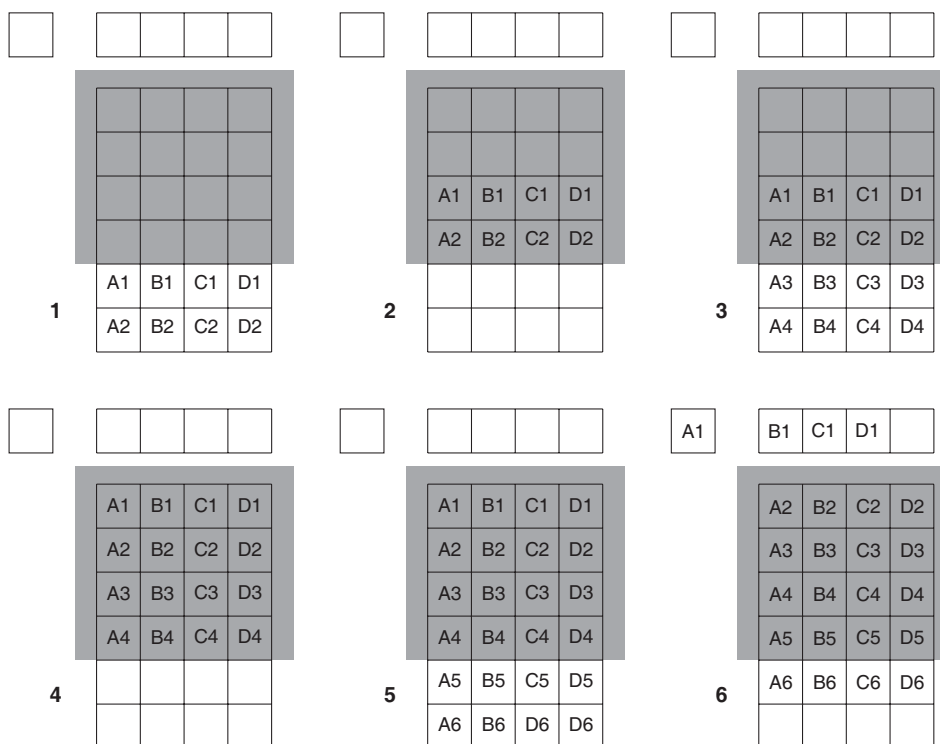


NOTE:

Because PI-MTE3 supports 1-, 2-, or 4-port data readout, Kinetics can be very complicated. However, LightField handles Kinetics operation automatically, and following each Kinetics shift, data readout via the selected port(s) occurs seamlessly.

Figure 10-1 illustrates Kinetics readout for a 4 x 6 CCD configured for 1-port readout. In this example, 2/3 of the array is masked, either mechanically or optically. The shutter opens to expose a 4 x 2 region. While the shutter remains open, charge is quickly shifted just under the mask, and the exposure is repeated. After a third image is collected the shutter is closed and the CCD is read out. Since the CCD can be read out slowly, very high dynamic range is achieved. Shifting and readout are portrayed Figure 10-1.

Figure 10-1: 1-Port Kinetics Readout

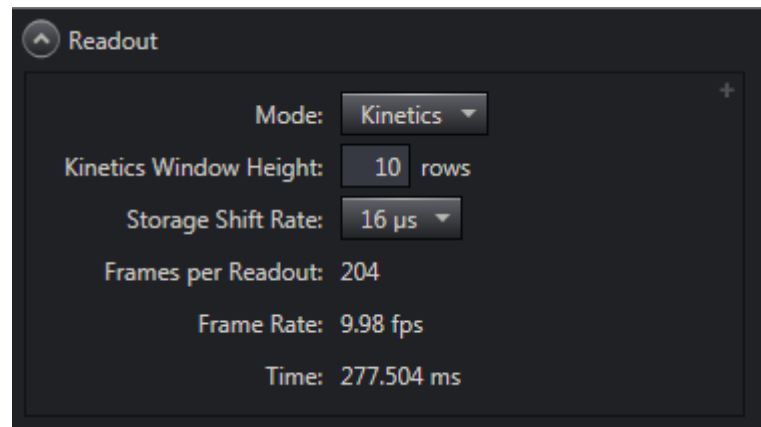


4411-0162_0035

10.1 Kinetics Mode Parameters

Kinetics mode is selected and configured on the Readout expander as shown in [Figure 10-2](#).

Figure 10-2: Typical Readout Expander: Kinetics Mode Parameters



4411-0162_0036

10.1.1 Kinetics Window Height

Defines the height, in rows, of the unmasked area of the CCD to be used for kinetics. Valid values are [1 ... 1024] rows, inclusive, in 1 row increments.

10.1.2 Storage Shift Rate

Defines the length of time required, in microseconds, to shift one row of acquired data into the sensor storage area.

Valid values are:

- 24 μs;
- 32 μs;
- 48 μs;
- 80 μs.

10.1.3 Frames per Readout

This is a calculated value that is dependent on the configured values for:

- Kinetics Window Height
- Storage Shift Rate

10.1.4 Frame Rate

This is a calculated value that is dependent on the configured values for:

- Kinetics Window Height
- Storage Shift Rate

10.2 Experiment Timing

For many experiments, the acquisition of quality/useful data is dependent on precise synchronization with external experiment events. Using the SYNC input on the rear of PI-MTE3, externally-generated trigger pulses can be used to control:

- Shutter Operation;



REFERENCES:

Refer to [Chapter 12, Shutter Configuration and Control](#), on page 105 for detailed information about each available shutter mode.



CAUTION!

Although NORMAL Shutter mode is available in Kinetics Readout, programming a PI-MTE3 for NORMAL mode when using Kinetics with a physical shutter is *strongly discouraged*. This combination will result in high shutter repetition rates and short exposure times which may permanently damage/destroy the shutter.

Shutters are not covered by the warranty.

NORMAL Shutter mode may be used when a physical shutter is not installed and the light source is being electronically controlled by the SHUTTER output. In this case the repetition rate could be limited by the user's light source.

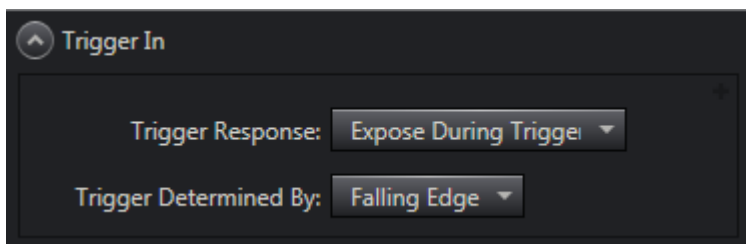
If an application utilizes a physical shutter and requires both NORMAL shutter mode and Kinetics Readout, contact Teledyne Princeton Instruments for assistance prior to attempting this configuration. Refer to [Contact Information](#) on page 126 for complete information.

- Data Readout.

This section describes how to configure PI-MTE3 to use incoming trigger pulses to precisely control experiment synchronization in Kinetics mode.

[Figure 10-3](#) illustrates a typical Trigger In expander.

Figure 10-3: Trigger In Expander



Depending on the specific experiment, two parameters are used to configure PI-MTE3's response to an incoming trigger pulse:

- [Trigger Response](#);
- [Trigger Determined By](#).

The following sections describe each of these options and how experiment synchronization is impacted. Within the following sections, the following symbols may be used:

- t_{exp} = exposure time;
- t_{O} = shutter opening delay;
- t_{C} = shutter closing delay;
- t_{R} = data readout time.

10.2.1 Trigger Response

The Trigger Response parameter defines how PI-MTE3 responds upon receipt of an incoming trigger pulse.

Supported Trigger Response modes are:

- [No Response](#);
- [Start on Single Trigger](#);
- [Readout Per Trigger](#);
- [Shift Per Trigger](#);
- [Expose During Trigger Pulse](#);

The following sections describe each of these trigger modes and how experiment synchronization is impacted based on the selected Shutter Mode.



NOTE:

Throughout the remainder of this section, for all timing diagrams, Trigger Determined By Rising Edge is illustrated.

10.2.1.1 No Response

When No Response is selected, any incoming trigger pulses are ignored.

In this mode, PI-MTE3 acquires a series of images, each with the Exposure Time that has been configured on the Common Acquisition Settings expander. The time between successive image frames may be as short as 24 μs and is limited by the time required to shift an image under the mask.

The time between successive image frames is calculated by multiplying the configured [Storage Shift Rate](#) (in ns/row) by the configured [Kinetics Window Height](#) in rows. The exact number of frames depends on the selected [Kinetics Window Height](#) and is equal to the number of pixels perpendicular to the shift register divided by the Window Size.



NOTE:

LightField displays only the integer result of this division in the Frames per Readout field.

Two integrate signals (Exposing) are provided on the LOGIC OUT connector for timing measurements. These signals are configured on the [Trigger Out](#) expander, and are named Output Signal and Output Signal-2.

Referring back to the example presented in [Figure 10-1](#):

- Six pixels are perpendicular to the shift register;
- The [Kinetics Window Height](#) is two pixels;
- The number of frames is 3.

When [Storage Shift Rate](#) rate is configured to 24 $\mu\text{s}/\text{row}$, the Shift time is 48 μs per frame. If the shift rate is increased to 80 $\mu\text{s}/\text{row}$, the Shift time increases to 160 μs per frame.

Supported Shutter modes are:

- [Normal](#);
- [Always Closed](#);
- [Always Open](#).

The following sections describe how each of these modes impacts experiment timing.

10.2.1.1.1 Normal



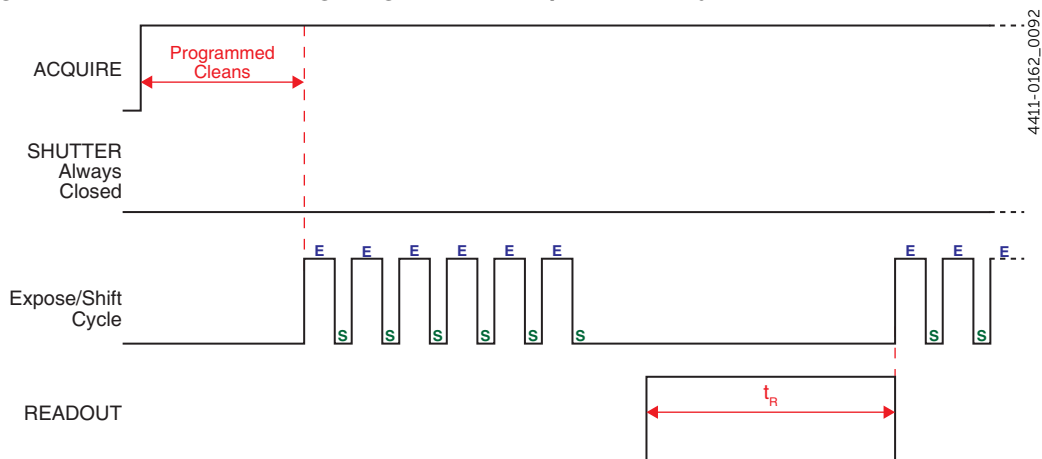
CAUTION!

The use of this mode is strongly discouraged. Contact Teledyne Princeton Instruments for assistance before implementing this mode. Refer to [Contact Information](#) on page 126 for complete information.

10.2.1.1.2 Always Closed

[Figure 10-4](#) illustrates the timing diagram for No Response mode combined with Always Closed shutter mode.

Figure 10-4: Kinetics Timing Diagram: No Response, Always Closed

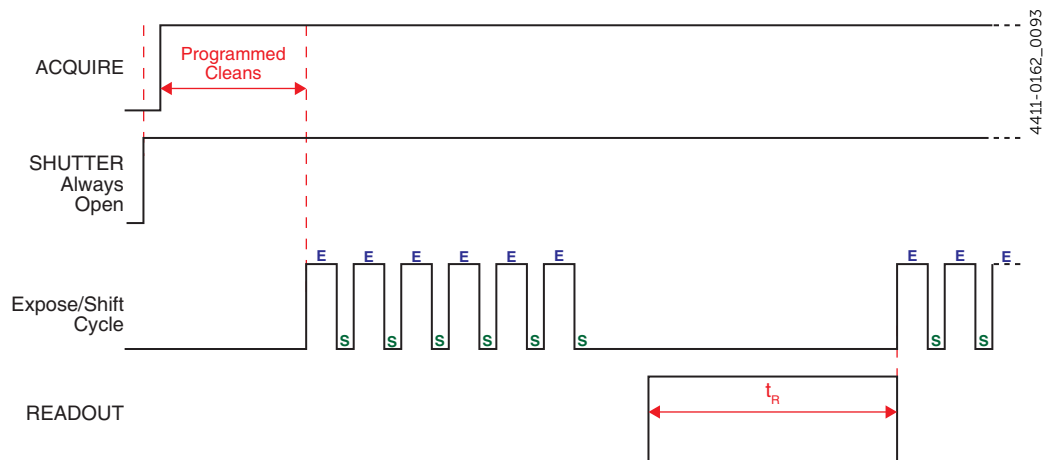


This mode is primarily used when acquiring a dark reference file. However, PI-MTE3 typically runs at such a low temperature that a dark reference file is often unnecessary.

10.2.1.1.3 Always Open

Figure 10-5 illustrates the timing diagram for No Response mode combined with Always Open shutter mode.

Figure 10-5: Kinetics Timing Diagram: No Response, Always Open



This mode is typically used when an experiment does not support waiting for the shutter to open. Ideally, the only light generated by the experiment is the signal of interest (e.g., a dark chamber with a spark discharge.)

10.2.1.2 Start on Single Trigger

Begins the experiment when the trigger is received.

One single incoming trigger causes the system to execute all programmed events, such as, but not limited to:

- Kinetics Exposures;
- Shifts;
- Readout;
- etc.

Supported Shutter modes are:

- Normal;
- Always Closed;
- Always Open;
- Open Before Trigger.

The following sections describe how each of these modes impacts experiment timing.



NOTES:

1. When Clean Until Trigger is enabled, an inherent jitter is introduced into the system Refer to [Section 7.3.1, Clean Until Trigger](#), on page 52 for additional information.
2. In all timing diagrams, Trigger Determined By Rising Edge is illustrated.

10.2.1.2.1 Normal

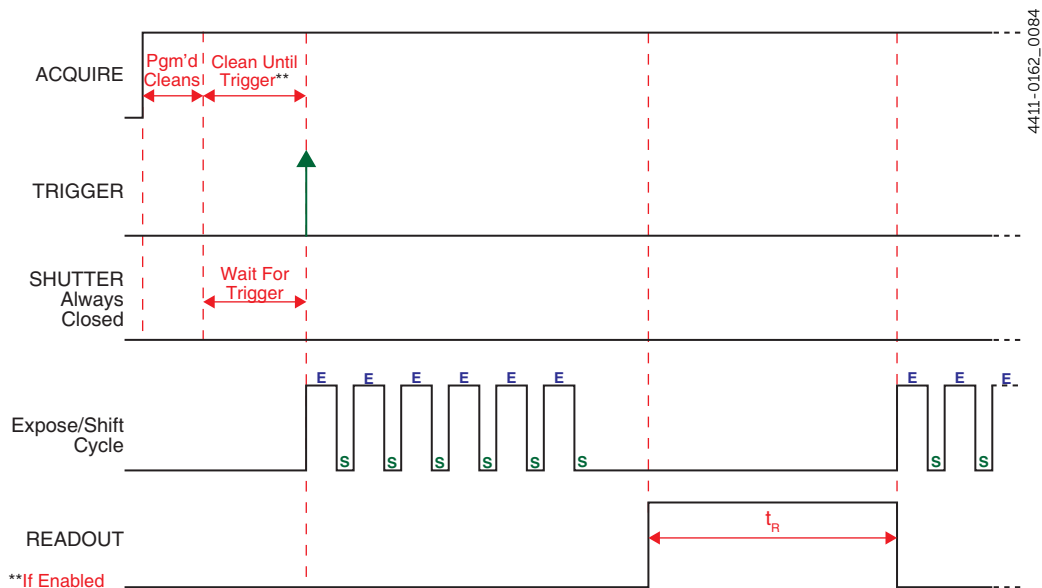
**CAUTION!**

The use of this mode is strongly discouraged. Contact Teledyne Princeton Instruments for assistance before implementing this mode. Refer to [Contact Information](#) on page 126 for complete information.

10.2.1.2.2 Always Closed

[Figure 10-4](#) illustrates the timing diagram for Start on Single Trigger mode combined with Always Closed shutter mode.

Figure 10-6: Kinetics Timing Diagram: Start on Single Trigger, Always Closed

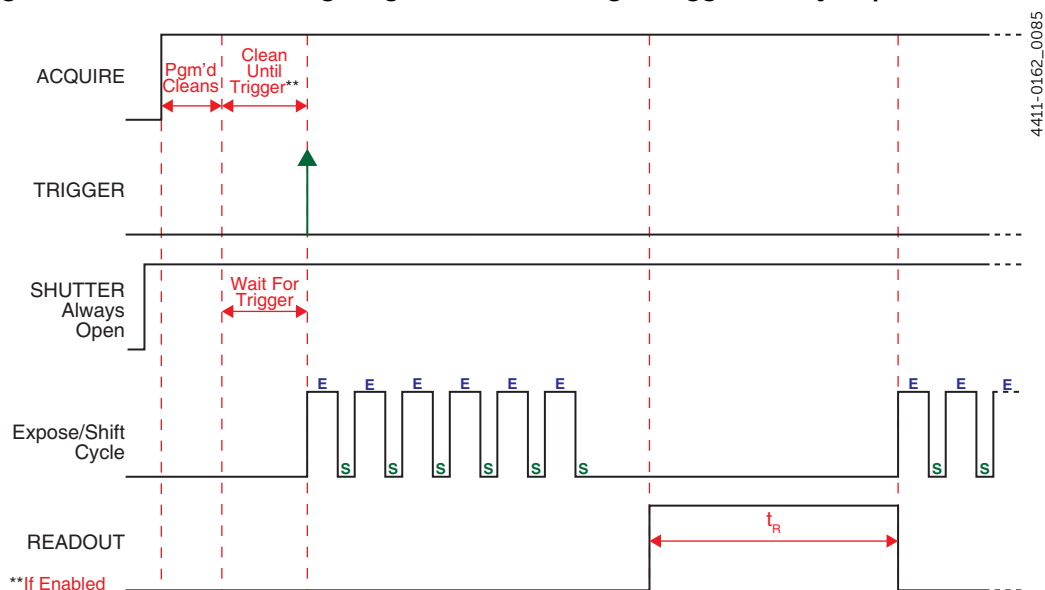


This mode is primarily used when acquiring a dark reference file. However, PI-MTE3 typically runs at such a low temperature that a dark reference file is often unnecessary.

10.2.1.2.3 Always Open

Figure 10-5 illustrates the timing diagram for Start on Single Trigger mode combined with Always Open shutter mode.

Figure 10-7: Kinetics Timing Diagram: Start on Single Trigger, Always Open

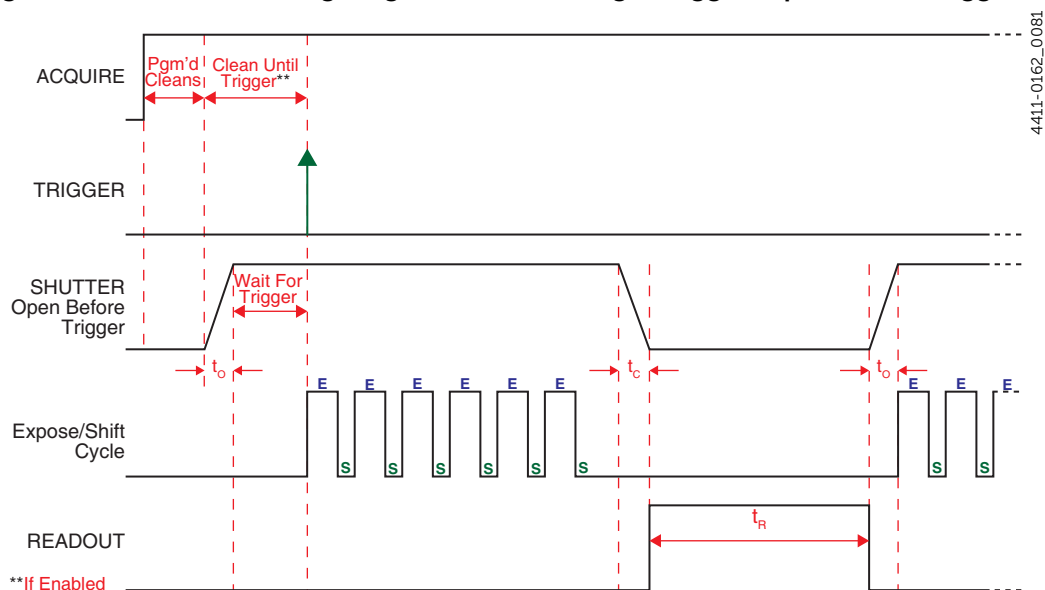


This mode is typically used when an experiment does not support waiting for the shutter to open. Ideally, the only light generated by the experiment is the signal of interest (e.g., a dark chamber with a spark discharge.)

10.2.1.2.4 Open Before Trigger

Figure 10-8 illustrates the timing diagram for Start On Single Trigger mode combined with Open Before Trigger shutter mode.

Figure 10-8: Kinetics Timing Diagram: Start On Single Trigger, Open Before Trigger



10.2.1.3 Readout Per Trigger

When configured for Readout Per Trigger, PI-MTE3 requires one trigger to initiate an entire series of exposure-shift cycles (e.g., one External Trigger pulse initiates the collection of six frames).

When Acquire or Run is selected:

- The active shutter is opened;
- PI-MTE3 acquires data using the configured Exposure Time;
- An external trigger is applied to the SYNC connector on the rear of PI-MTE3.

After a series of images has been acquired, the active shutter closes and the CCD is read out at normal speeds. Once readout is complete, PI-MTE3 is ready for the next series of exposures.

Supported Shutter modes are:

- [Normal](#);
- [Always Closed](#);
- [Always Open](#);
- [Open Before Trigger](#).

The following sections describe how each of these modes impacts experiment timing.



NOTES:

1. When Clean Until Trigger is enabled, an inherent jitter is introduced into the system. Refer to [Section 7.3.1, Clean Until Trigger](#), on page 52 for additional information.
2. In all timing diagrams, Trigger Determined By Rising Edge is illustrated.

10.2.1.3.1 Normal



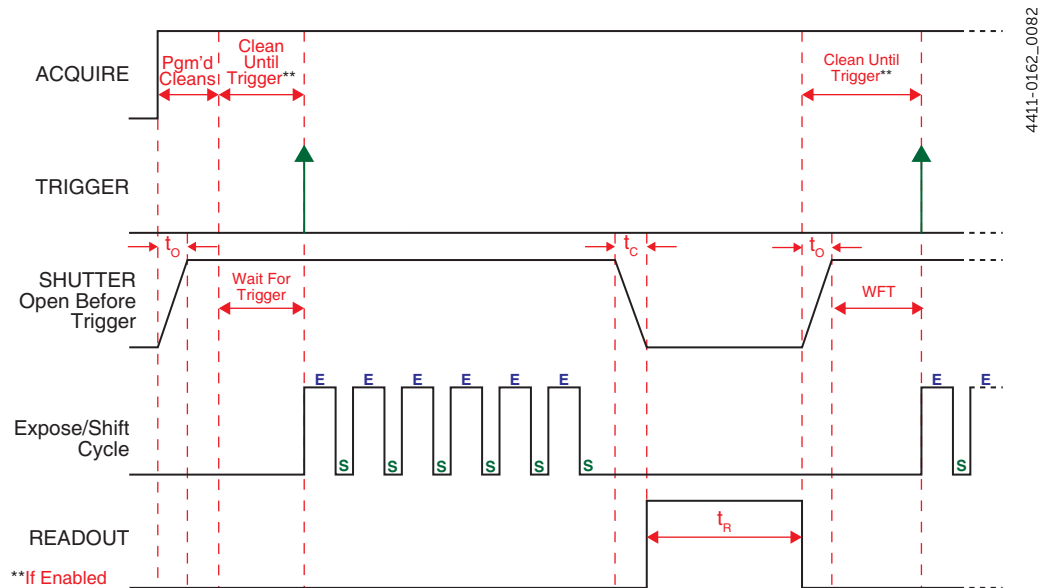
CAUTION!

The use of this mode is strongly discouraged. Contact Teledyne Princeton Instruments for assistance before using this shutter mode. Refer to [Contact Information](#) on page 126 for complete information.

10.2.1.3.4 Open Before Trigger

Figure 10-17 illustrates the timing diagram for Readout Per Trigger mode combined with Open Before Trigger shutter mode.

Figure 10-11: Kinetics Timing Diagram: Readout Per Trigger, Open Before Trigger



10.2.1.4 Shift Per Trigger

When configured for Shift Per Trigger, PI-MTE3's active shutter opens when Acquire or Run is clicked. Each exposure-shift cycle throughout the acquisition is triggered independently by a an incoming Trigger Pulse applied at the SYNC connector.

Shift Per Trigger is useful when each subframe must be synchronized with a pulsed external light source such as a laser. Once the series is complete, the active shutter closes and readout begins. Since the shutter is open during the entire series of images, irregularly spaced external pulses will result in exposures of different lengths. Once the series has been read out, the camera is ready for the next series.

Supported Shutter modes are:

- [Normal](#);
- [Always Closed](#);
- [Always Open](#);
- [Open Before Trigger](#).

The following sections describe how each of these modes impacts experiment timing.



NOTES:

1. When Clean Until Trigger is enabled, an inherent jitter is introduced into the system Refer to [Section 7.3.1, Clean Until Trigger](#), on page 52 for additional information.
2. In all timing diagrams, Trigger Determined By Rising Edge is illustrated.

10.2.1.4.1 Normal



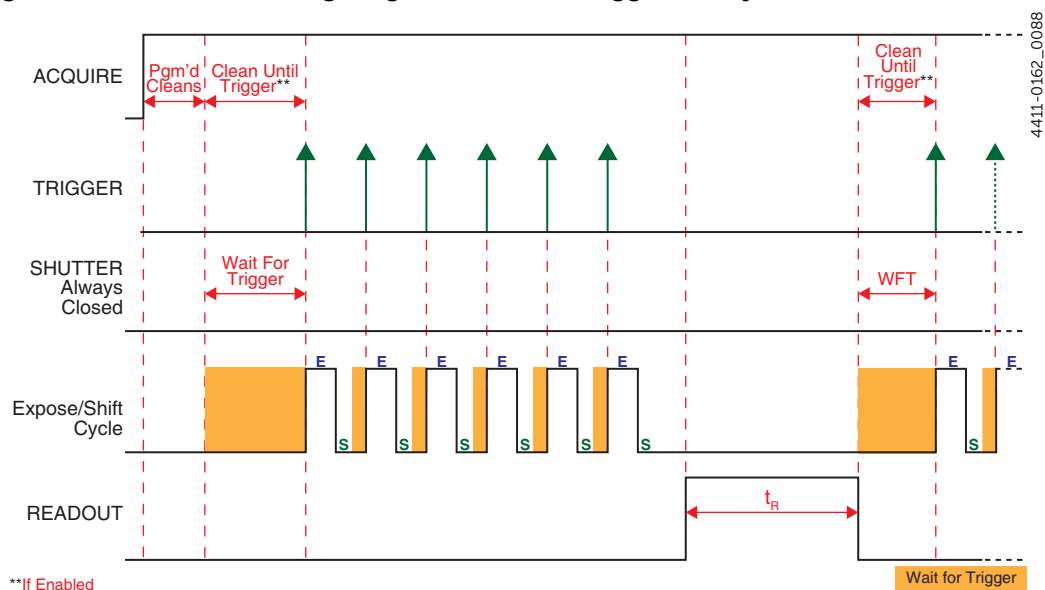
CAUTION!

The use of this mode is strongly discouraged. Contact Teledyne Princeton Instruments for assistance before using this shutter mode. Refer to [Contact Information](#) on page 126 for complete information.

10.2.1.4.2 Always Closed

Figure 10-15 illustrates the timing diagram for Shift Per Trigger mode combined with Always Closed shutter mode.

Figure 10-12: Kinetics Timing Diagram: Shift Per Trigger, Always Closed

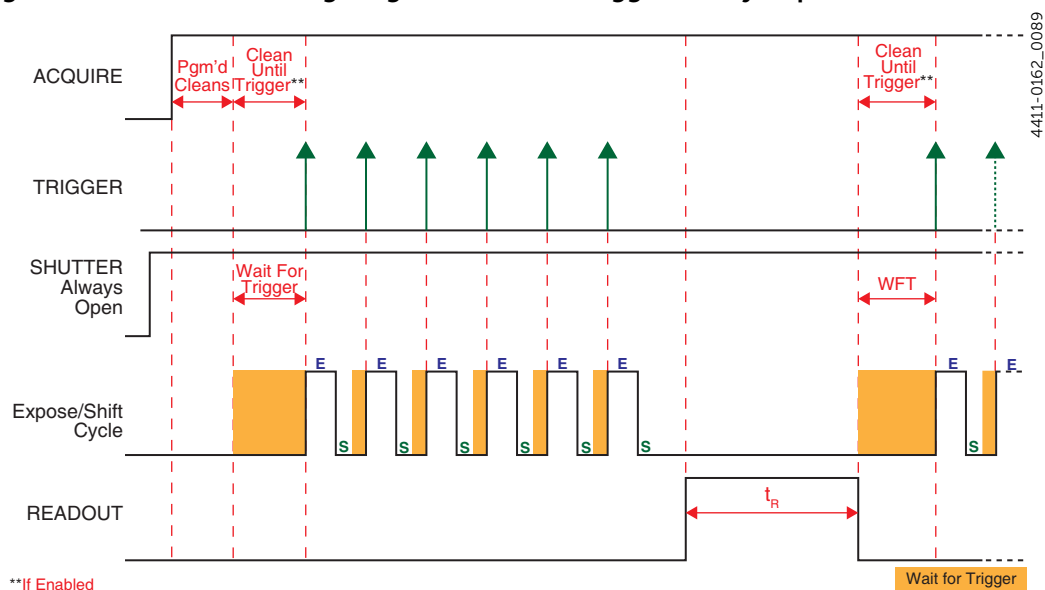


This mode is primarily used when acquiring a dark reference file.

10.2.1.4.3 Always Open

Figure 10-16 illustrates the timing diagram for Shift Per Trigger mode combined with Always Open shutter mode.

Figure 10-13: Kinetics Timing Diagram: Shift Per Trigger, Always Open

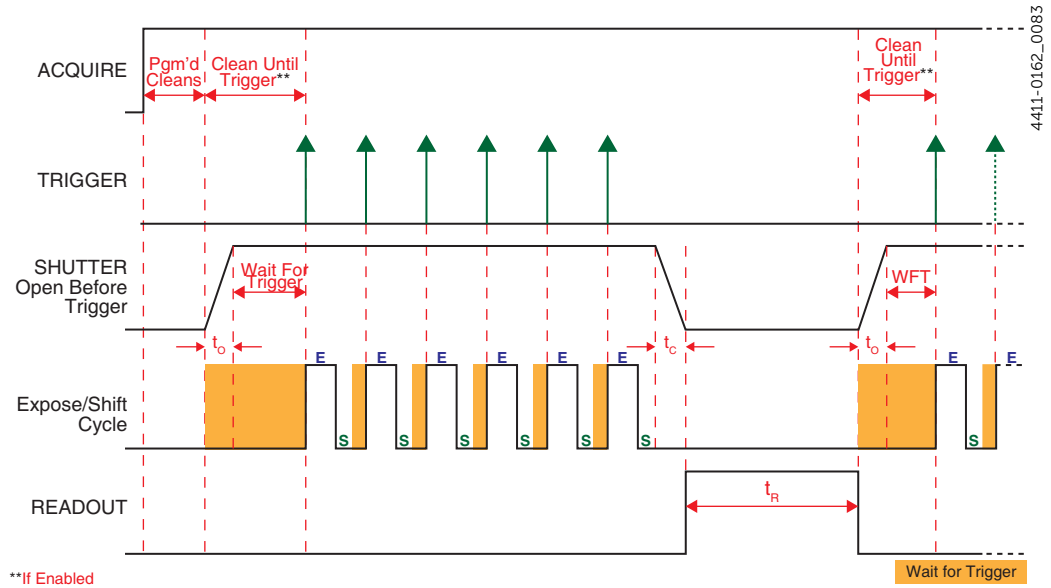


This mode is typically used when an experiment does not support waiting for the shutter to open. Ideally, the only light generated by the experiment is the signal of interest (e.g., a dark chamber with a spark discharge.) **Open Before Trigger** is closely related.

10.2.1.4.4 Open Before Trigger

Figure 10-17 illustrates the timing diagram for Shift Per Trigger mode combined with Open Before Trigger shutter mode.

Figure 10-14: Kinetics Timing Diagram: Shift Per Trigger, Open Before Trigger



**If Enabled

10.2.1.5 Expose During Trigger Pulse

When configured for Expose During Trigger Pulse, CCD exposure is controlled by the rising and falling edges of the incoming trigger pulse.

- The shutter begins opening on the leading edge of the incoming trigger pulse;
- The shutter begins closing on the falling edge of the incoming trigger pulse.

In this mode, both Shutter Opening and Shutter Closing times must be included in timing calculations.

Supported Shutter modes are:

- [Normal](#);
- [Always Closed](#);
- [Always Open](#);
- [Open Before Trigger](#).

The following sections describe how each of these modes impacts experiment timing.



NOTES:

1. When Clean Until Trigger is enabled, an inherent jitter is introduced into the system. Refer to [Section 7.3.1, Clean Until Trigger](#), on page 52 for additional information.
2. In all timing diagrams, Trigger Determined By Rising Edge is illustrated.

10.2.1.5.1 Normal



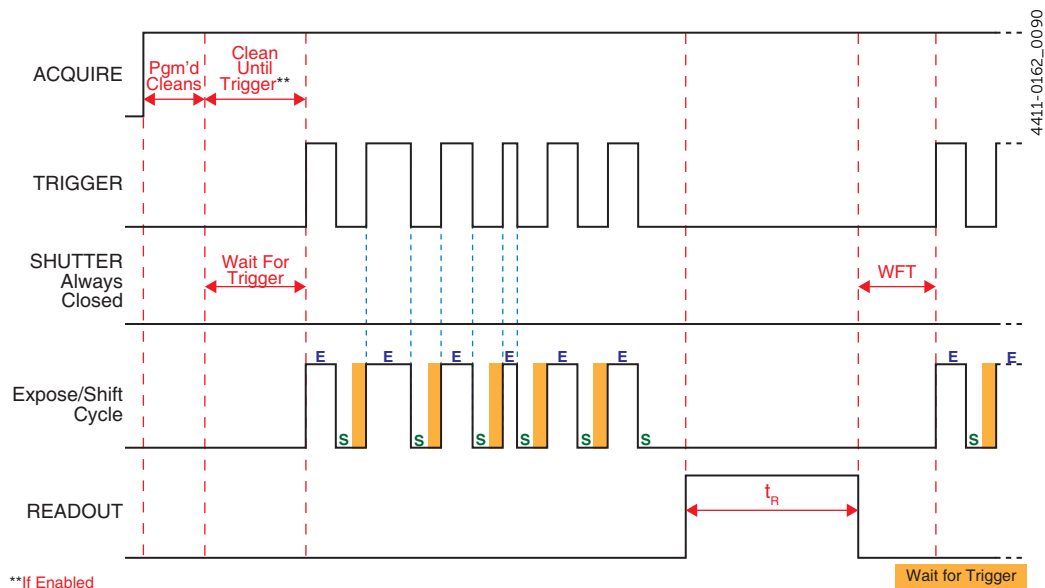
CAUTION!

The use of this mode is strongly discouraged. Contact Teledyne Princeton Instruments for assistance before using this shutter mode. Refer to [Contact Information](#) on page 126 for complete information.

10.2.1.5.2 Always Closed

Figure 10-15 illustrates the timing diagram for Expose During Trigger Pulse mode combined with Always Closed shutter mode.

Figure 10-15: Kinetics Timing Diagram: Expose During Trigger, Always Closed

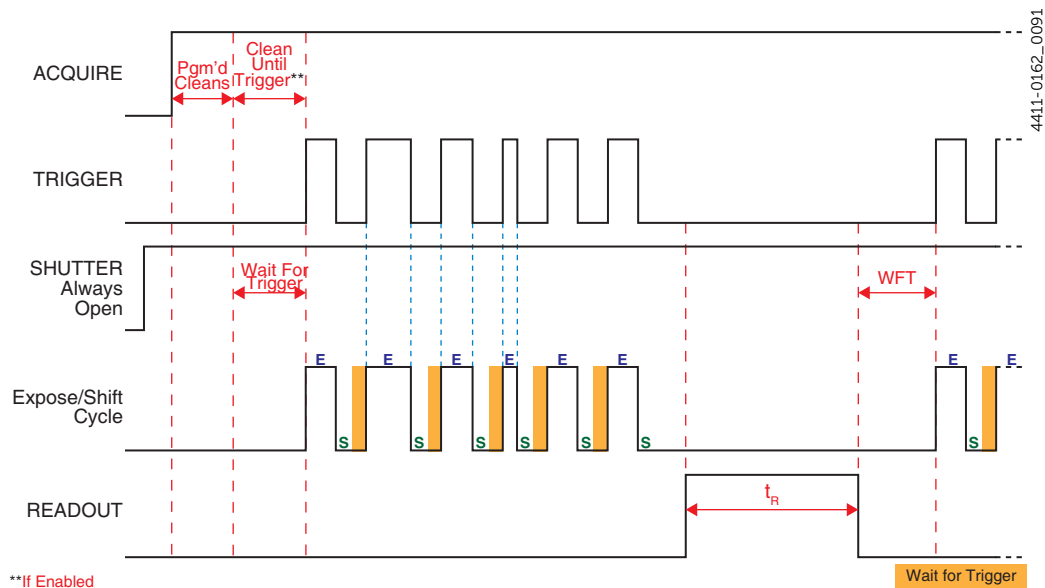


This mode is primarily used when acquiring a dark reference file. However, PI-MTE3 typically runs at such a low temperature that a dark reference file is often unnecessary.

10.2.1.5.3 Always Open

Figure 10-16 illustrates the timing diagram for Expose During Trigger Pulse mode combined with Always Open shutter mode.

Figure 10-16: Kinetics Timing Diagram: Expose During Trigger, Always Open

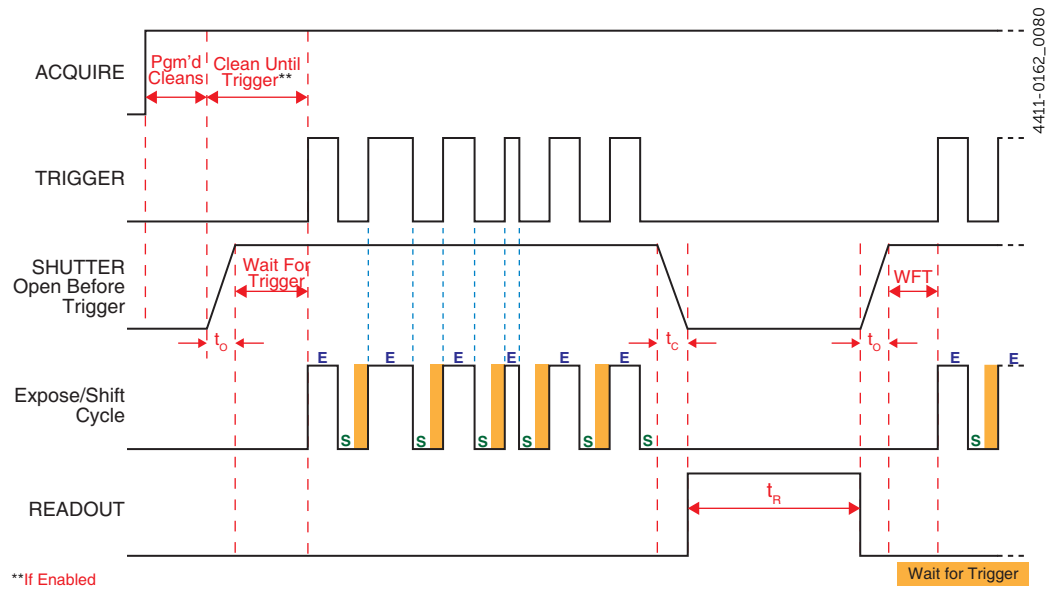


This mode is typically used when an experiment does not support waiting for the shutter to open. Ideally, the only light generated by the experiment is the signal of interest (e.g., a dark chamber with a spark discharge.) **Open Before Trigger** is closely related.

10.2.1.5.4 Open Before Trigger

Figure 10-17 illustrates the timing diagram for Expose During Trigger Pulse mode combined with Open Before Trigger shutter mode.

Figure 10-17: Kinetics Timing Diagram: Expose During Trigger Pulse, Open Before Trigger



10.2.2 Trigger Determined By

When using an external trigger to initiate a readout, PI-MTE3 can be configured to respond to:

- The rising edge of the incoming trigger pulse;
- The falling edge of the incoming trigger pulse.

The Trigger Determined By parameter configures this behavior. Valid values are:

- Rising Edge;

PI-MTE3 responds to the rising edge of incoming trigger pulses. Depending on the specific system configuration, one or more subsequent trigger pulses may be required (or ignored) by the system. Refer to [Section 10.2.1, Trigger Response](#), on page 84 for complete information about configuring incoming trigger responses.

When using [Expose During Trigger Pulse](#) mode:

- Exposure begins on the Rising Edge of each incoming trigger pulse;
- Exposure ends on the Falling Edge of the respective trigger pulse.

The timing diagrams in [Section 10.2.1.5, Expose During Trigger Pulse](#), on page 95 illustrate this.



NOTE:

If PI-MTE3 is busy when a subsequent trigger pulse is received, the trigger is ignored.

- Falling Edge.

PI-MTE3 responds to the falling edge of incoming trigger pulses. Depending on the specific system configuration, one or more subsequent trigger pulses may be required (or ignored) by the system. Refer to [Section 10.2.1, Trigger Response](#), on page 84 for complete information about configuring incoming trigger responses.

When using [Expose During Trigger Pulse](#) mode:

- Exposure begins on the Falling Edge of each incoming trigger pulse;
- Exposure ends on the Rising Edge of the respective trigger pulse.



NOTE:

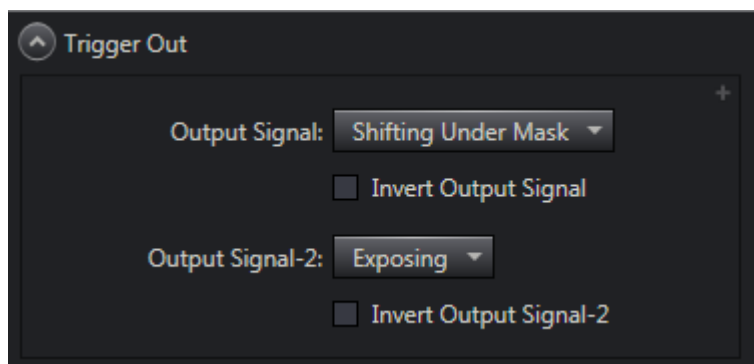
If PI-MTE3 is busy when a subsequent trigger pulse is received, the trigger is ignored.

10.3 Trigger Out

In addition to being able to synchronize PI-MTE3 with an experiment, additional equipment can be synchronized using the Trigger Out connector on the rear of PI-MTE3.

Two trigger out pulses are configured on the Trigger Out expander, shown in [Figure 10-18](#).

Figure 10-18: Typical Trigger Out Expander



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The following options are available for each of the two output signals:

- Acquiring;
The associated output signal is high when PI-MTE3 is acquiring or ready to receive the first trigger.
- Always High;
The associated output signal is always high.
- Exposing;
The associated output signal is high when the sensor is exposed as configured within LightField.
- Reading Out;
The associated output signal when data are being read out of the sensor.
- Shifting Under Mask;
This output indicates when Kinetics shifts are occurring.
- Shutter Open;
The associated output signal is high when the shutter is open.
- Waiting for Trigger.
The associated output signal when PI-MTE3 is waiting for an incoming trigger.

Each of these options can also be inverted to create active low signals using the Invert Output Signal option.

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Chapter 11: Binning

Binning is the process of summing data from adjacent pixels to form a single pixel, often called a Super Pixel. Binning can be accomplished in one of two ways:

- Hardware;
- Software.

Rectangular groups of pixels of any size may be binned together subject to some hardware and software limitations.

11.1 Hardware Binning

Hardware binning is performed on the CCD array before the signal is read out of the output amplifier. 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.

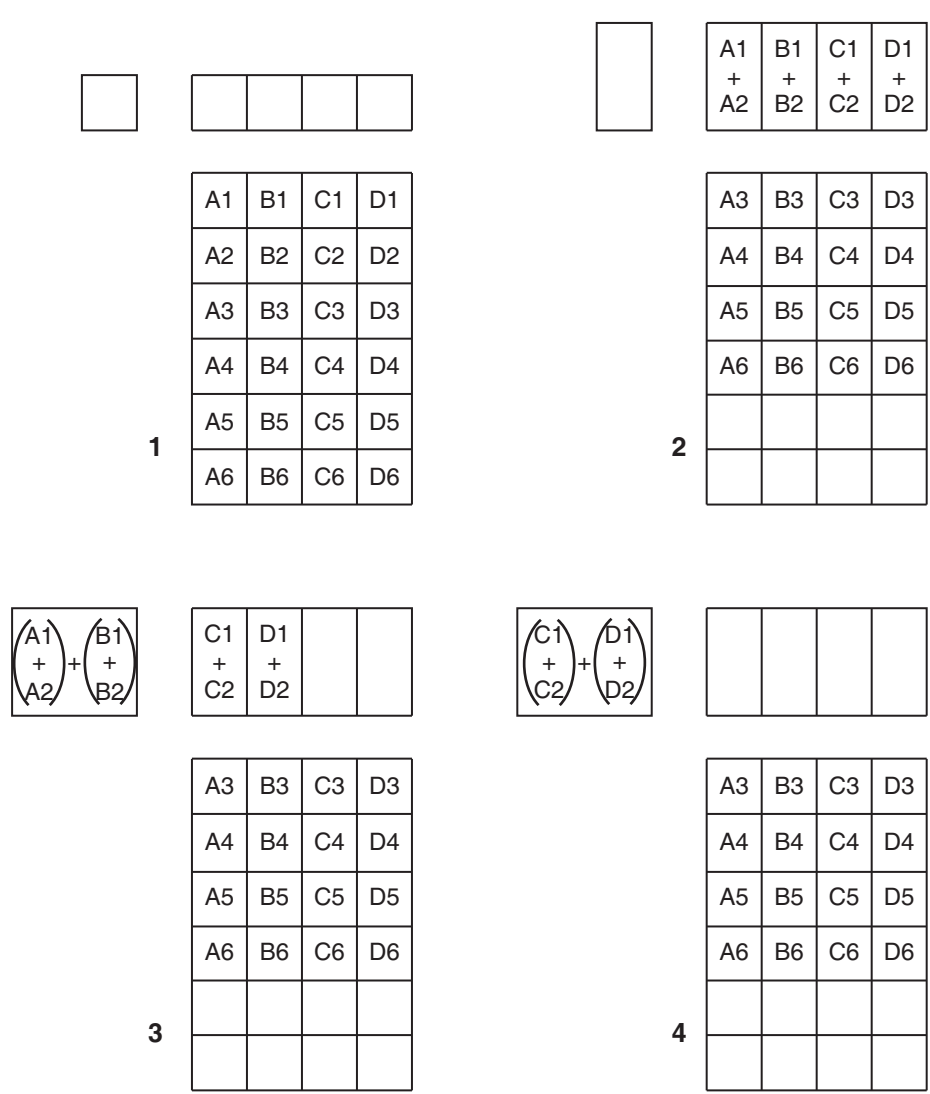
Binning reduces readout time and the burden on computer memory, but at the expense of resolution. Since shift register pixels typically hold only twice as much charge as image pixels, the binning of large sections may result in saturation and “blooming”, or spilling of charge back into the image area.

When PI-MTE3 is configured to use multiple output ports, there are symmetry requirements when performing hardware binning:

- When PI-MTE3 is configured to use 2-port readout, all binning regions must be symmetrical about the vertical center-line of the CCD.
- When PI-MTE3 is configured to use 4-port readout, all regions must be symmetrical about both the vertical and horizontal center-lines of the CCD.

[Figure 11-1](#) illustrates an example of 2 x 2 binning. Each pixel of the image displayed by the software represents 4 pixels of the CCD array. Rectangular bins of any size are possible. Binning also reduces readout time and the burden on computer memory, but at the expense of resolution. Since shift register pixels typically hold only twice as much charge as image pixels, the binning of large sections may result in saturation and blooming, or spilling of charge back into the image area.

Figure 11-1: 2 x 2 Binning



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11.2 Software Binning

One limitation of hardware binning is that the shift register pixels and the output node are typically only 2-3 times the size of imaging pixels. Consequently, if the total charge binned together exceeds the capacity of the shift register or output node, the data will be corrupted.

This restriction 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 binning is accomplished in software, producing a result that represents many more photons than was possible using hardware binning.

Software averaging can improve the S/N ratio by as much as the square-root of the number of scans. 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 limited rather than photon shot-noise limited, this theoretical signal improvement cannot be fully realized. Again, background subtraction from the raw data is necessary.

This technique 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.

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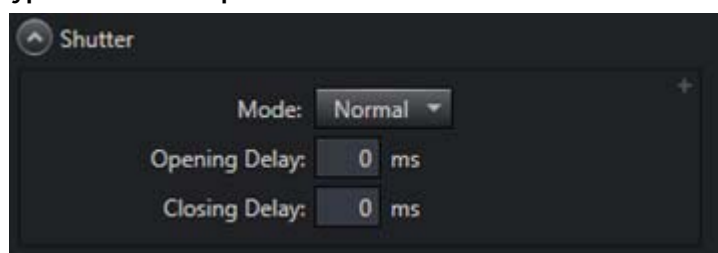
Chapter 12: Shutter Configuration and Control

This chapter provides information about shutter configuration and control

12.1 Configuration

Shutter information is configured within LightField on the Shutter expander. [Figure 12-1](#) illustrates a typical Shutter expander.

Figure 12-1: Typical Shutter Expander



4411-0162_0023

12.1.1 Mode

This parameter determines the shutter's opening and closing behavior during an experiment.

Depending upon the specific Trigger In ► Trigger Response that has been selected, supported Modes are:

- Normal;
The shutter opens for exposure, and closes when complete.



CAUTION!

Although NORMAL Shutter mode is available in Kinetics Readout, programming a PI-MTE3 for NORMAL mode when using Kinetics with a physical shutter is *strongly discouraged*. This combination will result in high shutter repetition rates and short exposure times which may permanently damage/destroy the shutter.

Shutters are not covered by the warranty.

NORMAL Shutter mode may be used when a physical shutter is not installed and the light source is being electronically controlled by the SHUTTER output. In this case the repetition rate could be limited by the user's light source.

If an application utilizes a physical shutter and requires both NORMAL shutter mode and Kinetics Readout, contact Teledyne Princeton Instruments for assistance prior to attempting this configuration. Refer to [Contact Information](#) on page 126 for complete information.

- Always Closed;
When selected, the shutter closes and remains in the closed position.
This mode is primarily used when acquiring a dark reference file.
- Always Open;
When selected, the shutter opens and remains open for the experiment duration.
This mode is typically used when an experiment does not support waiting for the shutter to open. Ideally, the only light generated by the experiment is the signal of interest (e.g., a dark chamber with a spark discharge.)
- Open Before Trigger
When selected, the shutter opens as soon as PI-MTE3 is ready to receive an External Sync pulse. This is required if the time between the External Sync pulse and the event is less than the time it takes the shutter to open which is a typically a few milliseconds.

12.1.2 Opening Delay

Specifies, in milliseconds, the length of time PI-MTE3 is to wait for the active shutter to open.

Valid values are [0 ... 1000] ms, inclusive, in 1 ms increments.

12.1.3 Closing Delay

Specifies, in milliseconds, the length of time PI-MTE3 is to wait for the active shutter to close.

Valid values are [0 ... 1000] ms, inclusive, in 1 ms increments.

12.2 Using an External Shutter

Since the PI-MTE3 does not have an internal shutter, shutter applications require the use of an external shutter with a shutter driver that accepts TTL level control signals.



NOTE:

A compatible Shutter Driver is typically available from the shutter's manufacturer. Contact the manufacturer for additional information.

Refer to the user manual provided by the shutter manufacturer for information about configuring and using the shutter.

Appendix A: Technical Specifications



CAUTION!

All specifications are subject to change.

This appendix provides some technical information and specifications for PI-MTE3 cameras and optional accessories. Additional information may be found on data sheets available on the Teledyne Princeton Instruments website (www.princetoninstruments.com).

A.1 System Dimensions and Weight

Refer to [Table A-1](#) for system dimensions and weight.

Table A-1: General System Specifications

Dimension	Specification	
	Camera Head	Controller
Length	8.56 in [217.6 mm]	11.77 in [299.0 mm]
Width	4.03 in [102.3 mm]	8.10 in [205.7 mm]
Height	2.91in [73.9 mm]	6.22 in [158.0 mm]
Weight	<i>6.0 lbs [2.7 kg]</i>	<i>8.5 lbs [3.9 kg]</i>

A.2 Camera Specifications

Refer to [Table A-2](#) for CCD array specifications for PI-MTE3 detectors.

Table A-2: CCD Array Specifications^a (Sheet 1 of 2)

Specification	PI-MTE3 2k by 2k
CCD	CCD230-42 BI, NO-AR
Image Type	Monochrome
Resolution	2048 x 2048
Pixel Size	15 μm x 15 μm
Imaging Area	30.7 mm x 30.7 mm
Frame Rate ^b	3.20 fps (full frame)
Readout Amplifiers (Ports)	4
ADC Speed/16 bits ^c	100 kHz, 1 MHz, 4 MHz
Vertical Shift Rate ^d	24 $\mu\text{sec/row}$

Table A-2: CCD Array Specifications^a (Sheet 2 of 2)

Specification	PI-MTE3 2k by 2k
Read Noise	6.5 e ⁻ rms @ 100 kHz 10.5 e ⁻ rms @ 1 MHz 25 e ⁻ rms @ 4 MHz
Non-linearity (typical)	< 2% @ 100 kHz
Optical Focal Distance	1.87" [47.50 mm]

- Specifications are valid as of the publication date of this manual. For up-to-date specifications, refer to the PI-MTE3 data sheets available for download from www.princetoninstruments.com.
- @ 4 MHz, 4-port readout, 24 μs vertical shift rate
- 4-port readout
- Software programmable

A.2.1 Thermal Characteristics

Refer to [Table A-3](#) for specific thermal information.

Table A-3: Default Operating Temperature

Specification	Cooling Medium	Specification
Default Operating Temperature	Liquid ^a	-50°C
Deepest Cooling Temperature	Liquid ^a	-65°C
Precision	–	±0.05 °C

- [chiller] liquid circulator required.

A.3 Power Specifications

PI-MTE3

All voltages required by PI-MTE3 cameras are generated and delivered by the MTE-3 Controller which receives its power from by plugging into an AC source of power, typically a wall receptacle.

MTE-3 Controller



WARNING!

There are no user-serviceable or replaceable components within the MTE-3 Controller.

The MTE-3 Controller can operate from any one of four different nominal line voltages:

- 100 V_{AC}
- 120 V_{AC}
- 220 V_{AC}
- 240 V_{AC}

Refer to the Voltage label on the back of the MTE-3 Controller for voltage and power rating information.

The plug on the power cord supplied with the MTE-3 Controller 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.



WARNING!

In case of a fire or other emergency, immediately remove the power supply's AC plug from the wall receptacle.



CAUTION!

Use of MTE-3 Controller other than that provided with the PI-MTE3 camera will void the camera warranty. For specific power supply requirements, contact Teledyne Princeton Instruments. Refer to [Contact Information](#) on page 126 for complete information.

Refer to [Table A-4](#) for power specifications for the MTE-3 Controller

Table A-4: Power Specifications

Parameter	Specification	Units
Input Voltage (nominal)	100 – 240	V _{AC}
Input Frequency (nominal)	50 – 60	Hz
Input Power (maximum)	410	W



NOTE:

The MTE-3 Controller tolerates short-term input voltage fluctuations up to $\pm 10\%$. However, the input voltage must remain within the specified voltage range long-term.

A.4 Environmental Specifications

Refer to [Table A-5](#) for environmental specifications.

Table A-5: PI-MTE3 Environmental Specifications

Parameter	Specification		
	Minimum	Nominal	Maximum
Storage Temperature	-20°C		+55°C
Operating Temperature	+5°C		+30°C
Operating Ambient Relative Humidity	<50% (non-condensing) ^a		
Altitude (above sea level)			2000 ft [610 m]

a. Applicable to controller only.



CAUTION!

The PI-MTE3 camera is typically operated in a vacuum environment and should therefore never be exposed to relative humidity conditions. Operation of the PI-MTE3 camera in air must be done with the chiller turned off. Any damage caused by condensation on the CCD is not covered under the warranty.

A.4.1 Ventilation

MTE-3 Controller

There are internal fans located on the rear panel behind an exhaust opening. Their purpose is simply to cool the controller electronics. The fans run continuously whenever the controller is powered. Air enters the unit through ventilation openings on the side panels, flows past the warm electronic components as it rises, and is drawn out the rear of the controller by the fans. It is important that there be an adequate airflow for proper functioning. As long as both the controller's intake ventilation openings and the fans' exhaust openings are not obstructed, the controller will remain quite cool.

A.5 External Coolant Circulator Specifications



CAUTION!

Never set the coolant temperature below the dew point.

Refer to [Table A-6](#) for external coolant circulator specifications.

Table A-6: External Coolant Circulator Specifications

Parameter	Specification
Coolant Flow Rate	0.8 gal/minute max
Coolant Pressure	20.0 psi max
Minimum Heat Load	150 W

A.6 Minimum Host Computer Specifications

**NOTE:**

Computers and operating systems experience frequent updates. Therefore, the following sections are intended to provide minimum system requirements for operating a PI-MTE3 camera.

A faster computer with 5 GB or larger memory (RAM) will greatly enhance the software performance during live mode operations.

Contact the factory to determine specific requirements.

The minimum system requirements for LightField are:

- Windows 7/8/10 (64-bit)
- 2 GHz dual core processor
- 4 GB RAM (or greater)
- CD-ROM drive
- Super VGA monitor and graphics card supporting at least 65535 colors with at least 128 MB of memory. Memory requirement is dependent on desired display resolution.
- Hard disk with a minimum of 1 GB available for installation. Additional space is required for data storage: the amount of space required depends 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.

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Appendix B: Outline Drawings

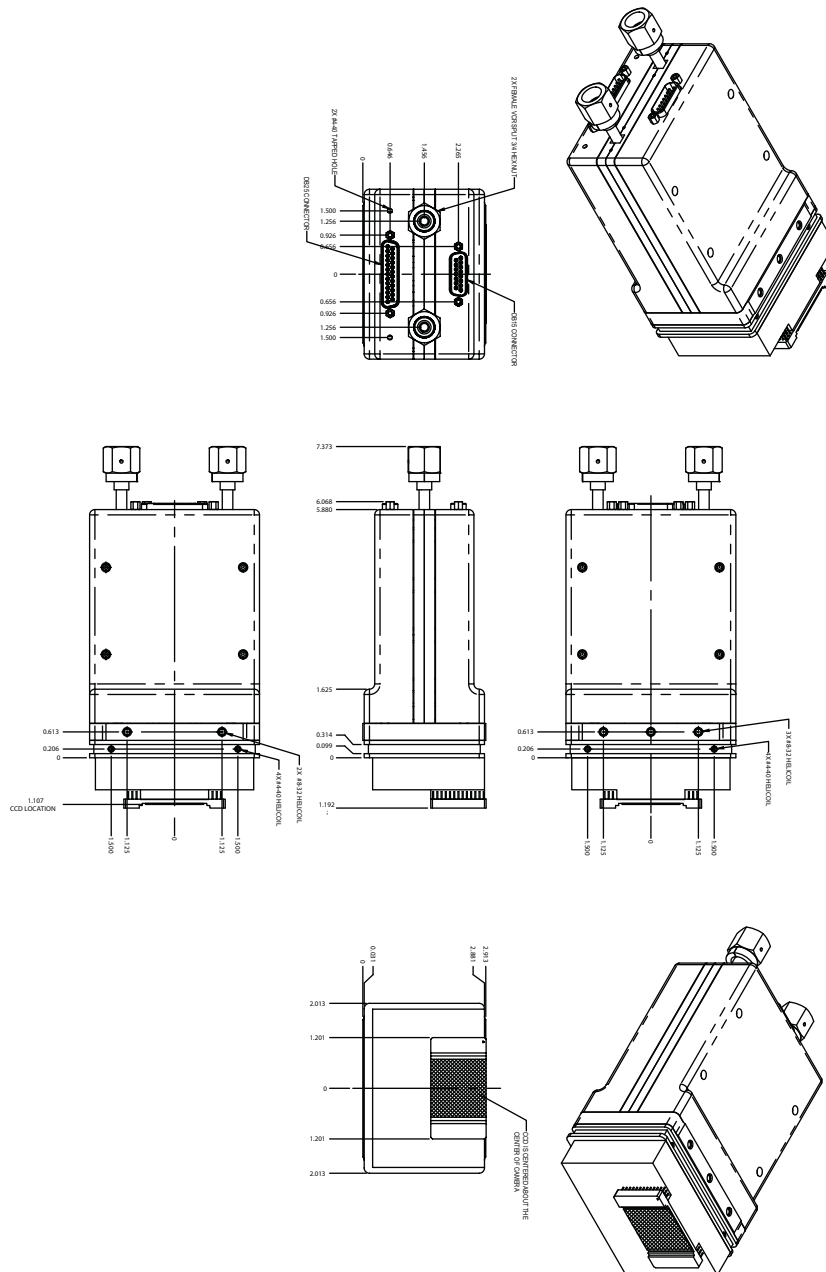


NOTE:

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

B.1 PI-MTE3

Figure B-1: PI-MTE3 2048 Camera Outline Drawing



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Appendix C: Troubleshooting



WARNING!

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

The MTE-3 Controller is equipped with a red FAULT LED on its front panel. When the system is operating normally, this LED is extinguished. However, when an error has been detected, the number of times the LED flashes is indicative of the specific fault. Refer to [Table C-1](#) for additional information.

Table C-1: Fault LED Error Codes

Flashes	Error/Fault
1	TEC Overcurrent
SOLID	Logic Power Supply Overcurrent



NOTE:

A Logic Power Supply Overcurrent error is an improbable event. In the event that the red LED is on SOLID, the system will most likely have to be returned for service. Refer to [Contact Information](#) on page 126 for complete information.

Additional troubleshooting guidelines for issues that may occur while working with a PI-MTE3 system are provided. Refer to [Table C-2](#) for specific troubleshooting sections.

Table C-2: Troubleshooting Index by Error/Fault Description (Sheet 1 of 2)

Error/Fault	Information begins on...
MTE-3 Controller Switch in On Position, But Power LED Extinguished	page 116
Overexposed CCD	page 116
Baseline Signal Suddenly Changes	page 116
Camera Stops Working	page 117
Temperature Lock Cannot be Achieved or Maintained	page 117
Camera Loses Temperature Lock	page 118
Gradual Deterioration of Cooling Capability	page 118
Low Coolant (Air in the Hoses)	page 119
Shutter Faults/Errors	page 119
Devices Missing	page 120

Table C-2: Troubleshooting Index by Error/Fault Description (Sheet 2 of 2)

Error/Fault	Information begins on...
Device is Occupied	page 121
Acquisition Started but Viewer Display Does Not Update	page 121

C.1 General Camera Faults/Errors

This section provides information about troubleshooting general camera and controller faults and errors.

C.1.1 MTE-3 Controller Switch in On Position, But Power LED Extinguished

If the MTE-3 Controller has been turned on (i.e., power switch is in the I position,) but the green POWER LED does not illuminate indicating the power supply is operational:

- Turn the power switch off (i.e., the 0 position);
- Wait approximately five seconds;
- Turn the power switch on (i.e., the I position)

If the green POWER LED still remains extinguished, check the power cord and power source. If these are both OK, the MTE-3 Controller must be returned to Teledyne Princeton Instruments for repair. Refer to [Contact Information](#) on page 126 for complete information.

C.1.2 Overexposed CCD

It takes an enormous power density to damage the CCD at room temperature or cooled. It can be done (e.g., imaging the sun with a large aperture lens, so that the silicon is heated.)

What can happen if the CCD is cold is a temporary elevation of the dark current. If the CCD is over-saturated, electrons pool in the substrate and are clocked out slowly (over hours or even days). To clear the charge, it is best to return the CCD to room temperature, then run the CCD (set short exposure, then click run in LF) while it is cooled down to normal operating temperature.

C.1.3 Baseline Signal Suddenly Changes

A change in the baseline signal is normal if the temperature, gain, or speed setting has been changed. If this occurs when none of these settings have been changed, there may be excessive humidity in the camera vacuum enclosure. Turn off the camera and contact Teledyne Princeton Instruments Customer Support. Refer to [Contact Information](#) on page 126 for complete information.

C.1.4 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, perform these preliminary system checks:

- Examine the two LEDs on the front panel of the MTE-3 Controller.
When the MTE-3 Controller is operating properly, the two LED statuses should be:
 - Green POWER LED is ON;
If the POWER LED is extinguished, it may indicate a blown fuse or general power outage.
 - Red FAULT LED is OFF and not flashing.
If the FAULT LED is either flashing or constantly ON, refer to [Table C-1, Fault LED Error Codes](#), on page 115 for additional information.
- Turn off all AC power.
- Verify that all cables are securely fastened.
- Turn the system back on.

If the system still does not respond, contact Customer Support. Refer to [Contact Information](#) on page 126 for complete information.

C.2 Cooling Faults/Errors

This section provides recommended troubleshooting guidelines for cooling-related issues.

C.2.1 Temperature Lock Cannot be Achieved or Maintained



CAUTION!

The most probable cause of a failure to lock is the setpoint has been programmed for a temperature lower than PI-MTE3 can achieve. Return the temperature setpoint to -50°C , the default for PI-MTE3.

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

- A hose is kinked. Unkink the hose.
- Coolant level is low. Add coolant. Refer to [Section C.2.4, Low Coolant \(Air in the Hoses\)](#), on page 119.
- There may be air in the hoses. Add coolant. Refer to [Section C.2.4, Low Coolant \(Air in the Hoses\)](#), on page 119.
- Circulator pump is not working. If you do not hear the pump running when the [chiller] is powered on, turn off the circulator and contact Customer Support. Refer to [Contact Information](#) on page 126 for complete information.
- If using a Teledyne Princeton Instruments supplied circulator, the circulator is higher than the camera. Reposition the circulator so that it is 6" [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.



NOTE:

Circulators from other manufacturers may not be prone to this.

- The camera's internal temperature may be too high which may occur if the operating environment is particularly warm or when attempting to operate at a temperature colder than the specified limit. PI-MTE3 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 after approximately ten minutes. Although the thermo-protection switch will protect the camera, it is nevertheless advised to power down the camera and correct the operating conditions that caused the thermal-overload to occur.
- The vacuum chamber being used may not be sufficiently evacuated, and should be inspected. Operating in a mediocre vacuum is not recommended since contaminants may be deposited on the CCD.

C.2.2 Camera Loses Temperature Lock

The internal temperature of the camera is too high. LightField typically displays an overheat icon if this happens.

The camera can also lose lock if the temperature set-point is too lower for the coolant temperature. This is commonly seen when the chiller is marginal for the camera heat load. The camera will initially lock, but as heat accumulates in the coolant, it heats up and causes the camera to lose lock.

This may also occur when the operating environment is particularly warm or when attempting to operate at a temperature colder than the specified limit. If this happens, an internal thermal overload switch will disable the cooler circuits to protect them. Typically, camera operation is restored in about ten minutes. Although the thermal overload switch will protect the camera, users are advised to power down and correct the operating conditions that caused the thermal overload to occur.

Additionally, repeated cycling can reduce the lifetime of the thermoelectric cooling system.

C.2.3 Gradual Deterioration of Cooling Capability

If there are no other problems indicated or observed, a gradual deterioration of the ability to cool is an indication that the TEC is deteriorating which may make it impossible to achieve temperature lock at the lowest temperatures. A build-up of residue in the coolant system may also cause this symptom. The PI-MTE3 requires factory service. Contact the factory to make arrangements for returning the camera to the support facility. Refer to [Contact Information](#) on page 126 for complete information.

C.2.4 Low Coolant (Air in the Hoses)



WARNING!

If more than 2" [50.8 mm] of a coolant line is filled with air, the pump will stop working and may be damaged. If flow stops while the pump is on, turn off the camera and [chiller], and then add coolant. Be sure to refer to the instructions for the [chiller] being used before performing this service.

1. Unscrew the reservoir cap and verify that the coolant reservoir contains coolant. If additional coolant is required, fill with a 50:50 mixture of water and ethylene glycol.
2. Screw the reservoir cap back in.
3. Make sure the power switch is turned off before plugging the [chiller] in.
4. Plug the [chiller] into a 100-240 V_{AC}, 47-63 Hz power source.
5. Turn the [chiller] 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 [chiller], particularly at start up and do not prevent proper operation.

- If no problems are observed, proceed to step 6.
 - 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, proceed to step 6.
6. Turn the camera on.
 7. Launch LightField.

C.3 Shutter Faults/Errors

This section provides information about troubleshooting third-party shutter-related issues.

C.3.1 Overexposed or Smeared Images

Verify that the shutter is opening and closing correctly. Potential shutter problems include:

- Complete shutter failure
The shutter no longer operates at all.
- The shutter may be stuck open
Result is overexposed or smeared images.
- The shutter may be stuck closed;
Result is no images acquired.
- One leaf of the shutter may break and no longer actuate.
Worn shutters can continue to open and close but opening and closing times can change and/or become erratic.

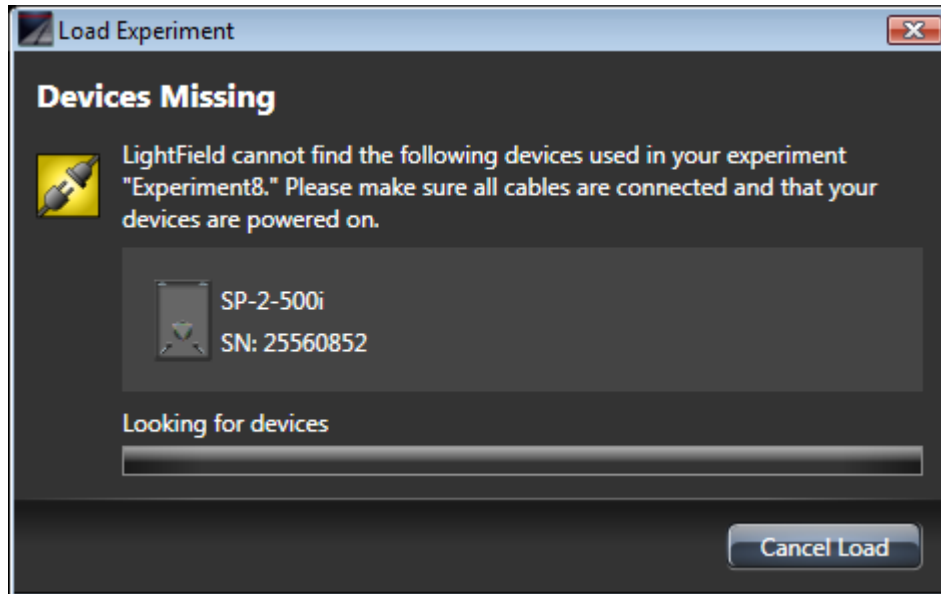
C.4 LightField Faults/Errors

This section provides information about troubleshooting problems that may occur with LightField.

C.4.1 Devices Missing

When LightField is started, it looks for devices that are powered on and connected via a communications interface to the host computer. If it cannot find a device that was used in the last experiment, the dialog shown in [Figure C-1](#) is displayed while LightField continues searching for the missing device.

Figure C-1: Devices Missing Dialog



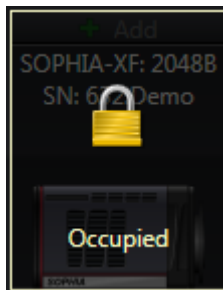
Perform the following steps to try to resolve this fault:

- Verify the device is connected and powered on.
If the device is connected but turned off, switch it on.
LightField should now find the device. If it does not, cancel the load and restart LightField.
- Cancel the loading of the experiment.
Canceling an experiment's loading means that the last used experiment will not be loaded automatically when LightField opens. However, the experiment may be loaded after all devices are available, a new experiment design can be started, or a different experiment can be loaded which uses the devices that are available.

C.4.2 Device is Occupied

Although multiple instances of LightField can be running at the same time, any device that is currently in use by one instance of LightField will be shown within the Available Devices area of all other instances as Occupied. See [Figure C-2](#).

Figure C-2: Typical LightField Occupied Device



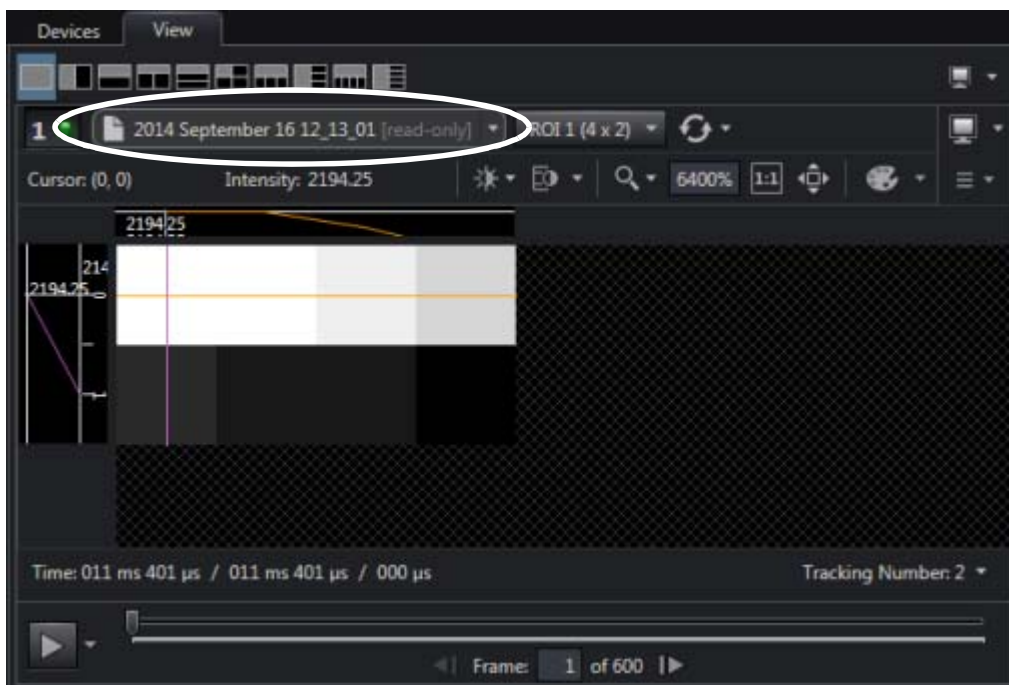
4411-0162_0071

To have a device become available to the current instance of LightField, either remove it from the Experiment Devices area in the other instance or close the instance that is using the device.

C.4.3 Acquisition Started but Viewer Display Does Not Update

Live data being acquired in either Preview or Acquire mode are displayed in a Data Viewer tab on the Experiment workspace. If the active Data Viewer's display is not being updated and data acquisition is occurring, determine if there is a filename displayed within the active Data View tab. See [Figure C-3](#).

Figure C-3: Typical Acquisition Display

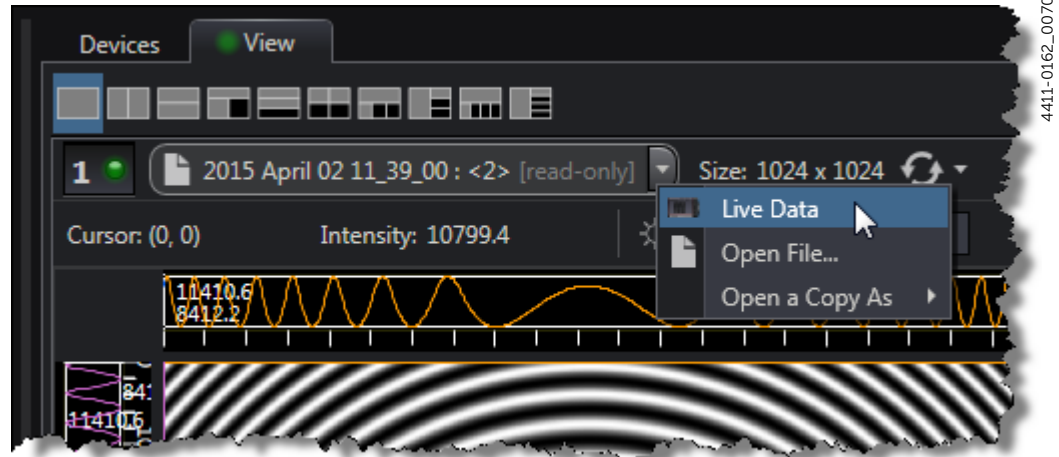


4411-0162_0069

When a filename is listed, it indicates that the data being displayed are static (i.e., data from the indicated file,) and not live data that are currently being acquired.

To return to a live data view, click on the  to the right of the filename to view the pull-down menu and select Live Data. See [Figure C-4](#).

Figure C-4: Data Viewer Menu



Warranty and Service

Limited Warranty

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

Basic Limited One (1) Year Warranty

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

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

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

XP Vacuum Chamber Limited Lifetime Warranty

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

Sealed Chamber Integrity Limited 12 Month Warranty

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

Vacuum Integrity Limited 12 Month Warranty

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

Image Intensifier Detector Limited One Year Warranty

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

X-Ray Detector Limited One Year Warranty

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

Software Limited Warranty

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

Owner's Manual and Troubleshooting

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

Your Responsibility

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

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

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

Contact Information

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

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

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

Fax: 1-609-587-1970

Customer Support E-mail: techsupport@princetoninstruments.com

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

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

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