CMOS linear image sensors

CMOS linear image sensors are used for applications including spectrometers, distance measurement, and machine vision cameras (dimension measurement, foreign object inspection). Hamamatsu CMOS linear image sensors are sensitive to non-visible light (ultraviolet, near infrared) as well as visible light, so they are commonly used in measurement and inspection that require detection of non-visible light. We also support products that have characteristics suitable for spectroscopic measurement, including high sensitivity in the ultraviolet region, sensitivity in the vacuum ultraviolet region, and smooth spectral response in the whole wavelength range.
Hamamatsu offers CMOS linear image sensors with various photosensitive areas, packages, and functions, with a focus on analog CMOS and assembly technologies uniquely cultivated at Hamamatsu's own factories. Custom devices are also available.

Hamamatsu CMOS linear image sensors

Type	Operation method	Photodiode	Output	Type no.	Number of pixels	Pixel pitch (μm)	Pixel height (μm)	Image size (mm)	Spectral response range (nm)	Line rate max. (lines/s)	Note
PPS	RS	Surface type	Analog	S9226 series	1024	7.8	125	7.9872 × 0.125	400 to 1000	194	
			Analog	S8377/ S8378 series	128 256 512	50	500	6.4 × 0.5 12.8 × 0.5 25.6 × 0.5	200 to 1000	3846 1938 972	
					256 512 1024	25	500	6.4 × 0.5 12.8 × 0.5 25.6 × 0.5		1938 972 487	
			Current	S15908-512Q	512	50	2500	25.6 × 2.5	200 to 1000	486	
				S15909-1024Q	1024	25	2500	25.6 × 2.5		243	
APS	GS	Surface type	Analog	S9227 series	512	12.5	250	6.4 × 0.25	400 to 1000	9434	
		Buried type	Analog	S11639-01	2048	14	200	28.672 × 0.2	200 to 1000	4672	
			Analog	S13488	2048	14	42	28.672 × 0.042	400 to 1000	4672	With color filter
			Analog	S13131 series	512 736 1536	5.5	63.5	2.816 × 0.0635 4.048 × 0.0635 8.448 × 0.0635		3774 2653 1287	Space saving type (COB package)
			Digital	S11720 series	1536 3072	127	127	194.972 × 0.127 390.044 × 0.127		45400	Long and narrow type (for close contact optical system)
			Digital	S13774	4096	7	7	28.672 × 0.007		100000	With ADC (High-speed type)
			Digital	S15611	1024	7	200	7.168 × 0.2		34000	With ADC (Compact type)

Note:
- PPS: passive pixel sensor
- APS: active pixel sensor
- RS: rolling shutter
- GS: global shutter

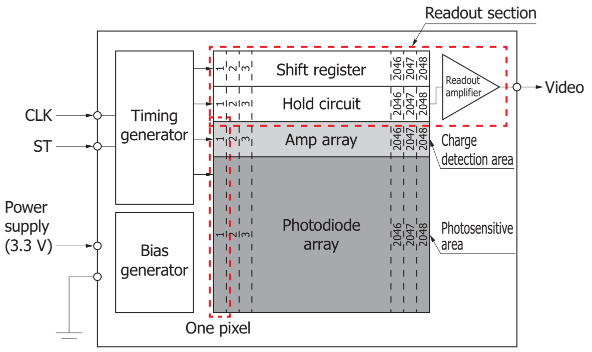
1. Structure

CMOS image sensors are devices that convert optical information into an electrical signal. They have a photosensitive area, charge detection section, and readout section [Figure 1-1]. In the photosensitive area, photodiodes detect incident light and converts this light into a signal charge through photoelectric conversion. The charge detection section converts the signal charge into an analog signal such as voltage or current. The readout section reads out the analog signal (video signal) for each pixel.

The CMOS process enables formation of a timing generator and bias generator within the CMOS image sensor chip. This makes it possible to simplify the external driver circuit. Handling is made easy, because it is possible to drive the CMOS image sensor just by inputting CLK, ST, and a single power supply (e.g., 3.3 V).

For a digital device to handle the analog signal output by the CMOS image sensor, it is necessary to convert the analog signal into a digital signal. Generally, an A/D converter in an external circuit is used to convert an analog signal to a digital signal, then that signal is transferred to a digital device. Hamamatsu also offers a digital output CMOS image sensor with A/D converters built into the chip.

[Figure 1-1] Block diagram of CMOS image sensor (typical example)



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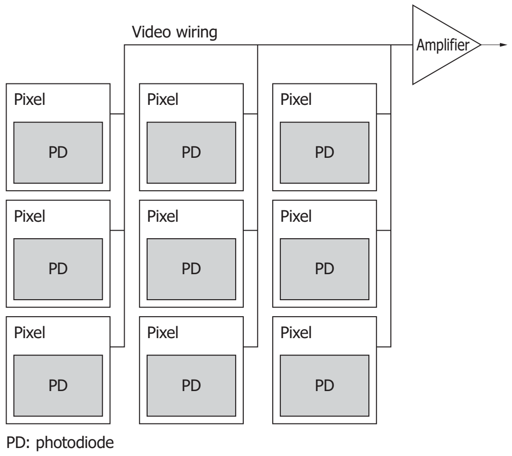
There are two types of CMOS image sensors: CMOS area image sensors with pixels arranged in two dimensions, and CMOS linear image sensors with pixels arranged in only one dimension [Figure 1-2]. In CMOS area image sensors, the area of the photodiodes per unit area (the fill factor) is small depending on the region occupied by the video wiring and circuits. On the other hand, the fill factor can be set to 100% with CMOS linear image sensors, making it is easy to achieve high sensitivity. Furthermore, they have the feature of easily forming rectangular pixels. CMOS linear image sensors are used for applications where it is necessary to detect one-dimensional position information of light. This technical note explains CMOS linear image sensors.

[Figure 1-2] Pixel arrangement of CMOS image sensors

(a) CMOS area image sensor



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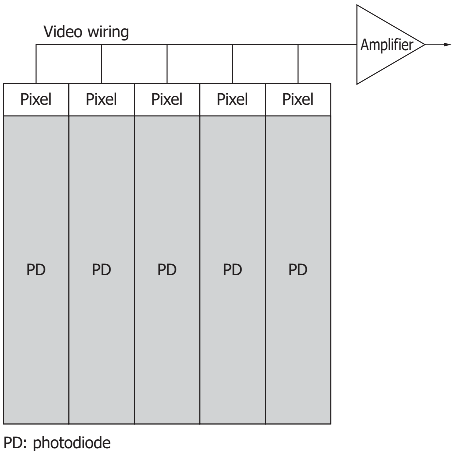
(b) CMOS linear image sensor



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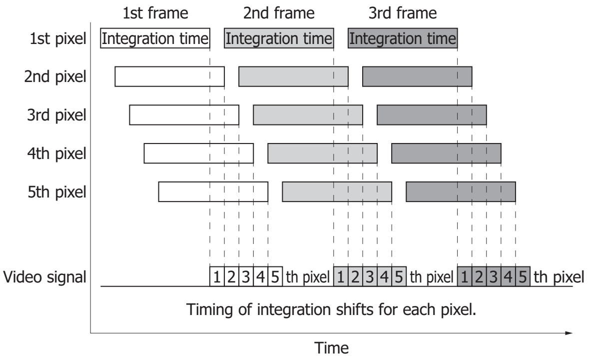
2. Operating principle

2 - 1 Shutter method

There are two operation methods for CMOS linear image sensors: rolling shutter and global shutter. With a rolling shutter, integration timing is shifted for each pixel [Figure 2-1 (a)], while with a global shutter, integration is done for all pixels at the same time [Figure 2-1 (b)]. When imaging a fast-moving object, rolling shutter will distort the image due to the time deviation in integration. With a global shutter, integration is done for all pixels at the same time, so there is no distortion in the image [Figure 2-2]. Therefore, a global shutter is used for imaging fast-moving objects and detecting light pulses, such as with machine vision. In contrast, a rolling shutter is used for detection of constant light. Most Hamamatsu PPS type (see "2-2. Passive pixel sensors, active pixel sensors") CMOS linear image sensors use a rolling shutter.

[Figure 2-1] Operation methods

(a) Rolling shutter



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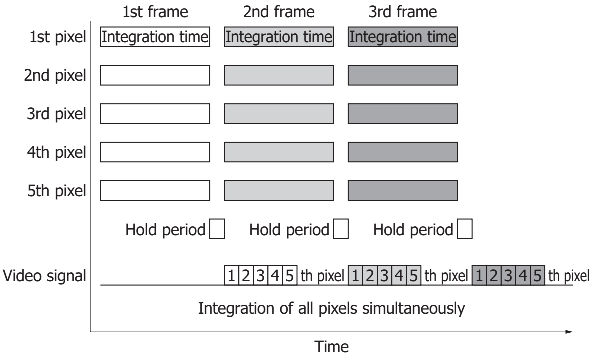
(b) Global shutter



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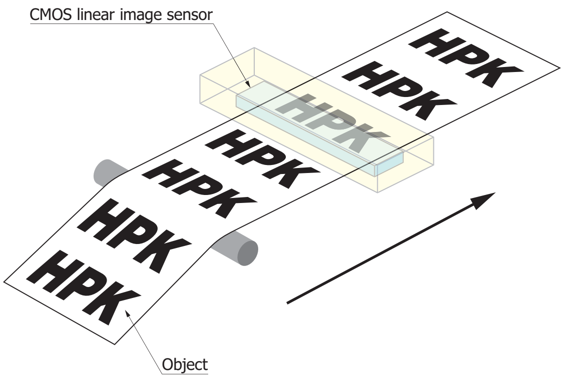
[Figure 2-2] Imaging of fast-moving objects



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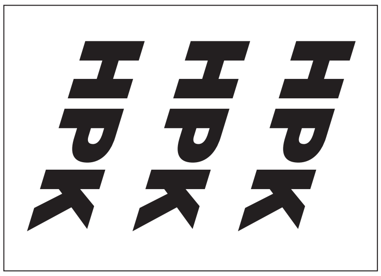
(a) Rolling shutter



The image is distorted.

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(b) Global shutter

The image is not distorted.

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Operation of rolling shutter and global shutter are explained below.

(1) Rolling shutter

Operation of a rolling shutter is shown in Figure 2-3 (a). Each pixel is connected to video wiring and an amplifier via a switch. Imaging with a rolling shutter CMOS linear image sensor is done in the following order.

1. In each pixel, when the switch is off, a photodiode converts light into an electric charge, then integrates the charge.
2. The switch of the first pixel is turned on to connect the pixel with the video wiring, and the pixel signal is transferred to the amplifier. The amplifier reads out the signal, then outputs a video signal. At this time, the photodiode charge is reset and it begins the next integration.

3. The same operation is done from the second pixel to the last pixel, and the video signals of all pixels is then output.

With a rolling shutter, integration starts at the first pixel, then continues in order from the second pixel to the third pixel, and so on. The timing of integration time of the first pixel and the final pixel will be shifted by as much as the number of pixels.

(2) Global shutter

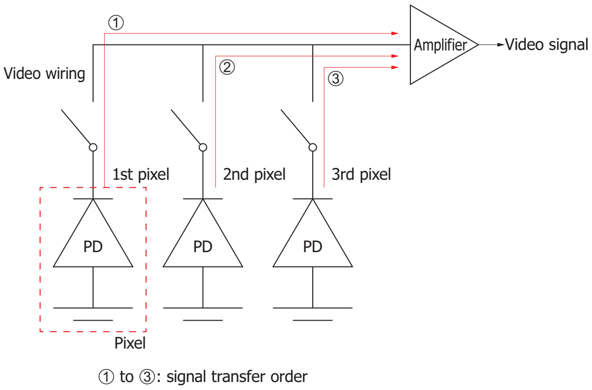
Operation with a global shutter is shown in Figure 2-3 (b). Unlike with a rolling shutter, a global shutter has each pixel connected to a hold circuit via a switch. This hold circuit is connected to an amplifier via a switch. Imaging with a global shutter CMOS linear image sensor is done in the following order.

1. When the switch between the photodiodes and the hold circuits are off, the photodiodes convert light into an electric charge at the same time for all pixels and integrates it.
2. The switches between the photodiodes and the hold circuits are turned on simultaneously for all pixels, then the signals are transferred to and saved at the hold circuits.
3. The switch is changed between the hold circuit and the video wiring in order, from the first pixel to the last pixel, and the signal of each pixel is transferred to its amplifier. The amplifier reads out the signal, then outputs a video signal.

With a global shutter, integration is done for all pixels at the same time, so there is no deviation in the timing of integration time.

[Figure 2-3] Operation of CMOS linear image sensors

(a) Rolling shutter



① to ③: signal transfer order

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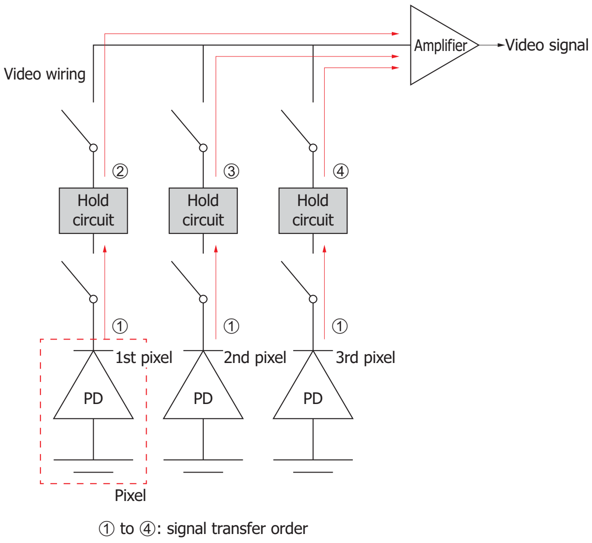
(b) Global shutter



① to ④: signal transfer order

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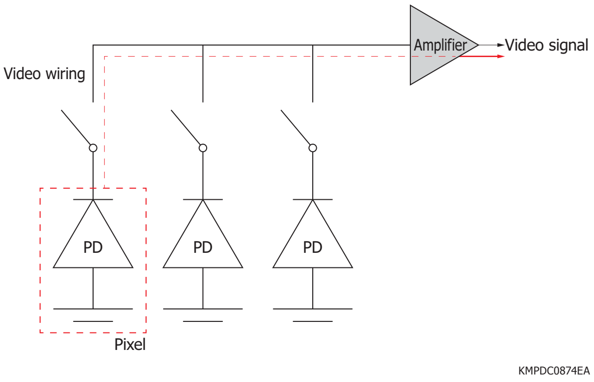
2 - 2 Passive pixel sensors, active pixel sensors

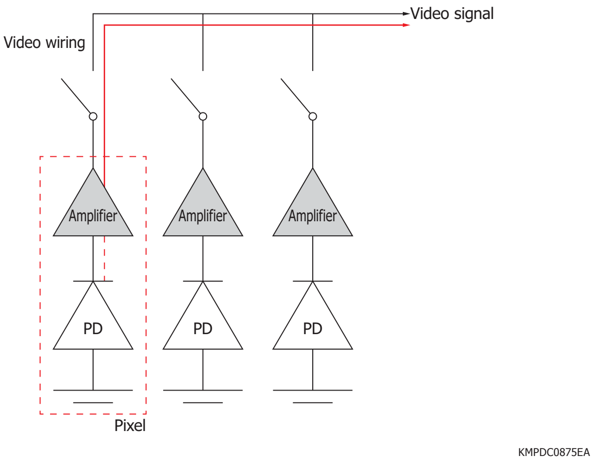
There are two CMOS linear image sensor structures: passive pixel sensor (PPS) and active pixel sensor (APS). PPS amplifies the signal after transferring it to the final stage amplifier [Figure 2-4 (a)]. APS has a structure with an amplifier placed on each pixel, and the amplifier in each pixel transfers the signal after amplifying the signal. [Figure 2-4 (b)].
PPS does not have an amplifier on each pixel, so it consumes less power. One amplifier is shared by all pixels, thereby achieving excellent output uniformity. A high-performance amplifier and high-capacitance capacitor are mounted in the final stage, realizing excellent output linearity and a large saturation charge, so PPS is used for applications such as spectrophotometry.
With APS, the signal is amplified by the amplifier of each pixel and then transferred. This reduces the effect of noise mixed into the circuit after each pixel, and realizes low noise. Because wiring between the photodiode and the amplifier is short, it is possible to suppress parasitic capacitance, as well as realize high-speed readout and high sensitivity. In addition to machine vision which requires high-speed detection, APS is used for a wide range of applications including consumer and spectrophotometry.

[Figure 2-4] Pixel structure

(a) PPS



(b) APS



[Table 2-1] Comparison of PPS and APS

Parameter	PPS	APS
Power consumption	Small	Large
Pixel output uniformity	Excellent	Good
Linearity	Excellent	Good
Saturation charge	Large	Small
Noise	Large	Small
Sensitivity	Low	High
Readout speed	Slow	Fast

2 - 3 Surface type photodiodes, buried type photodiodes

There are two photodiode structures for CMOS linear image sensors: surface type and buried type [Figure 2-5]. The surface type has a two-layer structure with an N$^+$ layer formed on the surface of the P layer of the silicon. The buried type has a three-layer structure, with an N$^-$ layer and a P$^+$ layer formed on top of the P layer of the silicon.

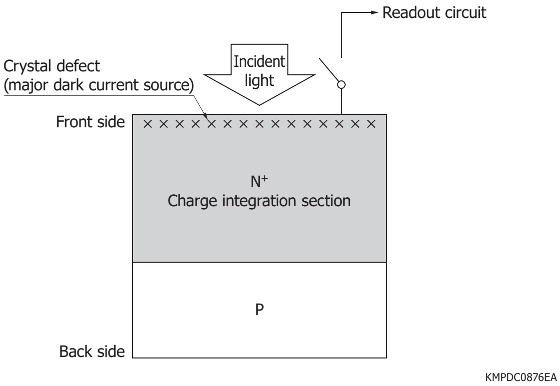
The light incident on the photodiode is subjected to photoelectric conversion into a signal charge. In the surface type, the signal charge is integrated in the N$^+$ layer, while in the buried type, the signal charge is integrated in the N$^-$ layer. The readout circuit then sequentially transfers the integrated signal charge (see "2-1 Shutter method").

Dark current is mainly generated by crystal defects on the surface of the photodiode. In the surface type, dark current generated by crystal defects are integrated in the charge integration section on the surface of the photodiode. In the buried type, dark current can be suppressed because the charge integration section is separated from the surface of the photodiode. The buried type can completely transfer (fully deplete) the all signal charge, so there is less image lag than the surface type. The buried type realizes both low dark current and low image lag, so it is used in a wide range of applications including spectroscopic measurements which require integration for a long time, as well as machine vision that does high-speed detection.

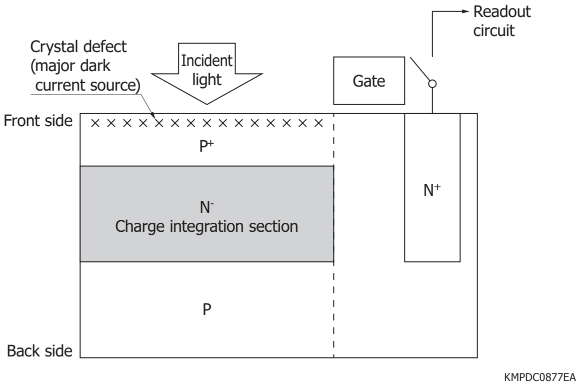
The surface type has a larger charge integration section than the buried type, realizing a large saturation charge. The charge integration section in the surface type has lower electrical resistance and faster charge transfer than the buried type, so it is possible to make the pixel size larger.

[Figure 2-5] Schematic cross section of photodiodes of CMOS image sensor

(a) Surface type photodiode



(b) Buried type photodiode



[Table 2-2] Comparison of surface type photodiode and buried type photodiode

Parameter	Surface type photodiode	Buried type photodiode
Dark current	Large	Small
Saturation charge	Large	Small
Larger area	Easy	Difficult

3. Characteristics

3 - 1 Spectral response

Typical Hamamatsu CMOS linear image sensors have sensitivity in the range of 200 to 1000 nm or 400 to 1000 nm, and peak sensitivity wavelength is around 700 nm [Figure 3-1].

The spectral response in the long wavelength region (near infrared) is determined by the material and thickness of the photodiode. If the material of the photodiode is silicon, when there is incident light with energy higher than the band gap energy (1.12 eV) of silicon, an electric charge is generated through photoelectric conversion. Light energy is expressed by equation (3- 1).

$$E = 1240/\lambda \cdots\cdots\cdots (3\text{-}1)$$

E: light energy [eV]
λ: wavelength [nm]

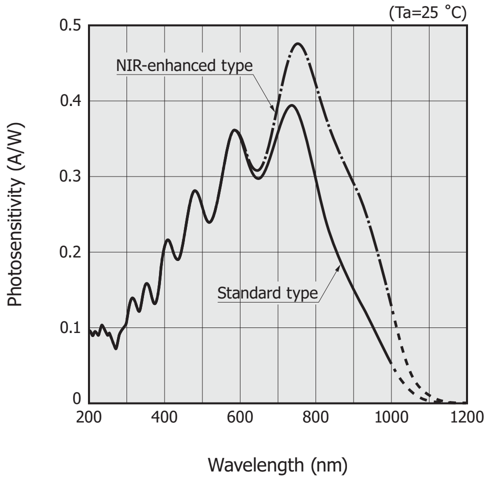
Light has higher energy at shorter wavelengths and lower energy at longer wavelengths. When the wavelength exceeds 1100 nm, there is no sensitivity because there is no photoelectric conversion. Light has longer penetration length at longer wavelengths, so a charge is generated even in the deep part of the photodiode. Therefore, it is possible to increase sensitivity in the near infrared region by increasing the thickness of the silicon. Hamamatsu offers a near infrared-enhanced type with thicker silicon than the standard type to increase the sensitivity in the near infrared region. However, the standard type has better resolution, so it is necessary to choose the type suitable for the application.

The spectral response to the short wavelength region (UV) is determined by the window material of the CMOS linear image sensor and the material of the protective film of the photodiode. UV light is easily absorbed by substances. Therefore, if a window material or protective film which easily absorbs UV light is used, the window material or protective film will absorb the UV light before it reaches the photodiodes, so there will be no sensitivity in the UV region.

When detecting UV light, UV light resistance is also necessary. When UV light is incident on a CMOS linear image sensor that is not UV resistant, the sensitivity of the photodiode surface drops. Short wavelength light such as UV light is subject to photoelectric conversion on the surface of the photodiodes, so UV light sensitivity will drop sharply if UV light is incident continuously on the photodiodes. Hamamatsu offers CMOS linear image sensors that realize both high

UV sensitivity and high UV resistance by making improvements to the structure of the photodiodes.

[Figure 3-1] Spectral response (typical example)



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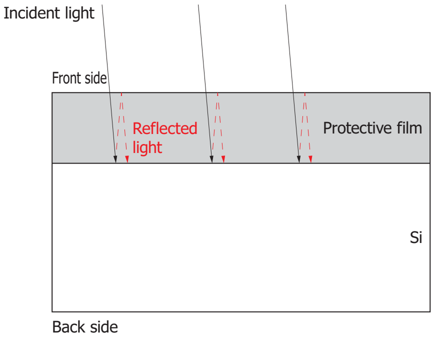
There are narrow peaks and valleys (strong/weak) in the spectral response. This is caused by light interference. Interference between incident light and reflected light inside the protective film formed on the surface of the photodiodes will cause peaks and valleys in the spectral response at specific wavelengths [Figure 3-2]. Hamamatsu offers CMOS linear image sensors with smooth spectral response at all wavelengths by making improvements to the structure of the photodiodes (see "4. Hamamatsu technologies").

[Figure 3-2] Schematic cross section of photodiode



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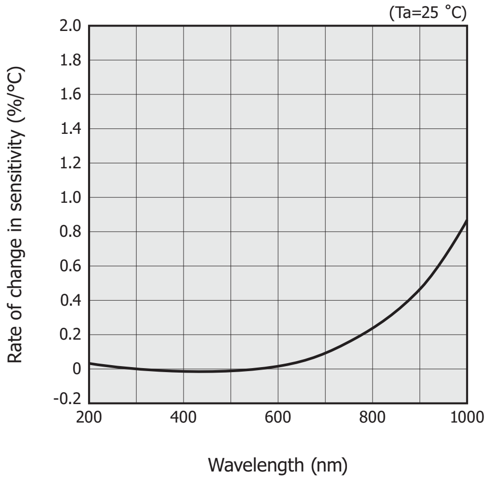
Sensitivity varies linearly with temperature changes. At wavelengths shorter than the peak sensitivity wavelength, temperature dependence becomes small [Figure 3-3]. The longer the wavelength region, the larger the temperature dependence, and the temperature coefficient at 1000 nm is approx. 0.8%/°C.

[Figure 3-3] Sensitivity temperature characteristics (typical example)



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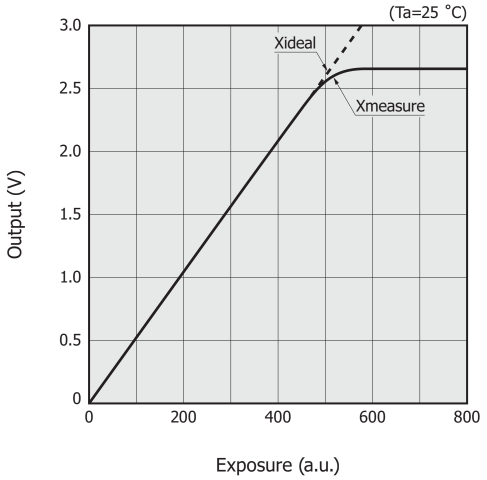
3 - 2 Input/output characteristics

The input/output characteristics express the relation between the incident light level and the output. Incident light level is expressed by exposure (illuminance × integration time).

Figure 3-4 shows a typical example of input/output characteristics. As exposure increases, output increases linearly until it reaches saturation. The exposure at which output reaches saturation is called saturation exposure. The saturation output is an index that determines the maximum level of the dynamic range (see "3-7 S/N, dynamic range") described later.

[Figure 3-4] Input/output characteristics (typical example)



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3 - 3 Linearity error

Ideal input/output characteristics are to have output change linearly according to the change in exposure.

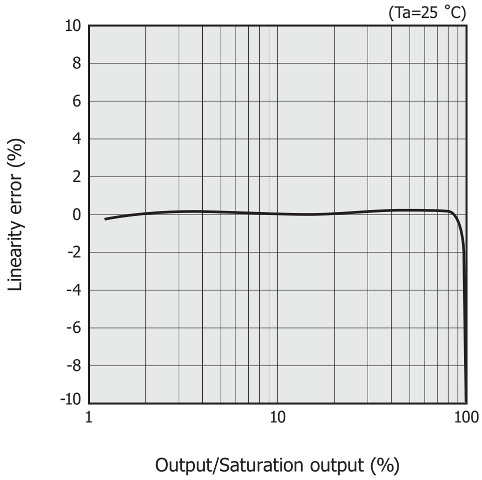
Deviation of input/output characteristics from this ideal straight line is called the linearity error and is defined by equation (3-2).

$$\text{Linearity error} = \frac{\text{Xmeasure - Xideal}}{\text{Xideal}} \times 100 \cdots\cdots\cdots \text{(3-2)}$$

Xmeasure: measured output value
Xideal : ideal straight line connecting the origin point and 5% of the saturation output [Figure 3-4]

Figure 3-5 shows a typical example of the linearity error.

[Figure 3-5] Linearity error (typical example)



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3 - 4 Photoresponse nonuniformity

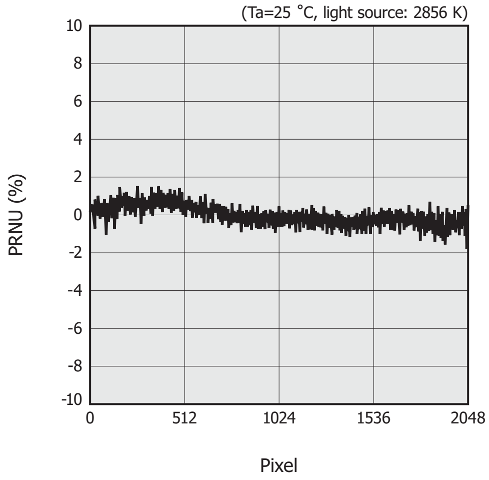
Photoresponse nonuniformity (PRNU) indicates variations in sensitivity between pixels. Multiple pixels in the CMOS linear image sensor have sensitivity nonuniformity caused by manufacturing variations in photodiodes and amplifiers. In Hamamatsu CMOS linear image sensors, photoresponse nonuniformity is defined as the output variation of all pixels when uniform light of about 50% saturation is incident on the entire effective photosensitive area of the photodiodes [equation (3-3)].

$$\text{PRNU} = (\Delta X/\text{Xaverage}) \times 100\ [\%] \cdots\cdots\cdots \text{(3-3)}$$

Xaverage: average of the output of all pixels
ΔX : difference between the Xaverage and the maximum or minimum pixel output

Figure 3-6 shows a typical example of photoresponse nonuniformity.

[Figure 3-6] Photoresponse nonuniformity (typical example)



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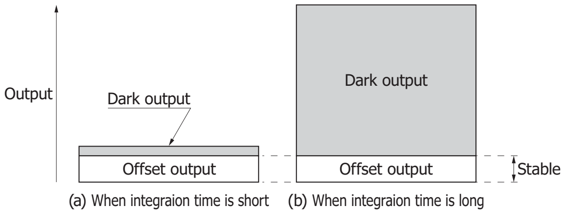
3 - 5 Offset output, dark output

The output in the dark state is expressed as the sum of offset output and dark output.

(1) Offset output

Offset output is caused by the circuit. Output in dark state includes offset output and dark output. Hamamatsu defines output with the shortest integration time for which dark output is negligible as offset output. Thus, offset output is constant even if integration time increases (Figure 3-7).

[Figure 3-7] Schematic diagram of offset output and dark output



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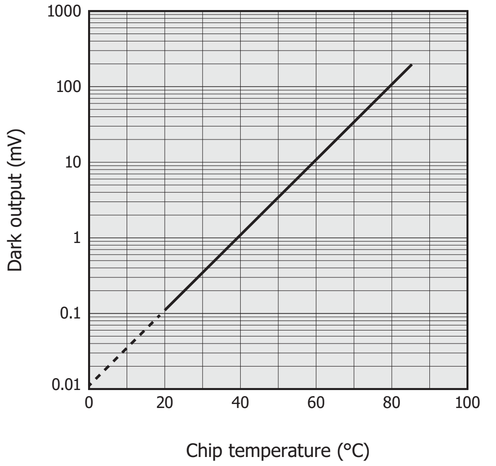
(2) Dark output

Dark output is caused by the photodiodes. Dark output is generated when carriers in the photodiodes get excited from the valence band to the conduction band by heat. It increases in proportion to integration time, so it is necessary to determine the integration time with consideration for the magnitude of the dark output.

The higher the temperature, the more carriers are excited from the conduction band to the valence band, so dark output changes exponentially relative to temperature changes [Figure 3-8]. With Hamamatsu CMOS linear image sensors, dark output doubles for every 5°C rise in temperature. When the temperature rises by 1°C, dark output increases by about 1.1 times, so when temperature rises by ΔT [°C], dark output increases by about $1.1^{\Delta T}$ times.

[Figure 3-8] Dark output vs. chip temperature (typical example)



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3 - 6 Noise

Noise is broadly separated into two types: random noise that fluctuates with time, and fixed pattern noise that is generated by specific pixels regardless of time.

(1) Random noise

Random noise can be separated into three types: shot noise, dark shot noise, and readout noise, depending on the factor that causes that noise.

Shot noise (Nshot)

Even when the strength of the light is constant, the number of photons incident on the photodiodes is not constant, so there are fluctuations. Noise caused by fluctuations in the number of photons is called shot noise. Shot noise is expressed by equation (3-4) according to the Poisson statistics.

$$\text{Nshot} = \sqrt{S} \cdots\cdots\cdots (3\text{-}4)$$

S: Number of signal electrons [e^-]

Dark shot noise (Nd)

Dark shot noise is caused by dark current and is proportional to the square root of the number of electrons generated in a dark state. When integration time is short enough, the dark current is small, so the effect of dark shot noise can be ignored.

Readout noise (Nread)

Readout noise is noise generated inside the readout circuit. It occurs even in the dark state, regardless of the light level. Measure the readout noise in the dark state and the shortest integration time. Readout noise is an index that determines the minimum level of the dynamic range (see "3-7 S/N, dynamic range") described later on.

Readout noise includes kTC noise caused by circuit switching during readout, thermal noise caused by thermal random motion of charges inside MOS transistors, and RTS (random telegraph signal) noise caused by defects in MOS transistors. RTS noise is a fine current that flows when carriers are captured and released by structural defects in the gate oxide film of a MOS transistor. With microfabricated CMOS processes in recent years, effects of these fine currents cannot be ignored. The strength of RTS noise varies depending on the pixel.

(2) Fixed pattern noise (Nfpn)

The cause of fixed pattern noise differs between dark state and light state. The primary causes of fixed pattern noise in the dark state are variations in offset output and dark current for each pixel. The primary cause of fixed pattern noise in the light state is photoresponse nonuniformity (see "3-4 Photoresponse nonuniformity"). Fixed pattern noise in the light state increases in proportion to the exposure.

The total noise (Ntotal) of a CMOS linear image sensor is given by equation (3-5).

$$\text{Ntotal} = \sqrt{\text{Nshot}^2 + \text{Nd}^2 + \text{Nread}^2 + \text{Nfpn}^2} \cdots\cdots\cdots (3\text{-}5)$$

3 - 7 S/N, dynamic range

The relationship between the noise and output vs. exposure of CMOS linear image sensor is shown in Figure 3-9.

(1) S/N

The higher the S/N, the better the CMOS linear image sensor’s image quality will be. The type of dominant noise and the S/N change depending on the strength of the output of the sensor.

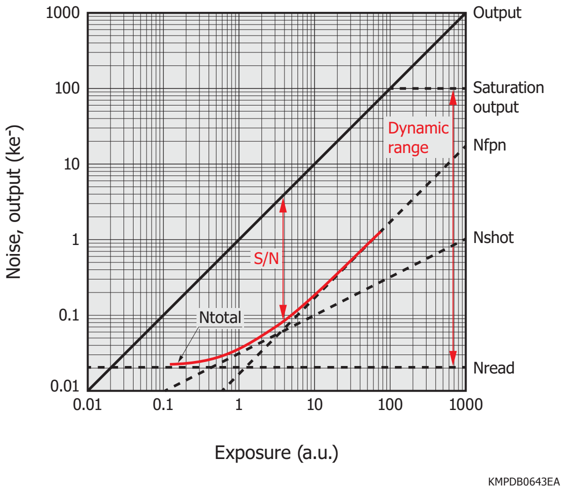
(2) Dynamic range

Dynamic range generally indicates the measurable range of a sensor and is defined as the ratio of the maximum level to the minimum level. The wider the dynamic range, the wider the measurable range will be. Hamamatsu defines the dynamic range in equation (3-6), with the upper limit of dynamic range as saturation output and the lower limit as readout noise.

$$\text{Drange} = \text{Vsat}/\text{Nread} \cdots\cdots\cdots \text{(3-6)}$$

Drange: dynamic range
Vsat : saturation output
Nread : readout noise

[Figure 3-9] Output, noise vs. exposure (typical example)



3 - 8 Resolution

Resolution is the degree of detail to which the input pattern is reproduced in the output. Figure 3-10 shows a schematic diagram of output when a repeating pattern image of square waves is incident. When the input pattern is wide, the image can be reproduced accurately. However, as the incident pattern becomes narrower, the output difference shrinks, so that the image can no longer be reproduced accurately. There are two causes of this phenomenon: optical crosstalk when incident light enters adjacent pixels, and electrical crosstalk when signal charges subjected to photoelectric conversion enter adjacent pixels due to diffusion.

Indicators of resolution include the modulation transfer function (MTF) for sine waves and the contrast transfer function (CTF) for square waves. Hamamatsu uses a square wave pattern test chart to evaluate CTF. CTF is defined by equation (3-7). The fineness of the black-and-white spacing of the input patterns is expressed with spatial frequency. Spatial frequency is the number of repeating patterns per unit length, and the reciprocal of the distance from one white part to the next in the pattern in Figure 3-10. The unit is normally line pairs/mm.

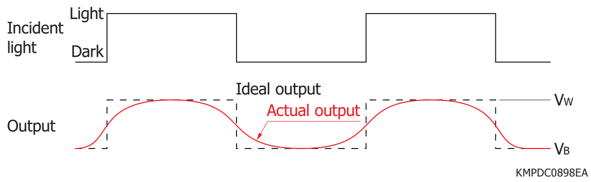
$$\text{CTF} = \frac{V_{WO} - V_{BO}}{V_W - V_B} \cdots\cdots\cdots \text{(3-7)}$$

V_{WO}: output white level
V_{BO} : output black level
V_W : output white level (when the input pattern is wide)
V_B : output black level (when the input pattern is wide)

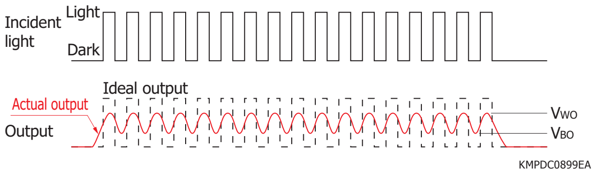
Figure 3-11 shows a typical example of CTF. The narrower the input pattern (i.e. the higher the spatial frequency), the lower the CTF will be. CTF is wavelength dependent. The longer the wavelength, the deeper the signal charge is generated in the silicon substrate, which increases electrical crosstalk and lowers CTF.

[Figure 3-10] Schematic diagrams of CTF characteristics

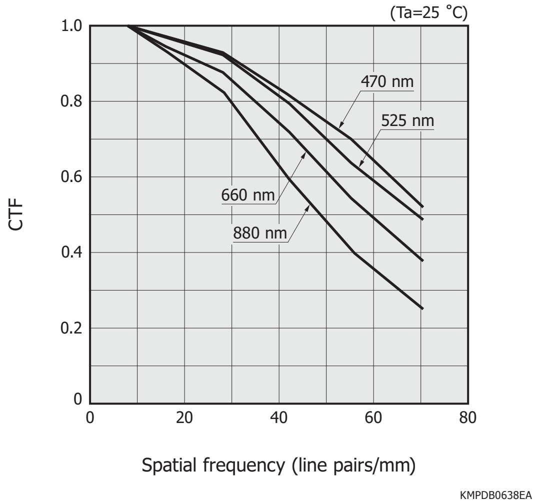
(a) When the input pattern is wide



(b) When the input pattern is narrow



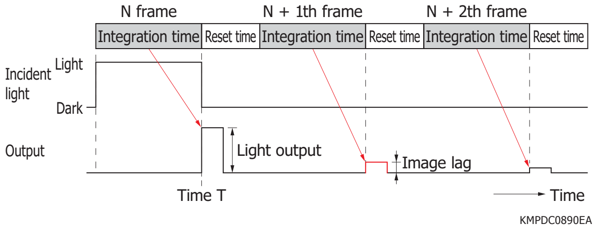
[Figure 3-11] CTF vs. spatial frequency
(typical example, pixel pitch: 7 µm)



3 - 9 Image lag

Image lag is a phenomenon in which output from the previous frame remains in the output of the next frame after the optical signal of the frame is read out. Figure 3-12 shows an example of the image lag. The incident light changes from the light state to dark state at time T. During readout of the Nth frame, light is incident during integration time, so the optical signal is read out. At the time of readout of N + 1th frame, no light is incident during integration time, so normally the optical signal is not read out. However, if the charge of the photodiode or the readout circuit cannot be completely reset when resetting the Nth frame and there is image lag, the image lagged signal is read out during readout the N + 1th frame.

[Figure 3-12] Example of image lag

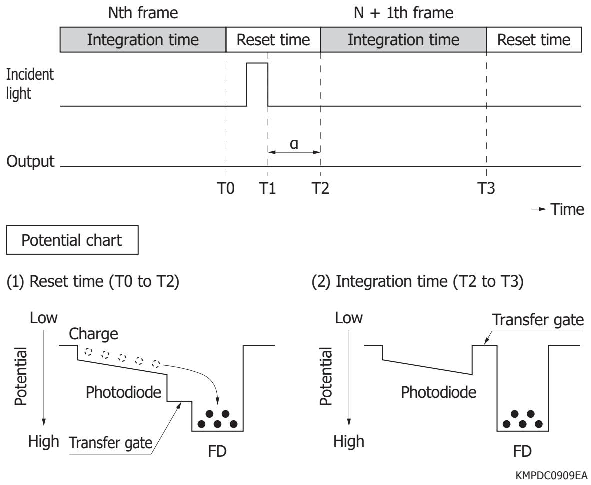


3 - 10 Shutter leak

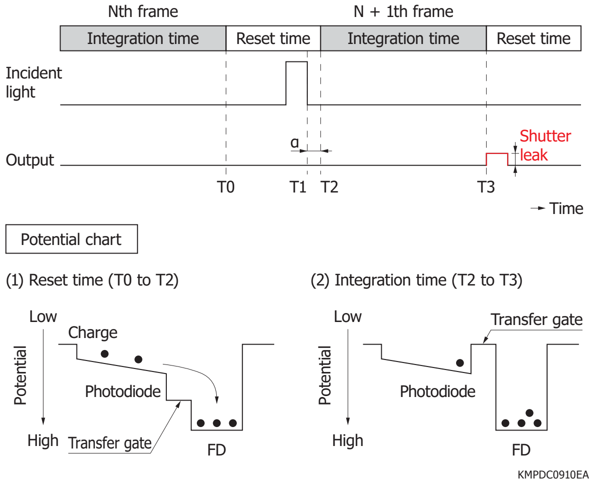
Shutter leak is a phenomenon in which not all of the charge of the photodiodes can be completely reset when light is incident near the end of the reset time.
An electrical charge is generated when light enters the photodiode. During integration time, the transfer gate is closed and the generated charge is integrated in the photodiode. Later, during reset, the transfer gate is opened, then the charge is transferred to floating diffusion (FD) and the photodiode charge is reset. And the transfer gate is closed again, integration is done in the next frame (charges transferred to the FD are sequentially read out by the later readout circuit). However, if light is incident near the end of reset time, not all charges on the photodiode can be reset at the reset time, which results in shutter leak.
Figure 3-13 shows an example of shutter leak. Shutter leak is evaluated by inputting light pulses during reset time. If time (α) from the end of light pulse (T1) to the start of integration time (T2) is long enough, the charge generated by the photodiode is reset when Nth frame is reset, so the output of N+1th frame will not be read out. However, if α is short, not all the charges in the photodiode can be reset at the reset time, and they will be read out as the output of N+1th frame.

[Figure 3-13] Examples of shutter leak

(a) When α is long enough



(b) When α is short



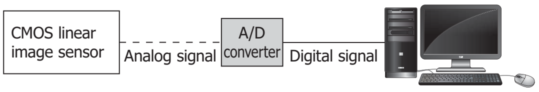
4. Hamamatsu technologies

4 - 1 With A/D converters

Hamamatsu offers digital output CMOS linear image sensors with A/D (analog-to-digital) converters, in addition to analog output CMOS linear image sensors. Analog output CMOS linear image sensors convert charges generated by the photodiodes into analog signals with voltage values or current values, then output those signals. However, in order to handle analog signals with a digital device, it is necessary to convert the analog signals into digital signals with A/D converters. Analog output CMOS linear image sensors do A/D conversion using an external A/D converter [Figure 4-1 (a)]. CMOS linear image sensors with A/D converters do A/D conversion using the built-in A/D converters, then outputs the digital signals [Figure 4-1 (b)]. Because this type uses digital output, it has several advantages, including resistance to noise, high-speed readout, and ease of handling.

[Figure 4-1] A/D conversion of CMOS linear image sensor

(a) Analog output type



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(b) With A/D converters (digital output type)

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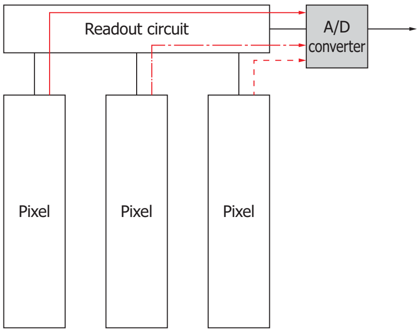
There are two types of CMOS linear image sensors with A/D converters: serial processing method and column parallel processing method [Figure 4-2]. In the serial processing method, A/D conversion is done by one A/D converter installed on the chip. There is only one A/D converter, so it does save some space compared to the column parallel processing method. With the column parallel processing method, A/D conversion is done by the A/D converter connected to each pixel. With the serial processing method, A/D conversion is done for each pixel. In contrast, with the column parallel processing method, A/D conversion is done for all pixels at the same time, making it easier to speed up. With the column parallel processing method, the line rate can be maintained even when the number of pixels increases [Figure 4-3]. For this reason, the column parallel processing method is more suitable for CMOS linear image sensors with a large number of pixels. Hamamatsu offers the serial processing CMOS linear image sensor S15611 and the column parallel processing CMOS linear image sensor S13774.

[Figure 4-2] CMOS linear image sensors with A/D converters

(a) Serial processing method



A/D conversion is sequentially done one pixel at a time.

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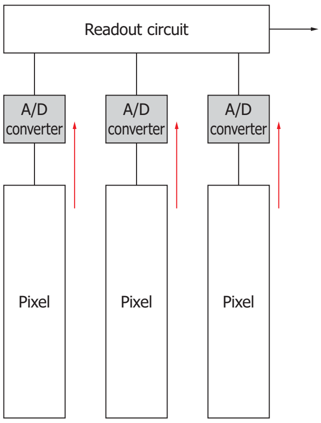
(b) Column parallel processing method



A/D conversion is done for all pixels at the same time.

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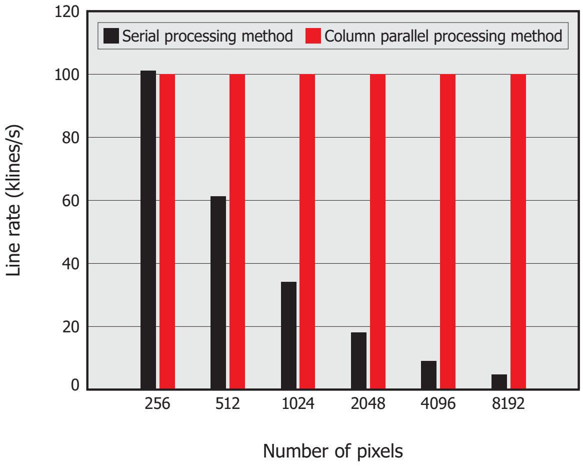
[Figure 4-3] Line rate vs. number of pixels
(CMOS linear image sensors with A/D converters)



Serial processing method:
The line rate decreases as the number of pixels increases.
Column parallel processing method:
Line rate stays steady even as the number of pixels increases.

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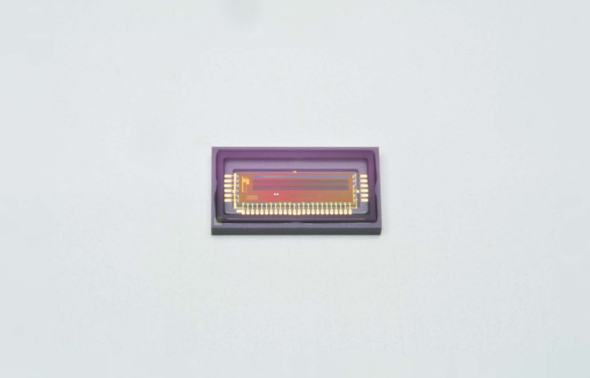
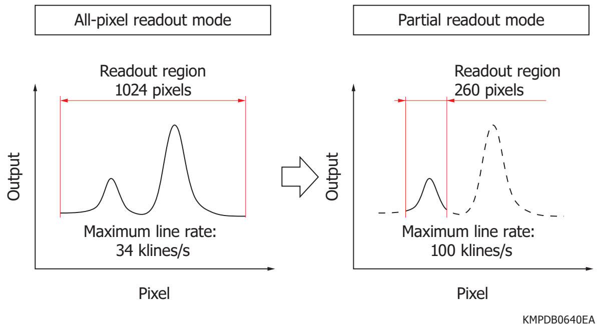
With serial processing method A/D converter S15611

The S15611 is a compact CMOS linear image sensor that uses a serial processing method A/D converter [Figure 4-4]. High-speed readout is possible, with a readout speed of 40 MHz max., and a line rate of 34 kHz max. Partial readout mode [Figure 4-5] and skip readout mode [Figure 4-6] make it possible to realize even higher speed line rates.

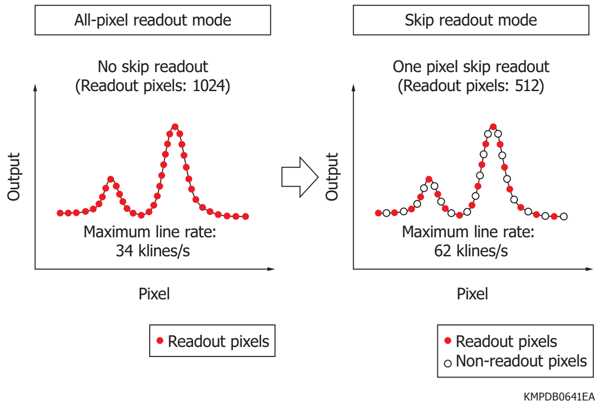
[Figure 4-4] With serial processing method A/D converter S15611



[Figure 4-5] Partial readout mode example



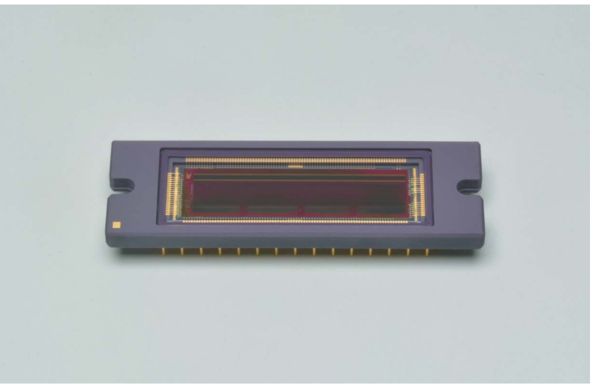
[Figure 4-6] Skip readout mode example



With column parallel processing method A/D converter S13774

The S13774 is a 4096-pixel CMOS linear image sensor that uses a column parallel processing A/D converter, and it was developed for applications in industrial cameras which require high-speed scanning [Figure 4-7]. A/D conversion is done for all pixels at the same time, making it possible to do high-speed readout (line rate: 100 klines/s) even with 4096 pixels.

[Figure 4-7] With column parallel processing method A/D converter S13774



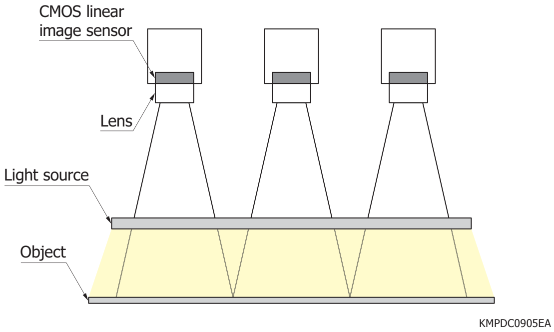
4 - 2 For reduction optical system and close contact optical system

There are two types of CMOS linear image sensor optical systems: reduction optical system and close contact optical system [Figure 4-8]. With a reduction optical system, a lens is used to form a reduced image of the object on the sensor. Due to the large depth of field, this type is suitable for imaging uneven or three-dimensional objects. In the close contact optical system, a rod lens array is used to image objects on the sensor at their actual size. This makes it possible to do imaging of a wide region in a small space without the need for a large-scale device. However, the depth of field is smaller than that of the reduction optical system. The close contact optical system is suitable for imaging long, narrow, and flat objects.

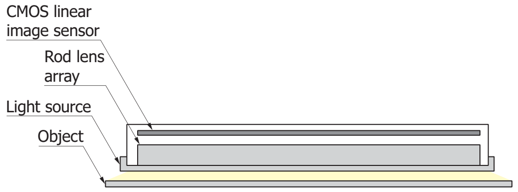
Hamamatsu offers CMOS linear image sensors for use with reduction optical systems or close contact optical systems.

[Figure 4-8] Optical systems of CMOS linear image sensor

(a) Reduction optical system



(b) Close contact optical system



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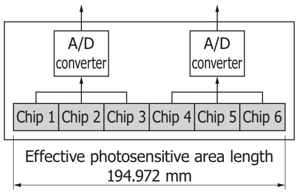
Long and narrow type for close contact optical systems S11720 series

The S11720 series is a long and narrow CMOS linear image sensor developed for close contact optical systems. Hamamatsu has realized a photosensitive area that is long in the horizontal direction by arranging CMOS chips in a row with high accuracy using Hamamatsu packaging technology [Figure 4-9]. It also has built-in A/D converters and uses digital output. It can be used for print inspection and film inspection, etc. in combination with the rod lens array for close contact optical systems.

[Figure 4-9] Structure

(a) S11720-20



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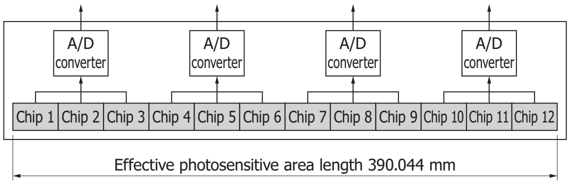
(b) S11720-40



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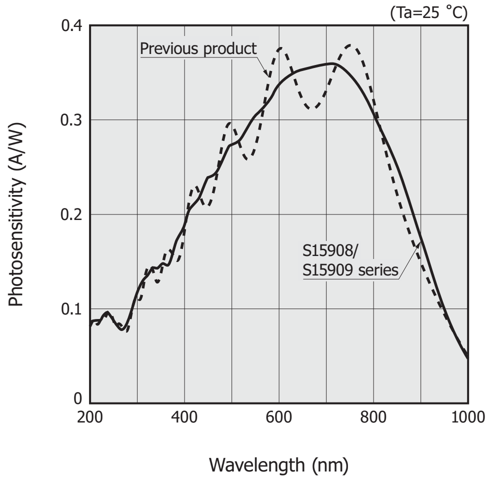
4 - 3 Smooth spectral response

Interference between incident light and reflected light on the protective film of the photodiode may cause peaks and valleys (strength/weakness) in the spectral response (see "3-1 Spectral response"). Hamamatsu has developed the CMOS linear image sensors S15908/S15909 series for spectrophotometry. This series realizes a smooth spectral response in the ultraviolet region to near infrared region by forming a fine structure on the photosensitive area [Figure 4-10].

[Figure 4-10] Spectral response (S15908/S15909 series)



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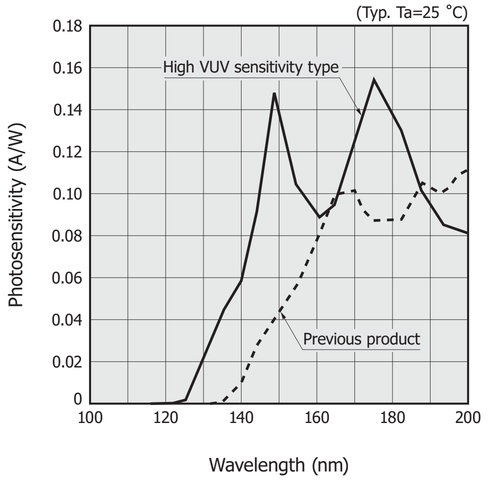
4 - 4 High VUV sensitivity

Hamamatsu offers a CMOS linear image sensor in which we realized high sensitivity in the VUV (vacuum ultraviolet) region of 200 nm or shorter wavelength by improving the photosensitive area [Figure 4-12]. This is suitable for applications that involve measurement in the VUV range, such as light emission analysis.

[Figure 4-12] Spectral Response (VUV-enhanced type)



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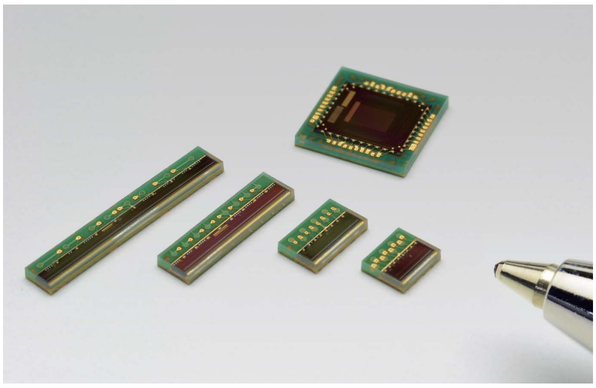
4 - 5 COB package

We have made the installation area smaller by mounting the CMOS linear image sensor chip in a thin and compact COB (chip on board) package of nearly the same size. COB package CMOS linear image sensors contribute to cost reduction, miniaturization, and high-volume producibility of equipment. They are used for a wide range of applications, including barcode readers and encoders.

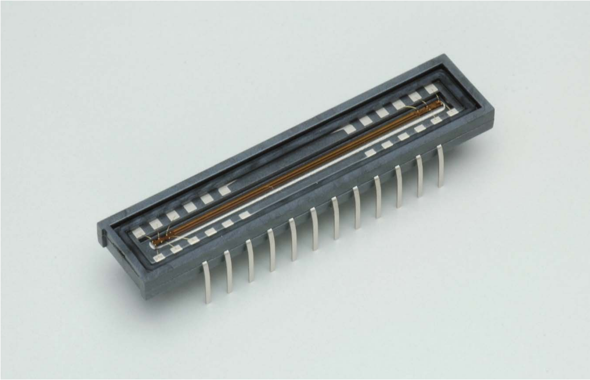
[Figure 4-13] COB package



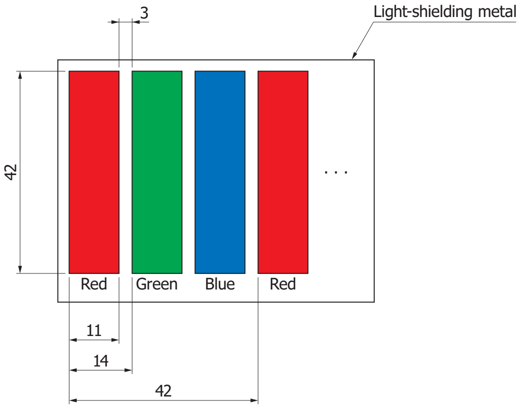
4 - 6 With color filters

The type with color filters that transmit only light of specific wavelengths on the photodiodes of the CMOS linear image sensor is capable of acquiring color information of the measurement object. The S13488 is a CMOS linear image sensor with color filters for red (630 nm), green (540 nm) and blue (460 nm).

[Figure 4-15] S13488 with color filters



[Figure 4-16] Enlarged view of the color filters (S13488, unit: μm)



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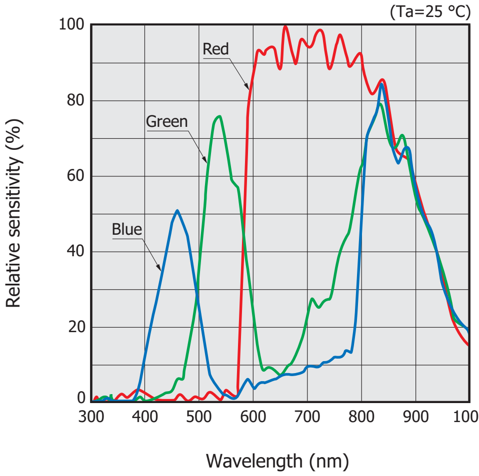
[Figure 4-17] Spectral response (S13488, typical example)



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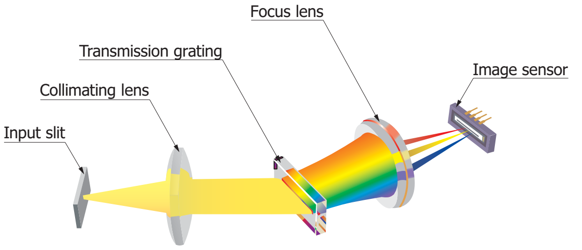
5. Application examples

[Figure 5-1] Application examples of CMOS linear image sensors

(a) Spectrometers



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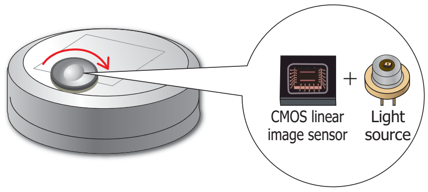
(b) Rangefinders (robot cleaner)



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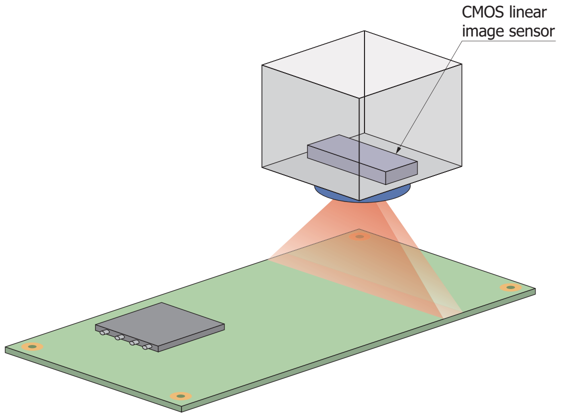
(c) Machine vision



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Cat. No. KMPD9017E01 Jun. 2021 DN