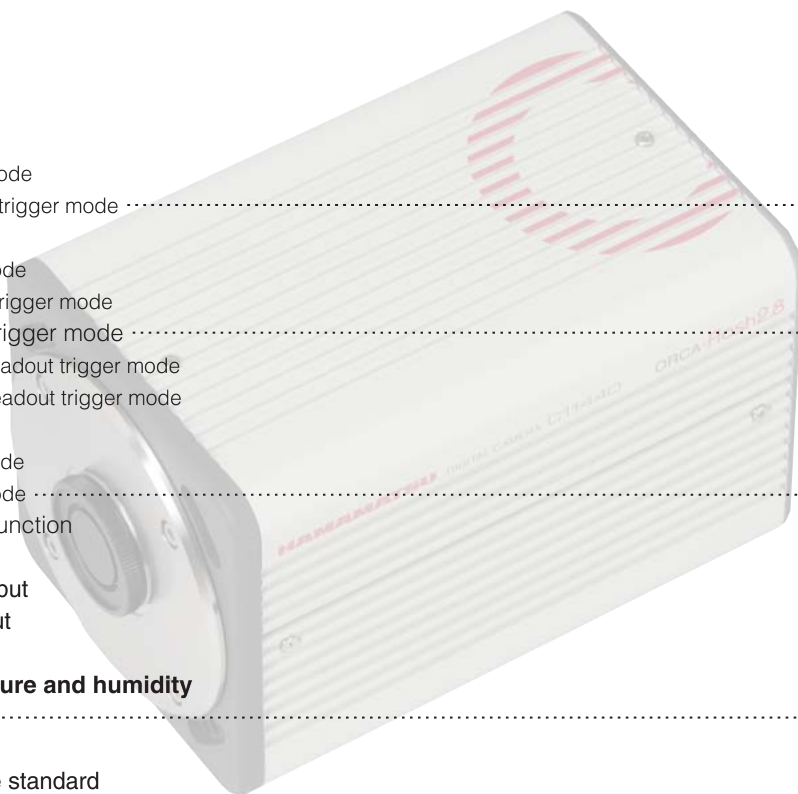
ORCA®-Flash2.8

Technical Note

March 2010

HAMAMATSU



1 Introduction

The Hamamatsu ORCA series of cooled CCD cameras have earned a world-wide reputation in many fields of scientific quantitative imaging. The newest addition to the series, the ORCA-Flash2.8 is a new cooled digital camera equipped with the scientific CMOS image sensor FL-280 that finally realizes the multiple benefits of high resolution, high readout speed, and low noise all at once.

The FL-280 is a newly developed scientific CMOS image sensor using the latest CMOS image sensor design and processing technology. It can have the scientific-grade image quality and the performance that overturns the common perception of conventional CMOS image sensor, and it is suitable for almost any scientific application from bright field imaging to low light fluorescence imaging.

This technical note is intended for the ORCA-Flash2.8 users and contains explanations of the new features and important information about the proper use of the camera for quantitative imaging.

2 Scientific CMOS Image Sensor FL-280

This chapter reviews some fundamental technologies required for the scientific CMOS image sensor FL-280.

2.1. CCD image sensor vs. FL-280

The CCD image sensor has been used for scientific measurement until now. However, the image quality of the FL-280 that adopts the latest CMOS image sensor technology has improved due to the quality of the semiconductor process and technology improvement, and the FL-280 can be used for scientific imaging. Here, the difference among the CCD image sensor, conventional CMOS image sensor and the FL-280 is explained.

2.1.1. Structure of CCD image sensor and CMOS image sensor

The pixel of the CCD image sensor is composed of the photodiode and the container (bucket) where the charge are stored. The entering light is converted into charge and accumulated in the container (bucket). The charge is carried by the bucket relay method, converted into voltage at the end, and output. (Fig. 1-1)

On the other hand, the pixel of a CMOS image sensor is composed of the photodiode and the amplifier that converts the charge into voltage. The entering light is converted into charge and converted into voltage in the pixel. The voltage of each pixel is output by switching the switch one by one. (Fig. 1-2)

Fig. 1-1 Structure of CCD image sensor

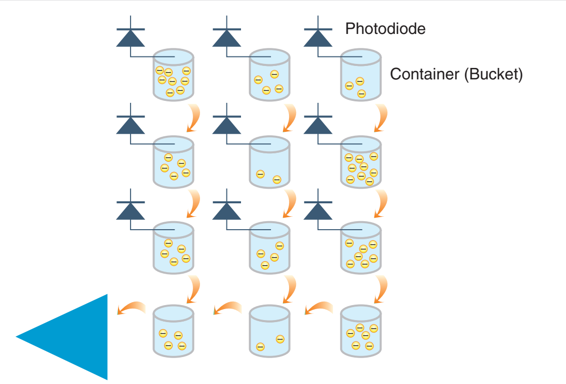


Fig. 1-2 Structure of CMOS image sensor

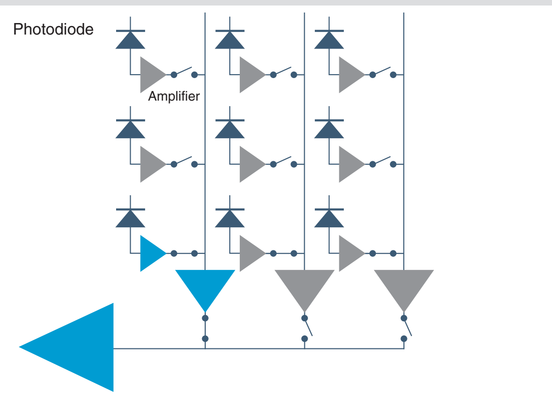


Fig. 1: Structure of CCD image sensor and CMOS image sensor

2.1.2. CCD image sensor vs. conventional CMOS image sensor

In order to throughly understand the FL-280 that adopts the latest CMOS image sensor technology, first the difference between a CCD image sensor and conventional CMOS image sensor is shown.

When the image quality of the CCD image sensor and the conventional CMOS sensor are compared, the CCD image sensor is adopted for scientific imaging because of its superior image quality.

● Noise

<<CCD image sensor>>

Low noise is achieved by adoption of the CDS (correlated double sampling) circuit for the readout amplifier and optimizing the semiconductor process. Moreover, it doesn't have fixed pattern noise because the CCD has only one readout amplifier.

<<Conventional CMOS image sensor>>

The readout amplifier characteristic for each pixel is not well optimized, and the difference between amplifiers is larger. It makes the conventional CMOS image sensor's readout noise and fixed pattern noise characteristics worse.

● Dark current noise

<<CCD image sensor>>

A low dark current has been achieved because a special, high-quality semiconductor processing technology is used and the buried channel photodiode is adopted.

<<Conventional CMOS image sensor>>

The dark current is rather large because a CMOS image sensor is manufactured by diverting the semiconductor structure for logic and the surface photodiode is adopted.

● Sensitivity

<<CCD image sensor>>

High sensitivity is realized because the effective aperture rate (fill-factor) is increased by adopting on-chip microlens.

<<Conventional CMOS image sensor>>

Sensitivity is not enough because of a small fill-factor, and it is limited by the semiconductor process.

● Power consumption

<<CCD image sensor>>

There is a necessity for transferring the charge at high speed, and the CCD image sensor requires input power. Moreover, the peripheral circuit expands because the drive and readout circuit is complex, and power consumption of the camera becomes large.

<<Conventional CMOS image sensor>>

It requires only small power consumption for readout switching. Also, the camera consumes less power because the peripheral circuit is small.

CCD image sensor		Conventional CMOS image sensor
Low noise	>	Large noise
Low dark current	>	Large dark current
High sensitivity	>	Low sensitivity
Large power consumption	<	Small power consumption

List 1: Comparison between CCD image sensor and conventional CMOS image sensor

2.1.3. CCD image sensor vs. FL-280

The quality of CMOS image sensors has been improving greatly by improving the quality and the technology in the CMOS process. By adopting this new CMOS image sensor technology, the FL-280 has the performance more than equal to the CCD image sensor.

● Noise

In the FL-280, the pixel amplifier is optimized: it has high gain from optimizing the semiconductor process, and the difference among pixel amplifiers is greatly minimized. In addition, the FL-280 has an on-chip CDS (correlated double sampling) circuit, which plays an important role in achieving low noise.

● Dark current

The FL-280 has buried channel photodiodes similar to CCD image sensors, so it has low dark current.

● Sensitivity

In the FL-280, the effective aperture rate (fill-factor) is increased by making the on-chip microlens efficient, so the sensor achieves high sensitivity.

● High speed

In the FL-280, the data of one horizontal line is read by the on-chip column amplifier and A/D in parallel and simultaneously. As a result, it achieves very fast readout speed while keeping very good low-noise performance.

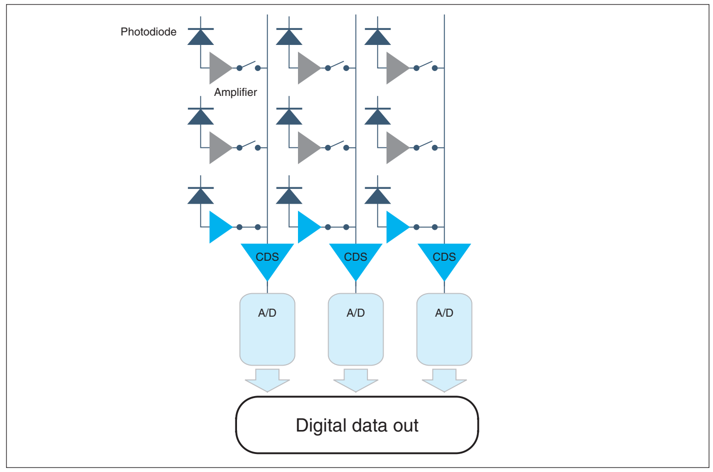


Fig. 2: Structure of the FL-280

CCD image sensor		FL-280
Low noise	≤	Low noise
Low dark current	=	Low dark current
High sensitivity	=	High sensitivity
Slow speed	<	High speed
Large power consumption	<	Small power consumption

List 2: Comparison between CCD image sensor and the FL-280

2.2. Quantum efficiency

In the FL-280, the light (or photon) into each pixel is converted into charge, and it is detected as a signal. The efficiency of converting photons into a charge, known as the quantum efficiency, is an important factor that decides sensitivity. Amplifiers are arranged in each pixel in the FL-280. Therefore, each pixel can use only a part of the pixel as the sensitive area. In the FL-280, the photon collection efficiency was dramatically improved by the addition of on-chip microlenses in each pixel (Fig. 3), and the sensitivity was improved.

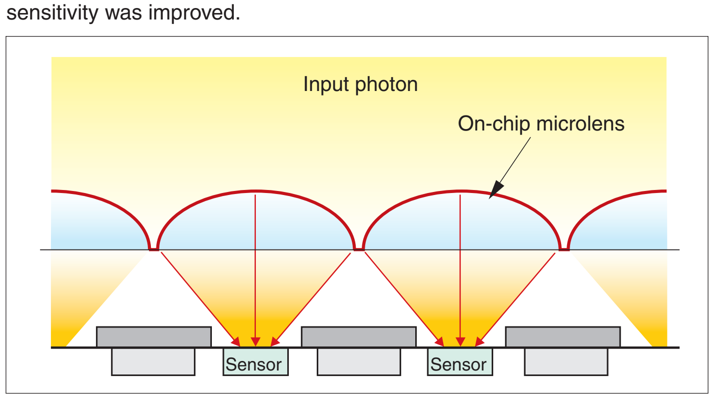


Fig. 3: Structure of on-chip microlens

2.3. Linearity

The linearity of the input/output (I/O) characteristic is very important to detect the signal accurately. The ORCA-Flash2.8 output is in proportion to the number of input photons into the pixel. This has been achieved with the good linearity characteristic of the FL-280 and the carefully designed circuit.

2.4. Readout noise

The key factors that decide the detection limit of the CCD image sensor and the FL-280 are the dark current of the sensor and the readout noise. These values are important parameters that decide the performance of the camera.

The dark current can be decreased by cooling the sensor. Therefore, the significant factor to decide the detection limit of the CCD image sensor and the FL-280 is the readout noise generated by the on-chip charge-to-voltage-conversion amplifier.

In the CCD image sensor, the signal charge forwarded to the horizontal serial register (H-CCD) is sent to the on-chip charge-to-voltage-conversion amplifier one by one. After readout, it is necessary to reset the charge of each pixel, and the noise generated by this resetting is a big factor of the readout noise. This noise can be greatly suppressed by the technique called correlated double sampling (CDS) in the electric circuit outside of the sensor. Moreover, the readout noise is frequency dependent, and can be lowered by operating the CCD at low speed.

In the FL-280, the charge accumulated in the photodiode is converted into voltage by the charge-to-voltage-conversion amplifier of each pixel. It has CDS circuits on the sensor, and therefore, the noise is suppressed in the FL-280, though the reset noise is still a problem as with the CCD image sensor. However, the readout noise is uneven because of the diffrences in characteristics of the amplifiers in each pixel. Moreover, the offset is also uneven for each pixel. However, the difference between each pixel has become small enough to be negligible by adopting the latest design and manufacturing process. Fig. 4 shows the readout noise frequency distribution of FL-280's pixels. This graph shows that most of the pixels have very small readout noise, around 3 electrons r.m.s.

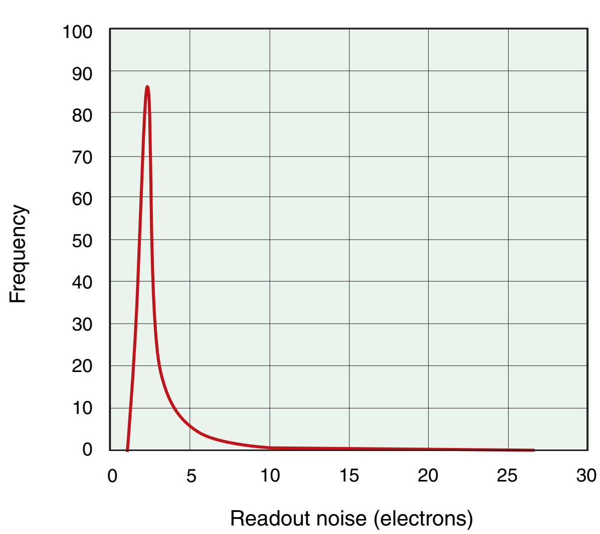


Fig. 4: Readout noise frequency distribution of FL-280

2.4.1. Readout noise measurement method

The CCD image sensor has only one readout amplifier. Therefore, the readout noise measured from a pixel with multiple readouts and the readout noise measured from multiple pixels in one image is basically equivalent. Therefore, the readout noise can be evaluated from one image.

In the FL-280, the readout noise in each pixel is different because the amplifier is in each pixel. Therefore, the readout noise is evaluated by measuring the readout noise in every pixel and calculating the mean value of multiple pixels in the FL-280.

2.5. Dark current

The dark current in the CCD image sensor and the CMOS image sensor is caused by thermal migration of electrons in the silicon, and it is one of the performances that decide the detection limit of the camera. The dark current depends on temperature, and it is known that it decreases by half when the temperature drops by about 7 to 8 ˚C. Therefore, it is apparent that cooling the sensor is a very good way to suppress the dark current very effectively. Though the dark current is different according to the type of image sensor, the dark current of the FL-280 is a small value because of the optimized semiconductor process. Thus the ORCA-Flash2.8 achieves low enough dark current performance at +5 ˚C. Moreover, the measurement data reproducibility is improved because the dark current is stable compared with a non-cooled camera.

2.6. Frame rate (readout speed)

The frame rate is the number of images that can be read out in 1 second when the image is continuously read out, and it is usually expressed as frame/second (or fps). Imaging a moving subject without blur or a subject with fast changing light intensity determines the time resolution, which is dependent on the frame rate.

The FL-280 realizes both low noise (3 electrons r.m.s.) and high speed readout (45 f/s with 1920 x 1440 pixels) simultaneously, owing to 1 line parallel simultaneous readout using column A/D.

2.7. Sub-array readout

Sub-array readout is a function to select an area of the CCD or CMOS image sensor and to read only the signal from that area. The readout time of one frame can be shortened by using this function, and the frame rate can be increased. In the CCD sensor, it is necessary to forward the charge one by one and discard the unwanted signal, so there is a limit to increasing the frame rate.

In the FL-280, only the necessary area is read out. Therefore, the improvement in frame rate is in inverse proportion to a decrease in the pixel number.

2.8. Binning

Binning adds the signal of the adjacent pixels, and is a method of achieving high sensitivity as a tradeoff for resolution. By using binning, the signal-to-noise ratio can be improved without decreasing the frame rate.

*Digital binning processing in the camera

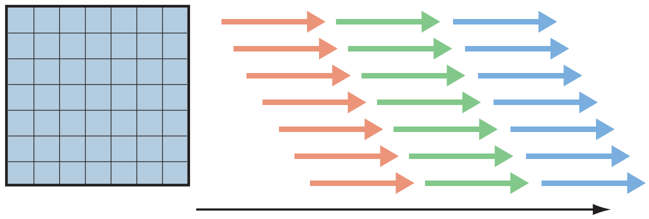
2.9. Rolling shutter / Global shutter

The exposure and the readout method of a CMOS image sensor are roughly classified into two types. One is a rolling shutter and another is global shutter.

In the rolling shutter, one pixel or one line is assumed to be one unit and the exposure and readout are done line by line. Therefore, the exposure timing is different on one screen. (Fig. 5-1)

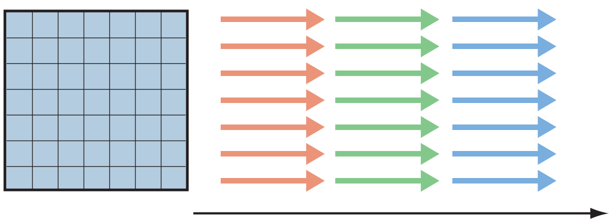
In the global shutter, the exposure and the readout timing in one screen is

Fig. 5-1 Rolling shutter



Rolling shutter (Readout lines at the same time)
Exposure length is same for all lines
Exposure timing is different for all lines

Fig. 5-2 Global shutter



Global shutter
Exposure length is same for all lines
Exposure timing is same for all lines

Fig. 5: Readout timing of global shutter and rolling shutter

In general, the readout noise and the dark current in the rolling shutter are smaller than the global shutter. The ORCA-Flash2.8 adopts the rolling shutter because readout noise and dark current performance are important factors for low light imaging such as fluorescence imaging under a microscope.

Moreover, rolling shutter has previously shown afterglow and smear characteristics. In the FL-280, these effects are minimized such that even if the object moves, the rollong shutter shows very little afterglow or smear in many cases.

▲ Global shutter ▲ Rolling shutter

Frame rate 45 frames/second
Sample movement speed: 30%/s (Moving direction left to right)
Sample: A square of 50% size of the field of view

A small distortion has been generated with 1 frame exposure time even in a global shutter because the object moves. The gap by the difference between global shutter and rolling shutter is not seen.

Fig. 6: Distortion in global shutter and rolling shutter

3 Features of ORCA-Flash2.8

This chapter summarizes the new features of the ORCA-Flash2.8.

3.1. Quantum efficiency

In the ORCA-Flash2.8, the photon collection efficiency was dramatically improved by the addition of on-chip microlenses on each pixel, and the sensitivity was improved to equal that of the conventional CMOS image sensor.

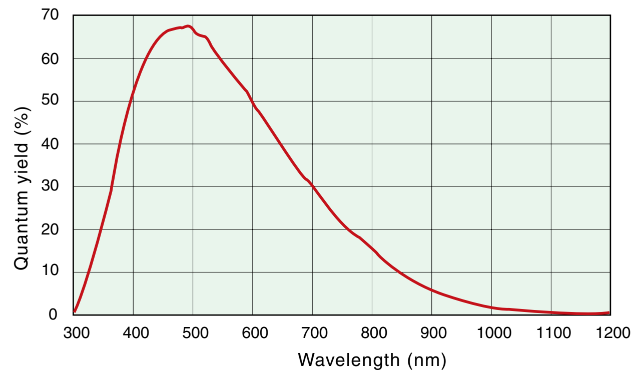


Fig. 7: Quantum efficiency

3.2. Linearity

In the ORCA-Flash2.8, the good linearity characteristic is secured with the FL-280 and the carefully designed circuit (Fig. 8).

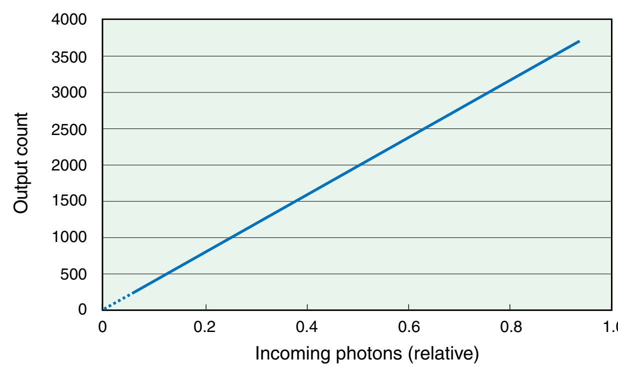


Fig. 8: Linearity characteristics

3.3. Readout noise

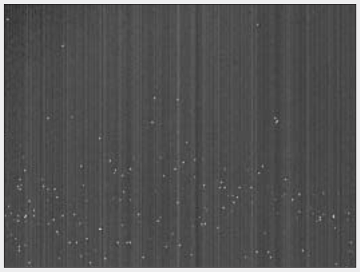
In the ORCA-Flash2.8, the pixel amplifier is optimized: it has high gain from optimizing the semiconductor process, and the difference among pixel amplifiers is greatly minimized. In addition, there is the on-chip CDS (correlated double sampling) circuit, which plays an important role in achieving low noise. Moreover, the data of one horizontal line is read by the on-chip column amplifier and A/D in parallel and simultaneously. As a result, it achieves very fast readout speed while keeping very good low-noise performance.

The ORCA-Flash2.8 has lower readout noise (3 electrons r.m.s.) than the conventional cooled CCD camera. Moreover, high-speed readout (45 f/s with 1920 x 1440 pixels) with very low readout noise, which was impossible, can now be achieved.

3.4. High image quality (no fixed pattern noise)

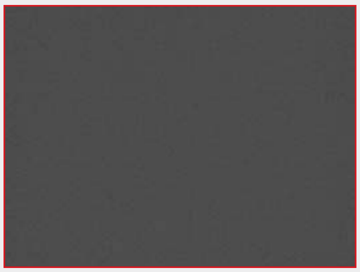
The FL-280 has a readout amplifier in each pixel and in each column. The amplifiers are well optimized, and the difference between them is greatly minimized by adopting the latest CMOS image sensor design and processing technology. As a result, FL-280 eliminates the fixed pattern noise that is the main cause of poor image quality in conventional CMOS image sensors (Fig. 9).

● Conventional CMOS camera (No image correction)



▲ Exposure time: 15 ms

● **ORCA-Flash2.8** (No image correction)



▲ Exposure time: 50 ms

Fig. 9: Comparison of noise

3.5. Cooling structure

In the ORCA-Flash2.8, the FL-280 is cooled down by the peltier element to suppress the dark current. If the FL-280 is exposed to the atmosphere, condensation of the moisture from the air might occur. The ORCA-Flash2.8 has a special hermetic chamber structure to isolate the sensor from the atmosphere, and the chamber is filled with nitrogen gas.

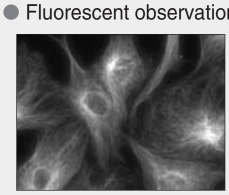
3.6. Dark current

The ORCA-Flash2.8 employs the FL-280, whose dark current is intrinsically low due to an advanced semiconductor process. In addition, +5 ˚C cooling further reduces the dark current.

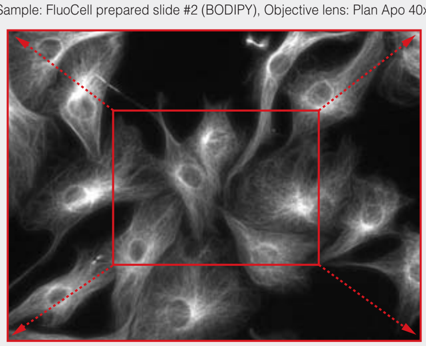
3.7. Pixel number and pixel size

The FL-280 equipped in the ORCA-Flash2.8 has 3.63 um x 3.63 um pixel size that is about half of the conventional CCD image sensor (2/3 inch, 1.3 megapixels). When using the camera with a microscope, the number of photons coming to one pixel can be made equal to the conventional CCD image sensor (2/3 inch, 1.3 megapixels) if 0.5x relay lens is used. Also, the ORCA-Flash2.8 can observe a wider field of view because the pixel number is about 2 times that of the conventional CCD image sensor (2/3 inch, 1.3 megapixels) (Fig. 10).

● Fluorescent observation (Sample: FluoCell prepared slide #2 (BODIPY), Objective lens: Plan Apo 40x)



▲ CCD (2/3 inch, 1.3 megapixels) (without relay lens)



▲ **ORCA-Flash2.8 (FL-280)** (0.5x relay lens used)

Fig. 10: Comparison of resolution between the conventional CCD and ORCA-Flash2.8

3.8. Readout method

The ORCA-Flash2.8 has a variety of readout methods. Three readout modes can be set independently

3.8.1. Sub-array readout

The ORCA-Flash2.8 has the sub-array function, and it is possible to achieve max. 1273 frames/second. In the sub-array readout mode, the frame rate can be made fast by decreasing the number of pixels to be read out without sacrificing the readout noise performance.

Readout method	Number of pixels	Readout speed (frames/second)
Full resolution	1920 (H) × 1440 (V)	45.4
Sub-array readout (Typical examples)	1920 (H) × 1080 (V)	60.0
	1920 (H) × 600 (V)	104.6
	1920 (H) × 240 (V)	236.8
	1920 (H) × 80 (V)	540.0
	1920 (H) × 8 (V)	1273.6

List 3: Readout method, number of pixels, and readout speed

3.8.2. Binning

Binning adds the signal of the adjacent pixels, and is a method of achieving high sensitivity as a tradeoff for resolution. In the ORCA-Flash2.8, the camera can perform 2 x 2 binning. The amount of the signal from a pixel can be quadrupled when 2 x 2 binning is done, and the output pixel count becomes 960 x 720 pixels.

*Digital binning processing in the camera

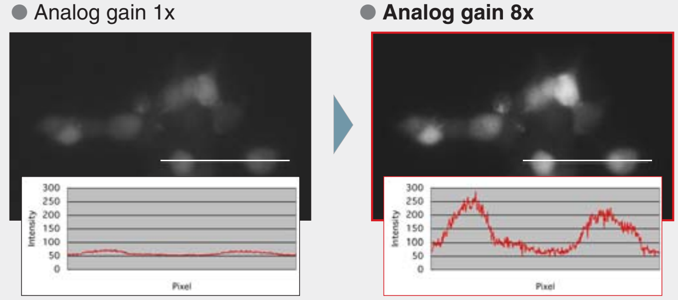
3.8.3. Analog gain

The ORCA-Flash2.8 features an on-chip gain control capability that can multiply the analog signal in the sensor prior to converting it into a digital signal. This has the effect of reducing the quantization error in the A/D converter, and the readout noise can be lowered to 3 electrons (r.m.s.) at analog gain 8x.

When low-light sample imaging in a short time is necessary and the output signal level is only a few to a few dozen ADU out of 12 bits (4096 ADU), the image quality can be improved by increasing the analog gain. It is necessary to note that the conversion coefficient* of the camera changes when the analog gain is increased.

* The conversion coefficient is the coefficient used to convert the electrons value to AD count, and the unit is electron/AD count. For example, 4.4 electrons/AD count means 1 AD count corresponds to 4.4 electrons.

● Analog gain 1x ● **Analog gain 8x**



▲ These graphs show the intensity profile of the white line in each image.
(Sample: Fluo-4-loaded Ins-1 cells)

Fig. 11: Analog gain comparison

3.9. Real-time correction functions

When using the camera, there is a chance that shading caused by uneven illumination and optics is not negligible in the image.

Also, there are a few pixels in FL-280 that have slightly higher readout noise performance compared with surrounding pixels. Therefore, the ORCA-Flash2.8 has real-time offset level, shading and defective pixel correction features to further improve image quality.

The correction is performed in real-time without sacrifying the readout speed at all.

3.10. CameraLink I/F

The ORCA-Flash2.8 realizes 45 frames/second high-speed data transfer for 2.8 megapixels by using the CameraLink I/F. Data is output with 75 MHz x 2 tap (12 bits) that follows the Base Configuration standard of CameraLink I/F, and images can be transferred into a personal computer by using a CameraLink board available in the market.

3.11. Camera operation modes

The ORCA-Flash2.8 supports various external trigger functions, and the camera's timing output functions ensure proper timing control with peripheral equipment to cover a wide range of applications. The camera has two operation modes: 1) the free running mode, in which the exposure and readout timing are controlled by the internal microprocessor, and 2) the external control mode, in which the exposure and readout timing are decided by an external trigger. (Fig. 12)

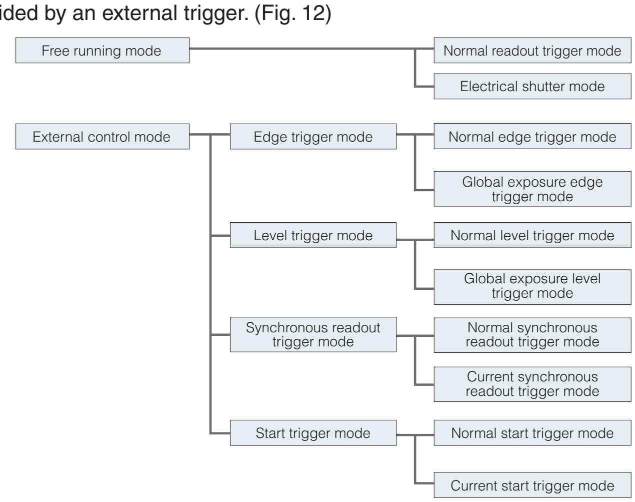


Fig. 12: Camera operation modes

3.11.1. Free running mode

The ORCA-Flash2.8 has the free running mode in which the exposure and readout timing can be set by software command and controlled by the internal microprocessor. The free running mode has normal readout mode (in which the exposure time is longer than the 1 frame readout time) and electrical shutter mode (in which the exposure time is shorter than the 1 frame readout time). These readout modes are automatically switched depending on the exposure time setting.

3.11.1.1. Normal readout mode

The normal readout mode is suitable for observation, monitoring, field of view and focus adjustment, and animation because it can operate at 45 fps with full resolution, which is faster than the video rate. In addition, the exposure time can be extended to collect more signals and increase the signal-to-noise ratio if the object is dark. In the normal readout mode, the exposure time is the same or longer than the 1 frame readout time. In this mode, the frame rate depends on the exposure time, and it becomes frame rate =1/exposure time. The maximum exposure time is 10 seconds.

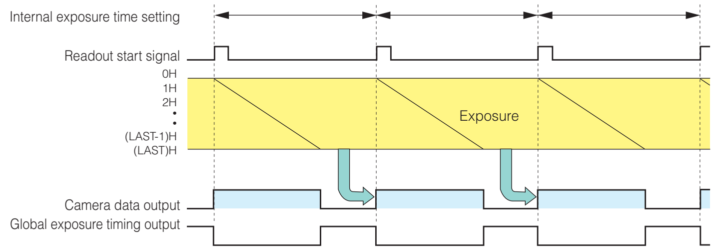


Fig. 13: Normal readout mode

3.11.1.2. Electrical shutter mode

The electrical shutter mode is used to get a proper signal level when signal overflow happens due to too much input photons in normal readout mode. In the electrical shutter mode, the frame rate is 45 fps at full resolution even when the exposure time is short.

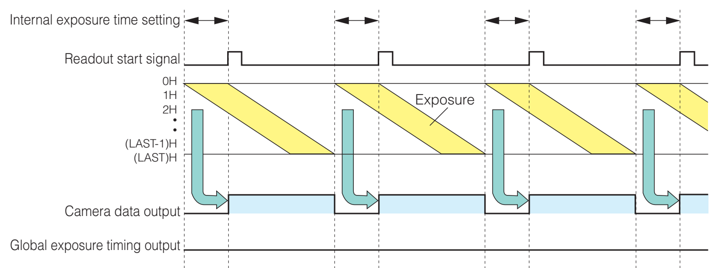


Fig. 14: Electrical shutter mode

3.11.2. External control mode

The ORCA-Flash2.8 has various external control functions to synchronize the camera with external equipment. In the external control mode, the external equipment becomes a master and the camera becomes a slave.

3.11.2.1. Edge trigger mode

The edge trigger mode is used so that the exposure is synchronized with an external signal.

3.11.2.1.1. Normal edge trigger mode

The normal edge trigger mode is used so that the exposure starts according to an external signal. Exposure time is set by software command. In the normal edge trigger mode, the exposure of the first line begins on the edge (rising/falling) timing of the input trigger signal into the camera (0H in Fig. 15). The exposure of the second line is begun after the readout time of one line passes (1H in Fig. 15), and the exposure is begun one by one for each line. The example timing chart below shows a rising edge trigger.

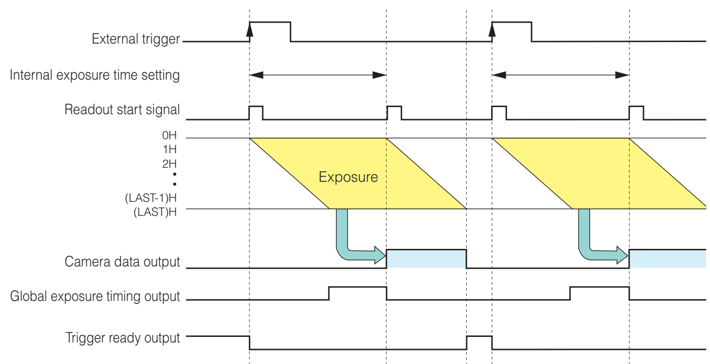


Fig. 15: Normal edge trigger mode

<Application: A wide field of view imaging>

When the entire object is large and high-resolution imaging is necessary, taking two or more images is needed. The object is positioned using an XY-stage. When the object is stopped in the target position, an external trigger signal is input to the camera and an image is acquired. This is repeated until the entire object is imaged.

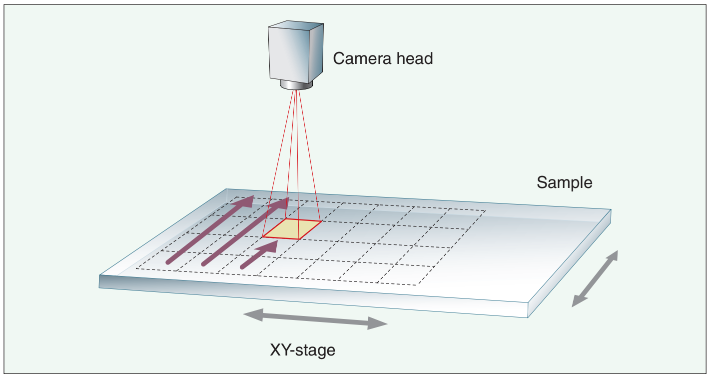


Fig. 16: A wide field of view image using XY-stage

3.11.2.1.2. Global exposure edge trigger mode

The global exposure edge trigger mode is used when imaging with a pulsed light source such as pulsed laser or flash lamp. The exposure time can be set by software command.

In this mode, the camera combines the frames right before and after the global exposure trigger signal (falling/rising edge) into one frame and output them as one frame of data. The exposure time of this second frame can be set by software command. Minimum value is about 22 ms (1 frame readout time).

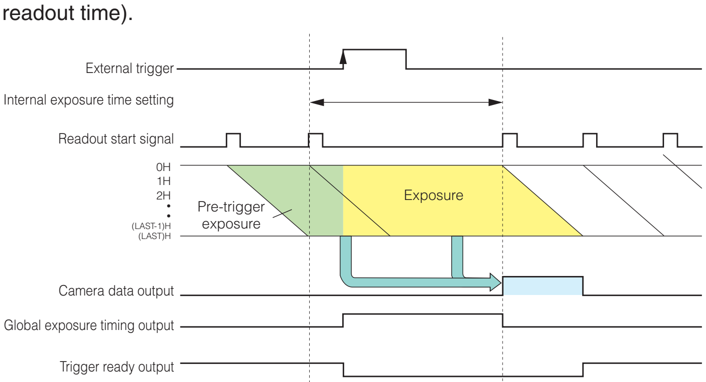


Fig. 17: Global exposure edge trigger mode

<Application: Moving object imaging using a pulsed laser>

There is a technique that uses a pulsed laser for the light source to obtain a snapshot of a moving object. In the global exposure edge trigger mode, a momentarily illuminated event can be acquired by synchronizing the timing of the pulse laser.

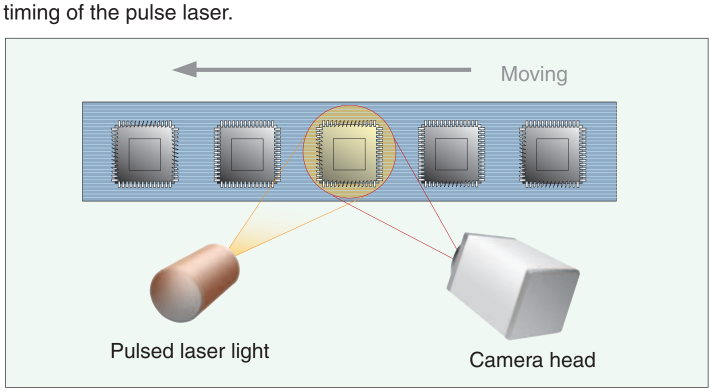


Fig. 18: Moving object imaging using a pulsed laser

3.11.2.2. Level trigger mode

The level trigger mode is used to control both exposure start timing and exposure time length by inputting external trigger pulses.

3.11.2.2.1. Normal level trigger mode

The normal level trigger mode is used to control both exposure start timing and exposure time length by inputting external trigger pulses.

In the normal level trigger mode, the camera starts the exposure at the start of high or low period of the input trigger pulse and stops the exposure at the end of high or low period of the input trigger pulse. The example below is for the trigger level High. The exposure of the first line begins when the trigger signal becomes High, and the exposure of the second line begins after the readout time of line one passes. Each exposure begins one by one for each line. The exposure of the first line is finished when the trigger signal becomes low, and signal readout is begun. The exposure time of each line is defined by the time that the input trigger is high.

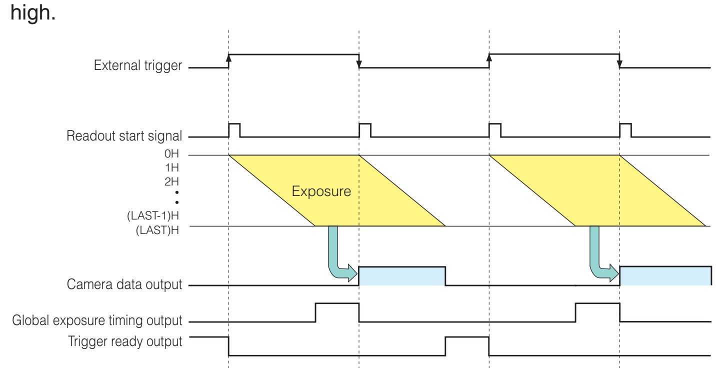


Fig. 19: Normal level trigger mode (rising edge)

3.11.2.2.2. Global exposure level trigger mode

The global exposure level trigger mode is used to take a snapshot of a moving object with a pulsed light source or get a momentarily illuminated event. The exposure time can be set by software command.

In this mode, the camera combines the frames right before and after the global exposure trigger signal (falling/rising edge) into one frame and output them as one frame of data. The exposure is finished when the trigger signal becomes inactive (falling/rising edge). Minimum value is about 22 ms (1 frame readout time).

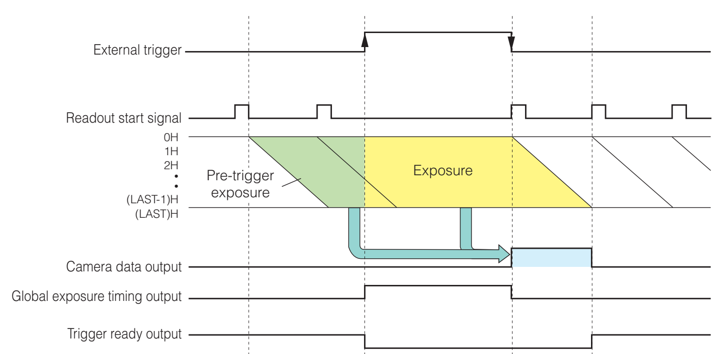


Fig. 20: Global exposure level trigger mode

3.11.2.3. Synchronous readout trigger mode

The synchronous readout trigger mode is used for continuous imaging when it is necessary to control the exposure start timing of each frame from an external source. It is useful for confocal microscopy. For example, when the ORCA-Flash2.8 is used with a spinning disk confocal microscope and the camera exposure time is synchronized to the spinning disk's rotation speed, it is possible to eliminate uneven illumination (called banding noise) caused by variation of the spinning disk rotation speed.
Also, it is useful for securing as long an exposure time as possible while controlling the exposure start timings by external trigger signals.

3.11.2.3.1. Normal synchronous readout trigger mode

The normal synchronous readout trigger mode is used for continuous imaging when it is necessary to control the exposure start timing of each frame from an outside source and also when it is necessary to secure as long an exposure time as possible. In the synchronous readout trigger mode, the camera ends each exposure, starts the readout and also, at the same time, starts the next exposure at the edge of the input trigger signal (rising /falling edge). That is, the interval between the same edges of the input trigger becomes the exposure time.

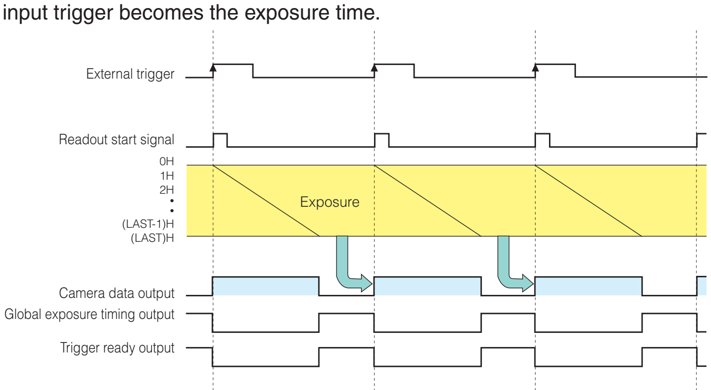


Fig. 21: Normal synchronous readout trigger mode (rising edge)

Also in the normal synchronous readout trigger mode, synchronous readout can be controlled by specifying, set by command, the number of timing pulses to use to determine the exposure time. Fig. 22 shows the exposure timing when the pulse count is set as 3.

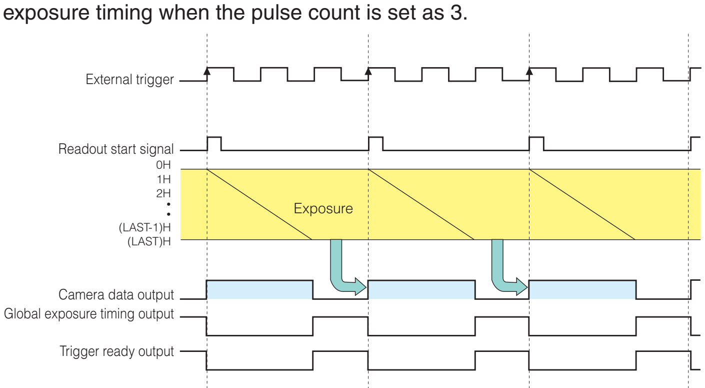


Fig. 22: Normal synchronous readout trigger mode (pulse count)

3.11.2.3.2. Current synchronous readout trigger mode

In the current synchronous readout trigger mode it is possible to control the exposure start timing by using ACT commands from application software.

First, the camera is set to be in idle condition by ACT S command input. In idle condition, the camera does not start exposure even by a trigger signal. Then, the camera starts an exposure by ACT I command, and then starts to read out by input external trigger.

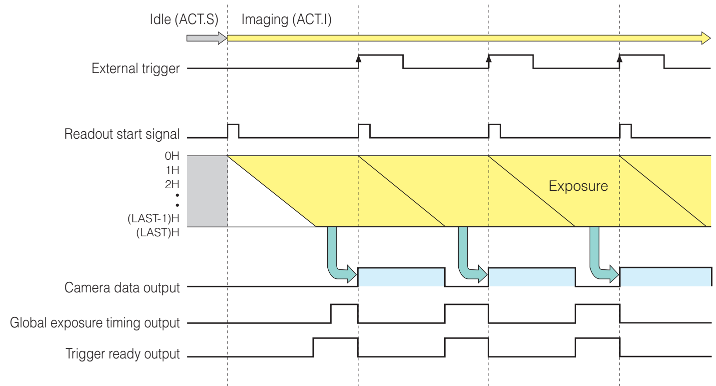


Fig. 23: Current synchronous readout trigger mode

3.11.2.4. Start trigger mode

The start trigger mode is used to start operating the camera by a trigger input for continuous imaging. It is useful to secure the frame rate as fast as possible for continuous image acquisition and not to sacrifice the exposure time. For example, when it is necessary to measure the phenomenon after a stimulation, it is possible to start continuous image acquisition at the stimulation timing.

3.11.2.4.1. Normal start trigger mode

The start trigger mode is used to start operating the camera by a trigger input for continuous imaging, and it works at the highest frame rate because it is operated in internal trigger mode.

In the start trigger mode, the camera starts exposure and switches to internal trigger mode by the edge of an external trigger signal (rising / falling edge).

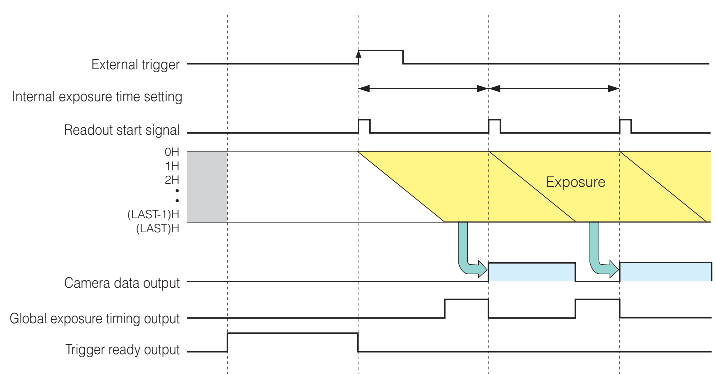


Fig. 24: Normal start trigger mode (rising edge)

<Application: Fluorescence imaging using electric stimulator>

By a trigger input signal, the camera starts the image acquisition, and controls various peripheral equipment according to various timing from the pulse generation device afterwards. The images are acquired while controlling the electric stimulator and the microscope in an electric physiology experiment or controlling the timing of the compounds administered in calcium imaging.

3.11.2.4.2. Current start trigger mode

In the current start trigger mode it is possible to control the exposure start timing by using a command from application software and external trigger pulses. The fastest frame rate is possible because the camera works in the internal trigger mode.

It is possible to control the exposure start timing from application software by using ACT commands. First, the camera is set in idle condition by ACT S command input. In idle condition, the camera does not start exposure even by a trigger signal. Then, the camera starts an exposure by ACT I command, and then the camera starts the second frame exposure by input external trigger and switches to internal trigger mode.

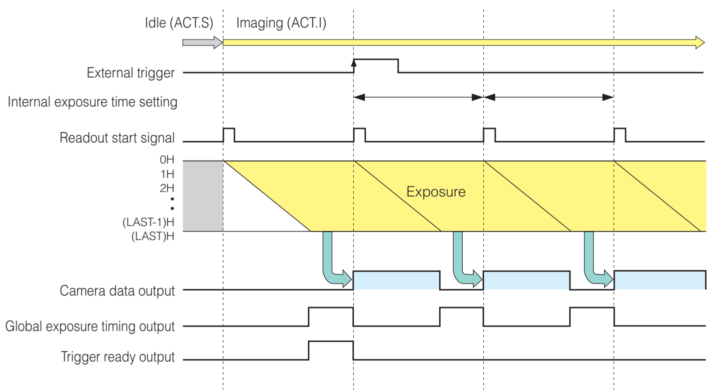


Fig. 25: Current start trigger mode

3.11.2.5. External trigger delay function

In most case when a delay between the laser pulse emission and the exposure start is needed, a delay unit is set between the laser and camera to control trigger timing.

In each external trigger mode of the ORCA-Flash2.8, the delay time can be set to the trigger signal input to the camera by commands. Therefore, a range of trigger timing can be arranged without a delay unit.

3.12. Trigger output

The ORCA-Flash2.8 provides a range of trigger output signals to synchronize with an external instrument, and the camera becomes the master and the external instrument the slave. There are three different trigger output functions as follows. Please refer to Fig. 13 to Fig. 25.

- Global exposure timing output
- Programmable timing output
- Trigger ready output

3.12.1. Global exposure timing output

It shows the global exposure timing where all lines are exposed at the same time. There is a case that one event is divided into two frames because the timing of the exposure in each line is different for the rolling shutter. However, by using the global exposure timing output, the global exposure becomes possible for the phenomenon that happens for this period.

Global exposure timing output shows the period where all lines are exposed at the same time.

3.12.2. Programmable timing output

By using the programmable timing output, synchronizing external devices is simple. A system that needs simple timing signal does not require a delay unit nor pulse generator.

It is possible to program and output a pulse that has an optional pulse width and an optional delay time to the exposure start timing of the camera by command.

3.12.3. Trigger ready output

The trigger ready output is useful to make the frame intervals as short as possible in external trigger mode.

For example, when the camera is working in the edge trigger mode, the next frame can start after the previous frame exposure is done. Thus, the camera can't accept a trigger for the next frame during the exposure period. To reduce useless time to be as short as possible, it is necessary to know the period when the camera can accept a trigger for the next frame. The trigger ready output shows the trigger ready period when the camera can accept an external trigger in the external trigger mode.

3.13. Ambient operating temperature and humidity

The ambient operating temperature is very important for an electric equipment or an electrical device. Using it outside this temperature range may not only make the camera performance worse but also lead to the breakdown of the camera. It is very important for cooled CCD or CMOS cameras, especially an air-cooled type, because high ambient temperature might lead to worse cooling performance and may increase the dark current noise.

Generally, the high-sensitivity camera head is often placed in a room with a blackout curtain or in a dark box to shut out the light, and the air flow is not good and the temperature is often high. The controller might be often similarly left in a place where the air flow is bad (such as in a corner of the room), and the temperature of such a place becomes higher than the room temperature. The ambient operating temperature of the ORCA-Flash2.8 is defined from 0 ˚C to +40 ˚C, which is rather wider than a normal room temperature range around +20 ˚C to +30 ˚C. Thus, it is possible to use the camera safely and with ease.

Moreover, the ambient humidity is also important because condensation may be generated when the surrounding humidity is high. The ambient humidity is especially important when the camera has a cooling function and has a part that is cooler than the ambient temperature.

It is recommended to use the ORCA-Flash2.8 with less than 70% ambient humidity with no condensation.

3.14. Specifications

3.14.1. Camera performance

Type number		C11440-10C (ORCA-Flash2.8)
Camera head type		Passive air-cooled head
Imaging device		Scientific CMOS Image Sensor FL-280
Effective number of pixels		1920 (H) × 1440 (V)
Cell size		3.63 µm (H) × 3.63 µm (V)
Effective area		6.97 mm (H) × 5.23 mm (V)
Readout mode/speed	Full resolution	45.4 frames/s (1920 (H) × 1440 (V))
	Sub-array (Typical examples)	60.0 frames/s (1920 (H) × 1080 (V))
		104.6 frames/s (1920 (H) × 600 (V))
		236.8 frames/s (1920 (H) × 240 (V))
		540.0 frames/s (1920 (H) × 80 (V))
		1273.6 frames/s (1920 (H) × 8 (V))
Binning*		2 × 2
Readout noise (r.m.s.) typ.		3 electrons (gain 8x)
Full well capacity typ.		18000 electrons
Analog gain		1x to 8x (256 steps)
Dynamic range typ.**		4500: 1 (gain 1x)
Cooling method		Peltier device + passive air-cooled
Cooling temperature		+5 ˚C (Ambient temperature: + 20 ˚C)
A/D converter		12 bit
Exposure time		20 µs to 10 s (at internal trigger / external trigger)
External trigger mode		Edge trigger, Level trigger Global exposure trigger Synchronous readout trigger Start trigger
Trigger delay function		0 µs to 10 s (10 µs step)
Trigger output		Programmable timing output Global exposure timing output Trigger ready output
Lens mount		C-mount
Interface		Camera Link Base Configuration
Connector		Mini-Camera Link
Power requirements		AC 100 V to AC 240 V, 50 Hz/60 Hz
Power consumption		About 45 V·A
Ambient storage temperature		- 10 ˚C to + 50 ˚C
Ambient operating temperature		0 ˚C to + 40 ˚C
Ambient storage/operating humidity		70 % max. (no condensation)

*Digital binning processing in the camera

**Calculated from the ratio of the full well capacity and the readout noise.

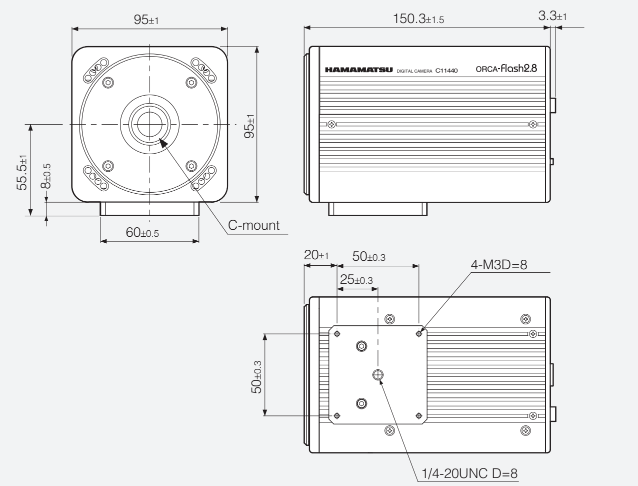
3.14.2. Safety standard, Applicable standard

CE standard

EMC	EMC:EN61326-1:2006 Class A

3.14.3. Dimensional outlines

■ Camera head (Approx. 1.5 kg) Unit: mm



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