user manual

pco.dicam C1
pco.dicam C4

pco.

PCO asks you to read this manual carefully before using the pco.dicam C1 / C4 camera system and follow the instructions.

Contact us for further questions or comments.

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The cover picture shows a typical pco.dicam C1 camera.
The lens is sold separately.

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pco.dicam C1/C4 user manual V2.00 © PCO AG, Germany

TABLE OF CONTENTS

1. INTRODUCTION

Advantages of the pco.dicam

After more than 30 years of experience with image intensified cameras, we are proud to introduce the new pco.dicam C1 and pco.dicam C4.

The pco.dicam is the first camera system with image intensifier technology that harnesses the full power of the sCMOS sensor. Unique is the optical connection of the high-resolution 25 mm image intensifier to the 16 bit sCMOS sensor via an efficient tandem lens. Individual photons are detected using the shortest exposure times.

10G fibre optic data interface (Camera Link HS) guarantees uncompressed and secure data transfer. The latest standard of high-performance data interfaces enables the bridging of long distances via fiber optic cable.

Main Features

- intensified sCMOS technology
- exposure times down to 4 ns
- double shutter mode with 300 ns / 500 ns interframing time (depending on your pco.dicam)
- optical coupling via ultra-speed tandem lens
- up to 3.4 GByte/s with 4 x 10 G fibre optic data interface (Camera Link HS) (pco.dicam C4)
- 2048 x 2048 pixels

1.1 INTENDED USE

This camera system is designed for use by technicians, engineers and scientists. It is a scientific measuring instrument, which provides images. The camera may only be used according to the instructions of this manual. Provisions, limitations and operating conditions stated in this manual must be respected. Unauthorized modifications and alterations of the device are forbidden for safety reasons.

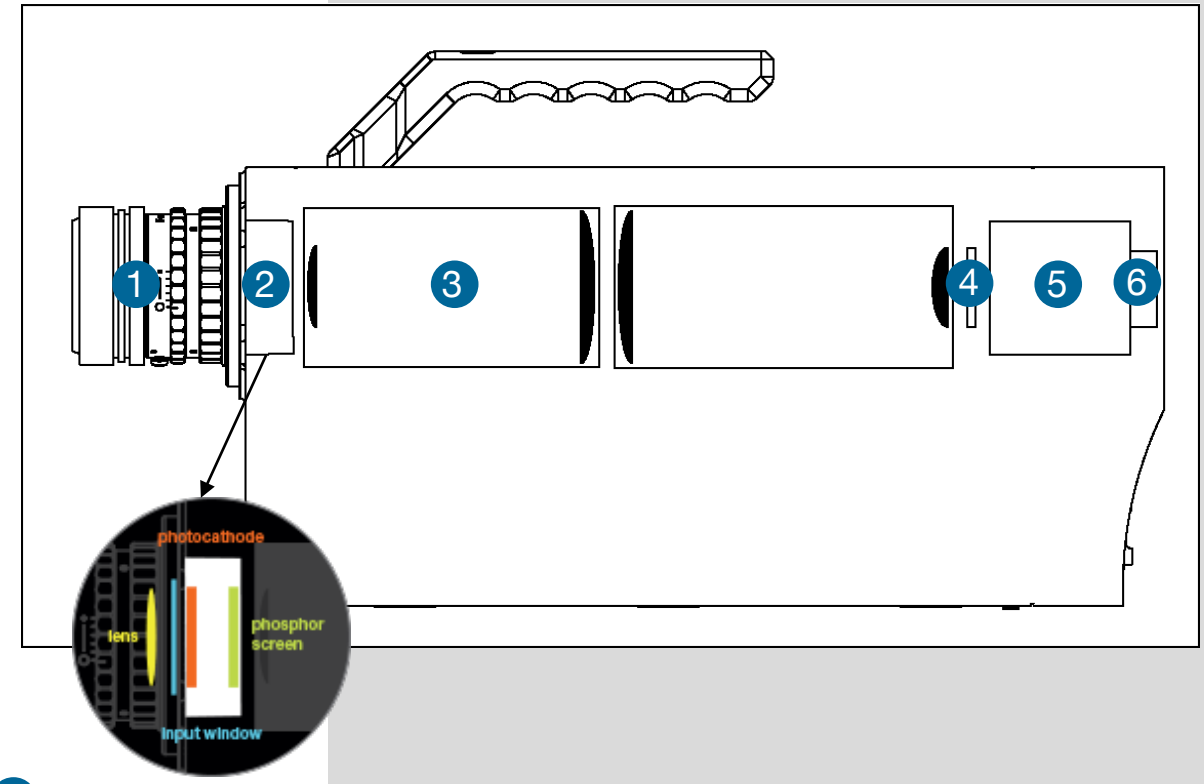
1.2 FORESEEABLE MISSUSE

- To avoid damages or loss of quality, the camera should not be operated with a too high light input →A few milliseconds or even microseconds may be sufficient to damage the photocathode if the light source is powerful enough.
- Do not open lens cap during day light or with external light source!
- If damaged, a complete replacement of the image intensifier is necessary (very expensive)
- Read the safety instructions for use of image intensifier chapter **2.1**

1.3 SCHEMATIC SKETCH

Layout of an intensified PCO camera (single channel)

1. Objective lens (not included)
2. Image intensifier
3. Tandem lens optical coupling system
4. sCMOS image sensor
5. Camera system
6. Camera Link HS interface
7. Camera Link HS frame grabber card



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Find further information on structure and function in the pco.dicam whitepaper.

2. SAFETY INSTRUCTIONS

CLASS 1 LASER PRODUCT
Risk of injury due to dazzle.
- ➔ Do not point the laser beam at persons.
- ➔ Do not look into the laser beam or at direct reflexes.
- ➔ Manipulations of the laser device are not allowed.

DANGER

DAMAGED POWER CABLE OR POWER PLUG
Danger to life due to electric shock.
- ➔ Each time the camera is used, check the power cable for damage.

WARNING

ELECTRIC SHOCK WARNING DUE TO VOLTAGE PARTS INSIDE
Risk of injury due to electric shock.
- ➔ Never slide any items through slits or holes into the camera.

CAUTION

MOISTURE
Risk of injury due to electric shock if moisture enters the camera.
- ➔ To avoid the risk of water condensation, protect the camera against extreme changes of ambient temperature.

CAUTION

TRIPPING HAZARD
Risk of injury from tripping over loose cables.
- ➔ Never position the cable in a way that it could become a tripping hazard.

NOTICE

HUMIDITY, DUST OR RADIATION
Humidity, dust or X-rays could damage the camera.
- ➔ Never operate the camera in humid or dusty environments or in places with high levels of X-ray radiation.

NOTICE

SHOCK & VIBRATION
To avoid damaging the camera it must be firmly mounted and protected against strong shocks or vibrations.
- ➔ Use the camera's mounting threads to secure it.

NOTICE

LENS MOUNTING
Do not force the lens onto the camera.
- ➔ Mount or screw in the lens gently to avoid thread or mount damage.

NOTICE

LIQUIDS DAMAGE CAMERA
If liquids have penetrated the device.
- ➔ Switch the camera off immediately, detach it from power and contact PCO's customer support.

NOTICE

DAMAGED CAMERA HOUSING
If the camera has been dropped or the camera's housing is damaged.
- ➔ Switch the camera off immediately, detach it from power and contact PCO's customer support.

2.1 SAFE USE OF IMAGE INTENSIFIER

NOTICE

LIGHT DAMAGES IMAGE INTENSIFIER
Too much light input during exposure time (gate=ON) lowers the lifetime of the image intensifier.

➔ Be careful with all kinds of light sources, a few milliseconds can be enough to damage the image intensifier irreversibly.

NOTICE

Working with Image Intensifiers: Safety Instructions

The camera contains a highly sensitive image intensifier. To avoid damages or loss of quality, the camera should not be operated with too high light input. The photocathode's lifetime and its loss of sensitivity depend directly on the amount of light impinging on it during exposure time. A few milliseconds or even microseconds of exposure time may be sufficient to damage the photocathode if the light source is powerful enough. The photocathode is a few µm thin layer of a photo sensitive material. It absorbs photons and in turn generates photoelectrons for amplification in the Micro Channel Plate (MCP). In case the photoelectron generation rate is too high due to intense light input, the photocathode might be eroded. In extreme cases the layer completely wears off and there a black spot appears. The photocathode is now 'blind' and there is no remedy except replacing the complete image intensifier tube. Bright light sources, e.g. lamps or daylight (for example while adjusting or focusing the camera) in a long exposure operation mode can permanently damage the photocathode, even when a monitor does not show any picture (if, for instance the ***Intensifier Voltage*** MCP-Gain is set to minimum).

Since the MCP is behind the photocathode, changing the MCP-Gain does not affect the load of the photocathode. It is a wrong conclusion to assume lower MCP-Gain would save the photocathode in an overexposed scene. The opposite is true.

Therefore for a safe camera operation we recommend to start with a nearly closed iris (high f-stop, e. g. 22), short exposure time and maximum MCP-Gain value (Image ***Intensifier Voltage*** set to maximum). If no image is visible to yield an image the exposure time may be carefully increased or the iris opened step by step.

If the camera is not in use replace the cap in front of the lens or intensifier.

Operational Lifetime Values

The manufacturer of the image intensifier tube specifies durability for continuous, non-gated operation only:
The half-life of the image intensifier (time taken for a 50% decrease in sensitivity) is approximately 2000 hours at a light input of 1 mlx. 10-times higher light input reduces the half-life to approximately 200 hours.

NOTICE

In the gated mode a linear correspondence of half-life and light input does not apply.
In this case substantially higher light inputs are allowed.

3. SYSTEM COMPONENTS

3.1 SYSTEM COMPONENTS PCO.DICAM C1

The camera system includes the following parts.

Camera

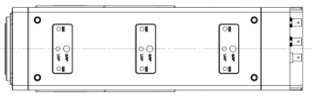
- F-mount optical connection (standard) for standard F-mount lenses and adapters
- C-mount ring for standard C-mount and microscopy connectors (optional)
- EF-mount with lens control (optional)

Rear Panel

- DC Power Jack connects to power supply
- Input / Output 5x BNC connectors, 1x ST bayonet fiber optic connector (BFOC)
- Interface: Camera Link HS LC
- LEDs indicate camera status

Serial Number Tag

- on the bottom of the housing



Mounting Thread

- 6x M6, 3x ¼”- 20 UNC, 3x ⅜” mounting threads

Frame Grabber Card PCI Express x4 Card

- PCI Express x4 Card (Camera Link HS)

Power Supply

- ***In:*** 100-240 V AC 50-60Hz, 1.4A max. ***Out:*** 24 V DC 2.7 A

Power Cord

- Standard IEC13 connector

Cable

- 10 m FOL LC/LC duplex OM2

Digital Camera Tools (USB Flash Drive)

- pco.camware: software for camera control & image acquisition
- Camera driver & tools
- Software development kit (SDK) & demo programs in C / C++

3.2 SYSTEM COMPONENTS PCO.DICAM C4

The camera system includes the following parts.

Camera

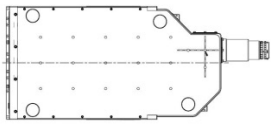
- F-mount optical connection (standard) for standard F-mount lenses and adapters
- C-mount ring provided for standard C-mount and microscopy connectors
- EF-mount with lens control (optional)

Rear Panel

- DC Power Jack connects to power supply
- Input / Output BNC connectors, ST bayonet fibre optic connector (BFOC)
- Interface: Camera Link HS 4x LC
- LEDs indicate camera status

Serial Number Tag

- on the front side of the housing



Mounting Thread

- 18x M8 mounting threads

Frame Grabber Card PCI Express Card

- PCI Express Card (4x Camera Link HS)

Power Supply (internal)

- ***In:*** 100-240V AC 50-60Hz, 180W

Power Cord

- Standard IEC13 connector

Cable

- 4x 10 m FOL LC/LC duplex OM2

Digital Camera Tools (USB Flash Drive)

- pco.camware: software for camera control & image acquisition
- Camera driver & tools
- Software development kit (SDK) & demo programs in C / C++

4. INSTALLATION

All necessary files are on the accompanying USB flash drive. You may also download the latest versions of our software, camera driver and third party software drivers from the PCO website.

Minimum System Requirements

- Intel® Core™ i7
- RAM > 8 GB DDR3
- Windows 7 or higher
- Full-HD resolution display
- PCI Express x8 Gen 3 (CLHS)

Contact PCO for an appropriate system configuration.

For the pco.dicam C4 a suitable and ready configured PC is included.

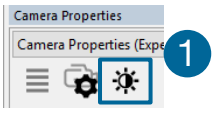
4.1 DRIVER

Image Data Transfer via Camera Link HS

The pco.dicam transmits the image data via Camera Link HS data interface.

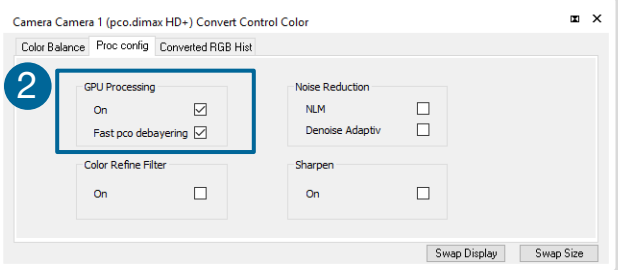
There is no extra PCO driver for the pco.dicam; install the accompanying Kaya frame grabber runtime package to run the camera.

For detailed installation instructions see chapter **A4**.



Graphic Card NVIDIA Cuda Driver

Update your NVIDIA driver for pco.camware. In case of an old driver version ***GPU Processing*** will not work properly and therefore slow down image processing.



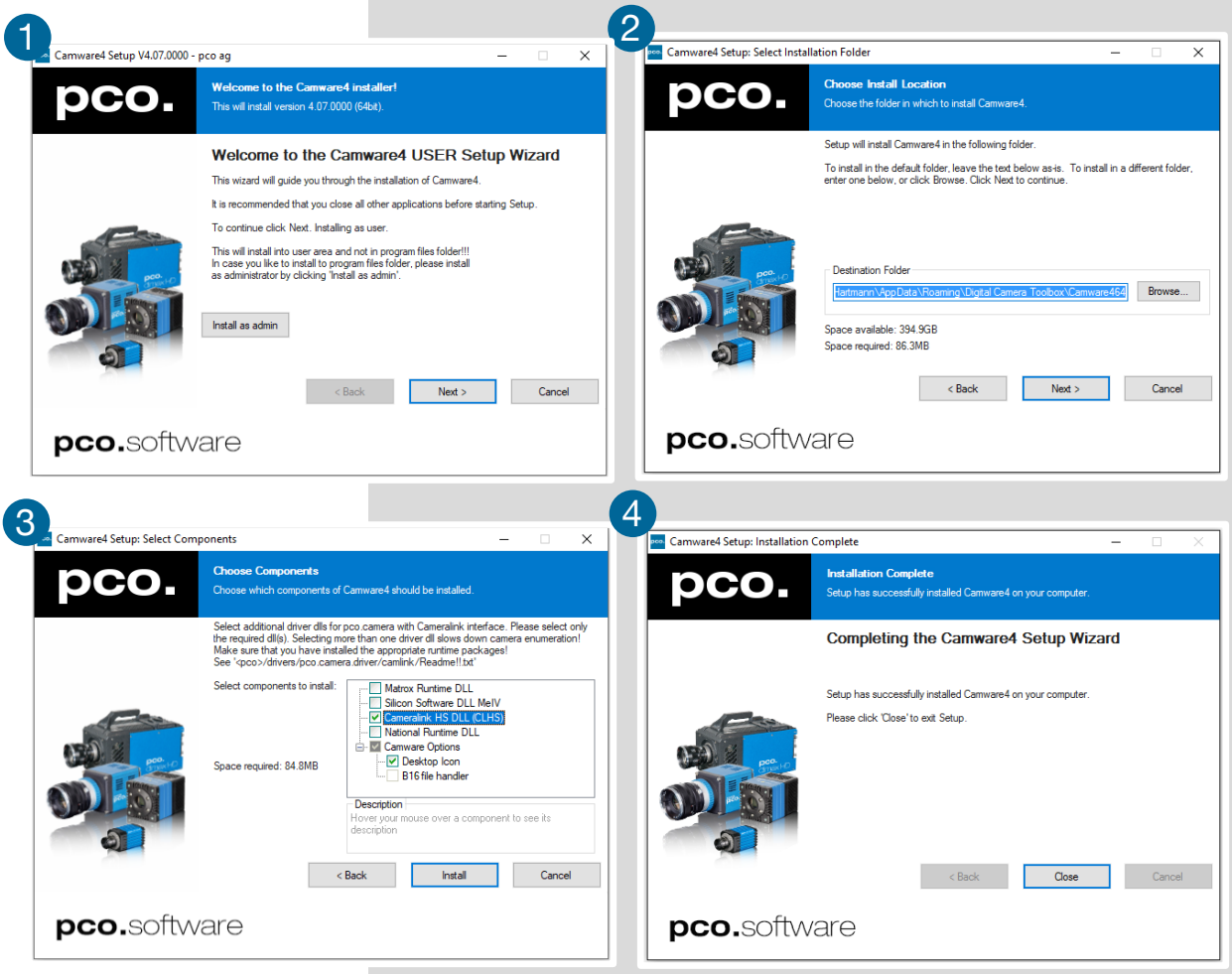
Check if ***GPU Processing*** is activated by having a look into the ***Proc config*** settings (2) in the ***Convert Control*** window (1) (see pco.camware manual).
If ***GPU Processing*** is disabled and shown grayed, update your NVIDIA driver or check the website of the computer manufacturer for graphic card driver updates.

4.2 CAMWARE

The pco.camware Windows application software enables you to control every camera parameter or setting. Images can be displayed on a monitor and may be downloaded and stored. The USB flash drive contains the installation files for the software for latest Windows operating systems in 32 & 64 bit.
After a successful installation, you will find the program folder Digital Camera Toolbox in your program directory and a pco.camware 32 / 64 button on your desktop.
To uninstall the pco.camware program, use the software feature under Windows' System Control.

Follow the installation wizard

1. ***Install as admin*** to install to program folder, otherwise it will be installed only to user folder
2. Then choose installation directory
3. Choose components: select additional drivers for ***Camera Link HS DLL (CLHS)***
4. After the next two screens installation is complete



5. FIRST START

In order to get familiar with your new camera and software it might be helpful, first to aim the camera at an object easy to focus and visible at normal light conditions.

NOTICE

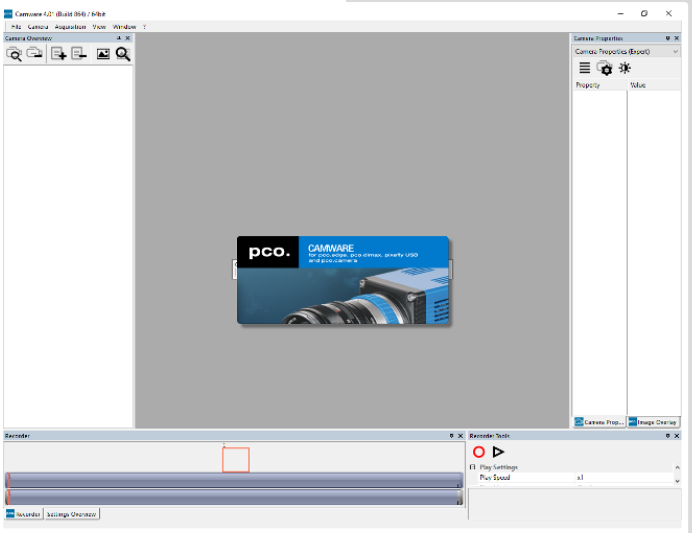
TAKE SPECIAL CARE WITH AN IMAGE INTENSIFIER CAMERA
Read all safety instructions for the image intensifier first (chapter **2.1**). Follow the instructions on chapter **5.3** briefly.

5.1 PREPARATION

- Computer is turned on
- Installation is finished (see chapter **4**)
- An appropriate lens is attached (remove cap) or the camera is attached properly to the microscope, spectrograph or other scientific device
- Camera is connected to the computer via Camera Link HS interface
- Camera is connected to the power supply switched on and ready

5.2 START

Start pco.camware and the graphical user interface will start up:



NOTE
Always install latest Camware version to use the full capabilities of your pco camera (www.pco.de/support).

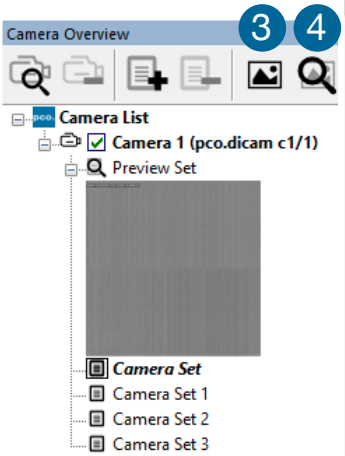
5.3 FIRST IMAGE

NOTICE

LIGHT DAMAGES IMAGE INTENSIFIER
Too much light input during exposure time (gate ON) lowers the lifetime of the image intensifier.
➔ Be careful with all kinds of light sources, a few milliseconds can be enough to damage the image intensifier irreversibly.

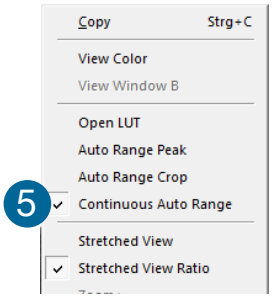
Introduction

Handling a camera with an image intensifier requires special care. Before starting the recording, make sure you have set the exposure times and the aperture of the lens correctly. Always start with aperture closed, image ***Intensifier Voltage*** (MCP-Gain) set to maximum and a very short exposure time.



Follow the Instructions

- pco.camware must be started 1
- A ***View Window*** 2 is shown automatically or open a new one 3
- Before you start ***Live Preview*** close the aperture of the lens
- Set ***Intensifier Voltage*** to maximum (see **8.3**)
- Select a very short exposure time for the ***Preview Set***, e.g. 10 µs to avoid damaging the image intensifier
- Start ***Live Preview*** 4



- Right-click in the ***View Window*** & apply ***Continuous Auto Range*** 5
- You may have to adjust ***Exposure*** time 6, aperture and focus of the mounted lens
- Now you should clearly see the object in the window 7

To change ***Exposure*** time (e.g. the image is still either too dark or too bright), go to chapter **8.1**.

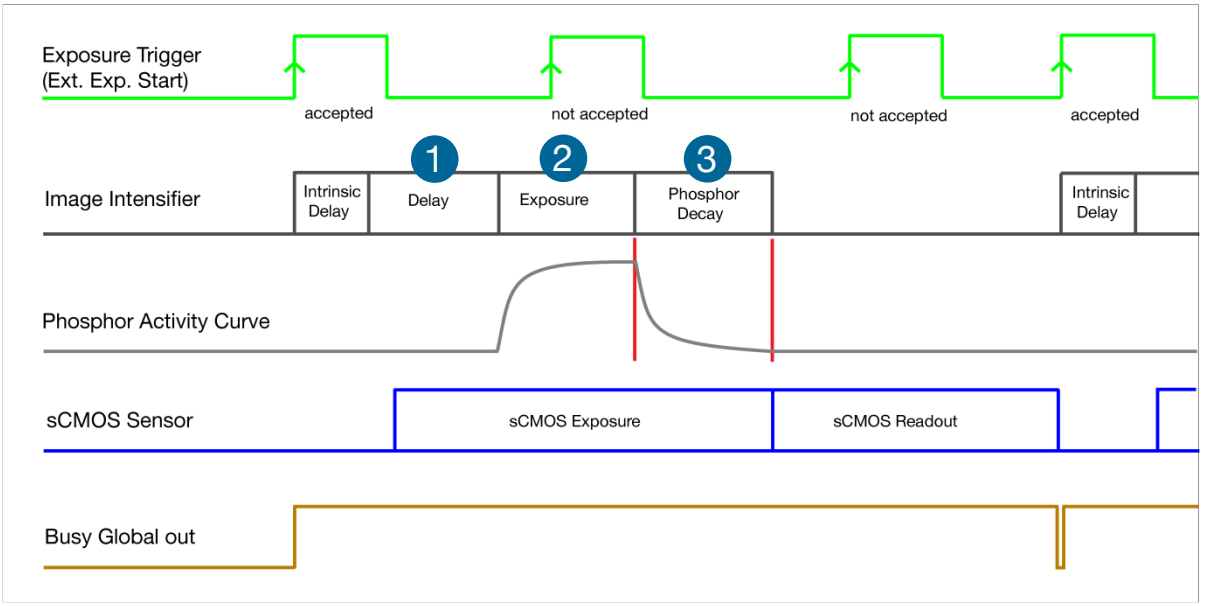
For recording and saving images or sequences, see pco.camware manual for detailed information.

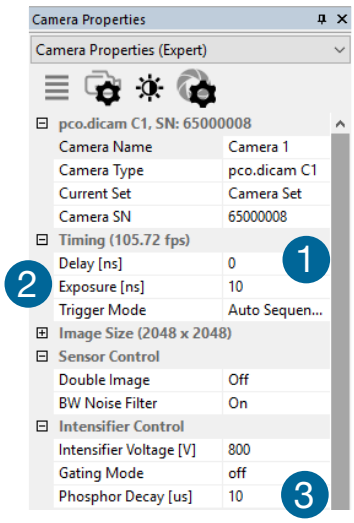
6. TIMING PCO.DICAM C1

6.1 SINGLE IMAGE MODE

Use this mode to acquire single images or sequences; for the alternative ***Double Image*** mode, see chapter **6.2**.
The functional principle of the single image mode is explained on the basis of the following timing diagram.

Timing Diagram





Exposure Trigger

In most practical applications an external exposure start trigger signal will be used as shown above. The triggering event is always the rising edge of the trigger pulse.
The camera works strictly sequentially; the next trigger signal is only accepted if the readout of the last image is completed; see trigger pulses marked as not accepted.

Image Intensifier

The image intensifier and the sCMOS sensor can be considered separately. For the proper operation of the intensified camera system both components are internally synchronized at highest precision.
The settings in pco.camware for exposure / delay time apply directly to the image intensifier itself and the sCMOS sensor follows automatically.
There are fixed parameters (intrinsic delay, phosphor decay) and selectable parameters (delay time, exposure time).

The four stages of the intensifier exposure process are listed:

- Fixed Intrinsic (system) Delay (about 50 ns, see pco.final test sheet for precise value of your camera)
- User selectable ***Delay*** time
- User selectable ***Exposure*** time

- Phosphor decay is a physical parameter of the image intensifier. After the photocathode is switched off, the phosphor screen's light emission decays with a characteristic time (see Phosphor Activity Curve). This "afterglow" can be captured by the sCMOS sensor with an additional exposure time. (= ***Phosphor Decay*** see **8.3**).

	Times	Steps
Exposure	4 ns, 10 ns fixed 20 ns ... 250 ns 260 ns ... 1 s	fixed 1 ns 10 ns
Delay	0 ns ... 250 ns 260 ns ... 1 s	1 ns 10 ns
Intrinsic delay	< 50 ns	
Jitter	< 1 ns	
Phophor decay	10 µs … 10 ms	1 µs

Phosphor Activity Curve

The phosphor activity curve shows schematically the decay of the phosphor screen. The various phosphor materials have very different decay times.

Phosphor	Phosphor decay typ. to …10%	 …1%	Typical efficiency
P43	1 ms	4 ms	100%
P46	0.2 … 0.4 µs	2 µs	30%

NOTICE

P46: the extremely short P46 decay process is automatically integrated into the sCMOS image.
P43: select a proper phophor decay time of up to 4ms!

sCMOS Sensor

Here the exposure and readout periods of the sCMOS sensor are shown relative to the action of the image intensifier. The sCMOS exposure includes the following stages of the image intensifier scheme:

- Delay time
- Exposure time
- ***Phosphor Decay*** time as described above (see **8.3**)

Example Timing & Frame Rate for P43 vs P46 Phosphor

Type	P43	P46
Exposure time	10 µs	10 µs
Configured phosphor decay time	4 ms	≥10 µs (minimum)
Readout time for a single image @full resolution	9.5 ms	9.5 ms
Frame time	13.5 ms	9.5 ms
Resulting frame rate @ full resolution	$\frac{1}{13.5\ ms} \approx 74\ fps$	$\frac{1}{9.5\ ms} \approx 106\ fps$

Note: selecting a long phosphor decay time for P43 phosphor reduces the max. frame rate!

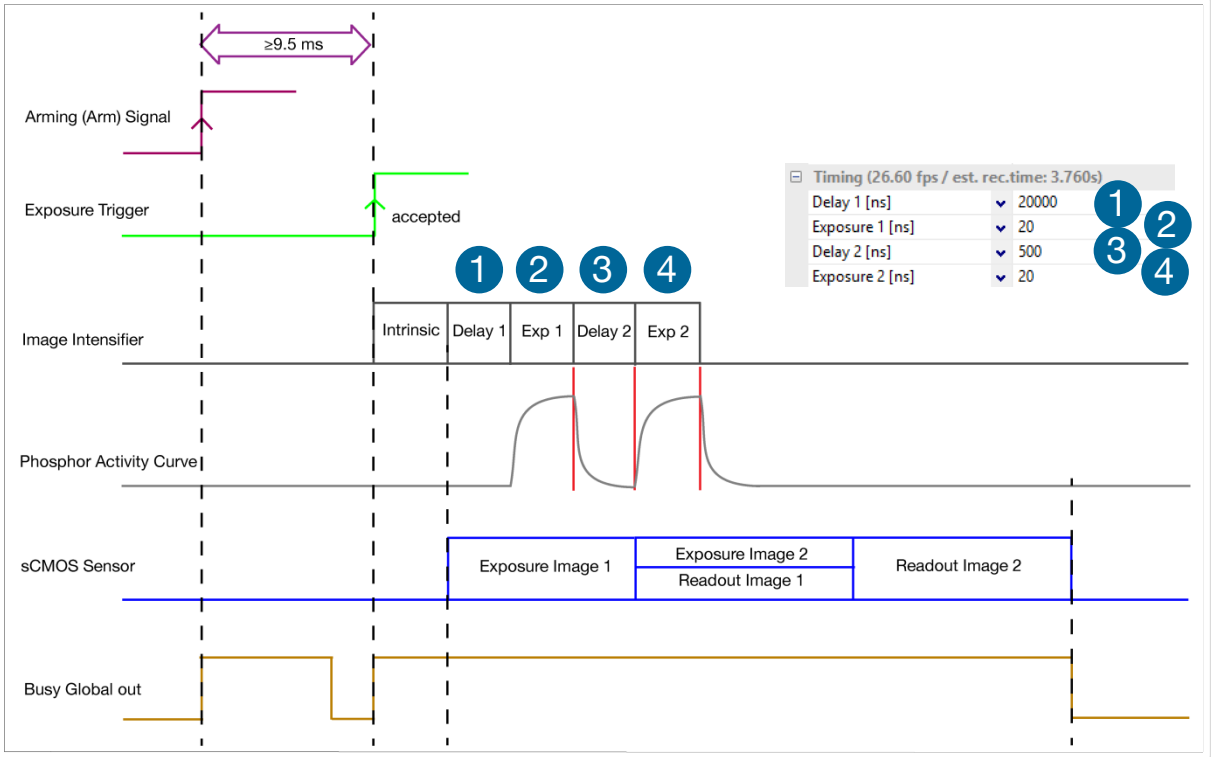
6.2 DOUBLE IMAGE MODE

With this mode it is possible to acquire two consecutive images with a fully configurable interframing time (minimum 300 ns / 500 ns depending on pco.dicam model).
Both, the duration of exposure 1 and exposure 2 are independently selectable.
Due to timing constraints of the on-chip image sensor control, the frame rate for ***Double Images*** at full resolution and exposure times in the ns / µs range is reduced to a quarter of the possible frame rate in ***Single Image*** mode.
The functional principle of the double image mode is explained on the basis of the following timing diagram.

NOTICE

Note that using double image mode with a P43 phosphor equipped image intensifier requires interframing times of > 1ms.

Timing Diagram



Arm Signal

The arming signal at the BNC ***Arm*** input connector (see **8.3**, **A1.3**, **A2.4**) is used to initialize the camera to a double image ready to record state. This rising edge signal is always needed at least 9.5 ms before an exposure trigger signal for a double image can be accepted. Due to the dark current, it is recommended to use <100 ms "arm" time, there is no fixed limit.

Unit	Time
Arm	9.5 ms … < 100 ms

Exposure Trigger

Most practical applications use an external trigger signal, at the BNC trig input connector (see **8.3**, **A1.3**, **A2.4**) as described in the diagram above. The triggering event is defined by the rising edge of the trigger pulse. For further trigger possibilities see chapter **8.1**.
The operational process of the camera is strictly sequential. Therefore, the next trigger signal is only accepted if the readout process is completed.

Image Intensifier

The image intensifier and the sCMOS sensor can be treated separately. For a proper operation of the intensified camera system both components are internally synchronized at highest precision.
The settings in pco.camware for exposure / delay time always apply directly to the image intensifier itself and the sCMOS sensor follows subsequently.
There are fixed parameters (intrinsic delay, phosphor decay) and selectable parameters (delay time, exposure time).

Steps processing a double image are listed:

- Fixed Intrinsic (system) Delay of 20 µs (about 70 ns, see pco.final test sheet for precise value of your camera)
- ***Delay 1*** (1) an additional user selectable delay time
- User adjustable ***Exposure 1*** (Exp 1) time (2)
- User adjustable ***Delay 2*** (3) (interframing time): a minimum of 300 ns / 500 ns is needed for the transfer of Image 1 and to capture the P46 phosphor decay time simultaneously. For P43 phosphor select ≥ 1 ms interframing time.
- User selectable ***Exposure 2*** (Exp 2) time (4)

Unit	Timing (10 ns steps)
Intrinsic Delay	20000 ns + 70 ns
Delay 1	0 ns … 1 ms
Exposure 1	20 ns ... 1 ms
Delay 2	300 ns / 500 ns ... 10 ms
Exposure 2	20 ns … 1 ms

Phosphor Activity Curve

The phosphor activity curve shows schematically the rising and the decay of the phosphor screen. See explanation chapter **8.3**

Phosphor	Phosphor decay typ. to …10%	…1%	Typical efficiency
P43	1 ms	4 ms	100%
P46	0.2 … 0.4 µs	2 µs	30%

sCMOS Sensor

The diagram shows schematically exposure and readout time of the sCMOS sensor.
Note that readout time of a frame is always 9.5 ms @ full resolution.

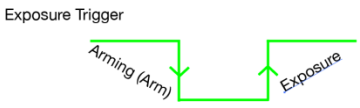
The double image exposure of the sCMOS sensor depends on the following elements of the image intensifier.

- Exposure Image 1:
  Delay 1 + ***Exposure 1*** + ***Delay 2***
- Exposure Image 2 / Readout Image 1:
  2x readout time (2x 9.5 ms)
- Readout Image 2:
  1x readout time (1x 9.5 ms)

Busy Global Out

This output signal, available at the BNC monitor output connector of each channel (see chapter **A1.3**) indicates the status of the double image recording. While the busy is high, no new trigger signal is accepted.
The busy signal is active while the camera is armed, then it turns low until the trigger is detected and then it is high again until the sCMOS readout is completed.

Double Image Timing Using Only Trigger Input



Only available for pco.dicam C1 or if you trigger to an individual channel of a pco.dicam C4.

Mandatory: set arming signal to ***Off*** (see chapter **8.3**). This is only available for ***Trigger Mode Ext. Exp. Start***.

You can use the falling edge of a signal to arm the camera for ***Double Image*** mode and the rising edge of the same signal pulse to start the exposure. The time distance between falling and rising edge must be at least 9.5 ms (@ full resolution).

7. TIMING PCO.DICAM C4

The following chapter assumes that you have carefully read the previous chapters about Single and Double Image mode timing of a single pco.dicam C1 (chapter **6**).

7.1 MASTER VS INDIVIDUAL CHANNEL TRIGGER

The pco.dicam C4 allows external triggering on the rear panel (see **A2.4**) in two different ways, which will be explained below.
See chapter **HARDWARE I/O CONTROL PCO.DICAM C4 8.5** to select the ***Master Trigger*** or ***Channel Trigger*** mode.

Master Trigger

The camera consists of four individual channels that can be configured and triggered completely independently of each other. For the typical application, however, it is much more convenient to synchronize all channels internally and to control them via a common ***Master Trigger***.

Note, the use of the ***Master Trigger*** causes an additional latency period of 10 ns electrically, or optically 15 ns which has to be added to the intrinsic delay (see **6.1**, **6.2**)

In order to activate the ***Master Trigger***, in pco.camware in ***Camera Properties*** under ***Timing*** the ***Trigger Mode Ext. Exp. Start*** must be selected, see **8.1.**

Operating Modes

- If you want to work with constant exposure time and frame rates: use ***Common Time Properties*** see **9.1** and ***Master Trigger***.
- In case you want to record with different exposure times and / or non-sequential or different channel order, you cannot use the ***Common Settings*** of ***Common Time Properties***. For triggering the ***Master Trigger*** or the four individual channel triggers can be used.

Individual Channel Trigger

For single triggering, a BNC socket (plus arm socket for double image operation) is available on each channel for electrical triggering.
For individual channel triggering, the latency time is minimal; compare to the final data sheet of your camera.

Note that no optical input is available for the individual ***Channel Trigger*** unlike the ***Master Trigger***!

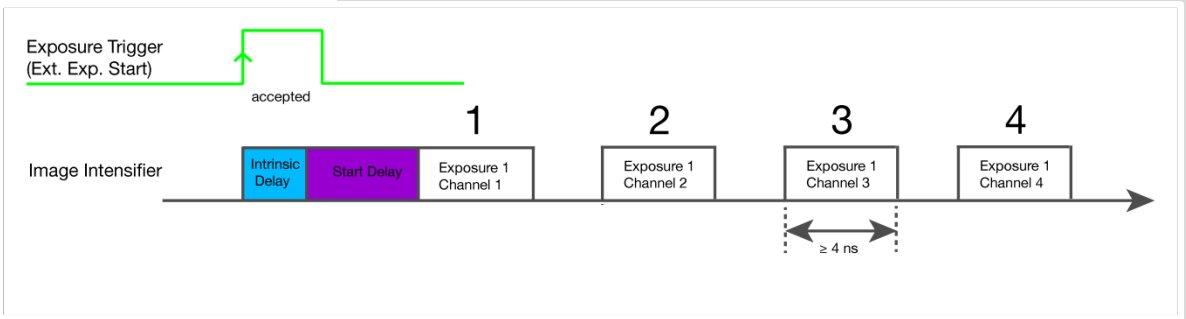
7.2 SINGLE IMAGE MODE 4 CHANNELS

Now that the functionality of a single channel has been explained, the interaction of all four channels of a pco.dicam C4 will be explained.

For typical ultra-speed applications the pco.dicam C4 is operated in 'burst' mode; i.e. the four images are recorded within a few microseconds or even less, the necessary readout of the four images causes a gap of at least 9.5 ms of 'dead time' until the next four image 'burst' can be captured.

This 'burst' mode can be configured by setting up and triggering each channel individually or more comfortably by using the ***Common Time Properties*** (see chapter **9.1**) and a single ***Master Trigger*** input (see rear panel **A2.4**).

Example: Timing Diagram



This diagram shows a single four image burst using ***Master Trigger***.

Explanation

- Exposure Trigger
- Fixed Intrinsic Delay
  - Typical values for 4 ns / 10 ns exposure time: 50 ns
  - Typical value for ⩾20 ns exposure time: 70 ns (See pco.final test sheet of your camera for precise values)
  - For electrical Master Trigger additional delay: 10 ns
  - For optical Master Trigger additional delay: 15 ns
- Selectable Start Delay
- Exposures of all 4 channels

NOTICE

Note that the type and length of the trigger cable can add extra delay.

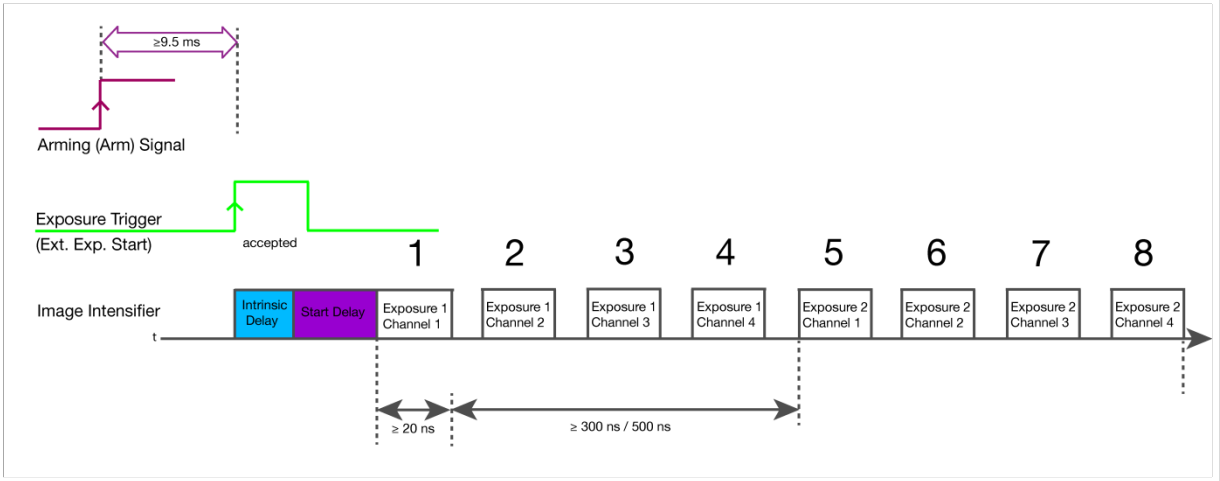
7.3 DOUBLE IMAGE MODE 4 CHANNELS

After the functionality of double image timing for one channel has been explained in chapter **6.2**, the interaction of all four channels of a pco.dicam C4 in double image mode will be explained.
For typical ultra-speed applications the pco.dicam C4 is operated in 'burst' mode; i.e. the eight images are recorded within a few microseconds or even less, the following readout of the eight images causes a gap of at least 38.4 ms of 'dead time' until the next eight image 'burst' can be captured.
This 'burst' mode can be configured by setting up and triggering each channel individually or more comfortably by using the ***Common Time Properties*** (see chapter **9**) and a single ***Master Trigger*** input (see rear panel **A2.4**).

NOTICE

Note that using double image mode with a P43 phosphor equipped image intensifier requires interframing times of > 1ms. Ultra fast sequences of 8 images are therefore not feasible with P43 phosphor.

Timing Diagramm



for a single eight image burst using ***Master Trigger***

Order of timing using ***Master Trigger***

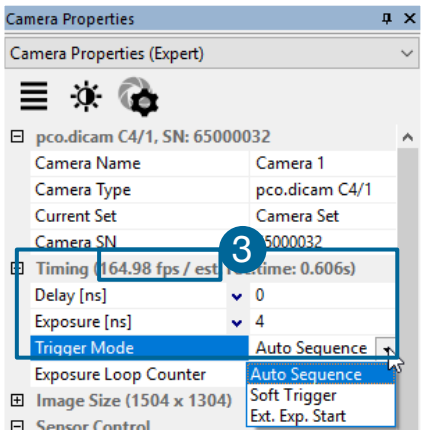
- Arming Signal: ⩾9.5 ms
- Exposure Trigger
- Fixed Intrinsic Delay
  - 20000 ns + 70 ns
  - For electrical Master Trigger additional delay: 10 ns
  - For optical Master Trigger additional delay: 15 ns
- Selectable Start Delay
- Double Exposures of all 4 channels sequentially interlinked

Condition for the sequential interlinking the four channels

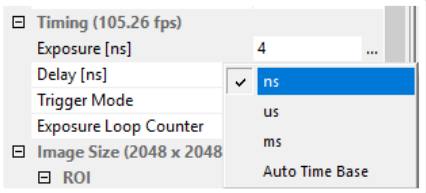
The time distance between ***Exposure 1*** and ***Exposure 2*** taken on the same channel has to be at least 300 ns / 500 ns (depending on your pco.dicam version) according to the minimum of the interframing time.

8. CAMWARE SOFTWARE

8.1 TIMING

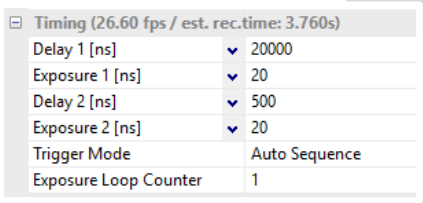


For detailed explanation on triggering single images and sequences or ***Double Image*** mode see chapter **8.2**.



Exposure Time and Time–base

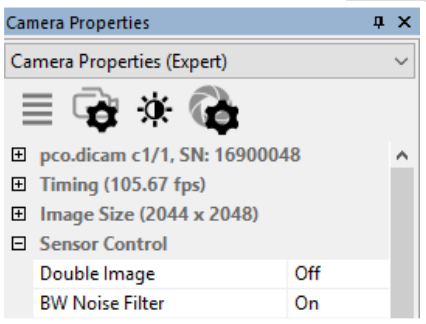
It is possible to change time-base from automatic to ns, µs or ms. If your input is out of the range of the camera, it is automatically changed to the next possible setting.



Double Image Mode

If ***Double Image*** mode is set to ***On*** in chapter **8.2** the ***Timing*** menu is changed and complemented by additional settings. Select individual ***Delay 1***, ***Exposure 1***, ***Delay 2*** and ***Exposure 2*** times. For detailed explanation on ***Double Image*** mode see **6.2**.

8.2 SENSOR CONTROL



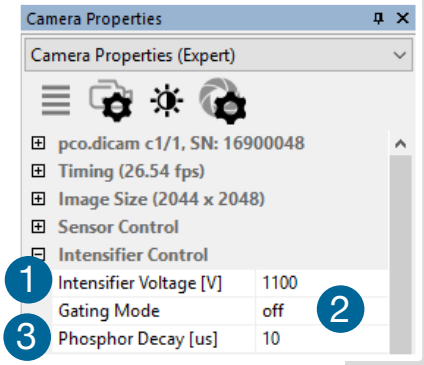
Double Image

Use double image mode to acquire so called double images:
With this mode it is possible to take two pictures with the shortest possible interframing time interval. Both exposure and delay times are configurable.
If ***Double Image*** mode is set to ***On*** the ***Timing*** menu (see **8.1**) is changed and supplemented with additional points for ***Exposure 2*** and ***Delay 2***.
For detailed explanation on ***Double Image*** mode see **6.2**.

8.3 INTENSIFIER CONTROL

NOTICE

LIGHT DAMAGES IMAGE INTENSIFIER
Too much light input during exposure time (gate ON) lowers the lifetime of the image intensifier.
➔ Be careful with all kinds of light sources, a few milliseconds can be enough to damage the image intensifier irreversibly.

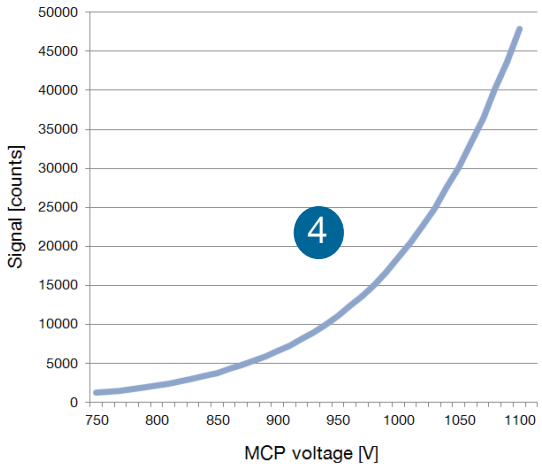


Intensifier Voltage 1

Select the amount of the MCP-Gain of the image intensifier. Adjustable is the voltage applied to the MCP (micro channel plate) in the range of 750 V to 1100 V for S20 image intensifiers and 750 V to 900 V for GaAs(P) intensifiers. The other two intensifier voltages for photocathode and phosphor screen are fixed and cannot be changed by the user.

Note that there is no linear correspondence between the MCP voltage and the amount of Gain. The Gain is exponential and typically doubles every 50 V.

The graph 4 shows exemplarily the signal output curve for constant light input in dependence of the applied ***Intensifier Voltage*** for an S20 image intensifier equipped pco.dicam C1.



Note: start with maximum ***Intensifier Voltage***, closed aperture and very short exposure times at each experimental setup to protect the image intensifier (see chapter **2.1** – safe use of image intensifier).

Gating Mode 2

Setting for the operating mode for the MCP part of the image intensifier, which controls the extinction ratio contribution (shutter ratio) of the MCP.

Especially uv and blue light is blocked less effectively outside the selected exposure time of the image intensifier. This light leakage can negatively influence the image acquisition!

To prevent this negative effect, the MCP ***Intensifier Voltage*** can be switched off outside the photocathode exposure time window to increase the system overall extinction ratio.

Explanation:

- ***Off***: MCP gating is disabled, ***Intensifier Voltage*** is continously on; there is no contribution of the MCP to the overall extinction ratio. Maximum fps can only be achieved with MCP gating ***Off***
- ***On:*** MCP gating is enabled; MCP ***Intensifier Voltage*** is switched off after the end of the photocathode exposure and reactivated immediately after the sCMOS sensor readout is done. With this setting, the MCP additionally contributes to the overall extinction ratio. Reactivation of the ***Intensifier Voltage*** takes an extra 4 ms; this mode slows down the maximum achievable framerate.

Example timing & frame rate for MCP Gating Mode "on":

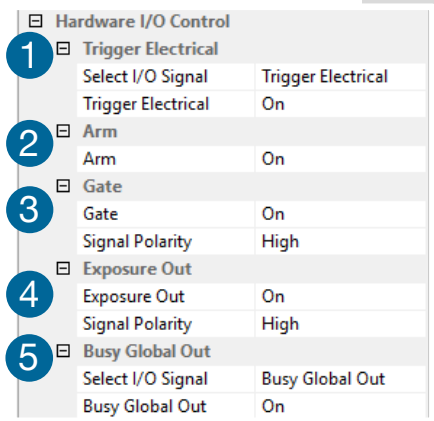
Type	Value
Type of phosphor	P46
Exposure time	10 µs
Configured phosphor decay time	10 µs
Readout time for a single image @full resolution	9.5 ms
MCP reactivation time	4 ms
Frame time	13.5 ms
Resulting frame rate @ full resolution	$\frac{1}{13.5\ ms} \approx 74\ fps$

Phophor Decay ③

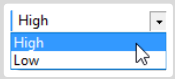
Additional configurable sCMOS exposure time to detect the "afterglow" of the phosphor screen. Each phosphor has a specific phosphor decay time, depending of the used material (P43, P46)
See detailed explanation in chapter **6.1** or **6.2**.

Phosphor	Phosphor decay typ. to …10%	…1%	Typical efficiency
P43	1 ms	4 ms	100%
P46	0.2 … 0.4 µs	2 µs	30%

8.4 HARDWARE I/O CONTROL PCO.DICAM C1



Change settings using the drop-down menu.



For electrical specification, see chapter **A1.3**

Trigger Electrical / Optical 1

If checked on, a signal for ***External Exposure Start*** (see chapter **6.3.1**) is accepted at the ***Exposure Trigger*** BNC input or at the optical input.

Select I/O Signal : Trigger Electrical ; Trigger Optical
Trigger Electrical / Optical: On; Off

Arm 2

If checked on, an ***Arm*** signal triggers the ***Double Image*** mode.
An exposure trigger signal is accepted after ⩾ 9.5 ms (full resolution) ***Arm*** signal.

Arm: On; Off

Gate 3

Allows to turn off the photocathode during a configured exposure time period.
Gate: On, Off
Signal Polarity: High; Low

Exposure Out 4

If checked on, a signal indicating photocathode exposure status is provided at the exposure out output.
For technical reasons, with exposure times of 4 ns and 10 ns, the length of the output signal is increased tenfold to 40 ns / 100 ns, from 20 ns the time is displayed correctly.

Exposure Out: On; Off
Signal Polarity: High; Low

Busy Global Out 5

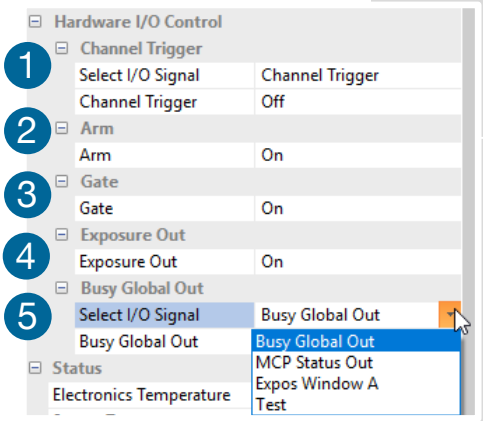
If checked on, a signal at the monitor output indicating exposure or readout status is provided at the exposure out output. During Busy active, no external trigger signal is accepted.

Select I/O Signal: Busy Global Out, MCP Status Out, Expos Window A
Busy / MCP / Expos: On; Off

Enabling and Polarity of I/O Signals (Gate / Eposure Out)

The polarity of the I/O signals indicating their active states is selectable (positive or negative logic).
The polarity of level-sensitive signals can be set to ***High*** (positive logic) or ***Low*** (negative logic).

8.5 HARDWARE I/O CONTROL PCO.DICAM C4



Change settings using the drop-down menu.

For electrical specification, see chapter **A2.4**

Channel Trigger / Master Trigger 1

Select if you want to trigger the camera by ***Master Trigger*** or individual ***Channel Trigger***. If checked on, a signal for ***External Exposure Start*** is accepted at the BNC input or at the optical input, see **7.1**.

Select I/O Signal : Channel Trigger; Master Trigger
Channel Electrical / Optical: On; Off

Arm 2

If checked on, an ***Arm*** signal triggers the ***Double Image*** mode.
An exposure trigger signal is accepted after ⩾ 9.5 ms (full resolution) ***Arm*** signal.

Arm: On; Off

Gate 3

Allows to turn off the photocathode during a configured exposure time period.
Gate: On, Off

Exposure Out 4

If checked on, a signal indicating photocathode exposure status is provided at the exposure out output.
For technical reasons, with exposure times of 4 ns and 10 ns, the length of the output signal is increased tenfold to 40 ns / 100 ns, from 20 ns the time is displayed correctly.

Exposure Out: On; Off

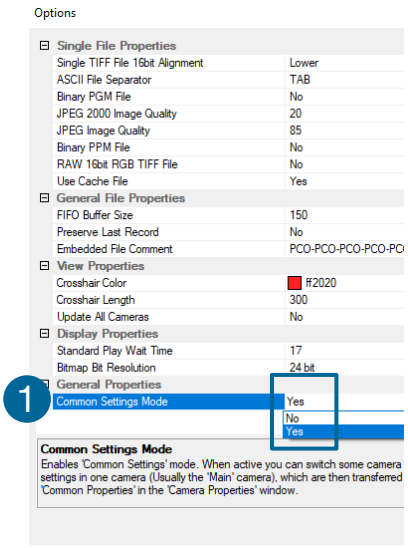
Busy Global Out 5

If checked on, a signal at the monitor output indicating exposure or readout status is provided at the exposure out output. During Busy active, no external trigger signal is accepted.

Select I/O Signal: Busy Global Out, MCP Status Out, Expos Window A
Busy / MCP / Expos: On; Off

9. SPECIAL FEATURES PCO.DICAM C4

9.1 COMMON TIME PROPERTIES



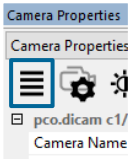
If you work with the pco.dicam C4, the ***Common Properties*** help to simplify the recording setup by determining which settings are common to all four cameras and which are set individually for each individual camera.

Prerequisite

The recording is planned with identical exposure times for all 4 channels and constant frame rate.

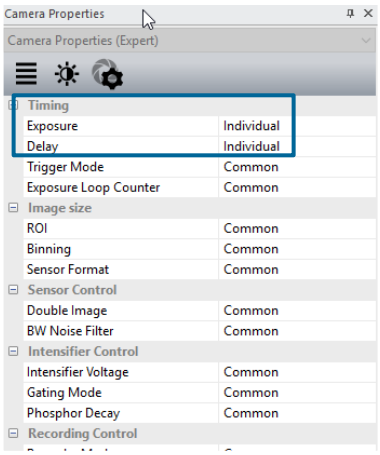
Common Settings Mode

In order to be able to use the ***Common Properties***, the ***Common Setting Mode*** must be activated. To do this, open the ***File*** menu and click ***Options.*** Under ***General Properties*** set the ***Common Settings Mode*** to ***Yes***.



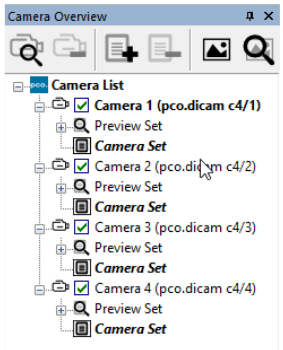
Common Properties

Now you can switch the menu in ***Camera Properties***. Click on the four horizontal lines. Immediately ***Camera Properties*** switches to the ***Common Properties***.



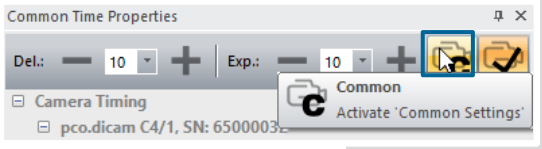
All settings for which ***Common*** is selected are configured only for ***camera 1*** and automatically apply to all 4 cameras.

The ***Camera Properties*** of camera 2, 3, 4, etc. only show the options set to ***Individual***, all others are hidden.
To make use of the comfortable method of setting up the timing for all channels with ***Common Time Properties*** menu, ***Exposure*** and ***Delay*** have to be set to ***Individual***.
This does not mean that the times have to be set individually, but the ***Common Properties*** function only has the necessary access to the ***Exposure*** / ***Delay*** time settings of each channel if the setting is set to ***Individual***.

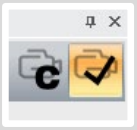


All other setting options can be set to ***Common***, so that an easy operation via ***Camera 1*** is possible.

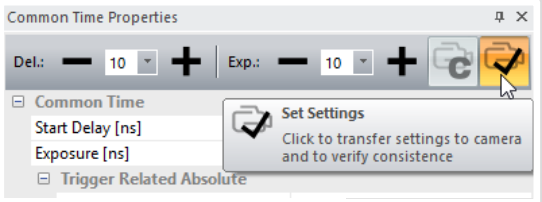
Significant are the effects of ***Common Settings Mode*** on the ***Camera Sets***. If you create a new set or edit an existing one and click on it to activate it, it will be duplicated on all other cameras.



Activate Common

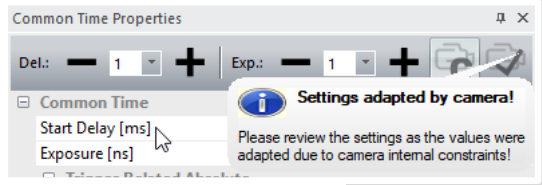


First activate ***Common Settings***
If it is highlighted, it is not activated.

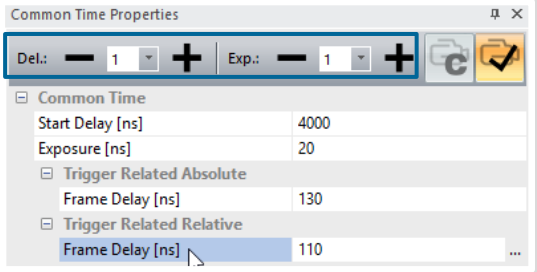


Set Settings to Camera

If all settings are set, the values must be transferred to the camera by pressing the ***Set Settings*** button.
This button is highlighted if the settings have not yet been transferred.



pco.camware will give a confirmation message after all settings have been accepted.
If incorrect values are entered, they are rejected by the camera and changed to an acceptable value.



Adjustable Values

The settings of delay and exposure times are configured centrally via the ± buttons. It is possible to adjust the jumps by dropdown. Or simply change the values by direct input.

The verification whether the set times are within the allowed parameter range is done by clicking the Set Settings button.

Term Explanations

Start Delay time
Additional delay time between the trigger signal and the first exposure of the following sequence.

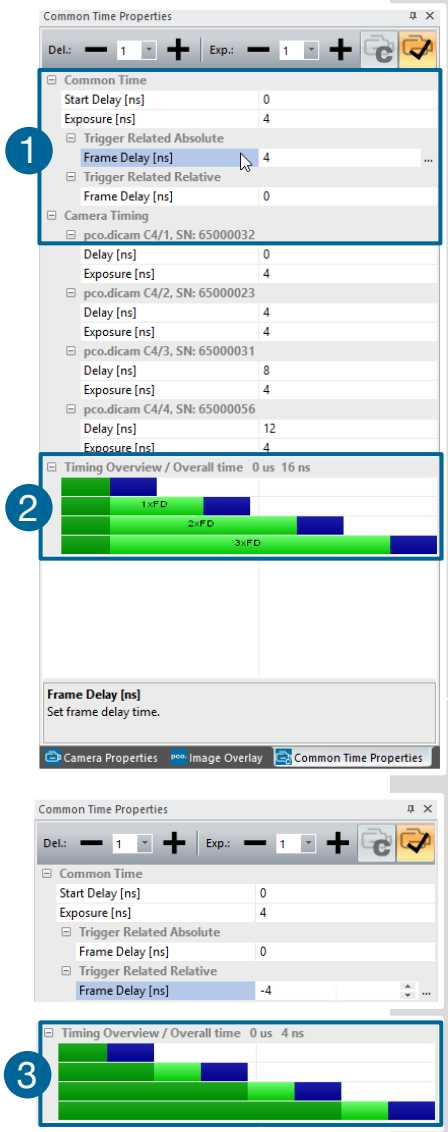
Exposure time
Constant exposure time for all four or eight images within the sequence

The two following delay times are interdependent.

Trigger Related Absolute
Time distance between the start of one exposure and the start of the following exposure within the sequence

Trigger Related Relative
Time distance between the end of one exposure and the start of the following exposure within the sequence

9.1.1 SINGLE IMAGE MODE



How to configure the timing for all channels in single image mode with ***Common Time Properties*** is explained in this chapter. This mode is recommended for the pco.dicam C4 for the most common application scenario where 4 identical exposure times shall be equidistantly positioned on the time line corresponding to a constant fps.

Only configure the four parameters accessible under ***Common Time*** (1). Do not adjust individual channel settings (***Camera Timing***), because if you change any value, the ***Common Time*** mode will be deactivated.

You just have to set ***Start Delay***, ***Exposure*** time and ***Trigger Related Absolute*** / ***Relative*** (only one of the two values has to be set, the other one is calculated automatically). The resulting settings for the four channels are calculated by pco.camware and displayed under ***Camera Timing***.

The ***Timing Overview*** (2) (3) shows schematically one time line per channel with the position of the actual exposure relative to the time lines of the three other channels.

Trigger Related Frame Delay

The offset of the exposure start of the channels, i.e. the delay between the individual channels in the ***Timing Overview*** is adjustable in two ways:

Trigger Related Absolute Frame Delay defines the time difference between the beginning of the exposure time on one channel and the beginning of the exposure time on the next channel. The minimum value is zero if all four exposure times start simultaneously. ***Frame Delay Absolute*** is displayed in light green as 1xFD, 2xFD, 3xFD (2).

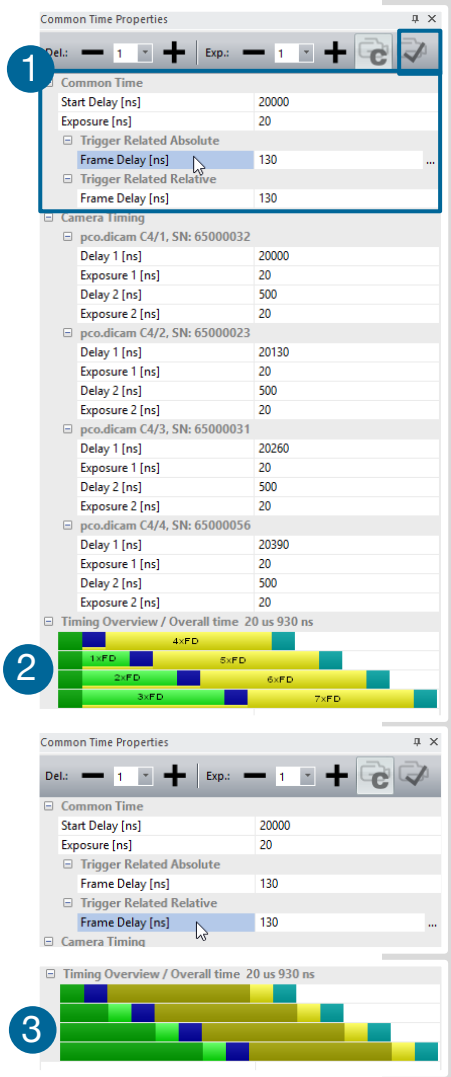
Trigger Related Relative Frame Delay (light green (3)) indicates the time interval between the end of the exposure time on one channel and the start of the exposure time on the next channel.
It can be zero or negative if consecutive exposure times are back to back or overlap.

The following times are the minimum values in ***Single Image*** mode:

- exposure time: 4 ns
- frame delay absolute: 0 ns (i.e. all 4 exposures start at the same time)
- frame delay relative: – 4 ns (i.e. all 4 exposures start at the same time)

Valid for 4 ns exposure time; the frame delay relative time can be less than the -4 ns, if the exposure time is longer.

9.1.2 DOUBLE IMAGE MODE



How to configure the timing for all channels in double image mode with ***Common Time Properties*** is explained in this chapter. This mode is recommended for the pco.dicam C4 for the most common application scenario where 8 identical exposure times shall be equidistantly positioned on the time line corresponding to a constant fps.

Only configure the four parameters accessible under ***Common Time*** 1. Do not adjust individual channel settings (***Camera Timing***), because if you change any value, the ***Common Time*** mode will be deactivated.

You just have to set ***Start Delay***, ***Exposure*** time and ***Trigger Related Absolute*** / ***Relative***. The resulting settings for the four channels are calculated by pco.camware and displayed under ***Camera Timing***.

The ***Timing Overview*** 2 shows schematically one time line per channel with the position of the actual two exposure times relative to the time lines of the three other channels.

Trigger Related Frame Delay

The offset of the exposure start of the channels, i.e. the delay between the individual channels in the ***Timing Overview*** is adjustable in two ways:

Trigger Related Absolute Frame Delay defines the time difference between the beginning of the exposure time on one channel and the beginning of the exposure time on the next channel. ***Frame Delay Absolute*** is displayed in light green as 1xFD, 2xFD, 3xFD for ***Exposure 1*** of each channel and in yellow for ***Exposure 2*** of each channel as 4xFD, 5xFD. 6xFD, 7xFD 2.

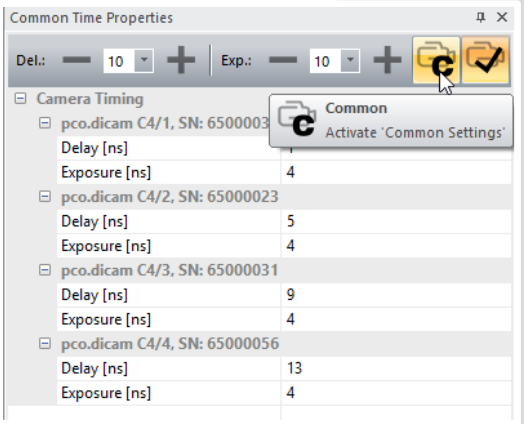
Trigger Related Relative Frame Delay (light green and yellow 3) indicates the time interval between the end of the exposure time on one channel and the start of the exposure time on the next channel.

The following times are the minimum values in ***Double Image*** mode:

- exposure time: 20 ns
- frame delay absolute: 80 ns
- frame delay relative: 60 ns
- interframing time between image 1 & 2 (same channel): 300 ns / 500 ns

Valid for 20 ns exposure time; the frame delay relative time can be > or < , if the exposure time is longer.

9.1.3 WITHOUT COMMON SETTINGS



This mode is recommended for advanced users only; it is recommended to use ***Common Settings*** as the default mode.

One of the great advantages of the pco.dicam C4 camera is its flexibility in setting up individual timing schemes without constant exposure times and fixed frame rate.

Each channel can be configured completely separately from the other channels. Even the two exposure times on the same channel (***Double Image*** mode) can be different.

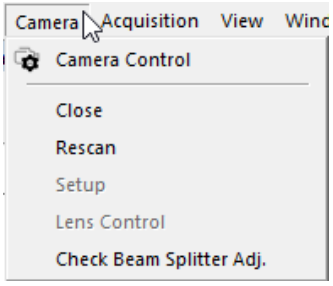
Doing so allows also changing the channel recording sequence which is fixed when using the ***Common Time Properties***.

If you want to switch to this mode and ***Common Settings*** is still active, just change the delay / exposure value of a single camera directly, pco.camware will switch off the ***Common Settings*** immediately and the ***Common Time*** area disappears.

It should be noted that all values have to be calculated and the timing overview is not available.

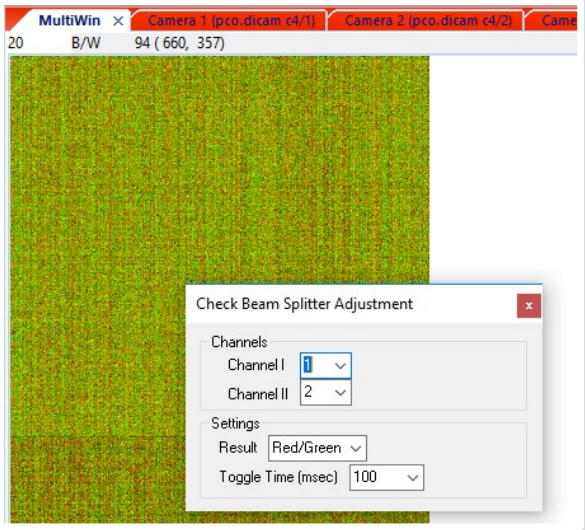
Individual setting of all four channels is also necessary if each channel should be externally triggered separately.

9.2 CAMERA MENU



Beam Splitter Alignment

A high performance optical beam splitter is placed between input lens and the four intensified cameras.
The beam splitter consists of image splitter cubes arranged in the infinite, parallel ray path, generated by a collimator lens at the common optical input. Each image splitter has an output lens coupled to the camera. This way eventual dust or particles on the optical components will not degrade the image quality.
The beam splitter's construction eliminates aberrations due to changes in wavelength, e.g. when placing filters in the optical path.



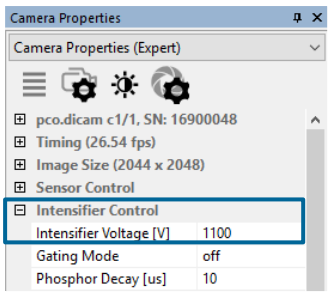
Check Beam Splitter Adj.

With this function you can control the optical alignment of the individual channels of a pco.dicam C4 to ensure best possible congruency of the images recorded by the four channels.

Select the ***Channels*** you want to compare.
Select the comparison: ***Red/Green*** or ***Alternate***.
Select the ***Toggle Time*** in ms.

Note: Only trained personnel should adjust the optical alignment of the individual channels! If you have questions or problems contact the PCO support, see **A6**.

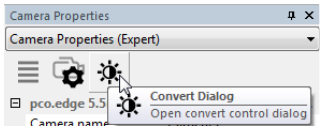
9.3 MATCHING THE 4 IMAGE INTENSIFIERS

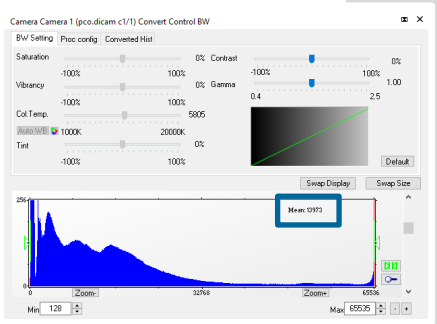


During production process, PCO tries to select and group four image intensifiers with similar image intensifier characteristics for a pco.dicam C4 camera.

The setting of the individual channels is adjusted for maximum intensifier voltage, so that the customer achieves the most homogeneous intensity result comparing the images of all four channels.

Additional fine tuning is possible to improve the channel matching at any desired image intensifier voltage different from the maximum or to compensate for aging effects of the image intensifier.
To set image intensifier voltage value, see **8.3**.





Procedure for Matching the 4 Channels

Set all 4 channels to maximum image intensifier voltage and same exposure time. Point the camera to a homogeneous object, e.g. a white wall.

Try to adjust the amount of illumination so that about 25% of saturation level (16.000 counts) are achieved as a mean value. Compare the mean values of all four channels.

The channel with the lowest mean value in the histogram (see pco.camware manual, chapter 3.3.8 Convert Control) is left at maximum intensifier voltage. The intensifier voltages of the other three channels are stepwise reduced until all of them reach the mean value of the previously identified weakest channel.

Note that this method might not produce perfect homogeneous results over the full dynamic range due to the non-linearity of the image intensifiers.

So it may well be that for a signal level of e.g. 1000 counts all four channels show approximately the same mean value, but differ for higher or lower signal level.

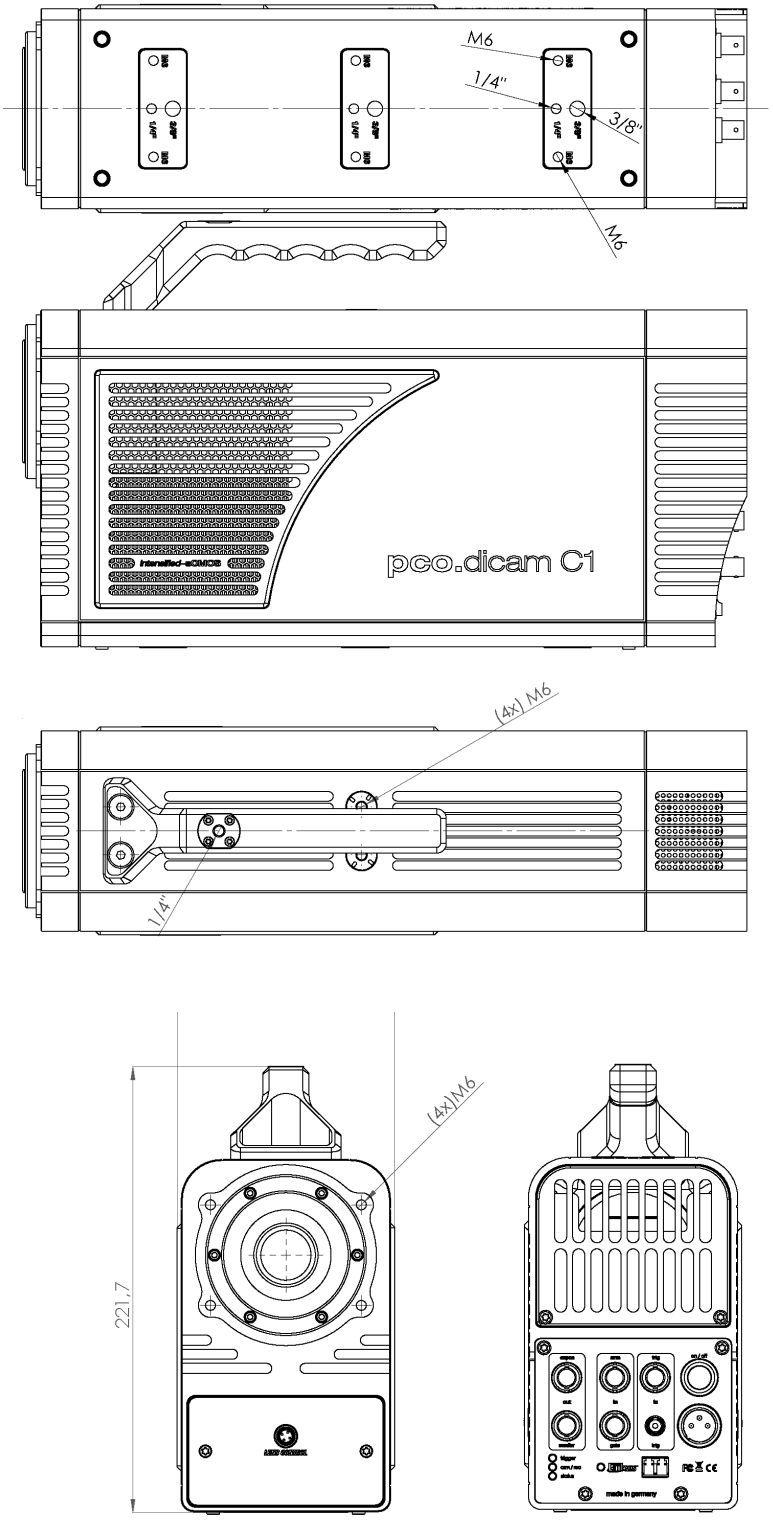
Of course, if you want to invest more time, you can still perform a subsequent calibration with the classical means of image processing.

APPENDIX

A1 TECHNICAL DATA PCO.DICAM C1

A1.1 MECHANICAL DIMENSIONS

All dimensions given in millimeter.



A1.2 SPECIFICATIONS

sCMOS Image Sensor	
Type of sensor	scientific CMOS (sCMOS)
Dynamic range	13 600 : 1 (82.7 dB) P46 27 200 : 1 (88.7 dB) P43
Resolution (h x v)	2048 x 2048 active pixels
Pixel size (h x v)	6.5 µm x 6.5 µm
Sensor format / diagonal	13.3 mm x 13.3 mm / 18.8 mm
Shutter mode	single image / double image
Fullwell capacity (typ.)	15 000 e^- P46 30 000 e^- P43
Spectral range	300 nm ... 1000 nm
Dark current	< 0.6 e-/pixel/s @ 7 °C
Quantum efficiency	58 % for P43 peak emission @ 545 nm 57 % for P46 peak emission @ 530 nm
Readout noise	1.1 med / 1.5 rms e^- single image 2.2 med / 2.5 rms e^- double image
DSNU	1.0 rms e^-
PRNU	< 0.6 %
Anti blooming factor	1 : 10 000

Image Intensifier	
Type	HighRes MCP (6 µm channel)
Input window	synthetic silica, borosilicate (MgF2 optional)
Output window	glass
Photocathode material	S20, GaAs, GaAsP (others on request)
Phosphor screen material	P43, P46
Image intensifier pitch distance	6 µm
Image intensifier MCP type	single stage low resistance MCP for high strip current
MCP operational modes	continuous gated for enhanced extinction ratio
Image intensifier diameter	25 mm (18 mm optional on request)
Image intensifier system resolution	> 50 lp/mm @ 5% MTF typical (depends on phosphor)
Shortest gating time	4 ns

Optical Coupling Lens System	
“ultra speed tandem lens” between image intensifier & sCMOS	
Transmission efficiency	> 30 %
Vignetting	< 3 %
Resolution	> 60 lp/mm
Scaling rates	ß=0.53 for 25 mm intensifier

General	
Power supply	18 ... 28 VDC
Power consumption	35 ... 40 W
Weight	7 kg
Operating temperature	+ 10 °C ... + 40 °C
Operating humidity range	10 % ... 80 % (non-condensing)
Storage temperature range	- 10 °C ... + 60 °C
Optical interface	F-mount; optional: C-mount, Canon mount
Lens remote controller	electronic control for Canon EF lenses
CE / FCC certified	yes

Exposure Modes

Single Image Mode	
Exposure times	4, 10 ns fixed 20 ns ... 250 ns (1 ns steps) 250 ns ... 1 s (10 ns steps)
Delay times	0 ns ... 250 ns (1 ns steps) 250 ns ... 1 s (10 ns steps)
Maximum repetition frequency	200 kHz (with external gating)
Intrinsic delay (trigger input - shutter)	< 50 ns
Jitter	< 1 ns

Double Image Mode	
Exposure times	20 ns ... 1 s (in 10 ns steps)
Delay settings	0 ns ... 10 ms (in 10 ns steps)
Minimum interframing time	300 ns / 500 ns .. 10 ms (in 10 ns steps)
Intrinsic delay (fixed)	20070 ns

Phosphor Data

Phosphor	Phosphor decay typ. to …10%	…1%	Typical efficiency
P43	1 ms	4 ms	100%
P46	0.2 … 0.4 µs	2 µs	30%

Photocathode Characteristics

Material	Peak wavelength [nm]	QE@ peak wavelength	Dark counts [s^{-1}/cm^2]
S20 (multialkali)	250	20	1500
GaAs	650	30	30000
GaAsP	500	55	10000

Camera Interface

Data transfer	Camera Link HS, FOL cable, frame grabber
Input signals	optical trigger (FOL), electrical trigger, arm input (TTL level, BNC connectors), gate disable (high speed TTL input, BNC connector
Output signals	gate/expos out monitor, user monitor output (TTL level, BNC connectors)

A1.3 REAR PANEL

Expos Out 1

Type	Digital output
Connector	BNC
Level	3.3 V LVTTL
Coupling	DC
Load current	Short circuit proof

Monitor Out 2

Type	Digital output
Connector	BNC
Level	3.3 V LVTTL
Coupling	DC
Preconfigured functions	Busy Global out
	MCP Status out
	Expos Window A
Load current	Short circuit proof

Arm In 3

Type	Digital input
Connector	BNC
Level	1.7 V LVTTL (5 V tolerant)
Impedance	1kΩ to ground
Slew rate	> 1 V/ms

Gate In 4

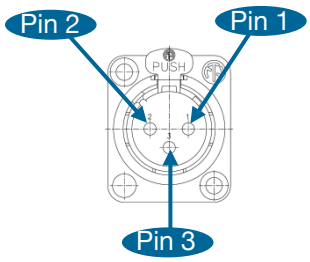
Type	Digital input
Connector	BNC
Level	≈1.5 V LVTTL (5 V tolerant)
Impedance	1 kΩ
Slew rate	> 1 V/ms

Trig In 5

Type	Digital input
Connector	BNC
Impedance	1 kΩ to ground
Level	1.7 V LVTTL (5 V tolerant)
Slew rate	> 1 V/ms

Trig In 6

Type	Optical input
Level	1 mW
Connector type	ST connector multi mode



Power Switch 7

On / off

Power Input 8

Pin	Assignment
Pin1	Ground
Pin2	VCC 18 V … 28 V
Pin3	Not used

XLR / Neutrik socket (fitting connector e.g. NC3MX-BAG)

Camera LEDs 9

Trigger LED		Description
Off	○	Not ready
Yellow	●	Camera is ready for operation
White blinking	○	Error

Arm / rec LED		Description
Orange continuous	●	Arm camera / rec state off
Orange blinking	●	Recording on

Status LED		Description
Red / green continuous	●	Camera is booting
Green	●	Camera is ready for operation
Red continuous	●	Error

Interface Status LED (Camera Link HS) 10

Off	○	No power and/or waiting for software
Green continuous	●	Link established; data transfer may take place
Green blinking	●	Hardware ok, but connection interrupted / not established

Interface Connector 11

Camera Link HS (Single F2,1X1, S10)

Power Output / Lens Control (Front side) 12

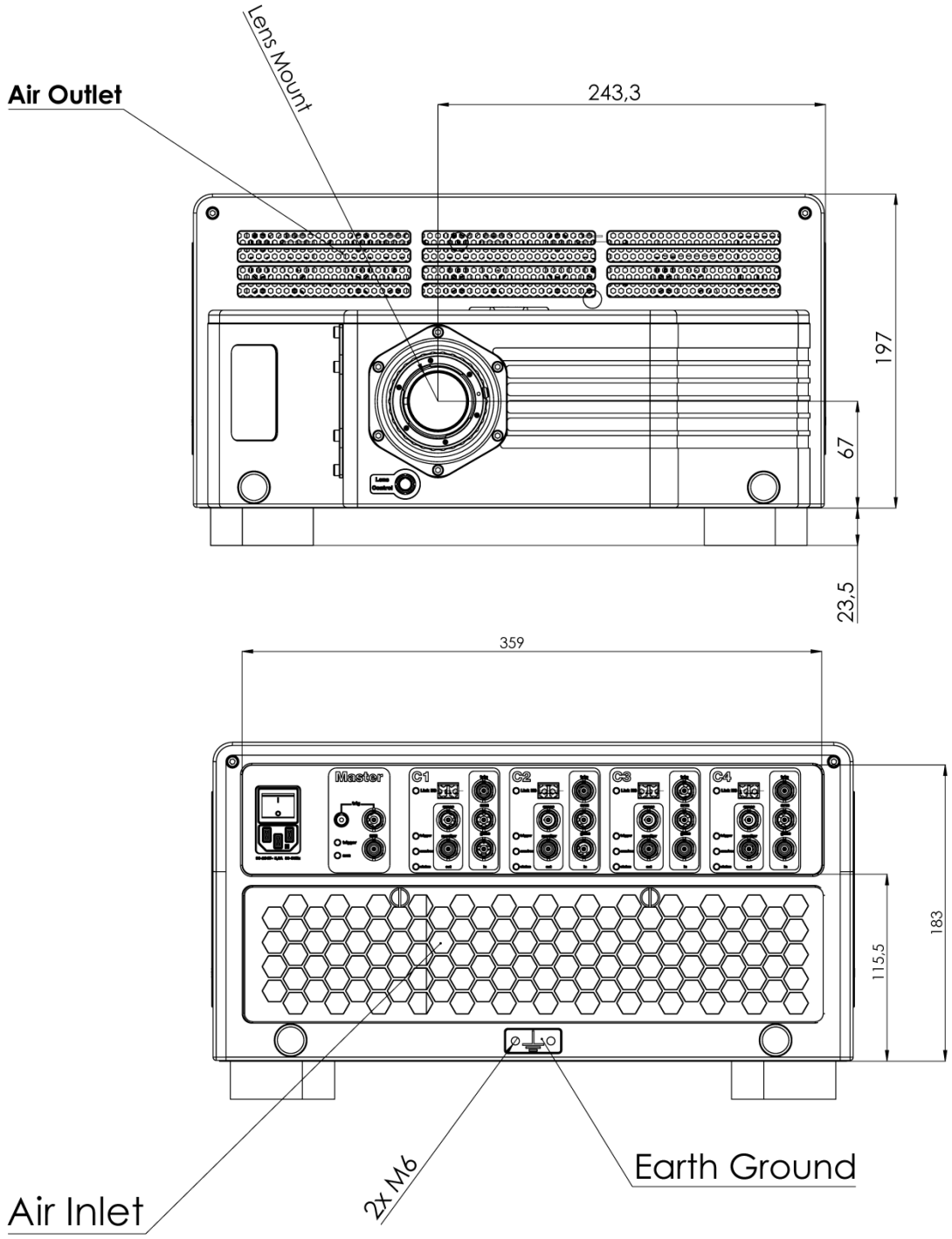
LEMO socket EEG.0B.304.CLN	
Pin1	12 V output (15 W)
Pin2	RXD (bidirectional modulated communication for lens control)
Pin3	TXD (communication for lens control)
Pin4	ground

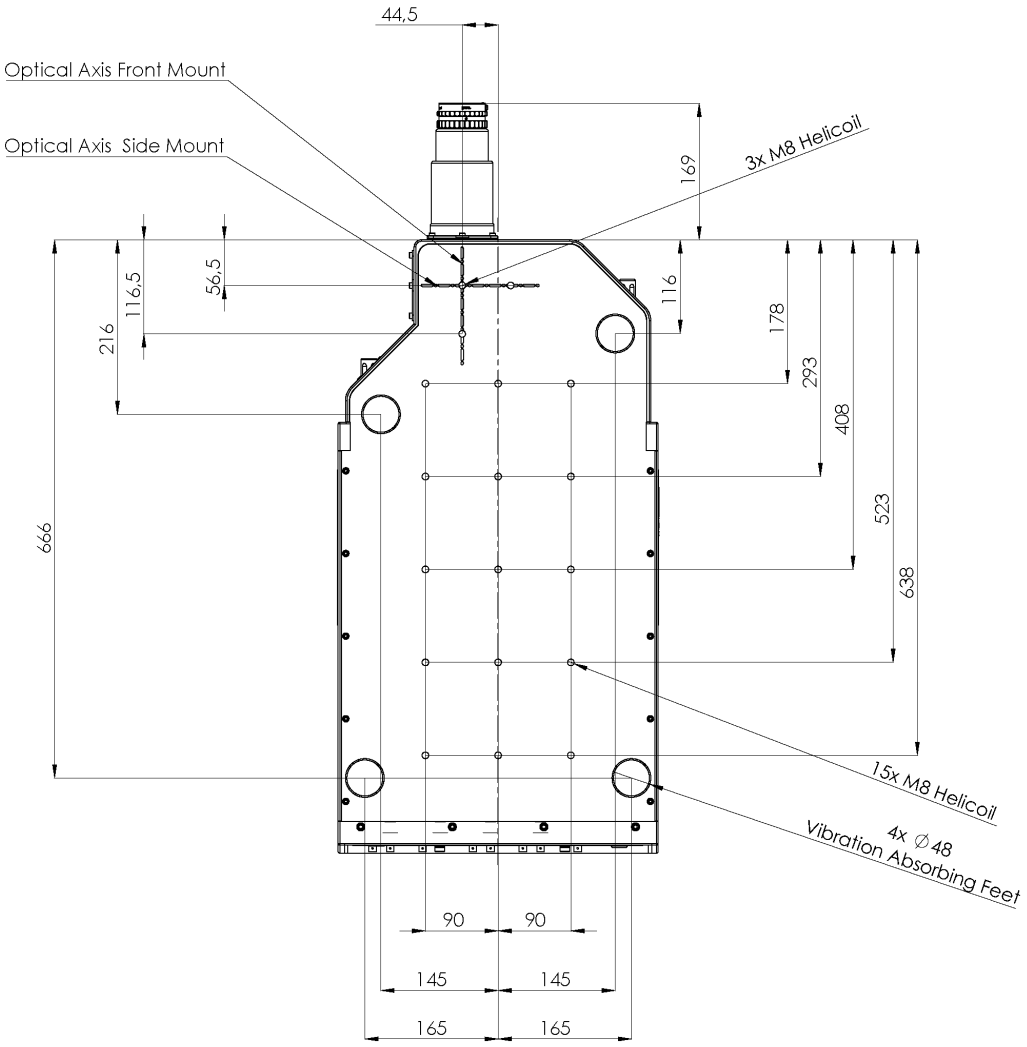
Appropiate Lemo plug: FGG.0B.304.CYCD52Z

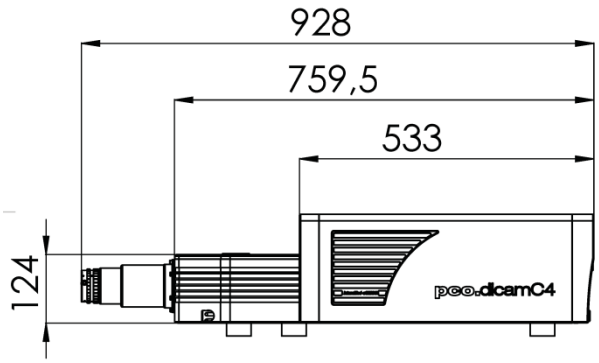
A2 TECHNICAL DATA PCO.DICAM C4

A2.1 MECHANICAL DIMENSIONS

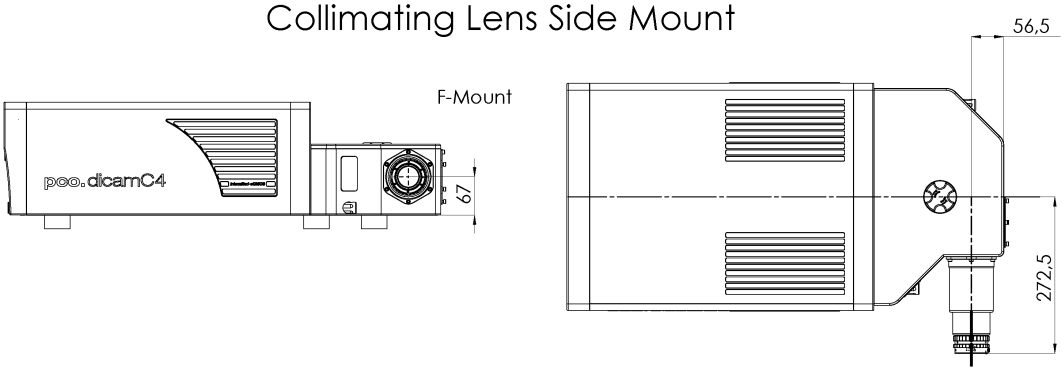
All dimensions given in millimeter.




44,5
Optical Axis Front Mount
Optical Axis Side Mount
169
3x M8 Helicoil
56,5
116,5
216
116
178
293
408
523
638
666
15x M8 Helicoil
4x ∅48
Vibration Absorbing Feet
90
90
145
145
165
165


928
759,5
533
124
pco.dicamC4

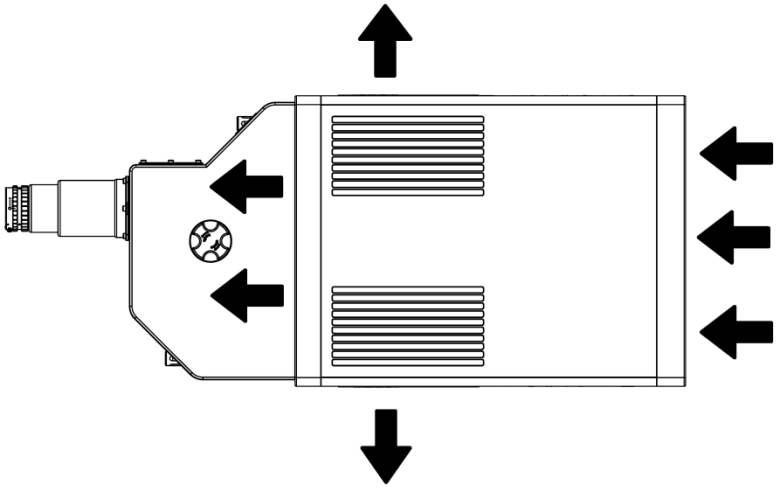
Collimating Lens Side Mount



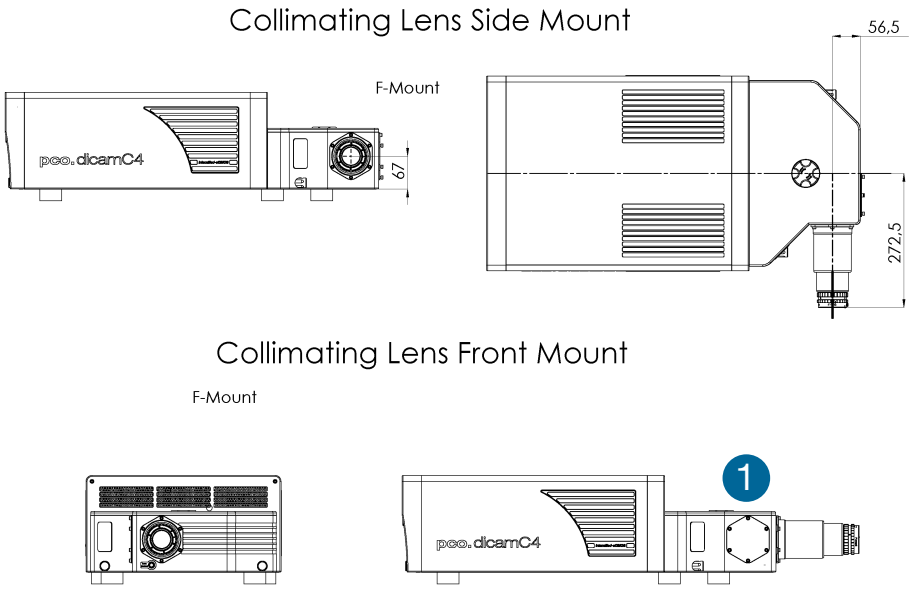
Collimating Lens Front Mount

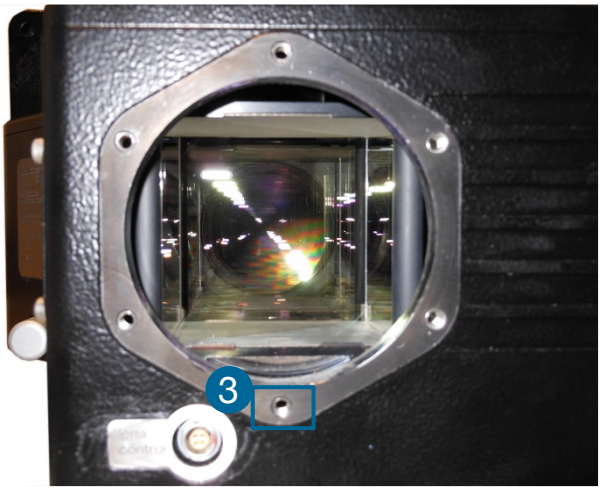
F-Mount

Air Flow Direction



A2.2 COLLIMATING LENS MOUNTING





How to mount the collimating lens.

The collimator lens is attached to the pco.dicam C4 system and has to be mounted before the camera can be used.

It can be mounted in two positions: front or side mount

First remove the protective cover from the position where you want to mount the lens. 1

Take the collimating lens by hand and pay attention to the "bottom" sticker. 2

The lens must be mounted with the bottom sticker facing down. See 3 for the correct mounting position.

A2.3 SPECIFICATIONS

sCMOS Sensor	
Type of sensor	scientific CMOS (sCMOS)
Resolution (h x v)	2048 x 2048 active pixel
Pixel size (h x v)	6.5 µm x 6.5 µm
Sensor format / diagonal	13.3 mm x 13.3 mm / 18.8 mm
Shutter mode	single image / double image
Fullwell capacity (typ.)	13 600 : 1 (82.7 dB) P46 27 200 : 1 (88.7 dB) P43
Readout noise	1.1 med / 1.5 rms e^- single image 2.2 med / 2.5 rms e^- double image
Dynamic range	15 000 e^- P46 30 000 e^- P43
Spectral range	300 nm ... 1100 nm
Dark current	< 0.6 e^-/pixel/s @ 7 °C
Quantum efficiency	58 % for P43 peak emission @ 545 nm 57 % for P46 peak emission @ 530 nm
Spectral range	300 nm … 1000 nm
DSNU	1.0 rms e^-
PRNU	< 0.6 %
Anti blooming factor	1 : 10 000

Image Intensifier 4x	
Type	HighRes MCP (6 µm channel)
Input window	synthetic silica, borosillicate
Output window	glass
Photocathode material	S20, GaAs, GaAsP (others on request)
Phosphor screen material	P43, P46
Image intensifier pitch distance	6 µm
Image intensifier MCP type	single stage low resistance MCP for high strip current
MCP operational modes	continuous gated for enhanced extinction ratio
Image intensifier diameter	25 mm (18 mm optional on request)
Image intensifier system resolution	> 50 lp/mm @ 5% MTF typical (depends on phosphor)
Shortest gating time	4 ns

Optical Coupling Lens System	
“ultra speed tandem lens” between image intensifier & sCMOS	
Transmission efficiency	> 30 %
Vignetting	< 3 %
Resolution	> 60 lp/mm
Scaling rates	ß=0.53 for 25 mm intensifier

General	
Power supply	100 … 240 VAC
Power consumption	180 W
Weight	43.3 kg
Operating temperature	+ 10 °C ... + 40 °C
Operating humidity range	10 % ... 80 % (non-condensing)
Storage temperature range	- 10 °C ... + 60 °C
Optical interface	F-mount (optional Canon mount)
Lens remote controller	electronic control for Canon EF lenses
CE / FCC certified	yes

Exposure Modes

Single Image Mode	
Exposure times	4, 10 ns fixed 20 ns ... 250 ns (1 ns steps) 250 ns ... 1 s (10 ns steps)
Delay times	0 ns ... 250 ns (1 ns steps) 250 ns ... 1 s (10 ns steps)
Maximum repetition frequency	4 x 7.2 kHz
Intrinsic delay (trigger input - shutter)	< 50 ns

Double Image Mode	
Exposure times	20 ns ... 1 s (in 10 ns steps)
Delay settings	0 ns ... 1 s (in 10 ns steps)
Minimum interframing time	300 ns / 500 ns ... 10 ms (in 10 ns steps)
Intrinsic delay (fixed)	20070 ns

Phophor Data

Phosphor	Phosphor decay typ. to …10%	…1%	Typical efficiency
P43	1 ms	4 ms	100%
P46	0.2 … 0.4 µs	2 µs	30%

Photocathode Characteristics

Material	Peak wavelength [nm]	QE@ peak wavelength	dark counts [s^{-1}/cm^2]
S20 (multialkali)	250	20	1500
GaAs	650	30	30000
GaAsP	500	55	10000

Camera Interface

Data transfer	Camera Link HS, FOL cable, frame grabber
Input signals	optical trigger (FOL), electrical trigger, arm input (TTL level, BNC connectors), gate disable (high speed TTL input, BNC connector
Output signals	gate/expos out monitor, user monitor output (TTL level, BNC connectors)

A2.4 REAR PANEL

The rear panel of the pco.dicam C4 is split into connectors for a

Power Input 1

Pin	Assignment
Pin1	Hot / Live
Pin2	Ground
Pin3	Neutral / Return

IEC connector (IEC-60320 C14) 100 V … 240 V

Power Switch 2

On / off

Optical Trig In 3

Type	Optical input
Level	1 mW

BNC Trig In 4

Type	Digital input
Electrical	1k pulldown
Level	1.7 V for rising edge

Camera LEDs 5

Trigger LED	Description
Off	Not ready
Yellow	Camera is ready for operation
White blinking	Error

Arm / rec LED	Description
Orange continuous	Arm camera / rec state off
Orange blinking	Recording on

Status LED	Description
Red / green continuous	Camera is booting
Green	Camera is ready for operation
Red continuous	Error

BNC Arm In 6

Type	Digital input
Level	1.7 V LVTTL (5 V tolerant)
Impedance	1kΩ
Slew rate	> 1 V /ms

Interface Status LED (Camera Link HS) 7

	Description
Off ○	No power and/or waiting for software
Green continuous ●	Link established; data transfer may take place
Green blinking ●	Hardware ok, but connection interrupted / not established

Interface Connector 8

Camera Link HS (Single F2,1X1, S10)

BNC Expos Out 9

Type	Digital output
Level	3.3 V LVTTL
Coupling	DC
Signal function	High, if image intensifier is open
Load current	Short circuit proof

BNC Monitor Out 10

Type	Digital output
Level	3.3 V LVTTL
Coupling	DC
Preconfigured functions	Busy global
	MCP-on
	Window A for double image
Load current	Short circuit proof

BNC Gate In 11

Type	Digital input
Level	≈1.5 V LVTTL (5 V tolerant)
Impedance	1 kΩ
Slew rate	> 1 V/ms

A3 ADAPTER / ACCESSORIES

A3.1 PCO.TRIGGER UNIT

The pco.trigger unit is optional for pco.dicam C1 and a standard accessory for pco.dicam C4.
With the help of this trigger unit, clear trigger signals for the camera can be generated and adjusted from your input signals.

First put power switch to ***on*** 1 and select the desired main function with the ***Central Tuning Knob*** 2.

Input Connectors

Comparator in 3

If there are spurious signals on the trigger line, then the comparator can be used to define a higher threshold for the trigger by adjusting the ***Level*** 4 knob (-0.5 V … 15 V). The reverse application is also possible: the camera is triggered by even the smallest voltage pulses. The Comparator Input can be used to generate proper TTL trigger signal.
Input: BNC Comparator 0 … 24 V

TTL in 5

TTL in is used to convert electrical TTL trigger signals to optical signals. For many experiments in the high-energy field, the optical triggering of the camera is necessary e.g. for signal protection and / or range extension. Define whether you want to use the falling or rising edge of the input TTL signal with the ***Central Tuning Knob*** 2.
Input: BNC TTL in 0 … 5 V

Photodiode in 6

For fast continuous processes, it is sometimes only important that the camera records in synchronization with pulsed lighting (flash, etc.). To generate the necessary trigger signal for the camera, a photodiode at the location of the experiment is the simplest method. The anode of the photodiode is to be connected to the screen of the BNC socket, the cathode to the inner conductor.
Adjust the trigger threshold with ***Sensitivity*** 8 knob.

7 Hz Test 8

Generation of external trigger signals with 7 Hz repetition frequency for test purposes.
To be used to verify the functionality of the cameras trigger input or during experimental setup.

Output Connectors

Both outputs electrical and optical always deliver a signal at the same time.

TTL out 9

BNC output for a rising TTL signal. Connect directly to the pco.dicam C1 / C4 ***trig in*** BNC connector.

OPTO out 10

ST Bayonet optical output, connect directly to the pco.dicam C1 / C4 ***trig in*** optical input

DC in 11

10 … 28 VDC; use the included power supply

LEDs 12

Power LED

When voltage is applied, the LED lights up green

Trigger LED

The LED lights up red in idle mode. When a trigger pulse occurs, it lights green for about 100 ms.

Protective function for the trigger input of the camera

The use of the pco.trigger unit automatically protects the trigger inputs of the camera against accidental electrical overvoltage (at the cost of latency or possible damage of the pco.trigger unit).
Usually It is easier to exchange the pco.trigger unit than the trigger input of the camera.

A3.2 PCO F-MOUNT ADAPTER

NOTICE

Make sure that the adapter is set correctly, as the image intensifier can be irreparably damaged by an accidentally fully opened aperture. The aperture should always be closed as far as possible to protect the image intensifier, i.e. the adapter ring has to be rotated so that the mark is in line with the small circle 1 (aperture closed).

PCO's proprietary F-mount adapter for lenses with automatic diaphragm. Allows to set manually the lens aperture by turning the ring on the adapter 1.

F-mount lenses without automatic diaphragm can be fastened to the camera's mount but the aperture not changed.

Adjust Back Focal Length

To adjust the back focal length (e.g. you cannot focus to infinity or to the minimum object distance of your lens), proceed as follows:
Set the focus of your lens to infinity. Look at an object in infinity and generate a sharp image by turning the adapter. Use the rearmost ring to fix the setting 2.

Matching Lenses with Automatic Diaphragm

Nikon: all Nikkor lenses of type D and type G (not for type E, this one is only electronic).

Zeiss: all ZEISS ZF.2 lenses (Otus, Milvus, Interlock, Distagon, Planar).

Sigma: only lenses, which already have a manual diaphragm ring; all other lenses have got an aperture control lever, but which does not spring back, if you turn the aperture ring at the adapter.

Tamron: only some lenses provide automatic diaphragm (no particular lens family):

Type 35mm F-Mount

- A012 -> SP 15-30mm F/2.8 Di VC USD
- A007 -> SP 24-70mm F/2.8 Di VC USD
- A009 -> SP 70-200mm F/2.8 Di VC USD
- A011 -> SP 150-600mm F/5-6.3 Di VC USD
- F012 -> SP 35mm F/1.8 Di VC USD
- F013 -> SP 45mm F/1.8 Di VC USD
- F017 -> SP 90mm F/2.8 Di MACRO 1:1 VC USD

Type APS-C(H) F-Mount

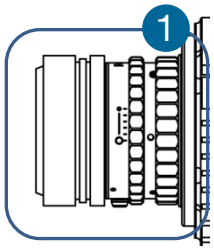
- B001 -> SP AF 10-24mm F/3.5-4.5 Di II LD Aspherical [IF]
- B005 -> SP AF 17-50mm F/2.8 XR Di II VC LD Aspherical [IF]
- G005 -> SP AF 60mm F/2.0 Di II LD [IF] Macro 1:1

A3.3 CHANGE FROM F-MOUNT TO C-MOUNT

How to change the optical input from F-mount to C-mount:

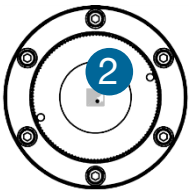
NOTICE

MECHANICAL DAMAGE OF THE C-MOUNT RING
Tightening the hexagon socket setscrews too tight will permanently damage the C-mount ring.
➔ Use a torque wrench and select a maximum torque of 1 Nm to tighten the hexagon socket setscrews.



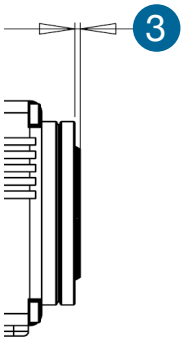
Step 1: Remove F–mount adapter

Turn the black lock ring 1 counterclockwise to loosen the F-mount adapter and then unscrew it.



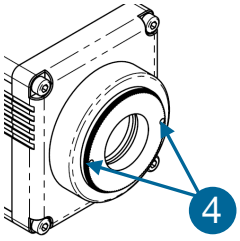
Step 2: Insert C–mount ring

Carefully screw the C-mount ring 2 clockwise so that the two hexagon setscrews are visible on the outside.



Step 3: Adjust flange focal distance

In order to reach the standard support dimension of C-Mount (17.526 mm), screw the C-mount ring so far that it protrudes by about 3.3 mm 3.
For fine adjustment use a suitable lens with large aperture.



Step 4: Fix the C–mount ring

To fix the C-mount ring, tighten both hexagon setscrews 4 (1.5 mm hex key) to a maximum torque of 1 Nm.

A4 KAYA FRAME GRABBER INSTALLATION

A4.1 INTRODUCTION

This chapter describes the installation of a quad port Kaya frame grabber.

A4.2 SYSTEM REQUIREMENTS

- PCIe Slot x8 or x16
- Recommended: Gen 3 and 8 lanes (see chapter **A4.5**)

A4.3 SAFETY INSTRUCTIONS

CLASS 1 LASER PRODUCT
Risk of injury due to laser beam.
- ➔ Do not look into the laser beam or at direct reflexes.
- ➔ Do not point the laser beam at persons.
- ➔ Manipulations of the laser device are not allowed.

WARNING

ELECTRIC SHOCK WARNING DUE TO VOLTAGE PARTS INSIDE
Risk of injury due to electric shock.
- ➔ Always pull the main plug before opening the computer.

A4.4 FRAME GRABBER INSTALLATION

Instructions for installing and testing the ***Kaya Camera Link HS*** grabber card. This card is required to be able to use a PCO camera with Camera Link HS interface. Installation must be performed by a technician, because high voltages can occur on the device.

WARNING

ELECTRIC SHOCK WARNING DUE TO VOLTAGE PARTS INSIDE
Risk of injury due to electric shock.
➔ Always pull the main plug before opening the computer.

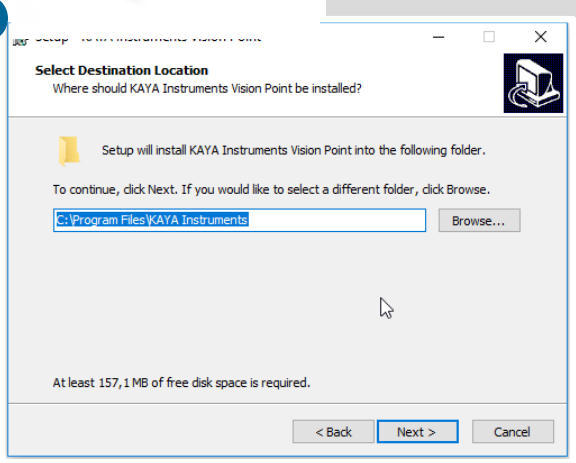
Install the latest Kaya package. (Download approved version from: **http://www.pco.de/support/)**

Only 64-bit computer systems are supported.

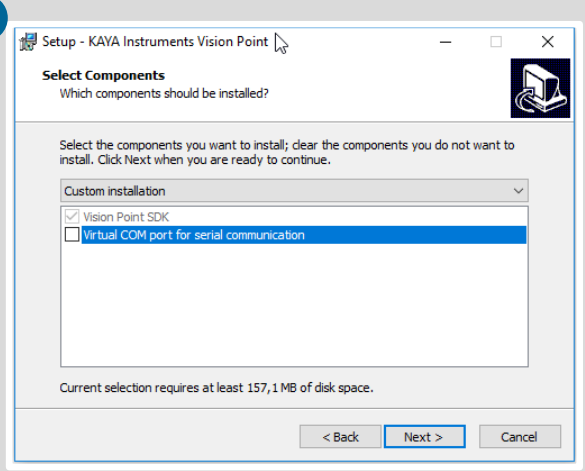
1. Shutdown your computer, open the computer case and install the frame grabber card
2. Select proper folder at your computer
3. Deselect ***Virtual COM port for serial communication***
4. The frame grabber card should be displayed within the device manager. If the device is not shown this way, reinstall the driver.
5. Start ***Vision Point*** application (see chapter **A4.5**)

1

2

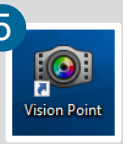


3



4

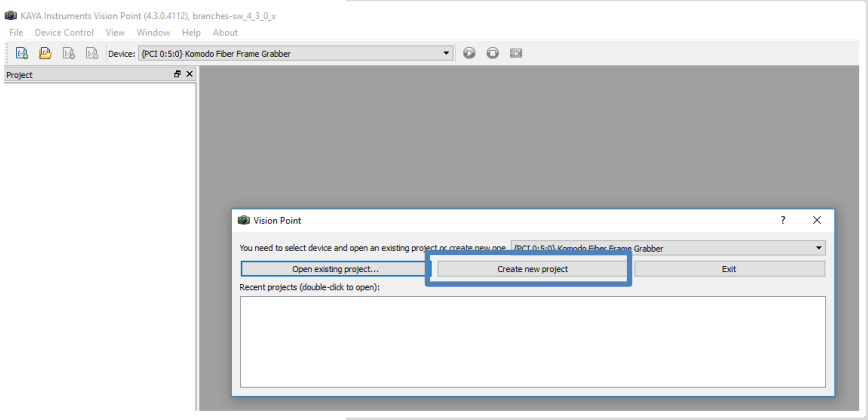
5



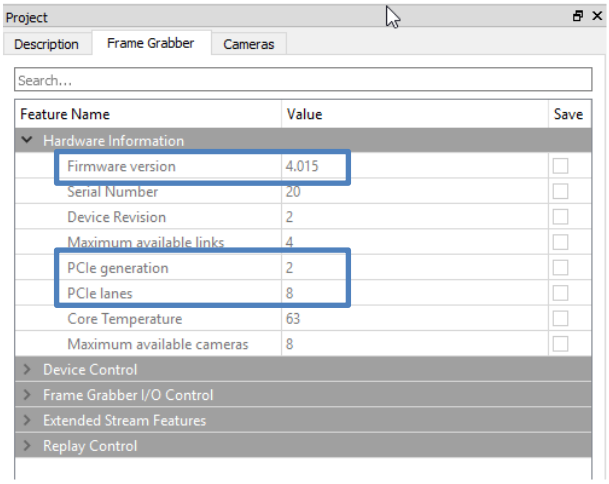
A4.5 VISION POINT SOFTWARE

After the installation is finished, open the Vision Point software and check the hardware information.

First click ***Create new project***



Take a look at the ***Project*** tab.
Click ***Frame Grabber→Hardware Information***



Check the following values:

- Firmware version: ≥ 4.015
- PCIe generation: 3 (see ***Notice***)
- PCIe lanes: 8

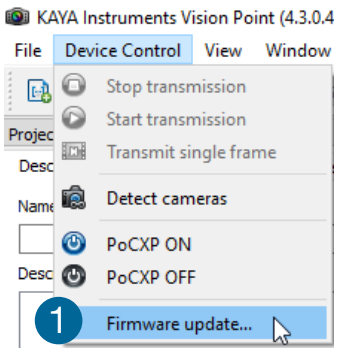
Grabber firmware must be updated if version is smaller than 4.015, see chapter **A4.6**.

NOTE

PCI Express Generation 2 / 3

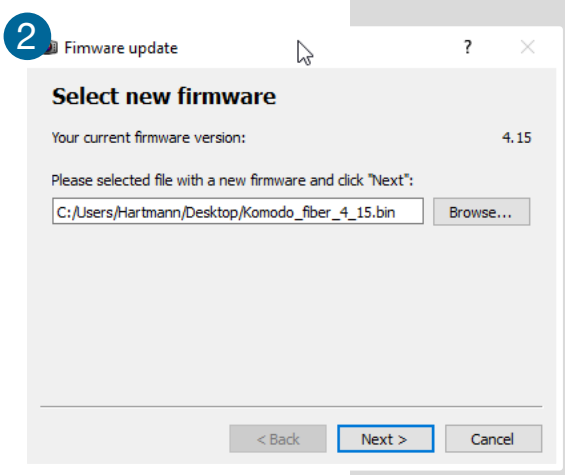
If the grabber is installed in a PCIe Slot with only Gen2 capability and/or with only 4 PCIe lanes, memory bandwidth for image transfers is limited and images might be lost.

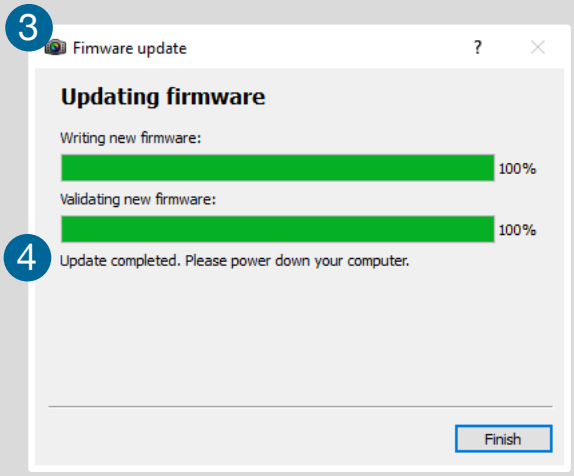
A4.6 UPDATE FIRMWARE OF THE GRABBER



How to update the firmware of a Kaya frame grabber card.

1. Select ***Device Control → Firmware update...***
2. Select proper firmware update file
3. Click next and wait till the update process is finished
4. Restart your computer





NOTE

Do not unplug
Do not unplug and/or switch off your computer during the update.

A5 IMAGE FILE FORMATS

There are several file formats available for saving camera images with Camware.

b16

The b16 16 bit format is similar to the bmp format. However, 16 bit pixel values are used instead of 8 bit pixel values.
The file format consists either of a Basic Header (6 Long-parameter) or an Extended Header (32 Long-parameter), the latter is optional for additional information. It might follow a variable comment field (ASCII code). Finally, there is the actual data set that is saved linearly (as in the case of BMP files).
With the exception of the first value, all parameters are Long Integers (4 Byte). The first 6 parameters must always exist. The rest of the parameters, as well as the comment field, are optional.

	Parameter	Function
1	pco-	the first 4 byte are the characters pco-
2	file size	file size in byte
3	header length	header size + comment field in byte
4	image width	image width in pixel
5	image height	image height in pixel
6	extended header	-1 (true), extended header follows
7	color mode	0 = monochrome camera, 1 = color camera
8	b/w min	black/white LUT-setting, minimum value
9	b/w max	black/white LUT-setting, maximum value
10	b/w linlog	black/white LUT-setting, 0 = linear, 1 = logarithmic
11	red min	red LUT-setting, minimum value
12	red max	red LUT-setting, maximum value
13	green min	green LUT-setting, minimum value
14	green max	green LUT-setting, maximum value
15	blue min	blue LUT-setting, minimum value
16	blue max	blue LUT-setting, maximum value
17	color linlog	color LUT-setting, 0 = linear, 1 = logarithmic
18-266	internal use	
Comment file in ASCII characters with variable length of 0…XX. The length of the comment field must be documented in the header length field.		
		16 bit pixel data
line 1, pixel 1		value of the first pixel
line 1, pixel 2		value of the second pixel
…		…

PCO recommends that all images should be saved first in the b16 or TIFF format. The advantage is to have the b16 or tiff images available all the time, having the maximum 16 bit information. Note that not all image analysis programs can accommodate 16 bit data. The 8 bit format saves only the information displayed on the monitor screen. The 16 bit information will be lost and cannot be recovered.

pcoraw

This 16 bit pco file format is based on the new BigTIFF format, thus allowing for file size > 4GB. A new pco proprietary compression scheme is added if it is necessary.

Standard File Formats

TIFF

Tag Image File Format, version 6.0 and lower. There is a 16bit monochrome and color image format.

BMP

Windows Bitmap Format, b/w or color 8 bit format-images, which have been saved in BMP format can be loaded later only as 8 bit images, i.e. part of the original information (16 bit) is lost.

FTS

Flexible Image Transport System, Version 3.1. It is a 16 bit image format defined by the NASA/Science Office of Standards and Technology (NOST) has defined this format. Some programs use the FIT extension for this format.

ASCII

16 bit format, some mathematical programs prefer ASCII data.

JPG

JPEG (named after the Joint Photographic Experts Group who created the standard) is a commonly used method of lossy compression for photographic images. The degree of compression can be adjusted, allowing a selectable tradeoff between storage size and image quality.

JP2

JPEG 2000 is a wavelet-based image compression standard and coding system. It was created by the Joint Photographic Experts Group committee in the year 2000 with the intention of superseding their original discrete cosine transform-based JPEG standard (created 1992).

AVI

Audio Video Interleave is a multimedia container format introduced by Microsoft in November 1992 as part of its Video for Windows technology.

MPG

MPEG-1, similar to JPEG, is a standard for lossy compression of video and audio developed by the Moving Picture Experts Group (MPEG).

WMV

Windows Media Video (WMV) is a compressed video format for several proprietary codecs developed by Microsoft. The original video format, known as WMV, was originally designed for Internet streaming applications, as a competitor to RealVideo.

A6 CUSTOMER SERVICE

A6.1 SERVICE

The camera is designed to operate with no need of special adjustments or periodic inspections.

A6.2 MAINTENANCE

CAUTION

UNPLUG CAMERA BEFORE CLEANING
Risk of injury due to electric shock!
- ➔ Unplug the camera from any power supply before cleaning it.

NOTICE

CLEANING
- ➔ Use a soft, dry cloth for cleaning the camera.
- ➔ Do not clean the input window unless it is absolutely necessary.
- ➔ Be careful and avoid scratches and damage to the input window surface.
- ➔ Do not use liquid cleaners or sprays.

NOTICE

LENS CLEANING
- ➔ The lens is best cleaned with pressurized air or with liquid cleaners such as pure alcohol or with special optical cleaners that are available at premium photo stores.
- ➔ Use a cotton swab dipped in pure alcohol or optical cleaning liquid and wipe only on the glass surface.
- ➔ Do not get any cleaning liquid on the metallic parts such as the lens thread, because tiny detached particles may scratch the surface.

NOTICE

CLEANING LIQUIDS
Aggressive cleaning liquids can damage your camera.
- ➔ Never use aggressive cleaning liquids such as gasoline, acetone, spirits or nitro cleanser.
- ➔ Every time the input window is cleaned, there is the possibility of surface damage.

NOTICE

PROTECTIVE CAP
Always store the camera with the protective cap or with a lens mounted to avoid dust and dirt on the input window.

A6.3 RECYCLING

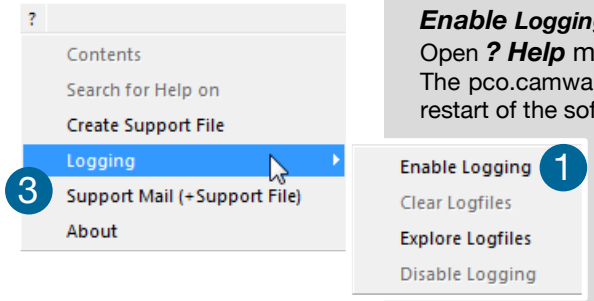
To dispose your camera, send it to PCO or take it to a local recycling center.

The camera includes electronic devices, which can contain materials harmful to the environment. These electronic devices must be recycled.

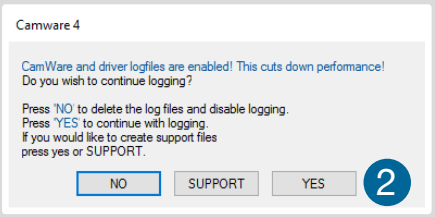
A6.4 TROUBLE SHOOTING

Use pco.camware to create logfiles for the PCO support.

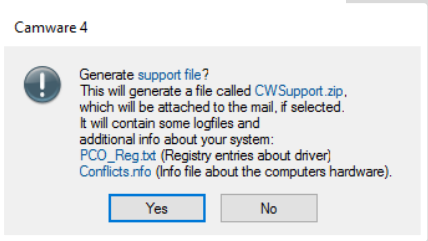
How to Create Logfiles



Enable Logging (1)
Open ***? Help*** menu, select ***Logging*** and then ***Enable Logging***
The pco.camware will ask you to press ***YES*** (2) to activate ***Logfiles*** after a restart of the software.



Repeat Workflow
The workflow which produces the error must be repeated while logging is enabled.



Support Mail (+Support File) (3)
Open ***? Help*** menu, select ***Support Mail (+Support File)*** and a support file with all necessary files is created

The pco.camware opens a new email addressed to support@pco.de, attach the ***Support File*** manually to this mail and send the mail to the PCO support.

Alternatively use the support form on our website: http://www.pco.de/support/ and upload the support file.

To Speed up Your Request

Give us the following information:

- Describe your problem!
- Your application?
- Your camera:
  - Type and version
  - Serial number
- Your setup:
  - Software version
  - Operating system
  - Processor and memory
  - Graphics card

Firmware, Software and Driver Update

You will find all necessary software and drivers on the accompanying USB storage device. For the latest versions check PCO website.

A7 COUNTRY SPECIFIC SPECIFICATION

Due to export restrictions for fast intensified cameras, we have developed a pco.dicam version, where the shortest exposure time and the maximum frame rate at full resolution are limited.

Single Image Mode

Minimum exposure time: 51 ns
Maximum frame rate: 4x 30 fps @ full resolution (pco.dicam C4)

Double Image Mode

Minimum exposure time: 60 ns
Maximum frame rate: 4x 15 double frames / s @ full resolution (pco.dicam C4)

NOTICE

Note that the values shown in the Timing ***Single Image*** mode and ***Double Image*** mode chapters and also in all other chapters and technical tables are limited to the above values!

See pco.dicam C1 & C4 51/120 data sheet for all technical details.

Adapted examples for a single channel of chapter **6**

Example Timing & Frame Rate for P43 / P46 Phosphor

Type	Value
Exposure time	10 µs
Fixed phosphor decay time	23 ms
Readout time for a single image @full resolution	9.5 ms
Frame time	32.6 ms
Resulting frame rate @ full resolution	$\frac{1}{32.5\ ms} \approx 30\ fps$

A8 INDEX

NOTE:
The mentioned page is always the starting page of a chapter!

ABOUT PCO

pco.history

"PCO" stands for what we are: a Pioneer in Cameras and Optoelectronics. With 30 years of expert knowledge and experience PCO has forged ahead to becoming a leading specialist and innovator in digital imaging used in scientific and industrial applications such as life and physical science, high-speed imaging and machine vision. However, the beginning of PCO's story of success dates back to the 1980s and a research project of the founder, Dr. Emil Ott, who was working at the Technical University Munich for the Chair of Technical Electrophysics. While performing measurements with intensified slow scan cameras, Dr. Ott realized that the existing standard did not meet the sophisticated requirements of scientific applications – and so PCO came to life in 1987. With a small team of engineers Dr. Ott began to develop his first image intensified camera followed by several variations on the original model, geared to overcoming all the existing flaws and surpassing standards of the day. During these early years PCO developed a now well established core of advance technologies used as the foundation to develop cutting edge products.

In the early 1990s PCO expanded its business activities to the global market by successfully establishing an international network of highly trained sales partners and customers. We entered additional fields beyond traditional scientific research expanding the potential for our cameras' applications in life science, automotive testing and even broadcasting. This step paved the way for a wide range of innovative highlights:

As of 2017, PCO has three decades of technical know-how and expert knowledge in the development and manufacturing of high-performing camera systems. In-house competence of all significant technical disciplines and partnering with leading image sensors manufactures ensures cutting edge sCMOS, CMOS and CCD technology for all PCO cameras.

pco.prospect

"If you want to do something special, particularly in the high end fields, you have to develop your own image sensors. So we work with partner companies who develop tailored sensors made especially for us. This is something we are doing continuously, so we're already working on the next generation of cameras that we will introduce in the coming years" – Dr. Emil Ott.

In PCO's first 30 years, Dr. Emil Ott took a company that he started right after finishing university and has built it into a major player in scientific and industrial cameras – and there's plenty more to come.

pco.