FIRST LIGHT
ADVANCED IMAGERY

OCAM²K & OCAM²S

User Manual

OCAM² User Manual_20160707

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Thank you for choosing OCAM²!

OCAM² features and performances are described in detail within this User Manual.
This User Manual contains all information and advice needed to get the optimum performance from OCAM².

You can also find an up-to-date version of this User Manual on our website:
www.first-light.fr/downloads/.
Please contact our support, should you have any question, at *support@first-light.fr.*

1.1. Caution

Your OCAM² camera contains fragile components, especially the EMCCD detector.

This User Manual describes precisely how to handle your material properly and to avoid accidents.

Please follow the instructions of use in order to take advantage of all OCAM² performances.
Please read carefully the warnings in section 2, and follow the safety precautions in order to avoid any personal injury or damage when using the camera.

1.2. Overview

OCAM² is a state of the art liquid-cooled high-speed, high-sensitivity, ultra-low noise camera for challenging scientific applications.

Equipped with an EMCCD (Electron Multiplying Charge Coupled Device) detector from e2v Technologies, OCAM² takes more than 2000 images per second at the full 240x240 resolution of its 24 µm pixels.
It has a CameraLink Full connectivity for low-latency output and can achieve single photon detection with extremely low noise of less than 0.1 e with EMCCD gain.

Your OCAM² camera contains fragile components, especially the detector. Please always handle your camera with care.

Always follow the instructions for use.

2.1. Never open your camera

Do not ever attempt to open your camera. There are indicators inside the camera,

If you try to open it your warranty will be void.

2.2. Power circuitry

Use the camera with the voltage indicated. Using a different voltage may damage your camera and lead to fire or electric shock.

Always use the supplied power unit.

2.3. Cooling water

Be sure that the cooling system is correctly connected before turning on the camera and check that no leaks are visible.

Any operation without water cooling can damage permanently the camera.

2.4. Thermal shock

Thermal shock is dangerous. The camera follows a slope of 6°C per minute when cooling or warming up. It is very important to allow the camera to properly warm up to ambient temperature before turning it off!

Before powering down the camera, it is very important to warm the detector back to ambient temperature to prevent thermal shock.

2.5. Gain

It is the responsibility of the user to apply an appropriate gain on the camera depending on the signal level.

Not respecting the gain is a case of misuse of the system and is not covered by the warranty.

3 CONTENTS OF PACKAGE

When you open the package, please check that all items described below are included:

General:

	OCAM²K	OCAM²S
CAMERA	1	1
DETECTOR (INTEGRATED IN THE CAMERA)	CCD220	CCD219
POWER SUPPLY	1	1
LEGRIS PARKER MALE CONNECTORS (IF NO ACCESSORY PACK)	1	1
LEMO CABLES FOR EXTERNAL TRIGGER	2	2
USB KEY WITH USER MANUAL + DEMO SOFTWARE + TEST REPORT	1	1

Optional:

WFS OPTION	Wavefront Sensor (mounted on the camera) see section 4.2 for standard specifications.	1
ACCESSORY PACK OPTION	Cooling Unit with power supply	1
	Personal Computer with power supply, screen, mouse, keyboard.	1
	Hoses for cooling fluid with Parker Legris male connectors.	2
	Acquisition Card (model depends on customer's choice) integrated in Personal Computer, 2 camera link cables.	1

NOTE 1 *The cooling unit and personal computer can be bought separately. Any reference is compatible with respect of the minimum requirements (see section 4).*

NOTE 2 *The softwares are downloadable on http://www.first-light.fr/category/downloads/softwares/ .*

NOTE 3 *Items may differ from pictures.*

NOTE 4 *If you bought your OCAM² system together with the cooling unit, please refer to the cooling unit instructions before handling the cooling unit (see section 4 for minimum requirements).*

4.1. EMCCD Sensor

4.1.1. Introduction to CCD220

Your camera is equipped with a CCD220 or a CCD219 from e2v technologies, depending whether it is an OCAM²K or OCAM²S model.
The main features of these sensors are quite the same except the shutter function for CCD219.

4.1.2. CCD219 (shuttered version) specifications

CCD219 presents the same characteristics as CCD220 but has an embedded electronic shutter that is able to deliver an arbitrary number of integration pulses that can be shorter than 1 µs with a precision better than 50 ns.

4.1.3. Main features

- 240X240 pixel image area.
- 24 µm square pixels
- Split frame transfer
- 100% fill factor
- Back-illuminated for high spectral response L3 Vision serial registers and very low noise outputs.
- Integral Compact Peltier Package.

4.1.4. Spectral response at 228k gain.

Wavelength (nm)	Minimum QE	Typical QE
500	65%	75%
550	75%	85%
600	80%	90%
650	85%	95%
700	85%	95%
750	85%	95%
800	80%	90%
850	75%	85%
900	60%	65%

4.2. Camera Specification and performances

4.2.1. OCAM²K & OCAM²S

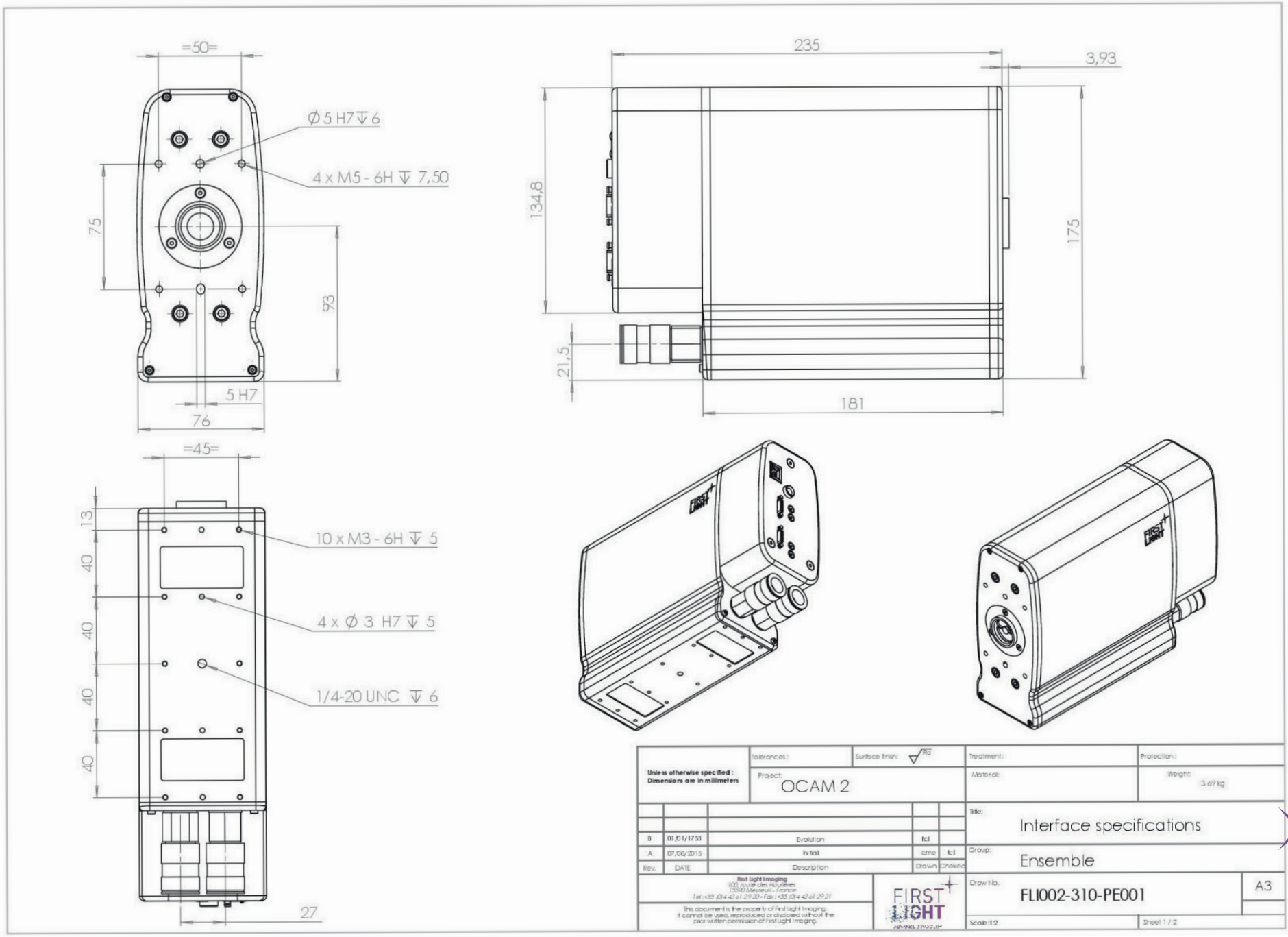
• Sub-electron readout noise with EMCCD gain
• Up to 2067 fps.
• 3625 fps in 2X2 binning mode
• Ultra-low latency camera link full interface : 43 µs

• Embedded Electronic shutter (OCAM²S)
• Internal or External Trigger modes: Single, Burst, Sweep triggering (OCAM²S).

Test Measurement	Unit	OCAM²K	OCAM²S
Mean Readout noise at 2000 fps and multiplication gain 600	e	0.3	
Quantization	Bits	14	
Dark Signal at 2000 fps at -45°C	e/ pixel/ frame	<0.01	
Detector operating Temperature	°C	-45	
Peak Quantum Efficiency at 650 nm	%	95	
Linearity at gain X1000 from 10e to 150e	%	<3	
Image full well capacity at gain X1	E	300 000	100 000
Parallel CTE at gain X1, 2000 fps	%	99.995	
Serial CTE at gain X1, 2000 fps	%	99.994	
Latency between exposure and first pixel availability	µs	43	
Minimal Pulse width	µs	N/A	<1

4.2.2. Mechanical and optical interfaces

The OCAM² camera is designed to deliver the best precision possible with regard to the optical alignment of the CCD.


=50=
Ø 5 H7↧6
4 x M5 - 6H ↧ 7,50
75
93
5 H7
76
=45=
13
40
40
40
40
10 x M3 - 6H ↧ 5
4 x Ø 3 H7 ↧ 5
1/4-20 UNC ↧ 6
27
235
3,93
134,8
175
21,5
181
Unless otherwise specified : Dimensions are in millimeters
Tolerances:
Surface finish:
Treatment:
Protection:
Project:
OCAM 2
Material:
Weight:
3.69 kg
Title:
Interface specifications
B 01/01/1753 Evolution fct
A 07/09/2015 Initial cme fct
Rev. DATE Description Drawn Checked
Group:
Ensemble
Draw No.:
FLI002-310-PE001
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Sheet 1 / 2
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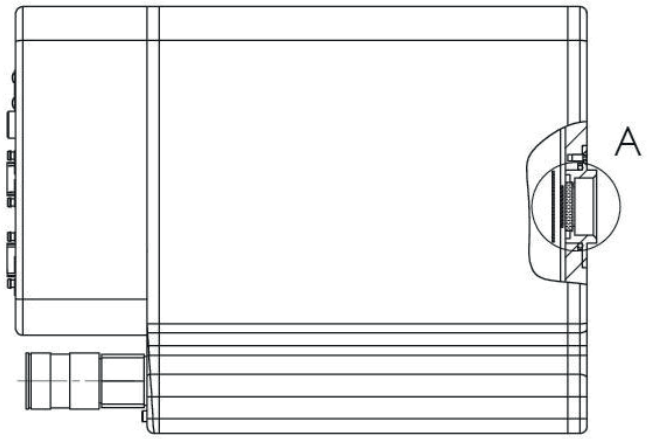
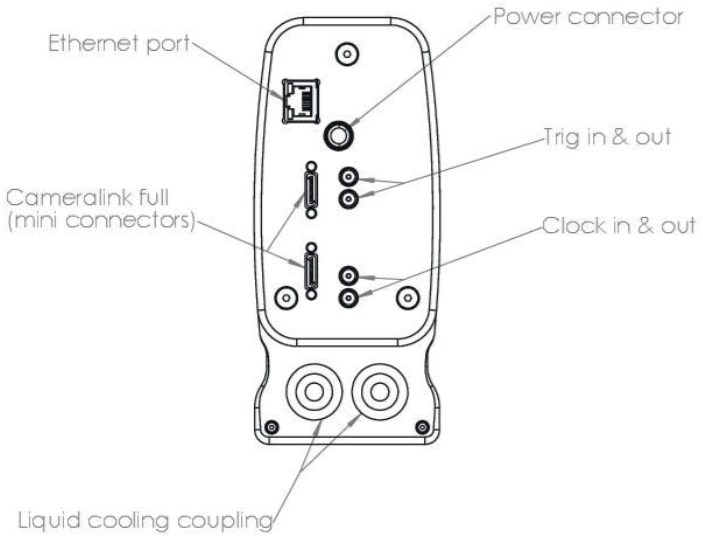
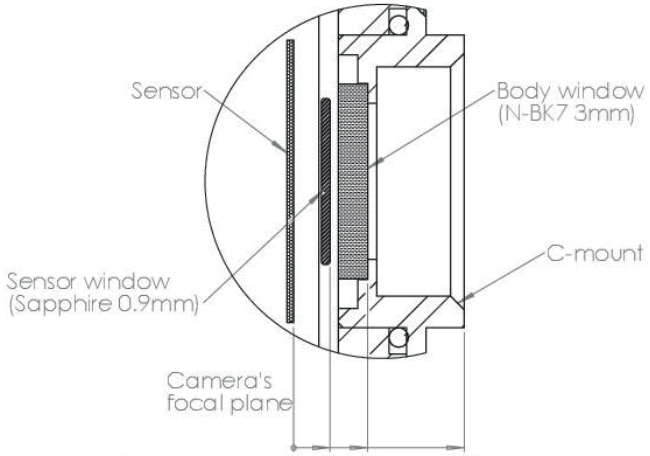






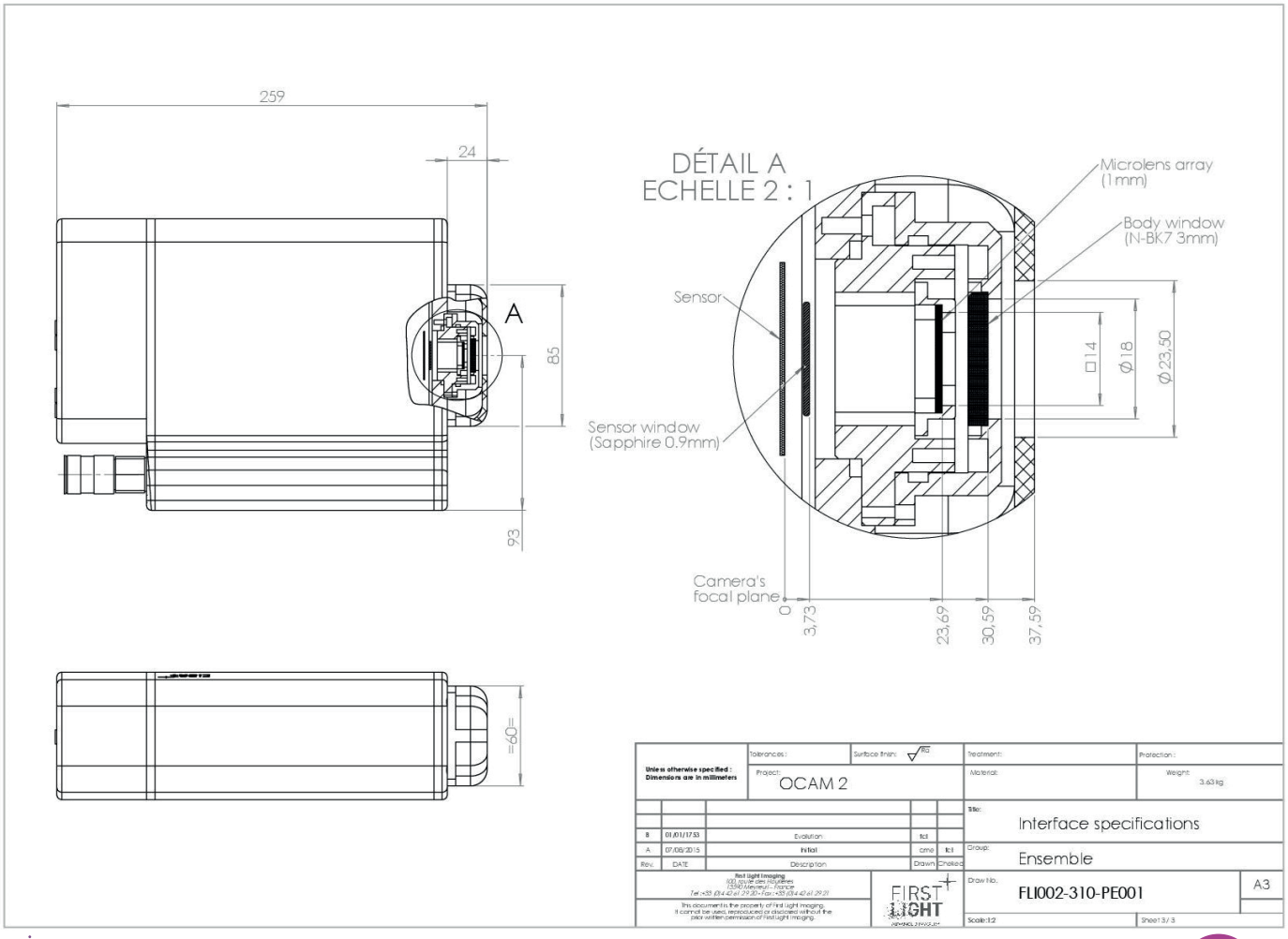
DÉTAIL A
ECHELLE 2 : 1

Unless otherwise specified : Dimensions are in millimeters	Tolerances :	Surface finish :		Treatment :	Protection :
	Project : OCAM 2			Material :	Weight : 3.69 kg
				Title :	Interface specifications
B	01/01/1753	Evolution	fcl		
A	07/08/2015	Initial	cme fcl	Group :	Ensemble
Rev.	DATE	Description	Drawn Checked		
First Light Imaging 100, route des Hauteures 13590 Meyreuil - France Tel : +33 (0)4 42 61 29 20 - Fax : +33 (0)4 42 61 29 21				Draw No.	FLI002-310-PE001 A3
This document is the property of First Light Imaging. It cannot be used, reproduced or disclosed without the prior written permission of First Light Imaging.				Scale : 1:2	Sheet 2 / 2

4.2.3. WFS module

An optional Wave Front Sensor (WFS) has in standard mode the following specifications (customizable upon request. If custom design: see test report for specifications):

Microlens array specifications (standard proposal)	Result	Unit
Focal Length (distance to maximum intensity) at 633nm	22	mm
Number of sub-apertures	20 X 20	N/A
Lens shape	Square	N/A
Lens pitch	288	µm
Lens clear aperture	>286	µm
Lens array position on substrate	Centered	N/A
Fill factor	>98	%



4.3. Description and Minimum Specifications for accessories

4.3.1. Power Input

OCAM² requires a single power supply.
Power supply should provide a stable 24V DC, with at least 6 A of current available. Thus a 24V, 150W power supply or above is adequate to power OCAM².
The mating connector is a LEMO® FGG.1B.304 series. Cabling is shown Figure 1.

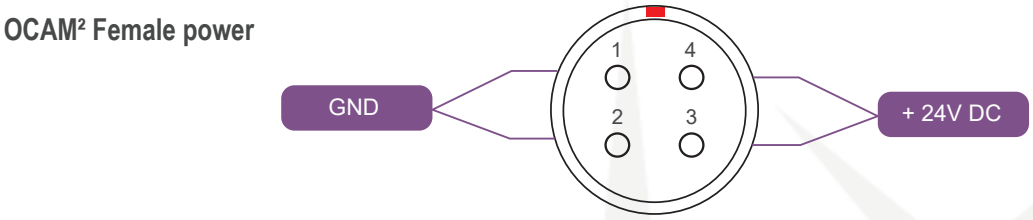


Figure 1 : OCAM² power connector cabling

Always use the provided power supply.

4.3.2. Cooling

In order to achieve its nominal performance the OCAM² camera requires liquid cooling.
The camera has its own internal thermal regulation (Electro Thermal) that cools the detector down to -45°C.

Parameters	Value
Flow	2 liters per minute minimum
Pressure	10 bars maximum
Temperature	35°C maximum
Liquid	Ethylen Glycol Distilled water or deionized water if liquid temperature is > 5°C

Heat is evacuated by circulating a cooling fluid through the two rear connectors Réf. Legris/Parker 9201 25 13, mating connectors are Réf. Legris/Parker 9286 25 13 mounted on flexible hoses (provided with a cooling system) or only connectors Réf. Legris/Parker 9285 25 08.

Be sure that the cooling system is correctly connected.

4.3.3. Data

OCAM² data connection uses the Camera Link standard to handle all communications.
The camera uses the CameraLink Full interface that requires two data cables.
OCAM² connectors are 2 female SDR-26 Mini CameraLink.
Connectors are numbered 1 and 2. Connector 1 is the one at the top of the camera as shown.
If the cables are cross-connected the camera will fail to send data properly but it doesn't have any harmful effect on the camera nor the grabber.

OCAM² firmware communicates with the user through the serial line embedded in the Camera-Link cables. Usually the driver for the Frame grabber will expose the serial line of the CameraLink standard as a virtual COM port on the acquisition system.

Please note that our cameras have been developed and tested with specific grabbers, and that we highly recommend to use these grabbers. Any malfunctions related to the use of a non-certified grabber will not be supported by First Light.

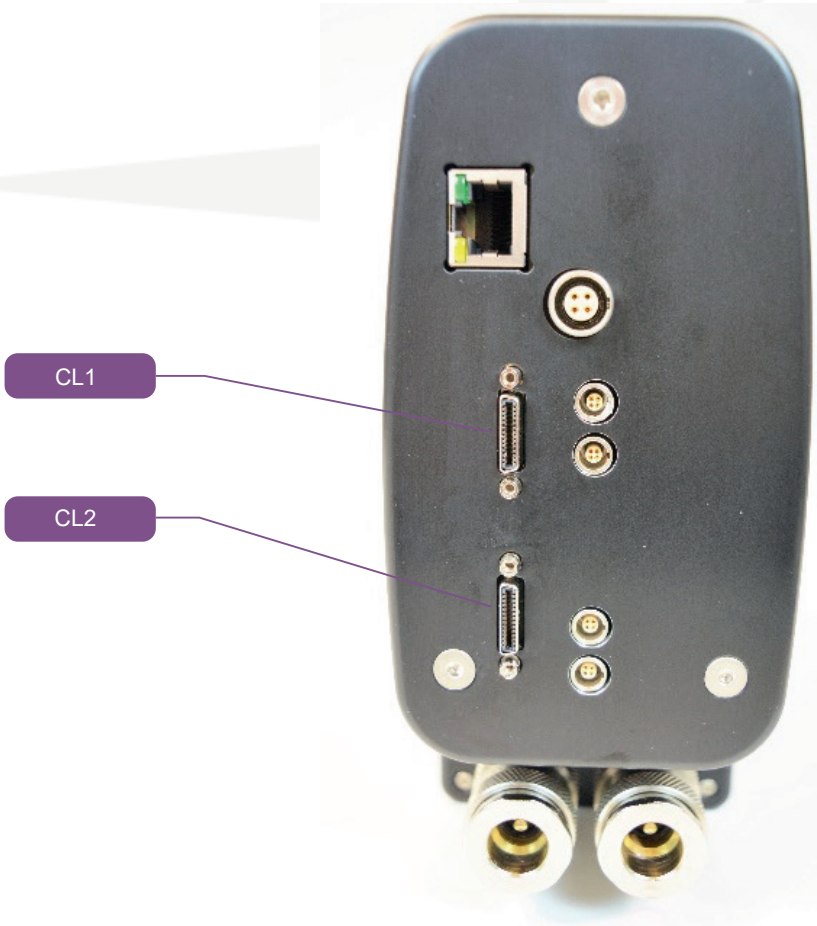


Figure 2 : CameraLink Output

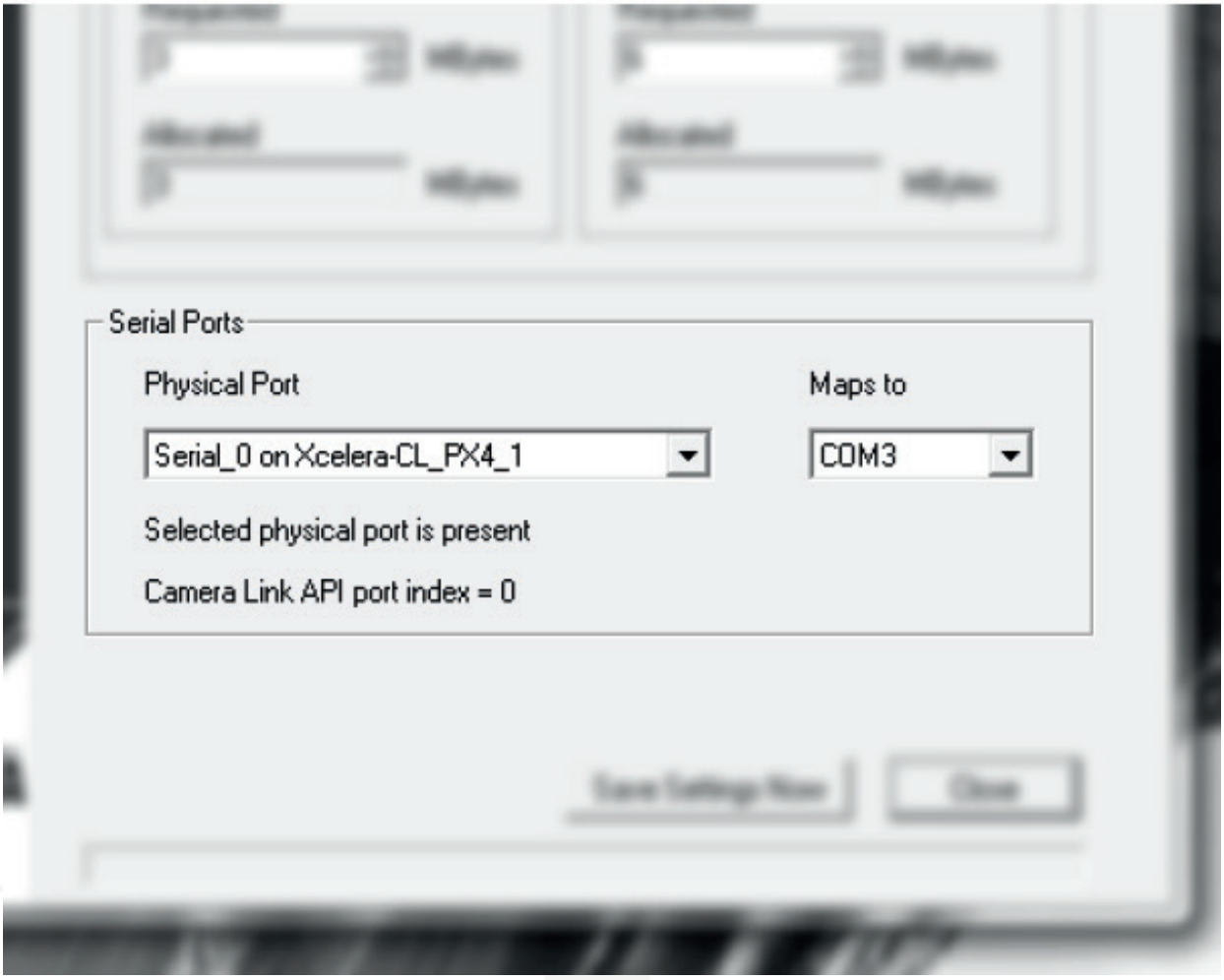


Figure 3 : CameraLink COM port mapping

In order to communicate both ways with the camera said COM port should be set to:
115200 Bauds, 8 bits, No parity, 1 Stop bit.

4.3.4. List of tested and recommended grabbers

-TELEDYNE DALSA PCX Xcelera-cl px8 full
-MATROX: solios eV-cl full

5.1. Connecting your camera

5.1.1. Cooling Hoses

Figure 4 : OCAM² coolant connectors

Insert the male connector into the socket until it locks in place. There should be an audible ‘click’ and the connector should not move until released by pushing the ring on the female (camera) side.

Figure 5 : Coolant connectors in place

Once cooling connectors have been correctly inserted, the coolant circulation can be turned on, and the user should check that no leaks are visible. Refer to the cooling unit user manual to ensure a proper operation.

Be sure that the cooling is on before turning on the camera.

Any operation without water cooling can damage permanently the camera.

5.1.2. CameraLink cables

Once the camera is properly cooled the CameraLink connectors should be plugged and fastened.

The CameraLink connections should be plugged or unplugged camera off. It is recommended to turn the acquisition computer ON before the camera.

> **NOTE** *Unlike the coolant connectors, the CameraLink cables are numbered. Connector 1 should go to the top of the camera, and connector 2 at the bottom.*
> *Connectors can be plugged in any order, but reversing the order (i.e. plugging camera output 1 to grabber input 2 and vice-versa) will prevent camera operation.*

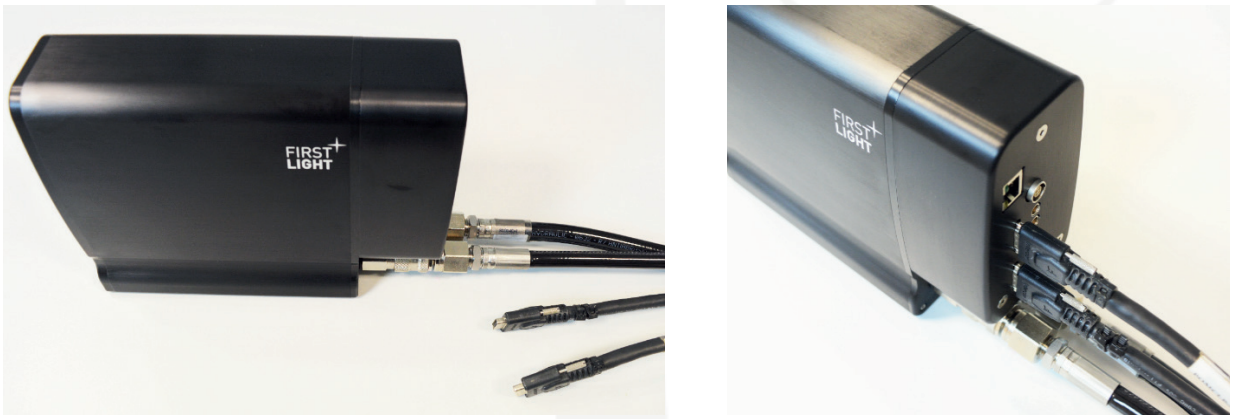


Figure 6 : CameraLink SDR-26 connector and cable

5.1.3. Power LEMO cable: powering up the camera

Once the camera has been connected to the cooling system and data acquisition, it is possible to power up the camera.

Plug firstly the LEMO power connector to the camera and then the power unit to the line plug.

The camera is on.

The camera power usage varies with regard to the cooling required. Without cooling the camera requires 65 Watts of power.

With cooling the figure can rise up to 140 Watts.

Typical power usage with CCD at -45°C and cooling fluid at 25°C will be about 90 Watts.

MIN	TYPICAL	MAX
60 W	90 W	140 W

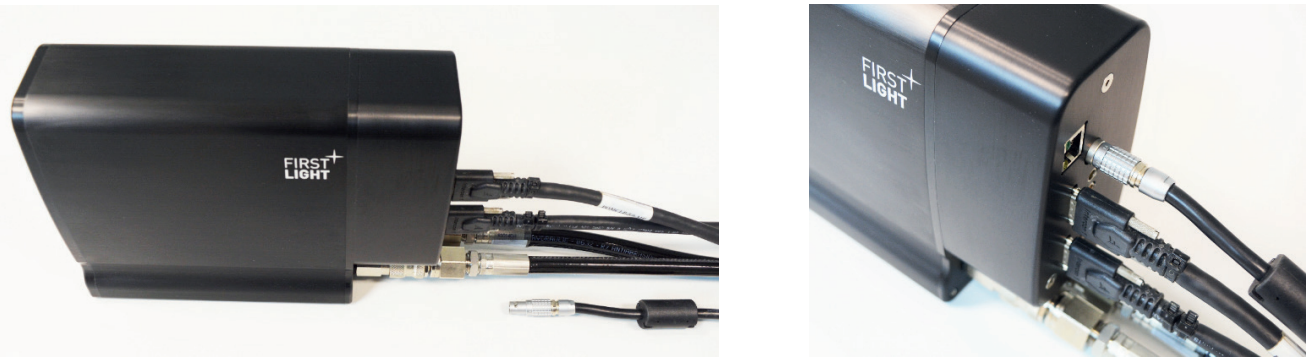


Figure 7 : Plugging the LEMO cable

5.2. Powering down the camera

Before powering down the camera, it is very important to warm the detector back to ambient temperature to prevent thermal shock.

This is done by sending the 'temp' command to the camera with a positive temperature. Example: 'temp 20' will warm the detector back to 20°C at a pace of 6°C per minute.

Once a positive temperature level is reached, the line side of power unit can be unplugged. The camera is off.

6.1. Acquiring images

At boot, the OCAM² camera self-checks and automatically starts acquiring images.
The boot procedure takes about 1 second, after which the grabber should start receiving images.

At first power up, OCAM² starts in normal mode (66x121x8 outputs @ 2067Hz), with unity gain and without sensor cooling.
Then for further starts up it begins in last selected mode and at full speed, sensor cooling is always off at start up.

The OCAM² camera running in standalone mode, without external sync, continually acquires images at the set speed.
By default speed is 2067 fps, corresponding to 484 µs exposure time.
The user can set the acquisition speed to any value between this speed and 1 fps (1 second exposure time).

6.2. Image Format

This section describes the image format used by OCAM², from its analogic source to unscrambling digital image data.

6.2.1. Detector geometry

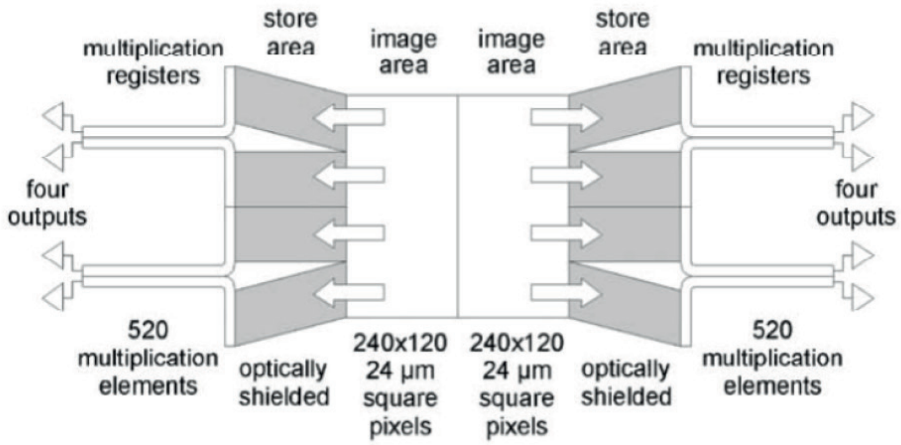


Figure 8 : The CCD220 geometry

The CCD220/219 is a 24 µm square 240x240 pixels split frame-transfer back illuminated L3Vision CCD.

6.2.2. Pixel format

OCAM² digitizes the signal from its CCD220/219 with 14-bit precision.
These 14 bits are padded to 16 bits by the adjunction of a sign bit.
The pixel values are in signed format and range from – 16 382 to 16 383 ADU's.
Pixel format is shown in Figure 9: OCAM² pixel format.

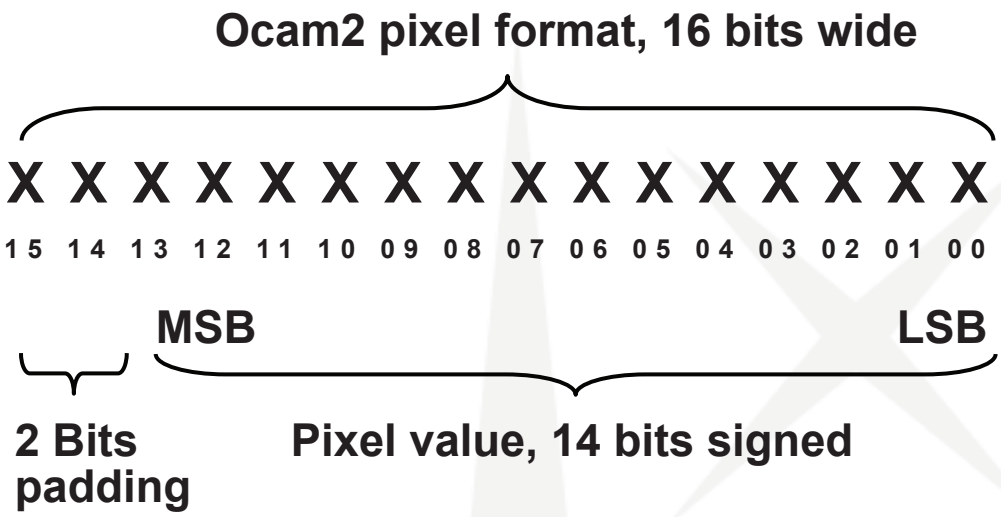


Figure 9 : OCAM² pixel format

6.2.3. CameraLink data format

The CameraLink specification does not allow directly for detector geometry such as the one of the CCD220/219, as it is not permitted to configure 8 outputs – 16 bits-per-pixel camera.

In order to comply with the CameraLink spec OCAM² has to multiplex its pixel data and act like an 8 outputs, 8 bits per pixel camera, but with twice the pixel clock speed.

The camera outputs Frame Valid (FVAL), Line Valid (LVAL) and Data Valid (DVAL) signals.
The frame grabber should thus synchronize acquisition with these signals.

As the image format for OCAM² does not fit within the constraints of the CameraLink standard, it is usually impractical to try to descramble the image data onboard of the grabber. See below for a detailed description of the descrambling procedure.
The CCD220/219 geometry imposes a minimal number of overscan (e.g. non-image) pixels.
These overscan pixels are transmitted over CameraLink and can vary in number depending on the intent of the user.

For regular use though, these overscan pixels are kept to a minimum, ensuring maximal speed is achieved. For technical reasons, the overscan pixels of line n are seen as prescan on line n+1.

A regular image (normal mode) acquired by OCAM² has a geometry of 66x121 pixels per output.
This translates into a grabber geometry of 1056x121 8-bits pixels.
Pixels are transmitted in INTEL - Little Endian byte order. This means LSB first, then MSB.

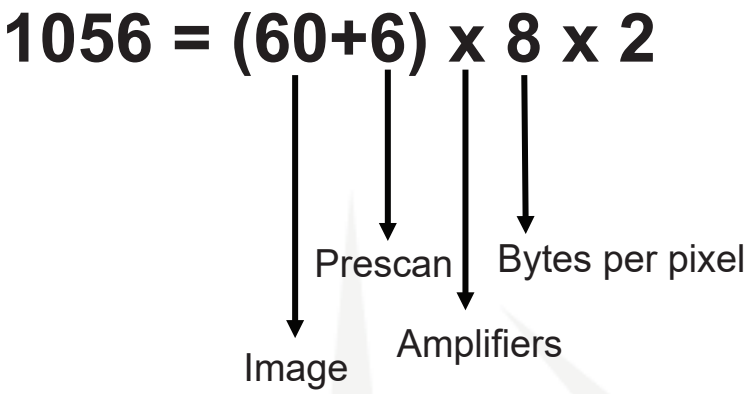


Figure 10 : Number of pixels per line with OCAM²

The framegrabber should be configured for images that are 1056 pixels wide and 121 lines high.

The actual 16-BPP (bits per pixel) pixels from the camera are temporally multiplexed to appear as twice the same number of pixels with only an 8-bits width.

Pixel clock should be set at 26 MHz. It is not required to give a precise pixel clock as the synchronization is given by the camera.

6.2.4. Binning Mode 120x120 pixels

OCAM² offers a 2x2 binning mode. In this mode the camera achieves 180% of its nominal speed, and 3623 FPS.
OCAM² binning mode offers 120x120 pixels. Image descrambling is essentially identical as for standard mode with the following differences:

- Horizontal resolution stays at 240 pixels, but the pixels are duplicated two by two.
- Vertical resolution is halved, down to 120 pixels.

To unscramble the OCAM² image, the operation is identical as for standard mode, one just need to skip one pixel over two horizontally, and only parse 120 image lines.
The unscrambled geometry for binning mode is 1056x62 8-bits pixels. Horizontal resolution stays unchanged, vertical resolution is halved, plus a little overhead.

OCAM² maintains separate Flat & Bias correction maps for binning and standard modes. To modify a table for binning mode, simply load it with binning mode active.

6.2.5. Unscrambling OCAM² data

The CCD220/219 at the heart of OCAM² is a split frame-transfer, 8 outputs CCD, as shown Figure 8.

As the pixels are digitized using 14 bits precision padded to 16 the camera geometry does not fit within regular CameraLink specifications.

CameraLink defines 8 ports labeled A, B, C, D, E, F, G, H that are 8-bits wide. In order to transfer the 8 ports 16 bits that OCAM² produces, these ports A, B, C, D, E, F, G, H are used in succession, clocking the first 4 pixels from OCAM². Basically what goes out for 1 pixel is 8 MSB group then 8 LSB group, turning in 4 complete pixels per clock cycle.
The first 4 pixels are the ones coming from the top of the camera sensor.
The next 4 pixels (on the second clock tick) are from the bottom of the CCD.

This 1056x121 (for normal operation) configuration ensures that the grabber will fill its memory without reordering data transmitted from the camera.
Once data has been written with 8 bit data the only task remaining is to read the buffer with 16 bits access (in unscrambling).

6.2.6. Pixel order

OCAM² sends the pixels in the amplifier order 01234567.

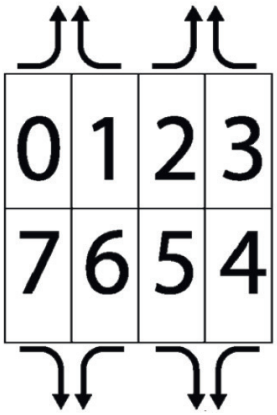


Figure 11 : OCAM² amplifier numbering

From the schematic in Figure 11 one can figure out the way pixels are transmitted.
The 8 amplifiers are interleaved, meaning a pixel from amplifier A gets transmitted every A.

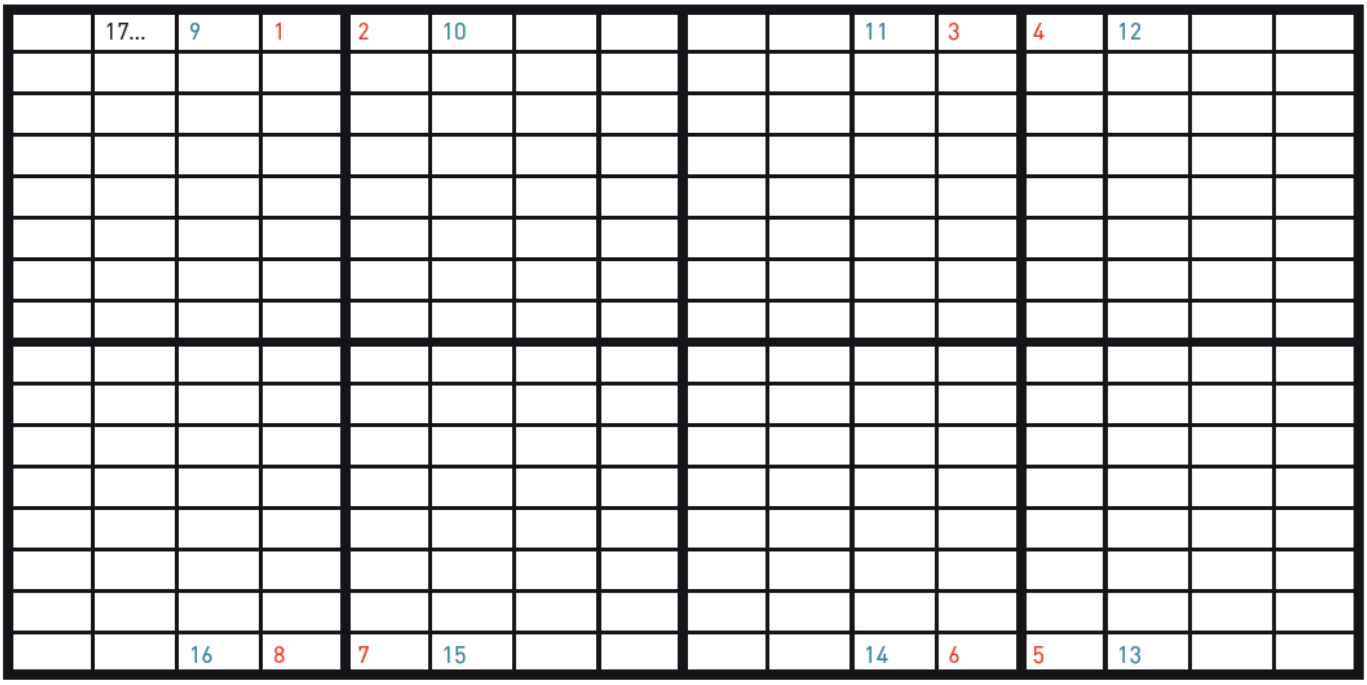


Figure 12 : Pixels descrambling. Each number gives the pixel order on the CameraLink bus

The table above shows the order by which the pixels are sent by the camera.

OCAM² has an embedded 32-bit unsigned frame counter that is reset at every powerup. The frame counter is transmitted at offset 8 (in bytes) of every image. This counter will cycle after 45 days of continuous operation at 2067 FPS.

6.3. Issuing commands to the camera – How to

OCAM² firmware communicates with the user through the serial line embedded in the Camera-Link cables. Usually the driver for the frame grabber will expose the serial line of the CameraLink standard as a virtual COM port on the acquisition system. See below an example for Dalsa Teledyne Xcelera-CL PX4 board.

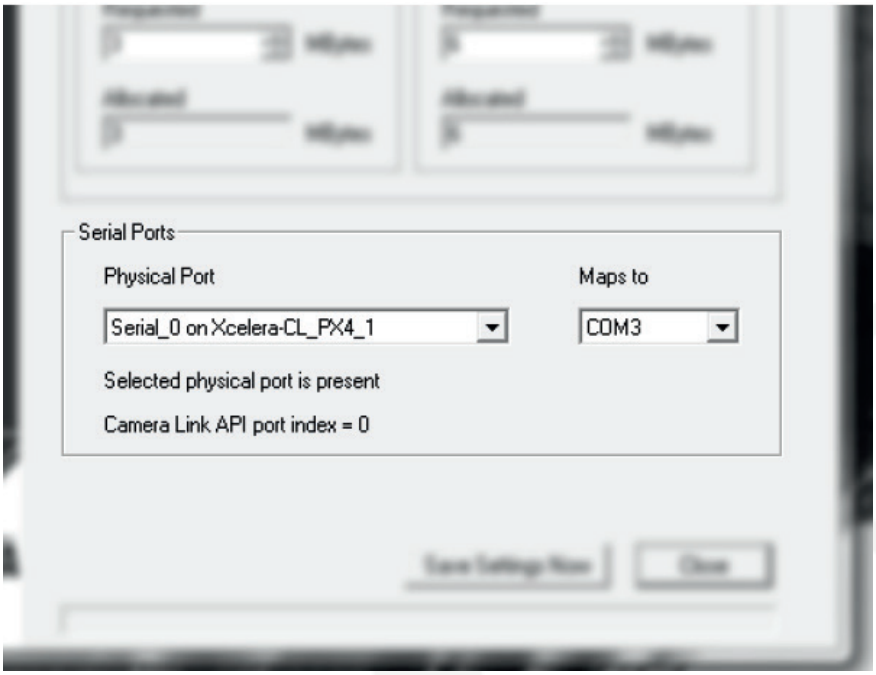


Figure 13 : CameraLink COM port mapping for Xcelera PX4 board

Please note that our cameras have been developed and tested with specific grabbers, and that we highly recommend to use these grabbers. Any malfunctions related to the use of a non-certified grabber will not be supported by First Light.

List of tested and recommended grabbers:
-TELEDYNE DALSA PCX Xcelera-cl px8 full
-MATROX: solios eV-cl full

In order to communicate both ways, the serial line must be configured with the following settings:
115200 Bauds, 8 bits, No parity, 1 Stop bit

The commands of the camera are sent as ascii characters sequence ended with '\r' (Carriage Return).
This is why the FLI "GUI OCAM DEMO" software can be used to send commands but also any terminal software, like putty for example.
However, in addition of commands, bias/flat images can be sent to the camera too.
These images are sent through the serial link using a proprietary binary format.

To send these images, the FLI "GUI OCAM BIAS/FLAT loader" software must be used, or it is possible to build your own tool using OCAM² SDK.

There is more information about First Light's softwares in **ocam2sdkDemo_usermanual.pdf.** Additional information regarding flat/bias images are available at **chap 6.6 Bias/Flat Correction.**

6.4. Basic parameters

This section covers adjusting fundamental image parameters such as gain and frame rate.

6.4.1. Sensor Cooling

At first the "temp reset" must be issued.
Then type "temp on" to start the cooling of sensor.
Type "temp" to know what is the temperature of the sensor.
Type "temp off" to stop the cooling process.

temp	Gives the current temperatures of the camera
temp reset	Resets the temperature alarm
temp on	Turns the cooling down of the camera on,
temp off	Turns the cooling of the camera off

« temp on » does not activate the external cooling system

6.4.2. Adjusting Frame rate / Exposure

To change the rate at which OCAM² acquires images the camera must be issued an 'fps' command.
Syntax is 'fps nnn' where nnn is the requested speed in frames per second.
Accepted range is 1 to 2067 Hz.
The special value 0 (as in 'fps 0') instructs the camera to operate at full speed (2067Hz).

6.4.3. Adjusting L3Vision gain

The L3 Vision gain on the OCAM² camera is factory calibrated for operation at CCD temperature of -45°C.

The requested gain can be adjusted by issuing the 'gain' command.

The gain can be freely adjusted by the user in the range from 1 (unity gain) to 600 by steps of 1.

NOTE *operating the camera with gain and intense lighting can trigger the integrated overillumination protection and cause the camera to revert to a safe level of unity gain.*

When triggered, the overillumination protection prevents any gain elevation above normal until the error has been acknowledged.
To acknowledge the protection type "protection reset" command.

See precaution of use for details on how the protection operates.

At powerup the camera operates at unity gain, and the overillumination protection is active.

6.4.4. Simulation (test) mode

OCAM² can provide test data for setting up purposes and generic setup of the acquisition chain.
The data sent is generated within the camera with a geometry of 66x121 pixels per amplifier, same as regular images.
Data is a simple counter (ramp) of pixel values, per amplifier.

See Figure 14 for an illustration of how a 1056 pixels-wide, 128 lines high OCAM² grab should look like.

See Figure 15 for an illustration of what the unscrambled, 8-outputs image should look like.

The camera test mode can be switched on/off by issuing the ‘test’ command
• ‘test on’ starts the simulation mode, and
• ‘test off’ turns it off, resuming normal imaging operation.

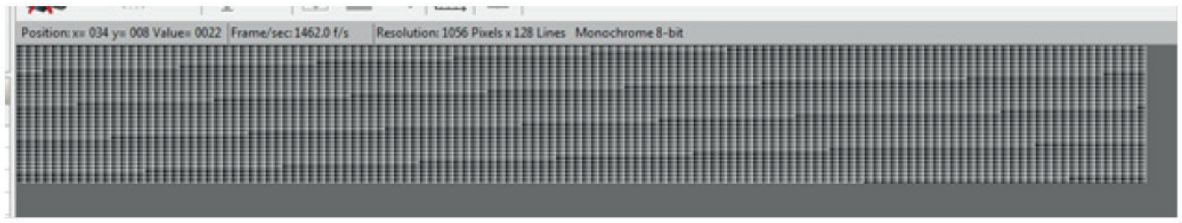


Figure 14 : OCAM² scrambled image as seen in framegrabber utility

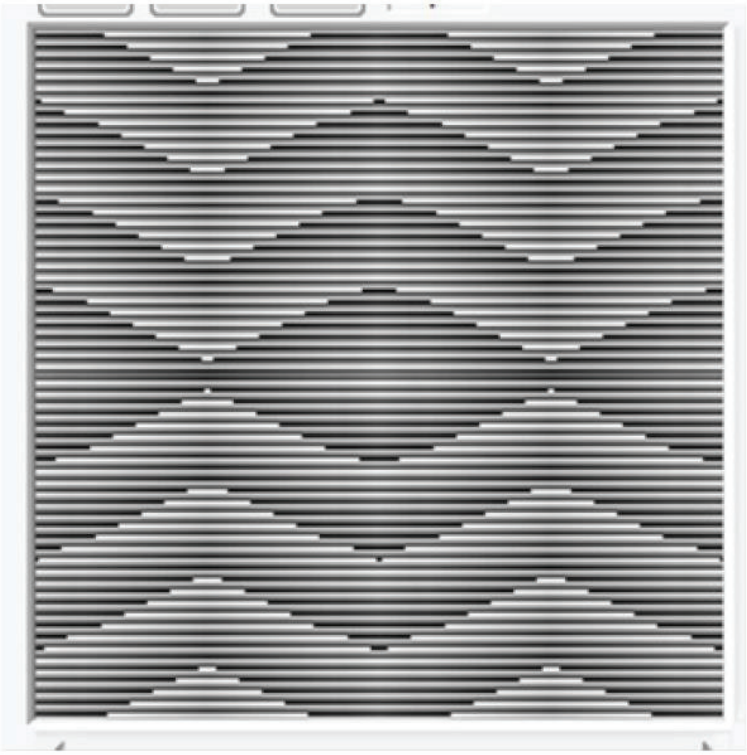


Figure 15 : OCAM² unscrambled test mode image

6.4.5. Real image data

In normal operation OCAM² acquires images at its full speed, i.e. 2067 by default.

Normal mode is defined as free-run, no external synchronization. See *External synchronization* on how to synchronize OCAM² image capture with external events.
In normal mode OCAM² amplifiers have a geometry of 66x121 pixels on all eight outputs. The first line is a prescan line and does not contain image data.
The first 6 pixels of each line are also prescan (actually, overscan from previous line) and contain no image data. See Figure 16 for an illustration of a normal mode image of one amplifier output.

Figure 16 : Single Amplifier image showing prescan data

6.5. Synchronization

6.5.1. Cable Assembly

Together with the OCAM² Camera with synchronization option are supplied 2 Lemo cables (FGG.00. 304.CLAD35).
These cables will allow you to use all the functionalities of the Synchro card.

Wiring is detailed below:

OCAM² Synchro Female Connector

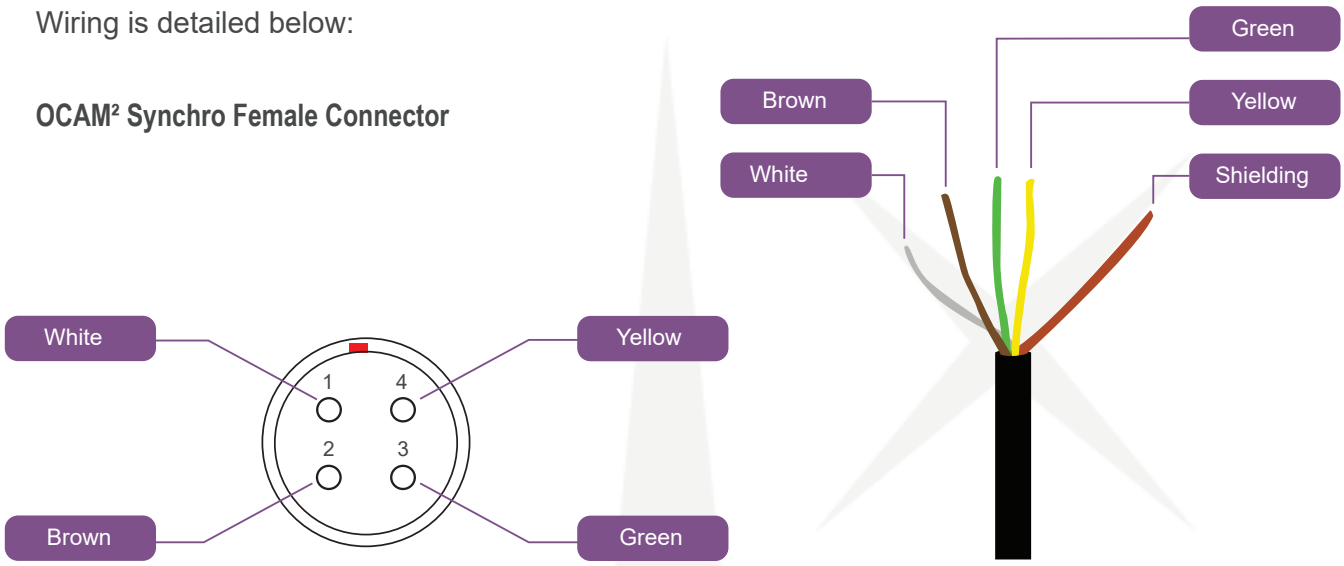


Figure 17 : Cabling

6.5.2. Synchro connection

OCAM² with Synchro Mode offers the possibility to drive the frame readout with an external trigger and can provide timing information through a 4-pin Lemo connector (Mating LEMO male connector reference is FGG.00.304. series connectors).
Both input and outputs are LVDS and require two wires, ground reference is the connector body.
Here is the Sync connector layout of the rear panel (from up to down):

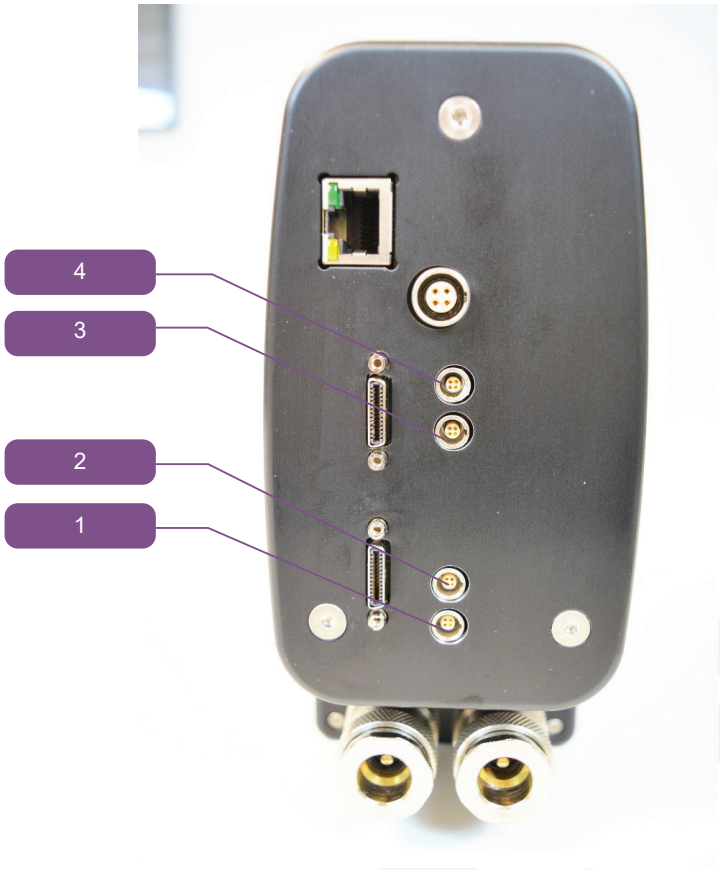


Figure 18 : Sync connectors on the rear panel.

The input port is only 3.3 V tolerant.

6.5.3. Input: Synchro-in

The frame rate of OCAM² can be driven by an external source plugged on connector 1.
OCAM² allows values between 0 and 2067 fps. The camera stays in integration mode while the synchro-in signal is high. When this signal goes low, it triggers the readout.
Valid data is present on the CameraLink bus 43 µs after this trigger (which corresponds to the camera latency). While the camera readout is initiated, the status of synchro-in is ignored, the next exposure starts in parallel. Once the sensor has been read-out, the camera stays in integration if the synchro-in signal toggled too high in the meantime. If the synchro-in is still low, then another sensor readout is issued immediately, and another image is sent on the CameraLink bus.
Cabling is shown in Figure 19.

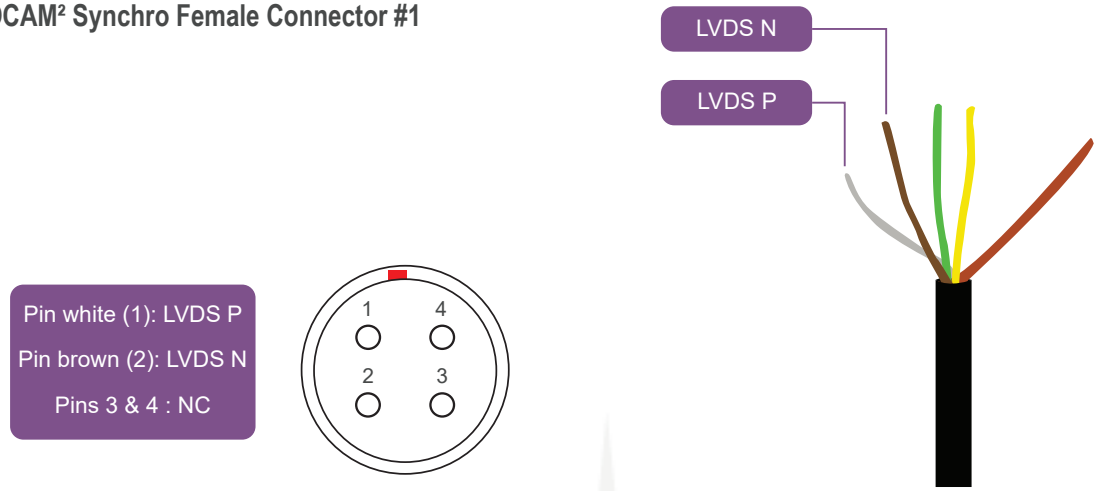


Figure 19 : Cabling.

➔ **Free Run vs Synchro operation.**

By default, OCAM2 runs at full speed with no synchronization. Integration time length is constraint by the readout, readout of frame N and integration of frame N+1 are done in parallel. Integration and readout times are the same.

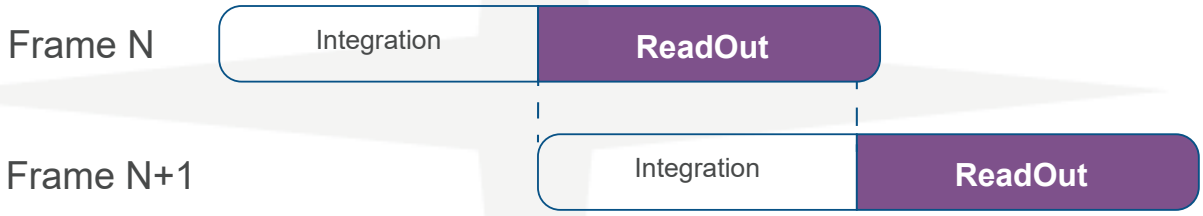


Figure 20 : Free run operation

The Synchro-In option allows to choose the exact time when Readout is done.

Synchro In

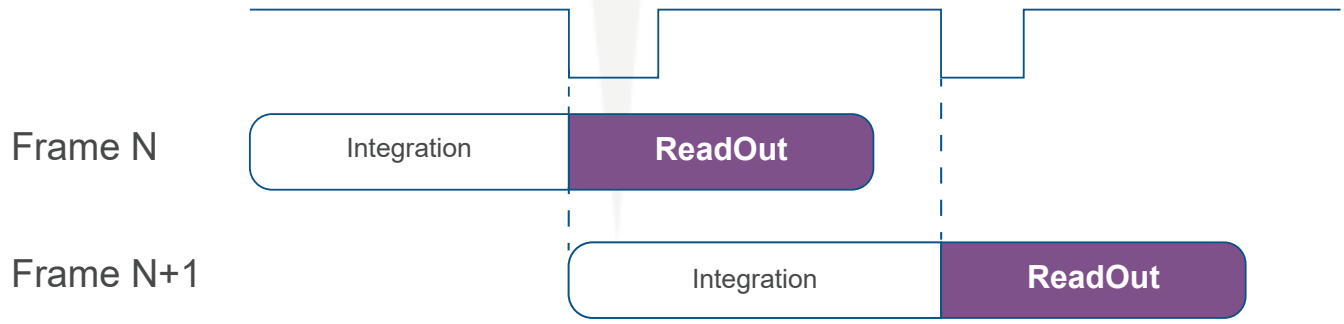


Figure 21 : Synchro operation.

6.5.4. Synchro-out

This output delivers a signal synchronized with each new image delivered by OCAM². The sync out is the mirroring of the FVAL (frame valid) CameraLink signal. It indicates when data is available on the bus and reflects the camera frame rate. It might be used to sync some equipment (tip tilt for example) using the camera as the timing master.
It goes low when readout since the falling edge of this signal gives the exposure start of the new frame as well as the start of the readout.
It goes high once the readout is finished indicating that the camera would be ready for the next readout.
It should have the same frequency as the input FPS sync when “Synchro Mode” is on.

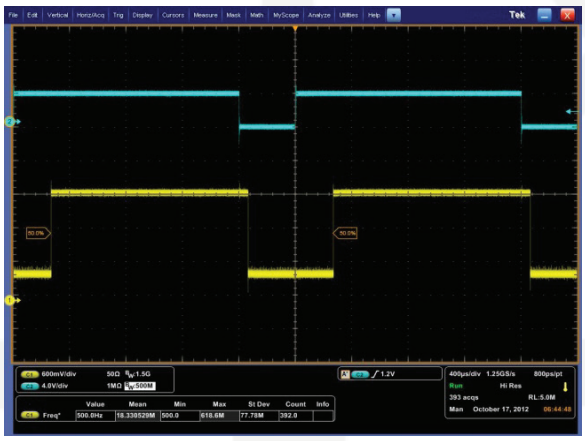


Figure 22 : Input and output signal display. Input is blue, output is yellow

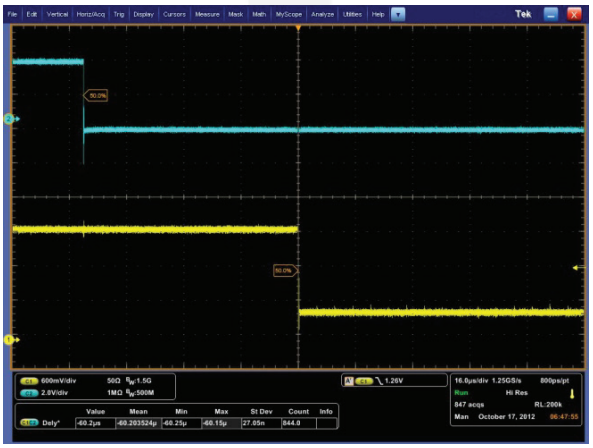


Figure 23 : Delay between synchro-in input (blue) and synchro-out output (yellow) is the total camera latency (45 µs)

Cabling is shown in Figure 24:

OCAM² Synchro Female Connector #4

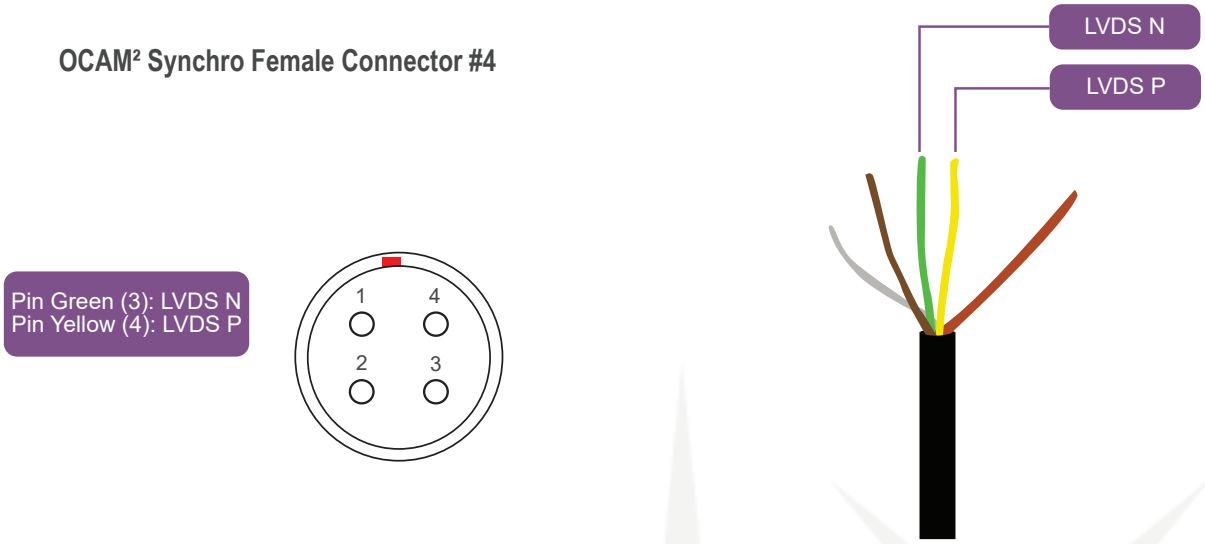


Figure 24 : Cabling of the Synchro-out connector

6.5.5. LVAL output

This output signal appears like bursts of 121 squares synchronized with every line of each images.
It is a duplicate of the CameraLink LVAL signal.

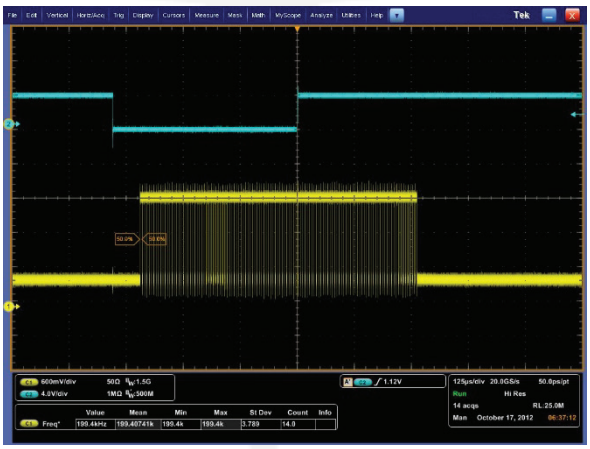


Figure 25 : Display of output LVAL

The duty cycle of the input frequency command should be carefully chosen to ensure that the image generation works properly. Indeed, if the lines cycle ends when the input Synchro-in signal is still at low level, a second image is generated and readout immediately. (See Figure 26).

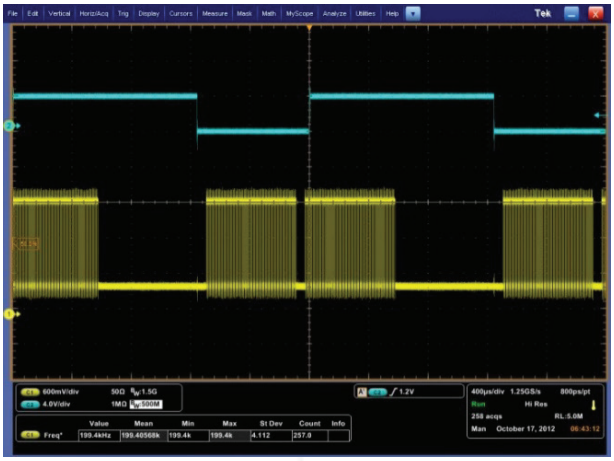


Figure 26 : Double frame triggered with long synchro in signal

Here is a summary of the duty cycle that should be chosen with the frequency:

$$DutyCycle(\%) \geq 100 * (1 - f_{sync_{in}} * t_{readout})$$

With $$t_{readout} \approx \frac{1}{2 * f_{max}}$$

Figure 27 : Duty cycle with the frequency.

The duty cycle should never be below 50%.

Cabling of this port is shown in Figure 28:

OCAM² Synchro Female Connector #4

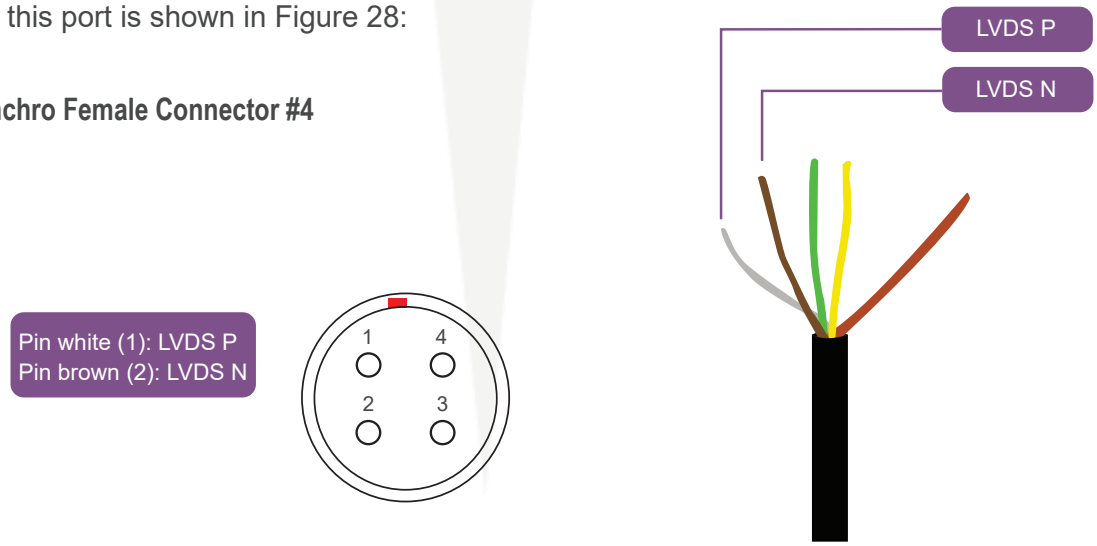


Figure 28 : Cabling of the Output LVAL

6.5.6. Output: Pixel Clock

This output delivers a signal at 18.64 MHz synchronized with the pixel readout of OCAM².

OCAM² Synchro Female Connector #3

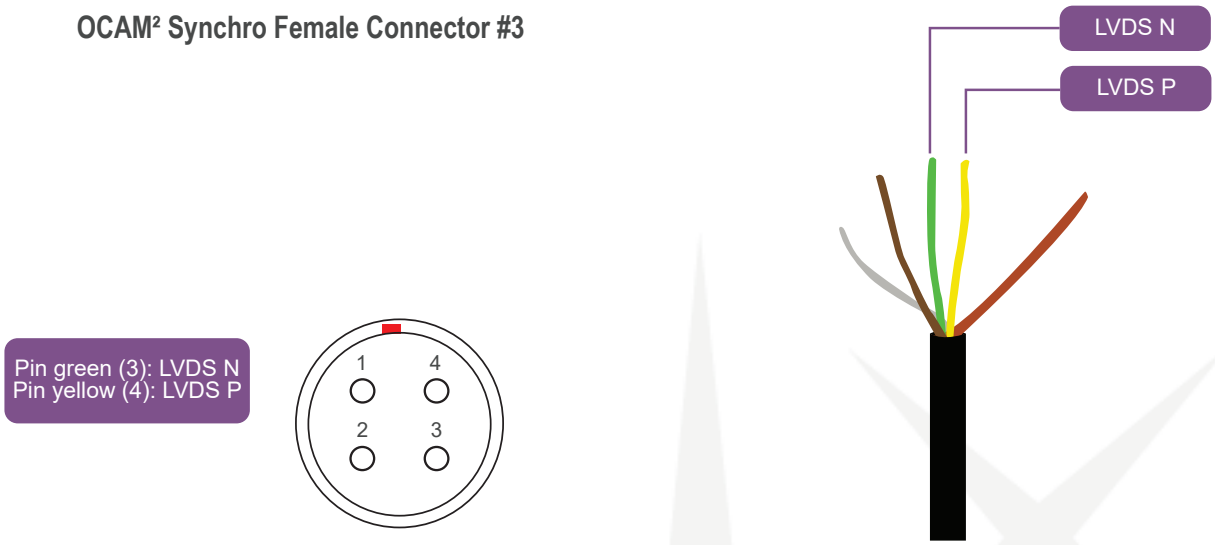


Figure 29 : Cabling of the Output « Pixel Clock»

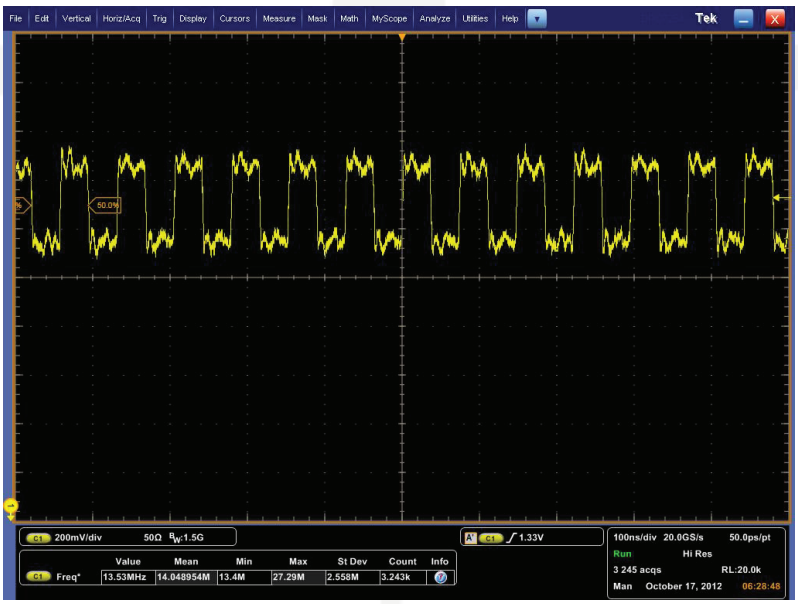


Figure 30 : Pixel clock signal at 18.64 MHz

6.6. Bias and Flat Correction

Bias and Flat correction can be done on the fly by the camera.
To do so, a bias and a flat image must be loaded in the camera.
The camera does the correction on the fly, however the bias and flat images computation must be done outside, on the acquisition computer.

The camera is provided with preloaded factory bias and flat images.

For use of personal images, please follow the process below:

1- Use the demo acquisition software (or your personal software) to grab at least a thousand images (in the dark for bias, in front of a flat field for the flat).
2- Start the OCAM² flat/bias loader software and check that the correct serial port is selected.
3- Load the previously grabbed images and select the correction type (bias or flat).
4- Then, send the bias or flat image to the camera.

The OCAM² flat/bias software does the bias/flat computation, although, you can compute these images by yourself, by adding the suffix .bias to your bias image and .flat to your flat image.
Then the images can be loaded directly from the software and sent unmodified to the camera.

More information about First Light's softwares is available in **ocam2sdkDemo_usermanual.pdf.**

7.1. Shutter operation

7.1.1. Sensor structure

The CCD219 is a derivative of the CCD220 used in standard OCAM²K cameras (schematic in Figure 31).
It is a 24 µm square 240x240 pixels split frame transfer back illuminated L3Vision CCD.
Each pixel has an embedded shutter system consisting of an extra drain. To provide shutter routing, the two central lines of the device are inactive.

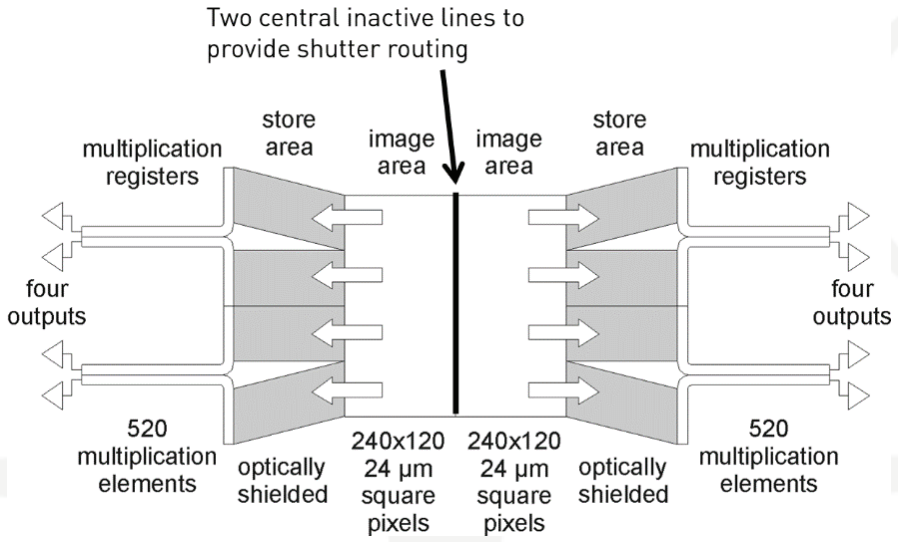


Figure 31 : Schematic of e2v technologies 240x240 pixel L3Vision CCD219. Eight electron-multiplying (gain) registers are used to obtain sub electron noise at frame rates above 2067 fps. The two central lines are inactive to provide routing for the shutter system.

The shutter mechanism is wavelength dependent, since redder photons will penetrate deeper in the silicon. The extinction ratio (ratio of the charges accumulated when the shutter is open and the charges accumulated when the shutter is closed) also depends on the electrical field structure.

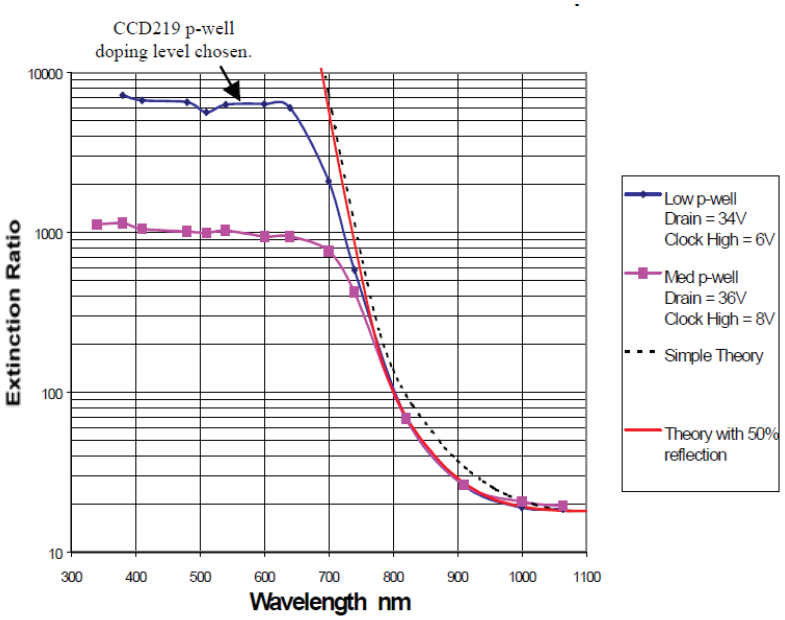


Figure 32 : Extinction ratio vs wavelength for various buried p-layer doping levels

The doping level of the device is different and this results in a lower full well capacity of the pixels compared to a classical CCD device (300 ke- typical for standard devices whereas **the shuttered version has ~100 ke- full well capacity).**

The shutter can be seen as an additional device that can be driven more or less independently from the CCD itself.

7.1.2. Shutter interface

The shutter can be driven externally through the backside synchro connectors, or internally synchronous with the CCD frame readout. The external drive is done through a 4-pin LEMO connector (Mating LEMO male connector reference is FGG.00.304. series connectors).

Both input and outputs are LVDS and require two wires, ground reference is the connector body. Here is the Sync connector layout of the rear panel (from up to down):

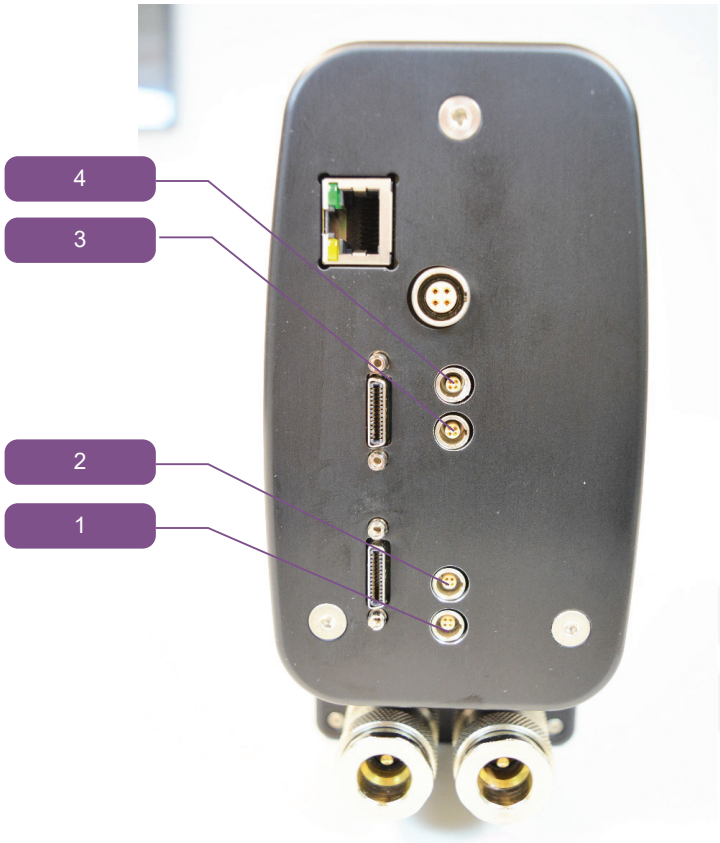


Figure 33 : Sync connectors on the rear panel.

The input ports are only 3.3V tolerant.

7.1.3. Synchro signals

The synchro I/O is not an option with OCAM²S cameras and is delivered as a standard feature. The interface provides all the signals available with the synchro option and in addition an extra input for the shutter.

The shutter-in input signal is present on the connector #1, pins 3 & 4.

Cabling is shown in Figure 34.

Pins 1 & 2 are frame synchro in, and may be used at the same time with shutter in input (see synchro option manual for the description of the frame sync input).

The signal is positive triggered: when a logical 1 is present on the input, the shutter is OPEN.

Figure 34 : Cabling.

7.1.4. Shutter limitations

It is not possible to operate the shutter during frame transfer. Frame transfer occurs just at the beginning of the frame readout and lasts 9 µs. During this time, the shutter input is overridden by internal camera logic and the shutter is maintained CLOSED.

When used in pulse operation (open pulse or closed pulse), the pulse width cannot be lower than 56 ns which is the minimal pulse response time. Pulses shorter than 1 µs will result in a partial shutter response, with a -3dB cutoff width (70% response) in the range of 300 ns. This cutoff width is measured individually for each camera and is in the camera test and characterization report.

7.2. OCAM²S camera specific commands

Following are the shutter-specific camera commands:

• ‘shutter on’ Turns on the electronic shutter
• ‘shutter off’ Turns off the electronic shutter
• ‘shutter internal’ Use camera internal clocking to operate the shutter
• ‘shutter external’ Use external signals to operate the shutter
• ‘shutter single’ Fire a single shutter opening per trigger
• ‘shutter burst’ Fire a burst of openings per trigger
• ‘shutter sweep 0|1|2’ Sets shutter sweep mode:
    a. Mode 0: Sweep OFF
    b. Mode 1: Sweep mode on internal clocking
    c. Mode 2: Reserved.
• ‘shutter pulse nnn’ Sets the shutter pulse width, in ns. *Internal mode only*
• ‘shutter blanking nnn’ Sets the shutter blanking period separating two pulses for burst mode. In nanoseconds. *Burst mode only.*
• ‘shutter position nnn’ Sets the position of the first pulse, in nanoseconds from integration start.
• ‘shutter step nnn’ Specifies the starting increment in ns, from frame to frame for sweep mode 1. *Sweep mode only*
• ‘shutter end nnn’ Specifies the duration of the sweep, in nanoseconds from first to last pulse. *Sweep mode only*
• ‘shutter count nnn’ Specifies the number of pulses to make per trigger for burst mode.
• ‘shutter blockonread 0|1’ Specifies if the shutter is disabled (1) or not (0) during CCD readout. Prevents shutter pixel bias glitch at lower than maximum frame rates.
• ‘shutter correctglitch 0|1’ Specifies if the shutter disturbance should be corrected on the fly (1) or not (0).

7.3. Camera operating modes

7.3.1. Camera as slave

When used in this mode:

The camera is a slave of a third-party master.
The shutter is driven externally.
The camera frame rate may be driven externally as well (optional full slave) or the master may be synchronized to the camera using the camera sync signals (FVAL and LVAL, see synchro manual).
See Figure 35 and Figure 36.

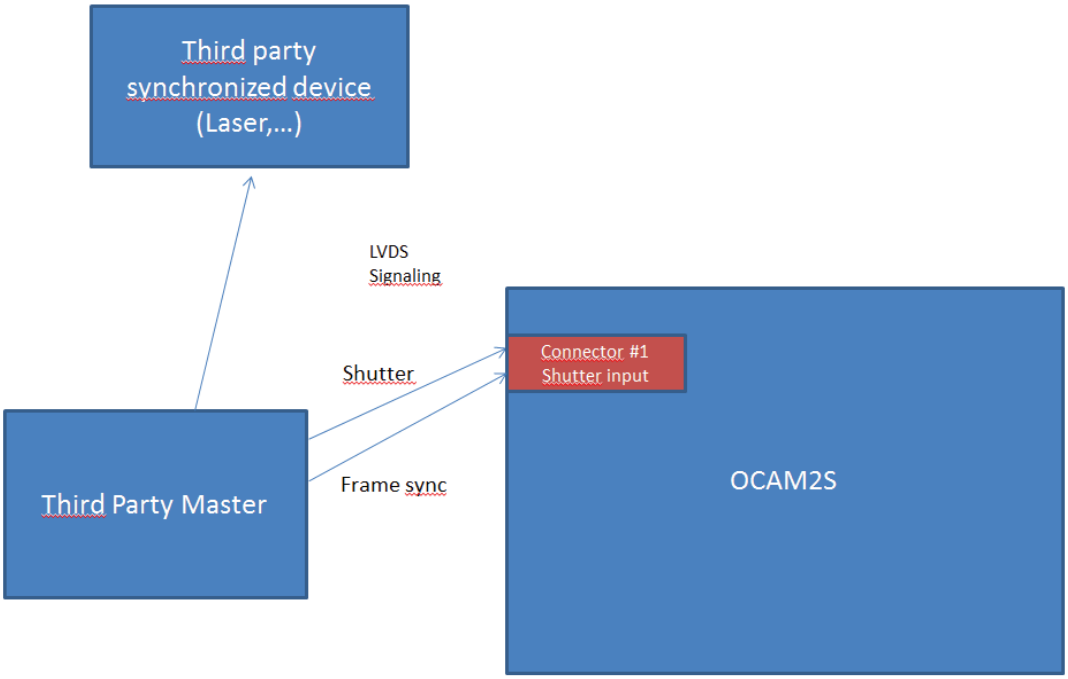


Figure 35 : Full slave mode schematic breakdown: The third party master drives the shutter as well as the camera frame rate through connector #1. The frame sync command must conform to the specifications detailed in the synchro option manual

.

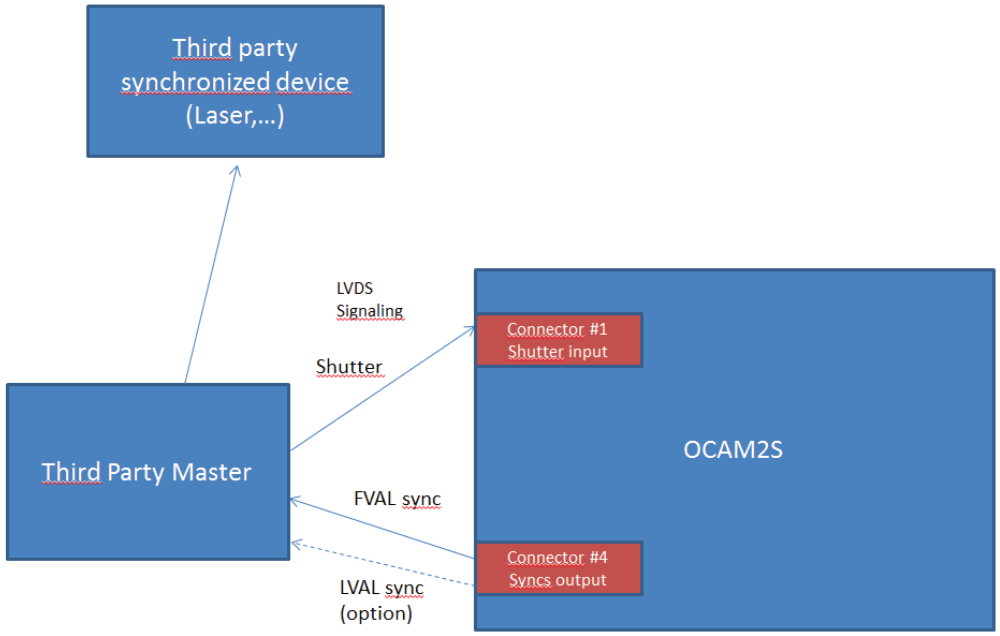


Figure 36 : Camera synchronized third party master. The camera is used in free run mode and the master uses the FVAL (frame valid) signal to synchronize itself to the camera.

To enter this mode, the following commands must be issued:

‘shutter on’
‘shutter external’

This will turn on the shutter and use the external shutter input.
In the full slave mode, the additional external synchro command must be issued:

‘synchro on’

7.3.2. Camera as master

In this mode the camera is used as the reference for the other third party subsystems. These subsystems are synchronized to the camera through the FVAL (field valid) signal and optionally the LVAL (line valid) signal.

To enter this mode, the following commands must be issued:

‘shutter on’
‘shutter internal’

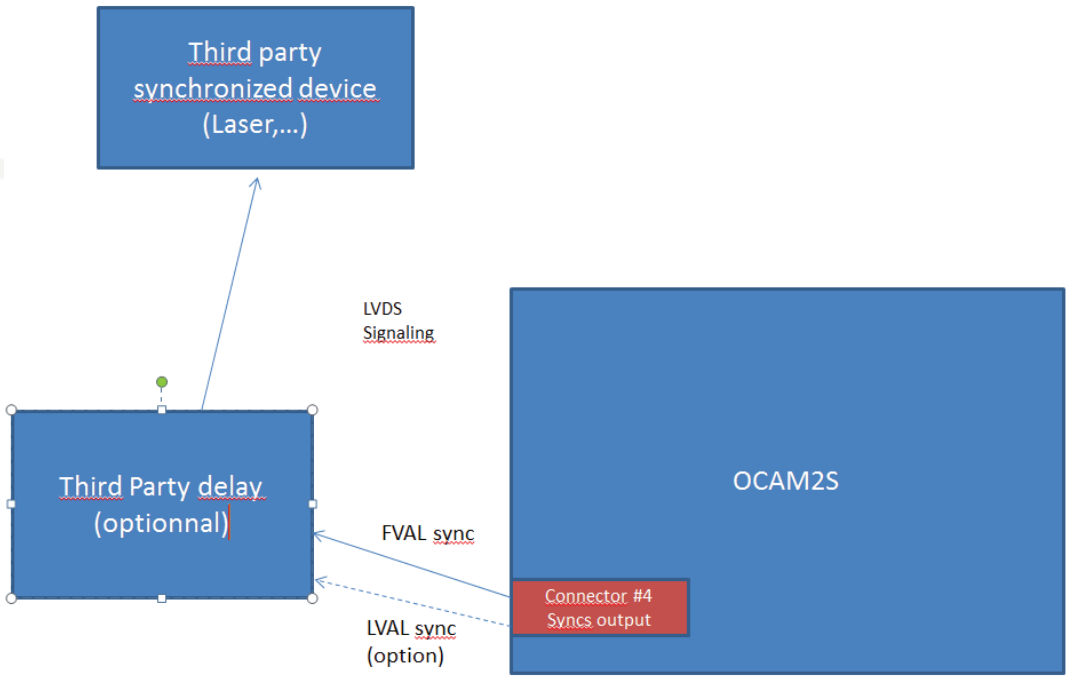


Figure 37 : Camera as master breakdown schematic. The camera is used as a timing master for all the third party devices using FVAL output signal (optionally LVAL output signal)

Using this mode the shutter is internally driven by the camera logic. The extra OCAM²S commands are available to configure the shutter operation.

7.3.3. Single mode operation

In this mode, a single shutter opening is issued. The trigger event for this mode is the frame integration start.

The shutter parameters are set by the following commands:

• ‘shutter single’ Fire a single shutter opening per frame.
• ‘shutter pulse nnn’ Sets the shutter pulse width, in ns.
• ‘shutter position nnn’ Sets the position of the first pulse, in nanoseconds from integration start.

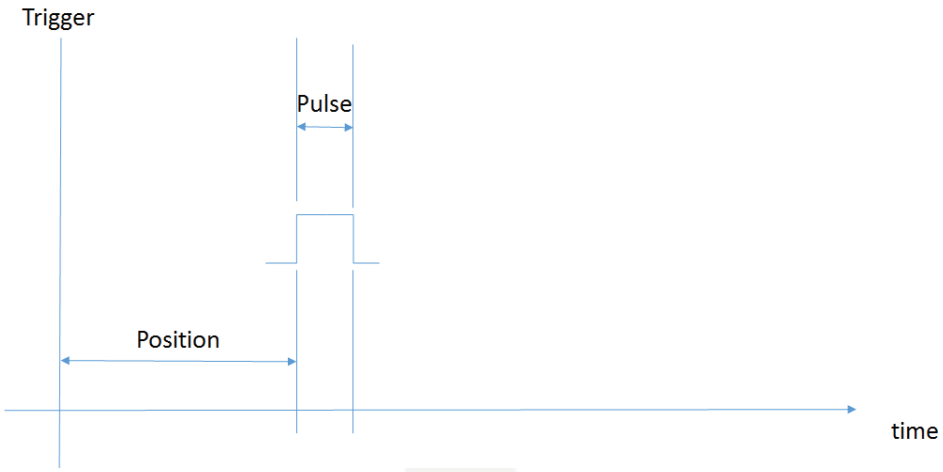


Figure 38 : Single mode operation

7.3.4. Burst mode operation

In this mode, multiple shutter openings are issued. The trigger event for this mode is the frame integration start.

The shutter parameters are set by the following commands:

• ‘shutter burst’ Fire a burst of shutter openings per frame.
• ‘shutter pulse nnn’ Sets the shutter pulse width, in ns.
• ‘shutter position nnn’ Sets the position of the first pulse, in nanoseconds from integration start.
• ‘shutter blanking nnn’ Sets the shutter blanking period separating two pulses for burst mode. In nanoseconds.
• ‘shutter count nnn’ specifies the number of pulses to make per trigger for burst mode.

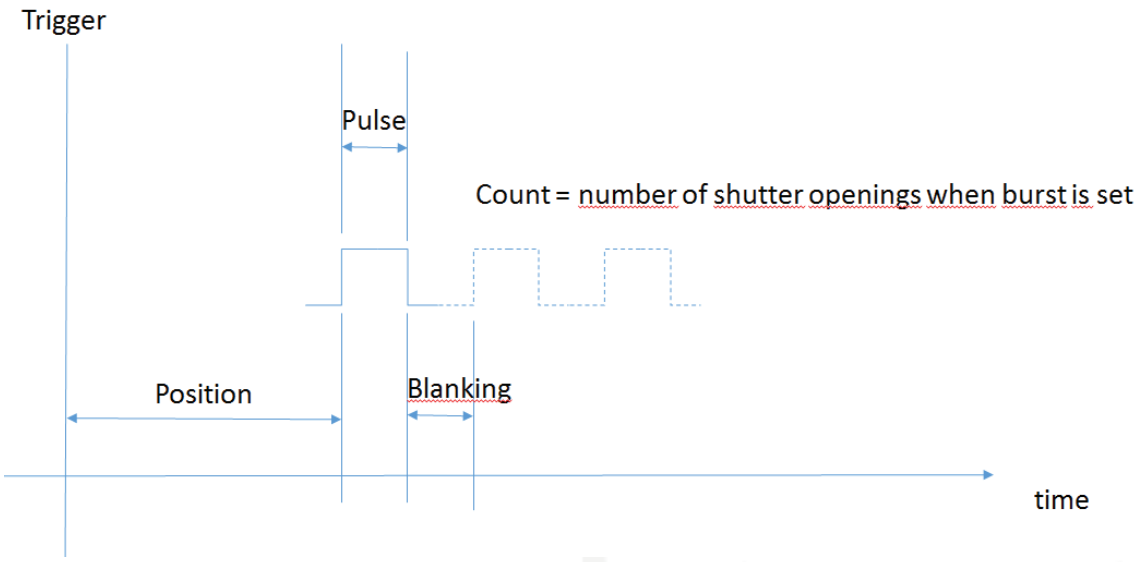


Figure 39 : Shutter burst mode operation

7.3.5. Sweep operation

In this mode, a single shutter opening is issued. The trigger event for this mode is the frame integration start, but for each frame, the shutter opening in incremented by a fixed value until it reaches a maximal value, and then starts over.

The shutter parameters are set by the following commands:

‘shutter sweep 1’ issue a sweep of openings each frame.

To disable the shutter sweep, issue the following command:

‘shutter sweep 0’

- ‘shutter pulse nnn’ Sets the shutter pulse width, in ns.
- ‘shutter position nnn’ Sets the position of the first pulse, in nanoseconds from integration start.
- ‘shutter step nnn’ Specifies the starting increment in ns, from frame to frame
- ‘shutter end nnn’ Specifies the duration of the sweep, in nanoseconds from first to last pulse.

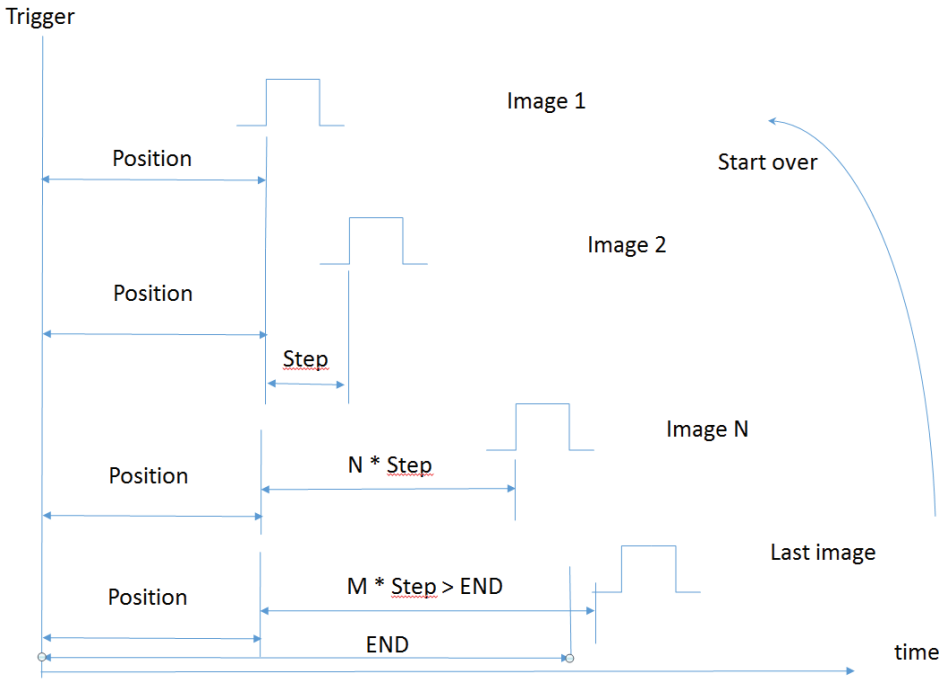


Figure 40 : Shutter sweep mode operation

7.4. Shutter glitch

When the shutter is operated during readout, there is a crosstalk through the CCD's amplifier that makes a glitch in the image (see Figure 41). This image glitch is a constant value added to the image but it is strongly temperature dependent.

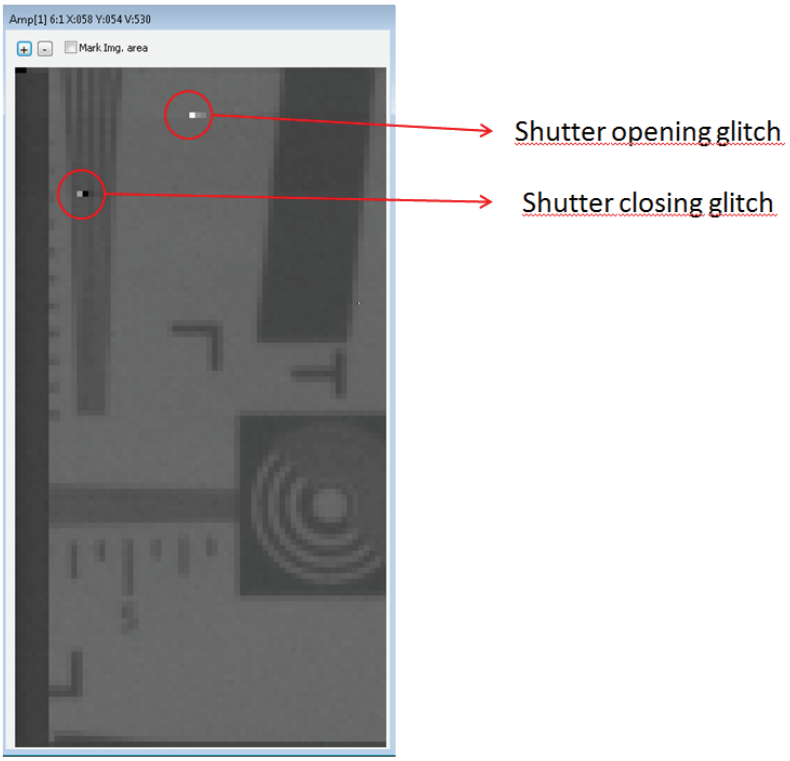


Figure 41 : Image glitch when the shutter is operated during CCD readout (only one CCD amplifier shown here)

7.4.1. Glitch suppression method 1: bias subtraction

The glitch level is a bias effect. It is possible to subtract it during a classical CCD bias correction process. This may be offline by the user taking dark reference images (1000 images for example), compute an averaged bias image and then subtract it to each incoming image from the camera. As the image glitch is strongly temperature dependent, all these operations must be made at the same CCD operating temperature.

This can be done offline by the user, or on-the fly by the integrated bias subtraction of the camera.
This method is valid only for a fixed shutter opening (not valid in sweep mode)

7.4.2. Glitch suppression method 2: shutter during readout inhibit

It is possible to forbid the shutter operation during readout to avoid glitches in the image. This is done issuing the command:

'shutter blockonread 1'

In the same way as the shutter is blocked during frame transfer, in this case the shutter is blocked during the whole image readout preventing any perturbation in the image. This is valid only for slow readout modes, when the camera speed is less than 2067 FPS because in this case the readout time equals the exposure time, there is no dead time where to put the shutter operation. When the integration time is longer (slower than 2067 FPS frame rate), shutter triggers should be issued after the frame readout (see Figure 42).
This mode is valid for master and slave (externally triggered) modes.

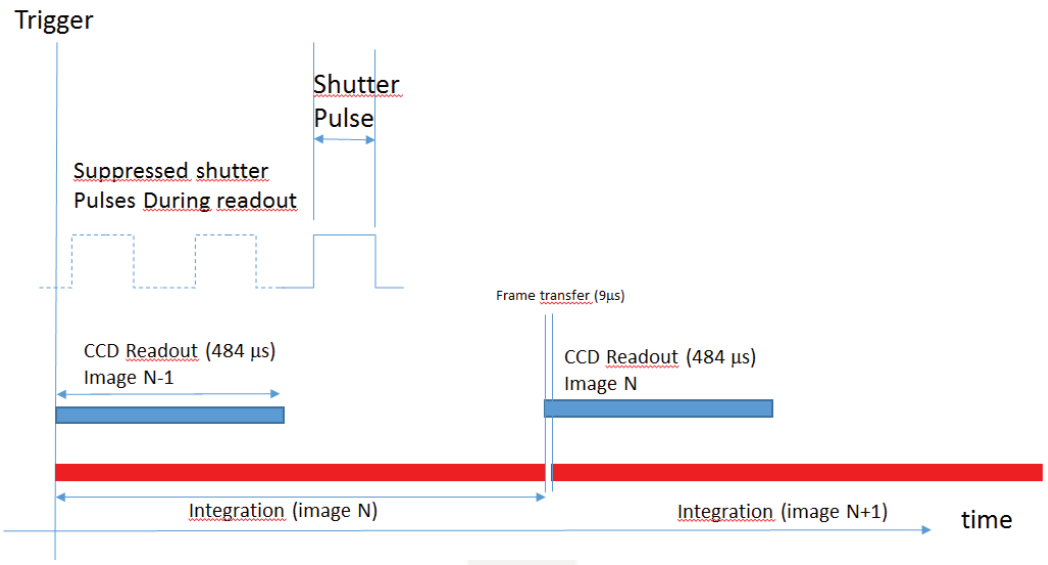


Figure 42 : Shutter inhibit during readout operation

The available time to issue shutter fires is given by the following equation

$$T = \frac{1}{FPS} - 0.000484$$

T is the available time in seconds, FPS is the frame rate (in Frames per second)

7.4.3. Glitch suppression method 3: use internal on-the-fly correction

This is the most powerful method but it requires a careful preliminary calibration, and is strongly CCD operating temperature dependent.
The camera is capable of subtracting a local bias each time the shutter is triggered (internally or externally). This local bias reflects the shutter perturbation in the image.
This can be done by computing a bias image with shutter on and shutter off, and sending the correction values to the camera. The method is fully described in the demo software, with an example code.

To activate the shutter glitch correction, issue the command:

‘shutter correctglitch 1’

To deactivate this correction, issue the command:

‘shutter correctglitch 0’

COMMAND	SYNTAX	FUNCTION
Bias	bias on bias off bias offset nnn bias reset	**Turns the bias on** **Turns the bias off** **Enters an offset value for the bias, nnn is the BIAS value** **Sets the bias to 0**
Binning	binning on binning off	**Turns the binning mode on** **Turns the binning mode off**
Cooling		**Same as temp**
Flat	flat on flat off flat reset	**Turns the flat on** **Turns the flat off** **Fix the flat to 1**
Fps	fps nnn fps 0	**Changes frame rate to nnn (nnn valid from 1 to 2067)** **Fix the fps max at 2067 fps**
Interface	interface 0 interface 1	**Compact mode** **Verbal mode**
Led	led on led off	**Switch on the LED** **Switch off the LED**
Mode	mode 1 mode 2	**Turns the mode 1 on (2067 fps)** **Turns the mode 2 on (binning mode)**
Protection	protection reset	**Resets the overillumination protection**
Shutter	shutter on shutter off shutter internal shutter external shutter single shutter burst shutter sweep 0 or 1 shutter pulse nnn shutter blanking nnn shutter position nnn shutter step nnn shutter end nnn shutter count nnn shutter blockonread 0 or 1 shutter correctglitch 0 or 1	**Turns shutter on** **Turns shutter off** **Uses camera internal clock to operate the shutter** **Uses external signals to operate the shutter** **Fires a single shutter opening per trigger** **Fires a burst of opening per trigger** **Sets shutter sweep mode,** **mode 0: sweep off,** **mode 1: sweep mode on internal clocking** **Sets the shutter pulse width, in ns.** *Internal mode only.* **Sets the shutter blanking period separating two pulses for Surst mode. In ns.** *Burst mode only.* **Sets the position of the first pulse, in ns from integration Start.** **Specifies the starting increment in ns, from frame to frame for sweep mode 1.** *Sweep mode only.* **Specifies the duration of the sweep, inns from first tio last pulse.** *Sweep mode only.* **Specifies the number of pulses to make per trigger for burst mode.** **Specifies if the shutter is disabled (1) or not (0) during CCD readout. Prevents shutter pixel bias glitch at lower than maximum frame rates.** **Specifies if the shutter disturbance should be corrected on the fly (1) or not (0).**
synchro	synchro on synchro off	**Turns the synchro option on** **Turns the synchro option off**
temp	temp temp nnn temp reset temp on temp off	**Gives the current temperatures of the camera** **Set the sensor temperature, nnn is a value in °C** **Resets the temperature alarm** **Turns the cooling down of the camera on** **Turns the cooling of the camera off** *> does not activate the external cooling system*

9.1. Precaution of use

Your OCAM² is a high end scientific instrument, if this equipment is used in a manner not specified by the manufacturer the protection provided by the equipment may be impaired and the warranty will not be applicable.
Your OCAM² is an electronic equipment that requires precaution regarding static shocks, it contains an EMCCD detector that requires illumination and cooling precaution.
As any scientific instrument, your OCAM² camera is fragile and should not be exposed to shocks, extreme temperatures and humidity.

Your OCAM² camera is an expensive and fragile product, handle it with care!

9.1.1. Static / electric shocks

Any electronic equipment that has to be connected to OCAM² should be fitted with appropriate protection on all power lines.
The power of connected equipment should be switched off before moving any connection between computer and OCAM².

9.1.2. Heating / cooling

Your OCAM² camera has been built to work with liquid cooling system: never use your camera without such a system connected to the camera via the liquid connectors, filled with cooling fluid and switched on.
Please use your cooling system in accordance to the cooling system instructions.
Dew point: even if OCAM² is hermetically sealed and not subject to dew issue, please use cooling fluid at a temperature not below the dew point, do not use a coolant fluid temperature below the ambient temperature.

9.1.3. Overillumination

Your OCAM² camera contains an EMCCD detector, and is equipped with an exclusive onboard illumination protection system.
At unity gain the sensor cannot be damaged by saturation, however do not expose it to direct high level light source.
When gain is applied, excess light can lead to the aging of the detector, depending on the intensity of gain and light, the detector can even be destroyed in seconds.
When an overillumination is detected, the camera will protect the CCD by reverting to a gain of 1.

When such an event occurs, the camera will refuse to apply gain until the error is acknowledged by issuing a protection reset command.
At startup, the camera is in protection mode. To apply gain, the user must issue the protection reset command.

9.2. Operational environment

Maximum cooling fluid temperature :	35°C
Minimum cooling fluid temperature :	Dew point of the room (recommended)

9.3. Maintenance

9.3.1. Never open the camera

There is no user-serviceable parts inside your camera, do not ever attempt to open it. There are some indicators inside the camera, if you try to open it your warranty will be void.

9.3.2. Cleaning of window

Never use an unclean cloth to wipe the window of the camera.
The window should be cleaned with a dry and soft cloth, you can use water or ethanol and gently wipe the window.
Please avoid touching the glass window.

9.3.3. Storage

When not in use, please store your camera in a dry place, in its box.

10.1. Image issues

IMAGE ISSUES		
The camera does not make images	The camera is not properly connected	**Check that :** **• Cables are connected properly,** **• Cooling system is switched on and filled with cooling fluid,** **• Camera link cables are in good position.** **• User acquisition software is running properly. Restart your computer.** **• Camera responds to software commands (i.e. thermal reading, monitoring functions)**
	Synchro signal is valid	**Type in the command line "synchro off" to switch back to free run mode and check that you have images. If when typing "synchro on" the frame rate drops to zero, then the synchro signal is not valid.**
	The temperature alarm level has been risen	**Type the command 'temp reset'**
Images appears to be incorrect	Some garbage is sent over the serial command	**Switch the two CameraLink cables.** **Restart the camera.** **Check illumination, sensor saturation can give strange images.**
There is a pattern image and no real image.	Test mode is on	**Send 'test off' command**

10.2. Cooling Issues

COOLING ISSUES		
Cooling does not start	Thermal protection has been set	**Check the temperatures and coolant flow. If everything is ok, send the 'temp reset' command.**
Cooling does not reach set temperature	The internal cooling of the camera is dimensioned to provide proper cooling to -45°C with water temperature below 25°C. If the set temperature goes below -45°C or the water temperature rises above 25°C, it is possible that the cooling system will fail to maintain the CCD temperature.	**Set the cooling to a reachable operating temperature. Reduce the water temperature and/or increase its flow.**
Cooling works then shuts down, image is gone.	Thermal load is too high. Water temperature rises above maximum temperature, the internal coolers are shut down to prevent damage to the CCD. Also the electronics shut down to reduce power usage to a minimum.	**Power down the camera, wait for it to cool down. Check the water flow, increase it if possible. Switch to an active water cooling (eg. water chiller). Reduce the thermal load by increasing the CCD temperature.**

10.3. Gain / Illumination issues

GAIN / ILLUMINATION ISSUES		
Overillumination is on	At unity gain the camera cannot be damaged by saturation at normal levels (never illuminate the camera directly with sunlight or laser sources). When gain is applied however, excess light can lead to aging of the detector. Depending on the intensity of gain and light the CCD could even be destroyed in seconds. In order to prevent this unfortunate event OCAM² cameras are equipped with an exclusive onboard illumination protection system. When an overillumination condition is detected, the camera will protect the CCD by reverting to an L3 Vision gain of 1. When such an event occurs, the camera will refuse to apply gain until the error is acknowledged by issuing a 'protection reset' command.	**Type 'protection reset' once the overillumination source is no more effective.**

11.1. For the USA

11.1.1. Limited Warranty

Subject to the limitations set forth herein, FLI represents and warrants that the Products (including the Sensor, if applicable) will correspond, at the time of delivery, to the specifications provided to FLI by Purchaser, and shall be free from defects in material and workmanship (the "Limited Warranty"). Such Limited Warranty shall remain in effect for a period of two (2) years from the date Purchaser takes delivery of such Products; provided, however, that such Limited Warranty as it relates exclusively to the Sensor (which shall be supplied by a third party manufacturer), if and as included in a Product, shall remain in effect for such length of time as the original manufacturer's warranty shall be in effect. Therefore, for example purposes only, if there shall be eight months remaining on the original manufacturer's warranty for the Sensor at the time Purchaser takes delivery of a Product which incorporates such Sensor, then the Limited Warranty hereunder as it relates exclusively to the Sensor shall be in effect for eight months. FLI shall inform Purchaser of the length of time remaining on the original manufacturer warranty for the Sensor at the time the applicable Product is delivered to Purchaser.

11.1.2. Conditions

The Limited Warranty specified above is subject to the following conditions:

• FLI shall be under no liability with respect to defects arising in the Products as a result of any incorrect drawing, design, or specification supplied by Purchaser;

• FLI shall have no liability with respect to any defect which arises from wear and tear, willful damage, negligent or abnormal use of the Product, mishandling of the Product, Force Majeure Events, or failure to comply with FLI's instructions regarding the use and maintenance of the Product, including, but not limited to, all written instructions, and all instructions contained in the Documentation;

• the Limited Warranty shall be limited to the Products themselves, and FLI shall have no liability with respect to any damages whatsoever which are caused to, or by, third party (or Purchaser's) parts, materials, or systems, as a result of or in connection with the integration or use of the Products.

11.1.3. Warranty Enforcement

To avail itself of the rights provided under the Limited Warranty, the Purchaser must submit, in writing, a detailed report regarding the defect exhibited by the particular Product (a "Defect Report"). Such Defect Report shall be submitted to FLI at **contact@first-light.fr**, with a copy of such Defect Report furnished to FLI by certified mail, or regular mail with return receipt requested, at the address listed below.

Purchaser shall have the burden of proving the defect is covered by the Limited Warranty. FLI shall have sole discretion to determine whether the Limited Warranty applies to any defect reported by Purchaser.

11.1.4. Returns

In the event the Limited Warranty applies, Purchaser shall return the Product to FLI within thirty (30) days of receiving written authorization from FLI to do so, in the same condition as the Product was originally delivered to Purchaser. Purchaser shall assume all costs, risk and liability in connection with the shipment and return of the Product. In the event the Product is not returned within the requisite time period, the Limited Warranty shall be void and of no further effect.

Purchaser agrees to the following limitations on FLI's liability in connection with the Products:

11.1.4.1. Liability Upon Delivery

Except as otherwise provided herein, FLI disclaims any and all liability in connection with purchaser's use of any products, including without limitation liability to third parties, to the fullest extent permitted by law, as of the date such product is delivered to purchaser.

11.1.4.2. Products Offered "As Is"

Except as provided in these terms, FLI provides the products "as is" and on an "as available" basis. Accordingly, and to the maximum extent permitted by applicable law, FLI makes no warranties, express or implied, that the products will be uninterrupted, error-free or free of harmful components.

11.1.4.3. No Other Warranties

Except as expressly set forth in these terms, and to the fullest extent permitted by applicable law, FLI does not make any warranty regarding the products or any other subject matter of these terms. Any implied warranty, including without limitation any implied warranty of merchantability and fitness for a particular purpose, shall be limited in scope to the extent permitted by applicable law, and shall be limited in duration to the duration of the limited warranty set forth above, or to such period of time as permitted by applicable law, whichever shall be shorter.

11.1.4.4. Limitation of Liability

To the fullest extent permitted by law, in no event will FLI, its affiliates, suppliers or distributors be liable for (a) any indirect, special, incidental, punitive, exemplary or consequential damages however caused, on any theory of liability, including but not limited to loss of use, loss of actual or anticipated profits or benefits, or the cost of procuring a replacement product, whether or not FLI has been advised of the possibility of such damages, arising in any way out of these terms or in connection with the products, or any undertaking or performance that may be promised, performed, or executed to implement these terms.

11.1.5. Purchaser Warranties

In addition to the other warranties, representations and covenants set forth in these terms, by using the products or placing an order, purchaser warrants and represents that purchaser has the right and authority to agree to these terms and to use the products, that purchaser's use of the products shall not violate the rights of any third party or any contract with any third party, and that purchaser's use of the products, FLI's fulfillment of any orders, and the delivery of any products, shall not violate any applicable laws.

11.1.6. Purchaser Indemnification

Purchaser agrees to defend, indemnify and hold FLI harmless from and against any and all claims, liabilities, damages, penalties, forfeitures, and associated costs and expenses (including attorneys' fees) that FLI may incur as a result of any breach by purchaser of any warranty, representation or covenant set forth in these terms.

11.2. For the rest of the World

11.2.1. FLI's legal guarantee and limit to the guarantee

FLI hereby exclusively guarantees the Product's compliance with the specifications agreed to within the limits of the legally applicable provisions.
FLI's guarantee is exclusively limited to repairs or replacement of any parts that are not in compliance.
If after reasonable efforts, FLI is not able to replace the non-compliant Product, the guarantee will be limited exclusively to the reduction of the purchase price or reimbursement of the price (after deduction of depreciation for wear and tear), after the Product is returned by the Purchaser.
FLI will not be liable for any indemnification of the Purchaser for specific or indirect damage, opportunity cost, loss of income, loss of enjoyment, damage to individuals or goods not related to the purpose of the contract.
For parts or supplies that are not manufactured by FLI, the guarantee is limited to those to which FLI is entitled from its own suppliers.
This guarantee does not cover the defects of the Product resulting from any cause external to the Product,
such as:

- Failure to comply with FLI's recommendations;
- Mishandling by the Purchaser;
- Intervention by a third party involving the Product ;
- Poor maintenance or misuse of the Product;
- Wear and tear;
- Damage caused by elements external to the Product or attributable to a case of force majeure: fire, lightning, water damage, external accident, etc.

11.2.2. FLI's liability

The Products are sold by FLI in compliance with French laws in effect. FLI cannot be held liable for any failure to comply with the laws in the countries where the Product will be used.
In the event where FLI is held liable due to its failure to satisfy any of its contractual obligations, the Purchaser may not seek any indemnification for loss of income or opportunity cost, loss of enjoyment, specific, accessory or indirect damage to individuals or to goods or assets, caused by any failure in the performance of its obligations. The total amount of the indemnities that FLI may be required to pay to the Purchaser in remedy for the prejudice it suffers may not exceed the amounts paid by the Purchaser for such Product, regardless of the legal grounds for the claim and the procedure employed to resolve it.

11.2.3. Liability in connection with defective products

FLI's liability in connection with defective products excludes remedy for any damage caused to the products through commercial use.

12.1. For the USA

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