OXFORD INSTRUMENTS ANDOR

Balor

Version 1.3 rev 18 February 2025

Hardware Guide

andor.oxinst.com

TABLE OF CONTENTS

Revision History

Version	Released	Description
1.0	14 Aug 2019	Initial release.
1.1	17 Jun 2020	Update to cooling safety information.
1.2	18 Jun 2024	Updated External Power Supply Requirements. Removed references to MyAndor. Removed old logo and updated cover. Updated Technical Support information. Minor update to cooling information.
1.3	18 Feb 2025	Updated Minimum Computer Requirements to include Windows 11 mention.

Updates to the Manual

Changes are periodically made to the product, and these will be incorporated into new editions of the manual. Please check for new releases of the manual at: andor.oxinst.com/downloads. If you find an issue in this manual, please contact your customer support representative, using the information from “1.1 Technical Support” on page 12, with a description of the issue.

Safety and Warning Information

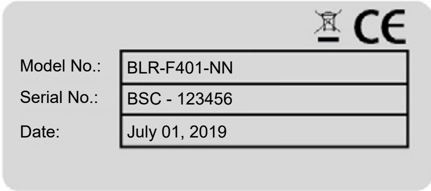
READ THIS INFORMATION FIRST

1. If the equipment is used in a manner not specified by Andor, the protection provided by the equipment may be impaired.
2. Before using the system, please follow and adhere to all warnings, safety, manual handling and operating instructions located either on the product or in this Hardware Guide.
3. Users must be authorized and trained personnel only; otherwise this may result in personal injury, and/ or equipment damage and impaired system performance.
4. There are no user-serviceable parts inside the product and the enclosure must not be opened. Only authorized service personnel may service this equipment.
5. Do not position this product so that it is difficult to operate the Mains Disconnecting Device. See SECTION 4.1, "Emergency Mains Disconnection".
6. Protective earth is an integral part of the protection against electric shock in this product, and is provided via the earth pin of the external power supply. Ensure that this is plugged into the building earth system via the mains socket. Do not tamper with any of the earthing measures.
7. Only the correctly specified mains supply should be used.
8. Only the AC/DC external power supply provided with the product should be used.
9. Only the power supply cord provided with the product should be used. Should this not be correct for your geographical area, contact your local Andor representative.
10. Make sure the power supply cord is located so that it will not be subject to damage. If replacement of the detachable power supply cord is required, ensure replacement is of same type and rating.
11. Performance of the system may be adversely affected by rapidly changing environmental conditions or operation outside of the operating conditions specified in "TECHNICAL SPECIFICATIONS"
12. While running an experiment, try to keep temperature as stable as possible.
13. This equipment has not been designed and manufactured for the medical diagnosis of patients.
14. Electromagnetic Compatibility: This is a Class A product. In a domestic environment this product may cause electromagnetic interference, in which case the user may be required to take adequate measures.
15. This product has been designed and tested to perform successfully in a normal (basic) electromagnetic environment, e.g. a typical test laboratory, as per the EU EMC Directive. It is not designed to operate in a harsh electromagnetic environment, e.g. close to the following equipment: EMI/RFI generators, electrostatic field generators, electromagnetic or radioactive devices, plasma sources, arc welders, x-ray instruments, intense pulsed sources, or other similar sources of high energy fields whose emissions are not within the normal range expected under the EU EMC Directive.
16. Please note that this product is not designed to provide protection from ionizing radiation. Any customer using this product in such an application should provide their own protection.
17. Your product is a precision scientific instrument containing fragile components. Always handle it with care.
18. Do not wet or spill liquids on the product, and do not store or place liquids on the product.
19. If spillage occurs on the product, switch off power immediately, and wipe off with a dry, lint-free cloth.

20. If any ingress of liquids has occurred or is suspected, unplug the mains cables, do not use, and contact Andor Customer Support.
21. Liquid Cooled Only models must be connected to a water/liquid cooling system that is switched on before the camera.
22. When using a liquid cooling system it is recommended that an overpressure device is fitted to avoid leaks that may find their way to the mains electricity supply and create a hazard. Refer to the information in SECTION 3.7 for general guidelines on the correct installation and use of a liquid cooling system.
23. See SECTION 5.1, “Cleaning and Decontamination”.
24. Do not expose the product to extreme hot or cold temperatures.
25. Do not expose the product to open flames.
26. Do not allow objects to fall on the product.
27. Keep this Hardware Guide in a safe place for future reference.

Warning and Safety Labels

The serial label of the Balor camera (below) is located on the back of the camera. It shows the product model, serial number and the build date.



Unpacking Information

Carefully unpack the unit and retain the packaging materials to transport or return equipment if required:

- If the equipment appears damaged in any way, return it to sales outlet in its original packaging.
- No responsibility for damage arising from the use of non-approved packaging will be accepted.
- Ensure all items and accessories specified at the time of ordering and as detailed on the packing list are present: if any items are missing, please contact your sales representative.
- The camera has a shipping cover - remove before use and store in a safe place so it may be used at a future time.

SECTION 1: INTRODUCTION

This manual provides an overview of the **Balor camera series**. Balor houses a large area high resolution 16.9 Megapixel sCMOS sensor and has cooling configurations to suit demanding applications such as Astrophysics and Astronomy or X-ray/Neutron radiography. This manual includes a description of the main features of Balor, its installation, routine operation and troubleshooting. It also provides a summary of some of the technical features of the Balor sCMOS camera series. For further information on operation and control of the Balor camera refer to the relevant software guide e.g. Solis, and to the Andor website for further technical information to help you get the best from your camera.

Figure 1: The large area Balor sCMOS Camera.

1.1 Technical Support

If you have any questions regarding the use of this equipment, please contact the representative* from whom your system was purchased, or:

Europe

Oxford Instruments Andor

7 Millennium Way

Springvale Business Park

Belfast

BT12 7AL

Northern Ireland

Tel. +44 (0) 28 9023 7126

USA

Oxford Instruments America Inc.

300 Baker Avenue

Suite # 150

Concord

MA 01742

USA

Tel. +1 (860) 290-9211

Asia-Pacific

Oxford Instruments KK

Sumitomo Fudosan Osaki Twin Building East,

5-1-18 Kita-Shinagawa,

Shinagawa-ku,

Tokyo141-0001,

Japan

Tel: +81(0)4510 3528

China

Oxford Instruments, China - Beijing

Floor 1, Building 17,

No.31 Xishiku Street, Xicheng Dist.

Beijing 100034

China

Tel: +86 (0)10 5884 7900

*** The latest contact details for your local representative can be found on the Contact and Support page of our website.**

1.2 Disclaimer

THE INFORMATION CONTAINED HEREIN IS PROVIDED “AS IS” WITHOUT WARRANTY, CONDITION OR REPRESENTATION OF ANY KIND, EITHER EXPRESS, IMPLIED, STATUTORY OR OTHERWISE, INCLUDING BUT NOT LIMITED TO, ANY WARRANTY OF MERCHANTABILITY, NON-INFRINGEMENT OR FITNESS FOR A PARTICULAR PURPOSE.

IN NO EVENT SHALL ANDOR BE LIABLE FOR ANY LOSS OR DAMAGE, WHETHER DIRECT, INDIRECT, SPECIAL, INCIDENTAL, CONSEQUENTIAL OR OTHERWISE HOWSOEVER CAUSED WHETHER ARISING IN CONTRACT, TORT OR OTHERWISE, ARISING OUT OF OR IN CONNECTION WITH THE USE OF THE INFORMATION PROVIDED HEREIN.

PLEASE NOTE, AI TRANSLATIONS OF THIS USER MANUAL MAY RESULT IN INCORRECT INFORMATION. IN THE EVENT OF A CONFLICT WITH A FOREIGN LANGUAGE TRANSLATION, ANDOR’S ENGLISH TRANSLATION WILL PREVAIL.

1.3 Copyright and Protective Notices

The publication of information in this documentation does not imply freedom from any patent or proprietary right of Andor Technology Ltd. or any third party.

1.4 Trademarks and Patent Information

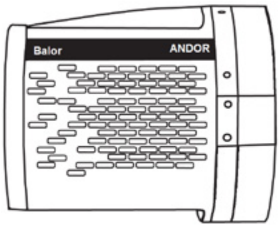
Andor and the Andor logo are trademarks of Andor Technology Ltd. Andor Technology Ltd. is an Oxford Instruments company. All other marks are property of their owners.

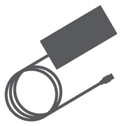
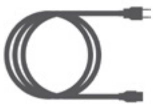
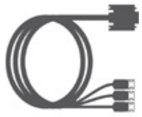
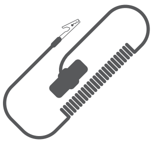
Balor Manufacturers Information

Oxford Instruments Andor,

Andor Technology Ltd., Belfast, BT12 7AL, UK.

1.5 Supplied Components

Description		Quantity
	Balor sCMOS Camera (model as ordered: refer to Section 1.5.1 Supplied with shipping plate fitted)	1

	**Software & Driver** (Solis is ordered separately)	1		Hardware Guide in electronic format	1
	Power Supply 1 x 15 V (Camera) 1 x 24 V (Camera TEC)	2		Power Cord (Country specific)	2
	CXP Card	1		Quick Start Guide	1
	CoaXPress Cable	1		Trigger Cable (BNC to D type)	1
	Anti-static Wrist band	1		Trigger Cable (BNC to SMB)	1
	Performance Sheet	1			
	Coolant hose inserts	2			

1.5.1 Balor Model Options

There are a number of models of Balor 17F-12 camera, based on the sensor variant and cooling performance (see also Section 2.1). The options for each model can be identified by the code suffixes added to the **BLR-** product code as outlined below:

Sensor	
Front illuminated sCMOS, 16.9 MP (4128[W] x 4104[H]) 12 µm pixels	**F401**

Cooling Options	
Liquid or air "Flexi"	**F**
Liquid Cooled Only	**W**

e.g. BLR-F401-W

Liquid Cooled Only (W)

1.5.2 Optional Accessories

A range of accessories are available for the Balor camera. Balor is intended only for use with accessories supplied and recommended by Andor. Please contact your local Andor representative if further information is required.

SECTION 2: PRODUCT OVERVIEW

This section provides an overview of the Balor. Please note that Balor configuration including housing, cooling connectivity and mounting flange may vary for your specific model. Please refer to the additional information supplied for details of any model specific differences.

2.1 External Features of the Balor

Figure 2: Balor large area sCMOS Camera.

Mounting Face

The standard configuration of mounting face has 8 x threaded holes for M5 bolts on 172 PCD. Refer to the additional supplied information or specification sheet appropriate for your specific model.

Sensor

Balor features a high resolution sCMOS sensor. Andor's unique UltraVac™ vacuum technology has been applied to the Balor camera. UltraVac provides a permanent hermetically sealed enclosure for maximum QE and cooling performance over many years operation.

Camera Window

There is a single AR coated UV grade silica window for optimum transmission. For more information on camera windows please see andor.oxinst.com/learning/view/article/camera-windows

Mounting Post Locations

Four sets of 2x ¼ -20 UNC mounting holes are located at each 90 degrees.

2.2 Rear Panel

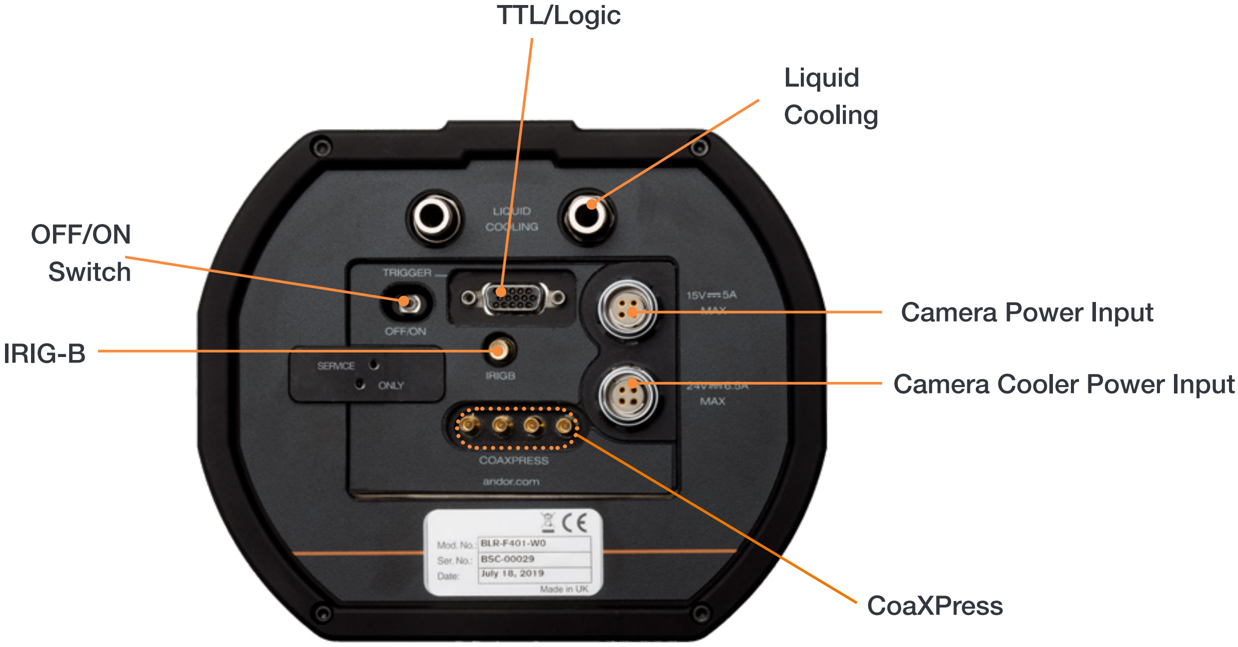


Figure 3: Rear panel.

CoaXPress

4 lane CoaXPress cable enables high speed connection to the control PC (@ 6.25 Gbps) at up to 25 m distances.

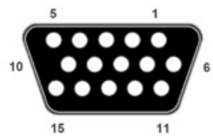
TTL / Logic

The TTL/Logic connection permit connection to other devices for synchronisation and control of fire, trigger and shutter operations. Connector type: D-type to BNC cable Fire (Output), External Trigger (Input), Shutter (Output).

Pinouts for the 15-way D type connector

Available using standard 3-way cable

Pin	3-way cable	Pin	3-way cable
1	ARM	9	Reserved
2	AUX_OUT_1	10	Reserved
3	Reserved	11	Reserved
4	Reserved	12	Reserved
5	Reserved	13	Reserved
6	Ground	14	Reserved
7	External Trigger	15	Reserved
8	Reserved		



Available using optional 7-way cable

Pin	7-way cable	Pin	7-way cable
1	ARM	9	Reserved
2	AUX_OUT_1	10	Reserved
3	FIRE N	11	Reserved
4	FIRE	12	Reserved
5	AUX_OUT_2	13	Reserved
6	Ground	14	Reserved
7	External Trigger	15	Reserved
8	Spare		

- **External Trigger** and **Spare** input are 5 V TTL input. By default they trigger on a rising edge
- **FIRE, FIRE N, Arm, AUX_OUT_1 and AUX_OUT_2** outputs are all TTL timing outputs
- **TTL I/O** can be individually inverted via software (e.g. Solis or SDK)
- **Pins 9 to 15** are reserved and should not be used

- **AUX_OUT_1** supplies the 'FIRE ALL' output by default. This is the logical AND of the FIRE pulses associated with Row #1 and Row #n (the last row read out in the image frame). Therefore the **FIRE ALL pulse represents the time within a frame when all rows on the sensor are simultaneously exposing**.
  AUX_OUT_1 is also configurable as FIRE, FIRE N and FIRE ANY. The **FIRE ANY pulse represents the time within a frame when any row of the image frame is exposing**. Refer to **Section 4** for the behaviour of these signals and to the SDK3 manual for configuring the AUX_OUT_1 output.
- **AUX_OUT_2:**
  1. Shutter (Default) – used to control an external shutter
  2. "Frame" clock – used to indicate when an image is being read from the sensor
  3. "Row" clock – used to indicate the "Row" period
  4. "Row" AND "FireAny" – used to indicate "Row" period during an exposure.

All other values reserved.

- **I/O Timing Interface cable** (Andor part number ACC-ACZ-05612) gives access to all of the above I/O functions (excluding Ground and Reserved).

Liquid Cooling Connections

Liquid cooling connections provide the facility for connection to a liquid cooling system. Refer to **Sections 3.6-3.8**.

WARNING: Liquid Cooled Only models must be connected to a water/liquid cooling system that is switched on and working before the camera is switched on.

Power Inputs: (Camera Power, Camera TEC)

Power input connection for connection to the PSU. Refer to **Section 2.3.**

Note: Minimum cable clearance required at rear of camera 150 mm.

2.3 Power Requirements

Ensure that the power connectors for the camera are inserted securely. The connectors are keyed to aid correct orientation. A 15 V DC External Power Supply supplies the camera electronics and a 24V DC External Power Supply supplies the Thermo-Electric Cooler. Refer to the Technical Specifications for the External Power Supply requirements

NOTES:

1. **The electrical mains leads should be certified for use in your country and in applicable countries the plug must be fitted with a 240 V 5 A fuse.**
2. **If users use any other power supplies than those that are supplied, they do so at their own risk.**

SECTION 3: INSTALLATION

WARNINGS:

- PRIOR TO COMMENCING INSTALLATION, THE USER SHOULD REFER TO THE SAFETY AND WARNING INFORMATION AND UNPACKING INSTRUCTIONS AT THE BEGINNING OF THIS MANUAL.
- THE BALOR WEIGHS ~9 KGS (~17.6 LBS). DUE CARE MUST BE TAKEN WHEN LIFTING THE CAMERA. ENSURE THAT THE MOUNTING AND CONNECTED ASSEMBLY IS SECURE AND ABLE TO SUPPORT THE WEIGHT OF THE CAMERA.
- POWER CABLING AND CONTROL CABLES SHOULD BE ROUTED TO PREVENT ACCIDENTS, DAMAGE AND ACCIDENTAL UNPLUGGING WHILE AVOIDING BEND RADII OF LESS THAN 30 MM.
- TEMPERATURE AND HUMIDITY MUST MEET THE SPECIFICATIONS DEFINED IN TECHNICAL SPECIFICATIONS.
- LIQUID COOLED ONLY MODELS MUST BE CONNECTED TO A WATER/LIQUID COOLING SYSTEM THAT IS OPERATING BEFORE THE CAMERA IS SWITCHED ON.

3.1 Transport and Storage Information

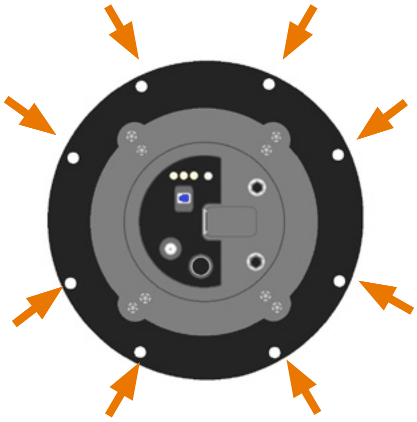
- The Balor is packed in normal transport packaging for shipping. Hard shell transport cases are available for the Balor for convenient and safe transport of the Balor to and from the installation site e.g. observatory. Please contact your sales representative for more information.
- Allow the product to reach the ambient temperature after unpacking- especially if moving from a colder environment to a warm environment as this may lead to condensation (see Section 6.1 for further information).

Storage

- Storage Temperature: -30°C to 50°C.
- If it is to be stored after use at a temperature below the coolant freezing point, ensure that all liquid coolant has been expelled from the camera.

3.2 Mounting the Balor using the Mounting Flange

The Balor mounting face features 8 off M5 tapped holes x10 deep on a 172 PCD. These can be used to secure the Balor camera to an appropriate mounting on a telescope or other optical system.



8 off M5 tapped holes x10 deep on a 172 PCD

3.3 Attaching to Mounting Posts

Four sets of 2x ¼ -20 UNC mounting holes are located at each 90 degrees.

For further information, refer to the mechanical drawings in **Appendix B**.

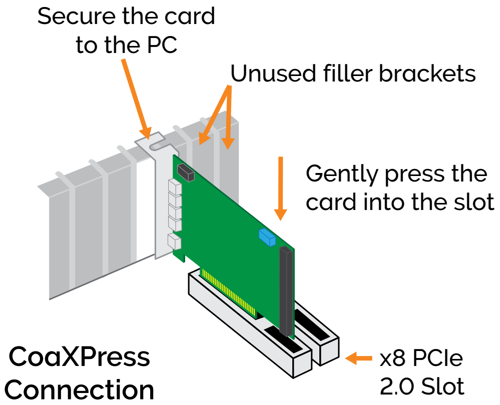
3.4 Connecting the Balor Camera to the PC

The Balor connects to a PC via CoaXPress (4 Lane CXP-6)- this enables a high speed connection over distances of up to 25 metres.

3.4.1 Installing the CXP Card in the PC

NOTE: Camera operation with PCIe cards not supplied by Andor cannot be guaranteed.

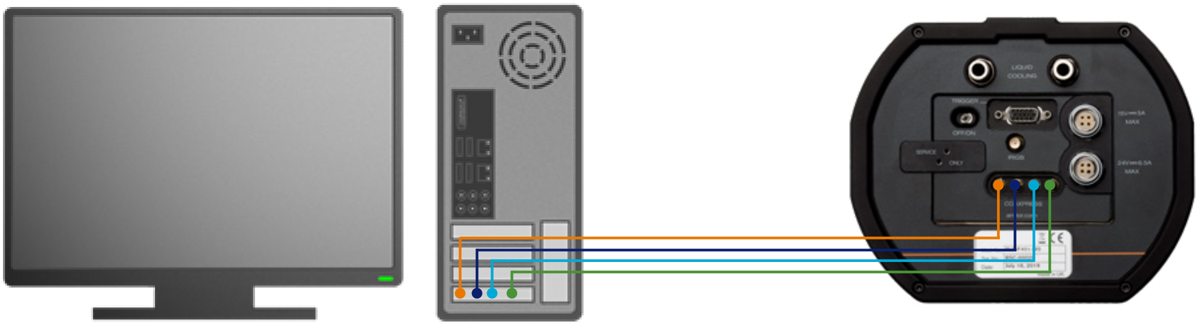
1. Turn off PC, unplug all cables from the rear of the computer.



2. Open the PC enclosure to gain access to the expansion slots.
3. Locate a suitable PCIe slot: use a minimum of x8 PCIe 2.0 slot.
4. If you are unsure which slot is correct, please consult the PC user manual.
5. Remove the filler bracket corresponding to the slot you intend to use.
6. Remove the controller card carefully from its protective ESD packaging and insert the card connector fully into the expansion slot.
7. Ensure the card's mounting bracket is flush with any other mounting or filler brackets to either side of it, then secure the controller card in place.
8. Replace the computer cover and secure with mounting screws if applicable.
9. Reconnect any accessories you were using previously.

3.4.2 Connecting the Camera to the CXP (PCIe) Card

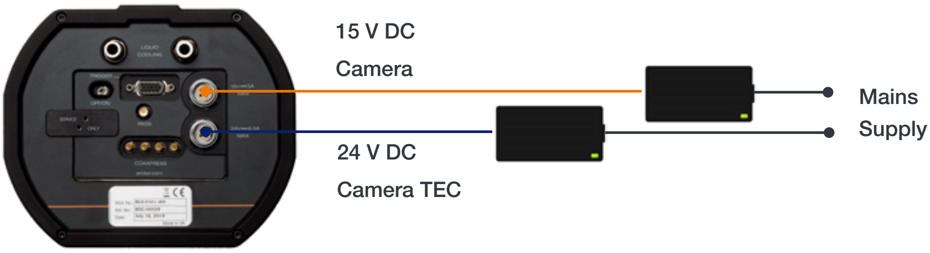
- Connect the 4 Lane CXP-6 cable from the camera to the CXP (PCIe) card on the control PC.



Note that the order of the CXP cables is not important- these are automatically configured by the camera and control card.

3.5 Connecting the Balor to the Power Supply

- Connect the mains power cable between the camera power input (15 V DC) and the 15 V DC Power Supply Unit.
- Connect the mains power cable between the camera TEC power input (24 V DC) and the 24 V DC Power Supply Unit.
- Connect PSU(s) to the mains power supply.



3.6 Connecting a Cooling System

The Balor camera is available as a Liquid Cooled Only or “Flexi” models. The Liquid Cooled Only model uses liquid cooling only so must be connected to an operational cooling system before it is switched on. This model has no internal fan or vents in the case, which limits thermal emissions in the immediate vicinity of the camera. The Flexi model can be configured for either air cooling, or optional liquid cooling.

3.6.1 Important Considerations when using Liquid Cooling Systems

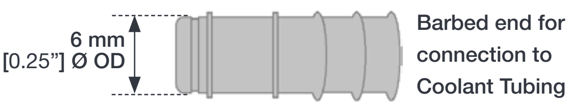
- **Before attempting to insert or remove the coolant hose connections, ensure that all coolant has been drained from the hoses and integral coolant channel within the camera head.**
- **Care must be taken to avoid permanent damage to the camera system resulting from either leakage of coolant during connection/removal of hoses or spillage of any residual coolant contained within the camera head once the hoses have been removed.**
- **Always ensure that the temperature of the liquid coolant circulated through the camera head is above the dew point of the camera ambient temperature and humidity conditions. Refer to the Dew Point graph in Appendix C for guidance.**
- **Use of coolant at or below the dew point can result in permanent damage to the camera head, due to formation of condensation on internal components.**
- **Never use damaged, split or worn hoses.**
- **The water cooling system of the camera is rated to 5 bar (500 kPa). If your water supply exceeds this value, then an overpressure safety device or regulator must be fitted to restrict the water pressure to less than or equal to this rating.**
- **In the event that replacement hose inserts/barbs are required, please contact your local Andor representative.**
- **Always remove residual coolant from the camera head if the camera is to be stored after operation- especially if the storage conditions are below the freezing point of the coolant.**

3.6.2 Cooling Hose Connectors

There are two cooling hose connectors (replacement part # MSC-10390) located on the rear plate for the connection of the Balor camera to a liquid cooling system.

Hose inserts are provided to enable connection to coolant hoses.

- **Coolant Hose Inserts:** Two barbed coolant hose inserts (replacement part # MSC-06489) are supplied as standard, suitable for connection to 6 mm [0.25”] internal diameter soft PVC tubing / hose.
- **Recommended tubing**: 10 mm [0.4”] outside diameter, i.e. a wall thickness of 2 mm [0.08”]. Alternative hose dimensions and materials should be thoroughly tested to ensure a leak tight seal is achieved with the barbed inserts.



Coolant Hose Connector

Coolant Tubing

3.7 Coolant Recommendations

Coolant temperature: Refer to the temperatures specified in Technical Specifications. Note that cooling performance may be affected by distance between camera head and cooler.

Recommended coolant: Water or water/ethylene glycol mix depending on the ambient environmental temperature during operation. De-ionized water (without additives) may be used as the coolant. Some mains supply water is heavily mineralised (i.e. “Hard”) which could cause deposits in the water circuit inside the camera. This can reduce the flow-rate and cooling efficiency.

Water can expand below +4°C and freeze somewhere around 0°C, so if you are operating or storing the product in these temperatures you should use an antifreeze. You should use ethylene glycol as we know that this works with the seals in the coolant system. Please follow the guidelines below if using ethylene glycol:

- Follow the manufacturer’s instructions in preparing a water/glycol mixture appropriate to the temperature that you are operating or storing the product.
- Ensure that your cooler, and coolant pipes and connectors will remain in working condition when exposed to ethylene glycol.
- Please note that it is better to empty your camera of coolant when storing in freezing conditions.

Please read the following warnings on the safe use of ethylene glycol:

- Drinking ethylene glycol, or products that contain it, can cause drunkenness-like symptoms, lung, heart and kidney damage, coma and potentially death.
- Ethylene glycol may cause irritation to the eyes.
- Long-term skin exposure to ethylene glycol may cause dermatitis.
- Follow your government’s and the chemical manufacturer’s advice for the safe use and handling of ethylene glycol, and for treating any incidents of exposure or contamination.

NOTE: The water cooling system of the camera is rated to 5 bar (500 kPa). If your water supply exceeds this value, then an overpressure safety device or regulator must be fitted to restrict the water pressure to less than or equal to this rating.

3.8 Connecting the Liquid Cooling System

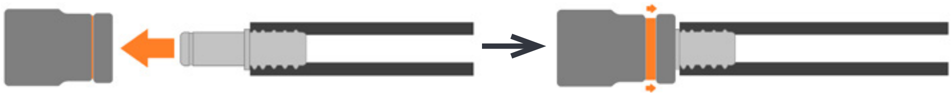
An overview for connecting a liquid cooling system is outlined below- please refer to the information supplied with your cooling system for further information.

Connect the coolant hoses between the camera and the liquid cooling system

3.8.1 Connecting the Coolant Hoses

1. Press the hose insert into the coolant hose, and repeat for the second hose.
2. Press the hose connectors into the connections on the camera head, ensure they click into place.
3. Confirm the hoses are connected securely by applying pressure on the front of the camera body and pulling backwards on each hose.

4. Connect the other ends of the coolant hoses to the cooling system- refer to the cooling system manual.



3.8.2 Disconnecting the Coolant Hoses

1. Press the latch on the camera hose connection away from the hose.
2. Hold the latch in and pull the hose backwards.
3. The hose should release from the camera connection with little resistance.

NOTE: If the hose does not release, ensure that the latch on the camera connection is pressed in fully.

3.9 Installing Software

3.9.1 Minimum Computer Requirements

- 3.0 GHz quad core processor or equivalent
- 16 GB RAM
- Hard drive: 3 GB/sec write speed recommended for the data rate associated with the max. frame rates. 200 MB free hard disc to install software x8 PCIe 2.0 slot.
- Windows (8.1, 10 or 11) or Linux 64-bit OS

3.9.2 Installing Solis Software and CXP Drivers

1. Terminate & exit any applications which are running on the PC.
2. Insert the Andor Solis CD. The InstallShield Wizard should now start. If it does not start automatically, run the setup.exe file directly from the CD.
3. Select appropriate location for installation of software and drivers on your computer / network.
4. Select **Balor**.
5. Continue installation and restart your computer - when prompted - to successfully complete the installation.
6. The shortcut icon for Solis will appear on the desktop on re-start.
7. The Balor is now ready to be connected to a PC / laptop and powered on.

3.9.3 Installing SDK

Andor SDK3 is a software development kit that allows you to control the Andor sCMOS cameras from your own application. Available as 64-bit libraries for Windows (8.1 and 10) and Linux. Compatible with C/C++, LabView and Matlab.

The most up to date version of Andor SDK can be downloaded from andor.oxinst.com/downloads/

3.9.4 Installing the CXP Card Drivers

If you are not using the Solis Software please take the following steps to install the CXP card drivers:

1. The CXP card driver should be detected automatically. If it is not it may need to be installed from the supplied software before use as they are not part of the SDK installation.
2. Refer to the supplied installation instructions for further information.
3. Ensure the latest drivers and firmware are installed.

NOTE: Ensure **sleep mode** functions of the PC are **deactivated**.

3.9.5 Checking & setting BIOS options (for PCs not supplied by Andor)

Enter the BIOS menu when starting PC. For Dell workstations, press F12 at start-up and select System Setup in the One Time Boot Menu. For Dell workstations 3 options in the Performance menu of the BIOS need to be checked/ set:

- C-States Control – Disable C-States
- Intel Speed-step – Disable Speed-step
- Memory Node Interleaving – Set from NUMA to SMP. Note: This option is only available on larger workstations with 2 physical processors and may have a different name- ensure that NUMA is disabled.

SECTION 4: OPERATION

WARNINGS:

- **IF THE EQUIPMENT IS USED IN A MANNER NOT SPECIFIED BY ANDOR OR ITS DISTRIBUTORS, THE PROTECTION PROVIDED BY THE EQUIPMENT MAY BE IMPAIRED.**
- **PLEASE READ THE USER GUIDES SUPPLIED WITH YOUR SYSTEM COMPONENTS AND CAMERA CONTROL SOFTWARE PRIOR TO USE.**

4.1 Emergency Mains Disconnection

In case of emergency, the disconnecting points of the equipment are the mains power cords connected to the external power supply, or the mains socket switches.

WARNING: SWITCH OFF THE POWER AT THE MAINS SOCKET AND REMOVE THE MAINS LEAD FROM THE EXTERNAL POWER SUPPLIES.

4.2 Power-up Sequence

1. Ensure that the camera is connected to the two mains power supplies.
2. Ensure that the CXP cable is connected between the camera and the PC.
3. Switch on the camera using the ON/OFF switch at the rear panel of the camera.
4. Start up the PC.
5. Launch your camera control software e.g. Solis
6. The camera will now start up under control of the software and you are ready to use the camera.
7. Refer to your software manual for set-up and image acquisition information.

4.3 Power-Down Sequence

1. Exit the camera control software.
2. Switch the camera off using the switch on the rear panel (Section 2.2).
3. If not using the camera for some time, disconnect from the mains power socket.

4.4 Using the Balor Camera

Once set-up the Balor camera is controlled through the camera control software. Please refer to the information supplied with the camera control software (available separately) for further details e.g. **Andor Solis** or **SDK3**. For information on the features available with the Balor please refer to the **remainder of Section 4**.

4.4.1 sCMOS Sensors: Structure and Operation

sCMOS technology has been developed specifically to overcome many of the limitations that have marred other scientific detector technologies, resulting in an imaging detector that provides exceptional performance for many applications.

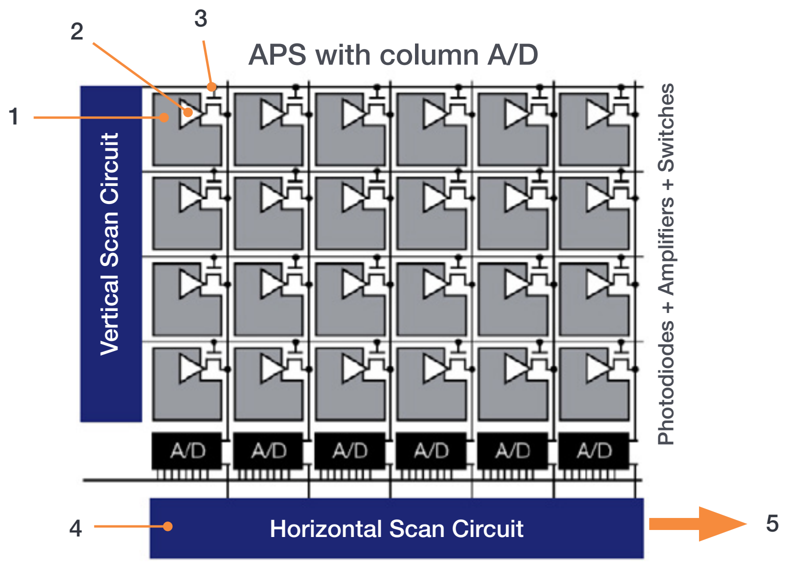


Figure 4: sCMOS sensor architecture.

An sCMOS sensor is an “Active Pixel Sensor” in that each pixel has its own integral amplifier. The basic operation is as follows:

1. Light (photons) hits the sensor and generates charge (electrons).
2. The photo-generated charge is converted to an analog voltage for each pixel amplifier.
3. These pixel voltages are transferred to the column bus via a row select signal.
4. The analog voltages are then converted to digital signals via columns of analog to digital (A/D) converters.
5. The final digitized signals are then read out at an effective pixel readout speed of up to 900 MHz.

sCMOS sensors provide benefits over more traditional CCD sensors in terms of speed and sensor size, making them ideal for many scientific applications. Please refer to the Andor website for a range of technical articles on sCMOS.

NOTES:

The diagram above is representative- the light sensitive area is contiguous as the photodiodes for each pixel are buried within the sensor. Each pixel also has a microlens to maximize sensitivity to light.

For Rolling Shutter mode operation, pixels in each row are exposed and the charge converted to a voltage simultaneously before being digitized then read out sequentially.

For Global Shutter mode, each pixel in the sensor begins an exposure simultaneously and then ends this exposure simultaneously.

4.4.2 Extended Dynamic Range (EDR)

Balor provides an exceptional dynamic range on account of the combination of low noise floor and high signal handling provided by the large well depth capacity.

Dynamic Range = well depth/noise floor

A multi amplifier architecture is utilised to enable both low noise, and maximum well depth to be used simultaneously. This delivers a very high linearity of >99.7% across this range allowing for quantitative analysis. When combined with the high frame rates and large sensor area this provides a lot of flexibility for how the camera may be used.

4.4.3 Binning

Binning is a process used for both CCD and sCMOS sensors in which the signal for a number of pixels is combined into a single array with a single signal output. For CCD sensors combining the charge from multiple pixels (in the analogue domain), e.g. 4 pixels (2x2 binning), into a single larger “super pixel” allows the signal to be digitized using a single read and therefore to have only a single read noise contribution from the digitization process (read noise is often the dominant noise source in CCDs). Binning is therefore commonly used for CCD cameras to increase the signal to noise ratio and speed of readout, at the expense of lower resolution. For further information refer to the technical note: CCD Binning.

However, for cameras with sCMOS sensors such as in the Andor Zyla, Neo, Sona, Marana and Balor models, the binning process is performed slightly differently. Binning is processed in the digital domain by the FPGA after the pixels have been readout- therefore there no speed increase (that would be observed in CCD cameras) from the reduced number of pixels being read out. After FPGA processing the pixel information is transmitted to the control PC - this may be faster when binning is applied under some conditions. For further information refer to the technical note: Binning in sCMOS cameras.

4.5 Modes of Sensor Operation: Rolling and Global Shutter

The sCMOS sensor used by the Balor offers a choice of both **Rolling** and **Global** Shutter, providing superior application flexibility. Rolling and Global Shutter modes describe two distinct sequences through which the image may be read off a sCMOS sensor. In Rolling Shutter, charge is transferred from each row in sequence during readout, whereas in Global Shutter mode each pixel in the sensor effectively ends the exposure simultaneously. However, lowest noise and fastest frame rates are achieved from Rolling Shutter mode.

Traditionally, most CMOS sensors offer either one or the other, but very rarely does the user have the choice of both from the same sensor.

4.5.1 Rolling Shutter

The Balor can function in what is termed Rolling Shutter operation. This describes the sequence in which successive rows of pixels are read from the sensor array in a "rolling wave" effect. In Rolling Shutter, adjacent rows of the array are exposed at slightly different times as the reset and readout waves sweep through the sensor. Each row will start and end its exposure slightly offset in time from its neighbour, but each row will have experienced the same exposure duration. The Rolling Shutter readout mechanism is illustrated in Figure 5 below.

Figure 5: An illustration of Rolling Shutter sensor exposure.

- At the start of an exposure, the "Reset" wave sweeps through the sensor clearing any accumulated charge from the pixels. The pixels then start accumulating light induced charge.
- At the end of the exposure, the "Readout" wave sweeps through the sensor, transferring the charge from each row into the readout node of each pixel.

A potential downside of Rolling Shutter is spatial distortion resulting from the above described exposure mechanism. This has historically been more apparent in devices such as CMOS camcorders, where the entire image field could be moved (for example by the user rapidly panning the camera) at a rate that the image readout could not match; thus, objects could appear angled compared to their actual orientation. In reality, despite the time-offset readout pattern, Rolling Shutter mode is appropriate for the majority of scientific applications, especially where the exposure time is equal to or greater than the sensor readout time, discussed later.

Rolling Shutter can also be operated in a '100% duty cycle' mode when capturing a kinetic series of images, whereby after each row has been read out it immediately enters its next exposure (no "Reset" wave). The exposure time and the cycle time are the same.

4.5.2 Global Shutter

Global Shutter mode, which can also be thought of as a 'snapshot' exposure mode, means that all pixels of the array are exposed simultaneously. In most respects, Global Shutter can be thought of as behaving like an Interline CCD sensor. Before the exposure begins, all pixels in the array will be held in a 'keep clean state', during which charge is drained into the anti-bloom structure of each pixel. At the start of the exposure each pixel simultaneously begins to collect charge and continues to do so for the duration of the exposure time. At the end of exposure each pixel transfers charge simultaneously to its readout node. Importantly, Global Shutter can be configured to operate in 100% duty cycle mode (analogous to Interline CCD), whereby an exposure can proceed as soon as the previous exposure has ended. This results in optimal time resolution and photon collection efficiency.

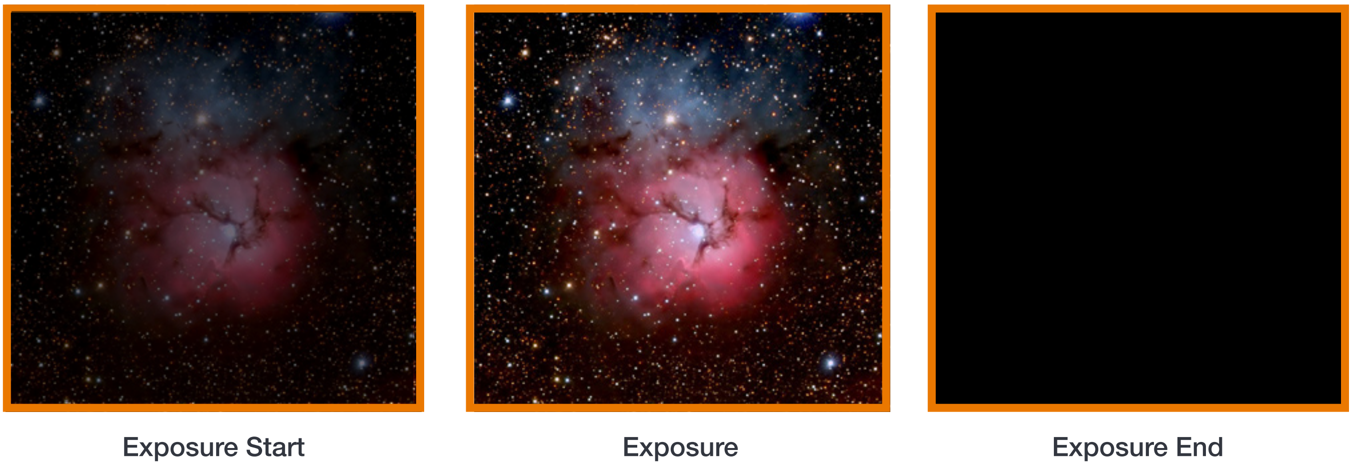


Figure 6: An illustration of Global Shutter sensor exposure.

However, the mechanism of Global Shutter mode demands that a reference readout is performed 'behind the scenes', in addition to the actual readout of charge from each pixel. Due to this additional reference readout, Global Shutter mode carries the trade-off of reducing the maximum frame rate that would otherwise have been achieved in Rolling Shutter mode. In addition, Global Shutter also increases the RMS read noise by a factor of ~1.4 over Rolling Shutter readout.

4.5.3 Selecting Rolling Shutter or Global Shutter

The selection of Rolling Shutter or Global Shutter modes depends on your specific experimental conditions. A summary of the key parameters for each mode is shown in Table 1:

Table 1: Key parameters of Rolling and Global Shutter modes.

Parameter	Rolling Shutter Mode	Global Shutter Mode
Frame rates	Maximum avaliable	Maximum frame rate significantly less than Rolling Shutter
Read Noise	Lowest	Higher by factor of ~1.4
Spatial distortion	Dependent on object dynamics	None

Rolling Shutter Mode: with the enhanced frame rates and lower noise, is likely to suit the majority of scientific applications. As long as the frame rate is such that the camera is temporally oversampling object dynamics within the image area, negligible spatial distortion will be observed. Such oversampling is good imaging practice, since it is undesirable to have an object travel a significant distance during a single exposure.

Global Shutter Mode: with its simpler readout scheme, to both understand and use (no skewed row exposures, easy to sync with light sources), Global Shutter will be the mode of choice for many users. Global Shutter will have a higher read noise and lower frame rate compared to Rolling Shutter. Some specific applications for which Global Shutter will be a necessity are shown in Section 4.5.4. Refer also to Andor Technical Note, Rolling and Global Shutter

4.5.4 Examples of Typical Applications for Global Shutter Mode

- **Applications that require exact time correlation between two (or more) points of an image that are separated vertically within the image:** In Rolling Shutter it takes 18 µs per row for the readout front to move across the image from the bottom upwards, reading out one row at a time. That means an object at the bottom of the image will begin and end an exposure ~18.5 ms before an object located at the very top (although remember that each object will be subject to the same overall exposure time). If a particular application requires that 'moving or changing' objects separated by relatively large distances (vertically) be subject to the same beginning and end of exposure, then Global Shutter mode is required.
- **Applications were every point in the image must be logged accurately (down to nanosecond accuracy) relative to a GPS timestamp.** In Global Shutter all pixels start the exposure simultaneously and all pixels end the exposure simultaneously.
- **Applications where relatively large objects in the image field are moving fast (relative to a Rolling Shutter readout sweep).** Rolling Shutter can sometimes create distortion effects under such circumstances, making Global Shutter a good option.
- **Applications that require 'microsecond' time gating synced to a pulsed light source: e.g. Laser Induced Breakdown Spectroscopy (LIBS).** Global readout involves a step that simultaneously transfers the signal charge of each pixel into the corresponding readout node for that pixel. This transfer step is 80 µs, facilitating fast exposure end, i.e. 'Electronic gating'
- **'Double Exposure' applications:** e.g. Particle Imaging Velocimetry (PIV), which requires that two back-to-back exposures are acquired with minimal time separation between them. The Global Shutter 80 µs transfer time into the readout node defines the minimum time between two consecutive exposures

4.5.5 Overview of the Rolling Shutter and Global Shutter Mechanisms

In Rolling Shutter mode, charge transfer happens on a per row basis whilst in Global Shutter charge transfer happens for the whole sensor or globally.

To read out a pixel in Rolling Shutter mode, the following occurs within the analog circuitry:

1. The read out node is reset
2. The node level (reference level) is sampled
3. Charge is transferred from photodiode to node
4. The node level (signal level) is sampled
5. Reference level (Step 2) is subtracted from signal level (Step 4) to get real signal

This process is commonly referred to as CDS (Correlated Double Sampling) and is done in the analog domain before digitization. The reason it is required is due to what is known as reset noise, this arises because every time the node is reset it does not settle at exactly the same level and hence the actual level must be measured (**Step 2.**) and subtracted from the signal level (**Step 4**) to get the real signal.

As mentioned above in Rolling Shutter charge transfer happens on a per row basis; therefore each row follows steps 1 – 5, until the entire sensor is read out. The disadvantage of this is that the start and end exposure time moves by the Row read out time for each subsequent row. So whilst each row of pixels is exposed for exactly the same length of time they do not all start and end at exactly the same time.

In Global Shutter the read out node reset and the charge transfer happen globally. Since the same read out circuitry is used for every row there is nowhere to store the measured reference level for every pixel and so a reference frame is digitized and read out from the sensor before the charge transfer occurs. Then the signal frame is digitized and read out from the sensor. The two are subtracted in the digital domain to get the 'real signal'. Reading two frames to get a real signal frame effectively doubles the cycle time when compared to Rolling Shutter.

4.6 Understanding Read Noise in sCMOS

sCMOS technology boasts an ultra-low read noise floor that significantly exceeds that of even the best CCDs, at such high pixel readout speeds. For those more accustomed to dealing with CCDs, it is useful to gain an understanding of the nature of read noise distribution in CMOS imaging sensors.

CCD architecture is such that the charge from each pixel is transferred through a common readout structure, at least in single output port CCDs, where charge is converted to voltage and amplified prior to digitization in the Analog to Digital Converter (ADC) of the camera. This results in each pixel being subject to the same readout noise. However, CMOS technology differs in that each individual pixel possesses its own readout structure for converting charge to voltage. During readout, voltage information from each pixel is fed directly to the appropriate amplifier/ADC, a row of pixels at a time (see Technical Note on Rolling and Global Shutter modes).

As a consequence of each pixel having its own individual readout structure, the overall readout noise in CMOS sensors is described as a distribution, as exemplified in Figure 7 below, which is a representative noise histogram from a Balor. It is standard to describe noise in CMOS technology by citing the median value of the distribution. In the data presented, the median value is 2.6 e- RMS.

This means that 50% of pixels have a noise less than 2.6 e-, and 50% have noise greater. While there will be a small percentage of pixels with noise greater than 6 e-, observable as the low-level tail towards the higher noise side of the histogram.

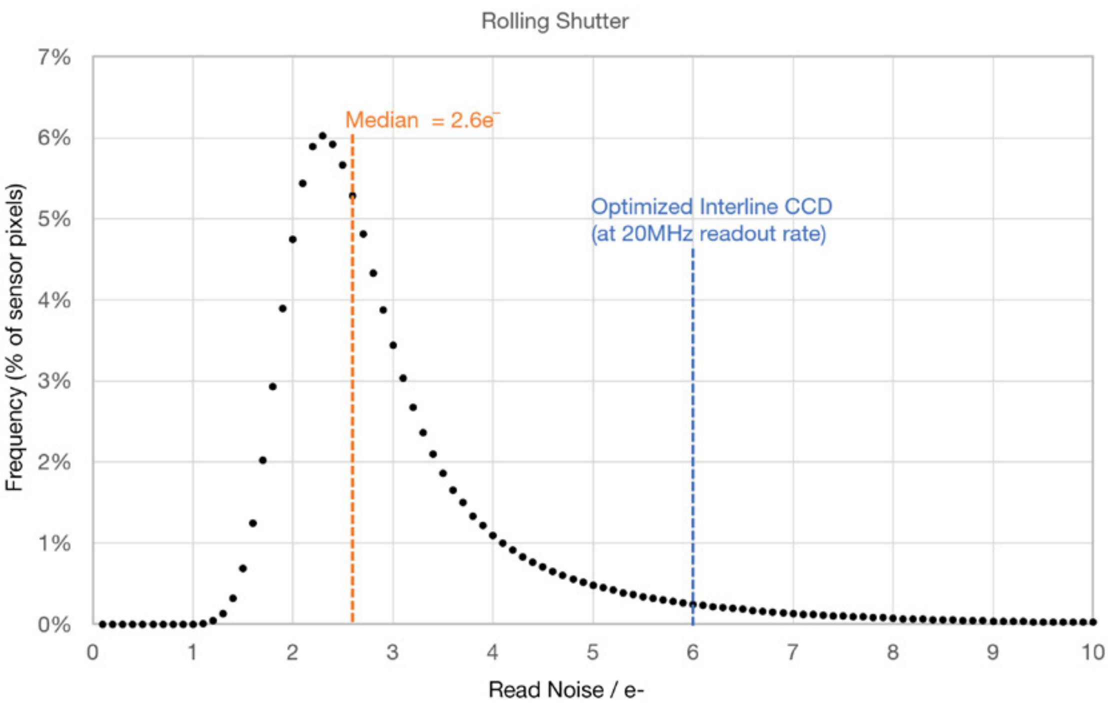


Figure 7: Representative histogram showing read noise distribution at fastest readout speed of the Balor. The line at 6 e- represents a typical read noise value from a well optimized Interline CCD – all pixels in a CCD essentially share the same noise value.

4.6.1 Spurious Noise Filter

The **Spurious Noise filter** corrects for pixels that would otherwise appear as spurious 'salt and pepper' noise spikes in the image. The appearance of such noisy pixels is analogous to the situation of Clock Induced Charge (CIC) noise spikes in EMCCD cameras, in that the overall noise of the sensor has been reduced to such a low level, that the remaining small percentage of spurious, high noise pixels can become an aesthetic issue. The filter actively corrects such high noise pixels, replacing them with the mean value of the neighbouring pixels. The filter can be switched on and off by the user prior to data acquisition.

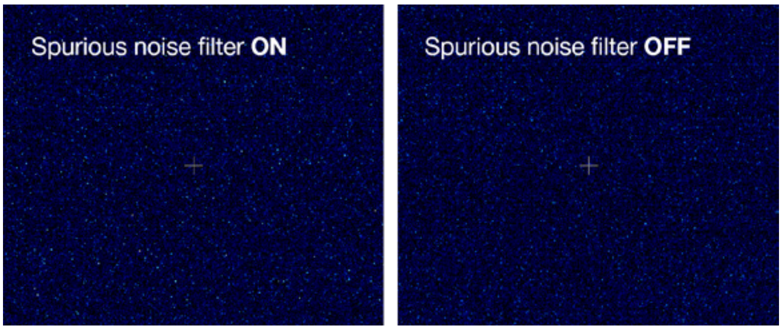


Figure 8: A demonstration of the effect of the Spurious Noise Filter, on a dark image, 20 ms exposure time.

4.6.2 Blemish Correction Filter

The **Blemish Correction Filter** identifies and compensates for three types of blemishes during the FPGA processing step:

1. Hot Pixels
2. Noisy Pixels
3. Unresponsive Pixels

sCMOS sensors are particularly susceptible to hot pixel blemishes. These are pixels that have significantly higher darkcurrent than the average. Through deep TE cooling of the sensor, it is possible to dramatically minimize the occurrence of such hot pixels within the sensor, and still use them for quantitative imaging. However, if the cooling is not sufficient to remove the hot pixels they are marked as blemishes and interpolative filters are used to correct them. These filters work by taking the mean of the surrounding 8 pixel values and replacing this hot pixel blemish with this mean value.

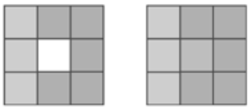


Figure 9: Hot, noisy or unresponsive pixel value (left) may be interpolated using values from the surrounding 8 pixels (right).

Such interpolation can be detrimental in some applications that depend on total quantitative integrity over a limited set of pixels (e.g. PALM and STORM techniques) as well as astronomy. In these applications it is essential for the user to be able to switch off interpolative corrections. Furthermore, having access to the location of these blemishes allows an accurate map of 'good' pixels to be determined by the user. The end user can request a 'hot pixel map' of their sCMOS sensor from Andor.

4.6.3 Multi amplifier dynamic range

The multi-amplifier architecture of the sCMOS sensor in Balor eliminates the need to choose between low noise or high capacity, and the signal can be sampled simultaneously by all amplifiers. As such, the lowest noise of the sensor can be harnessed alongside the maximum well depth, affording the widest possible dynamic range. Traditionally, scientific sensors including CCD, EMCCD, ICCD and CMOS, demanded that the user must select 'upfront' between high or low amplifier gain (i.e. sensitivity) settings, depending on whether they want to optimise for low noise or maximum well depth. Since the true dynamic range of a sensor is determined by the ratio of well depth divided by the noise floor detection limit, then choosing either high or low gain settings will restrict dynamic range by limiting the effective well depth or noise floor, respectively.

For example, consider a large pixel CCD, with 16-bit Analog to Digital Converter (ADC), offering a full well depth of 150,000 e- and lowest read noise floor of 3 e-. The gain sensitivity required to give lowest noise is 1 e-/ADU (or 'count') and the gain sensitivity required to harness the full well depth is 2.3 e-/ADU, but with a higher read noise of 5 e-. Therefore, it does not automatically follow that the available dynamic range of this sensor is given by 50,000:1 (=150,000/3). This is because the high sensitivity gain of 1 e-/ADU that is used to reach 3 e- noise means that the 16-bit ADC will top out at 65,536 e-, well short of the 150,000 e- available from the pixel. Therefore, the actual dynamic range available in 'low noise mode' is 65,536/3 = 21,843:1. Conversely, the lower sensitivity gain setting means that the ADC will top out at ~ 150,000 e-, but the higher read noise of 5 e- will still limit the dynamic range to 150,000/5 = 30,000:1 in this 'high well depth mode'. The sCMOS sensor offers a unique amplifier architecture, meaning that the signal from each pixel is first sampled in the analog domain to determine which gain channel to digitally sample the signal. This allows the signal in each pixel to be measured using the appropriate gain channel resulting in the final image exhibiting the full dynamic range of the sensor.

4.7 Sensor readout optimization

To allow the camera to be optimized for the widest range of applications it is important to have flexibility in the readout options available, some of these include the following:

- Shutter mode
- ROI sub image settings
- Triggering / Synchronization options (see Section 4.8 Trigger Modes)

Table 2: Maximum sustainable frame rates for all electronic shutter modes, readout speeds and gain channel combinations for various ROIs at a maximum frame rate of 16-bit.

	Rolling Shutter - 100% Duty Cycle	Rolling Shutter	Global Shutter - 100% Duty Cycle	Global Shutter
4128 x 4104	54	44	34	34
2048 x 2048	108	88	68	68
1920 x 1080	205	167	126	127
1024 x 1024	216	176	132	134
512 x 512	431	350	252	258
128 x 128	1684	1337	785	840

NOTE: The write speed of the PC hard drive can impose a further restriction on the maximum sustainable frame rate.

4.7.1 Using ROIs (AOIs)

Region of Interest (ROI) also called Area of Interest (AOI) can be selected so that only a defined region of the sensor is used. This smaller "cropped" region of the sensor can subsequently be read out much faster than the full sensor area so that frame rates may be significantly higher (see the preceding table). Pre-set ROIs may be selected as well as manually defined ROIs with a 1 pixel granularity [min size. 64 (h) x 64 (w)].

Figure 10: The ROI can be used to focus on a sub-region of an image.

4.8 Trigger Modes

Balor cameras have the following triggering modes:

- **Internal Trigger -** the camera determines the exact time when an exposure happens based on the acquisition settings entered by the user. This is the most basic trigger mode and requires no external intervention.
- **External Trigger -** the camera and software are in a high state of readiness to accept a trigger from an external source. Refer to Table 10 for the minimum pulse width required to guarantee a trigger. The external trigger is fed via the External Trigger input on the I/O Connector on the camera head (or via the External Trigger input on the CoaXPress card)
- **Software Trigger (Manual Trigger)** works in a similar manner to External Trigger mode whereby the camera and software are in a high state of readiness and can react extremely quickly to a trigger event issued via software in response to a key press or when the user needs to control other equipment between each exposure and does not know in advance how long such control will take or if the time taken changes randomly.
- **External Start** is a mode where the camera will wait for one external trigger event to occur after the acquisition sequence has been started. Once this external trigger event is detected, the camera will start the Internal Trigger read out process and will progress as if the camera was in internal trigger mode.
- **External Exposure Trigger** is a mode of operation where the exposure time and cycle time are controlled by the external trigger input.

The TTL inputs and outputs may be used to synchronize the camera operation with external events or equipment.

The individual outputs are described in the following sections 4.10.2 and 4.10.3.

The AUX_OUT_1 output can be configured via software (Solis or SDK3) to provide one of the following outputs: FIRE, FIRE N, FIRE ALL, or FIRE ANY. The default state provides FIRE ALL on this output.

The polarity of the TTL inputs and outputs can also be inverted (individually) via either Solis or SDK3.

NOTE: 'Row 1' is the first row read out in the image frame. 'Row N' is the last row read out in the image frame.

NOTE: Trigger diagrams are for outlining the events and timing of outputs in the various trigger modes and not to scale.

4.9 Rolling Shutter

4.9.1 Rolling Shutter Mechanism

The basic mechanism of Rolling shutter has previous been described, see section 4.5.5, this section looks in more detail at the read out under differing acquisition settings, for example exposure length, cycle time and triggering scheme. It also describes timing differences between Rolling Shutter and Rolling Shutter - 100% Duty Cycle.

In order to achieve the very high frames rates the Balor sensor simultaneously operates on 4 adjacent rows and hence all references to a row being reset actually results in 4 rows being reset and a row being read out results in 4 rows being read out. In the following timing tables a “Row Time” is the time taken to read out a group of 4 rows. To estimate how long it will take to read out an ROI which is 1000 rows high you need to take this grouping into account, hence the read out time is ~1000/4 * Row Time. The 4 row grouping is fixed in that rows 1-4, 5-8, 9-12 etc are always grouped, hence if the first row in an ROI is not the first row in a group extra rows will be required. This is all handled with the system and any extra rows read will not be transferred to the user.

With the Rolling Shutter - 100 Duty Cycle the readout of one exposure starts the exposure of the next and hence all exposure times are exact multiples of the Row Time (18 us in this case). However, for Rolling Shutter this is not the case and positions within the row readout for the pixel reset and charge transfer result in exposure times which are given by the formula “n*Row Time + 15 us” (Row Time = 22 us).

4.9.2 Rolling Shutter Signals

The Rolling Shutter signals in the diagrams are as follows:

- **EXT/SW:** Represents an external TTL trigger supplied to the camera or a trigger command sent via software in response to a user action (e.g. a button press).
- **FIRE 1**: (Exposure for Row 1): In Rolling Shutter mode, the FIRE output from the camera indicates to the user the exposure time for the first Row.
- **FIRE Row N**: (Exposure for Row N): The exposure for Row 2 is delayed by one Row time relative to Row 1, Row 3 is delayed by one Row time relative to Row 2, etc. for all rows in the frame (up to Row N). This signal is connected to an external output from the camera known as FIRE Row N.
- **FIRE ALL**: The FIRE ALL output from the camera indicates when all rows within a frame are being simultaneously exposed.
- **FIRE ANY**: The FIRE ANY output indicates when any Row within a frame is being exposed.
- **ARM**: The ARM output from the camera is used in external and software triggering modes to indicate when the camera is ready to accept an incoming trigger. If ARM is low when a trigger event occurs, it will be ignored.

Additional signals to aid end user understanding:

- **Global Clear**: The entire sensor can be held in a global clear state which ensures that there is no charge build-up on the sensor.
- **Frame Readout Phase**: This signal shows the period during which the signal frame is read out from the sensor.
-  : Marks the start of an exposure.
-  : Marks the end of an exposure.

4.9.3 Timing Parameters and External Triggering

The timing tables accompanying each of the triggering diagrams that follow indicate the exposure and cycle times achievable in each triggering mode. These are based on Frame and Row Periods as shown below.

Table 3: Timing parameters based on sensor clock speed.

Parameter		
	Rolling Shutter	100% Duty Cycle
1 Row	22 µs	18 µs
1 Full Frame	22.6 ms	18.5 ms
T_{res}	15 µs	0 µs

NOTE: Exposure time is set with a granualrity of 1 row i.e. EXP = n ^ RRT + T_{res}.

1 Row is the time taken to perform 616 (504 in Rolling Shutter - 100% Duty Cycle) clock cycles. The sensor read out is designed to digitise 4 rows simultaneously hence a Full Frame readout is 4104/4 rows x 616 clock cycles.

"T_{res}" is the extra time added to an exposure to account for the relative position within a Row Time of the start and end of an exposure.

For sub-images the frame readout time scales approximately with the number of rows being read out.

In External and External Start Triggering Modes, the minimum trigger pulse width detected by the camera is shown below in Table 4:

Table 4: Minimum EXT trigger width.

Parameter	Sensor Read out Rate
EXT Trig Pulse Width (2 clock cycles)	71 ns

4.9.4 Rolling Shutter Internal Triggering

Internal Trigger Mode allows the user to configure an exposure time and cycle time. For Internal Triggering, the exact acquisition sequence depends on the exposure time and cycle time set as shown in Figures 11 to 13. The following diagrams show the behaviour of TTL outputs 'FIRE', FIRE N', 'FIRE ALL' and 'FIRE ANY'.

Initially, the entire sensor is held in a global clear state to ensure that there is no charge build-up on the sensor, once the acquisition sequence starts the sensor switches to Rolling Shutter and a Reset phase starts. This starts the actual exposure. When the exposure period has completed, a signal frame read out phase begins. When safe a new continuous rolling reset is started and lasts until the user specified cycle time has been reached at which point a normal Reset phase is started to start the next exposure. This sequence continues until the full acquisition sequence specified by the user as completed.

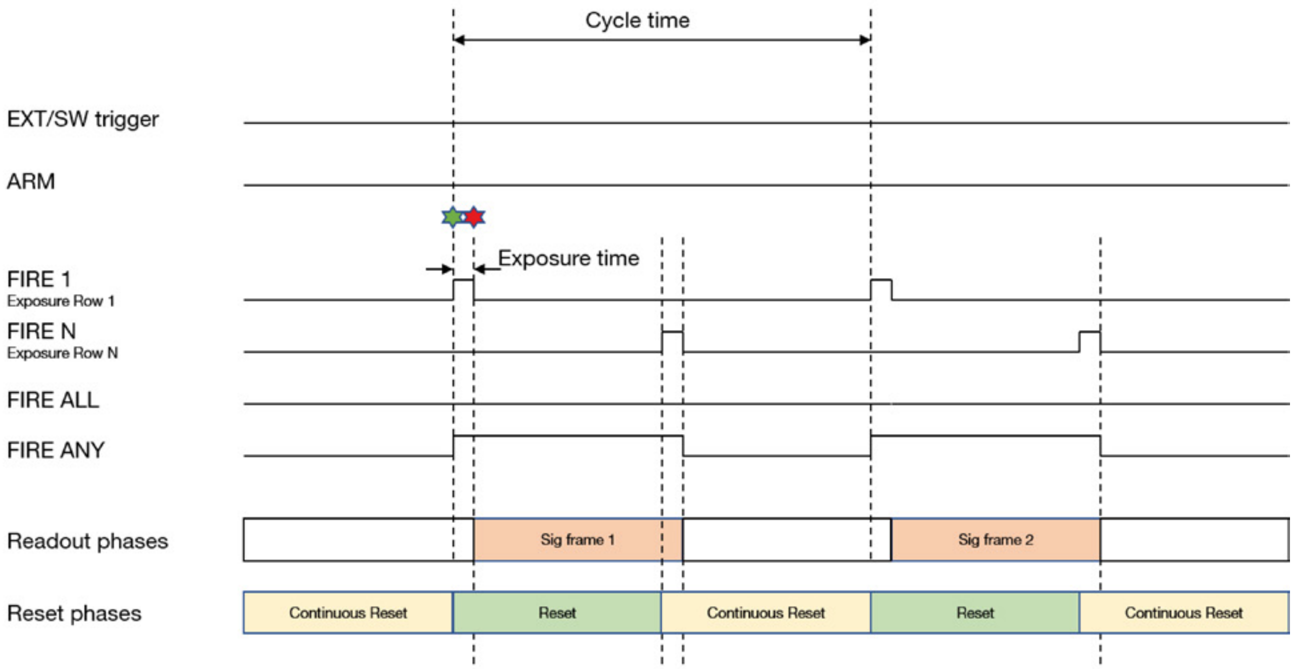


Figure 11: Rolling Shutter Internal Triggering (Part 1: exposure time < readout time).

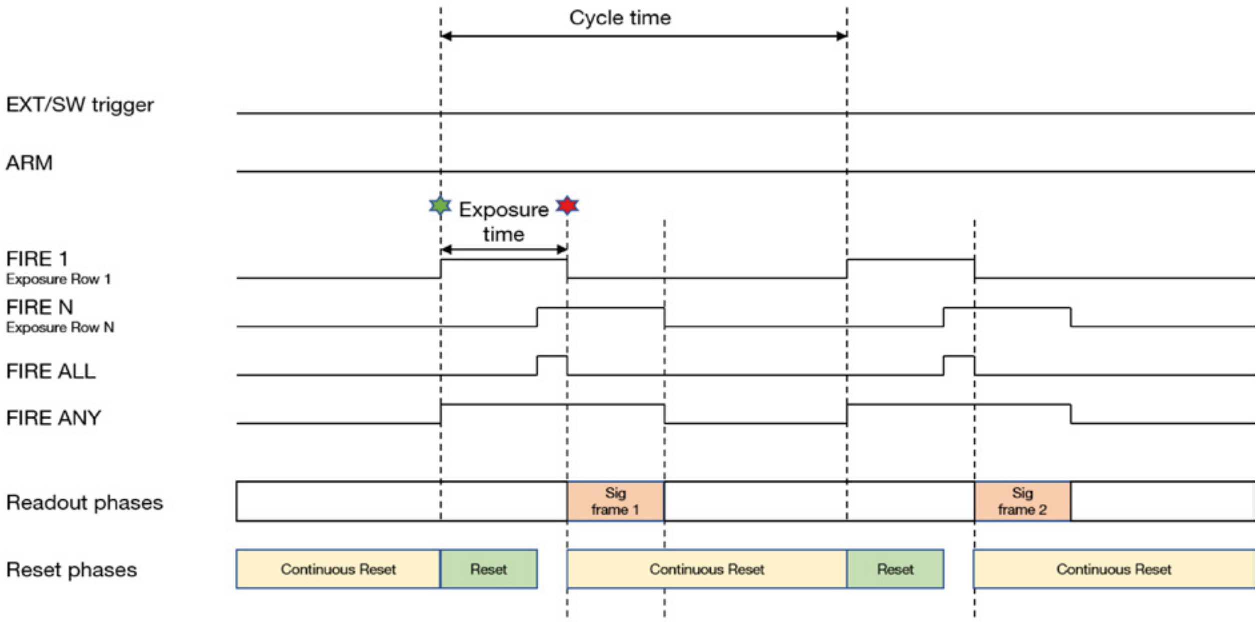


Figure 12: Rolling Shutter Internal Triggering (Part 2: exposure time > readout time).

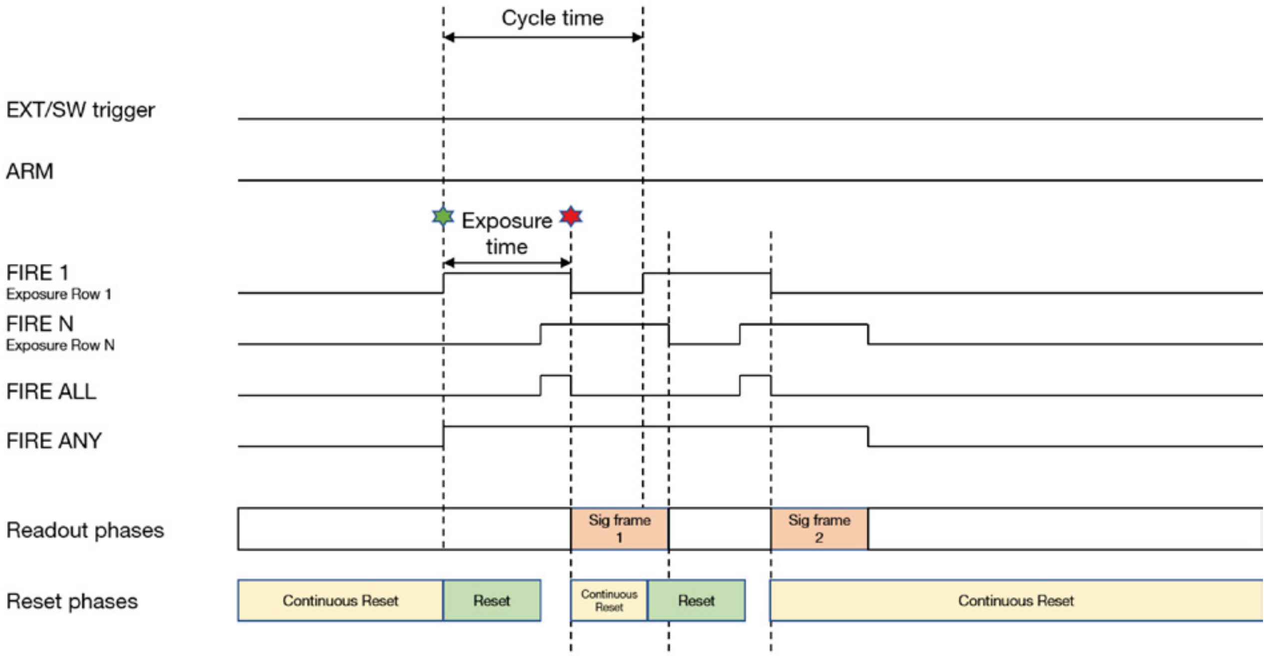


Figure 13: Rolling Shutter Internal Triggering (Part 3: Row 1, of the second exposure starts before, Row N, of the first exposure completes).

Table 5: Rolling Shutter Internal Triggering Timing Parameters.

Parameter	Minimum	Maximum
Exposure	1 Row	3600 s
Cycle Time (1/Frame Rate)	Maximum of: (Exposure + 4 Row) or (1 Frame + 2 Row)	20,000 s

* True minimum exposure time is the quoted value + T_{res}

4.9.5 Rolling Shutter - 100% Duty Cycle Internal Triggering

Rolling Shutter - 100% Duty Cycle in Internal Trigger maximizes the acquisition duty cycle and the frame rate by removing the Reset phase from the acquisition sequence. In this mode, the action of reading out also starts the next acquisition and hence the cycle time is the same as the exposure time.

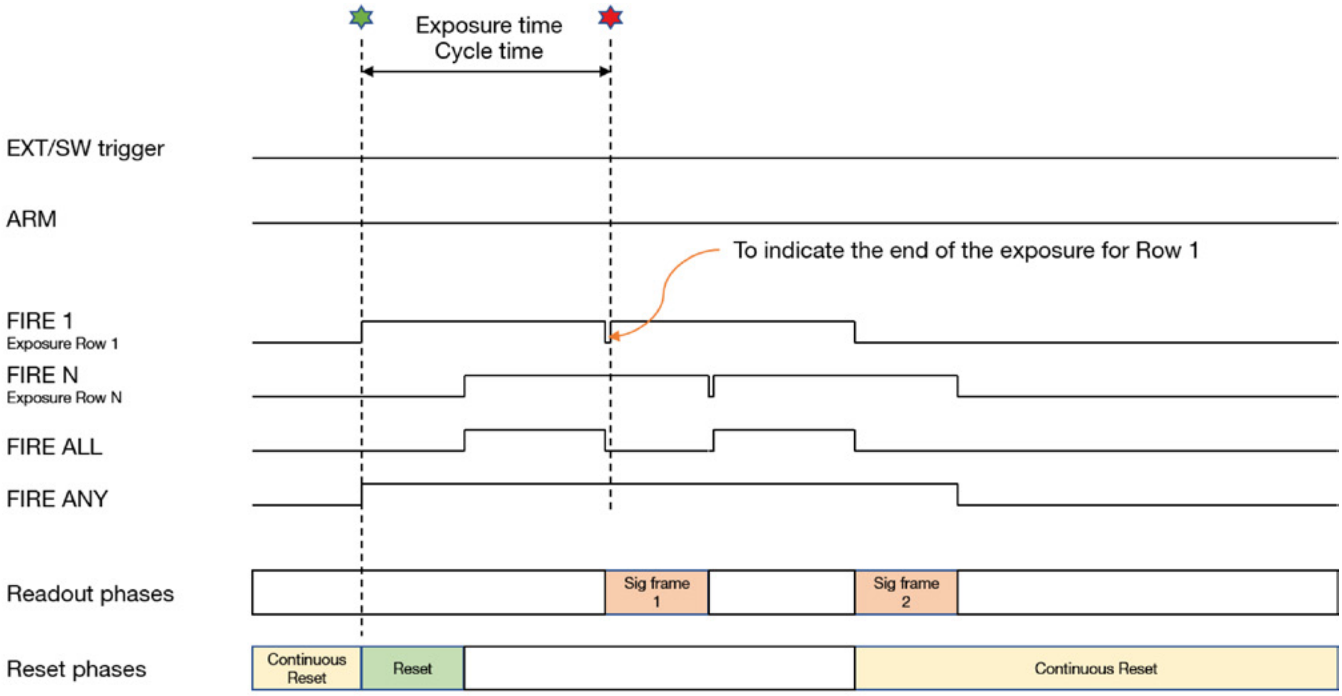


Figure 14: Rolling Shutter - 100% Duty Cycle - Internal Triggering.

Table 6: Rolling Shutter - 100% Duty Cycle Internal Triggering Timing Parameters.

Parameter	Minimum	Maximum
Exposure	1 Frame + 1 Row	3600 s
Cycle Time (1/Frame Rate)	Exposure time	Exposure time
FIRE ANY low period	1 Row	

4.9.6 External / Software Triggering

In this section, both External and Software Trigger are described in the same diagram as the acquisition sequence is the same. The trigger event can either be from the EXT Trigger input or sent via software. While waiting on the trigger event, the sensor is put into a “pre-scan read out cycle” which performs a continuous Rolling Reset which ensures that charge build up on the sensor is kept to a minimum while waiting for the trigger event. The ARM signal is asserted to indicate it is ready to detect an incoming trigger input.

Once the trigger event is detected, a Rolling Reset is initiated. When the exposure period has completed, a signal frame read out phase begins. Once the frame has been read out, the Arm signal goes high and the camera waits for the next trigger event to be detected.

The external trigger is fed via the EXT Trigger input on the I/O Connector on the camera head or via the EXT trigger input on the CoaXPress card.

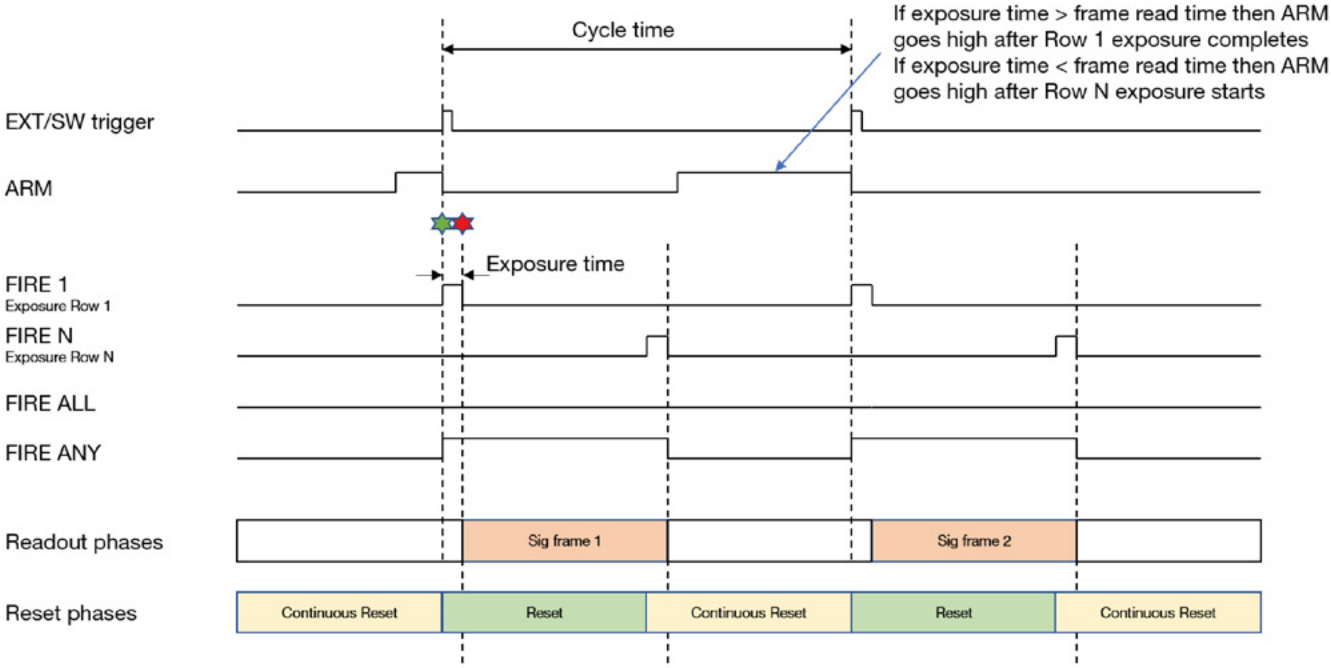


Figure 15: Rolling Shutter - External Triggering (Part 1: exposures separated).

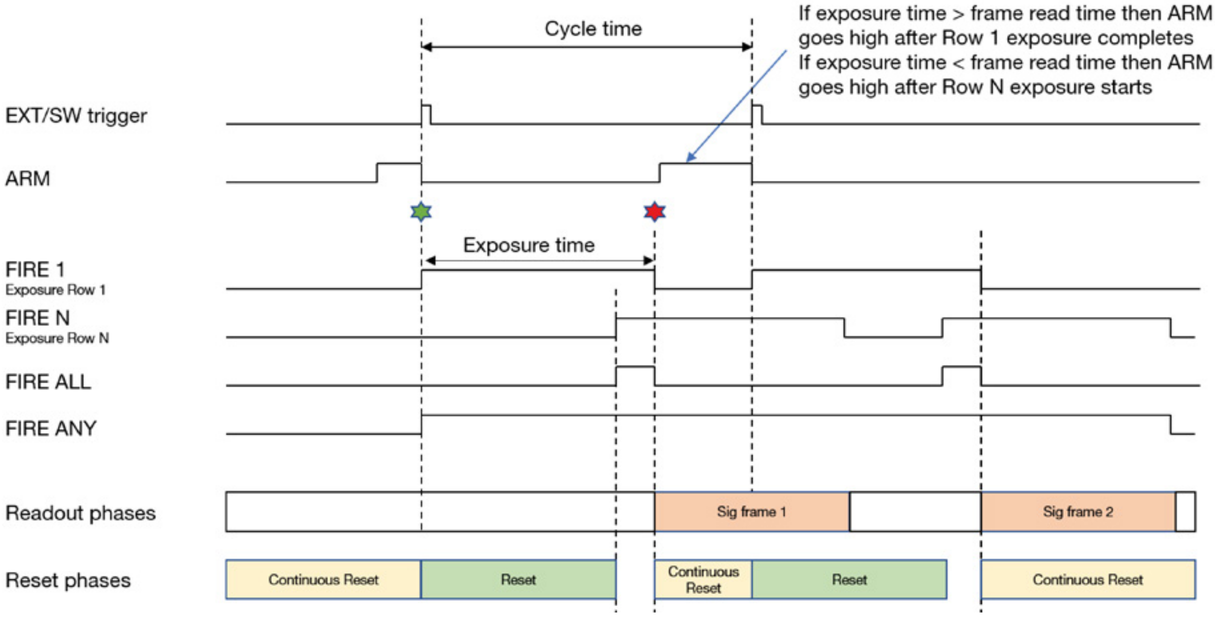


Figure 16: Rolling Shutter - External Triggering (Part 2: Second exposure starts before readout completes).

Table 7: Rolling Shutter External/Software Triggering Timing Parameters.

Parameter	Minimum	Maximum
Exposure	1 Row	3600 s
Cycle Time (1/Frame Rate)	Maximum (Exposure + 5 Row, 1 Frame + 3 Row)	-
EXT Trig Pulse Width	2 Sensor Speed Clock Cycles	-

* True minimum exposure time is the quoted value + T_{res}

4.9.7 Rolling Shutter External Exposure Triggering

While waiting on the trigger event, the sensor is put into a “pre-scan read out cycle” which performs a continuous Rolling Reset which ensures that charge build up on the sensor is kept to a minimum while waiting for the trigger event. The ARM signal is asserted to indicate it is ready to detect an incoming trigger input.

Once the trigger event is detected, a Rolling Reset is initiated. When the external trigger pulse goes LOW, a signal frame read out phase begins. Once the frame has been read out completely the Arm signal goes high and the camera waits for the next trigger event to be detected.

The external trigger pulse width defines the exposure time for all rows but is only coincident with the exposure time for Row 1. The exposure for Row 2 will be delayed by one Row time relative to Row 1 and so forth.

The period of the external trigger pulse defines the overall cycle time. If the width of the trigger event is less than 2 rows, the falling edge will be missed, and a subsequent falling edge will be required to end the exposure.

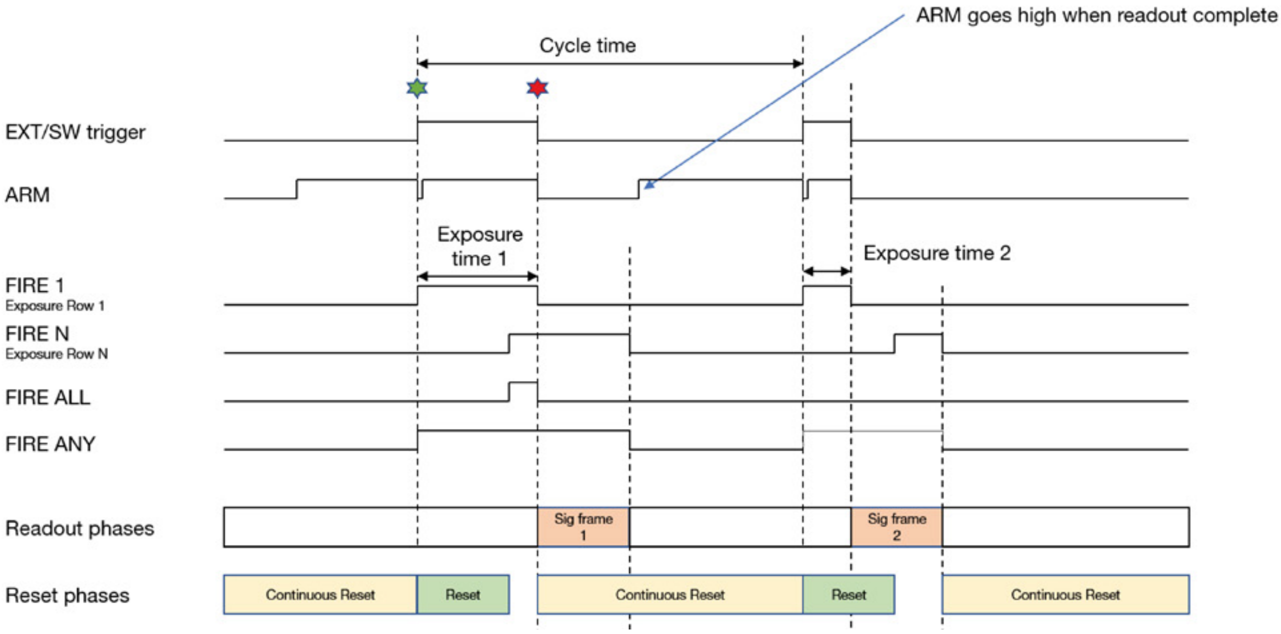


Figure 17: Rolling Shutter - External Exposure (Note exposure time can vary during series).

Table 8: Rolling Shutter External Exposure Triggering Timing Parameters.

Parameter	Minimum	Maximum
Exposure	2 Rows	3600 s
Cycle Time (EXT Trig Period)	Exposure + 1 Frame + 3 Row	-
EXT Trig Pulse Width	2 Rows	-

* True minimum exposure time is the quoted value + T_{res}

4.9.8 Rolling Shutter - 100% Duty Cycle External Exposure Triggering

In this mode, every positive edge of the external trigger will initiate a frame read out and start a new exposure. The period of external trigger pulse defines exposure and cycle time for each frame read out.

On detection of the first positive edge, a frame read out is initiated, this frame is discarded as it does not contain the correct exposure period. Reading out this first frame effectively begins the first exposure. When the next positive edge of the external trigger is detected, a signal frame read out phase begins, ending the first exposure and starting the next.

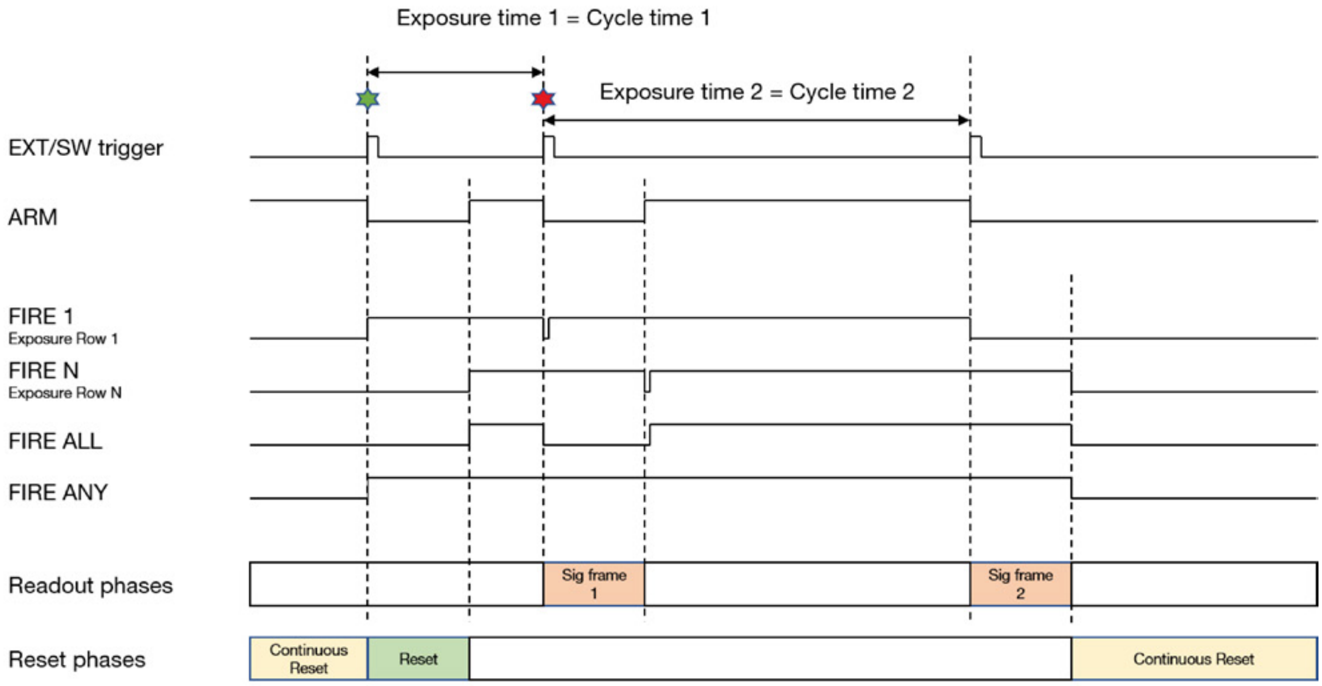


Figure 18: Rolling Shutter - 100% Duty Cycle - External Exposure.

Table 9: Rolling Shutter - 100% Duty Cycle External Exposure Triggering.

Parameter	Minimum	Maximum
Exposure	1 Frame + 3 Row	3600 s
Cycle Time (EXT Trig Period)	Exposure	-
External Delay	1	2 Row
EXT Trig Pulse Width	2 Sensor Speed Clock Cycles	-
FIRE low period	1 Row	-

4.9.9 Rolling Shutter Start Triggering

In this mode the camera will wait for a single external trigger event. Once this external trigger event is detected, the camera will progress as if the camera was in internal trigger mode (see Section 4.10.4). The ARM signal indicates to the user when the camera is ready to detect an External Start Trigger. The delay from the External Trigger to start of exposure is 1 Row.

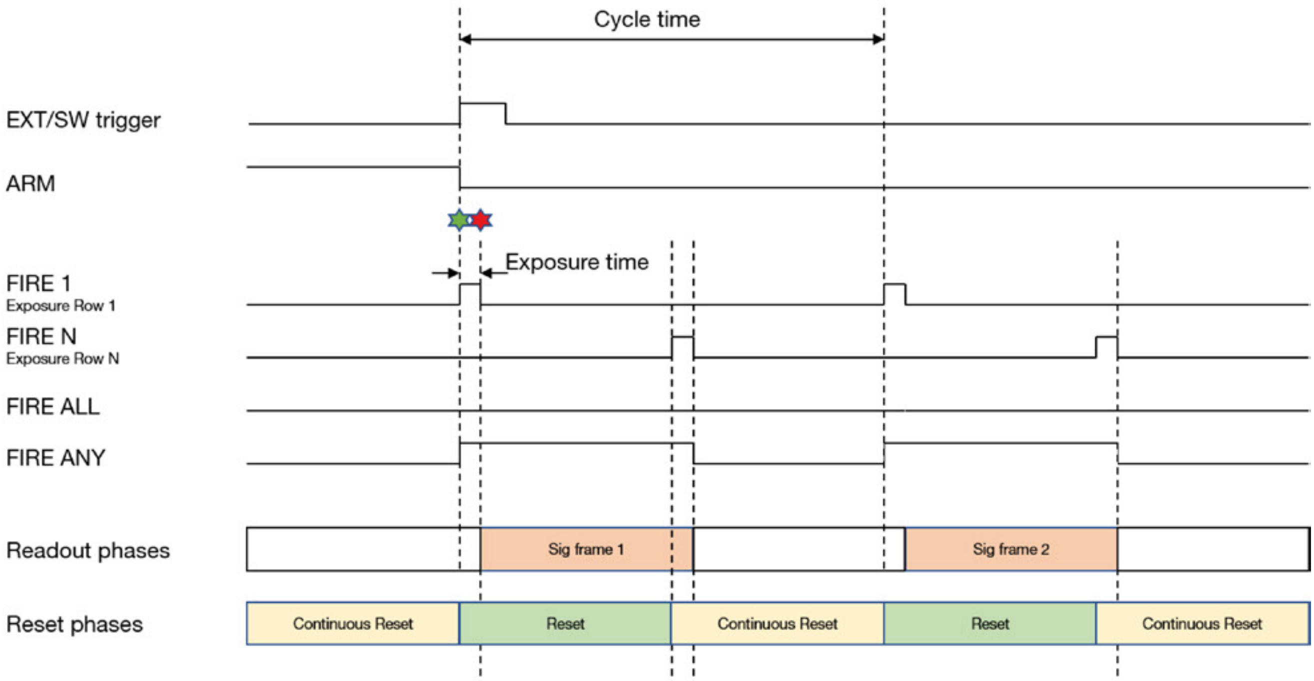


Figure 19: Rolling Shutter - External Start Triggering.

4.9.10 Rolling Shutter Triggering Constraints

Table 10 below shows a summary of constraints when operating in Rolling Shutter mode:

Table 10: Summary of Rolling Shutter constraints.

Rolling Shutter Triggering Modes		Exposure Range	Max Trigger Jitter	Min Trigger Pulse Width	Fast Exposure Switching
Internal	User settable exposure time and Cycle time	1 Row to 3600 s	-	-	✓
Internal (Rolling Shutter - 100% Duty Cycle)	User settable exposure time	(1 Frame + 1 Row) to 3600 s	-	-	✓
External/Software	User settable exposure Time. Cycle time controlled via period of external trigger pulse	1 Row to 3600 s	1 Row	2 Sensor Clocks	✓
External Exposure	Exposure time controlled by width of external trigger pulse. Cycle time controlled via period of external trigger pulse	2 Rows to 3600 s	1 Row	2 Sensor Clocks	✗
External Exposure (Rolling Shutter - 100% Duty Cycle)	Exposure time controlled by period of external trigger pulse	(1 Frame + 3 Rows) to 3600 s	1 Row	2 Sensor Clocks	✗
External Start	User settable exposure time. User settable Cycle Time.	1 Row to 3600 s	1 Row (4 Row delay)	2 Sensor Clocks	✓

NOTES:

1. **Exposure time granularity for all modes is sensor Row based so the exposure time in the dialog will always be rounded to the nearest integer number of Row Readout times (+ T_{res})**
2. **1 Row is the time taken to perform a full Row Readout.**
3. **1 Frame is the image height rounded up to a multiple of 4. The Frame Readout time for any ROI can be requested via the SDK3 (refer to SDK3 User Guide for details).**

4.10 Global Shutter

4.10.1 Global Shutter Mechanism

Global Shutter can also be thought of as a 'snapshot' exposure mode, meaning that all pixels of the array are exposed simultaneously. Before the exposure begins, all pixels in the array are cleared of charge using the Global Clear. At the start of the exposure each pixel simultaneously begins to collect charge and is allowed to do so for the duration of the exposure time. At the end of exposure, all pixels transfer their accumulated charge simultaneously to their read out node. In order to obtain a low read noise Global Shutter requires a reference frame to be read out of the sensor in addition to the signal frame, this effectively halves the frame rate that could have been achieved in Rolling Shutter mode.

4.10.2 Global Shutter Signals

The Global Shutter signals shown in the diagrams are as follows:

- **EXT/SW Trigger:** Represents an external TTL trigger supplied to the camera or a trigger command sent via software in response to a user action (e.g. a button press).
- **FIRE**: In Global Shutter mode, the FIRE output indicates the exposure period, which is identical for all pixels. This pulse is available to the user via the FIRE output pin. **NOTE: In Global Shutter Mode the behaviour of FIRE Row N, FIRE ALL and FIRE ANY are identical to that of FIRE and therefore not shown in the diagrams.**
- **ARM**: The ARM output from the camera is used for external and software triggering modes to indicate when the camera is ready to accept another incoming trigger pulse.

Additional signal to aid end user understanding:

- **Global Clear**: Global Shutter uses Global Clear to begin a new exposure. When this pulse is HIGH, charge is drained from every pixel thus preventing the accumulation of charge on the sensor. When the pulse is LOW, any photo-electrons generated are accumulating within the pixels, ready for transfer to the sense node for subsequent readout. The falling edge indicates the start of an exposure.
- **Charge Transfer**: This signal indicates when charge in the pixel is transferred to the measurement node and effectively ends the exposure. The charge is transferred while the pulse is HIGH and is shown in the diagrams to indicate there is a specified time between reading out the reference and signal frames.
- **Frame Read Out Phase**: This signal indicates when reference and signal frames are read out of the sensor.
- : Marks the start of an exposure.
- : Marks the end of an exposure.

4.10.3 Timing Parameters and External Triggering

The timing tables accompanying each of the triggering diagrams that follow indicate the exposure and cycle times achievable in each triggering mode. These are based on Frame and Row Periods as shown below:

Table 11: Timing parameters based on Sensor Clock Speed for Global Shutter.

Parameter	Time
1 Row (392 clock cycles)	14 µs
1 Full Frame (4104 Rows)	14.36 ms
Charge Transfer Time	80 µs

1 Row is the time taken to perform 392 clock cycles. The sensor read out is designed to digitise 4 rows simultaneously hence a full Frame readout is 4104/4 rows x 392 clock cycles.

4.10.4 Global Shutter Internal Triggering

In Global Shutter Internal Triggering, a new exposure cannot start until the previous exposure has been read out. The exact acquisition sequence depends on the exposure time. The two scenarios are shown in Figure 20 and Figure 21. If the exposure time is less than the time it takes to read out a frame, then the exposure period occurs between reading out the reference and the signal frames as shown in Figure 20.

In this scenario, the reference frame is read out before the Global Clear is performed. The negative edge of the Global Clear begins an exposure. After the user-defined exposure time, the Charge Transfer signal is applied to transfer charge from all pixels in the sensor. The signal frame is then read out.

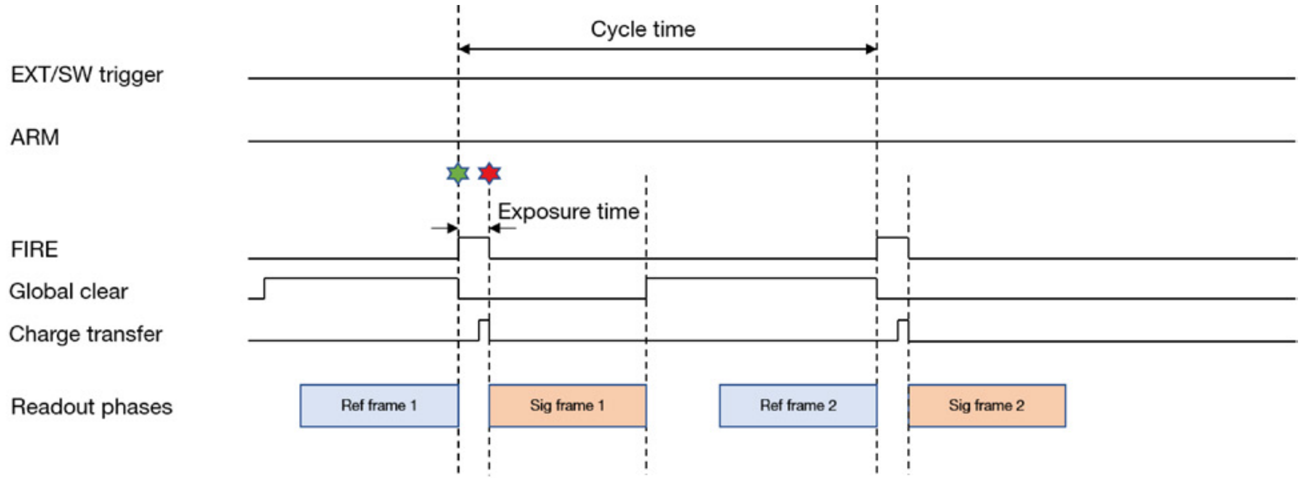


Figure 20: Global Shutter Internal Triggering – Short Exposures.

Table 12: Global Shutter Internal Triggering - Short Exposures Timing Parameters.

Parameter	Minimum	Maximum
Exposure	8 Rows	1 Frame + 20 Rows
Cycle Time (1/Frame Rate)	Exposure + 2 Frames + 13 Rows	20,000 s

If the exposure time is greater than a frame read out time, the exposure starts first by pulsing the Global Clear. The Reference frame is read out during the exposure such that the end of the Reference read out is coincident with the end of the exposure. The Charge Transfer pulse then is applied to transfer charge from all pixels in the sensor. Finally, the signal frame is then read as shown below in Figure 21.

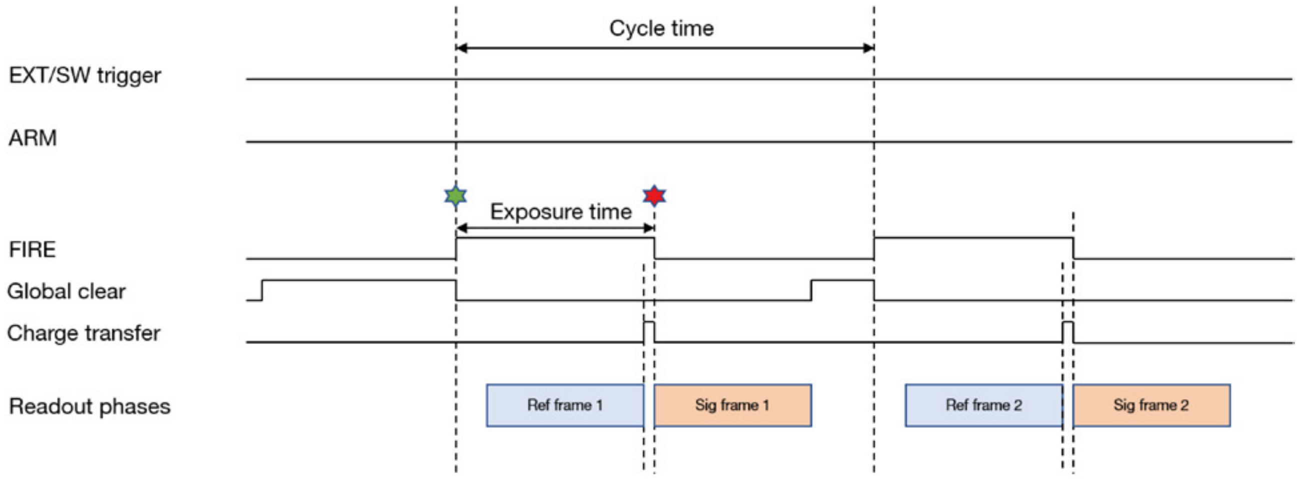


Figure 21: Global Shutter Internal Triggering – Long Exposures.

Table 13: Global Shutter Internal Triggering - Long Exposures Timing Parameters.

Parameter	Minimum	Maximum
Exposure	1 Frame + 21 Rows	3600 s
Cycle Time (1/Frame Rate)	Exposure + 1 Frames + 6 Rows	20,000 s

4.10.5 Global Shutter - 100% Duty Cycle Internal Triggering

Global Shutter - 100% Duty Cycle maximizes the frame rate achievable for a given exposure time by starting the next exposure as soon as the current exposure finishes. This, however, reduces the flexibility of the acquisition sequence as the exposure time and the cycle time are same. The minimum exposure time is also limited to the time is takes to read out both the Reference and Signal frames.

In this scenario, the exposure begins by pulsing the Charge Transfer. A signal frame is read out but discarded. The reference frame is also read out during the exposure such that the end of the Reference read out is coincident with the end of the exposure. The Charge Transfer is pulsed HIGH to transfer charge from all pixels in the sensor, this also starts the next exposure. The signal frame is then read out.

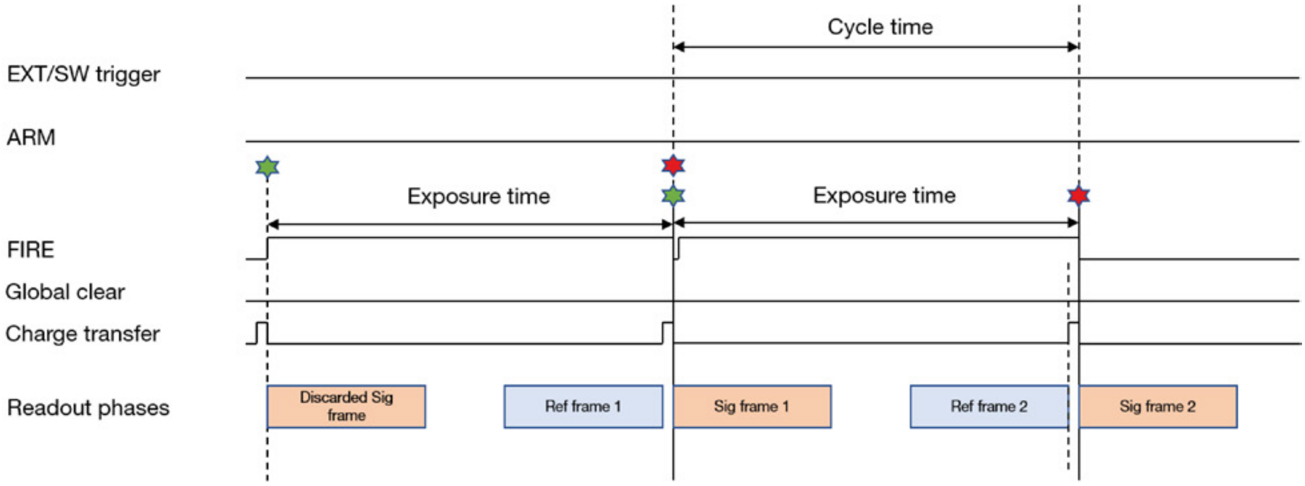


Figure 22: Global Shutter - 100% Duty Cycle Internal Triggering.

Table 14: Global Shutter - 100% Duty Cycle Internal Triggering Parameters - cycle time dependency on exposure.

Parameter	Minimum	Maximum
Exposure	2 Frame + 27 Rows	3600 s
Cycle Time (1/Frame Rate)	Exposure	Exposure

4.10.6 External/Software Triggering

In this section, both External and Software Trigger are described in the same diagram as the acquisition sequence is the same. The trigger event can be supplied either from the external input or sent via software. While waiting on the trigger event, the sensor is put into a “pre-scan read out cycle”. On detection of the trigger, the Global Clear line is pulsed to clear the charge and start the exposure from the sensor. The exposure period lasts for the user defined exposure time. The reference frame is read out during the exposure such that the end of the reference read out is coincident with the end of the exposure. The Charge Transfer pulse then goes HIGH to transfer charge from all pixels in the sensor. Finally, the signal frame is then read. The camera then returns to the “pre-scan read out cycle” waiting for the next trigger.

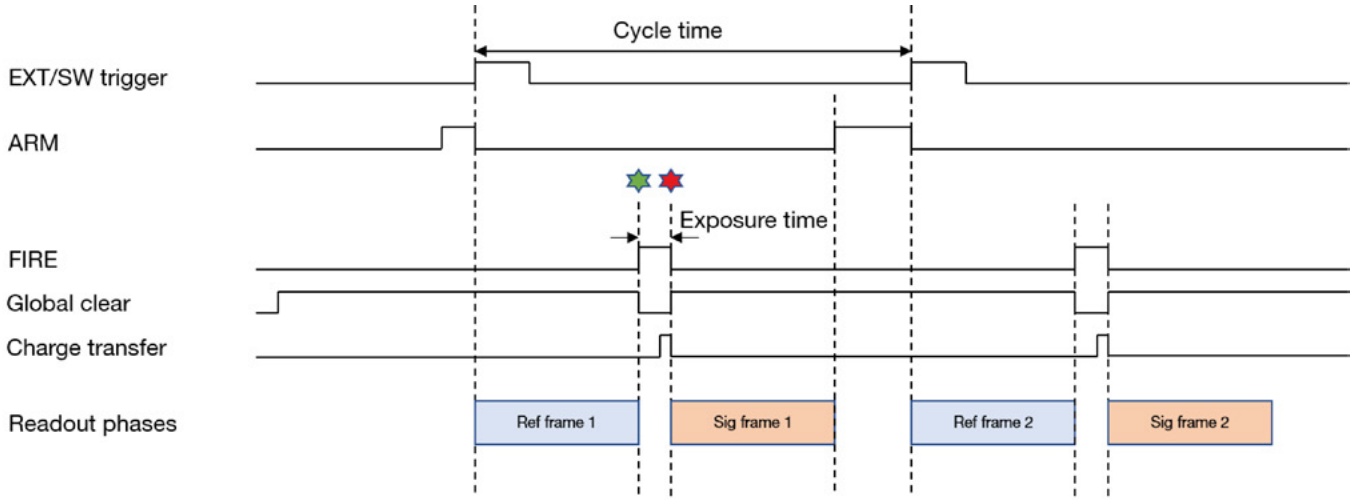


Figure 23: Global Shutter External/Software Triggering Short Exposure.

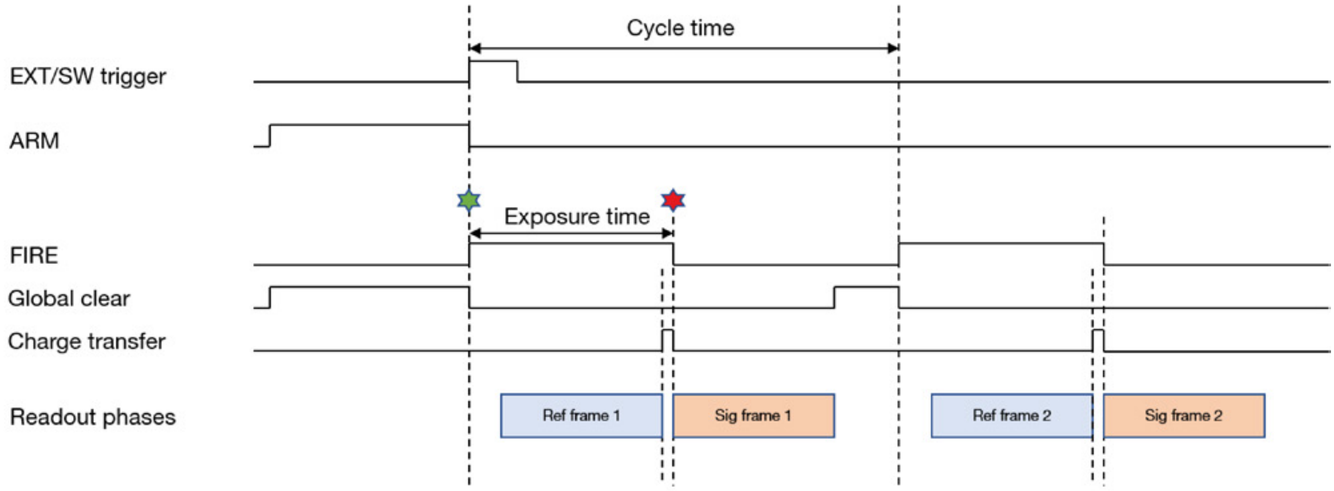


Figure 24: Global Shutter External/Software Triggering Long Exposure.

Table 15: Global Shutter External/Software Triggering Timing Parameters.

Parameter	Minimum	Maximum
Exposure	8 Rows	1 Frame + 20 Rows
Cycle Time (1/Frame Rate)	Exposure + 2 Frame + 13 Rows	-
External delay	~ 1 Frame	-
Exposure	1 Frame + 21 Rows	3600 s
Cycle Time (1/Frame Rate)	Exposure + Frame + 6 Rows	-
External delay	1 Row	2 Rows
EXT Trig Pulse Width	2 Sensor Speed Clock Cycles	-

4.10.7 External Exposure Triggering

While waiting on the trigger event, the sensor is put into a “continuous global clear”. On detection of the trigger event, the Global Clear is pulsed to clear the charge from the sensor. The exposure period lasts for the width of the External Trigger. During the exposure period, a reference frame is read immediately as the system has no method to know how long the External Trigger will be HIGH. This means that as the exposure time increases the time between the reference and signal frame increases which results in a increase in the read noise. Please note that separation of the reference and signal frames is kept to a minimum in modes with a known exposure time. When the external trigger input goes LOW, the exposure ends by transferring the charge in all pixels simultaneously to the measurement node. A signal frame read out then begins. The period of the external trigger pulse defines the overall cycle time. If the width of the trigger event is less than the frame read out time, the falling edge will be missed and a subsequent falling edge will be required to end the exposure.

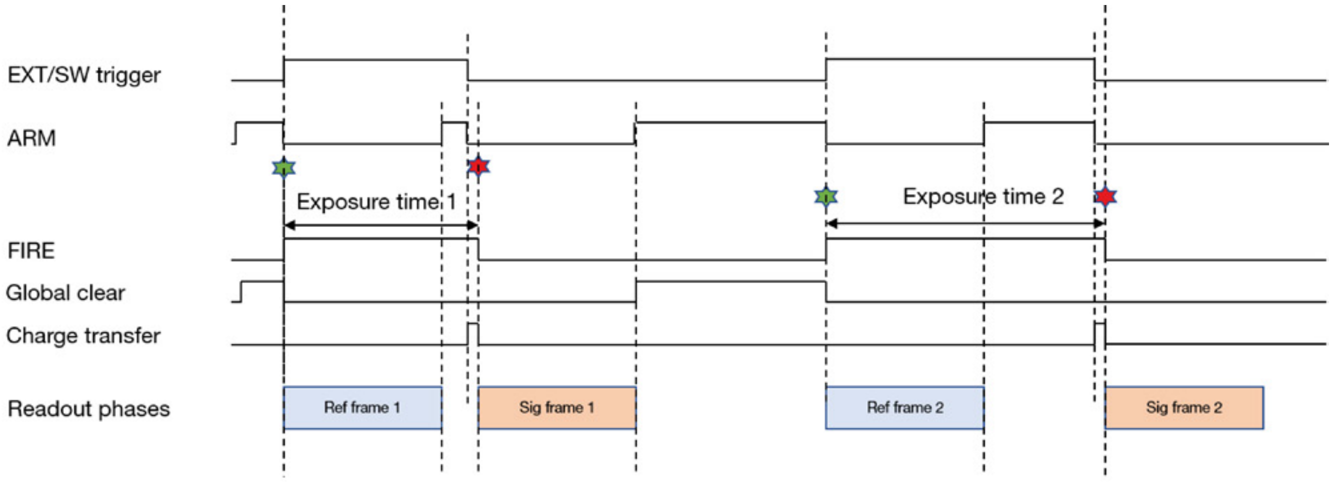


Figure 25: Global Shutter External Exposure Triggering.

Table 16: Global Shutter External Exposure Triggering – Timing Parameters.

Parameter	Minimum	Maximum
Exposure (EXT Trig Pulse Width)	1 Frame + 16 Rows	600 s
Cycle Time (EXT Trig Period)	EXT Trig Pulse Width + 1 Frame + 7 Rows	-
External Delay	1 Row	2 Rows
EXT Trig Pulse Width	1 Frame + 4 Rows	

NOTE: Recommended maximum exposure due to read noise dependency.

4.10.8 Global Shutter - 100% Duty Cycle External Exposure Triggering

In Global Shutter - 100% Duty Cycle External Exposure Triggering mode, every positive edge of an External Trigger will initiate a signal frame read out and start a new exposure. The period of External Trigger pulse defines both the exposure time and cycle time. Note that when an acquisition starts, the first positive edge of the trigger will initiate the first exposure but also output a frame that has an incorrect exposure which is therefore discarded i.e. is not transmitted or included as part of the frame count/series length. The next positive edge of the trigger will end the first exposure and start a frame read out. From the figure below, it is can be seen that the minimum exposure time is approximately two frame read out periods. The first read out period is used to read out the "Signal" frame while the second is used to read out the "Reference" frame for the subsequent "Signal" frame. As the exposure time increases the time between the reference and signal frame increases which results in a increase in the read noise.

If the period of the external trigger is less than the minimum period discussed above any positive edge occurring during the "Signal" and "Reference" frames will be ignored. The ARM signal indicates when positive going edges will be accepted.

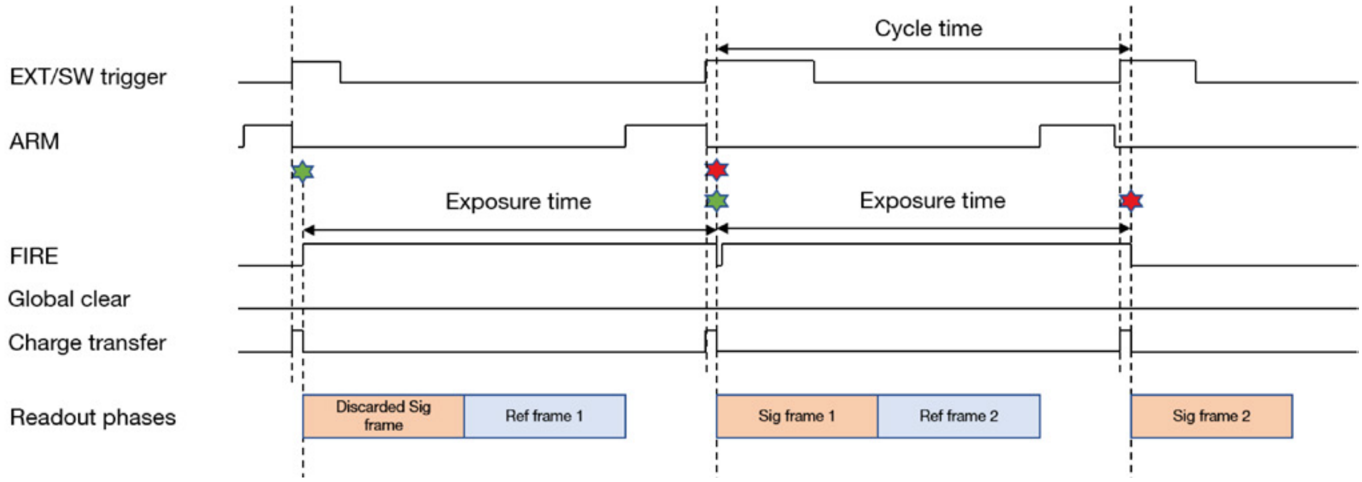


Figure 26: Global Shutter - 100% Duty Cycle External Exposure Triggering.

Table 17: Global Shutter - 100% Duty Cycle External Exposure Timing Parameters.

Parameter	Minimum	Maximum
Exposure (EXT Trig Period)	2 Frames + 26 Rows	600 s
Cycle Time (EXT Trig Period)	Exposure	Exposure
External Delay	6 Rows	7 Rows
EXT Trig Pulse Width	2 Sensor Speed Clock Cycles	-

NOTE: Recommended maximum due to read noise dependency.

4.10.9 External Start Triggering

In this mode the camera will wait for a single external trigger event. Once this external trigger event is detected, the camera will progress as if the camera was in Internal trigger mode. The ARM signal indicates to the user when the camera is ready to detect an External Start Trigger. The diagram below shows the External Start used with a long exposure.

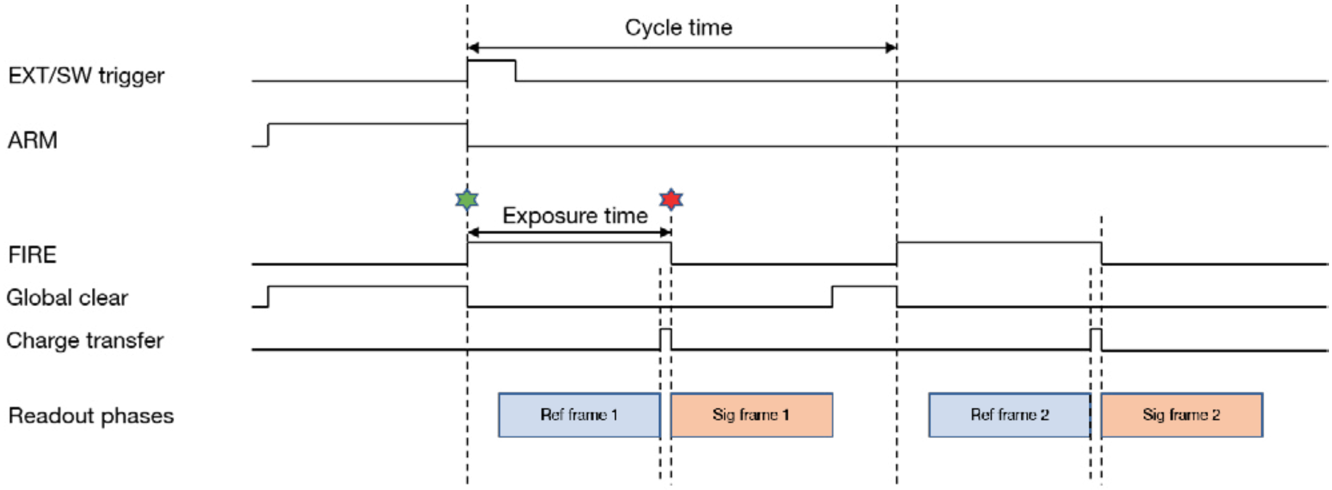


Figure 27: Global Shutter External Start Triggering.

Table 18: Global Shutter External Start Triggering Timing Parameters.

Parameter	Minimum	Maximum
Exposure	8 Row	1 Frame + 20 Rows
External Delay	4 Rows	5 Rows
EXT Trig Pulse Width	2 Sensor Clock Speed Cycles	
Exposure	1 Frame + 21 Rows	3600 s
External start Delay	4 Row	5 Rows
EXT Trig Pulse Width	2 Sensor Clock Speed Cycles	

4.10.10 Global Shutter Triggering Constraints

Table 19 below shows a summary of constraints when operating in Global Shutter mode:

Table 19: Global Shutter mode triggering constraints.

Global Shutter Triggering Modes		Exposure Range	Max Trigger Jitter	Min Trigger Pulse Width	Fast Exposure Switching
Internal	User settable exposure time and Cycle time	Short Exp: 8 Rows to (1 Frame + 20 Rows) Long Exp: 1 Frame + 21 rows to 3600 s	-	-	✓
Internal 100% Duty Cycle	User settable exposure time	2 Frames + 27 Rows to 3600 s	-	-	✓
External/Software	User settable exposure Time. Cycle time controlled via period of external trigger pulse	Short Exp: 8 Rows to 1 Frame + 20 Rows Long Exp: 1 Frame + 21 Rows to 3600 s	1 Row	2 clks	✓
External Exposure	Exposure time controlled by width of external trigger pulse. Cycle time controlled via period of external trigger pulse	1 Frame + 16 Rows to 3600 s	1 Row	1 Frame + 4 Rows	
External Exposure 100% Duty Cycle	Exposure time controlled by period of +ve edge of external trigger pulses. Cycle time is exposure time	2 Frames + 26 Rows to 600 s		2 clks	
External Start	User settable exposure time and Cycle time but sequence initialized via external trigger pulse	Short Exp: 8 Rows to 1 Frame + 20 Rows Long Exp: 1 Frame + 21 Rows to 3600 s	1 Row	2 clks	

NOTES:

1. Exposure Time granularity for all modes is sensor row based so the exposure time in the dialog will always be rounded to the nearest integer number of Row readout times.
2. 1 Row is the time taken to perform a full row readout (392 clock cycles).
3. 1 Frame is the image height rounded up to a multiple of 4. The frame readout time for any ROI can be requested via the SDK3 (refer to SDK3 User Guide for details).

4. **A short exposure refers to an exposure that is less than a Frame readout time. (Depends on ROI selected).**
5. **A long exposure refers to an exposure time that is greater than a Frame readout time. (Depends on ROI selected).**
6. **Image acquisition must be stopped to change between short and long exposures. Fast Exposure Switching can occur in the triggering modes shown above but the exposure time is then limited to the exposure range shown for each sequence.**
7. **Fast exposure switching only avaliable within the short or long exposure range not across these regimes.**

4.11 Acquisition Modes

The following acquisition modes can be supported:

- Single Scan
- Kinetic Series
- Accumulate
- Run Till Abort

NOTES:

1. **The term 'User Frame', in this section refers to a single frame in Rolling Shutter mode and a Reference/Signal frame pair in Global Shutter mode.**
2. **The term 'valid trigger' refers to a trigger that is applied when the camera is ready to accept it.**

4.11.1 Single Scan

Single Scan refers to an acquisition in which only one user frame is transmitted from the camera.

A user frame is output from the sensor on receipt of a valid trigger of the selected type and then transmitted from the camera. Note that any subsequent triggers within the same acquisition are ignored.

4.11.2 Kinetic Series

Kinetic Series refers to an acquisition in which a finite number of user frames are transmitted from the camera. The number of frames in a Kinetic Series is defined by the user. One user frame is output from the sensor on receipt of each valid trigger of the selected type. Valid triggers continue to output user frames from the sensor until the defined number of user frames has been reached. **Note that after the required number of valid triggers has been received, any subsequent triggers within the same acquisition are ignored.**

4.11.3 Accumulate

Accumulate refers to an acquisition in which a number of frames in a series are accumulated together into a single image. This accumulation of user frames is performed off-camera. Either all the user frames in a series are accumulated to give a single accumulated image or a smaller number of user frames in the series are accumulated to give a series of accumulated images.

4.11.4 Run Till Abort Acquisition

Run Till Abort refers to an acquisition in which an infinite number of user frames can be transmitted from the camera and the acquisition will continue to run until it is aborted.

One user frame will be output from the sensor on receipt of each valid trigger of the selected type. All valid triggers will output another user frame from the sensor. Frames are transmitted from the camera in as quick succession as possible.

4.11.4.1 Live Mode

Live Mode refers to a version of Run Till Abort in which each user frame will be the latest frame output by the sensor and will have the minimum amount of latency through the camera as possible.

Live mode requires the use of SW Trigger. In order to ensure that frames are buffered in the on-camera memory for the shortest possible time, the next SW trigger must not be sent until the user frame has been transmitted from the camera. This ensures that the on-camera memory only stores a single user frame at a time and no additional latency builds up.

NOTE: The frame rate achievable in Live Mode is dependent on the performance of the system that the camera is attached to.

4.11.5 Fast Exposure Switching

During an acquisition the user can change the exposure time, within allowable limits. Once a new exposure value has been written, it will be applied to the next user frame after the current frame exposure has completed. The exposure time can be changed any number of times before the acquisition finishes.

4.11.6 Frame Rate Control

If Internal Trigger is being used, the camera will trigger the sensor at the fastest possible rate by default. The user can reduce this trigger rate by defining a frame rate that is less than the maximum possible rate. Frame rate must be set before the acquisition starts.

SECTION 5: MAINTENANCE

THERE ARE NO USER-SERVICEABLE PARTS INSIDE THE CAMERA. DAMAGE CAUSED BY UNAUTHORIZED MAINTENANCE OR PROCEDURES WILL INVALIDATE THE WARRANTY.

5.1 Regular Checks

- The state of the product should be checked regularly, especially the integrity of the PSU, the mains cables and water tubing.
- Do not use equipment that is damaged.

5.2 Annual Electrical Safety Checks

- It is advisable to check the integrity of the insulation and protective earth of the PSU on an annual basis, e.g. U.K. PAT testing.
- Do not use equipment that is damaged.

5.3 General Cleaning & Decontamination Information

- The camera body can be cleaned with a soft cloth and dampened by water or glass cleaner.
- Never spray liquids directly on the camera; apply cleaning solution to the cloth, then wipe the camera body with the dampened cloth.
- Do not use abrasive or other detergents to clean the camera.
- Decontamination: In the event any product must be returned the customer must complete a decontamination form to declare the equipment is contamination free and safe for Andor employees to work on: andor.oxinst.com/support/decontamination-form

5.4 Cleaning the Camera Window

At some point, it may become necessary to clean debris that may have settled on the sCMOS imaging sensor window. Cleaning the camera window can provide effective results providing you carefully follow these step-by-step directions.

WARNINGS

- **The glass is located very close to the sCMOS imaging sensor. Scratching the window may require the window to be replaced.**
- **Cleaning the window is done entirely at the customers risk, window replacement is not covered under the warranty. It's better to under-clean than to over-clean.**

5.4.1 Tools Required

- Compressed Air Can (or source of clean compressed air)
- Optics Brush

5.4.2 Window Cleaning Procedure

1. Remove the camera from your telescope (or other optical equipment) and place it on a clean dry surface.
2. Guidelines for using compressed air:

   i. If you are using a compressed air can always test-blast away from window before blowing air on the window. When you test-blast, you'll notice a spray of condensation shoot out from the can.

   ii. If condensation does form on the window, do not wipe it off. Allow it to fully dry before proceeding.

   iii. Always orient the compressed air can in an upright position before spraying.

   iv. A clean source of compressed air such as an air can is recommended- do not use a compressor that may spray fine droplets of oil, or an unfiltered air supply that may spray dust particles onto the camera window.
3. Turn the camera on its side making it easier for particles to fall out of the camera head. Face the window toward you at the edge of a table.
4. Give the window short blasts of compressed air to work dust particles out of the camera head.
5. If there are still particles stuck on the window use an optics brush to very carefully dislodge them from the window surface. Then spray the dust particles out of the camera head with compressed air.
6. Make sure to use compressed air to clean your adapter tubes and focal reducers as well so you don't get more dust once everything's assembled.

5.5 Fuse Replacement

In the U.K, Ireland and some other countries, the supplied mains cable has a BS 1363 (or Type G) plug that includes an integrated fuse. Only replace with fuse of the same type and rating for continued protection. The characteristics of a replacement fuse are as follows:

- **Rating**: 5A 240 VAC
- **Type**: BS 1362, size: ¼ × 1" (6.3 × 25.4 mm) cartridge

5.6 Cooling Hoses and Connections

The user should routinely check all cooling hoses and connections for signs of leakage, damage or wear. All seals must be intact before powering on camera system and any worn/damaged items must be replaced immediately.

SECTION 6: TROUBLESHOOTING

6.1 Preventing Condensation

Key Risks

- Take special care during installation as the temperature of the camera may be low from shipping or storage. When moved to a warmer environment such as a lab, there is a higher risk of condensation forming. Therefore, ensure that sufficient time is allowed for the product to reach the ambient temperature of the operating environment before use (this may take several hours).
- Never use water that has been chilled below the dew point of the ambient environment to cool the camera.

How may Condensation be detected?

You may see condensation on the outside of the camera body if the cooling water is at too low a temperature or if the water flow is too high. The first signs of condensation will usually be visible around the connectors where the water tubes are attached. If this occurs carry out the following actions:

1. Switch off the system
2. Wipe the camera with a soft, dry cloth.

NOTE: It is likely there will already be condensation on the cooling block and cooling fins inside the camera.

3. Set the camera aside to dry for several hours before you attempt reuse.
4. Before reuse blow dry gas through the cooling slits on the side of the camera to remove any residual moisture.

Use warmer water or reduce the flow of water when you start using the device again.

Refer to **Appendix C** for a Dew Point Graph.

6.2 Quick Troubleshooting Guide

Issue	Possible Cause	Action
Camera buzzer does not sound on start-up. The camera buzzer should be audible momentarily (as a long beep) when the camera is switched to ON. Note that camera buzzer volume is low.	Camera not receiving power.	• If the buzzer does not sound, ensure that power is connected to the camera and the ON/OFF switch is set to ON. • Possible cause is that the camera has over heated. Turn off camera power (at mains) and wait for up to 30 minutes to allow the internal components to cool. Then restart the camera.
Camera buzzer does not beep two times to indicate the firmware has initialized. Note: camera buzzer volume is low.	Electronic issue on the camera.	• Contact Andor customer support.
Sensor temperature has not stabilized.	• Malfunction of liquid cooler unit (Liquid Cooled Only models). • Malfunction of liquid cooler unit or fan is obstructed or not working correctly (Flexi models). • Camera is being operated outside of stated operating conditions. • Camera cooler power cable is not connected and/or main power switched OFF.	• Check the temperature status in the software. • If using a cooler unit, check that the cooler unit is functioning correctly. • Check the fan has been enabled. Increase fan speed if not set to maximum speed. • Check visually that the fan is not obstructed and free of dust. Remove any obstruction. • Check visually that the fan is rotating. Contact Andor customer support if a replacement is required. • Check the camera cooler power supply is ON and connected. • Check the operating conditions, e.g. ambient temperature, water temperature, cameras set temperature. • The system may take up to 10 minutes for temperature to stabilise.

Camera overheating (Buzzer sounding).	• Malfunction of liquid cooler unit (liquid cooled models). • Malfunction of liquid cooler unit or fan is obstructed or not working correctly (Flexi models). • Camera is being operated outside of normal operating conditions.	• If using a liquid cooler unit, check that the cooler unit is functioning correctly. • Check the fan has been enabled. Increase fan speed if not set to maximum speed. • Check visually that the fan is not obstructed and free of dust. Remove any obstruction. • Check visually that the fan is rotating. Contact Andor customer support if a replacement is required. • Check the camera cooler power supply is ON and connected. • Check the operating conditions, e.g. ambient temperature, water temperature, cameras set temperature. • Turn off camera power (at mains) and wait for up to 30 minutes to allow the internal components to cool. Then restart the camera.
Camera is not recognized by PC.	• Camera has not completed its initialisation phase yet. • Camera cables have been disconnected. • Application software and/or device drivers have not been installed properly or are not up to date.	• Ensure camera is switched to ON (The camera must be powered up and the two beeps heard before the software is initiated). • Check that the camera cables are securely and correctly connected between the camera head and the CoaXPress card on the PC. • Check that the CoaXPress card and drivers have been installed properly. Green lights should illuminate on the CoaXPress card. (If you have purchased the Andor SDK kit please see section 1.5.1 in the “Andor Software Development Kit” manual for details to confirm correct card and driver installation).

APPENDIX A: TECHNICAL SPECIFICATIONS

System Specifications •1

Array Size	4128 (W) x 4104 (H)
Pixel Size	12 x 12 µm
Image Area	49.5 mm x 49.2 mm (69.9 mm diagonal)
System window type	AR coated UV grade fused silica window (>98% transmission)
Interface	CoaXPress (4 Lane CXP-6)
I/O	Fire Row1, Fire Row N, Fire All, Fire Any, Arm, Shutter, Ext Trigger
Trigger Modes	Internal, External, External Start, External Exposure, Software

Note: Refer to the Balor Specification Sheet for full specifications.

General Specifications •1

	Rolling Shutter	Global Shutter
Dark Current •2	$0.35\ e^-$/pix/sec (@ 0°C) $0.08\ e^-$/pix/sec (@-10°C) $0.03\ e^-$/pix/sec (@-30°C)	$0.5\ e^-$/pix/sec (@ 0°C) $0.15\ e^-$/pix/sec (@-10°C) $0.065\ e^-$/pix/sec (@-30°C)
Read Noise (e^-) median	$2.9\ e^-$	$4.3\ e^-$
frame rates (full resolution)	54	34
Active area pixel well depth	$80\ 000\ e^-$	
Peak QE •3	61% (@ ~ 600 nm)	
Photon response non-uniformity (PRNU)	< 0.5%	
Region of Interest	User-definable, 1 pixel granularity	
Linearity•4	> 99.7%	
Data Range	16-bit (extended dynamic range)	

Environmental Specifications

Usage	Indoor use only
Altitude Limit for Air-cooling	Up to 6000 m
Altitude Limit for Water-cooling	Up to 6000 m
Operating Temperature	-30°C to 30°C ambient (using standard Shutter)
Storage Temperature	-30°C to 50°C
Operating Relative Humidity	< 70% (non-condensing)
Ingress Protection	IP20
Overvoltage Category	CAT II. An overvoltage category of CAT II means that the equipment is designed to cope with transient voltages above the rated supply that would be experienced by any product connected to a mains socket in a building.
Rated Pollution	Pollution Degree 2. Normally only non-conductive pollution occurs. Occasionally, however, a temporary conductivity caused by condensation must be expected.
Ventilation Requirements	Ensure that ventilation slots are not obstructed when in air cooled mode.

Cooling Specifications •5

Balor has two variants for cooling: Liquid Cooled Only and Flexi Cooled. Flexi offers both air and liquid cooling capability, and both variants offer the same liquid cooling temperature of -30°C. However, the Liquid Cooled Only variant is supplied without air vents, useful for minimizing any residual thermal bloom from the camera body in extremely temperature controlled environments, such as in Radial Velocity experiments.

During air cooling, the user must be aware of the ambient air temperature and altitude at which the camera is operated as both will have an impact on the extent of sensor cooling. The table below offers a guide to selecting the available sensor cooling set points under different environmental conditions. The table also shows the recommended liquid temperature with minimum flow rate of 2 $L \cdot min^{-1}$ in order to achieve -30°C sensor temperature for both the Liquid Cooled Only and Flexi cooled systems.

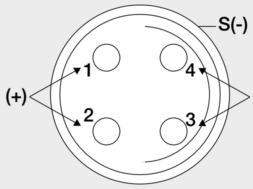
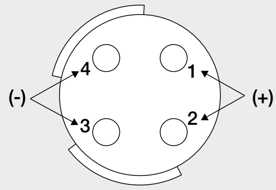
Sensor Temperature	-30°C	-10°C	0°C
Altitude	Liquid cooling (recommended coolant temperature)	Air Cooling (maxiumum ambient air temperature)	
Sea level	16°C	25°C	30°C
< 3000 m	16°C	15°C	20°C
< 6000 m	16°C	5°C	10°C

The user must also be aware of the possibility of condensation forming on the camera, for further information refer to Appendix C.

Footnotes

1. Figures are typical and target specifications and therefore subject to change.
2. Dark current are typical median values, measurement is averaged over the sensor area excluding any regions of blemishes.
3. Quantum efficiency as supplied by the sensor manufacturer.
4. Linearity is measured from a plot of Signal vs. Exposure Time as per EMVA 3.0.
5. Specified minimum temperature with coolant assumes coolant temperature of 16°C at a flow rate of 2 litres per minute, measured at the camera head. Air cooling performance is at the ambient temperature listed. Note that cooling performance may be affected by the distance between camera head and coolant system.

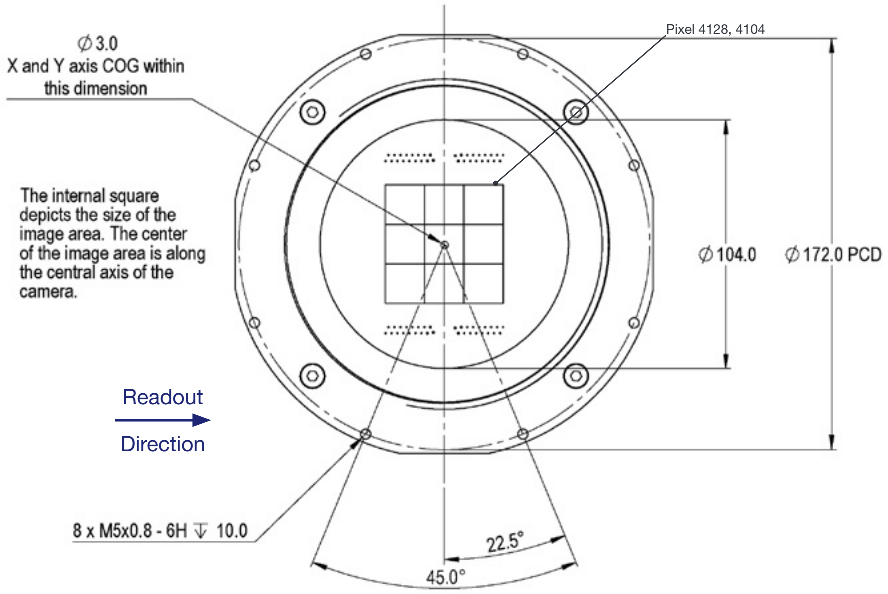
External Power Supply Requirements

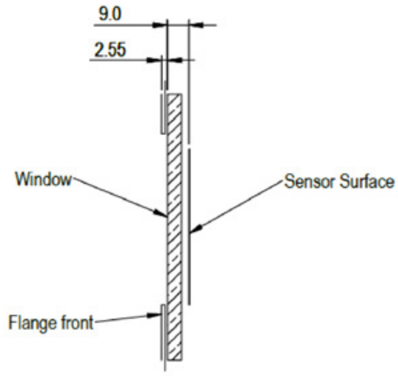
Low Voltage Supply Input	15 V +/- 5%	24V +/- 5%
Low Voltage Supply Current	8 A	6.6 A
Low Voltage Supply Cable Connector	**Right-angle Plug:** Fischer WSO 104 A037-130+ **Straight Plug:** Fischer S 104 A037-130+ **Required Cable Clamp Set:** Fischer E3 104.3/6.7+B	**Right-angle Plug:** Fischer WSO 104 A037-230+ **Straight Plug:** Fischer S 104 A037-230+ **Required Cable Clamp Set:** Fischer E3 104.3/6.7+B
Low Voltage Supply Connector Pin Connections	Pins 1 & 2: +15 V Pins 3 & 4: 0 V Shield: 0 V	Pins 1 & 2: +24 V Pins 3 & 4: 0 V Shield: 0 V
Low Voltage Supply Cable Connector Plug Insertion View		
Ripple	150 mV peak-to-peak	240 mV peak-to-peak
In-rush Current Capability	Shall start up a load whose in-rush current from a 0.1 Ω source resistance is 5 A min. Peak and a pulse width of 300 us min. measured at half the peak	Shall start up a load whose in-rush current from a 0.1 Ω source resistance is 8.2 A min. Peak and a pulse width of 1.2 ms min. measured at half the peak
Safety	Certified to an appropriate IEC standard, e.g. IEC 60950-1, and meet the reinforced insulation from mains requirement of IEC 61010-1	
Environmental	Ensure that the EPS meets the environmental specification of the overall product (see above)	

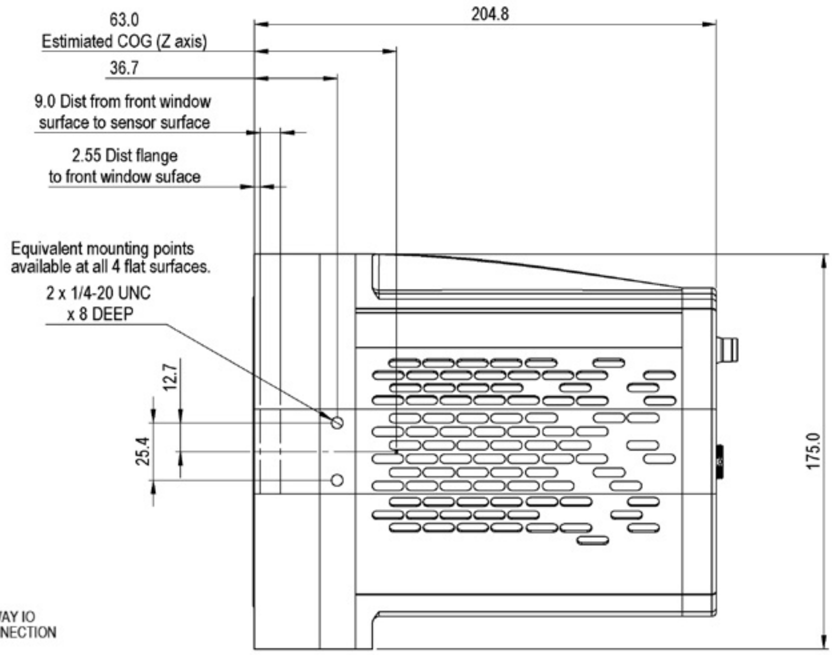
Camera Power Requirements

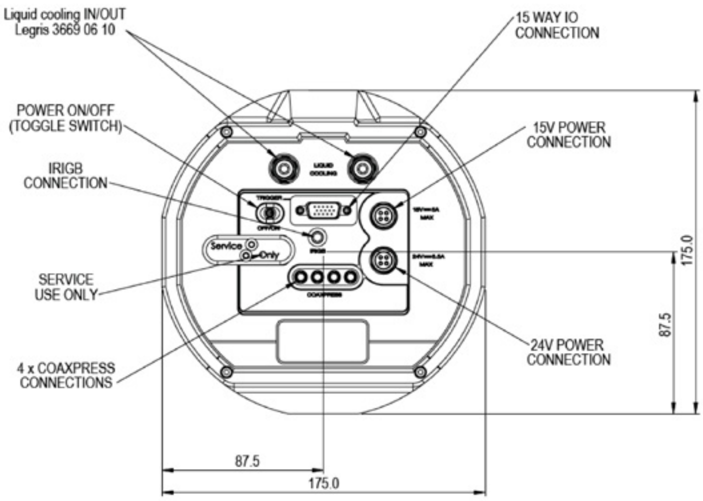
Mains Input for Supplied External Power Supply	100 – 240 VAC, 50 – 60 Hz	
Power Consumption	**Camera (electronics) + External Power Supply:** Air cooled. 56 W typical, 84 W max. Water cooled, 57.5 W typical, 86 W max. **Camera (TEC) + External Power Supply:** Sensor cooled to -30°C: 66 W typical. 181 W max. Sensor cooled to -10°C: 25 W typical. 181 W max. Sensor cooled to 0°C: 15 W typical. 181 W max. **Camera (electronics) only:** Air cooled. 49.5 W typical, 73.7 W max. Water cooled, 50.8 W typical, 75 W max. **Camera (TEC) only:** Sensor cooled to -30°C: 57 W typical. 156 W max. Sensor cooled to -10°C: 22 W typical. 156 W. Sensor cooled to 0°C: 13 W typical. 156 W max.	
Voltage Rating	15 V	24 V
Current Rating	5 A	6.5 A

APPENDIX B: MECHANICAL DRAWINGS









Weight (approx):

Liquid Cooled: ~9 kg [19 lbs 8]

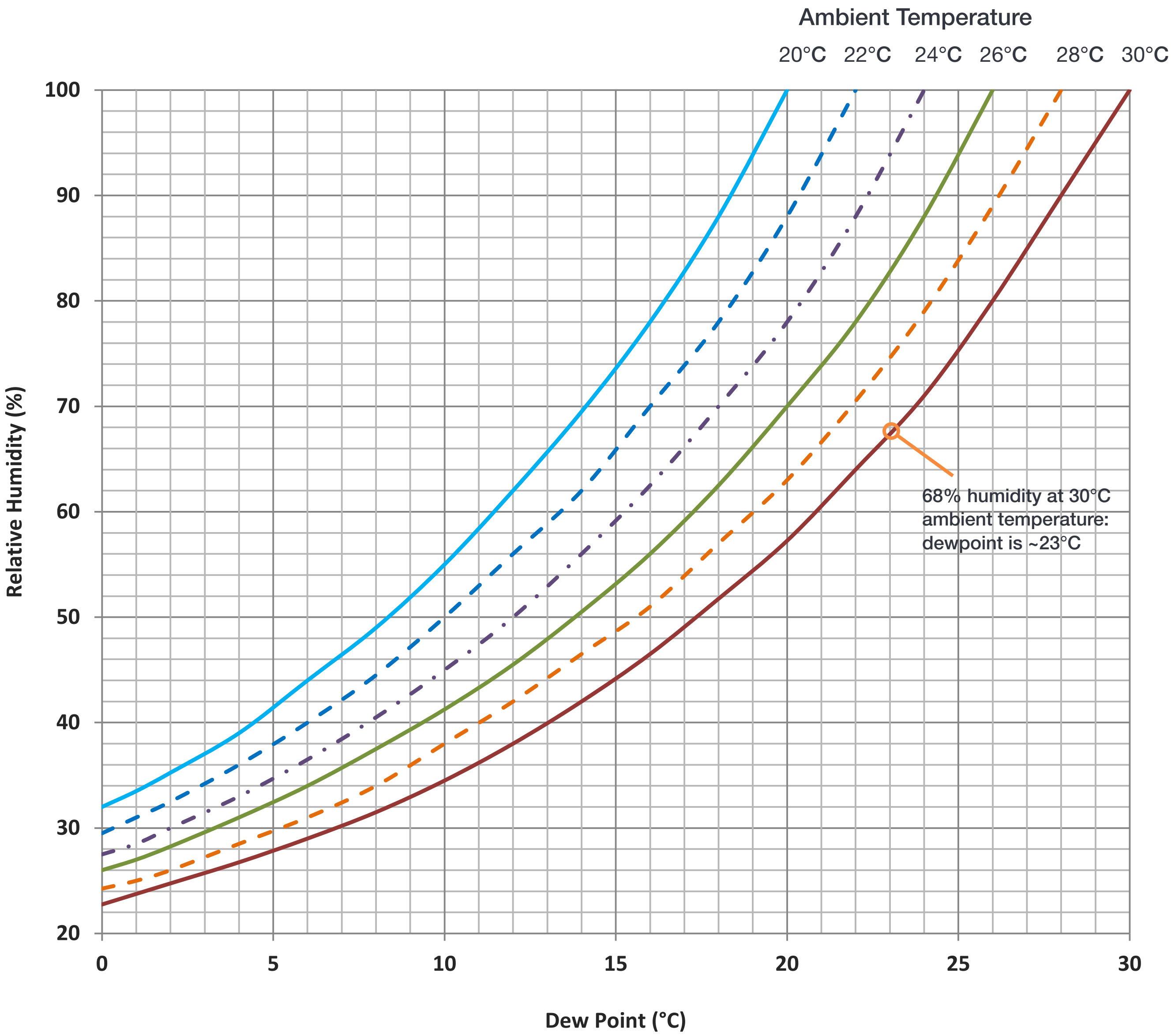
Flexi Cooled: ~9 kg [19 lbs 8]

Note: air vents are not present in the housing of the Liquid Cooled Only model (not shown). This option can be selected for minimal thermal bloom.

APPENDIX C: DEWPOINT INFORMATION

To avoid issues with condensation, the coolant temperature must be set above the dewpoint- the temperature at which condensation (dew) will form. In the relatively dry conditions of an air conditioned lab, or a cool dry climate, use of a coolant temperature of 10°C should not cause any problems. As relative humidity or ambient temperature increase however, the dewpoint temperature will also increase so that the minimum coolant temperature that can be used will have to increase accordingly. This will therefore limit the maximum cooling performance that can be achieved.

The first signs that condensation is forming will be on the coolant connections entering and exiting the camera. Use of coolant at or below the dewpoint can result in permanent damage to the camera head due to formation of condensation on internal components. It is therefore very important to ensure that coolant temperature is above the dewpoint. Further guidelines are provided in **Section 6.1**. The relationship between Relative Humidity and dewpoint at varying ambient temperature is shown below. Solis features a dewpoint calculator and there are also a range of dewpoint calculators on-line that you can enter ambient temperature and relative humidity to calculate the dewpoint for your conditions.

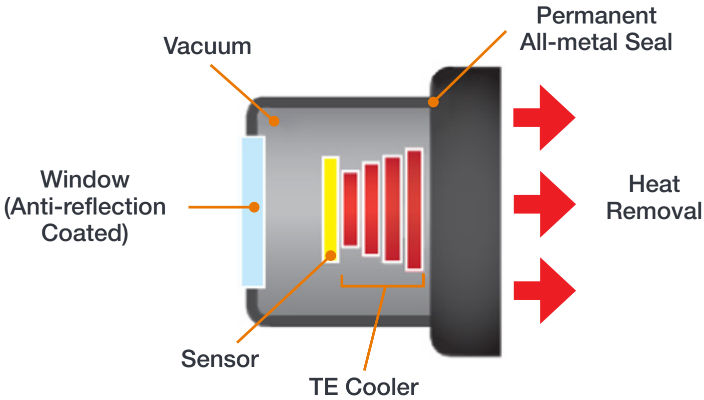


APPENDIX D: REFERENCE INFORMATION

UltraVac™ Technology

UltraVac is Andors proprietary vacuum technology that provides a permanent, hermetically sealed enclosure (without O-rings) for the sensor. This ensures maximum cooling performance, with a reliability proven through years of use in Andor cameras such as the iXon EMCCD, iKon and Newton series- the Mean Time Between Failure (MTBF) value is > 100 years.

Outgassing is minimized through assembly in a state of the art facility, with a stringent protocol and use of proprietary materials (Outgassing is the release of trapped gasses that would otherwise degrade cooling performance and potentially cause sensor failure). UltraVac also features a single camera window for the best optical performance. For more information about our UltraVac technology, please visit our website and view the technical article on UltraVac.



APPENDIX E: OTHER INFORMATION

Terms and Conditions of Sale and Warranty Information

The terms and conditions of sale, including warranty conditions, will have been made available during the ordering process. The current version for the US is available here, for all other regions (except Japan) please click here.

EU/UK REACH Regulation Statement

Andor's EU/UK REACH Regulation statement is available at the following link.

Waste Electronic and Electrical Equipment

The company's statement on the disposal of WEEE can be found in the Terms and Conditions.