HAMAMATSU
PHOTON IS OUR BUSINESS

InGaAs linear image sensors

Contents

InGaAs linear image sensors are designed specifically for near infrared detection. These image sensors successfully minimize adverse effects from dark current by driving the InGaAs photodiode array at zero bias, and they deliver a wide dynamic range in the near infrared region. In the InGaAs linear image sensors for foreign object detection, we have realized both high-speed readout and high gain by improving ROIC. Hamamatsu InGaAs linear image sensors have the following features.

- Wide dynamic range
- Low dark current due to zero bias operation
- Wide spectral response range
- High gain due to charge amplifier
- Low noise due to CDS circuit
- Internal saturation control circuit
- Internal timing generator allows simple operation.
- Low crosstalk
- Selectable gain
- Hybrid type: includes a back-illuminated chip for different spectral response ranges

Hamamatsu InGaAs linear image sensors

Illumination type	Application	Spectral response range (μm)	Number of pixels	Pixel size [μm (H) × μm (V)]	Package
Front-illuminated type	Spectrophotometry (standard type)	0.9 to 1.7	128	50 × 250	Ceramic
			256	50 × 250, 50 × 500	Ceramic, metal
			512	25 × 250, 25 × 500	
	Spectrophotometry (Raman spectroscopy)	0.85 to 1.45	512	25 × 500	Metal
	Foreign object detection	0.9 to 1.7	256	50 × 50	Ceramic
			512	25 × 25	
			1024	25 × 25, 25 × 100	
	Spectrophotometry (long wavelength type)	0.9 to 1.85	256	50 × 250	Metal
			512	25 × 250	
		0.9 to 2.05	256	50 × 250	
		0.9 to 2.15	256	50 × 250	
			512	25 × 250	
		0.9 to 2.25	256	50 × 250	
		0.9 to 2.55	256	50 × 250	
			512	25 × 250	
Back-thinned type	Spectrophotometry (standard type)	0.95 to 1.7	128	50 × 250, 50 × 500	Ceramic
			256	25 × 250, 25 × 500, 50 × 500	Ceramic, metal
			512	25 × 500	
	Foreign object detection	0.95 to 1.7	256	50 × 50	Ceramic
			512	25 × 25	
			1024	12.5 × 12.5	
		1.12 to 1.9	512	25 × 25	
	Spectrophotometry (hybrid type)	0.95 to 2.15	508 (254 + 254)	25 × 250	Metal

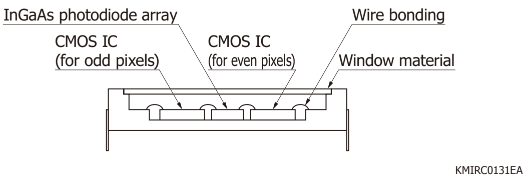
1. Structure, operating principle

1 - 1 Structure

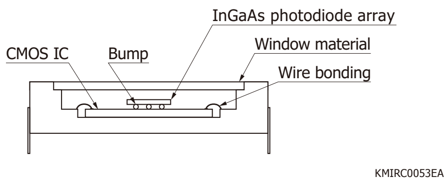
InGaAs linear image sensors consist of an InGaAs photodiode array and a CMOS IC (ROIC) including a charge amplifier array, sample-and-hold circuit, shift register, readout circuit, and timing generator. The InGaAs photodiode array and CMOS IC are connected by wire bonding in the front-illuminated type, and by bump bonding in the back-illuminated type. Figure 1-1 shows cross section views, and Table 1-1 shows features of the front-illuminated and back-illuminated types. Available packages include a ceramic package for room temperature operation and a metal package with a built-in thermoelectric cooler, which are selectable according to application. A typical block diagram for TE-cooled InGaAs linear image sensors is shown in Figure 1-2. An analog video output (Video) and digital outputs (AD_trig, AD_sp) for sample-and-hold can be obtained by supplying analog inputs of Vdd (+5 V or +3.3 V), GND, a charge amplifier reset voltage (INP), pixel voltage (PDN), and readout circuit reset voltages (Vinp, Fvref), as well as digital inputs of master clock pulse (CLK) and integration time control pulse (Reset).

[Figure 1-1] Cross sections

(a) Front-illuminated type



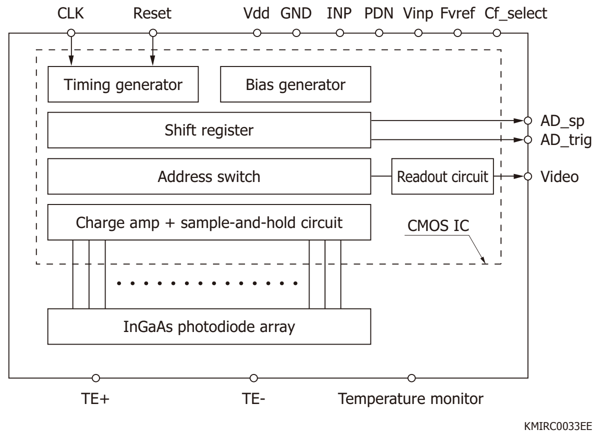
(b) Back-illuminated type



[Table 1-1] Features of front-illuminated type and back-illuminated type

Front-illuminated type	Back-illuminated type
· Wide spectral response range · High quantum efficiency	· Enables narrow pixel pitch · Enables more compact size · Enables hybrid mounting of multiple chips with different spectral response ranges

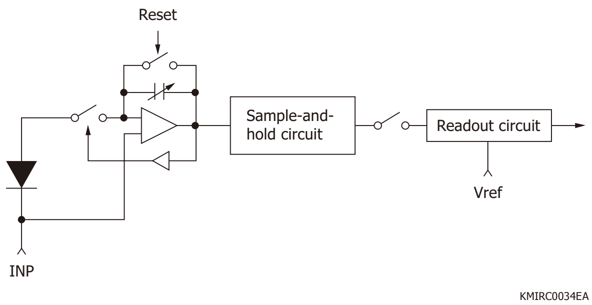
[Figure 1-2] Block diagram (TE-cooled type)



1 - 2 Operating principle

In the CMOS IC for InGaAs linear image sensors, a "charge amplifier and sample-and-hold circuit" array is formed and connected one-to-one to each pixel on the InGaAs photodiode array. Figure 1-3 shows an equivalent circuit for one pixel.

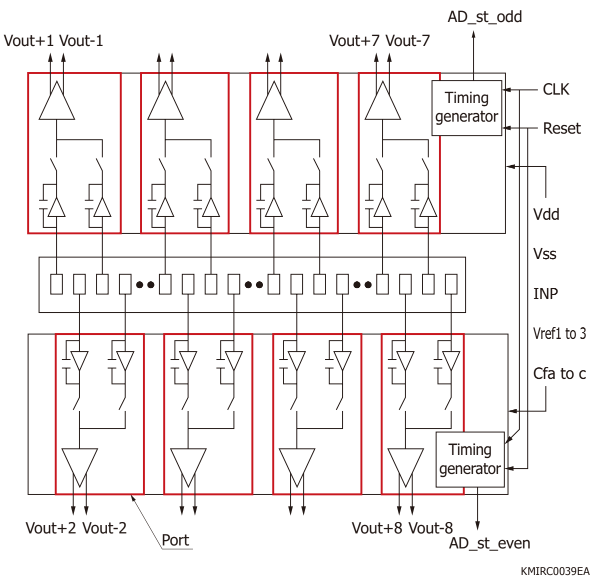
[Figure 1-3] Equivalent circuit (for one pixel)



When light enters the photodiodes of an InGaAs linear image sensor, electric charges are generated and flow into the feedback capacitance of the charge amplifier. This differential-input charge amplifier can operate photodiodes at nearly zero bias, which suppresses the dark current. However, this output caused by the dark current is a fixed pattern, so only the output signal resulting from light input can be extracted by subtracting the output due to the dark current from the output signal obtained with light incident on the image sensor. Since InGaAs photodiodes are made from a compound semiconductor, there are lattice defects and the dark current has relatively large absolute values and variations compared to Si photodiodes. The maximum integration time (integration time needed to reach saturation due to dark current) of InGaAs photodiodes therefore varies among the pixels. If a pixel with high dark current becomes saturated yet the charge integration still continues, then the charges that are no longer stored in the charge amplifier's feedback capacitance will flow out to the adjacent pixels, degrading the purity of the signal output (this is known as "blooming"). To avoid

this blooming, each pixel has a circuit for stopping the charge integration by sensing whether the charge amplifier's feedback capacitance is saturated.
To extract continuous signals, the integration capacitance of the charge amplifier must be reset. A drawback of this, however, is that a large reset noise occurs. This reset noise must be removed to make measurements with high accuracy. In the CDS circuit for InGaAs linear image sensors, the integration start output is held in the signal processing circuit immediately after reset and the integration end output is then held to obtain the difference between the two outputs to eliminate the reset switching noise.
Incidentally, high-speed type image sensor circuitry gives priority to high-speed readout while standard type image sensor circuitry gives priority to a wide dynamic range.
To achieve even higher speeds, the multi-port types employ a format that reads out the data in parallel by dividing the pixels into multiple ports [Figure 1-4].

[Figure 1-4] Multi-port readout example (8-port)

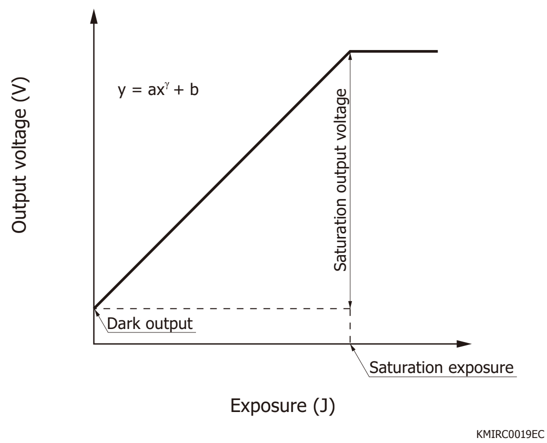


2. Characteristics

2 - 1 Input/output characteristics

The relation between the light level incident to the image sensor and the signal output is referred to as the input/output characteristics. Since InGaAs linear image sensors operate in charge amplifier mode, the incident light exposure (unit: J) is expressed by the product of light level (unit: W) and integration time (unit: s).
The output from an InGaAs linear image sensor is represented in voltage. Figure 2-1 shows a schematic graph of input/output characteristics. The slope in the figure can be expressed by equation (2-1).

[Figure 2-1] Schematic graph of input/output characteristics (log graph)



$$y = ax^{\gamma} + b \quad \cdots\cdots\cdots\cdots (2\text{-}1)$$

y: output voltage
a: sensitivity (ratio of output with respect to exposure)
x: exposure
γ: slope coefficient
b: dark output (output when exposure=0)

Since the upper limit of the output voltage is determined by the output voltage range of the charge amplifier, the input/output characteristics will have an inflection point even if the incident light exposure is increased linearly. The incident light exposure at this inflection point is referred to as the saturation exposure, the output voltage as the saturation output voltage, and the amount of charge stored in the charge amplifier as the saturation charge.
In our InGaAs linear image sensor datasheets, the saturation output voltage (Vsat) is defined as the saturated output voltage from light input minus the dark output.
Saturation charge (Qsat) is expressed by equation (2-2).

$$Qsat = Cf \times Vsat \quad \cdots\cdots\cdots\cdots (2\text{-}2)$$

Cf: integration capacitance of charge amplifier [F]

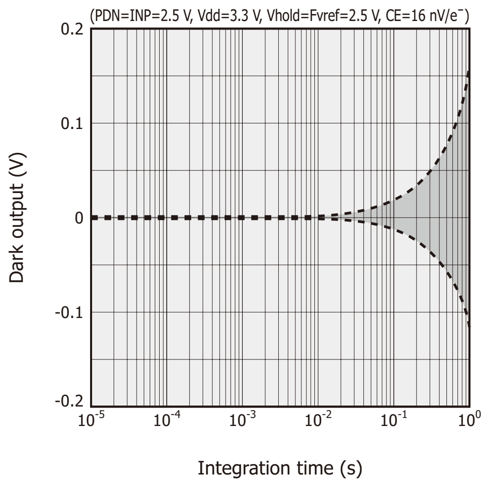
If the integration capacitance is 10 pF and the saturation output voltage is 2.8 V, then the saturation charge will be 28 pC.

The photodiodes can be driven with almost zero bias by setting the charge amplifier reset voltage (INP) and pixel voltage (PDN) to the same potential. But in reality, the charge amplifier has an offset voltage, and the voltage applied to each pixel varies by several millivolts. Therefore, when there is no illuminating light (dark state) and integration time is extended, there are pixels with output growing in the positive direction (light output direction), as well as pixels with output growing in the negative direction (opposite of the light output direction).

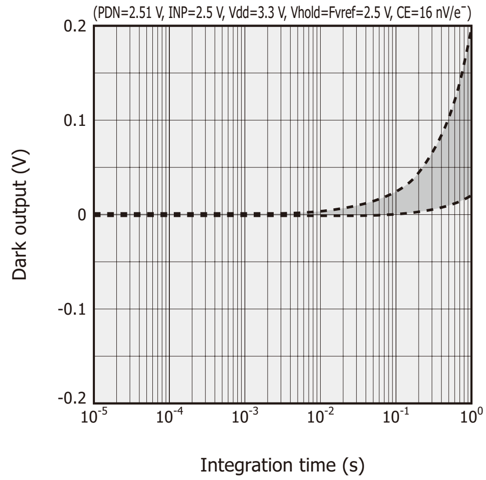
Output range in the negative direction is determined by the output voltage range of the charge amplifier, and it reaches saturation at about 0.3 to 0.5 V. If it would not be convenient for output to grow in the negative direction, set PDN to a potential slightly higher than INP to apply reverse bias to the photodiodes, such that all pixel outputs to be aligned in the direction of the light output. At that time, the dark current will become larger than when the photodiodes are driven with zero bias. Figure 2-2 shows the relationship between dark output and integration time.

[Figure 2-2] Dark output (video signal minus offset voltage) vs. integration time (G13913-256FG, typical example)

(a) Drive the photodiodes with zero bias



(b) Drive the photodiodes with reverse bias

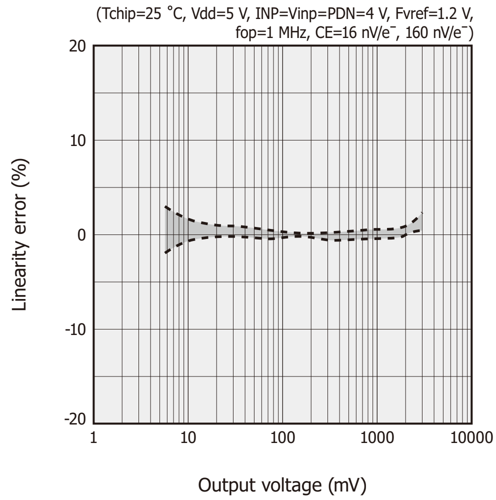


2 - 2 Linearity error

The slope coefficient (γ) of input/output characteristics shown in the preceding section corresponds to the slope plotted on the logarithmic graph. This γ value is 1, but during actual measurement, the input/output characteristics will slightly deviate from this. This deviation is known as the linearity error and is expressed in percentage.

Figure 2-3 shows the linearity error obtained by random sampling. The linearity error at 95% or below the saturation exposure is within ±3%, which is quite small.

[Figure 2-3] Linearity error (G11508-512SA)



2 - 3 Conversion efficiency

Conversion efficiency (CE) is output voltage per charge stored in the charge amplifier. With Hamamatsu InGaAs linear image sensors, it is possible to select from several conversion efficiencies by switching the integration capacitance (Cf) of the charge amplifier using external voltage. Conversion efficiency is expressed by equation (2-3). The smaller the integration capacitance, the higher the conversion efficiency and gain.

$$CE = \frac{q}{Cf} \cdots\cdots\cdots\cdots (2\text{-}3)$$

q: electron charge [C]

2 - 4 Spectral response

When light energy incident on the photosensitive area formed with a PN junction is greater than the InGaAs band gap energy, the electrons in the valence band are excited into the conduction band, generating electron/hole pairs. This generated charge diffuses toward the photodiode depletion layer where the electric field accelerates the charge to pass through the PN junction, resulting in a signal for readout. If the light energy is smaller than the band gap energy, it cannot be detected. The cutoff wavelength (λc) is given by equation (2-4).

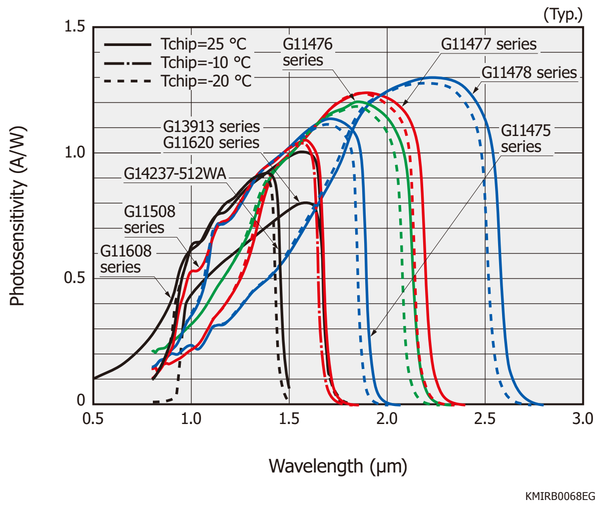
$$\lambda c = \frac{1.24}{Eg} \ [\mu m] \cdots\cdots\cdots\cdots (2\text{-}4)$$

Eg: band gap energy [eV]

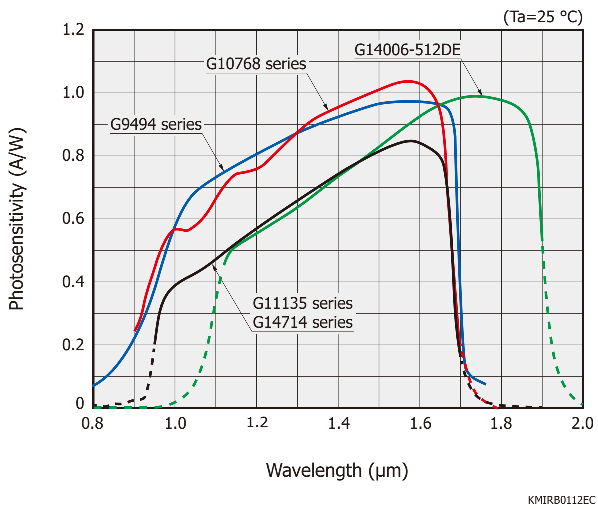
The band gap energy for $In_xGa_{1-x}As$ (x=0.53) is 0.73 eV at room temperature, so the cutoff wavelength will be 1.7 μm. On the long wavelength type $In_xGa_{1-x}As$ (x=0.82), the band gap energy is 0.48 eV at room temperatures, so the cutoff wavelength will be 2.6 μm.
The light absorption coefficient for InGaAs differs depending on the light wavelength. The longer the light wavelength, the smaller the light absorption coefficient, and near the cutoff wavelength it decreases abruptly. The incident light at longer wavelengths penetrates deeper into the InGaAs substrate, generating carriers in deep positions within it. Since these carriers have a limited life, they can only diffuse a certain distance (diffusion length) after being generated. This means that, even when the same amount of light enters the InGaAs linear image sensor, the probability that the generated carriers can reach the depletion layer and eventually be detected as an output signal depends on the wavelength. Moreover, how the incident light undergoes interference, reflection, and absorption on the surface passivation film of the photodiode (such as the insulation film) depends on the wavelength and affects the sensitivity.
Figures 2-4 shows examples of spectral response. The spectral response varies with the temperature. This is because the band gap energy is temperature-dependent. The InGaAs band gap energy increases as the temperature drops, causing the peak sensitivity wavelength and cutoff wavelength to shift to the short wavelength side.
The back-illuminated type has lower sensitivity than the front-illuminated type. The InGaAs photodiodes are formed on an InP substrate with a thickness of approximately 300 μm, but in the back-illuminated type, the light is absorbed by the InP substrate. Most light of wavelengths 0.95 μm or shorter is absorbed by the InP substrate, so sensitivity to light of wavelengths 0.95 μm or shorter is extremely low in the back-illuminated type.

[Figure 2-4] Spectral response

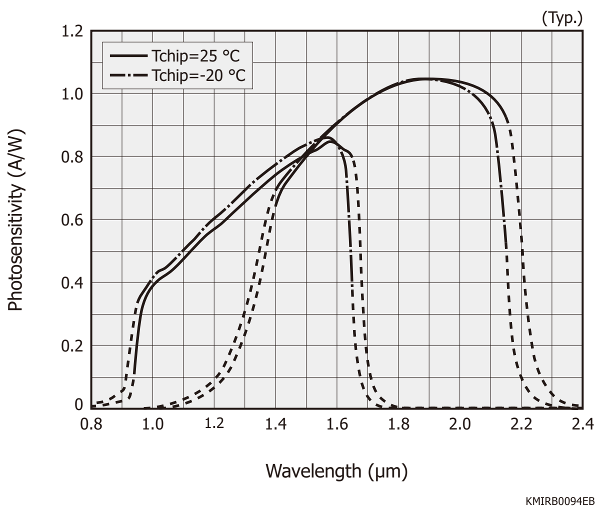
(a) For spectrophotometry



(b) For foreign object detection



(c) Hybrid type (G12230-512WB)



2 - 5 Photoresponse nonuniformity

InGaAs linear image sensors contain a large number of InGaAs photodiodes arranged in an array, yet sensitivity of each photodiode (pixel) is not uniform. This may result from crystal defects in the InGaAs substrate and/or variations in the processing and diffusion in the manufacturing process as well as inconsistencies in the CMOS charge amplifier arrays. For our InGaAs linear image sensors, variations in the outputs from all pixels measured when the effective photosensitive area of each photodiode is uniformly illuminated are referred to as photoresponse nonuniformity (PRNU) and defined as shown in equation (2-5).

$$PRNU = (\Delta X/X) \times 100\ [\%] \cdots\cdots\cdots\cdots (2\text{-}5)$$

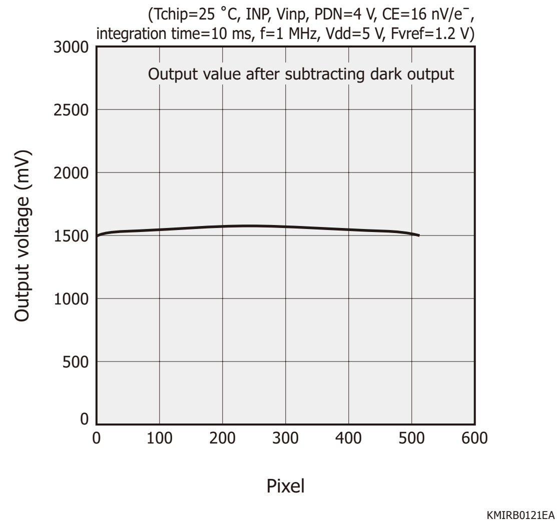
X : average output of all pixels
ΔX: absolute value of the difference between the average output X and the output of the maximum (or minimum) output pixel

In our outgoing product inspection for photoresponse nonuniformity, the output is adjusted to approx. 50% of the saturation output voltage and a halogen lamp or infrared LED is used as the light source. Since InGaAs linear image sensors use a compound semiconductor crystal for light detection, the photodiode array may contain crystal defects, resulting in abnormal output signals from some of the pixels (defect pixels). The photoresponse nonuniformity specification is ±5% to ±20%.

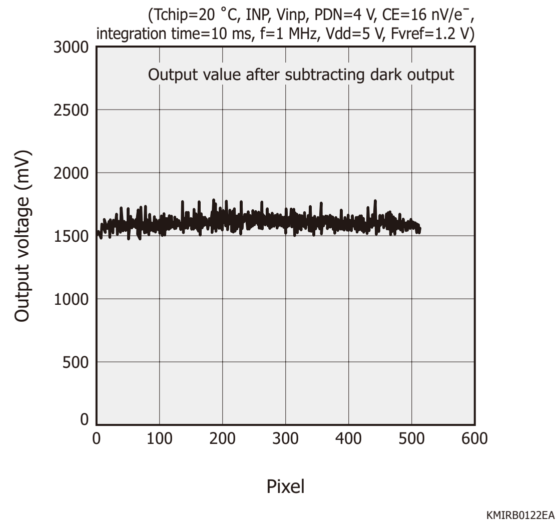
Scratches and dust on the light input window may also cause the sensitivity uniformity to deteriorate. So caution should be exercised on this point when handling image sensors. Figure 2-5 shows typical examples of photoresponse nonuniformity. These data were obtained by random sampling.

[Figure 2-5] Photoresponse nonuniformity (typical example)

(a) G11508-512SA



(b) G11478-512WB



2 - 6 Dark output

The dark output is the output generated even when no incident light is present. This output is caused by the dark current (sum of diffusion current, recombination current, and surface leakage current) of the photodiode, which flows to charge the charge amplifier and is converted into a voltage output. Dark current (I_D) and dark output (Vd) are expressed by equations (2-6) and (2-7).

$$Vd = I_D \times (Ts/Cf) + Voff \cdots\cdots\cdots\cdots (2\text{-}6)$$

Vd : dark output [V]
I_D : dark current [pA]
Ts : integration time [s]
Cf : integration capacitance [pF]
Voff: ROIC output offset voltage [V]

$$I_D = Cf \times \frac{Vd_1 - Vd_2}{Ts_1 - Ts_2} \cdots\cdots\cdots\cdots (2\text{-}7)$$

Vd_1: dark output at integration time Ts_1 [V]
Vd_2: dark output at integration time Ts_2 [V]

Since the upper limit of the sensor output is determined by the saturation output voltage, a large dark output narrows the dynamic range of the output signal. The output signal is the sum of the output generated by light and the dark output, so the purity of the output signal can be improved by using signal processing to subtract the dark output from each pixel.
The integration time must be determined by taking the magnitude of the dark output into account. When rewriting the above equation in terms of integration time (Ts) by substituting the saturation output voltage (Vsat) for the dark output (Vd), the maximum integration time (Tsmax) is expressed by equation (2-8).

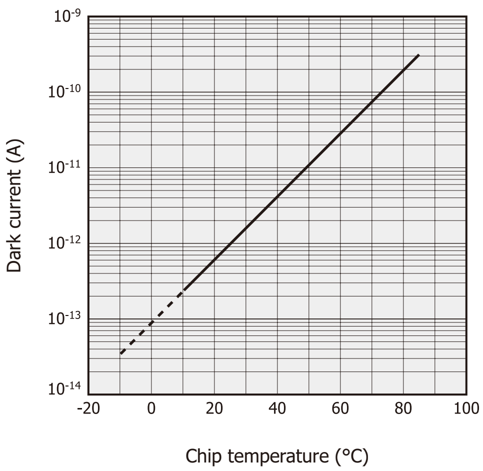
$$Tsmax = Cf \times Vsat/I_D \quad \cdots\cdots\cdots\cdots (2\text{-}8)$$

The band gap widens as the temperature decreases, so the number of carriers thermally excited into the conduction band from the valence band decreases, causing the dark current to reduce exponentially with the temperature. In our InGaAs linear image sensors, the temperature coefficient β of the dark current is 1.06 to 1.1. If the dark current at temperature T_1 (unit: °C) is I_{DT1} (unit: A), then the dark current I_{DT} at temperature T is given by equation (2-9).

$$I_{DT} = I_{DT1} \times \beta^{(T - T_1)} \text{ [A]} \quad \cdots\cdots\cdots\cdots (2\text{-}9)$$

Figure 2-6 shows dark current temperature characteristics (random sampling) of the type with a cutoff wavelength of 1.7 μm (G9204-512S). In addition to temperature, dark current changes depending on the reverse voltage applied from the ROIC to the InGaAs photodiodes, and temperature dependence of the reverse voltage.

[Figure 2-6] Dark current vs. chip temperature (G9204-512SA, typical example)



2 - 7 Noise

InGaAs linear image sensor noise can be largely divided into fixed pattern noise and random noise.
Fixed pattern noise includes photodiode dark current which is current noise from the DC component. The magnitude of the fixed pattern noise is constant even if readout conditions are changed, so it can be canceled by using an external signal processing circuit.
Random noise, on the other hand, results from fluctuations in voltage, current, or charge that are caused in the signal output process in the sensor. When the fixed pattern noise has been canceled by external signal processing, the random noise will then determine the InGaAs linear image sensor's lower detection limit or lower limit of dynamic range.
Random noise includes the following five components:

① Dark current shot noise (Nd)
② Signal current shot noise at light input (Ns)
③ Photodiode Johnson noise (Nj)
④ Charge amplifier reset noise (Nr)
⑤ CMOS charge amplifier readout noise (N_R)

Normally, reset noise of the charge amplifier in ④ is dominant, but reset noise can be significantly reduced with a CDS circuit. The main components of dark state noise are shot noise due to dark current in ①, Johnson noise from photodiodes in ③, and readout noise from the CMOS charge amplifier in ⑤. Dark current shot noise results from erratic generation of the output charge due to dark current. This noise becomes larger as the output charge due to dark current increases, and therefore varies depending on operating conditions such as integration time and temperature. Johnson noise from the photodiodes is caused by the thermal noise current of the photodiode shunt resistance Rsh.
Shot noise in ② is caused by fluctuations due to irregular arrival of photons when there is incident light.
The total noise (N) is expressed by equation (2-10).

$$N = \sqrt{Nd^2 + Ns^2 + Nj^2 + N_R^2} \quad \cdots\cdots\cdots\cdots (2\text{-}10)$$

The dark current shot noise (Nd) and signal current shot noise at light input (Ns) can be expressed as equations (2-11)(2-12) by representing them as an "equivalent input noise charge" which is a value converted to a charge quantity for input to the image sensor.

$$Nd = \sqrt{\frac{2I_D \times Ts}{q}} \text{ [e}^- \text{ rms]} \quad \cdots\cdots\cdots\cdots (2\text{-}11)$$

$$Ns = \sqrt{\frac{2Is \times Ts}{q}} \text{ [e}^- \text{ rms]} \quad \cdots\cdots\cdots\cdots (2\text{-}12)$$

q : electron charge[C]
I_D : dark current [A]
Ts: integration time [s]
Is : signal current by light input [A]

The thermal noise current (Ij) of photodiodes is expressed by equation (2-13).

$$Ij = \sqrt{\frac{4k \times T}{Rsh \times Ts}} \text{ [A]} \cdots\cdots\cdots\cdots (2\text{-}13)$$

k : Boltzmann's constant [J/K]
T : absolute temperature [K]
Rsh: shunt resistance of the photodiode [Ω]
Ts : Integration time [s]

We specify the noise level in InGaAs linear image sensors as fluctuations in the output voltage of each pixel by using root-mean-square noise voltage (V rms) units. Converting equations (2-11)(2-12)(2-13) into voltage therefore gives equations (2-14)(2-15)(2-16), respectively.

$$Nd = \frac{\sqrt{2q \times I_D \times Ts}}{Cf} \text{ [V rms]} \cdots\cdots\cdots (2\text{-}14)$$

$$Ns = \frac{\sqrt{2q \times Is \times Ts}}{Cf} \text{ [V rms]} \cdots\cdots\cdots (2\text{-}15)$$

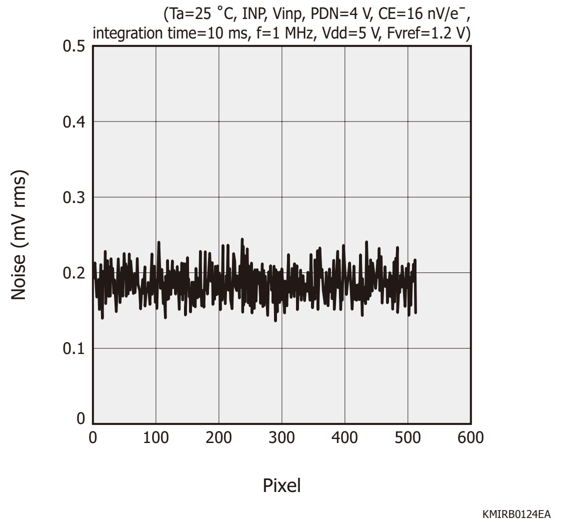
$$Nj = \sqrt{\frac{4k \times T \times Ts}{Rsh \times Cf^2}} \text{ [V rms]} \cdots\cdots\cdots\cdots (2\text{-}16)$$

Cf: integration capacitance of charge amplifier [F]

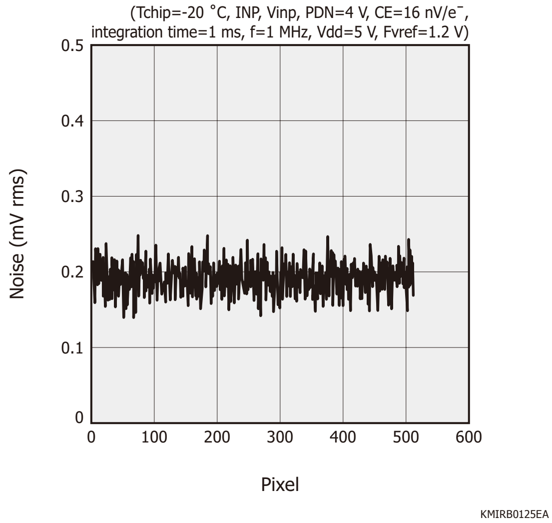
When the CMOS charge amplifier readout noise (Nread) is measured at Ta=25 °C using an integration time of 1 ms, a data rate of 1 MHz, and an integration count of 50, the standard deviation in the G11508-512SA is calculated to be 190 µV rms at Cf=10 pF and 250 µV rms at Cf=1 pF. The noise levels listed in the datasheet are measured at Tchip=25 °C and integration time of 0.1 to 20 ms, or Tchip=-10 °C or lower and integration time of 1 ms or less. Figure 2-7 shows noise output fluctuations measured with the G11508-512SA and G11478-512WB with no incident light. These data were obtained by random sampling.

[Figure 2-7] Noise output fluctuations (typical example)

(a) G11508-512SA



(b) G11478-512WB



3. How to use

This section explains how to use and operate InGaAs linear image sensors including handling precautions and setting drive conditions.

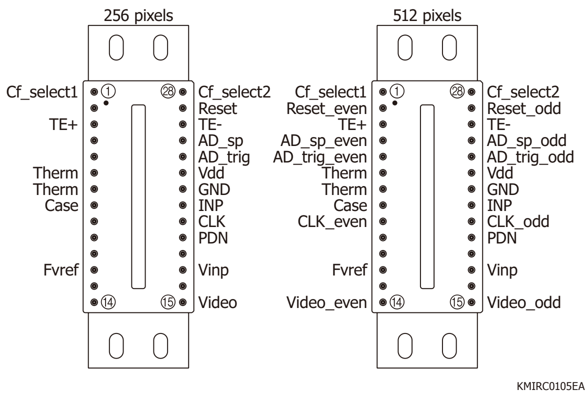
3 - 1 Setups

InGaAs liner image sensors include a TE-cooled type and a non-cooled type, and also a type with a built-in thermistor and a type without a thermistor. The drive method is the same for all except for whether or not cooling is provided.

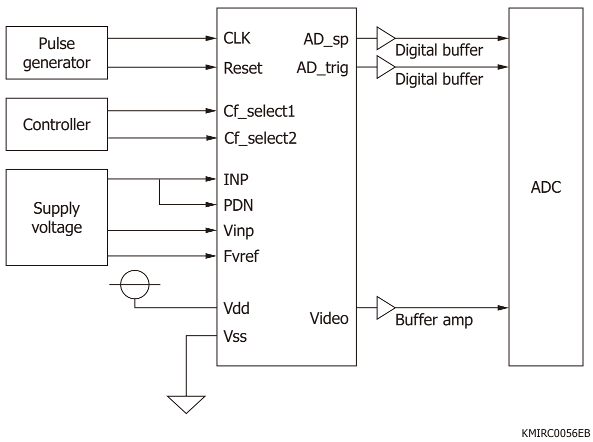
(1) Connections

Make connections by referring to Figures 3-1 and 3-2 and to Table 3-1.

[Figure 3-1] Pin connections (G11508/G11475 to G11478 series, top view)



[Figure 3-2] Setup diagram (G11508/G11475 to G11478 series)



Power supply

Connect Vdd to the power supply for both analog and digital. In addition, connect INP, PDN, Vinp, and Fvref to an analog power supply. Use these power supplies with low noise and low ripple as much as possible, and make the wiring as thick as possible, so the power supply line has low impedance. Noise generated here can be a factor in determining the ultimate noise level. When incorporating this part into a device, connect to a ground with consideration for the potential difference of other devices.

Pulse generator

Connect a pulse generator that supplies the two types of signals (CLK, Reset), which are needed to drive the InGaAs linear image sensor.

[Table 3-1] Terminal functions and recommended connections (G11475 to G11478 series)

Terminal name	Input/output	Function and recommended connection
CLK	Input	Clock pulse for operating the CMOS shift register
Reset	Input	Reset pulse for initializing the feedback capacitance in the charge amplifier formed on the CMOS chip. The width of the reset pulse is the integration time.
Vdd	Input	Supply voltage for operating the signal processing circuit on the CMOS chip
GND	Input	Ground for the signal processing circuit on the CMOS chip (0 V)
Case	Input	Connect to GND.
INP	Input	Reset voltage for the charge amplifier array on the CMOS chip
PDN	Input	Cathode bias terminal of InGaAs photodiode
Vinp	Input	Video line reset voltage
Fvref	Input	Differential amplifier reference voltage on the CMOS chip
AD_sp	Output	Digital start signal for A/D conversion
AD_trig	Output	Sampling sync signal for A/D conversion
Video	Output	Analog video signal
Cf_select	Input	Voltage that determines the feedback capacitance (Cf) on the CMOS chip
Therm	Output	Thermistor terminal for monitoring temperature inside the package
TE+, TE-	Input	Power supply terminal for the thermoelectric cooler for cooling the photodiode array

▸ Oscilloscope

Connect the Video terminal to the input terminal of the oscilloscope. To synchronize video signal, input reset pulse from the pulse generator to the Ext.trig terminal of the oscilloscope. When doing this, use an external circuit to buffer the video signal. Be sure to use shielded cables to prevent the effect of external noise. Be sure to connect it to an oscilloscope to check whether the linear image sensor is operating normally.

▸ A/D converter

When inputting video signal to an A/D converter, use video signal and AD_trig. Carefully check the specifications of the A/D converter before connecting the device to the A/D converter.

▸ Power supply for thermoelectric cooler

The temperature control circuit monitors the resistance value of the thermistor inside the linear image sensor package, in order to determine how much power to supply to the TE-cooler. Use the power supply with low noise and low ripple as much as possible, and make the wiring as thick as possible, so the power supply line has low impedance. The TE+ and TE- wires in particular must be sufficiently thick (<18 awg). Take care so as not to do faulty wiring for the TE-cooler.

(3) Heatsink

▸ Selecting a heatsink

When cooling a one-stage thermoelectrically cooled device to -10 °C, select a heatsink of 0.5 °C/W or less including a safety margin. When cooling a two-stage thermoelectrically cooled device to -20 °C, select a heatsink of 0.4 °C/W or less.
Equipment should be carefully designed so that the heatsink is not placed where heat builds up. Provide good air ventilation to allow heat emitted from the heatsink to sufficiently dissipate by installing air fans and ventilation ducts. Note that the heatsink thermal resistance varies according to forced air cooling.

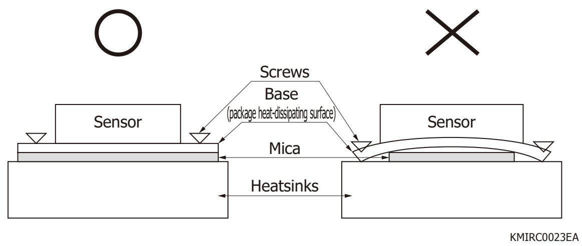
▸ Heatsink mounting method

To allow the thermoelectric cooler to exhibit fullest cooling capacity, the heatsink must be mounted correctly onto the sensor package. Mount the heatsink while taking the following precautions.

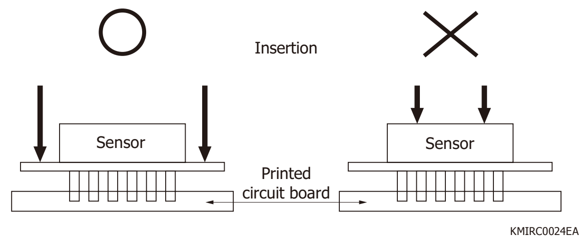
- Check that the heatsink attachment surface and the heat-dissipating surface of the InGaAs image sensor package are clean and flat.
- Mount the heatsink so that it makes tight contact with the entire heat-dissipating surface of the package. The heat-dissipating surface area should be large to improve the cooling efficiency and prevent possible damage.
- Apply a thin coat of heat-conductive grease uniformly over the attachment surface in order to lower thermal resistance between the package heat-dissipating surface and the heatsink. When fastening screws, alternately tighten the left and right screws slowly so that thermal conductive grease spreads out adequately. When a mica sheet is used, it must also make contact with the entire heat-dissipating surface of the package. The cooling efficiency will degrade if the sensor package is fastened to the heatsink with screws while the mica sheet is still too small to cover the screw positions. This may also warp the package base, causing damage to the TE-cooler [Figure 3-3 (a)].
- Do not press on the upper side of the package when fastening the sensor package to the heatsink or printed circuit board. If stress is applied to the light input window, this may cause the window to come off or may impair airtightness of the package [Figure 3-3 (b)].

[Figure 3-3] Sensor mounting method

(a) Example 1



(b) Example 2



(4) Video signal monitoring

The image sensor output end does not have drive capability, so in order to monitor the video signal, the sensor output should be amplified by a buffer amplifier and then fed to an oscilloscope.

3 - 2 Drive method

Sensor operation should be checked in a dark state. Block the light falling on the photosensitive area before checking operation.

(1) Turning on power to the driver circuit

First check the voltages (Vdd, INP, Vinp, etc.) supplied to the sensor, and then turn the power on. At this point, also check that the current values are correct.

If excessive current is flowing, the power supply line might be shorted so immediately turn off the power and check the power supply line.

(2) Inputting control signals from the pulse generator

While referring to the timing chart shown in Figure 3-4, input the control signals from the pulse generator to the InGaAs linear image sensor (G11508/G11475 to G11478/G14714 series). Two control signals (CLK and Reset) are input to the image sensor and must be H-CMOS level inputs. The image sensor may malfunction if other control signal levels are used. The CLK frequency determines the video signal readout frequency, and the Reset pulse interval determines the integration time. Normal operation is performed whether the CLK and Reset signals are synchronized or not.

(3) Setting the drive timing

▸ Example 1: When operating the InGaAs linear image sensors G11508/G11475 to G11478 series at CLK frequency of 1 MHz

The G11508/G11475 to G11478 series use an integration then readout (ITR) method. Since the video signal readout frequency is the same as the CLK signal frequency, the readout time (tr) per pixel is 1 µs. The time required for one readout is therefore given by equation (3-1).

$$\begin{aligned} tscan &= (tc \times 28) + (tr \times N) \cdots\cdots (3\text{-}1) \\ &= 1\,[\mu s] \times 28 + 1\,[\mu s] \times 256 \\ &= 284\,[\mu s] \end{aligned}$$

tc: CLK period
N: number of pixels

Line rate is calculated using integration time [high period of Reset in Figure 3-4 (a)] and reset time [low period of Reset in Figure 3-4 (a)]. In this case, it is necessary to set reset time longer than the readout time calculated with equation (3-1), so set the reset time to >284 µs. The readout time becomes slightly longer depending on the reset pulse width and the synchronization with the CLK.
Since the maximum CLK frequency is 5 MHz and the minimum integration time is 6 CLK for the G11508/G11475 to G11478 series, the maximum line rate is expressed by equation (3-2).

$$\begin{aligned} \text{Maximum line rate} &= 1/(\text{Minimum integration time} + \text{Minimum tscan}) \cdots\cdots (3\text{-}2) \\ &= 1/(1.2\,[\mu s] + 56.8\,[\mu s]) \\ &= 17241\,[\text{lines/s}] \end{aligned}$$

The longer the integration time, the lower the line rate.

▸ Example 2: When operating the InGaAs linear image sensor G14714 series at a CLK frequency of 15 MHz

The G14714 series is designed for foreign object detection. It uses an integration while readout (IWR) method in order to support high-speed readout. During integration, it does readout of the signal stored in the previous frame. Since the video signal readout frequency equals the CLK signal frequency, the readout time (tr) per pixel is 66.7 ns. The time (tscan) required for one integration and readout is therefore given by equation (3-3). This time may be slightly longer, depending on the pulse width of Reset and the way Reset and CLK are synced.

$$\begin{aligned} tscan &= (tc \times 6) + 3\,[\mu s] + (tr \times N) \cdots\cdots (3\text{-}3) \\ &= 66.7\,[ns] \times 6 + 3\,[\mu s] + 66.7\,[ns] \times 256 \\ &= 20.48\,[\mu s] \end{aligned}$$

tc: CLK period
N: number of pixels

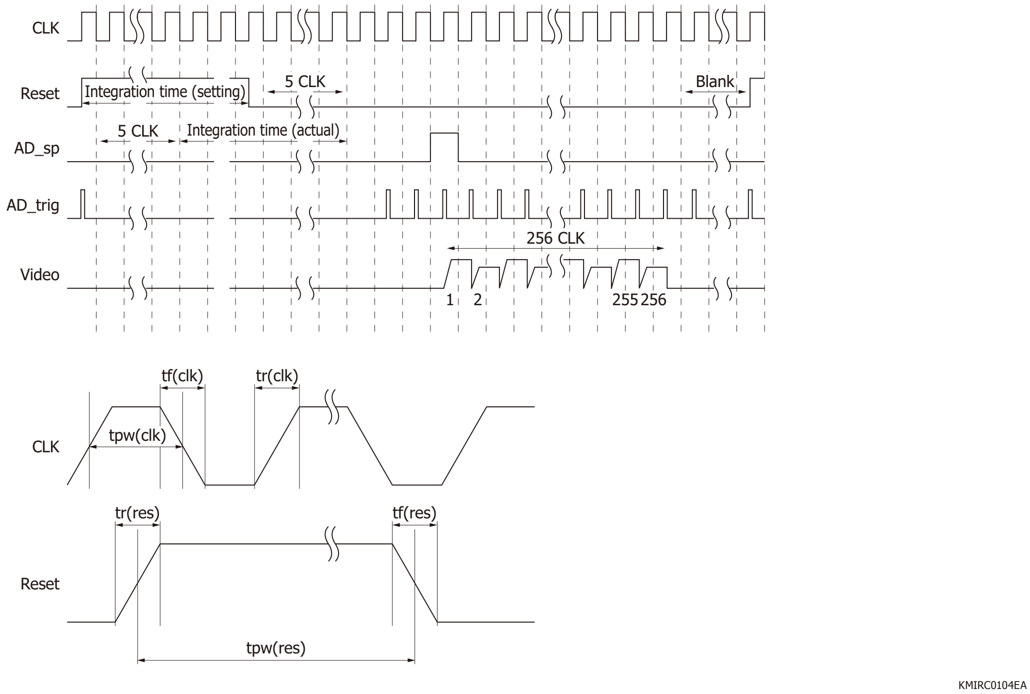
Line rate is calculated using integration time, readout time (high period of Reset [Figure 3-4 (b)]), and reset time (low period of Reset [Figure 3-4 (b)]). At this point, set the reset time to 4 µs or more. Since the maximum CLK frequency is 15 MHz for the G14714 series, the maximum line rate is expressed by equation (3-4).

$$\begin{aligned} \text{Maximum line rate} &= 1/(\text{Minimum tscan} + \text{Minimum reset time}) \cdots\cdots (3\text{-}4) \\ &= 1/(20.48\,[\mu s] + 4\,[\mu s]) \\ &= 40850\,[\text{lines/s}] \end{aligned}$$

Set sampling period for video signal in the range between 84 and 96 ns after the 4th CLK, which is 4th falling edge from the CLK fall immediately after the rising edge of Reset.

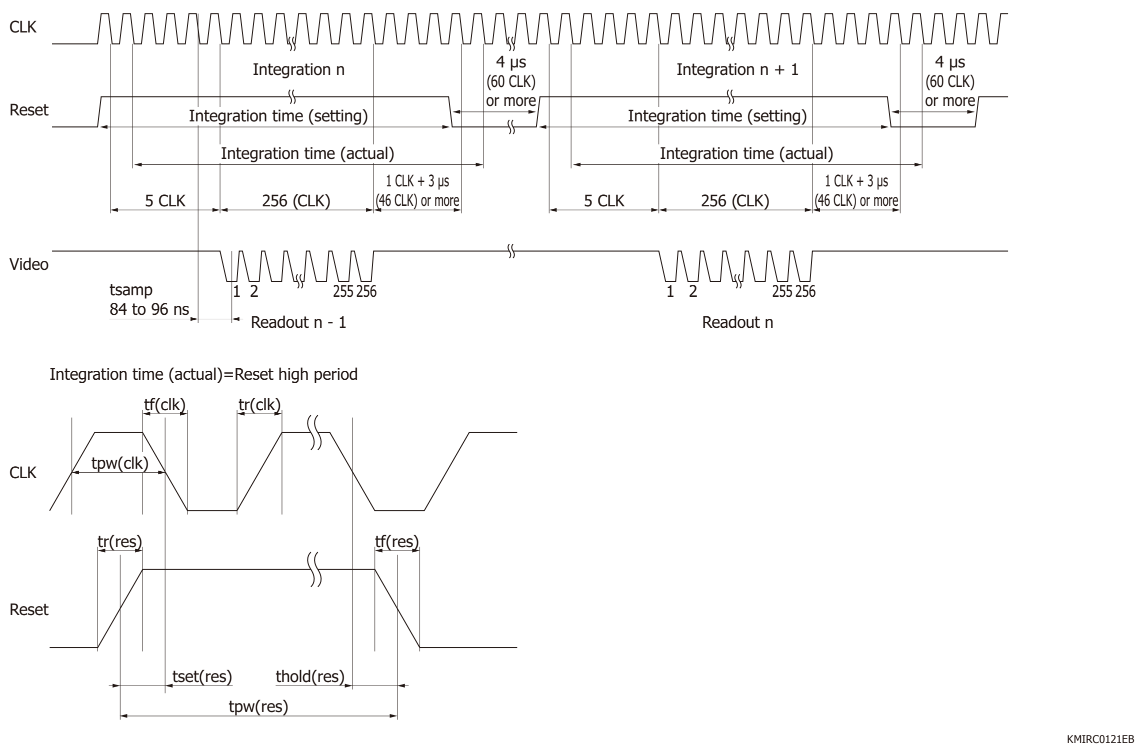
[Figure 3-4] Timing chart

(a) G11508/G11475 to G11478 series (integration then readout method, each video line)



Parameter		Symbol	Min.	Typ.	Max.	Unit
Clock pulse frequency		fop	0.1	1	5	MHz
Clock pulse width		tpw(clk)	60	500	5000	ns
Clock pulse rise/fall times		tr(clk), tf(clk)	0	20	30	ns
Reset pulse width	High	tpw(res)	6	-	-	clocks
	Low		284	-	-	
Reset pulse rise/fall times		tr(res), tf(res)	0	20	30	ns

(b) G14714 series (integration while readout method)



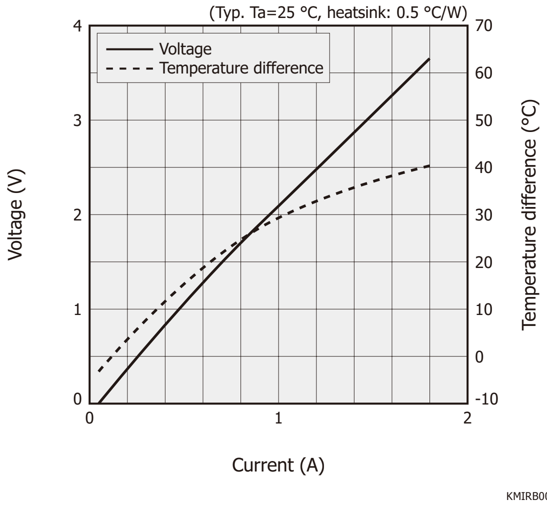
Parameter		Symbol	Min.	Typ.	Max.	Unit
Operating frequency		fop	0.1	-	15	MHz
Clock pulse width		tpw(clk)	-	33.3	5000	ns
Clock pulse rise/fall times		tr(clk), tf(clk)	0	5	10	ns
Reset pulse width	High	tpw(res)	262 CLK + 3 μs	-	-	-
	Low		4 μs	-	-	
Reset pulse rise/fall times		tr(res), tf(res)	0	10	20	ns
Clock setup time		tset(res)	10	-	-	ns
Clock hold time		thold(res)	10	-	-	ns

(4) Turning on the power supply for the thermoelectric cooler

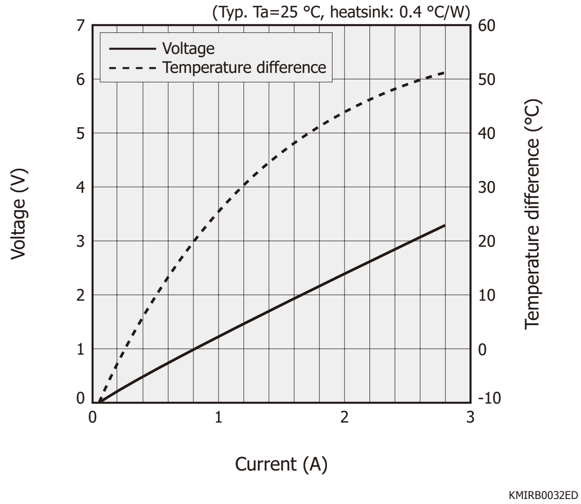
Use extra caution to avoid damaging the image sensor when turning on the power to the thermoelectric cooler. Take the following precautions when designing a power supply circuit for the thermoelectric cooler.

· Never exceed the absolute maximum ratings for the thermoelectric cooler.
· Make sure that the power supply voltage and connection polarity are correct. Turning on the power supply with the wrong voltage or polarity will damage the image sensor.
· A power supply with the lowest possible noise and ripple should be used. Also, use power supply wires thick enough to keep impedance as low as possible. The TE+ and TE- wires in particular must be sufficiently thick.
· Be sure to provide an over-current safeguard circuit to protect the thermoelectric cooler from being damaged.
· Provide a protection circuit that monitors the temperature on the heat-emitting side of the heatsink to prevent the heatsink temperature from exceeding the specified level due to excessive cooling.
· While referring to Figures 3-5 and 3-6, set the optimum voltage and current values that maintain the target temperature.

[Figure 3-5] Temperature characteristics of one-stage thermoelectrically cooled device



[Figure 3-6] Temperature characteristics of two-stage thermoelectrically cooled device



4. Driver circuit

Figure 4-1 shows the recommended driver circuit for the InGaAs linear image sensors G11508/G11475 to G11478 series.

» Precautions on circuit preparation

(1) Bias generation circuit

- We recommend using a circuit structure that applies the voltage buffered by the amplifiers. Noise can be suppressed by limiting the bandwidth of the amplifiers appropriately. We recommend inserting an RC filter after the amplifier output (e.g., 10 Ω, 0.1 μF, f=approx. 160 kHz).
- The InGaAs image sensor can be driven using only the voltage generated by resistance voltage divider. However, we do not recommend this, because characteristics such as linearity will degrade due to the response speed and impedance.
- Use an op amp with adequate phase margin (AD8031, etc.). If the phase margin is inadequate, the op amp may oscillate depending on the bypass capacitor.
- We do not recommend linear regulators because they have insufficient ability to draw current and degrade characteristics such as linearity.
- The stability of the bias voltage affects the sensor noise, so make sure to check with an oscilloscope.
- A relatively large current may flow momentarily through the bias generation circuit. Use a voltage source that can supply at least 10 times the maximum value of the supply current shown on the datasheet.

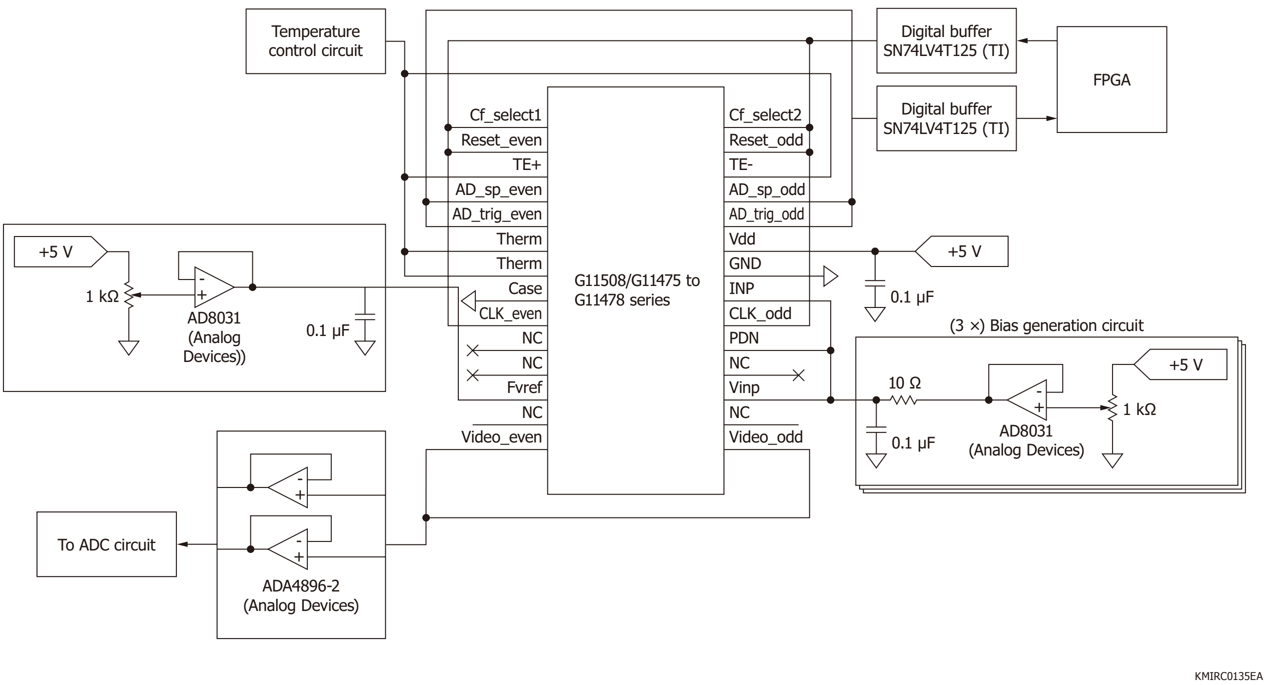
(2) Power supply

- Supply power from a stable external power supply or power supply circuit.
- Decouple with a capacitor (0.1 μF) near the sensor terminal.
- Be careful, as a relatively large current may flow momentarily, and if a choke coil is used, then a voltage drop may occur.

(3) Readout circuit

- The sensor has a relatively high output impedance, so buffer it near the sensor output end.
- To reduce noise, keep the bandwidth of the readout circuit at three to ten times the pixel rate (we recommend about five times).

[Figure 4-1] Recommended driver circuit (analog front end circuit)

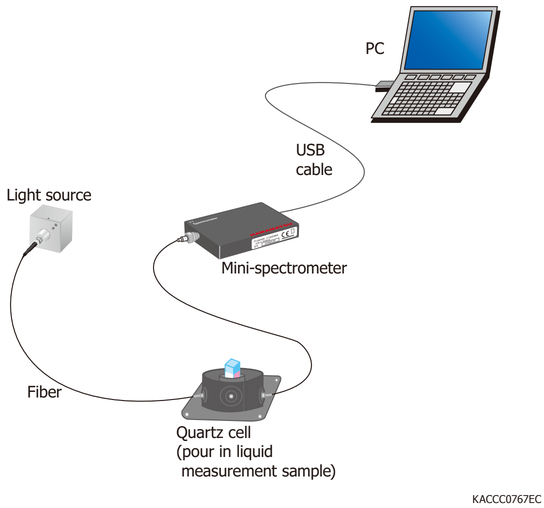


5. Applications

5 - 1 Mini-spectrometers

Hamamatsu offers mini-spectrometers with an InGaAs linear image sensor. Spectrum data can be acquired by guiding measurement light into a mini-spectrometer through an optical fiber and transferring the measured results to a PC via the USB connection. Since there are no moving parts inside the device, constantly stable measurements can be expected. Moreover, the optical guiding section uses an optical fiber making connection to the measured object flexible.

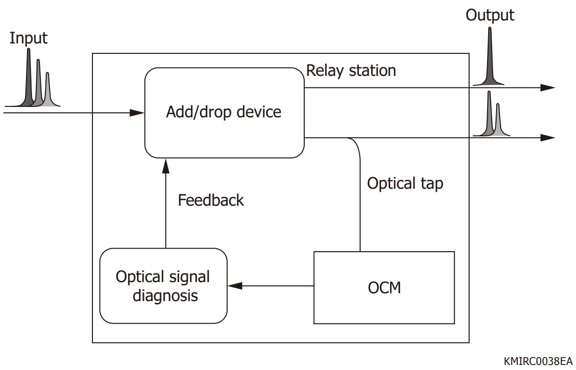
[Figure 5-1] Connection example of mini-spectrometer (transmitted light measurement)



5 - 2 Optical channel monitors

Devices called optical channel monitors (OCM) fulfill an important role in monitoring the signal wavelength and power on wavelength division multiplexing (WDM) networks that carry huge quantities of information. InGaAs linear image sensors used in the OCM detect light spatially separated by spectral-dispersion elements.

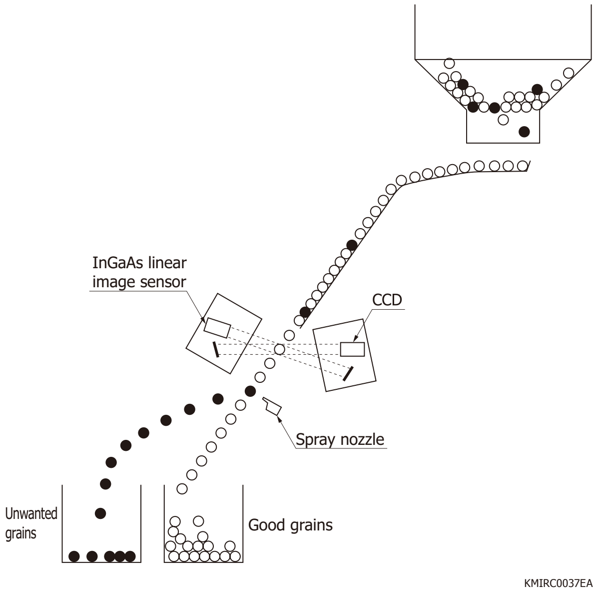
[Figure 5-2] Schematic of optical channel monitor



5 - 3 Grain sorters

Grain sorters irradiate light onto the falling grain, identify unwanted items from the reflected or transmitted light, and then remove those from the grain by high-pressure air spray. Using InGaAs linear image sensors in the grain sorter allows simultaneously identifying multiple grain types while analyzing grain components.

[Figure 5-3] Schematic of grain sorter



Information described in this material is current as of May 2021.
Product specifications are subject to change without prior notice due to improvements or other reasons. This document has been carefully prepared and the information contained is believed to be accurate. In rare cases, however, there may be inaccuracies such as text errors. Before using these products, always contact us for the delivery specification sheet to check the latest specifications.
The product warranty is valid for one year after delivery and is limited to product repair or replacement for defects discovered and reported to us within that one year period. However, even if within the warranty period we accept absolutely no liability for any loss caused by natural disasters or improper product use.

HAMAMATSU

www.hamamatsu.com

HAMAMATSU PHOTONICS K.K., Solid State Division
1126-1 Ichino-cho, Higashi-ku, Hamamatsu City, 435-8558 Japan, Telephone: (81)53-434-3311, Fax: (81)53-434-5184
U.S.A.: Hamamatsu Corporation: 360 Foothill Road, Bridgewater, N.J. 08807, U.S.A., Telephone: (1)908-231-0960, Fax: (1)908-231-1218, E-mail: usa@hamamatsu.com
Germany: Hamamatsu Photonics Deutschland GmbH: Arzbergerstr. 10, D-82211 Herrsching am Ammersee, Germany, Telephone: (49)8152-375-0, Fax: (49)8152-265-8, E-mail: info@hamamatsu.de
France: Hamamatsu Photonics France S.A.R.L.: 19, Rue du Saule Trapu, Parc du Moulin de Massy, 91882 Massy Cedex, France, Telephone: (33)1 69 53 71 00, Fax: (33)1 69 53 71 10, E-mail: infos@hamamatsu.fr
United Kingdom: Hamamatsu Photonics UK Limited: 2 Howard Court, 10 Tewin Road, Welwyn Garden City, Hertfordshire AL7 1BW, UK, Telephone: (44)1707-294888, Fax: (44)1707-325777, E-mail: info@hamamatsu.co.uk
North Europe: Hamamatsu Photonics Norden AB: Torshamnsgatan 35 16440 Kista, Sweden, Telephone: (46)8-509 031 00, Fax: (46)8-509 031 01, E-mail: info@hamamatsu.se
Italy: Hamamatsu Photonics Italia S.r.l.: Strada della Moia, 1 int. 6, 20044 Arese (Milano), Italy, Telephone: (39)02-93 58 17 33, Fax: (39)02-93 58 17 41, E-mail: info@hamamatsu.it
China: Hamamatsu Photonics (China) Co., Ltd.: 1201 Tower B, Jiaming Center, 27 Dongsanhuan Beilu, Chaoyang District, 100020 Beijing, P.R.China, Telephone: (86)10-6586-6006, Fax: (86)10-6586-2866, E-mail: hpc@hamamatsu.com.cn
Taiwan: Hamamatsu Photonics Taiwan Co., Ltd.: 8F-3, No. 158, Section2, Gongdao 5th Road, East District, Hsinchu, 300, Taiwan R.O.C. Telephone: (886)3-659-0080, Fax: (886)3-659-0081, E-mail: info@hamamatsu.com.tw

Cat. No. KMIR9001E03 May 2021 DN