

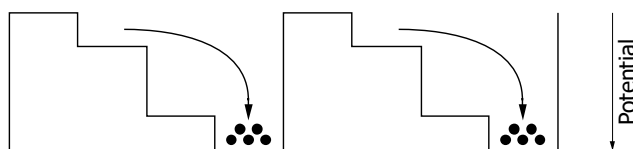
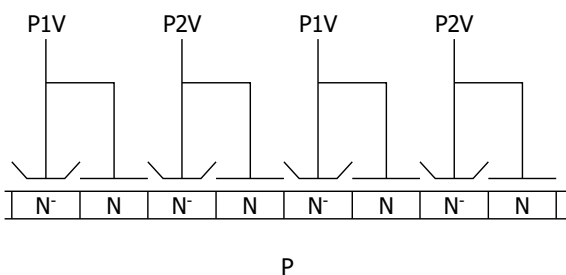
Resistive gate type CCD linear image sensor with electronic shutter function

1. Features

- Long photosensitive area, high-speed transfer of charges from the photosensitive area, small image lag

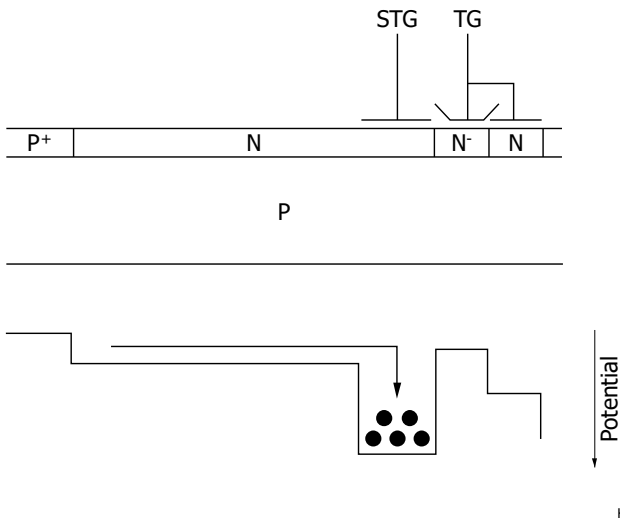
In ordinary CCD image sensors, one pixel contains multiple electrodes and a signal charge is transferred by applying different clock pulses to those electrodes [Figure 1]. In photodiode type CCD linear image sensors, because there is no potential slope in the active area, very large image lag occurs for rectangular pixels [Figure 2]. In resistive gate structures, a single high-resistance electrode is formed in the active area, and a signal charge is transferred by means of a potential slope that is created by applying different voltages across the electrode [Figure 3]. Compared to a CCD area image sensor which is used as a linear sensor by line binning, a resistive gate type CCD linear image sensor offers higher speed transfer of charges in the photosensitive area. In addition, compared to photodiode types, resistive gate types can transfer charges with small image lag in a short period of time even for long photosensitive areas.

[Figure 1] Schematic diagram and potential of ordinary 2-phase drive CCD area image sensor

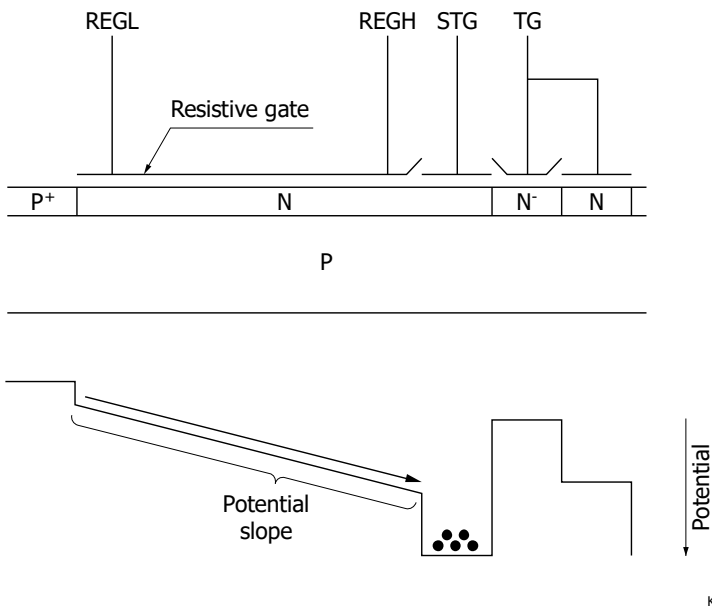


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[Figure 2] Schematic diagram and potential of photodiode type CCD linear image sensor



[Figure 3] Schematic diagram and potential of resistive gate type CCD linear image sensor



- Electronic shutter

The electronic shutter function can be used to accumulate a signal charge in as short a time as a few microseconds. The shutter timing can be synchronized with an external trigger (see "4. Electronic shutter and anti-blooming").

- Anti-blooming function

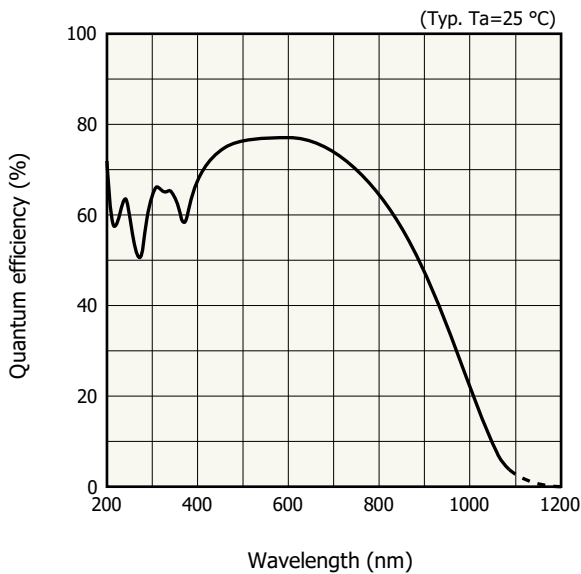
Setting the all reset gate voltage enables controlling of not only the electronic shutter but also the anti-blooming function (see "4. Electronic shutter and anti-blooming").

- Capable of both non-MPP operation and MPP operation

When performing repeated measurements over a short integration time (e.g., 1 ms or less) in which dark current can be ignored, use the sensor in the state where a potential slope is always formed at all times (non-MPP operation). On the other hand, when accumulating over a long integration time, dark current may be a problem. In this situation, apply a specific voltage to the resistive gate during integration. This will set the portions under the resistive gate to the inverted state, thus reducing the dark current (MPP operation, see "5. Non-MPP operation and MPP operation").

- High sensitivity over a wide spectral range, nearly flat spectral response [Figure 4]

[Figure 4] Spectral response (without window)

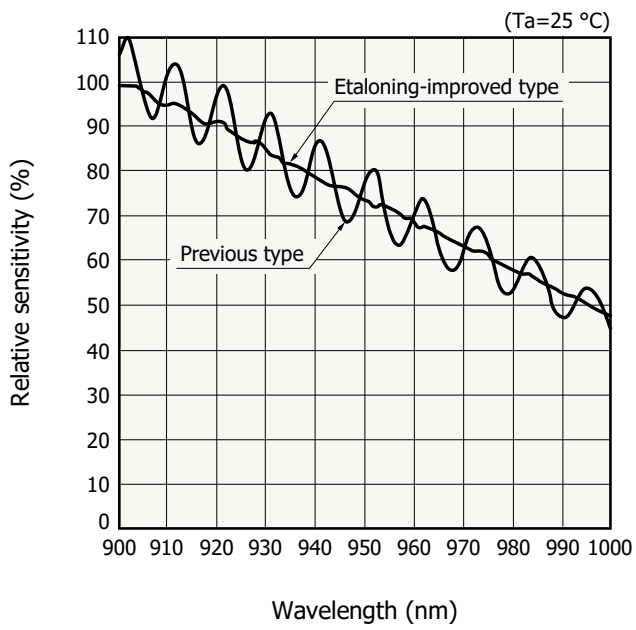


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- Low etaloning

With back-thinned CCDs, when the incident light has a long wavelength, etaloning may occur due to interference. This product uses a back-thinned CCD, but etaloning is reduced by adopting our unique structure that is less prone to interference [Figure 5].

[Figure 5] Etaloning characteristics (typical example)



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[Table 1] Comparison of CCDs with similar pixel sizes (Typ.)

Product name	CCD area image sensor		Resistive gate type CCD linear image sensor with electronic shutter function	
	Type no.	S10420-1106-01	S11071-1106	S11155/S11156-2048
			-01 (Previous type)	-02 (Improved type)
Features	<ul style="list-style-type: none"> • Low dark current • High sensitivity • No image lag • Low noise 	<ul style="list-style-type: none"> • Low dark current • High sensitivity • No image lag • High-speed readout 	<ul style="list-style-type: none"> • High-speed readout • Long photosensitive area • Small image lag • Electronic shutter function 	
Application example	Spectrophotometry (low-level light)	Spectrophotometry (low-level light)	Spectrophotometry (low to high-level light)	
CCD type	Back-thinned type	Back-thinned type	Back-thinned type	
Photosensitive area structure	CCD	CCD	Resistive gate type CCD	
Pixel pitch	14 μm	14 μm	14 μm	
Photosensitive area length	896 μm	896 μm	S11155 series: 500 μm S11156 series: 1000 μm	
CCE	6.5 μV/e ⁻	8 μV/e ⁻	8 μV/e ⁻	10 μV/e ⁻
Full well capacity	300 ke ⁻	200 ke ⁻	200 ke ⁻	
Dark current (MPP operation)	3.5 ke ⁻ /pixel/s (full line binning)	3.5 ke ⁻ /pixel/s (full line binning)	S11155 series: 4 ke ⁻ /pixel/s S11156 series: 8 ke ⁻ /pixel/s	S11155 series: 10 ke ⁻ /pixel/s S11156 series: 15 ke ⁻ /pixel/s
Dark current (non-MPP operation)	-	-	S11155 series: 50 ke ⁻ /pixel/s S11156 series: 100 ke ⁻ /pixel/s	S11155 series: 100 ke ⁻ /pixel/s S11156 series: 200 ke ⁻ /pixel/s
Readout noise	6 e ⁻ rms	30 e ⁻ rms	30 e ⁻ rms	
Dynamic range	50000	6670	6670	
Output circuit	Low-noise amp	High-speed amp	High-speed amp	
Pixel rate	0.25 MHz typ.	5 MHz typ.	5 MHz typ.	
Line rate	0.1 kHz typ. (full line binning)	0.65 kHz typ. (full line binning)	2 kHz typ.	
Integration time*1	5 ms to 40 s	1.3 ms to 30 s	2 μs to 1 ms (Non-MPP operation) 1 ms to 7 s (MPP operation)	
Image lag*2	None	None	0.1% typ., 1% max.	
Electronic shutter	None	None	Yes	
Readout time of charges in the photosensitive area*3	-	-	S11155 series: 80 μs S11156 series: 300 μs	S11155 series: 5 μs S11156 series: 20 μs
Anti-blooming function	Yes (horizontal register)	Yes (horizontal register)	Yes (storage gate)	
Horizontal register light shield	-	-	Light shielding property on -02 is better than -01.*4	

*1: Varies depending on the operating conditions

*2: Varies depending on the light incident conditions and sensor operating conditions (see "6. Unread charges")

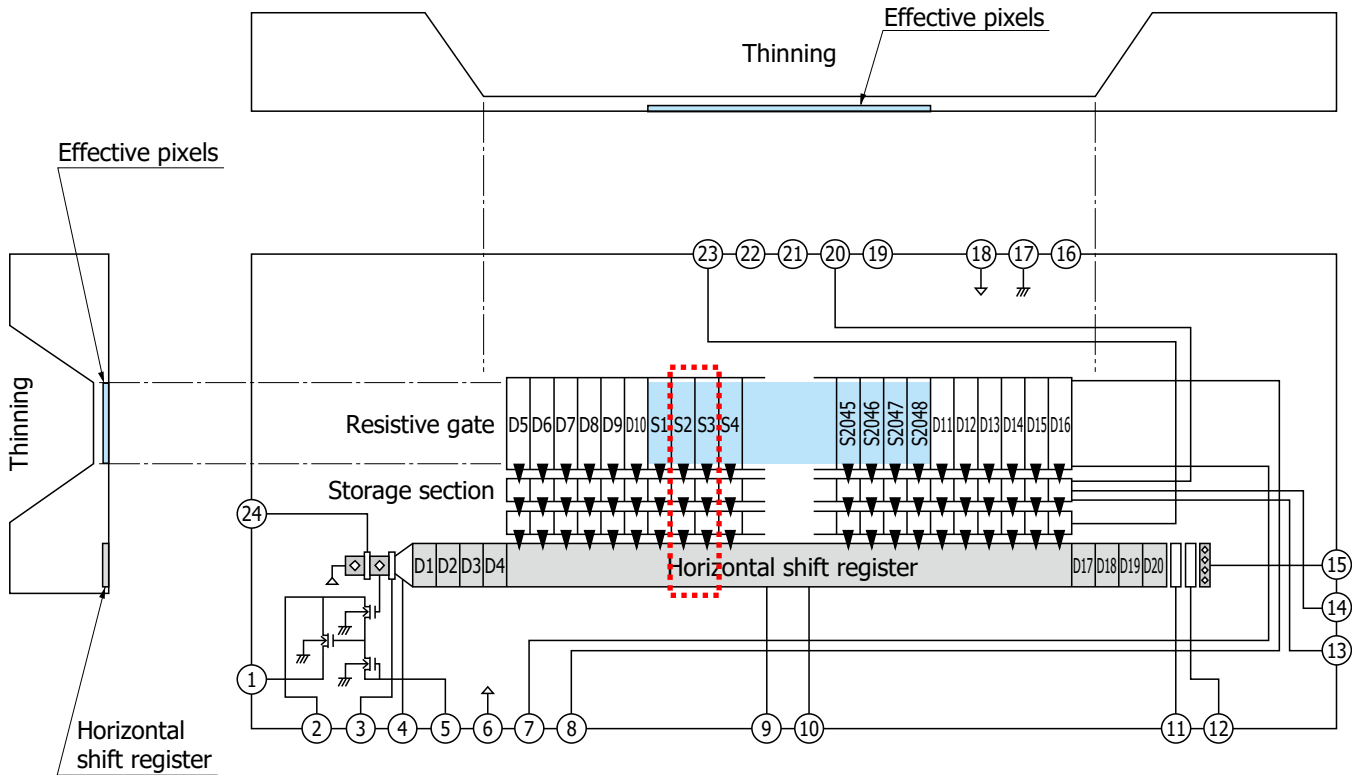
*3: Time when image lag in the photosensitive area becomes 0.1% typical or less

*4: See "(3) Light shielding of the horizontal shift register in 12. Other information"

2. Device structure

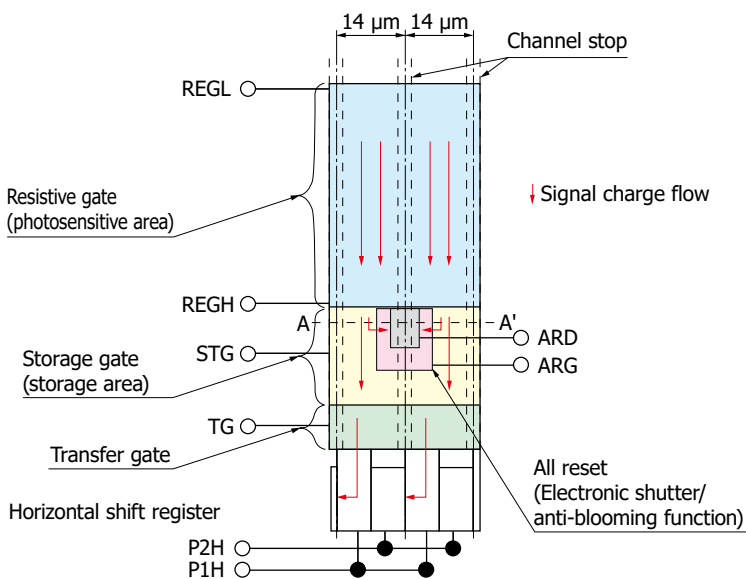
[Figure 6] Device structure (S11155/S11156-2048-01)

(a) Entire device drawing



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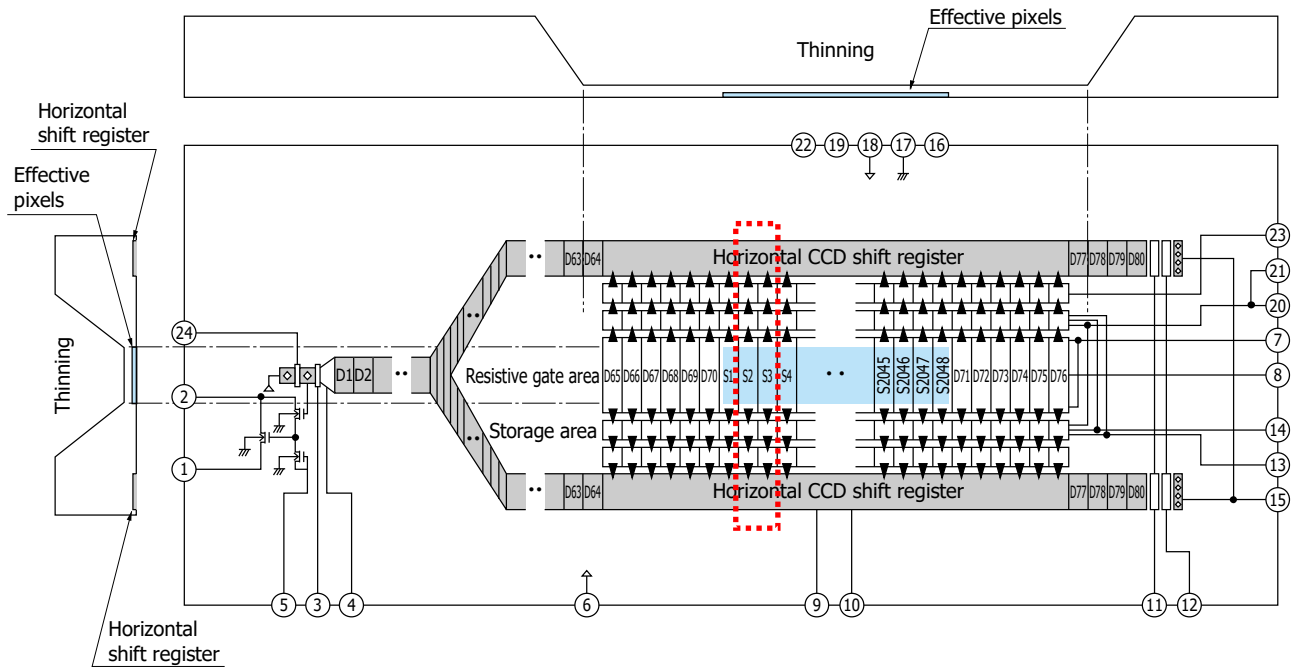
(b) Enlarged view [dotted line section in (a) Entire device drawing]



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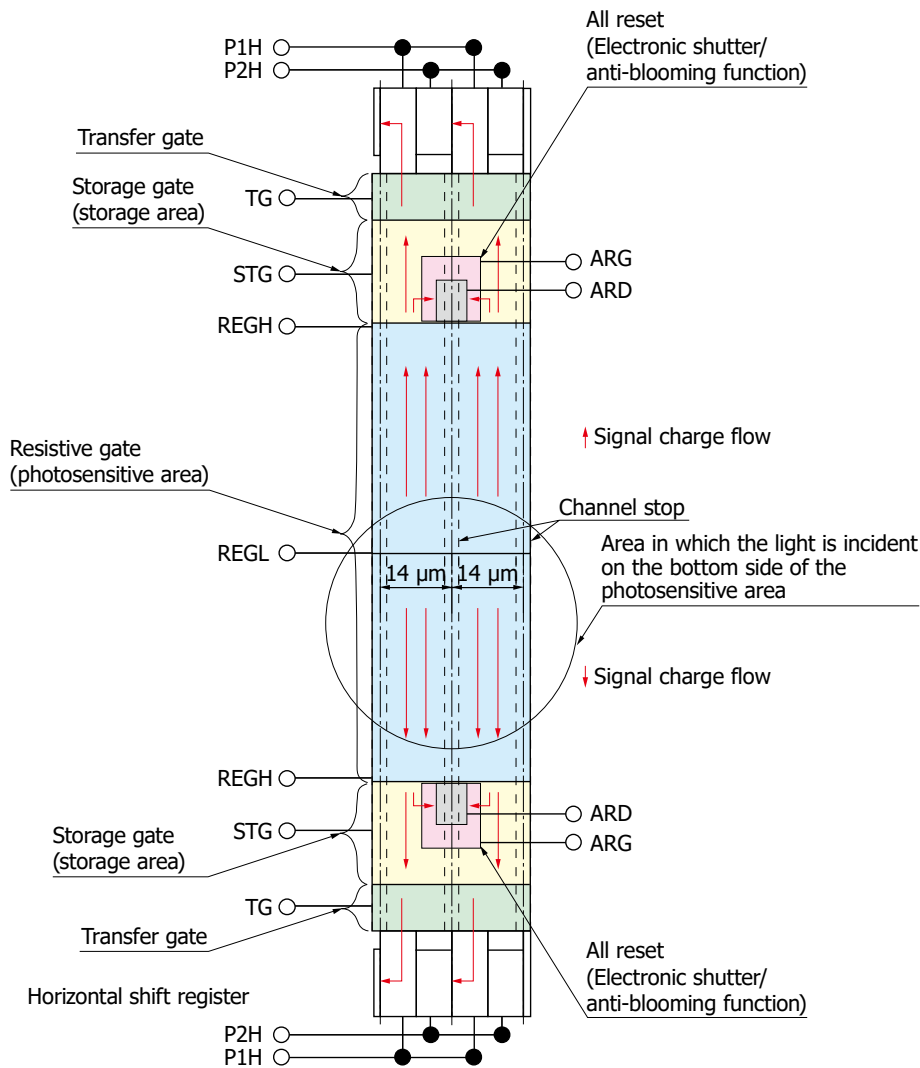
[Figure 7] Device structure (S11155/S11156-2048-02)

(a) Entire device drawing



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(b) Enlarged view [dotted line section in (a) Entire device drawing]



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In the case of the improved type (S11155/S11156-2048-02), signal charges generated by photoelectric conversion at each pixel of the photosensitive area are directed upward or downward based on the boundary line at the center of the photosensitive area and transferred. Then, the signals are combined through the horizontal shift register and read out by a single amplifier. With the improved type, the charge transfer distance can be reduced even with the same photosensitive area height. This has enabled the reduction of the readout time (charge transfer time).

Note that since the improved type has a structure that combines signals with horizontal shift register and reads out the results, there are more horizontal blank pixels than the previous type (S11155/S11156-2048-01) (number of blank pixels: previous type: 4, improved type: 64). The improved type has more number of horizontal readout pixels than the previous type, but the line rate is the same (2 kHz typ.).

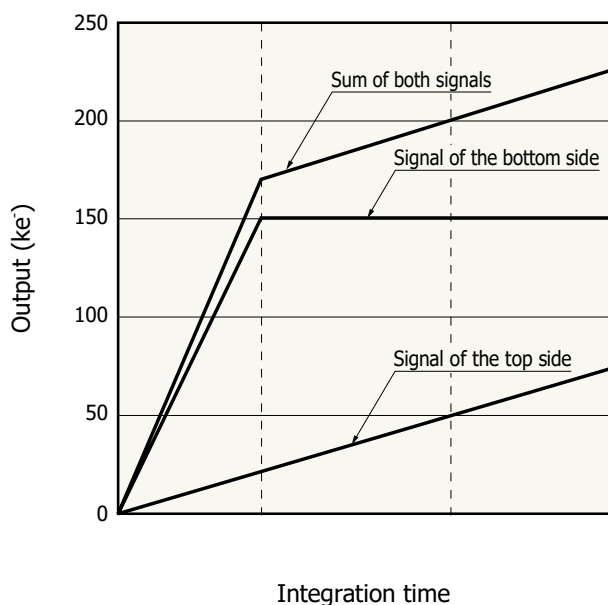
To accumulate as many signal charges as possible, the light incident position and distribution must be made as horizontally symmetrical as possible at the center of the photosensitive area. As shown in Figure 7 (b), if the light incident position and distribution are greatly offset upward or downward, signal charges may exceed the saturation charge of the storage gate. The saturation charge of the top and bottom storage gates is approximately 150 ke⁻ each, and any charges exceeding this value are

discarded in the adjacent all reset drain (ARD). As a result, as shown in the graph of Figure 8, the linearity of the "sum of the signals of each side" changes during the integration time in which the "signal of the bottom side" has reached saturation. In addition, when the "signal of the bottom side" saturates, the difference in the output of odd and even pixels becomes apparent. This phenomenon occurs because the full well capacity of the storage gate is different between odd and even pixels (due to the ARD position offset).

If the bias in the light cannot be avoided, the applied ARG or ARD voltage must be changed in order to increase the saturation charge of the storage gate on one side (in this case, anti-blooming does not work).

Example: ARG's low voltage: +1 V → 0 V, ARD: +14 V → +13 V

[Figure 8] Output linearity when the light is incident on the bottom side of the photosensitive area [typical example, see Figure 7 (b)]



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3. Signal detection flow

- Resistive gate (photosensitive area)

To perform charge transfer at high speeds, a resistive gate structure is used in the photosensitive area. The back of the resistive gate is thinned, which enables the CCD to achieve high quantum efficiency over a wide spectral range in the same manner as ordinary back-thinned CCDs. The signal charge that is generated through photoelectric conversion at the resistive gate is transferred to the storage gate by the potential slope that is formed by the difference in the voltages that are applied across the resistive gate (applied to REGH and REGL).

Furthermore, the photosensitive area has a structure that suppresses the etaloning (an interference phenomenon that is characteristic of back-thinned CCDs) that occurs in near infrared wavelengths. Light incidence is suppressed in the areas of the chip other than the photosensitive area by a thick layer of silicon substrate.

- Storage gate

The signal charge that is transferred from the resistive gate is accumulated in the storage gate. A lateral type anti-blooming structure is next to the storage gate. This provides both an anti-blooming function and an electronic shutter function (see “4. Electronic shutter and anti-blooming”).

- Transfer gate

The transfer gate is located between the storage gate and the horizontal shift register. When the transfer gate is set to high level, the signal charge that is accumulated in the storage gate is transferred to the transfer gate. When the transfer gate is then set to low level, the signal charge is transferred to the horizontal shift register.

- Horizontal shift register

The signal charge that has been transferred to the horizontal shift register is transferred to the output stage when clock pulses are applied to the horizontal shift register.

- Output stage

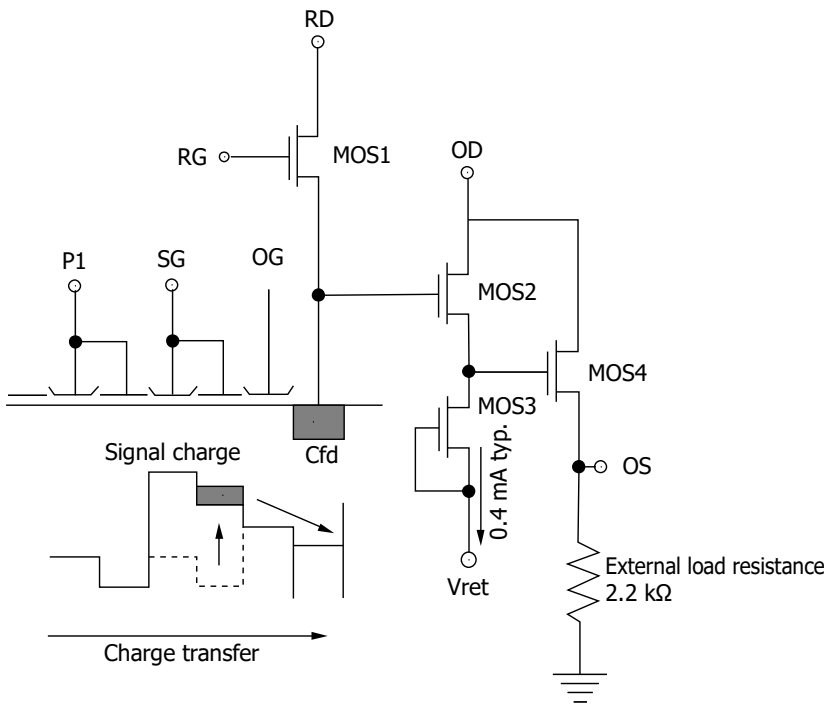
A MOSFET for charge-to-voltage conversion that is known as an FDA (floating diffusion amplifier) is embedded in the output stage [Figure 9]. The signal charge is transferred to capacitance Cfd, and the charge-to-voltage conversion occurs [Equation (1)].

$$V_{fd} = \text{Signal charge} / C_{fd} \dots\dots\dots (1)$$

Vfd: output voltage

This voltage is impedance-converted through a two-stage MOSFET source follower circuit (gain < 1) and output from the OS terminal. Because the CCD does not include an external load resistance (2.2 kΩ), it must be provided through an external circuit.

[Figure 9] CCD output section using FDA



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4. Electronic shutter and anti-blooming

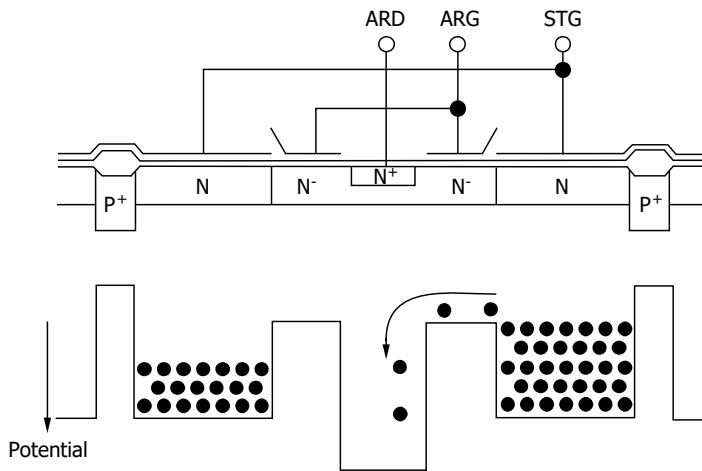
A lateral type overflow drain structure (one for 2 pixels) is provided next to the storage gates of the resistive gate type CCD linear image sensor to achieve the electronic shutter function.

When the all reset gate (ARG) is set to low level, the signal charge is accumulated in the storage gate (STG). This is the state when the electronic shutter is open [Figure 10 (a)]. Any signal charge that exceeds the full well capacity is carried away into the all reset drain (ARD). This prevents blooming. When the all reset gate is set to high level, the signal charge is carried away from the storage gate into the all reset drain. Therefore, the signal charge is not accumulated. This is the state when the electronic shutter is closed [Figure 10 (b)].

The full well capacity of the storage gate can be controlled by the all reset gate voltage. If the saturation charge of the storage gate is increased, blooming may occur at the storage gate. If the saturation charge of the storage gate is increased even further, blooming will occur in the latter-stage horizontal shift register and the like.

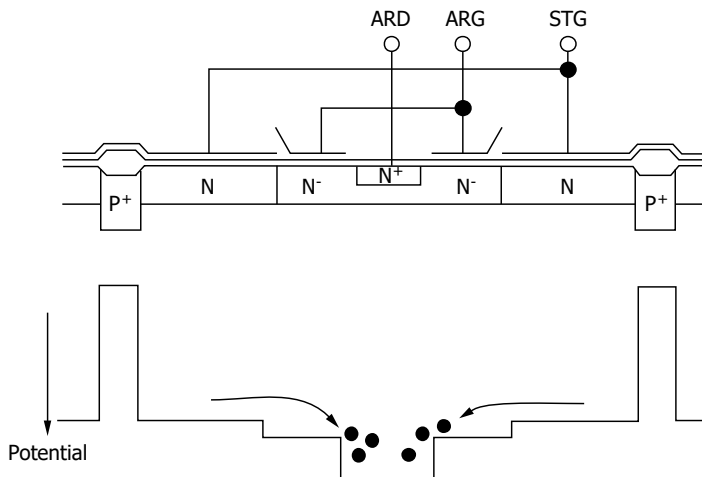
[Figure 10] Schematic diagram and potential of all reset section (cross-section structure of the area denoted by broken line A-A' in [Figure 6 (b)])

(a) ARG: low level, Electronic shutter: open [integration state (anti-blooming state)]



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(b) ARG: high level, Electronic shutter: closed (reset state)



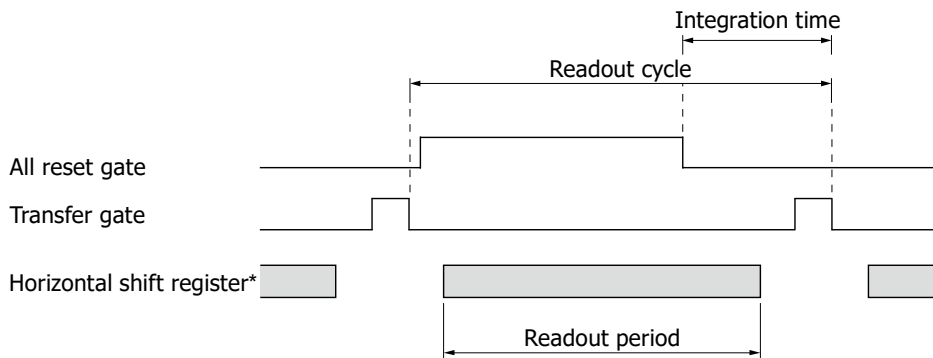
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- Integration time

When an electronic shutter is used, the integration time is defined as the time from when the all reset gate is set to low level to when the accumulated signal charge is transferred to the horizontal shift register (the length of time until the transfer gate becomes low level [Figure 11]). Any signal charge that is generated outside of this period is carried away into the all reset drain during the period that the all reset gate is set to high level and is not read out as signals.

If the electronic shutter function is not used, the all reset gate is set to low level at all times. In this situation, the integration time is the same as the readout cycle.

[Figure 11] Timing chart (when electronic shutter is in use)



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5. Non-MPP operation and MPP operation

MPP (multi-pinned phase) operation is performed by setting the portions under all MOS structure gates, which constitute the CCD electrodes, to the inverted state (except for storage gate). In MPP operation, the oxide film interface is inverted by holes supplied from the channel stop region. The generation of thermally excited electrons on the oxide film interface is drastically suppressed, thus resulting in a state with low dark current. This state is known as pinning. By precisely applying the pinning voltage (the gate voltage during pinning), the dark current can be greatly reduced. This operation is suitable for integrations over a long period of time. Consider the amount of dark current generated and the length of time needed to read out the signals (shutter time), and select non-MPP operation or MPP operation according to the operating conditions.

(1) Non-MPP operation

In non-MPP operation, a different fixed voltage is applied to the resistive gate (REGH, REGL) to form a potential slope at all times. In this situation, if a voltage lower than the pinning voltage is applied, the potential slope does not form in the CCD channels, and the image lag increases. In non-MPP operation, because the portions under the resistive gate are not in the pinning state, the dark current becomes large. However, this operation is suitable for integrations over a short period of time where the effect of dark current is small. Non-MPP operation is suitable when detecting intense light by using an electronic shutter to decrease the integration time and reduce the incident light level.

The potentials at various times [Figure 12] in non-MPP operation are shown in Figure 13.

- T1

The signal charge that is generated through photoelectric conversion at the resistive gate (REG) is transferred to the storage gate by the potential slope.

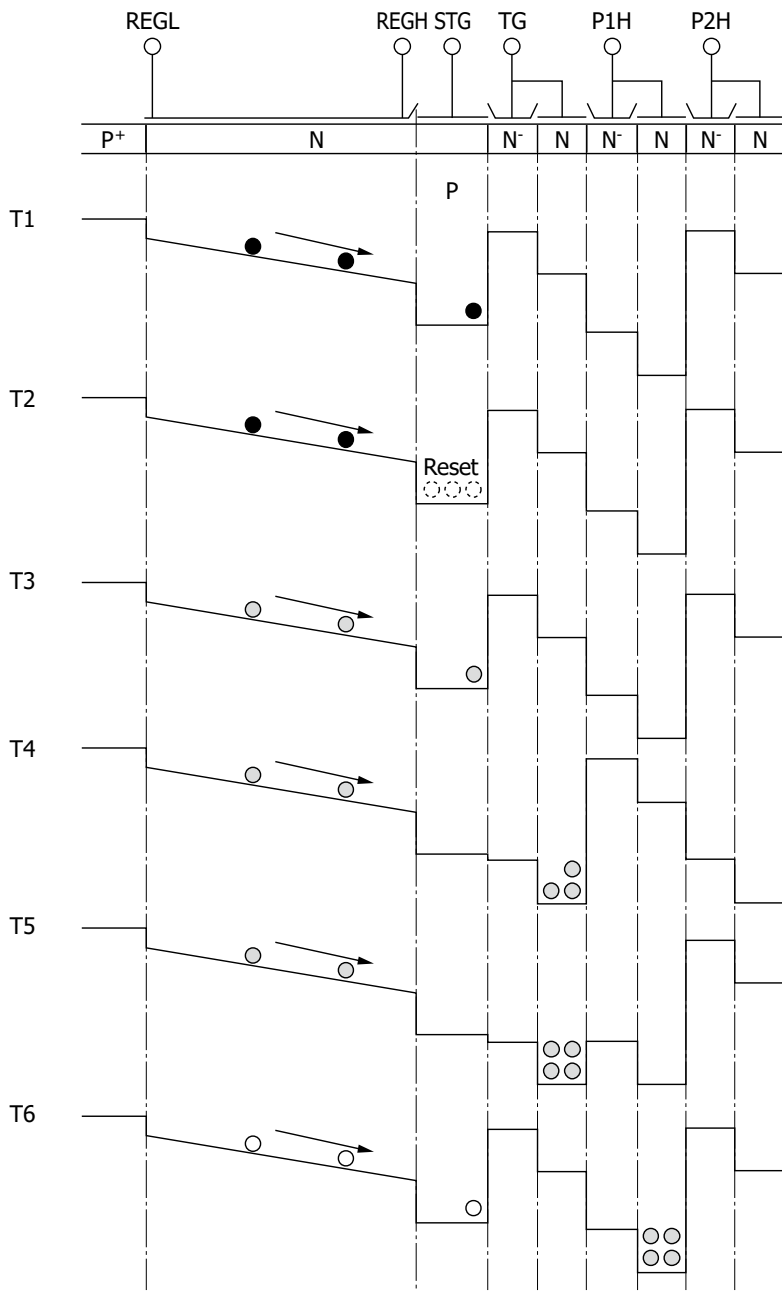
- T2

The all reset gate is set to high level. The signal charge is carried away into the all reset drain. Any signal charge that was generated by incident light before this period is not read out (electronic shutter: closed).

- T3

The all reset gate is set to low level, and signal charge is integrated (electronic shutter: open).

[Figure 13] Potentials at various times in non-MPP operation



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(2) MPP operation

In MPP operation, the same pinning voltages are applied to both ends of the resistive gate to reduce dark current during integration. MPP operation is suitable for detecting low-level light over a long time period. However, because the image lag in the photosensitive area becomes large in this state, when transferring the charge, to form a potential slope, a voltage must be applied to the resistive gate at the same level as the voltage applied during non-MPP operation, and the readout time must be set to ① or ② shown below. To apply anti-blooming at intense level, ① is recommended.

- ① Change the REGH and REGL voltage levels to high before the TG level becomes high to make the high level time longer [Figure 14].

-
- ② Make the high level voltage period of REGH and REGL longer by synchronizing to the TG high level period (T_{pwv}).

The potentials at various times [Figure 14] in MPP operation are shown in Figure 15.

- T1

The signal charge that is generated by light entering the resistive gate (REG) is accumulated in the storage gate.

- T2

The all reset gate is set to high level. The signal charge is carried away into the all reset drain. Any signal charge that was generated by incident light before this period is not read out (electronic shutter: closed).

- T3

The all reset gate is set to low level, and signal charge is integrated (electronic shutter: open).

The voltage that is applied across the resistive gate is set to a voltage that is less than the pinning voltage. This is the state in which the dark current generated in the resistive gate is reduced (the potential slope does not form).

- T4

Different voltages are applied across the resistive gate. The potential slope forms, and the signal charge that was generated by light entering the resistive gate is transferred to the storage gate. Note that a portion of the signal charge that is generated during this period is also read out.

- T5

The transfer gate is set to high level. The signal charge that was accumulated in the storage gate is transferred to the transfer gate. Note that a portion of the signal charge that is generated during this period is also read out.

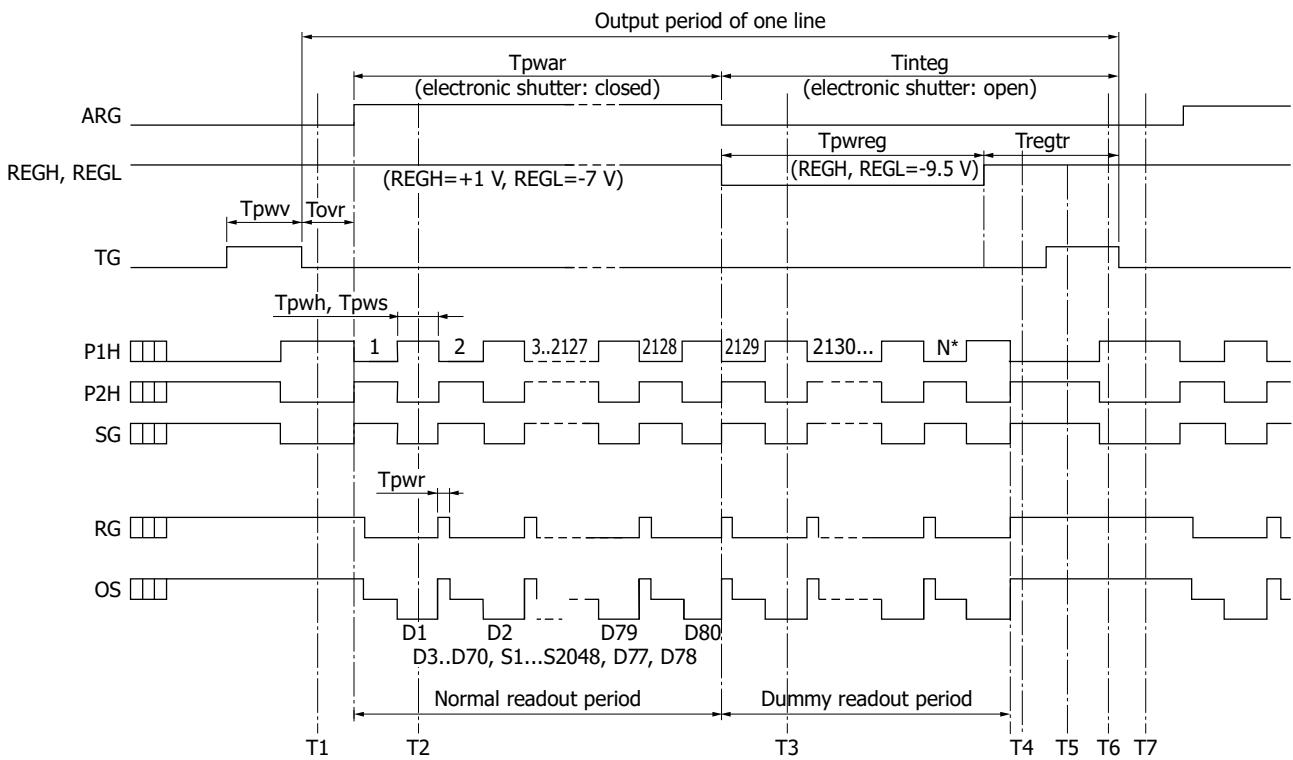
- T6

P1H is set to high level. Note that a portion of the signal charge that is generated during this period is also read out.

- T7

The transfer gate is set to low level. The signal charge is transferred from the transfer gate to the horizontal shift register (P1H). After this point, when clock pulses are applied to P1H and P2H, the signal charge is transferred to the output stage via the horizontal shift register.

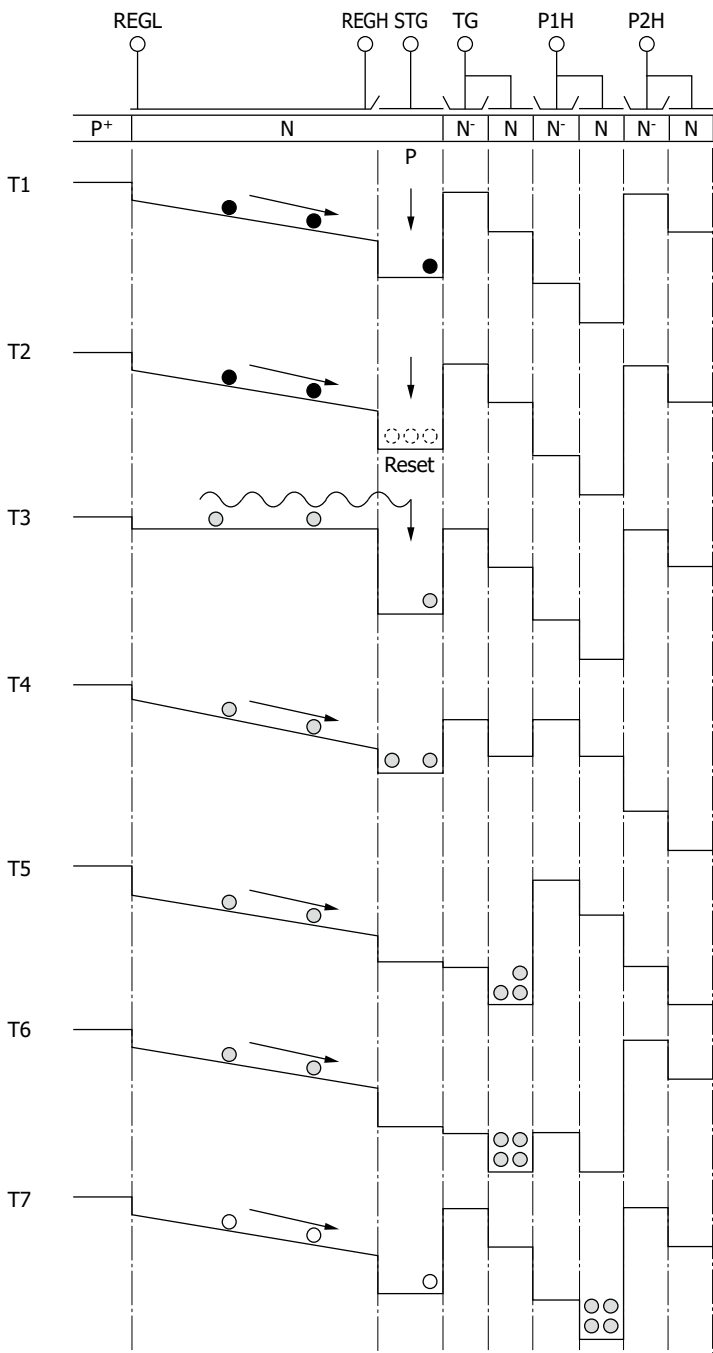
[Figure 14] Timing chart (S11155/56-2048-02, MPP operation)



* Set the total number N of clock pulses according to the integration time.

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[Figure 15] Potentials at various times in MPP operation



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6. Unread charges

Unread charges (image lag) are defined as a percentage of the signal level left unread of the incident light level and are expressed by equation (2).

$$L = (\text{Slag}/S) \times 100 [\%] \dots\dots\dots(2)$$

L: image lag

Slag: unread signal level

S: input signal level

Image lag occurs in the resistive gate and storage gate and is evaluated using different methods.

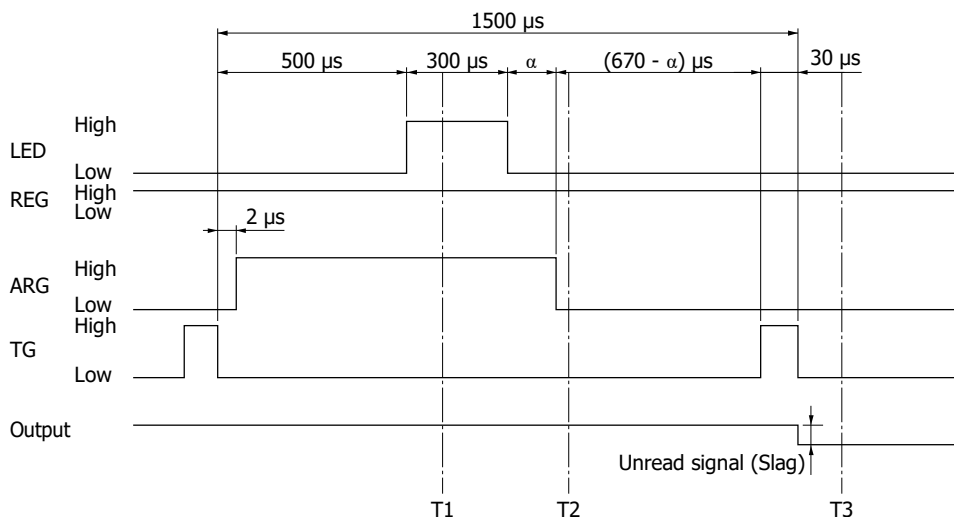
(1) Measurement method and characteristics of image lag in the resistive gate

Image lag in the resistive gate is measured in the following manner at the timing shown in Figure 16.

- ① Use a pulse-driven LED (peak emission wavelength: 660 nm), and adjust its output so that a signal about half the full well capacity is applied to the photosensitive area. During this adjustment, set ARG to low level when the LED is on. The input signal level at this point is S [Equation 2].
- ② While the LED is on, set the ARG to high level (electronic shutter: closed). The charges transferred to the storage gate are carried away into the ARD (T1 in Figure 16).
- ③ When a given period (α) elapses after the LED is turned off, set the ARG to low level (electronic shutter: open). Unread charges in the resistive gate (Slag) are accumulated in the storage gate (T2).
- ④ Charges accumulated in the storage gate (see ③) are output (T3).

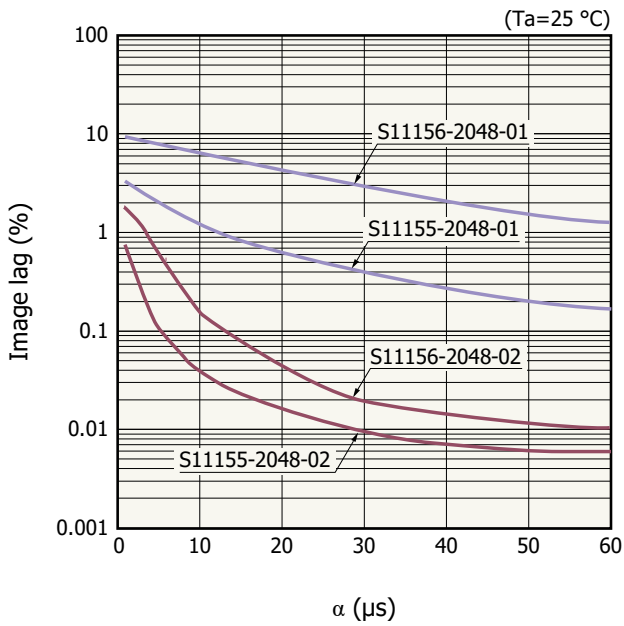
The longer the resistive gate, the longer the charge transfer time and the larger the image lag. With the improved type, the charge transfer speed was increased by optimizing the resistive gate structure and forming a steep potential slope between the resistive gates. Given the same charge transfer time, the image lag is shorter on the improved type than the previous type [Figure 17].

[Figure 16] Timing chart example for measuring image lag in the resistive gate



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[Figure 17] Image lag in the resistive gate vs. time (α) (typical example)

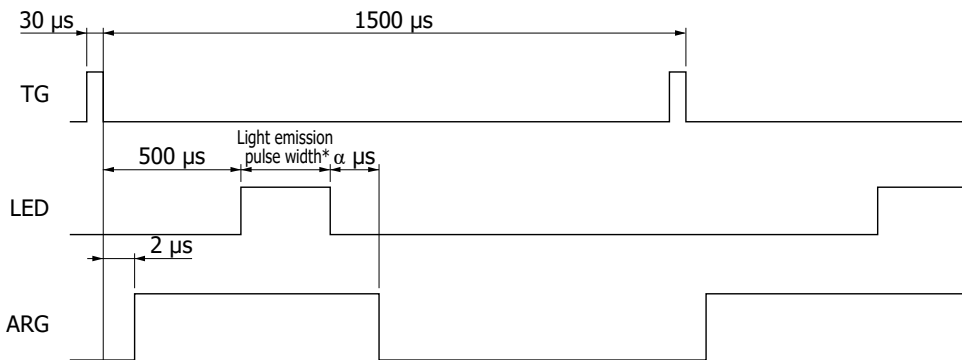


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- Relationship between the image lag in the resistive gate and input light pulse width

Figure 19 shows the image lag when the input signal level is constant and the LED's light emission pulse width is changed at the timing shown in Figure 18. The larger the pulse width, the smaller the image lag. As the signal charge that is converted from the incident light is transferred to the storage gate by the potential slope of the resistive gate, the image lag will be smaller when a low level light is applied over a long time period.

[Figure 18] Timing chart example for measuring image lag in the resistive gate

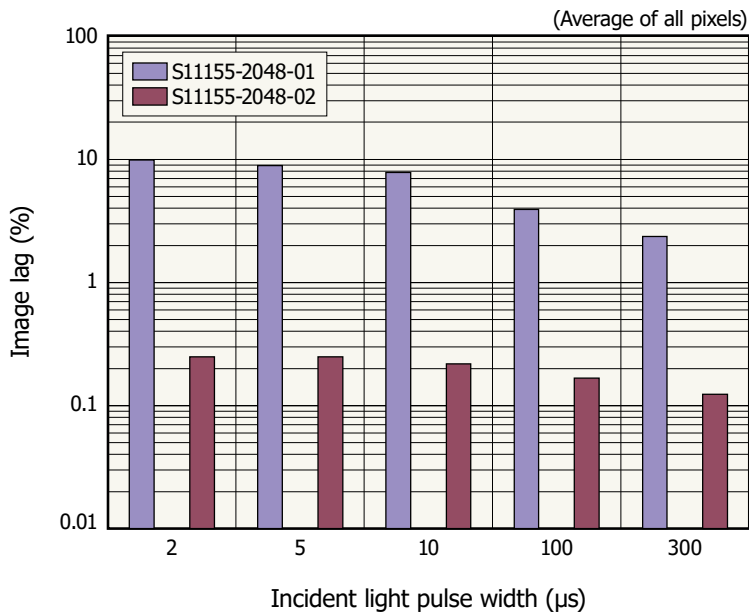


* 2 μ s, 5 μ s, 10 μ s, 100 μ s, 300 μ s

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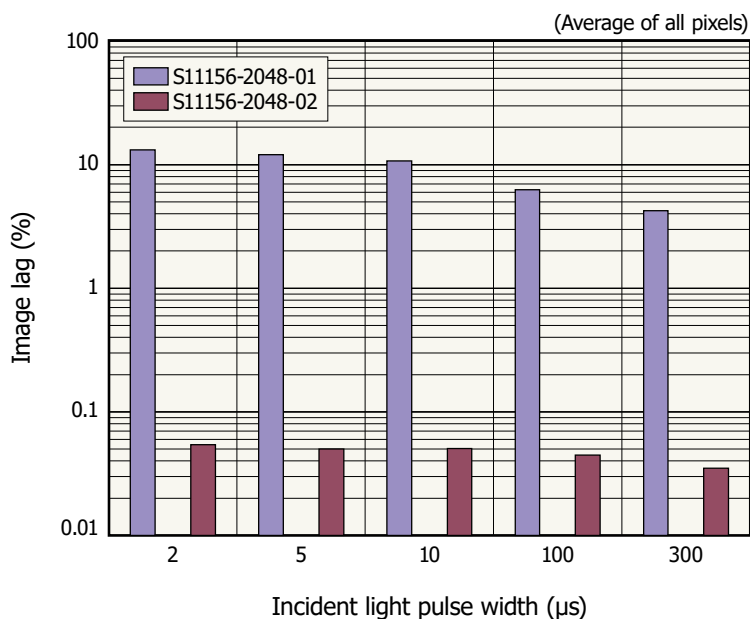
[Figure 19] Image lag in the resistive gate vs. incident light pulse width (typical example)

(a) S11155-2048-01/-02 ($\alpha=5 \mu\text{s}$)



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(b) S11156-2048-01/-02 ($\alpha=20 \mu\text{s}$)



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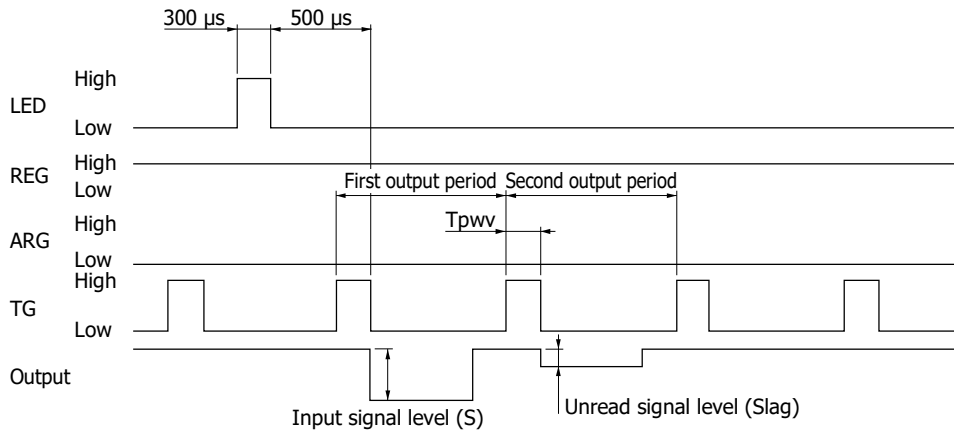
(2) Measurement method and characteristics of image lag in the storage gate

As shown in Figure 20, a pulse-driven LED (peak emission wavelength: 660 nm) is used at about half the saturation output. After sufficient time (approx. 500 μs) elapses for the charge generated in the resistive gate to be transferred to the storage, the TG voltage is set to high level to transfer the charge to the horizontal shift register. Most of the input signal level (S) of equation (2) is read out during the first output period, and the remaining signal (Slag) is output during the second output period.

It is possible to reduce the image lag in the storage gate as the TG high level period (T_{pw}) is

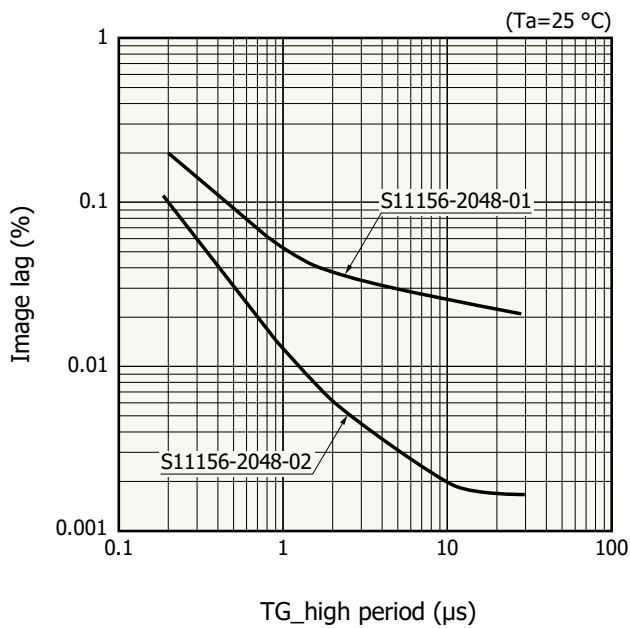
increased. With the improved type, the potential structure of the storage gate is optimized to reduce the image lag in the storage gate as compared to the previous type [Figure 21].

[Figure 20] Timing chart example for measuring image lag in the storage gate (Non-MPP operation)



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[Figure 21] Image lag in the storage gate vs. TG_high period (typical example)

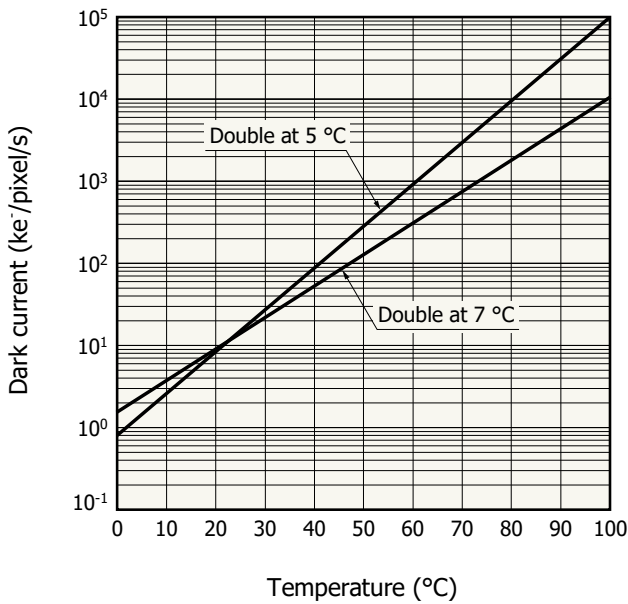


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7. Dark current temperature dependence

Dark current has temperature dependence. For example, in the case of the S11156-2048-02, the temperature dependence during MPP operation is as shown in Figure 22.

[Figure 22] Dark current temperature dependence (S11156-2048-02, MPP operation, typical example)

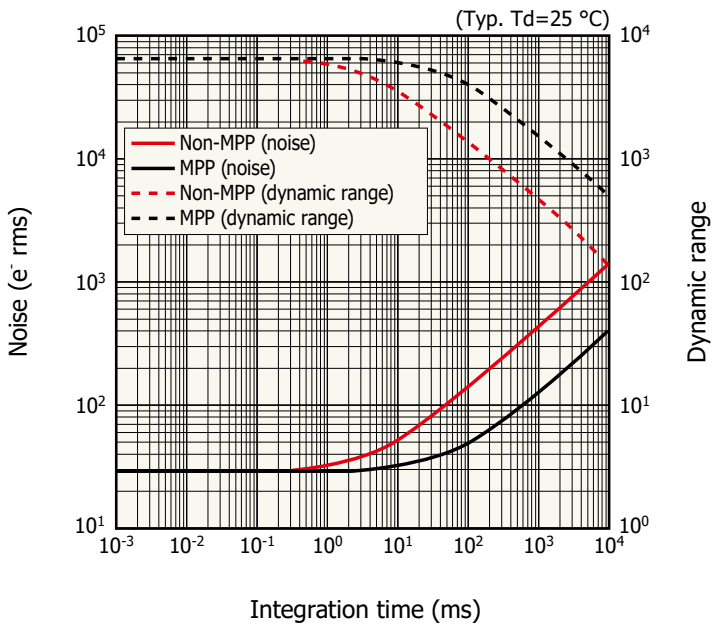


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8. Dark shot noise and dynamic range

As the integration time is increased, the dark shot noise is also increased. This causes the dynamic range to be reduced. Figure 23 shows an example.

[Figure 23] Noise (readout noise + dark shot noise), dynamic range vs. integration time



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9. Linearity

Figure 24 shows the linearity error (S11156-2048-02) when the incident light level is made constant, and the signal charge level is varied by changing the integration time with the electronic shutter.

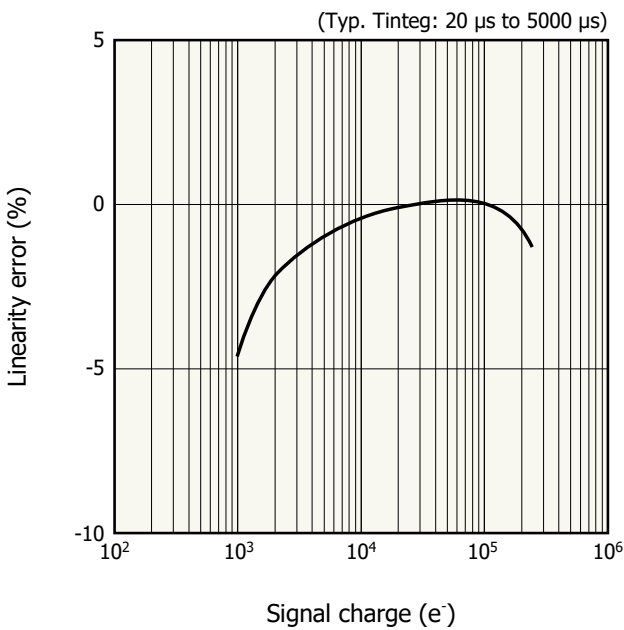
- Measurement conditions
 - Light source output: constant, on at all times
 - Tpwv [period in which TG is at high level]=20 μs
 - Average the data that has been acquired consecutively 64 times and then average all the channels to derive the signal.

$$\text{Linearity error} = \{1 - (S_m/T_m)/(S/T_{\text{integ}})\} \times 100 [\%] \dots\dots\dots(3)$$

S_m : signal level at one-half the saturation charge
 T_m : integration time at one-half the saturation charge
 S : signal
 T_{integ} : integration time

If the integration time (T_{integ}) is short, the image lag increases, and the linearity error shifts in the negative direction.

[Figure 24] Linearity error vs. signal charge (integration time varied with electronic shutter: $T_{\text{integ}}=20 \mu\text{s}$ to $5000 \mu\text{s}$)



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10. Operation method

(1) Operating voltage

To reduce image lag, the operating voltage on the improved type was changed [Table 2].

[Table 2] Voltage applied to each terminal (comparison between the previous type and improved type)

Terminal name	S11155/S11156-2048-01 (Previous type)			S11155/S11156-2048-02 (Improved type)		
	Min.	Typ.	Max.	Min.	Typ.	Max.
VOD	12	15	18	12	15	18
VRD	14	15	16	13	14	15
VARD	14	15	16	13	14	15
VARGH	7	8	9	7	8	9
VARGL	-2	-1.5	-1	0.5	1	2
VOG	2.5	3	3.5	2.5	3.5	4.5
VSTG	-	0	-	2.5	3.5	4.5
VSS	-	0	-	-	0	-
VREGHH	-4.5	-4	-3.5	0.5	1	1.5
VREGHL	-9	-8	-7	-10.5	-9.5	-8.5
VREGLH	-	VREGHH - 2.5	-	-	VREGHH - 8	-
VREGLL	-9	-8	-7	-10.5	-9.5	-8.5
Vret	-	1	2	-	1	2
VISH	-	VRD	-	-	VRD	-
VIGH	-9	-8	-	-10.5	-9.5	-
VPHH	4	5	6	5	6	8
VPHL	-8	-7	-6	-6	-5	-4
VSGH	4	5	6	5	6	8
VSGL	-8	-7	-6	-6	-5	-4
VRGH	7	8	9	7	8	9
VRGL	-6	-5	-4	-6	-5	-4
VTGH	8.5	9	9.5	9.5	10.5	11.5
VTGL	-7.5	-7	-6.5	-6	-5	-4

(2)Current flowing through terminals

Table 3 indicates an example of current that flows through each terminal (S11156-2048-02). Use this as a reference to design your circuit.

[Table 3] Approximate current that flows through each terminal

Terminal name	S11155/ S11156-2048-01		S11155/S11156-2048-02	
	Supply voltage	Current (mA)	Supply voltage	Current (mA)
	Typ.		Typ.	
OS	-	-	-	-
OD	+15	+6	+15	+6
OG	+3	+0.1	+3.5	+0.1
SG	+5/-7	+0.1/-0.1	+6/-5	+0.1/-0.1
Vret	+1	-0.4	+1	-0.4
RD	+15	<<0.1	+14	<<0.1
REGL	-6.5/-8	-1/-0.2	-7/-9.5	-10/-0.2
REGH	-4/-8	+1/-0.2	+1/-9.5	+10/-0.2
P2H	+5/-7	+0.1/-0.1	+6/-5	+0.1/-0.1
P1H	+5/-7	+0.1/-0.1	+6/-5	+0.1/-0.1
IG2H	-8	-0.1	-9.5	-0.1
IG1H	-8	-0.1	-9.5	-0.1
ARG	+8/-1.5	+0.1/-0.1	+8/+1	+0.1/+0.1
ARD	+15	<+0.1	+14	<+0.1
ISH	+15(=VRD)	<<+0.1	+14(=VRD)	<<+0.1
STG	+3	+0.1	+3.5	+0.1
NC(STG)	-	-	-	-
TG	+9/-7	+0.1/-0.1	+10.5/-5	+0.1/-0.1
RG	+8/-5	+0.1/-0.1	+8/-5	+0.1/-0.1

The Vret and REGL power supplies must be of a sink type, and REGH of a source type. The power supplies of other terminals must be of a source type if the applied voltage is positive and sink type if negative. Inrush current and the like are different from the values in Table 3 (they depend on the capacitance and resistance of the sensor and the driver circuit).

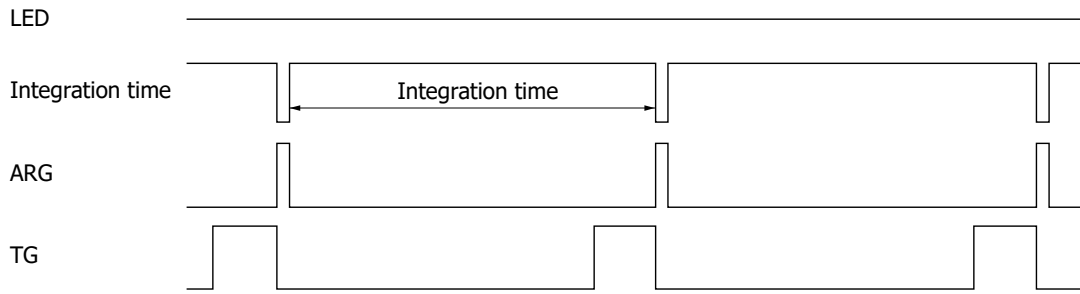
11. Use examples

(1) Controlling the incident light level with electronic shutter

If the incident light level is large, any signal charge that exceeds the saturation charge is carried away into the all reset drain. At this point, the signal output saturates and becomes constant, making the verification of the output difference between each pixel impossible. In such situations, the output difference between each pixel can be verified by controlling the signal level by varying the integration time with an electronic shutter [Figure 26]. Multiple signals with different integration times are acquired, and the data is processed using the signals of unsaturated pixels and their integration times to virtually increase the dynamic range. Note that the integration time can be reduced to 2 μ s in the case of a resistive gate type CCD linear image sensor with an electronic shutter function.

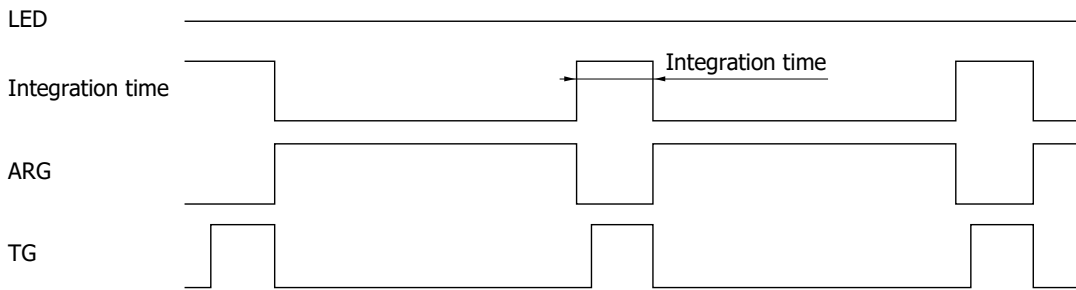
[Figure 25] Timing example when electronic shutter is in use

(a) Long integration time



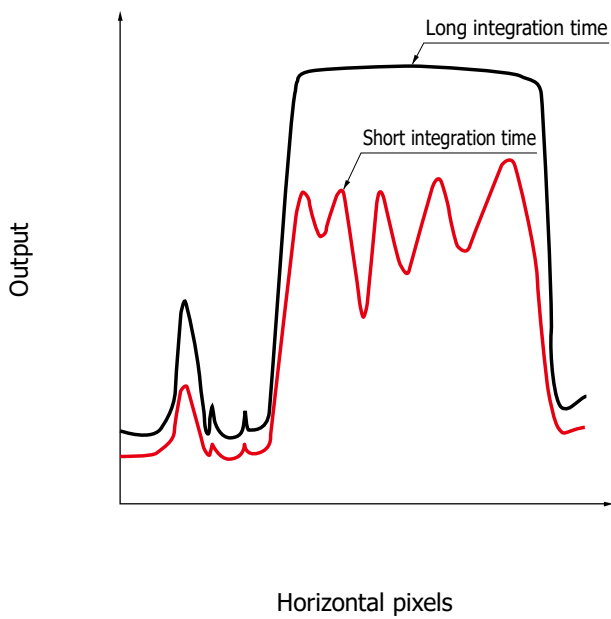
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(b) Short integration time



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[Figure 26] Output example when electronic shutter is in use

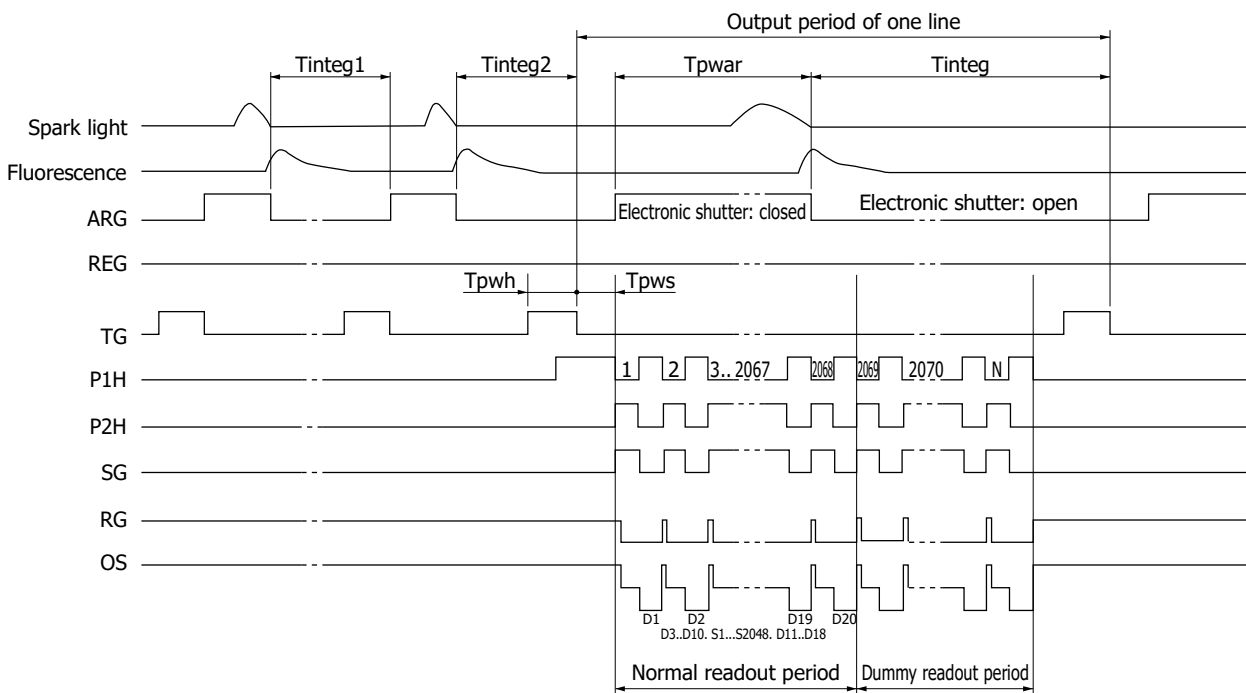


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(2) Integrating the signal obtained through multiple electronic shutter operations

If the product is operated at the timing shown in Figure 27, excitation operation is repeated due to the spark light, and the resulting fluorescence signal charge is accumulated temporarily in the transfer gate. Then, the horizontal shift register can be used to read out the signal of each channel. This readout method is effective in increasing the signal level when the signal light obtained by each excitation operation is small.

[Figure 27] Timing chart (when accumulating and reading out the signal obtained through multiple electronic shutter operations)



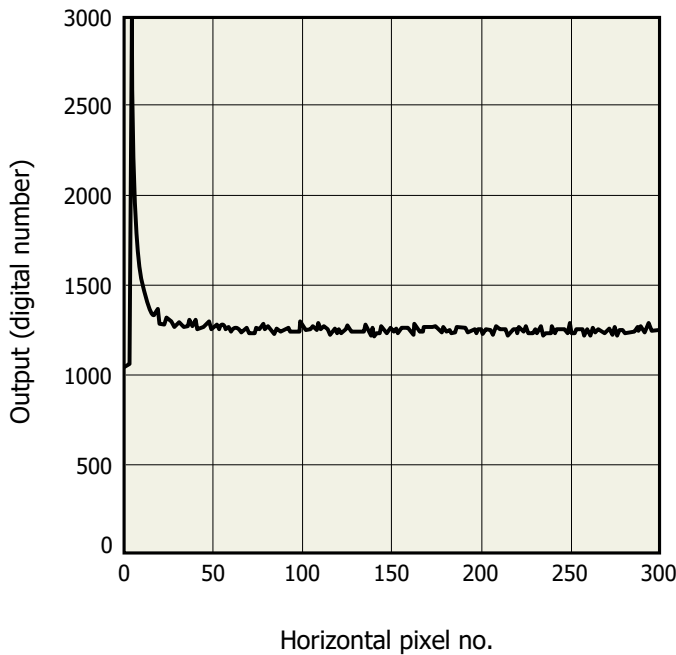
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12. Other information

(1) Measures to eliminate the effect of light from the output circuit

If the operating conditions are not appropriate, light may be generated from the output circuit. If this generated light is received by the resistive gate, storage gate, or horizontal shift registers, a phenomenon may occur in which the output is large for the first pixels that are read [Figure 28].

[Figure 28] Effect of the light generated by the output circuit (horizontal profile in a dark state, typical example)

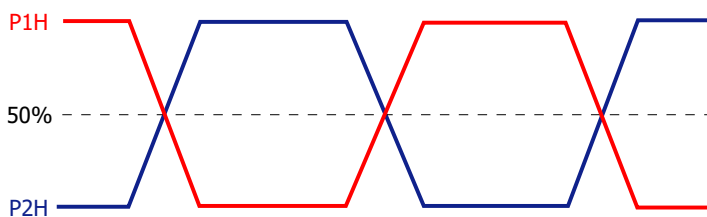


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To reduce the effect of this light emission, the following measure is effective.

- ① Apply a positive voltage to the Vret terminal (the optimal voltage varies depending on the product).
- ② Make the horizontal shift register clock pulses (P1H, P2H, SG) cross each other at 50% ± 10% of their amplitudes [Figure 29].

[Figure 29] Example of horizontal shift register clock pulse waveform



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- ③ After all pixels are read out, perform dummy readout in the horizontal direction until right before TG goes to high level.

When performing a comparatively long integration, to carry away the charge that is accumulated in the horizontal shift registers, even after all pixels are read out, perform dummy readout of the horizontal shift register until right before the transferring of the signal charge to the transfer gate begins (see *1 of Figures 12 and 14).

(2) All reset gate (ARG) pulse timing and effect on OS output

If accumulation is started (the ARG pulse falls) at any time during the signal readout period, the ARG's clock feedthrough is mixed into the OS signal and becomes noise (see *2 of Figure 12). To reduce this

effect, in the datasheet (S11155/S11156-2048-01/-02), the minimum value of the ARG's fall time (T_{pfar}) is set to 200 ns.

(3) Light-shielding of horizontal shift register

When the back-thinned CCD is viewed from the light input side, the horizontal shift register is covered by the thick area of the silicon (insensitive area), and short-wavelength light hardly reaches the horizontal shift register. However, long-wavelength light may pass through the insensitive area of the silicon and may be received by the horizontal shift register [Figure 31].

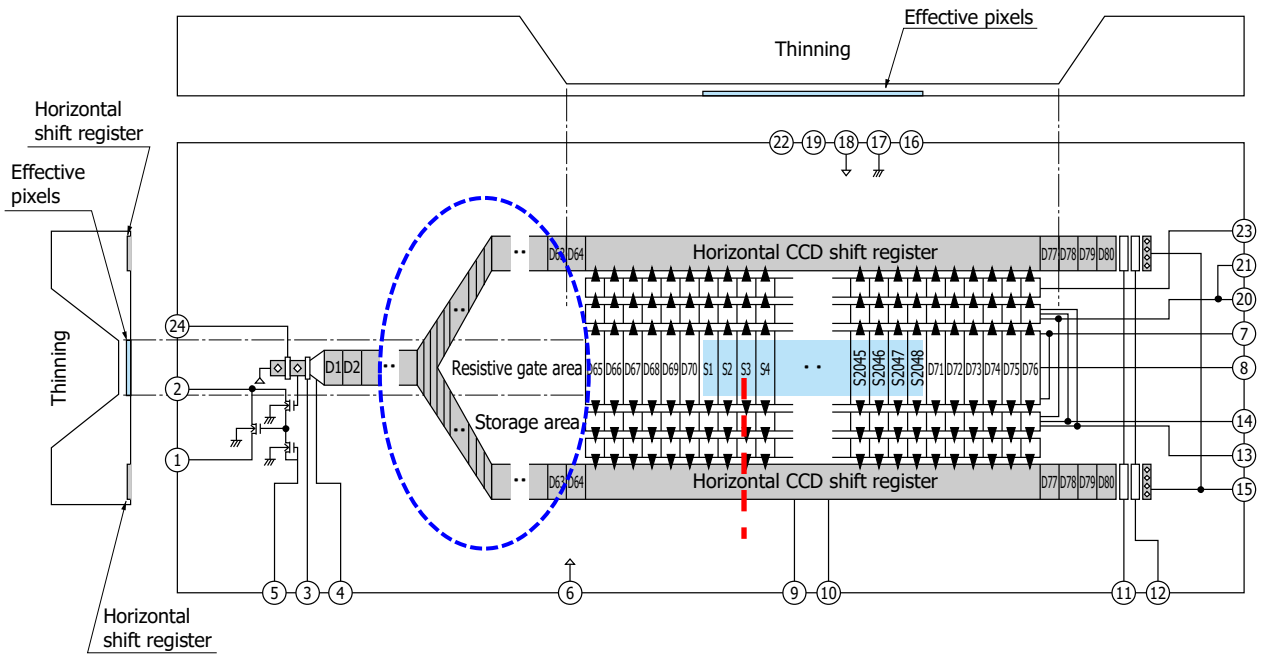
If a mechanical shutter or the like is not used, light will enter the horizontal shift register during charge integration and transfer, and the spurious signal will be superimposed on the actual signal. For example, if a time invariant light enters the horizontal shift register, the output signal of each channel will increase by the same proportion. These effects will be smaller with shorter horizontal transfer time periods (higher output signal frequency).

The horizontal shift register is shielded from light in the following ways.

- ① Apply light only during the integration period, read out the unneeded charges accumulated in the horizontal shift register during this period, and then read out the actual signal.
- ② Adjust the position where the light is directed to prevent light from entering the horizontal shift register.
- ③ Attach a light-shielding mask to prevent light from entering the horizontal shift register.

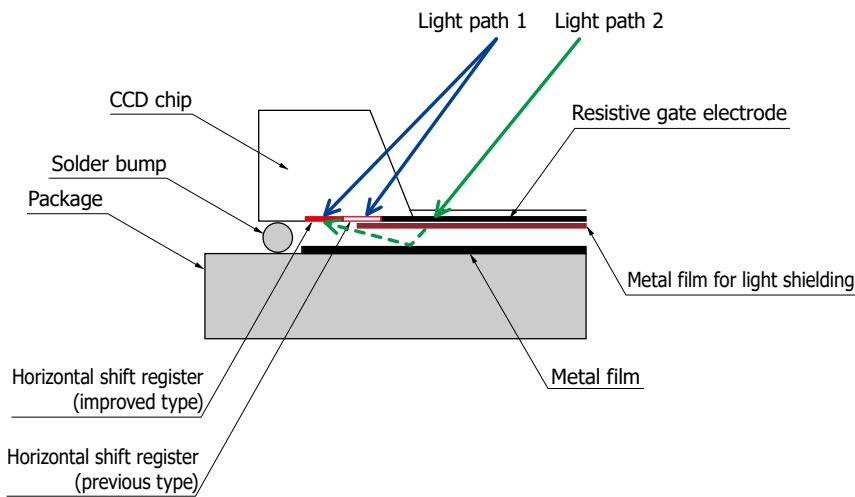
With the improved type, the horizontal shift register has been moved away from the photosensitive area to reduce the effects of the light transmitted by light path 1. [Figure 31]. In addition, the light-shielding metal attached to the front side of the CCD chip reduces components of light transmitted through the photosensitive area, reflected by the metal film of the package (light path 2), and entering the horizontal shift register. As a result, the light input to the horizontal shift register was reduced to approximately 1/40 to 1/50 (LED peak wavelength: 880 nm) as compared with the previous product.

[Figure 30] Device structure (improved type)



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[Figure 31] Sensor cross section (cross section at the red dotted line in Figure 30), incident light path to the horizontal shift register



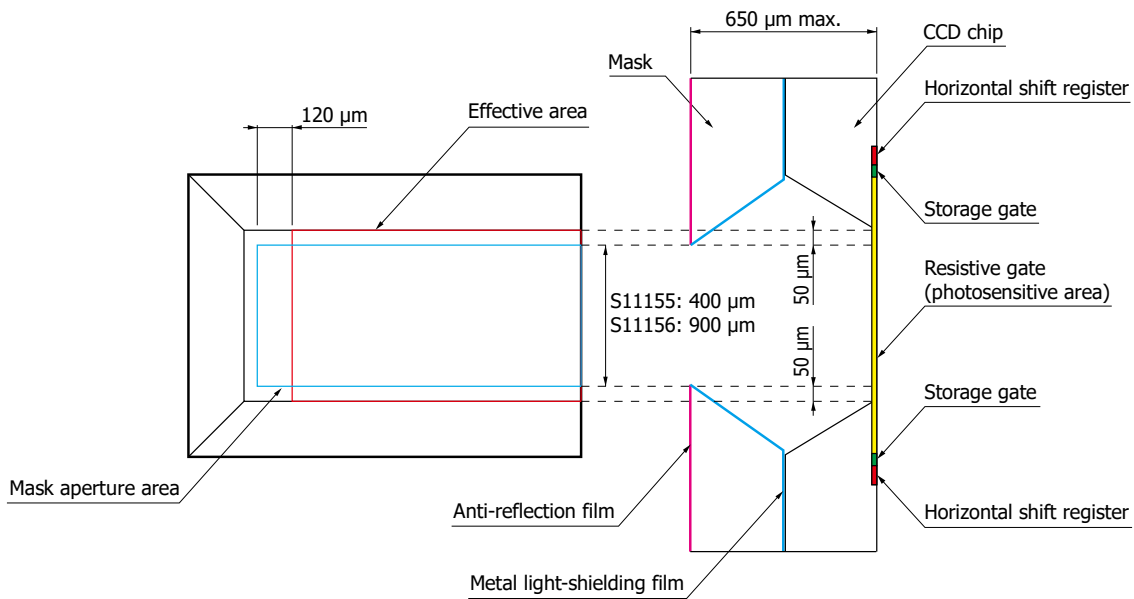
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Note that on the improved type, a charge transfer register (blank pixels of the horizontal shift register) is arranged also on the side with the readout amplifier (area indicated by blue dotted line in Figure 30). As this area may also detect long-wavelength light, it must be shielded.

- Light-shielding mask for horizontal shift register

To further increase the light-shielding property of the horizontal shift register, Hamamatsu light-shielding mask can be mounted on the CCD chip [Figure 32]. The vertical aperture size of the light-shielding mask is 400 μm on the S11155-2048-02 and 900 μm on the S11156-2048-02. Note that the light-shielding effect varies depending on the light incident angle and the like.

[Figure 32] Sensor configuration (light-shielding mask mounting: only available for the -02 type)



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(4) Power consumption of resistive gate

The resistive gate is composed of a high-resistance electrode. Applying a voltage across the resistive gate transfers the signal charge. In this situation, the resistive gate consumes the power that depends on the supply voltage and its electrode resistance [Table 4].

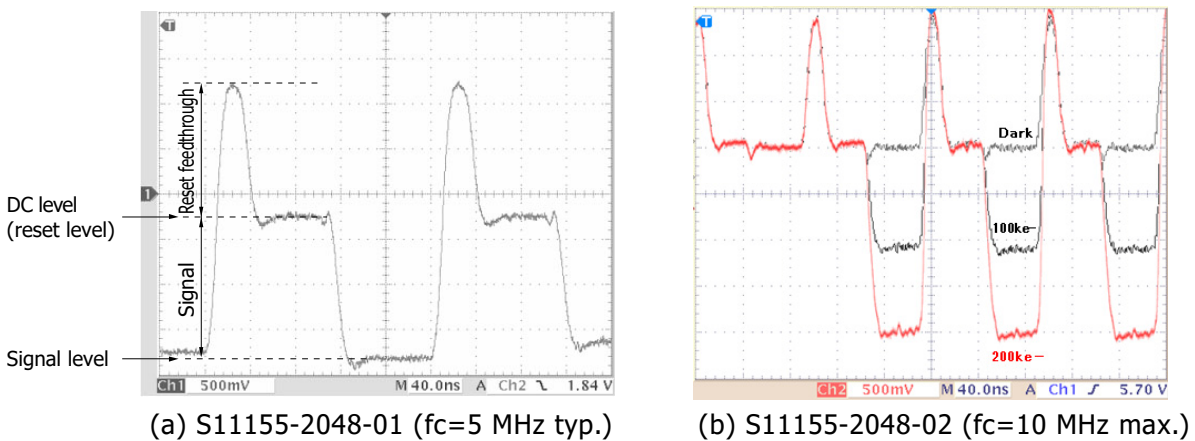
[Table 4] Power consumption and resistance of the resistive gate

Parameter	Type no.	Symbol	Min.	Typ.	Max.	Unit
Power consumption	S11155-2048-01	P _{REG}	1.4	2.5	12.5	mW
	S11155-2048-02		50	100	160	
	S11156-2048-01		0.7	1.3	6.3	
	S11156-2048-02		30	60	90	
Resistance	S11155-2048-01	R _{REG}	0.5	2.5	4.5	kΩ
	S11155-2048-02		0.4	0.7	1.4	
	S11156-2048-01		1	5	9	
	S11156-2048-02		0.7	1.1	2.2	

(5) Output waveform example

The readout amplifier on the improved type is improved to support wide bandwidth.

[Figure 33] OS output waveform example (operating conditions: Typ., unless otherwise noted)

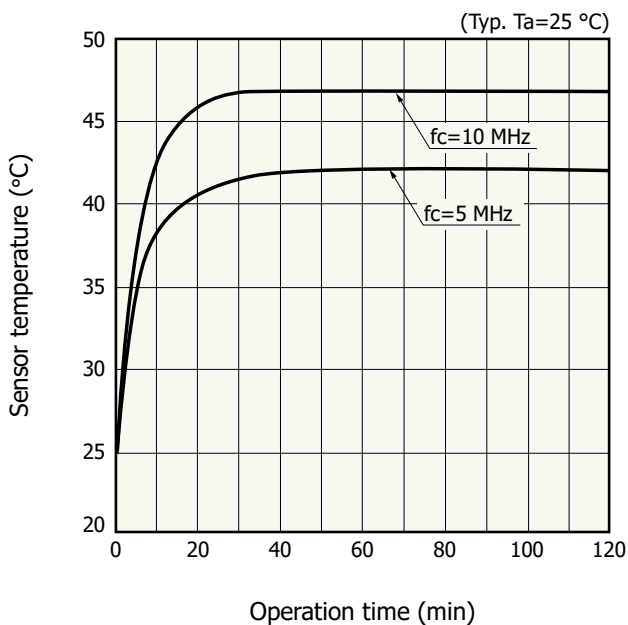


(6) Sensor temperature

Figure 34 is a measurement example showing the relation between the sensor temperature and the operating time when the S11156-2048-01 is operated with our evaluation circuit (circuitry is placed a sealed case with no heat dissipation measures). The sensor temperature increases markedly when operated at high speed. Since the rise in the sensor temperature increases the dark current and accelerates device degradation, we recommend taking heat dissipation measures, such as attaching a heatsink to the sensor or using a cooling fan.

If you want to achieve stable sensor temperature that is lower than room temperature, using a similar product, S13255/6 series, with a one-stage TE-cooler is recommended.

[Figure 34] Sensor temperature vs. operating time (using a Hamamatsu evaluation circuit)



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13. Driver circuit

(1) Transfer clock pulse generator

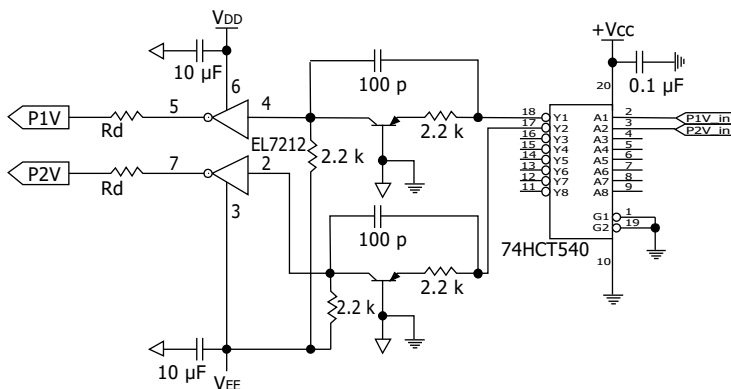
As stated above, clock pulses with high and low levels of voltage amplitude are required to operate a CCD. These clock pulses must drive the vertical shift register and horizontal shift register at high speeds, which have an input capacitance of several hundred picofarads to several nanofarads. For this purpose, MOS driver IC is commonly used to drive a CCD since it is capable of driving a capacitive load at high speeds.

Normally, the timing signal generator circuit uses a PLD or FPGA that can generate TTL or CMOS logic level output. The output voltage is +3.3 V or +5.0 V, so a level converter circuit must be connected to the MOS driver IC.

In 2-phase CCD operation, the clock pulses for driving the vertical and horizontal shift registers must overlap with each other. For this reason, a resistor R_d with an appropriate value (damping resistor: a few ohms to several kilohms) should be placed between the MOS driver IC and the CCD in order to adjust the rise time and fall time of the clock pulses.

To minimize noise intrusion to the CCD from digital circuits, it is recommended that the analog ground and digital ground be set to the same potential by the transfer clock pulse generator.

[Figure 35] Example of transfer clock pulse generator



V_{DD} : high level voltage of clock pulse^L
 V_{EE} : low level voltage of clock pulse^L
 R_d : damping resistor (a few to several dozen ohms)

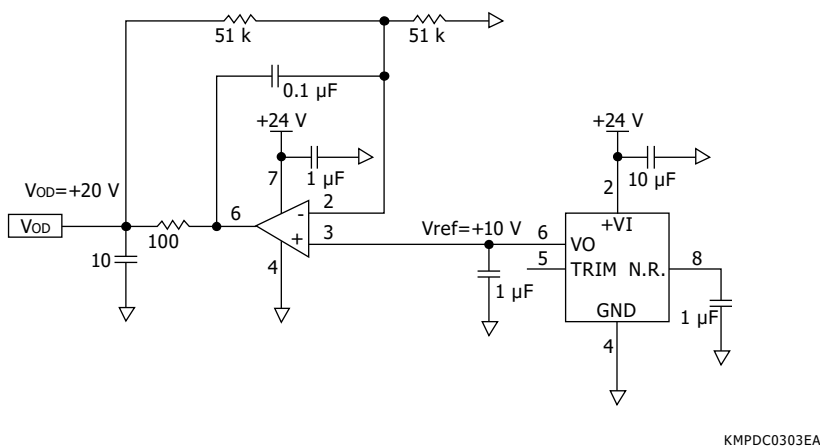
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(2) Bias generator circuit

The bias voltage is mainly applied to the peripheral section of the CCD output amplifier, so use a stable power supply with low noise. It is also important to note the voltage accuracy, voltage fluctuation, ripple, output current, and the like.

Figure 36 shows an example of a bias voltage generator circuit for the OD terminal. The reference voltage is generated from the reference power supply IC and is set to a specified voltage value by the amplifier making up the low-pass filter. This allows the user to obtain a highly stable and accurate voltage with low noise. Note that there are cases where low-noise linear regulator is used as a bias voltage generator circuit.

[Figure 36] Example of bias voltage generator circuit



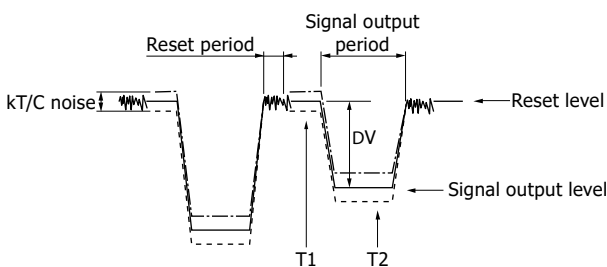
- Signal processing circuit

Major sources of noise from a CCD are the well-known kT/C noise and $1/f$ noise. The kT/C noise is generated by a discharge (reset operation) in the FDA. This noise is inversely proportional to the square root of the node capacitance (C_{fd}) of the FDA and makes up a large percentage of the total noise of a CCD. The $1/f$ noise is generated by the MOSFET constituting the FDA and is inversely proportional to the frequency.

These noises degrade the S/N in the CCD system and therefore should be reduced as much as possible in the signal processing circuit. A typical circuit for this purpose is a CDS circuit.

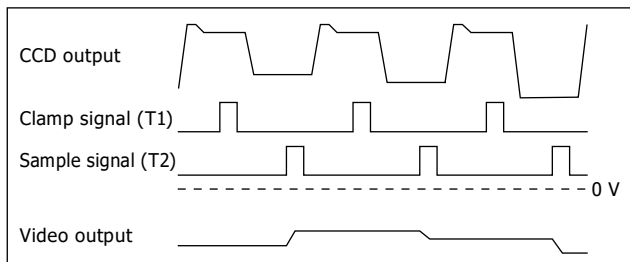
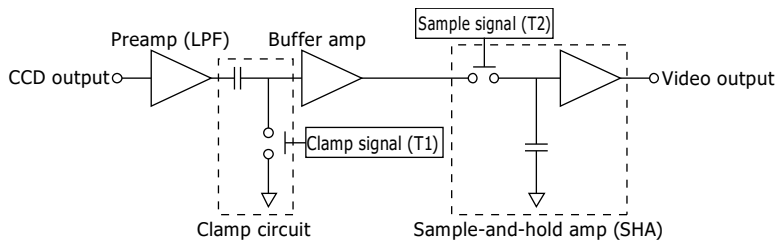
The operating principle of the CDS circuit is described below. Figure 37 shows an output waveform from a CCD. As stated above, kT/C noise occurs during a reset period in the FDA. At the point where the reset period has ended, the voltage level varies due to kT/C noise. Therefore, if data is acquired at time T_2 , the S/N deteriorates by an amount equal to the kT/C noise variation. In contrast, acquiring data at times T_1 and T_2 on the output waveform and then obtaining the difference between them will extract only a signal component ΔV with the kT/C noise removed. DC components such as the offset voltage component and reset feed-through are removed at the same time.

[Figure 37] CCD output waveform



There are two types of CDS circuits: "Type 1" that uses a clamp circuit in combination with a sample-and-hold amplifier (SHA), and "Type 2" that uses a SHA in combination with a differential amplifier. Type 1 has a very simple circuit configuration [Figure 38]. But if the ON resistance of the switch used in the clamp circuit is large, the amount of noise that can be removed will be small or a DC voltage error will occur. Ideally, the ON resistance should be 0Ω .

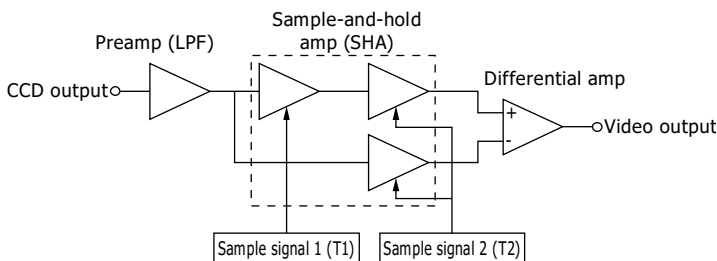
[Figure 38] CDS circuit block diagram (using clamp circuit and SHA)



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Type 2 uses a larger number of components but removes noise more effectively than Type 1. However, since Type 2 makes an analog calculation of the SHA output, the noise of the SHA itself may be added, resulting in increased noise in some cases. The SHA noise should be small enough so that the kT/C noise can be ignored.

[Figure 39] CDS circuit block diagram (using SHA and differential amplifier)



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A circuit example of Type 1 is shown in Figure 40.

The preamp gain should be set high in order to sufficiently amplify the CCD output signal. Since the CCD output signal contains DC voltage components, a capacitor is used for AC coupling. Note that this capacitor can cause a DC voltage error if the preamp bias current is large. Therefore, a preamp with a small bias current must be selected. A JFET or CMOS input amplifier is generally used. It is also necessary to select a low-noise amplifier with a bandwidth wide enough to amplify the CCD output waveform.

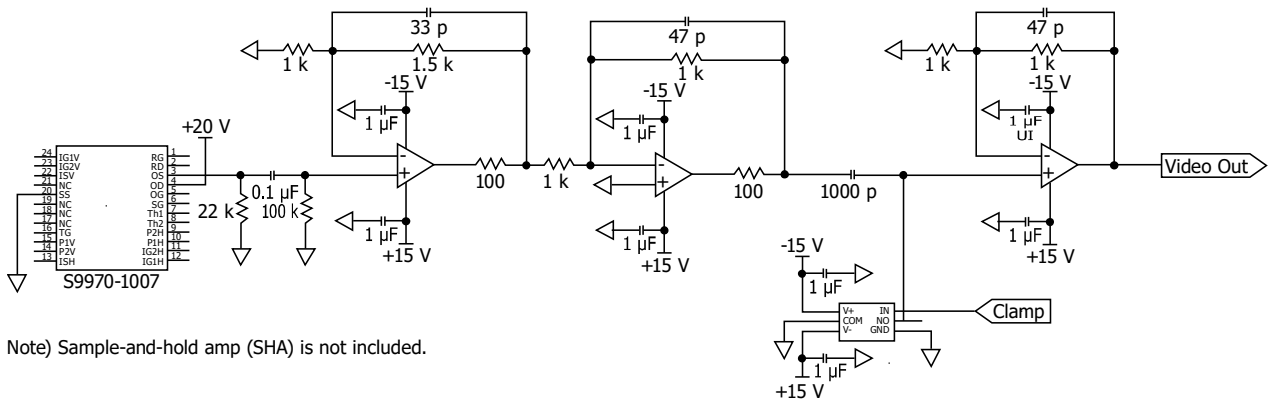
The clamp circuit is made up of capacitors and an analog switch. As the analog switch, we recommend using a high-speed type having low ON resistance and small charge injection amount.

As with the preamp, the last-stage amplifier is AC-coupled via a capacitor, so a JFET or CMOS input amplifier should be selected. In addition, a non-inverted amplifier must be configured to allow high input impedance.

Incidentally the CCD provides a negative-going output while the last-stage amplifier gives a positive-going output to facilitate analog-to-digital conversion. For this reason, an inverted amplifier is

connected after the preamp.

[Figure 40] CDS circuit example



Note) Sample-and-hold amp (SHA) is not included.

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