Technical note

FEB 2020

ORCA®-Lightning

Digital CMOS camera
C14120-20P

HAMAMATSU

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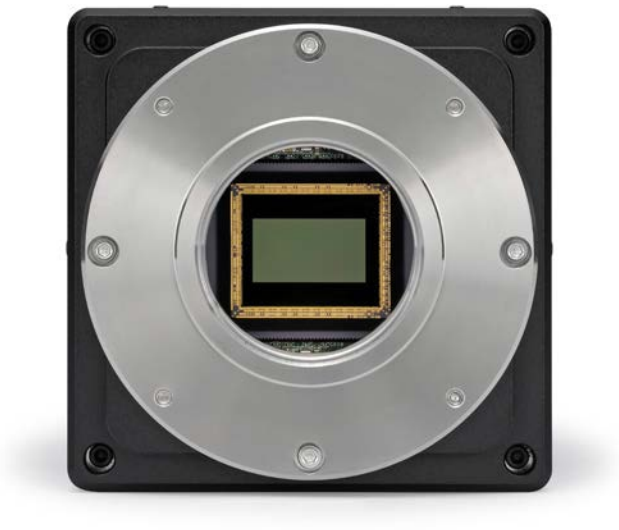
Introduction

The ORCA-Lightning is a unique sCMOS camera combining high speed, large pixel number and low readout noise. With approximately three times the speed and three times the number of pixels as common 2k×2k sCMOS cameras it maintains similar noise characteristics and as such is aimed at applications requiring both high speed and resolution. The low read noise of the ORCA-Lightning also benefits high speed, low photon budget applications allowing improved signal to noise ratio compared to other high speed camera technologies.



1. Specifications

Product number		C14120-20P	
Full Well Capacity mode		Standard Full Well Capacity mode	High Full Well Capacity mode
Imaging device		Scientific CMOS image sensor	
Effective number of pixels		4608 (H) × 2592 (V)	
Pixel size		5.5 µm (H) × 5.5 µm (V)	
Effective area		25.344 mm (H) × 14.256 mm (V)	
Quantum efficiency	at 550 nm	Over 60 %	
Full well capacity (Typ.)		1000 electrons	38 000 electrons
Readout noise (Typ.)		1.5 electrons median, 2.0 electrons rms	2.2 electrons median, 2.7 electrons rms
Dark current (Typ.)	Air cooled (cooling temperature: +20 ˚C)	15 electrons/pixel/s	
Linearity error *1	EMVA 1288 standard	1 % or less	
	< 500 electrons signal	1 % or less	
Photo Response Non-Uniformity (PRNU) *1		–	3 % or less (at 20 000 electrons signal)
Dark Signal Non-Uniformity (DSNU) *1		0.5 electrons rms	
Dynamic range (Typ.)		650 : 1	17 000 : 1
Cooling temperature	Forced-air cooled (Ambient temperature: +25 ˚C)	+20 ˚C	
	Water cooled	+20 ˚C	
Interface		CoaXPress (Quad CXP-6)	
Digital output		12 bit	16 bit
Exposure time	Internal trigger mode/Full resolution	6.304 µs to 1 s	50.432 µs to 1 s
Binning		2×2, 4×4	
Sub-array		Yes	
Readout mode		Normal readout mode/Lightsheet readout mode	
Lightsheet readout mode	Readout time (4608×2592)	8.2 ms to 129.6 ms *2	32.7 ms to 129.6 ms *3
	Minimum readout interval (4608×2592)	8.3 ms	32.7 ms
	Readout mode	Full area/Sub-array	
	Readout direction	Forward direction	
External trigger input mode		Edge trigger, Global reset edge trigger, Level trigger, Global reset level trigger, Synchronous readout trigger, Start trigger	
Trigger input connector		SMA	
Trigger output		Global exposure timing output, Trigger ready output, High output, Low output, 3 programmable timing outputs	
Trigger output connector		SMA	
Trigger delay function		0 s to 10 s in 1 µs steps	
Power consumption		Approx. 200 VA	
Ambient operating temperature	Forced-air cooled (With no condensation)	0 ˚C to +40 ˚C	
Ambient operating humidity		30 % to 80 %	

*1 Typical value
*2 Setting range of 4H: 12.608 µs to 200 µs
*3 Setting range of 4H: 50.432 µs to 200 µs

2. Sensor structure

2-1. Fundamental structure

The sensor of ORCA-Lightning has a structure which allocates thousands of correlated double sampling (CDS) circuits and analog to digital (A/D) converters on the upper and bottom portions of pixel columns, similar to those found in the ORCA-Flash4.0 series. Readout noise is reduced by reading out each pixel slowly through the column CDS and A/D converter and the high frame rate is realized by the parallel readout with thousands of A/D converters.

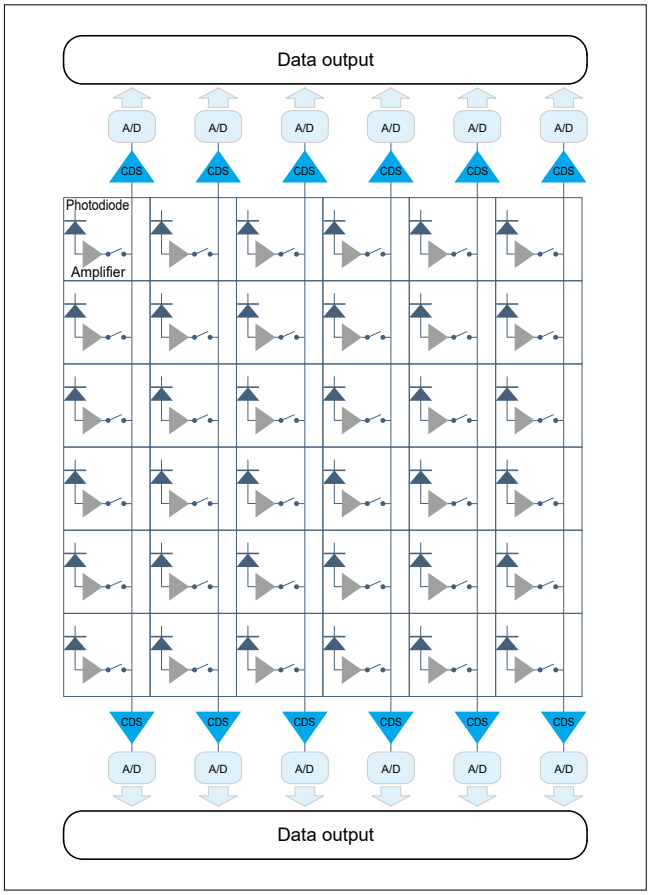


Fig. 1 Fundamental structure

2-2. Readout scheme and direction

The sensor readout of ORCA-Lightning is quite different from the ORCA-Flash4.0 series which is readout from the center in two directions towards the top an bottom of the sensor. (Fig. 2). In the ORCA-Lightning the multiplexing CDS and A/D converters read 4 horizontal lines concurrently at high line rates. The concurrent readout of 4 lines is repeated from top to bottom by allocating odd and even rows to the top and bottom CDS and A/D converters accordingly. (Fig. 3).

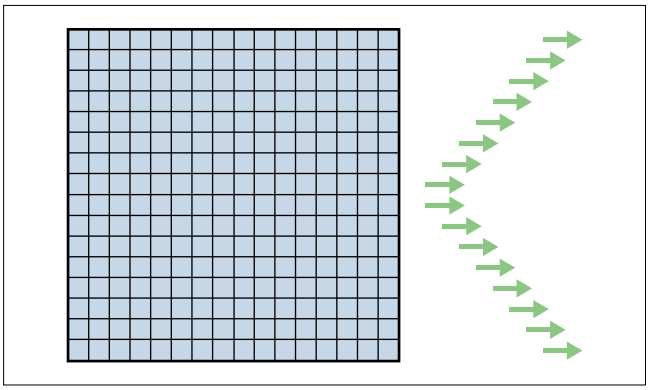


Fig. 2 The readout direction of ORCA-Flash4.0 series

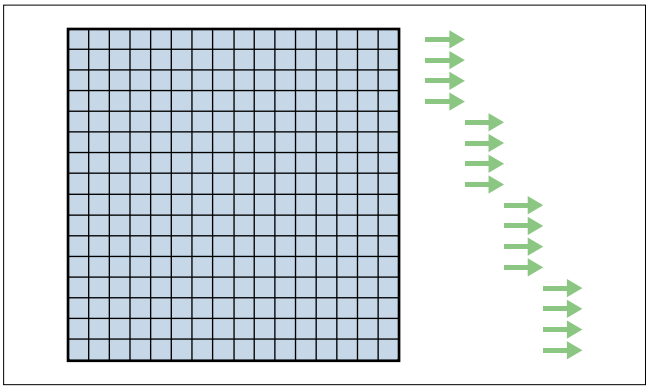


Fig. 3 The readout direction of ORCA-Lightning

2-3. Quantum efficiency

The ORCA-Lightning's pixels utilize on-chip lenses and are 5.5 µm×5.5 µm in size. The peak quantum efficiency (QE) is 60 % with greater than 50 % in the 500 nm to 700 nm range.

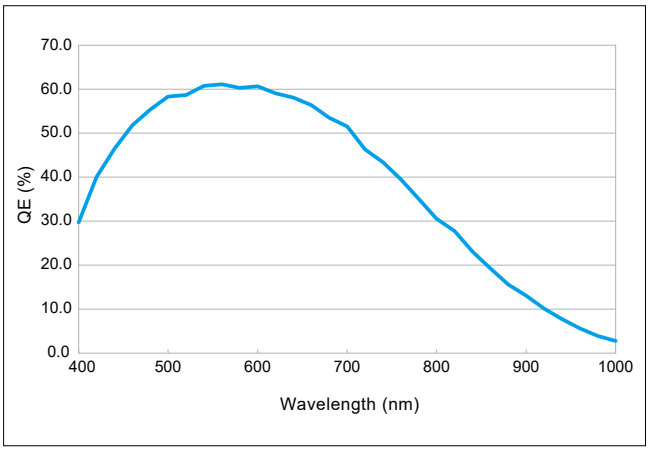


Fig. 4 Quantum efficiency (QE)

3. Sensor size

3-1. Field of view

The sensor of the ORCA-Lightning has 4608 pixels horizontally and 2592 pixels vertically, for a total of approximately 12 megapixels. Given that the pixel size is 5.5 µm, the field of view (FOV) is 25.3 mm horizontally and 14.3 mm vertically with a resultant 29.0 mm diagonal.

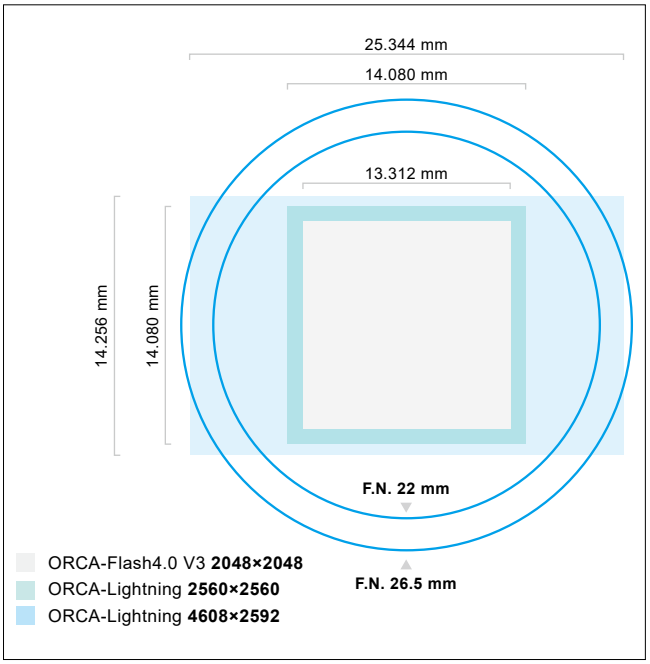


Fig. 5 Field of view

3-2. Pixel size

The pixel size of ORCA-Lightning is 5.5 µm and unique among large array CMOS cameras (greater than 10 megapixels) which typically have much smaller pixels. This pixel size allows for high signal to noise ratio, low magnification imaging (for instance with a macro lens).

3-3. Camera mounts

Because the ORCA-Lightning FOV is 29.0 mm diagonally objective field numbers of up to 26.5 mm can be accommodated. The available camera mounts are F-mount, C-mount or TFL II-mount (Fig. 6) and can be changed in the field.

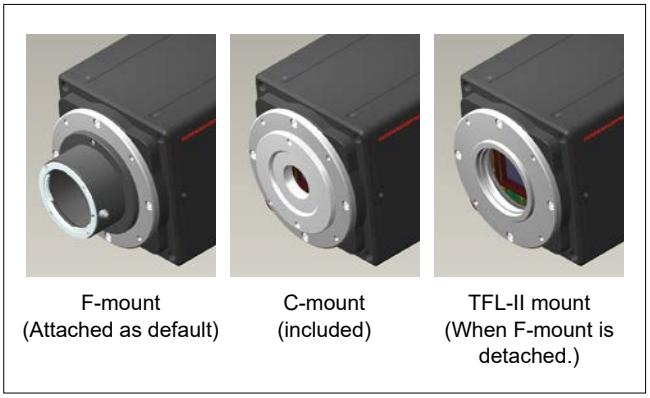


Fig. 6 Camera mounts

4. Readout modes

4-1. Normal Area Mode

The ORCA-Lightning employs a rolling shutter readout which reads the rows from top to the bottom. The area readout mode can operate in “normal readout mode” or “normal shutter readout mode”. The time span between readouts becomes the exposure time in normal readout mode. Because 4 rows are readout concurrently as described in section 2-2 the start of the exposure of each set of 4 concurretnly read rows are shifted accordingly.

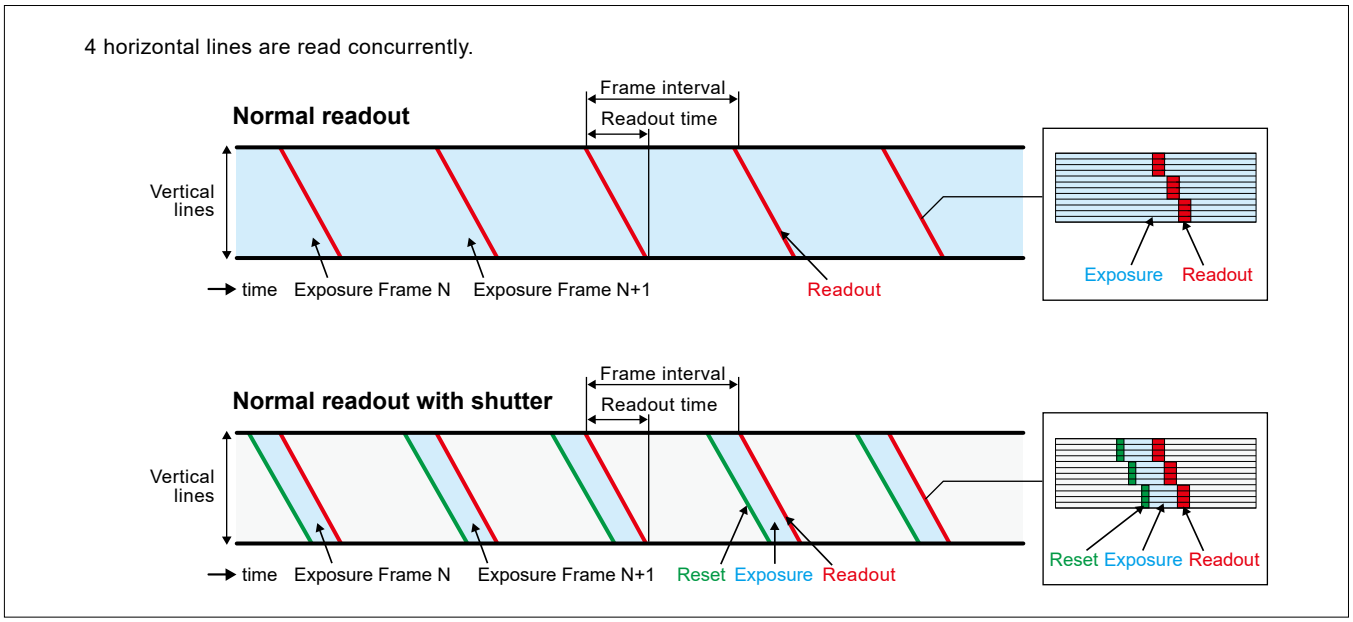


Fig. 7 Normal Area Mode

4-2. Lightsheet Readout Mode

Lightsheet Readout Mode in the ORCA-Lightning is a method synchronizing the exposure position of the pixel rows to the position and speed of the excitation light beam. When the excitation light beam scan is slow it can be synchronized by delaying the readout timing of the rows (Fig. 8).

In Lightsheet Readout Mode the exposure time of the camera is relative to the illumination slit width. While shortening the exposure time makes the slit width more narrow and removes scattered light caused by diffraction, it also can result in fewer photons available to the camera. If the image is very dim there is no advantage to increasing the exposure time. Instead, try increasing laser power or reducing the scan speed of the light sheet to increase the signal to noise ratio of the images. When the setting exposure time and readout delay timing keep in mind that adjustments should be in 4 rows steps due to the concurrent readout scheme described in section 2-2.

When using the camera in “external trigger input timing” jitter must be accounted for. Under this condition the ORCA-Lightning has a jitter which is equivalent to one horizontal readout time so the exposure start should be adjusted accordingly.

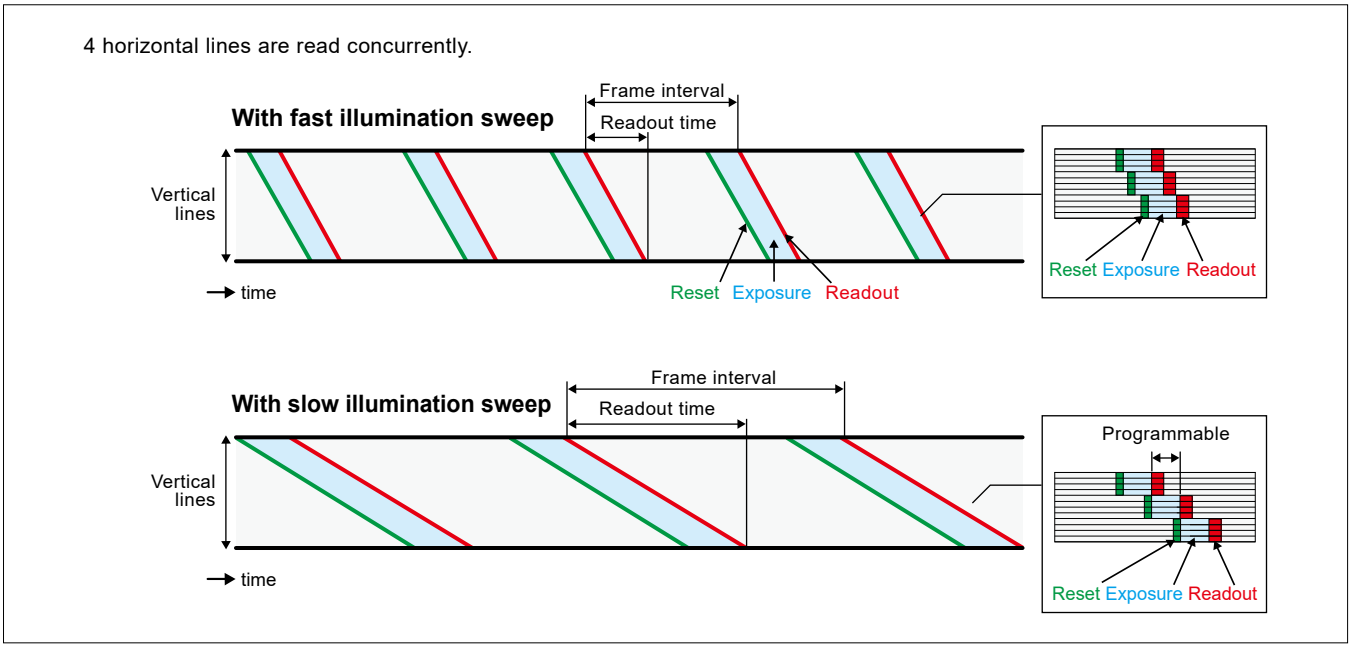


Fig. 8 Lightsheet Readout Mode

5. Maximum frame rates

5-1. Sensor and interface speeds

The maximum possible full frame output data rate of the ORCA-Lightning sensor is larger than any current (as of this writing) computer interface can accommodate. The ORCA-Lightning is provided with a CoaXPress (Quad CXP-6) lane interface which allows for acquisition of full frame rates of 121 frames/s in Standard Full Well Capacity (hereinafter referred to as FWC) mode.
By using the camera in sub-array mode the number of pixels that must be transferred becomes fewer and the maximum sensor data rate becomes slower than the interface. Under these conditions the maximum sensor frame rate is equal to the maximum camera frame rate.

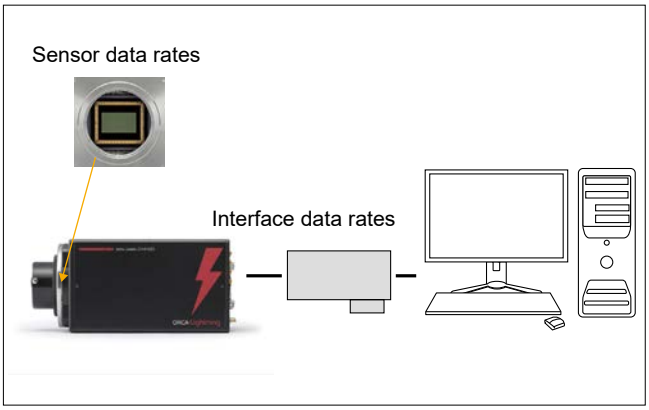


Fig. 9 Sensor and interface

5-2. Frame rates at Normal Area Mode

Calculation of the maximum frame rates of the ORCA-Lightning is complicated by the limitations of the interface in standard FWC mode. For reference, typical frame rates using area readout mode are shown in Fig. 10.

Format H×V (pixel)	@ High FWC mode (frames/s)	@ Standard FWC mode (frames/s)
4608×2592	30	121
2560×2560	30	221
2048×2048	38	307
1024×1024	76	610
512×512	150	1201
256×256	291	2332
128×128	550	4406

Fig. 10 Typical frame rates at Normal Area Mode

If the horizontal pixel number of a sub array is 2304 pixels or less the camera speed in standard FWC mode is limited by the sensor output speed. If the horizontal pixel number of the sub array in standard FWC mode is greater than 2304 pixels the camera speed is limited by the interface speed.

Format H×V (pixel)	@ High FWC mode (frames/s)	@ Standard FWC mode (frames/s)
4608×128	550	2203
4608×64	991	3965
4608×8	3304	13 219
4608×4	3965	15 862

Fig. 11 Typical frame rates at 4608 horizontal pixels

Format H×V (pixel)	@ High FWC mode (frames/s)	@ Standard FWC mode (frames/s)
2048×128	550	4406
2048×64	991	7931
2048×8	3304	26 438
2048×4	3965	31 725

Fig. 12 Typical frame rate at 2048 horizontal pixels

5-3. Frame rates at Lightsheet Readout Mode

In the ORCA-Flash4.0, because its readout is simultaneous bi-direction readout from center to top and bottom, the maximum frame rate at Lightsheet Readout Mode in standard FWC mode becomes 50 frames/s and slower than 100 frames/s at the normal area mode. However in the ORCA-Lightning, because its readout is single direction from top to bottom, the maximum frame rate at the Lightsheet Readout Mode is almost the same as its normal area mode. The maximum frame rate at 2048×2048 pixels and standard FWC mode of the ORCA-Lightning is 305 frames/s and about 6 times faster than 50 frames/s of the ORCA-Flash4.0.
Typical frame rates in Lightsheet Readout Mode are shown in Fig. 13.

Format H×V (pixel)	@ High FWC mode (frames/s)	@ Standard FWC mode (frames/s)
4608×2592	30	121
2560×2560	30	220
2048×2048	38	305
1024×1024	75	603
512×512	146	1175

Fig. 13 Typical frame rates in Lightsheet Readout Mode

5-4. How to compare ORCA-Lightning frame rates to other cameras.

As an example Fig. 14 shows a speed comparison of the ORCA-Flash4.0 and ORCA-Lightning in normal readout, light sheet readout mode and pixel rates. The frame rate varies by the number of pixels in the sub-array used. In order to compare the absolute speed of the ORCA-Lightning to other cameras you should be certain each camera is outputting frames with the same number of pixels.

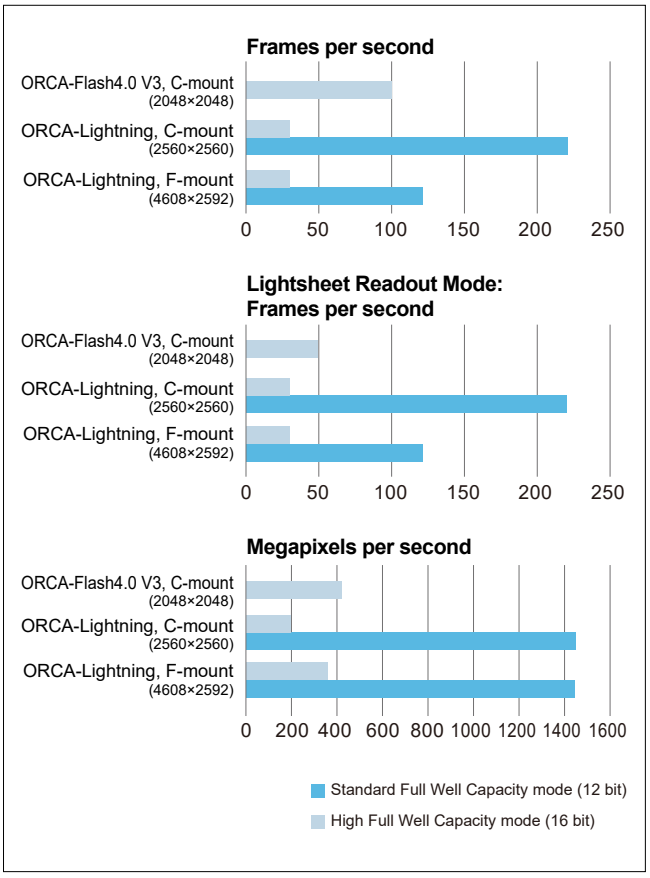


Fig. 14 Speed comparison

6. Dark current and cooling

The sensor temperature of a CMOS camera affects the dark current and the lower sensor temperature is the lower dark current. Because the sensor of the ORCA-Lightning runs at high speeds and the resultant power consumption is large, considerable heat is generated. The ORCA-Lightning is designed to keep its sensor temperature at +20 °C with either air or water cooling. Both air and water cooling capabilities are built into the ORCA-Lightning. To utilize water cooling an optional water chiller is required.

At +20 °C dark current is mitigated to a level that allows for good signal to noise ratio for typical experiments in which the speed of the ORCA-Lightning is required.

7. Options

7-1. Adjustable support poles

Adjustable support poles are available as an option for the ORCA-Lightning when using the side port of a microscope.

Adjustable pole for C14120-20P (2 pieces)
A14490-01

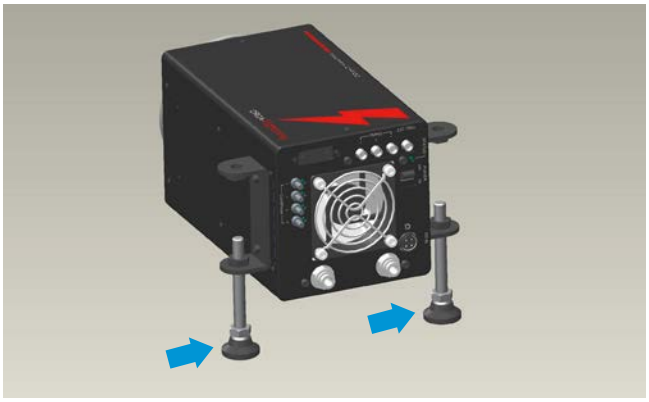


Fig. 15 Adjustable support poles

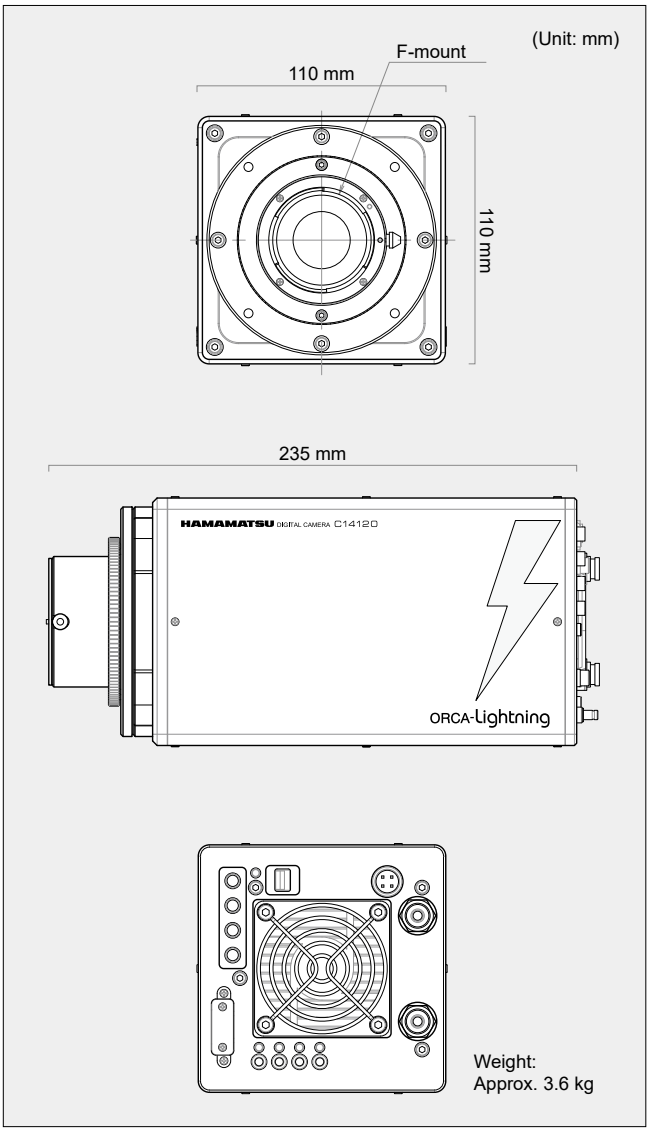
7-2. Tripod mount plate

An optional tripod mount plate is available for the ORCA-Lightning with a 1/4 inch, 20 TPI (Threads per inch).

Base plate for C14120-20P
A14491-01

Fig. 16 Tripod mounts

8. Dimensional outlines



9. System configuration

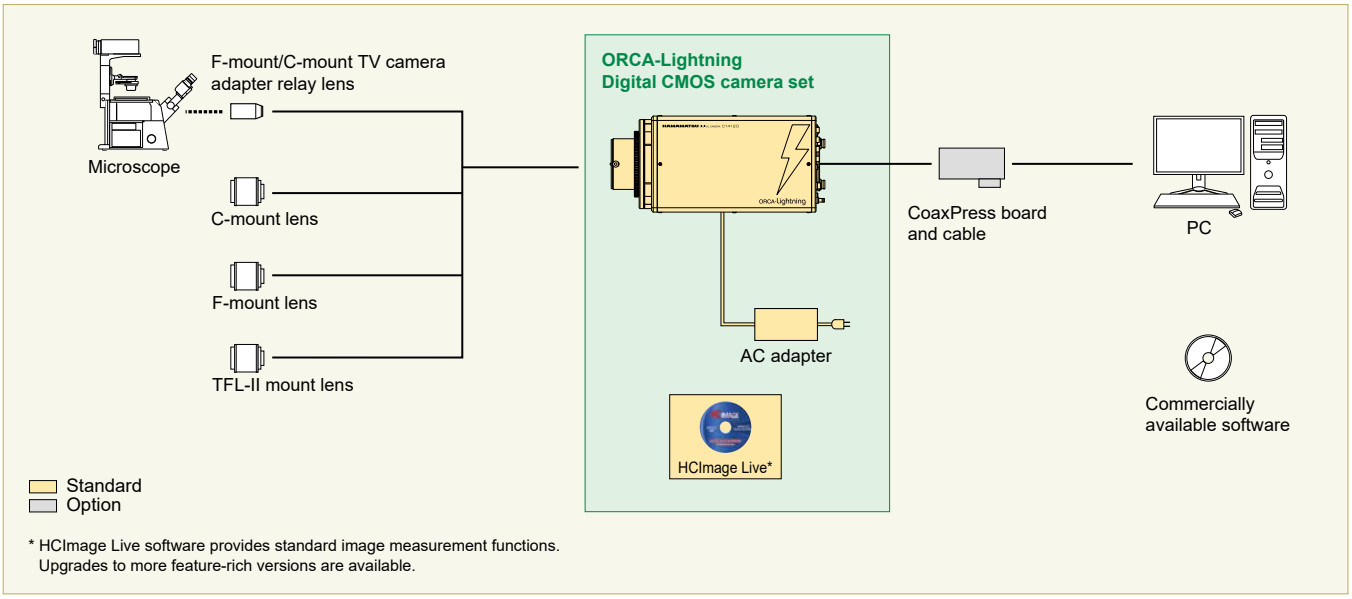


Fig. 17 System configuration example

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