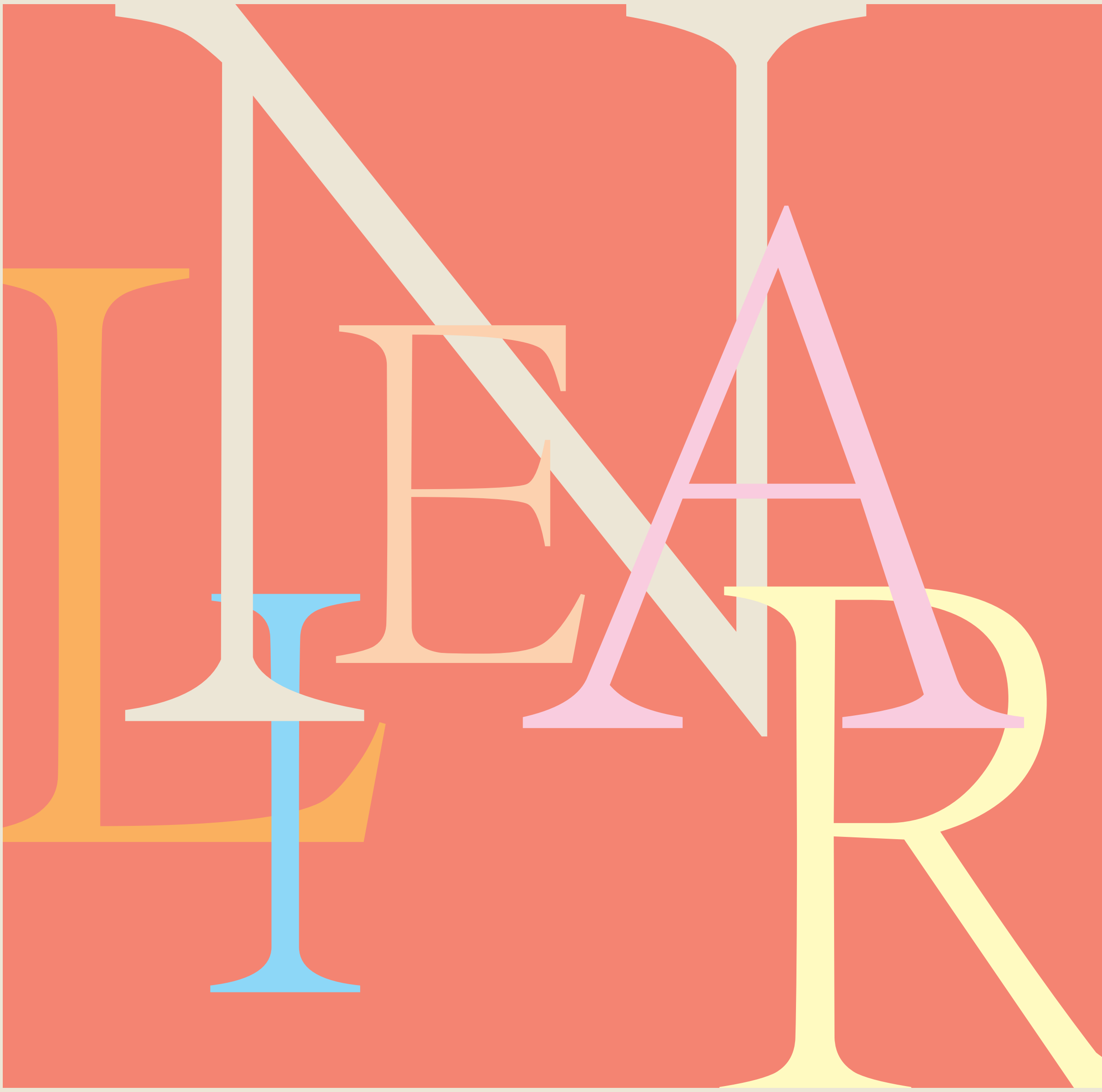
SONY

PRODUCT

SEMICONDUCTOR SELECTION GUIDE

Linear Sensor

Linear Sensor

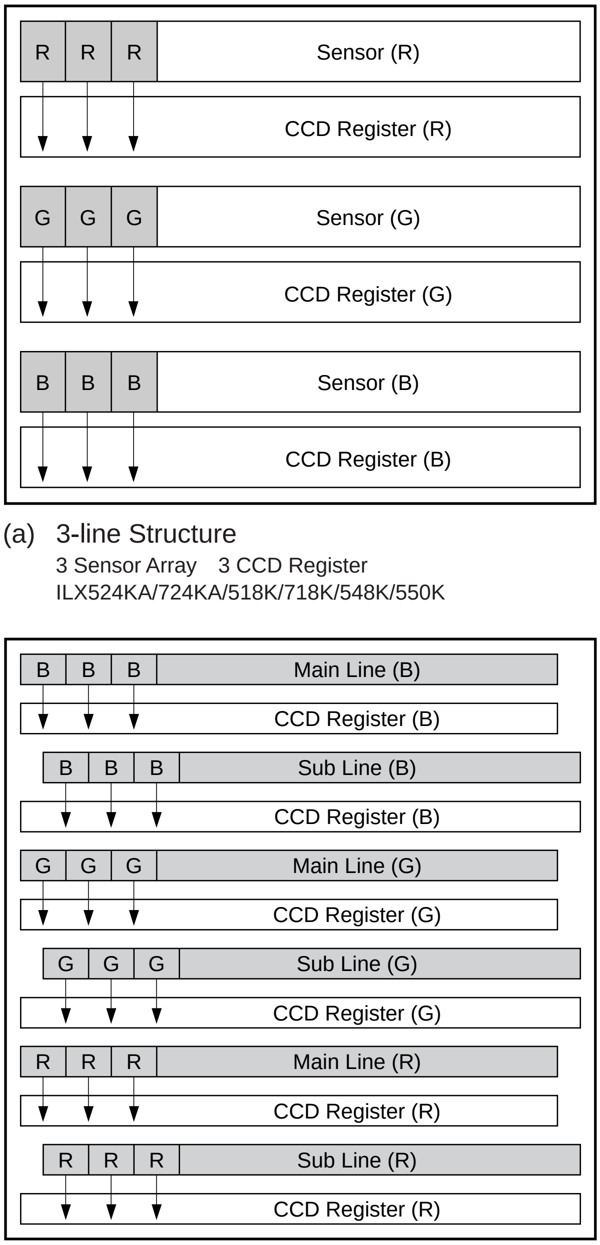


CONTENTS

1. Lineup and Future Outlook

1-1. Lineup and Applications

The ILX series devices are reduction-type linear sensors ideally suited for such applications as copiers, facsimiles, image scanners, and bar code readers. Sony's linear sensors employ the unique HAD (hole-accumulation-diode) sensor technology to accomplish complete readout and therefore exhibit ultra-low image lag, good linearity in low illumination conditions, low dark signal output, and various other excellent electro-optical characteristics. A host of B/W sensors are also available to cover a wide variety of applications. They range from the 256-pixel ILX521A which operates on a single 5 V power supply to the 7500-pixel ILX532A with a built-in 40 MHz drive clamp circuit. In recent years, the need for color linear sensors has rapidly increased in line with widespread use of personal computers. Sony provides the lineup of color linear sensors which operate on various structures (See Fig. 1-1.).



(a) 3-line Structure
3 Sensor Array 3 CCD Register
ILX524KA/724KA/518K/718K/548K/550K

(b) 6-line Structure
6 Sensor Array 6 CCD Register
ILX128MA

Fig. 1-1

Table 1-1 Lineup

☆Under development

Product name	Classification	Effective pixels	Pixel size (μm)	Sensitivity (V/(lx • s))	Maximum data rate (MHz)	Resolution (DPI)	Package	Pins
ILX521A	B/W	256	14 × 14	19	2	—	SDIP	12
ILX521AA	B/W	256	14 × 14	19	2	—	Plastic SOP	20
☆ ILX554A	B/W	2,048	14 × 56	260	2	—	Cer-DIP	22
ILX103A (Provided with shutter function)	B/W	3,000	7 × 200	300	1	—	Cer-SIP	16
ILX526A (Provided with shutter function)	B/W	3,000	7 × 200	300	1	—	Cer-DIP	22
☆ ILX551A	B/W	2,048	14 × 14	40	5	B4 200	Cer-DIP	22
☆ ILX751A (Provided with shutter function)	B/W	2,048	14 × 14	40	5	B4 200	Cer-DIP	22
ILX523A	B/W	2,700	11 × 11	95	5	A4 300	Cer-DIP	22
ILX531A	B/W	5,150	7 × 7	11	40	A4 600/ A3 400	Plastic DIP	22
☆ ILX553A	B/W	5,150	7 × 7	13	15	A4 600	Plastic DIP	22
ILX532A	B/W	7,500	7 × 7	11	40	A3 600	Cer-DIP	28
ILX524KA	Color (RGB)	2,700 × 3	8 × 8 (8 μm pitch)	R 2.0, G 3.2, B 2.5	5 × 3 (R, G, B)	A4 300	Plastic DIP	22
ILX724KA (Provided with shutter function)	Color (RGB)	2,700 × 3	8 × 8 (8 μm pitch)	R 2.0, G 3.2, B 2.5	5 × 3 (R, G, B)	A4 300	Plastic DIP	22
ILX518K	Color (RGB)	5,363 × 3	8 × 8 (8 μm pitch)	R 2.0, G 3.2, B 2.5	5 × 3 (R, G, B)	A4 600	Plastic DIP	22
ILX718K (Provided with shutter function)	Color (RGB)	5,363 × 3	8 × 8 (8 μm pitch)	R 2.0, G 3.2, B 2.5	5 × 3 (R, G, B)	A4 600	Plastic DIP	22
☆ ILX548K	Color (RGB)	5,340 × 3	4 × 4 (4 μm pitch)	R 2.5, G 2.9, B 2.6	5 × 3 (R, G, B)	A4 600	Cer-DIP	22
☆ ILX550K	Color (RGB)	10,680 × 3	4 × 4 (4 μm pitch)	R 2.5, G 2.9, B 2.6	5 × 3 (R, G, B)	A4 1200	Plastic DIP	24
☆ ILX128MA (Provided with shutter function)	Color (RGB)	5,350 × 2 × 3	6 × 8 (8 μm pitch)	R 1.9, G 4.3, B 2.6	6 × 3 (R, G, B)	A4 1200	Plastic DIP	24

Product name	Functions	Package	Pins
CXA1439M	Analog signal processor with a built-in CDS, 6 dB amplifier and 9.5 dB amplifier	SOP	8
CXD1175AM	8-bit, 20MSPS, built-in sample and hold, A/D converter	SOP	24
CXD2310AR	10-bit, 20MSPS, A/D converter	LQFP	48

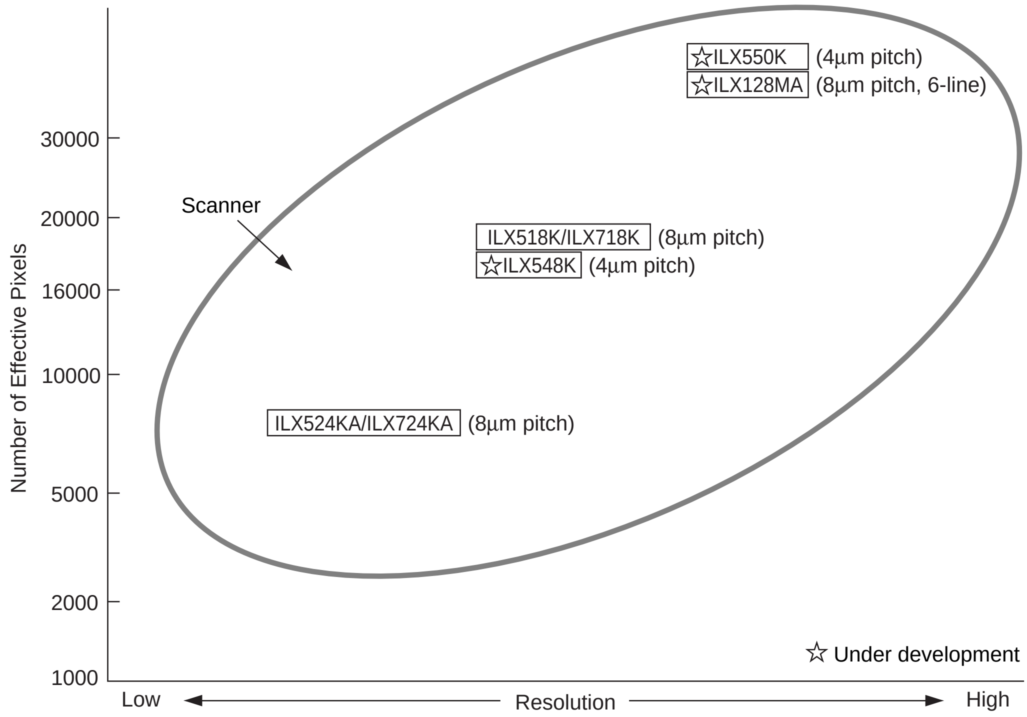


Fig. 1-2 Application of CCD Color Linear Sensor

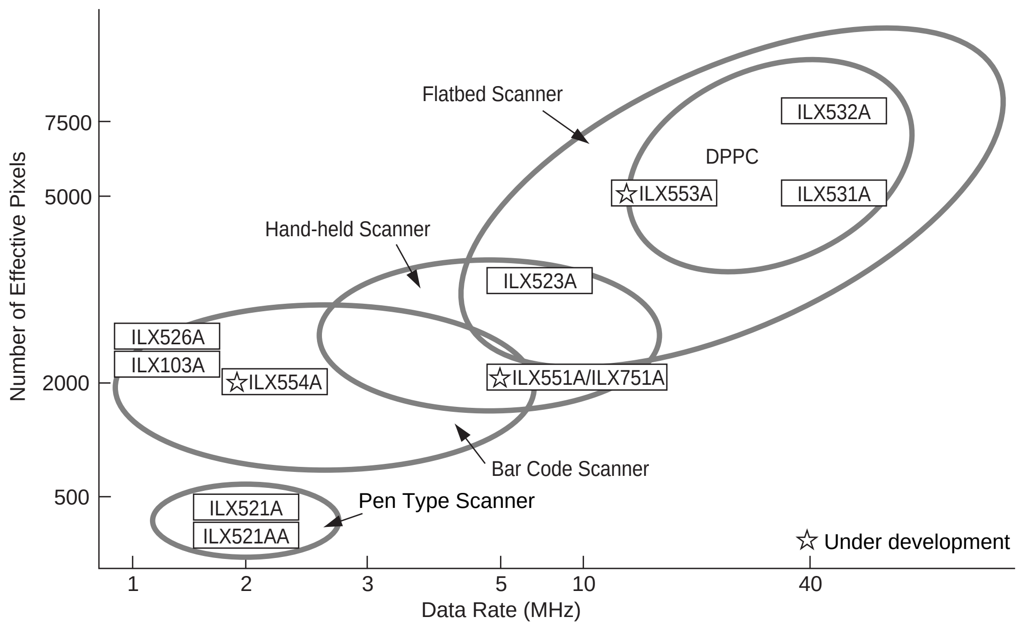


Fig. 1-3 Application of CCD B/W Linear Sensor

1-2. Future Outlook

CCD linear sensors are enjoying tremendous popularity with the digitization of AV-IT products.
In particular, along with the spread of home-use personal computers, the image scanner market is increasingly growing in scale, bringing about rapid increase in the demands for CCD color linear sensors which serve as the image input elements of these image scanners.
Meanwhile in the office automation applications, as black and white DPPCs as well as color DPPCs continue to advance, demands for high speed driven color linear sensors are growing ever more stronger.
The growth of the bar code market used in the production, distribution, sales, and service fields has also led to increased growth of the markets of the bar code scanners and handy terminals used as information input devices.
The market of the CCD linear sensor continues to grow too with increased demand for measuring accuracy and compact size of the auto focus linear sensor required for silver-chloride cameras.
CCD linear sensors will thus continue to be used in large numbers in new markets such as the multi-function printer and position detection elements.
The CCD linear sensor is the most outstanding sensor of the many sensors available in all aspects such as resolution, dynamic range, S/N ratio, drive frequency. It is used as a key device in all of these fields.
In this way, the necessity and importance of linear sensors will significantly increase in line with the emergence of an even wider array of digital products.
We will continue to make vigorous efforts to offer CCD linear sensors satisfying the needs of such markets and CCD linear sensors that will create new markets, and hope that the linear sensors we produce in the future, in addition to our current products, will continue to serve our customers' needs.

2. Device Structure

2-1. HAD (Hole-Accumulation-Diode) Sensors

CCD linear sensors have a number of formations depending upon the element structure. Two typical basic constructions are PN junction diodes and hole-accumulation-diode (HAD) sensors. Because of the simple structure, PN junction diodes (Fig. 2-1) have been prevalent, but suffered from a major shortcoming: large dark current. Fig. 2-2 shows a cross section of a HAD sensor used in Sony's linear sensors. A hole accumulated layer located on the surface of the sensor (shaded portion), suppresses dark current which becomes the source of noise to a minimum.

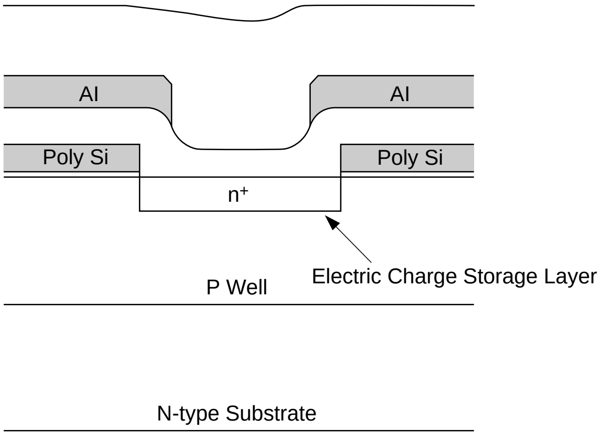


Fig. 2-1 PN Junction Diode Structure

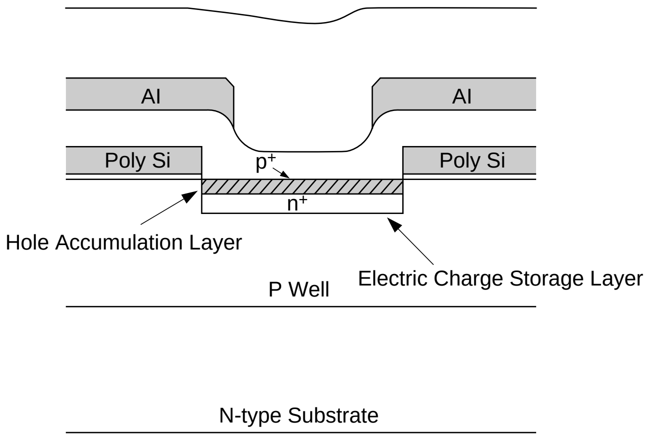


Fig. 2-2 HAD Sensor Structure (P^+NP Junction)

2-2. Pixel Structure

In a linear sensor, two adjacent pixels are separated by a region called a "channel stop." In a B/W linear sensor, the effective sensor aperture is determined by this channel stop. In the case of the ILX503A, the channel stop has 2 µm width, so the effective sensor aperture is 14×12 µm^2 (Fig. 2-3). In a dot sequential color linear sensor, the pixels are separated by the channel stop and aluminum electrode which shields light. In this case, the sensor aperture is determined by the aluminum.

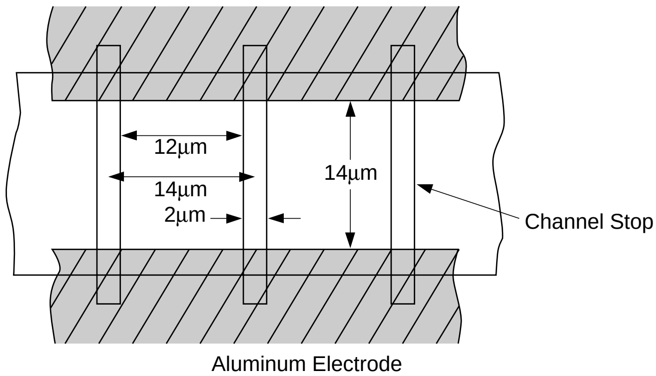


Fig. 2-3 Pixel Structure of ILX503A

2-3. Electronic Shutter Function

The ILX703A is the first product as a linear sensor to be equipped with an electronic shutter function. This function can control the sensor signal storage time independently of the readout gate pulse (ΦROG). For example, when the sensor is being used in such a way that the readout period is extremely long, the charge of the sensor signal may overflow. By using the electronic shutter function, the signal can be obtained without the signal charge overflowing. Other applications for this function include sensitivity compensation in an automatic sensitivity adjustment circuit that absorbs the degradation of the light source, and resetting the charge remaining when the light source is switched in a light-source switching color image scanner.
The shutter operation is explained on the following paragraph.

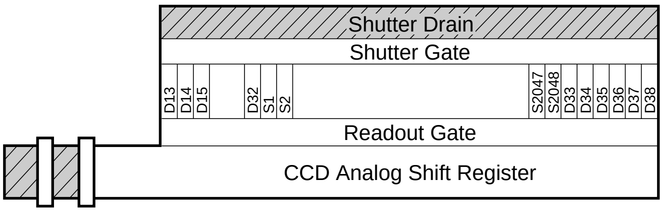


Fig. 2-4 Block Diagram of ILX703A Sensor

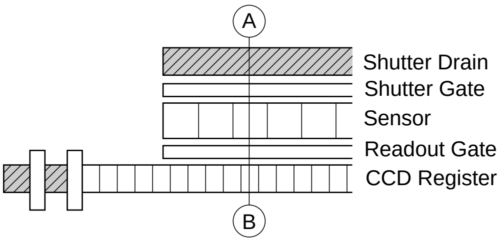


Fig. 2-5

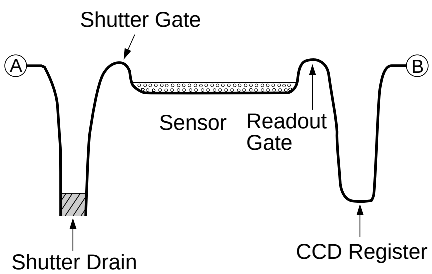


Fig. 2-6 Potential Diagram at Cross Section of A-B in Fig. 2-5

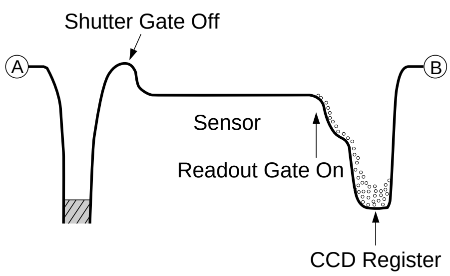


Fig. 2-7 Normal Readout Mode

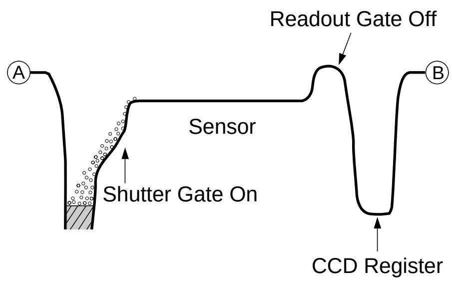


Fig. 2-8 Shutter Mode

Fig. 2-4 is a block diagram of the ILX703A sensor. Fig. 2-6 is a potential diagram showing a cross section Ⓐ - Ⓑ in Fig. 2-5 when the signal charge is stored. In normal use, the readout gate is turned on and the accumulated charge is transferred to the CCD register as shown in Fig. 2-7. When the shutter is used, the shutter gate is turned on and the accumulated charge in the sensor is discharged to the shutter drain as shown in Fig. 2-8.

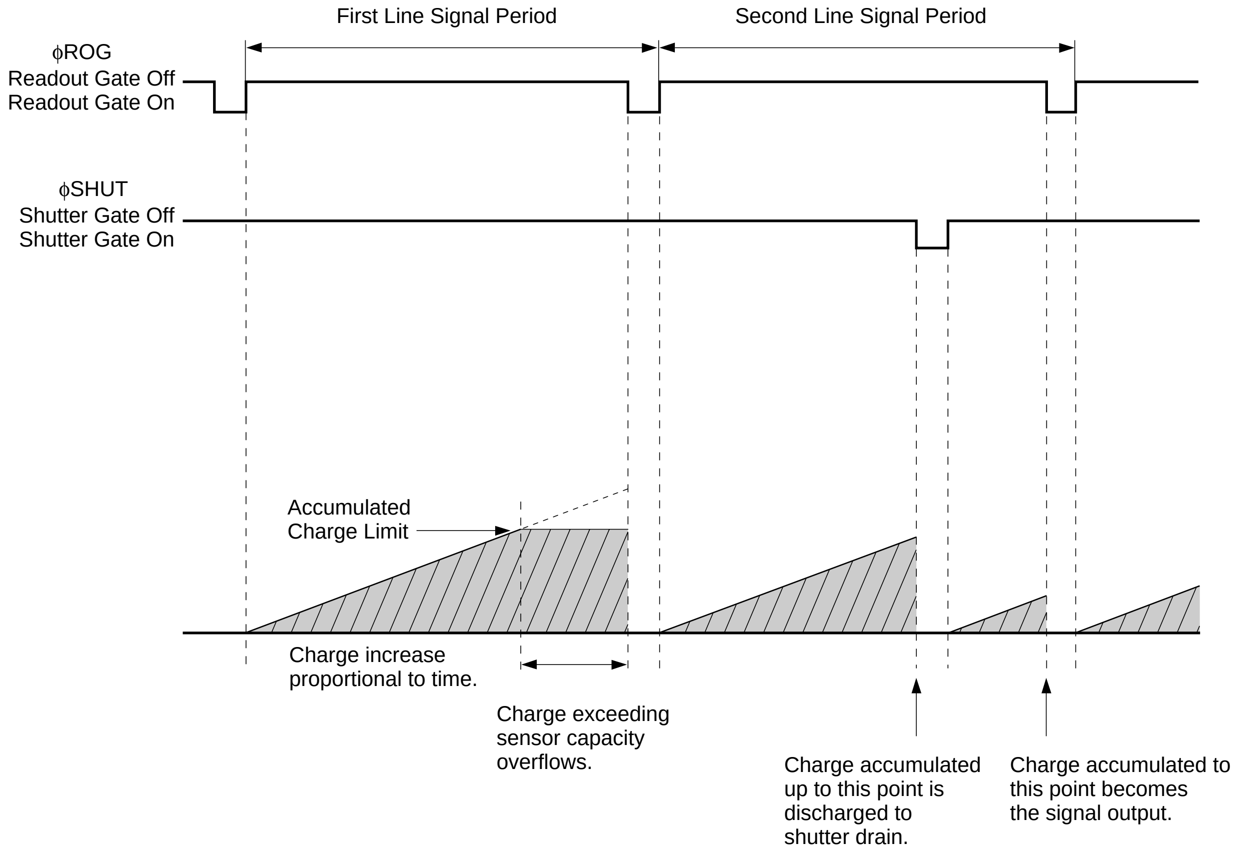


Fig. 2-9 Operation of Electronic Shutter

Description of Operation

The diagram above focuses on a single sensor showing the differences in the charge accumulated in the sensor depending on whether the shutter is used or not. The first line illustrates the case where the shutter is not used, and the second line illustrates the case where the shutter is used. While a sensor is exposed to certain amount of light, the charge accumulated increases in proportion to time, but when the exceeds charge the accumulated capacity of the sensor, it overflows into adjacent pixels. If the shutter is used, the charge in the sensor can be discharged into the shutter drain before the charge overflows, thus eliminating this problem. Therefore, by using shutter function, output signals can be controlled. If the shutter is turned on during the effective pixel period, a signal level difference arises by shutter pulse coupling.

3. Technical Descriptions

3-1. Sensitivity

Sensitivity is expressed by the ratio of output voltage to the amount of incident light. This holds true for CCD area image sensors and CCD linear sensors. In general, the area image sensor sensitivity is indicated in mV, on the other hand the linear sensor sensitivity is indicated in V/(lx·s). Although these two sensitivity indication systems look considerably different, they are, in reality, exactly the same.
As defined above, the sensitivity is the ratio of output voltage to incident exposure. The incident exposure represents the total amount of incident photon upon sensor. It is expressed by the product of illumination on a sensor surface and time. To be brief, the illumination is considered the amount of incident photon per unit time, and the incident exposure (that is, the total amount of incident photon upon sensor) is considered the time integral of photon incidence per unit time.
For area image sensors which make measurement according to the TV format, the integrating time is fixed at 1 field (1/60s (by NTSC or EIA)). Further, the incident exposure can be determined uniformly by fixing the luminance conditions of light source. Under such condition, the sensitivity is stipulated by measuring the output voltage. This measurement method also conforms to the usage of area image sensors and helps the customer thoroughly understand the area image sensor characteristics. Linear sensors, on the other hand, are operated at various frequencies depending on individual customer requirements. Further, the storage time cannot be fixed because a wide variety of sets are used. In marked contrast to area image sensors, the light source conditions for linear sensors cannot be uniformly determined to satisfy all customers. Therefore, it is necessary to use a standardized value as the incident exposure, that is, the product of illumination on a sensor surface and time (the unit "lx·s" needs to be used). Consequently, the sensitivity is stipulated as the ratio of output voltage to standardized exposure.
Due to the device structure, the sensitivity value is influenced by two factors. One is photoelectric conversion efficiency to CCD block and the other is output amplifier block gain. The sensitivity is determined by the product of these two factors.
It means that the sensitivity value greatly varies with the employed incident light source. Therefore, in same cases, use of μJ/cm^2, which is based on the energy in the associated wavelength band, may be more appropriate than lx·s for the incident exposure unit (See the section "3-2. Sensitivity Dependence on Light Sources").

Finally, consider the relationship between the amount of incident light and output voltage in the case of the ILX503A. When, for instance, the ILX503A is driven at a data frequency of 1 MHz, the minimum storage time is 2.2 ms. When a 3200K light source (with the CM-500S IR cut filter) having an illumination on a sensor surface of 10 lx is employed in such a situation, the output voltage is as follows:

$V_{OUT} = 30\ V/(lx \cdot s) \times (2.2\ ms \times 10\ lx) = 660\ mV$

As implied above, a high sensitivity contributes to decrease of incident exposure. It means that a low light source intensity or a short storage time (high-speed readout) can be achieved.

3-2. Sensitivity Dependence on Light Sources

The sensitivity of linear sensor depends a great deal on the spectrum of the light source.
This is because:

- The amount of incident light is denoted as the illumination (lx)
- The sensitivity of the linear sensor has the spectral sensitivity.

The illumination is the sum of the light energy per unit of area; however, a coefficient adjusting for luminous efficiency to incident light must be factored in. A distribution for the luminous efficiency is shown in Fig. 3-1, with a peak at λ = 555 nm. The value of illumination is calculated as follows:

$\text{Illumination} = \int E(\lambda) \times L(\lambda)\, d\lambda$

where:

$E(\lambda)$: luminous energy at a specific wavelength

$L(\lambda)$: luminous efficiency coefficient at a specific wavelength

If green light and red light are compared, the illumination value of the red light will be much lower at the same energy.
Consider this phenomenon for light that has an bright-line spectrum and compare green light (λ = 555 nm) and red light (λ = 660 nm) (Shaded portion in Fig. 3-2). As shown by Fig. 3-2, the luminous efficiency of red light is 1/16 that of green. Conversely, if red light and green light are compared in the same illumination, red light has energy 16 times that of green light.

Next, consider the effect spectral sensitivity of linear sensors give. With a B/W linear sensor, when the light spectrum of the incident light is uniform, the spectral sensitivity characteristics of the linear sensor show a peak in the region of λ = 460 nm. (Fig. 3-3 is for the ILX511.) The output voltage in this case is proportional to the integrated value of the spectral sensitivity along the wavelength axis, which is equivalent to the area for the shaded portion in the Fig. 3-4. The equation for expressing the relationship with the output voltage for incident light is as follows:

$V_{OUT} \propto \int V(\lambda) \times E(\lambda)\, d(\lambda)$

where:

V (λ) : spectral sensitivity at a specific wavelength

E (λ) : luminous energy at a specific wavelength

Consider a specific example comparing the sensitivity for green light (λ = 555 nm) and red light (λ = 660 nm) for the bright-line spectrum used in the previous examples (ILX511). As shown by Fig. 3-4, if light with the same energy is applied, the output for the green light is approximately 1.4 times that of the red light.

As the summary:

- The output voltage is determined as the integral of the product of the luminous energy spectrum and the HAD sensor spectral sensitivity along the wavelength axis.
- The amount of incident light is determined as the integral of the product of the spectral characteristics of luminous efficiency and the energy spectrum along the wavelength axis.

The difference between these two spectral sensitivity is the reason why sensitivity depends on the spectrum of the light source. Consider the spectrum of a bright line mentioned earlier. When the light with same energy is applied, the output voltage for the green light is 1.4 times that of red light, and the illumination value of the red light is 1/16 that of green light.

The sensitivity ratio is calculated as follows:

Green sensitivity: Red sensitivity = 1.4/1 : 1/(1/16) = 1 : 12

Actually the measurement data under the light source of 570 and 660 nm LED shows that the red sensitivity is higher than the green sensitivity (See Table 3-2).

When it comes to practically used light sources, the light spectral distribution is complicated so that comparison is not easy. In the case of light sources with a continuous spectrum, however, light sources with lower color temperatures tend to provide higher sensitivities. This phenomenon occurs because light with a long wavelength does not contribute to the illumination but does contribute to the output value. In a region where the luminous efficiency is low, it is better that the exposure be expressed in $\mu J/cm^2$ instead of lx·s because the former is based on the energy of the associated wavelength band (See Table 3-1).

Even when the same light source is used, the characteristic of IR-cut filter causes even greater changes in the sensitivity. This is because the light spectrum changes a great deal depending on the spectral transmission characteristics of the IR-cut filter. For example, C-500 (t = 1 mm) and CM-500S (t = 1 mm), which are both used often in specifications etc., have spectral characteristics similar to those shown in Fig. 3-5. In this case, the sensitivity of the C-500 (t = 1 mm), with its high transmittance for light of infrared wavelength, provides higher sensitivity.
In the case of light sources having a bright-line energy spectrum such as a three-wavelength fluorescent lamp, an illumination comparison may occasionally show that the resulting sensitivity is different from that derived from the use of a 3200K white light source. In this situation, the unit of sensitivity should be V/(µJ/cm^2) rather than V/(lx·s).

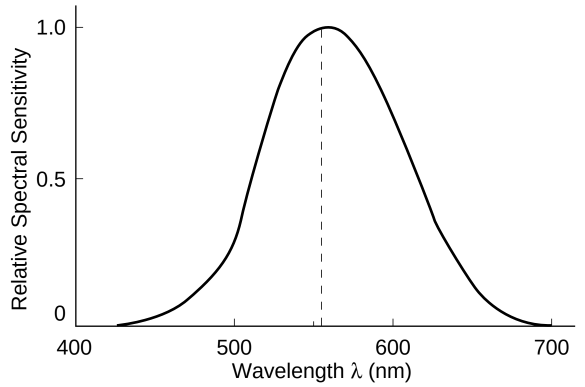


Fig. 3-1 Spectral Characteristics of Luminous Efficiency

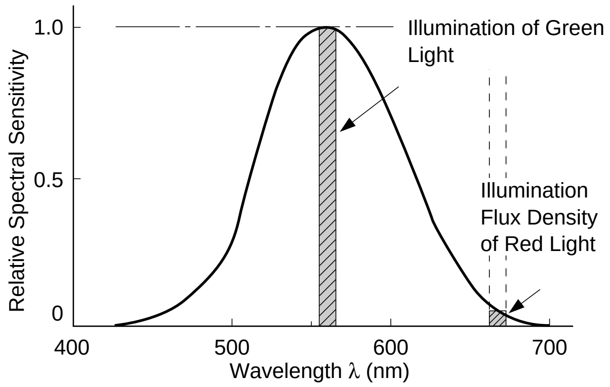


Fig. 3-2 Illumination as a Function of Wavelength

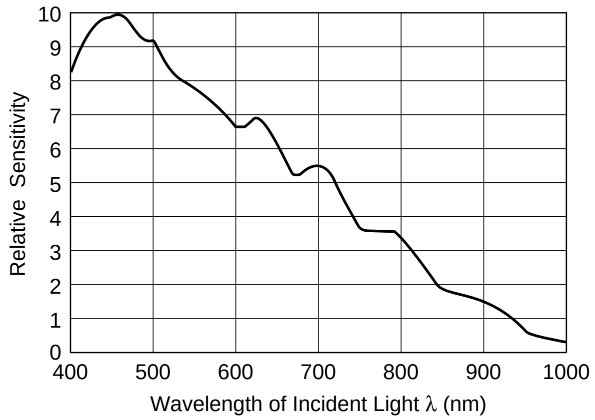


Fig. 3-3 Spectral Sensitivity Characteristics of ILX511 (Standard Characteristics)

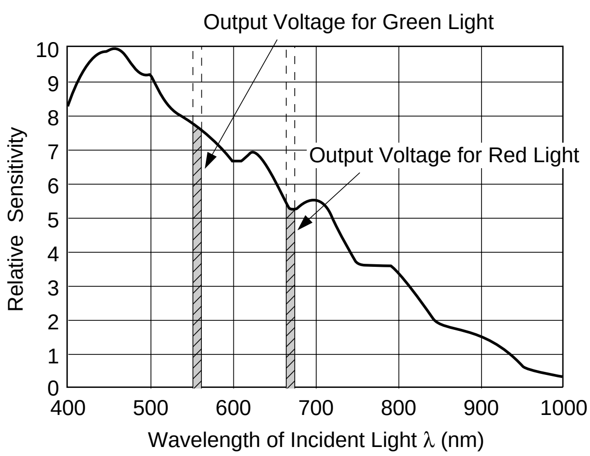


Fig. 3-4 Output Voltage as a Function of Wavelength

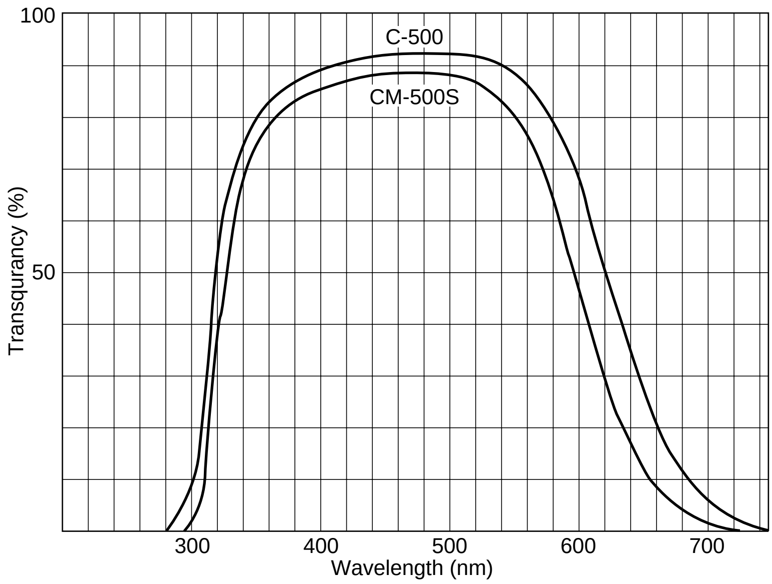


Fig. 3-5 Spectral Characteristics of an IR-cut Filter

Table 3-1 ILX503A LED (λ = 660 nm) Sensitivity Comparison

When lx·s is used	500V/(lx·s)
When μJ/cm² is used	100V/(μJ/cm²)

Table 3-2 Typical Sensitivity of ILX511

Light source	Filter	Sensitivity V/(lx·s)
Tungsten light source (3200K)	CM-500S (T = 1mm)	200
LED (= 570nm)	None	154
LED (= 660nm)	None	1800

3-3. Sensitivity Nonuniformity (PRNU)

Sensitivity nonuniformity (PRNU) refers to situations where an output signal amplitude varies for each pixel in all of effective pixels when they are exposed to a uniform illumination. Sony defines the sensitivity nonuniformity as follows:

$$\text{PRNU} = \frac{(\text{Vmax.} - \text{Vmin.})/2}{V_{AVE}} \times 100$$

Where the maximum output of effective pixels is Vmax., their minimum output is Vmin. and their average output is V_{AVE} (See Fig. 3-6).

As for double-sided readout type of linear sensors, the sensitivity nonuniformity is defined separately for even and odd pixels. For color linear sensors, the sensitivity nonuniformity is defined for each color.

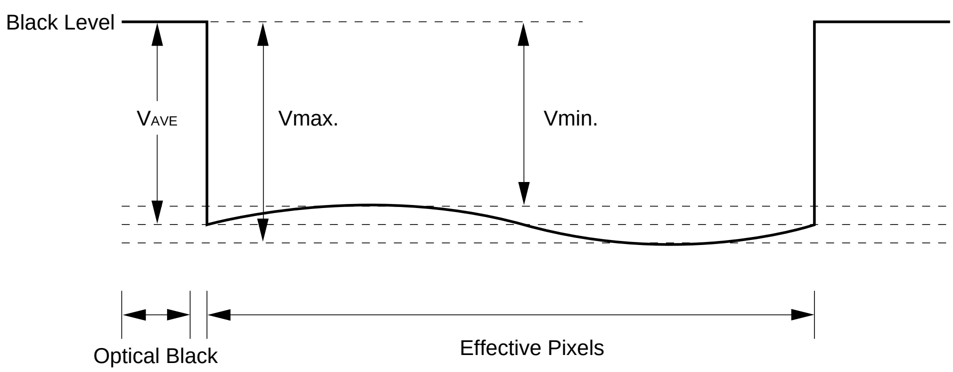


Fig. 3-6 Definition of Sensitivity Nonuniformity

3-4. Dark Voltage Average (VDRK)/Dark Signal Nonuniformity (DSNU)

The dark voltage average refers to the average output value in the absence of incident light; the dark signal nonuniformity refers to the distribution of the dark output voltages for each pixel. The dark voltage average is caused by charge generated without any relationship to light. Because this charge is generated on a steady state, the dark voltage average is proportional to the storage time. Fig. 3-7 shows the temperature characteristics of the dark voltage average. The dark voltage average at 25°C is 1 on the vertical line. This average is normally measured at a 10 ms storage time of optical signal and ambient temperature of 25°C.
In the ILX503A, if the maximum output voltage generated by all of effective pixels in the absence of incident light is Vmax. and the minimum is Vmin., the dark signal nonuniformity (DSNU) is defined as the greater of Vmax. – VDRK and VDRK – Vmin. (See Fig. 3-8).

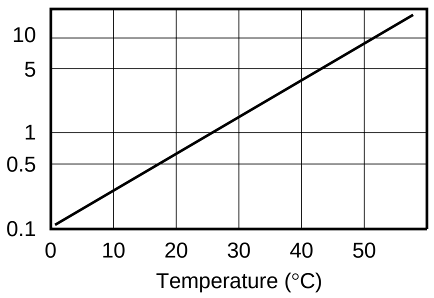


Fig. 3-7 Dark Voltage Average Temperature Characteristics of ILX503A

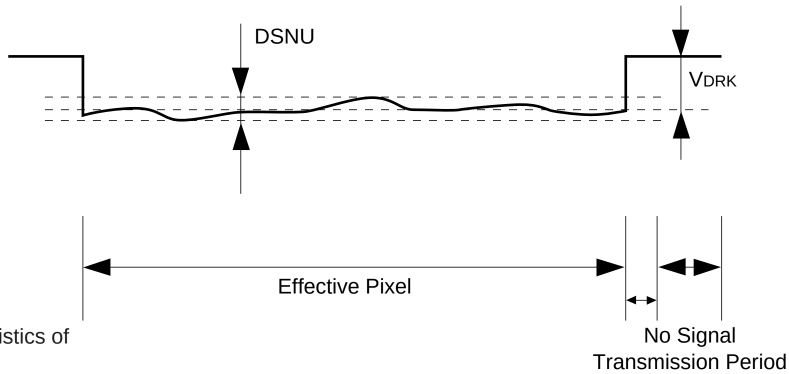


Fig. 3-8 Definition of Dark Voltage Average and Dark Signal Nonuniformity

Note that when the dark voltage average (VDRK) and the dark signal nonuniformity (DSNU) are small, the noise component is also small. To increase the number of gradations in an image, a device with a good signal to noise ratio must be used. Therefore, the device must not only have high sensitivity (i.e., the signal component), but must also have a small noise component.

3-5. Image Lag

Image lag refers to the phenomenon that is a portion of the CCD signal charge in transferred at previous transfer time. This occurs because the signal charge produced by photoelectric conversion in the sensor section is not transferred completely when it is transferred to the CCD analog shift register through the readout gate (i.e., part of the charge is left behind). The portion of the electric charge that was not transferred mixes with the signal in the next line and appears as image lag. (Image lag is the primary cause of performance degradation at low-light exposure.) Possible causes of this incomplete transfer may include problems with the structure of the sensor and problems with the use of the sensor, such as a short readout gate time. Fig. 3-9 shows signal charge readout properties for various sensor structures. In conventional sensors, because the structure was that of a PN diode sensor, an almost infinite amount of time would be required to completely transfer the signal charge. Sony's HAD sensors feature a special attribute, a readout electric field, which effects a complete transfer in a short period of time. Therefore, when used under the recommended conditions, Sony's linear sensors have practically no image lag (approximately 0.02% for the ILX503A).

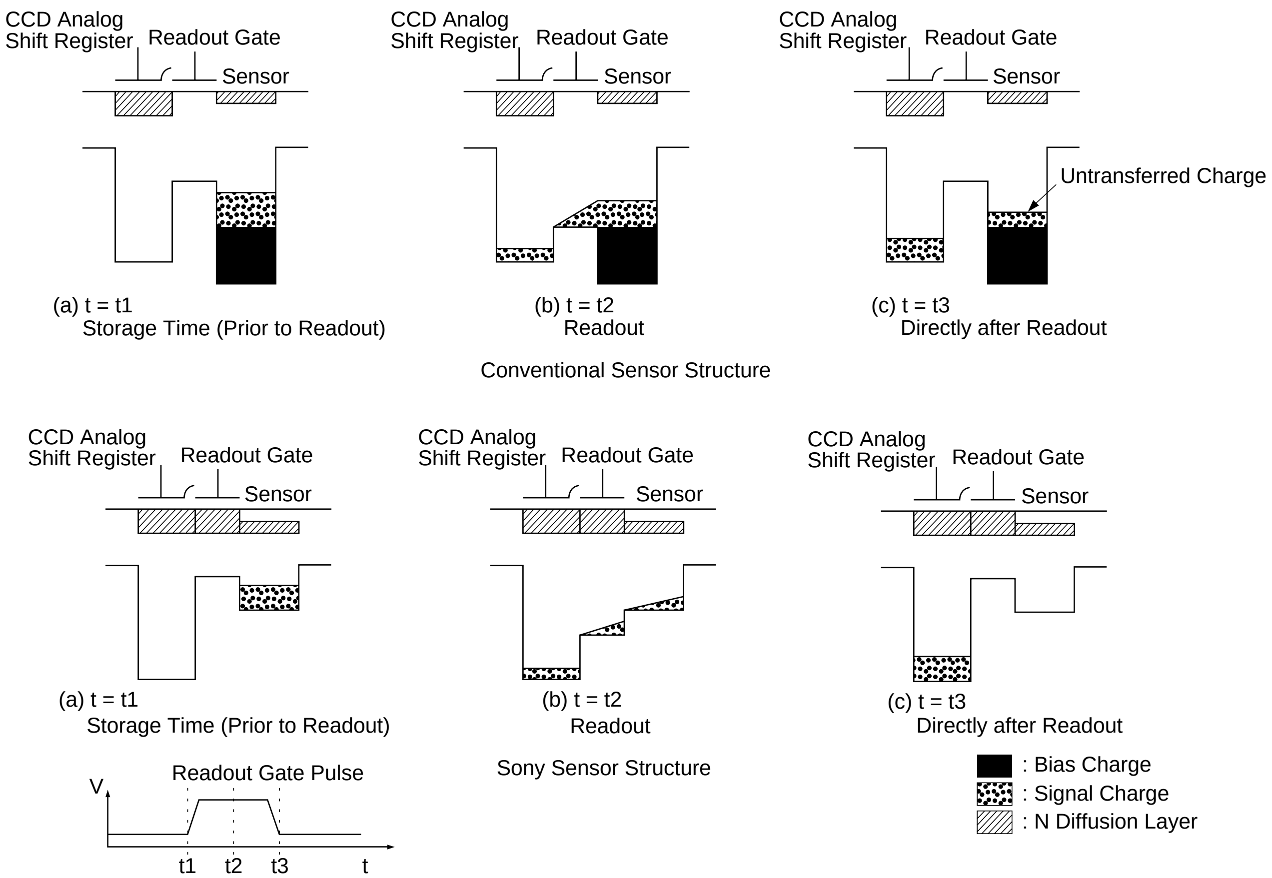


Fig. 3-9 Principles of Signal Charge Readout

3-6. Linearity

Linearity refers to the linearity of the output voltage (V) versus exposure (illumination × storage time: lx·s). Fig. 3-10 shows the relationship between the output voltage and the level of exposure (actual measurement data of the ILX503A specific sample). If the gradient is constant, the sensor has a good linearity. When the exposure becomes larger, the gradient decreases and the output voltage soon reaches saturation. The exposure at which the gradient begins to decrease is called the "saturation exposure level," and the output voltage at that point is defined as the saturation output voltage. Therefore, in order to obtain output with good linearity, the exposure must be set so that the output voltage is less than the saturation output voltage. Note that the linearity of Sony's linear sensors is determined mainly at the output circuit; the exposure at which the CCD analog shift register overflows is set greater than the saturation exposure level. The linearity characteristic at low exposure is the very important factor in the performance of the sensor because the small amount of signal charge accumulated in the sensor must be detected. Complete readout from sensor to CCD register ensures good linearity. In this respect, because of its HAD sensor structure and the complete readout feature, Sony's linear sensor realizes excellent linearity even under small exposure (See the section "3-5. Image Lag").

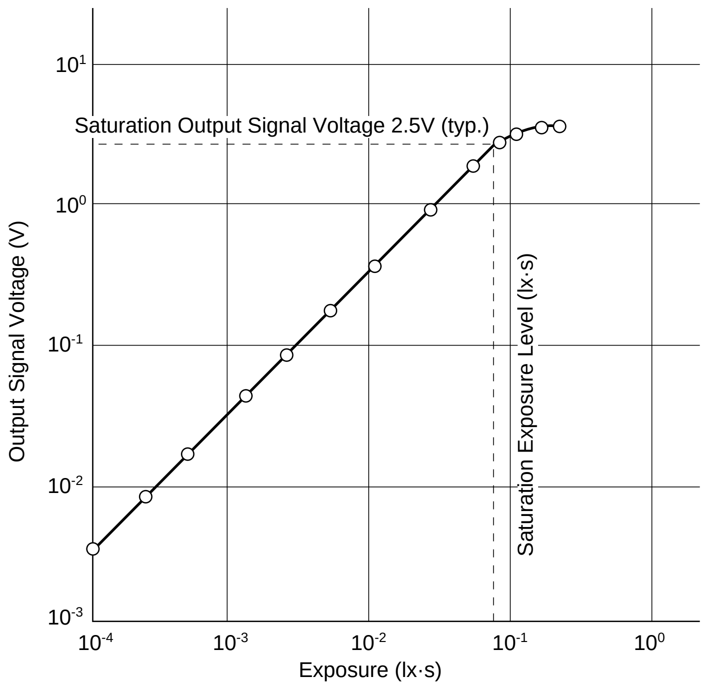


Fig. 3-10 Exposure Level vs. Output Voltage (Actual Measurement of ILX503A Specific Sample)

3-7. Even/Odd Black Level DC Difference

There are two main types of linear sensors, the double-sided readout system and single-sided readout system. In the double-sided readout system, signal charge is transferred in different directions for even and odd pixels and requires two CCD registers (Fig. 3-11 (a)); in the single-sided readout system, signal charge is transferred in the same direction for all pixels and requires one CCD register (Fig. 3-11 (b)). To obtain the CCD output signal, clock pulses for transfer (Φ1 and Φ2) and a reset pulse (ΦRS) are required. The data rate is the same as the frequency (fΦRS) of the ΦRS pulse. With the single-sided readout system, fΦRS is the same as the frequencies (fΦ1, fΦ2) of Φ1 and Φ2. In the double-sided readout system, however, fΦRS is twice as fΦ1 (or fΦ2). In general, the DC level difference between even pixels and odd pixels arises in the double-sided readout system because there is a one-half clock pulse of the data rate in the device.

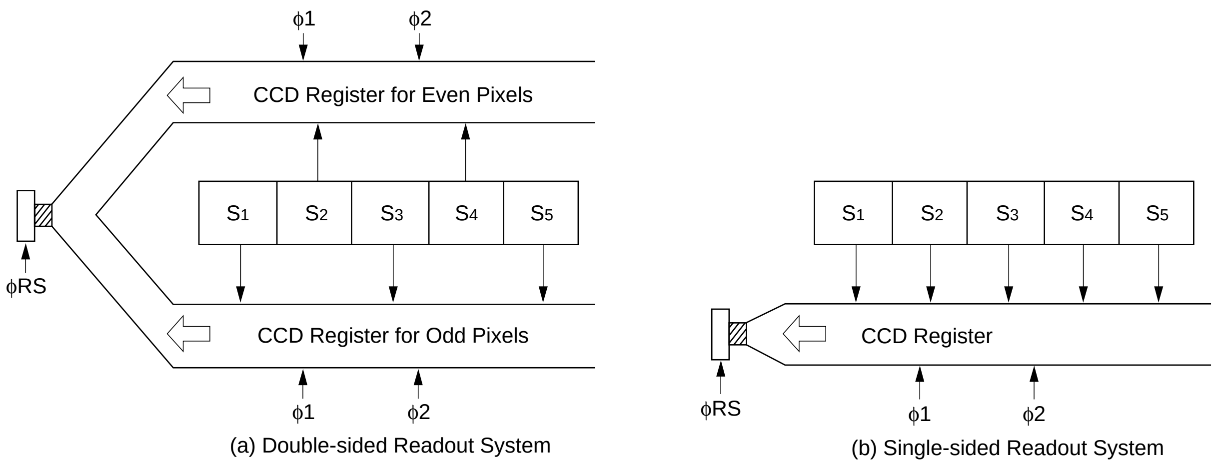
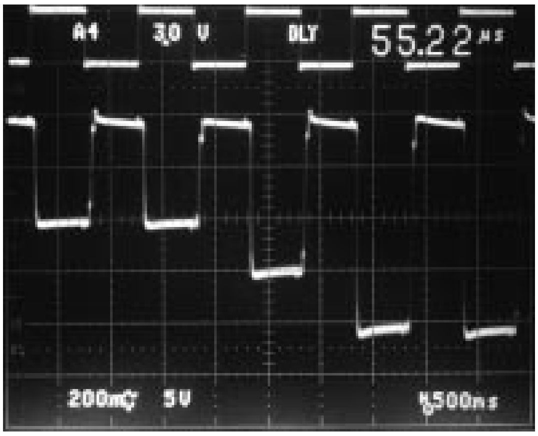


Fig. 3-11 Readout Systems of Linear Sensors

The ILX506, ILX508A, ILX514, and ILX526A adopt the double-sided readout system, and suppress DC level difference between even pixels and odd pixels with the improved internal timing circuit (See Fig. 3-12).
Focusing on the single-sided readout system where DC level difference between even pixels and odd pixels does not exist theoretically, Sony has adopted this system for the ILX503A and ILX505A as well as for 3-line color linear sensors (ILX518K, ILX524K, etc.) with small pixel size (8 µm).



ILX506
(Internal ΦRS Mode)

Fig. 3-12 VOUT Waveform when ΦCLK = 1 MHz of ILX506

3-8. Output DC Level

The output DC level of the linear sensor is specified as the "offset level Vos." This value is measured at the output pin (VOUT) of the linear sensor, and is specified by the voltage of the OPB (optical black) section of the linear sensor.

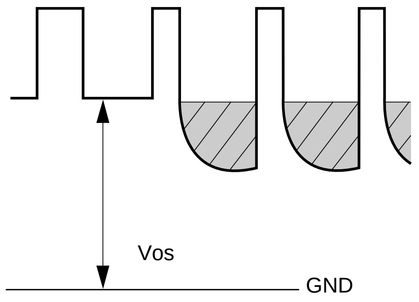


Fig. 3-13 Definition of Vos

3-9. Current Consumption Dependence on Operating Frequency

Fig. 3-14 shows the relationship between current consumption and operating frequency of the ILX503A. The 5 V power supply is used in the digital section such as the timing generator and clock driver, therefore the current consumption depends on the operating frequency. On the other hand, because the 9 V power supply is mainly used in the analog sections such as the output circuits, its current consumption does not depend on the operating frequency.

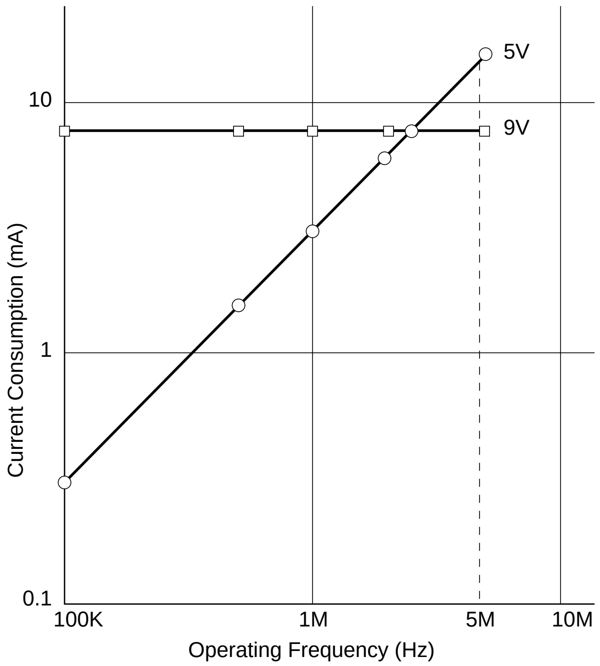


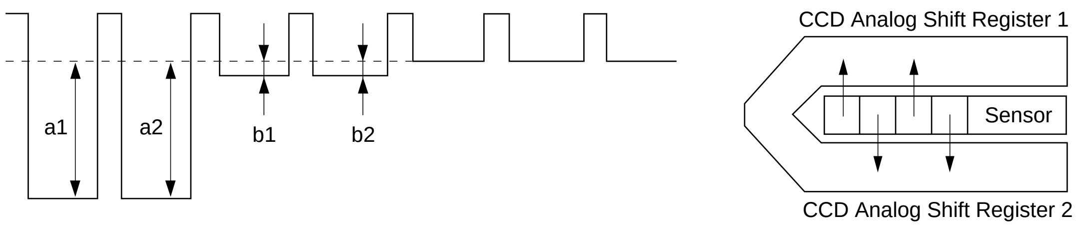
Fig. 3-14 Current Consumption vs. Operating Frequency

3-10. Total Transfer Efficiency (TTE)

The transfer efficiency indicates the proportion of the signal charge which is propagated per transfer stage in the CCD analog shift register. The total transfer efficiency is specified for the whole CCD analog shift register. If the transfer efficiency values for stage 1, 2, ... n of the CCD analog shift register are defined as $\eta 1$, $\eta 2$, ... ηn, respectively, the total transfer efficiency (TTE) is defined using the following equation.

$$TTE = \eta 1 \times \eta 2 \times \eta 3 \ldots \eta n\text{-}1 \times \eta n$$

If the total transfer efficiency degrades, the resolution of the output image also degrades.
The measurement method of TTE is described here. In the case of double-sided readout system, there are two CCD analog shift registers; because every other signal passes through the same register, the total transfer efficiency is defined as follows:



a2 : Final effective pixel

Total transfer efficiency for shift register 1 : $TTE1 = \dfrac{a1}{a1 + b1} \times 100\ (\%)$

Total transfer efficiency for shift register 2 : $TTE2 = \dfrac{a2}{a2 + b2} \times 100\ (\%)$

Total transfer efficiency (TTE) is the lesser of TTE1 and TTE2.

Fig. 3-15 Double-sided Readout System

In the case of single-sided readout system, TTE is defined as follows:

a : Final effective pixel

Total transfer efficiency (TTE) = $\dfrac{a}{a + b} \times 100\ (\%)$

Fig. 3-16 Single-sided Readout System

3-11. Output Signal Phase Difference between Use and Nonuse of Internal Sample-and-Hold Circuit

As shown in Fig. 3-17, the output signal phase varies depending on whether the internal sample-and-hold circuit is used or not. Therefore, pay due attention to the data acquisition point for external signal processing.
An example presented below is for the ILX523A.

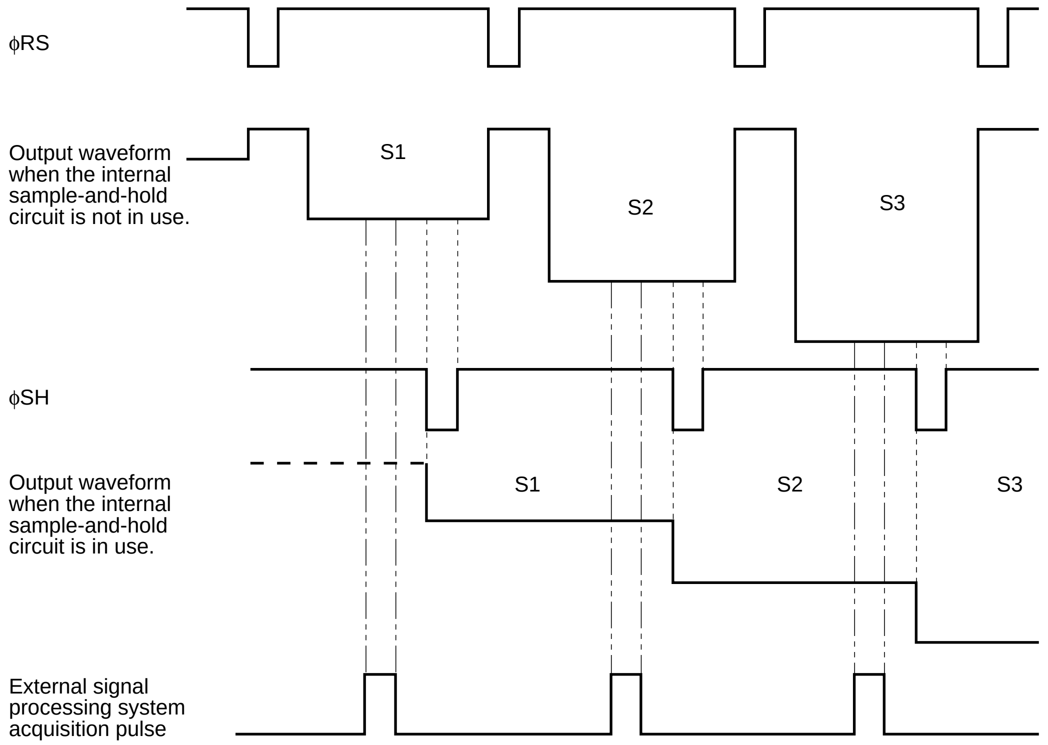


Fig. 3-17

In Fig. 3-17 the acquisition point of external signal processing system is positioned before an internal sample-and-hold pulse. When the internal sample-and-hold circuit is used, the data is acquired which is the one bit before the data that would be acquired against when the internal sample-and-hold circuit is not used.

3-12. Spectral Sensitivity Characteristics

These characteristics show spectral wavelength of the linear sensor. Specifically, light of a single wavelength with a fixed energy level is extracted from a spectroscope in the range of 400 to 1000 nm (B/W type) or 400 to 700 nm (color type), and radiated on the linear sensor. And then, the gained output voltage is measured. Measurement is made radiating light of a single wavelength directly onto the light reception surface of the linear sensor not to affect lens, filters, etc. Fig. 3-18 shows a system for performing these measurements.

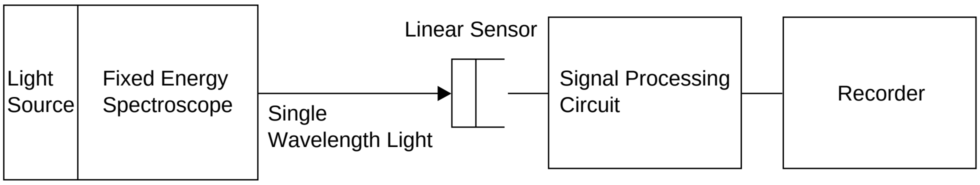


Fig. 3-18 Spectral Sensitivity Characteristics Measurement System

The following figures show examples of relative spectral sensitivity characteristics for B/W and color types. (The "relative spectral sensitivity" refers to the normalized characteristics at peak value for output signal.)

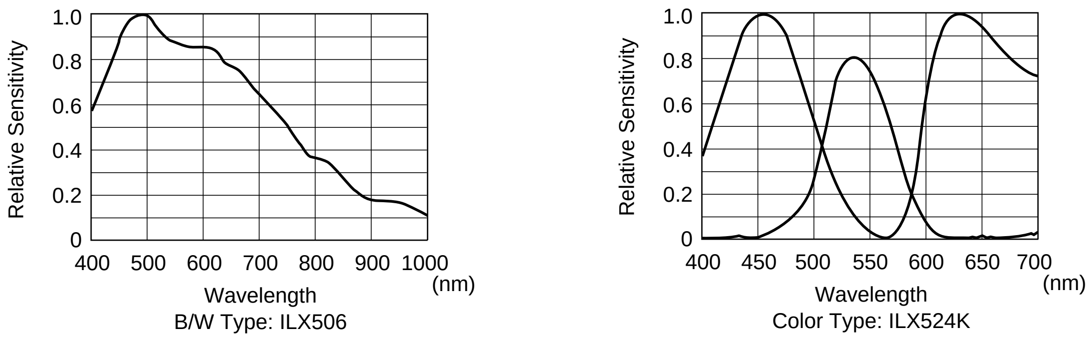


Fig. 3-19 Spectral Sensitivity Characteristics

3-13. Input Clock Voltage

On-chip timing generator and driver have a CMOS structure manufactured through Sony's original N-sub CMOS CCD process. This makes the 5 V logic system available for input clock. The recommended input clock voltage of the ILX503A is shown in Table 3-3.

Table 3-3 Recommended Input Clock Voltage of ILX503A

Item	Min.	Typ.	Max.	Unit
High level of input clock voltage	4.5	5.0	5.5	V
Low level of input clock voltage	0.0	—	0.5	V

4. Usage

4-1. Resolution

When linear sensors are used in office automation applications (DPPC, scanner, facsimile, etc.), the resolution is expressed in DPI (Dot Per Inch) unlike the CCD camera horizontal resolution. The linear sensor resolution is determined by dividing the number of pixels by the paper length to read out.
In the case of the ILX523A, for instance, the number of effective pixels is 2700. When this sensor reads out A4 size documents, its resolution is calculated as follows:

2700 pixels $\div$ 8.27 inches $\approx$ 326 $\approx$ 300 DPI

Even when the same sensor is used, the resolution used in office automation applications varies with the employed paper size. Therefore, the selection of required number of pixels varies with the product plan for the set. Conversely, the number of pixels can be determined by the document length and required resolution. When, for instance, A4 size paper (whose short side length is 210 mm or approximately 8.27 inches) need to read out with a resolution of 600 DPI, the required minimum number of linear sensor pixels is calculated as follows:

8.27 inches $\times$ 600 DPI = 4962 pixels

Reference data derived from the above calculations are compiled into the following table which shows the minimum number of pixels for various combinations of paper size and required resolution.

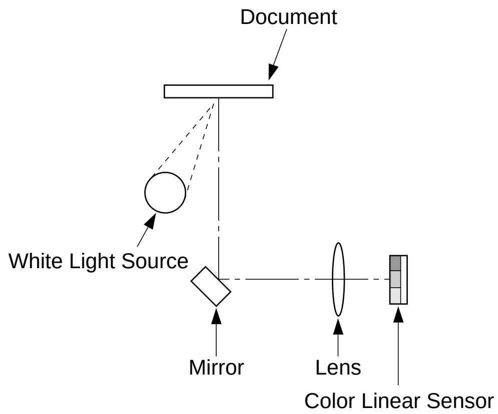
Table 4-1 Relation between Number of Pixels and Resolution

Paper size			200DPI	300DPI	400DPI	600DPI	800DPI
Photo size	3.23inch	(82mm)	646	969	1292	1938	2584
Post card size	3.94inch	(100mm)	788	1182	1576	2364	3152
A6 size	4.14inch	(105mm)	828	1242	1656	2484	3312
A5 size	5.83inch	(148mm)	1166	1749	2332	3498	4664
A4 size	8.27inch	(210mm)	1654	2481	3308	4962	6616
US letter size	8.50inch	(216mm)	1700	2550	3400	5100	6800
A3 size	11.66inch	(296mm)	2332	3498	4664	6996	9328

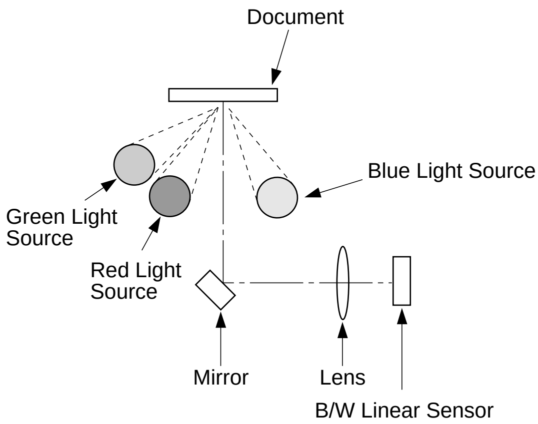
4-2. Color Image Readout

In order to read out color images with a linear sensor, the color separation (red, green, and blue) is necessary. The following three methods are used to achieve the optimal performance.

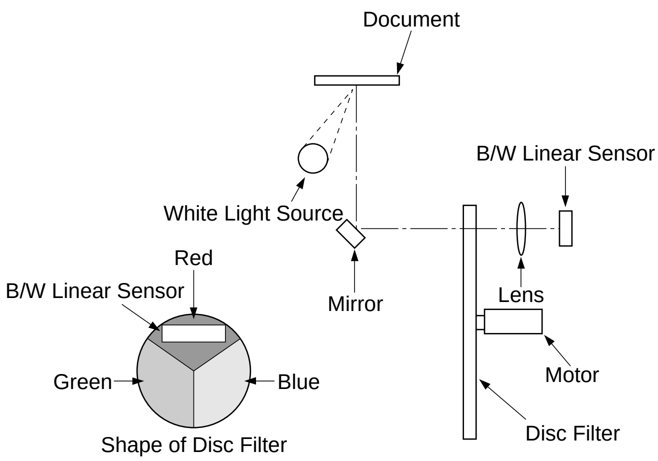
(1) Color linear sensor method
On-chip color filters (red, green, and blue) are applied to accomplish color separation.



(2) Light source switching method
To accomplish color separation, three different light sources (red, green, and blue) are sequentially switched in place of a white light source.



(3) External color filter switching method
To accomplish color separation, color filters are mechanically switched by inserting color filters between a white light source and a B/W linear sensor.



4-3. External ΦRS Mode

Because some Sony's linear sensors have timing generators on chip, there is basically no need for inputting an external ΦRS. Some products, however, have an external/internal switching pin for the ΦRS in order to permit the input of an ΦRS externally. In other words, when set to the internal ΦRS mode, two input clocks (ΦROG, ΦCLK) are required, but when set to the external ΦRS mode, three input clocks (ΦROG, ΦCLK, ΦRS) are required. Selecting the external ΦRS makes an additional input clock necessary, and doing so offers the following benefit:

CDS (Correlated Double Sampling) is possible → Noise reduction

■ CDS

The VOUT waveform in internal ΦRS mode is as shown in Fig. 4-1; the precharge section does not appear. However, if external ΦRS mode is selected and of ΦCLK and ΦRS are in phase, then the precharge section appears as shown in Fig. 4-2; as a result, CDS can be used for noise reduction in later stages of signal processing (See the section "4-7. Noise Reduction by CDS").

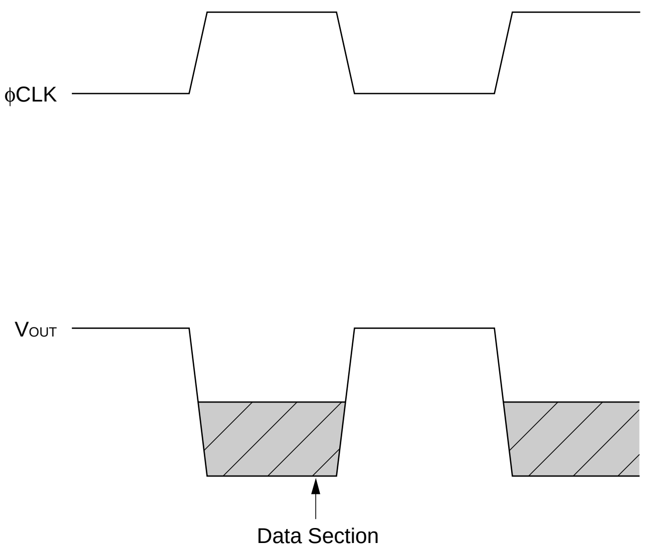


Fig. 4-1 Waveform Example in Internal ΦRS Mode

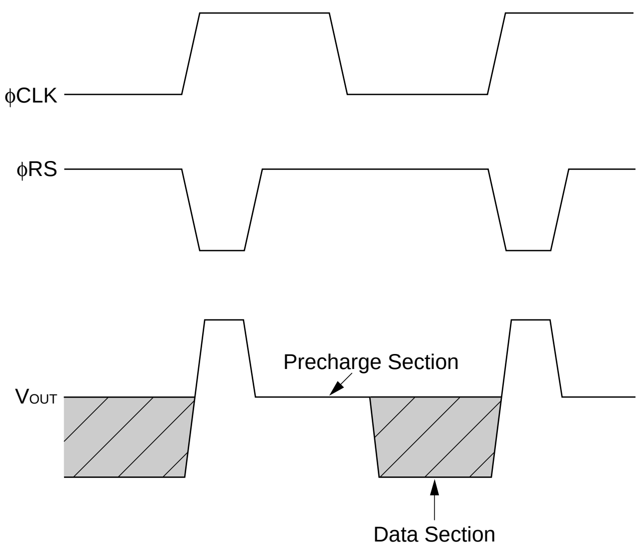


Fig. 4-2 Waveform Example in External ΦRS Mode

4-4. Storage Time Setting

In the case of linear sensors, the output voltage depends on exposure. The output signal voltage is proportional to the level of exposure if that does not reach saturation. As a result, when the incident light is insufficient, the output voltage can be increased by elongating the storage time. However, if the storage time is elongated, the noise component known as the dark voltage becomes larger in proportion to the storage time (assuming a fixed temperature). Therefore, the ratio of the incident light of the light source and the storage time must be determined after taking the required gradations and the S/N ratio into full consideration.

4-5. Latch-up Prevention for Power Supply ON/OFF

For linear sensors which operate on two power supplies, latch-up prevention must be guarded during power supply on/off. Accordingly, the power supply sequence shown in Fig. 4-3 is necessary for prevention of latch up.
When the power supply is turned on, V_{DD1} (9 V) should rise first, and then V_{DD2} (5 V). When the power supply is turned off, V_{DD2} (5 V) should fall first, and then V_{DD1} (9 V) (See Fig. 4-3). Note that latch up tends to occur more easily if $\Delta V \geq 0.5$ V or above as shown in Fig. 4-4.

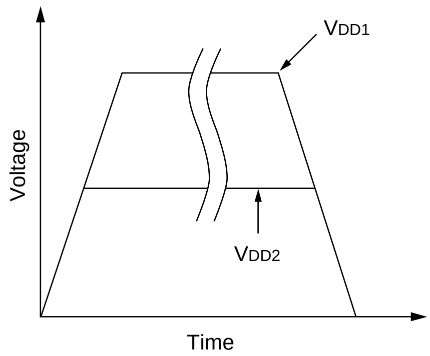


Fig. 4-3

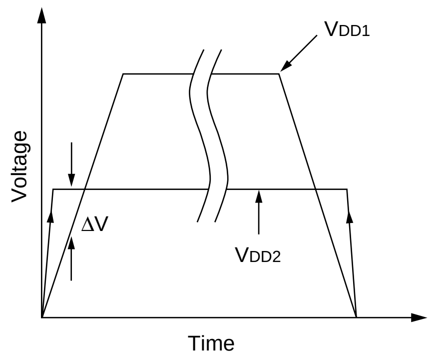


Fig. 4-4

<Circuit example 1 >
In the ILX503A, prevention of latch up can be easily implemented by using diodes and resistors as shown in Fig. 4-5.
In this circuit, even when VDD2 (5 V) power supply is turned on first, the time constant determined by resistor R1, capacitors C1 and C2, and the VDD2 pin capacity is greater than the time constant determined by the diode D1, capacitors C3 and C4, and the VDD1 pin capacity. The IC power supply sequence shown in Fig. 4-3 is satisfied. Note that the constants shown in this circuit differ depending on the linear sensor model.

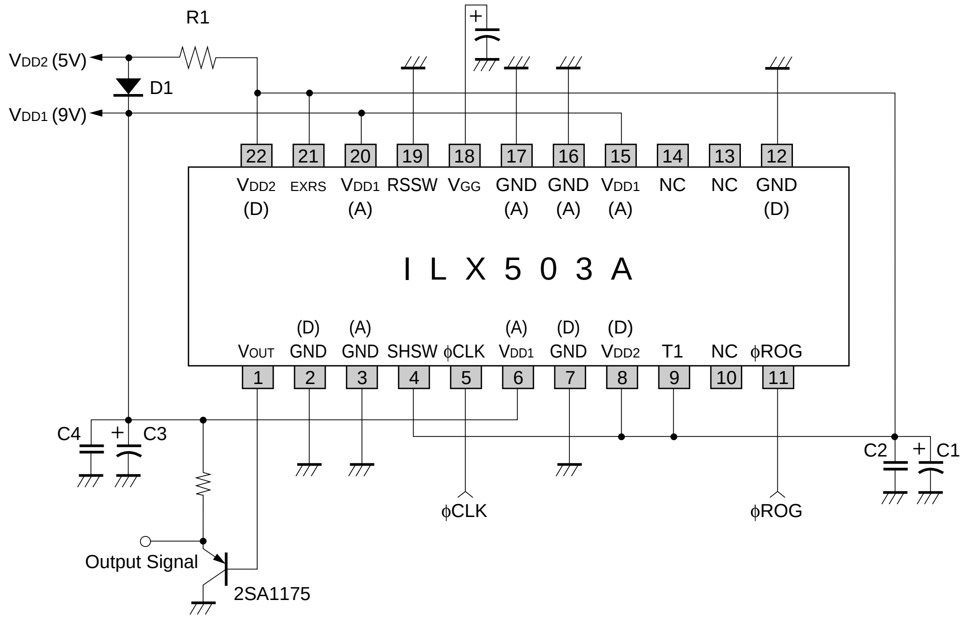


Fig. 4-5 Circuit Example 1

<Circuit example 2>
Fig. 4-6 shows a circuit example for the ILX506. By feeding the 5 V power supply from the 9 V power supply using a three-terminal regulator, the sequence shown in Fig. 4-3 is satisfied.

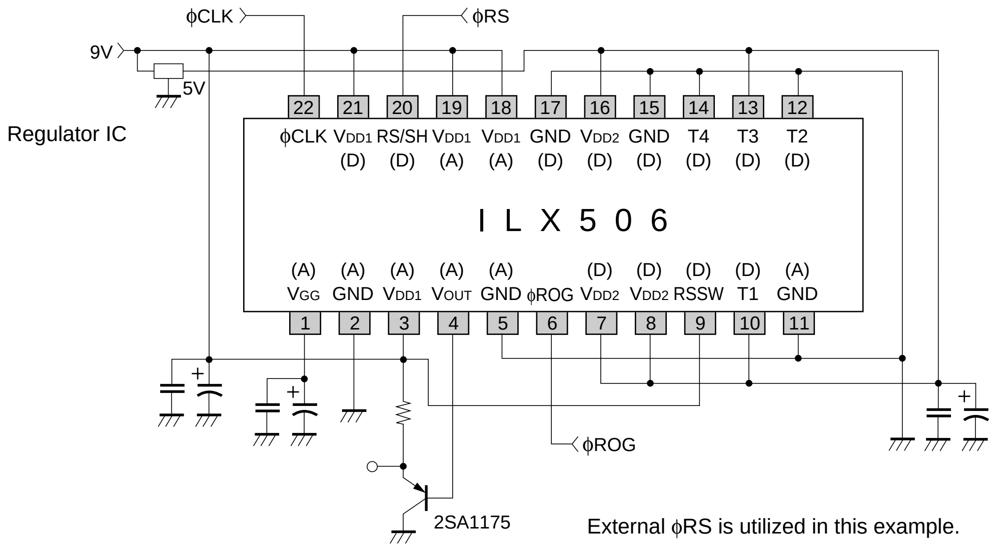


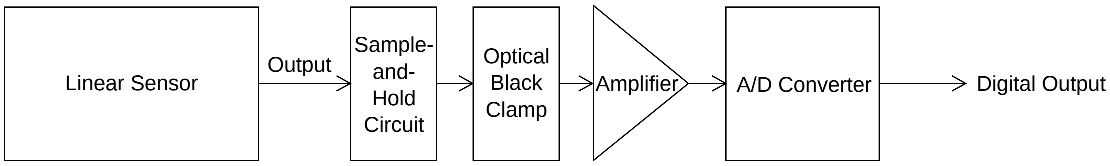
Fig. 4-6 Circuit Example 2

4-6. Signal Processing Diagram

While there are many possible signal processing circuits for linear sensors, the followings are given as representative examples:

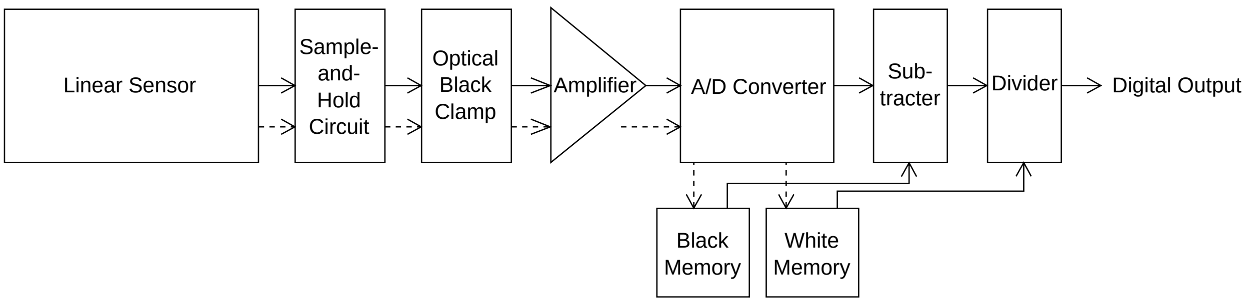
(1) Processing example when B/W compensation is not performed for each pixel.
The information of optical black is clamped for every line, and is fixed as the black reference.

* When using an internal sample-and-hold circuit, there is no need to provide an external one.



(2) Processing example when B/W compensation is performed for each pixel.
Black compensation (subtraction) and white compensation (division) are performed to the readout data after the black reference output and white reference output are stored in the memories for each pixel.

* The dotted line indicates the flow of execution for detecting the reference signal before starting readout of image data.
* This processing also includes shading compensation.



4-7. Noise Reduction by CDS (Correlated Double Sampling)

"CDS" stands for "Correlated Double Sampling", a type of circuit system devised for reducing noise generated in the linear sensor output circuit. The noise is suppressed by using the noise correlation in the precharge and data sections of the linear sensor output.

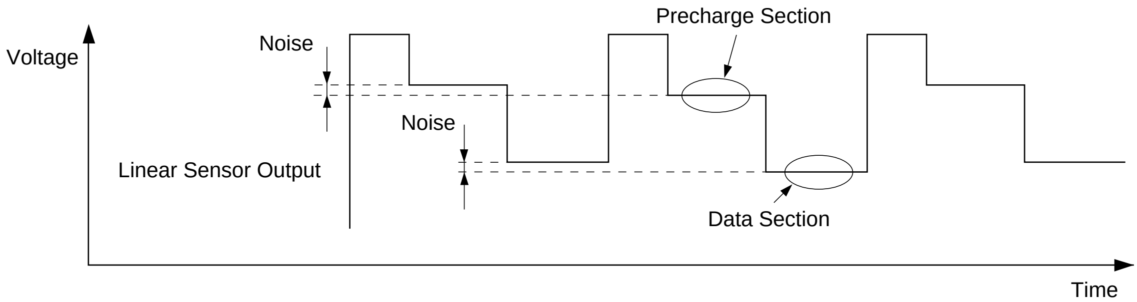


Fig. 4-7

There are two basic methods of CDS:
1) Clamp method
2) Subtraction method

The effects of the clamp method are the elimination of reset noise and low-frequency noise suppression. The subtraction method provides these effects as well as a reduction in sample-and-hold pulse feed-through.
The circuit configuration (a), timing (b), and effects (c) are explained below.

1) Clamp method

(a) Circuit configuration (The ILX503A is used as an example.)

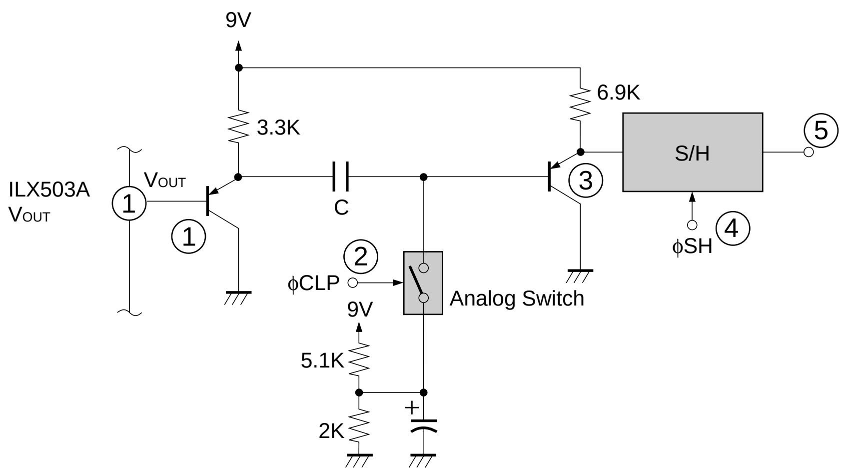


Fig. 4-8

(b) Timing

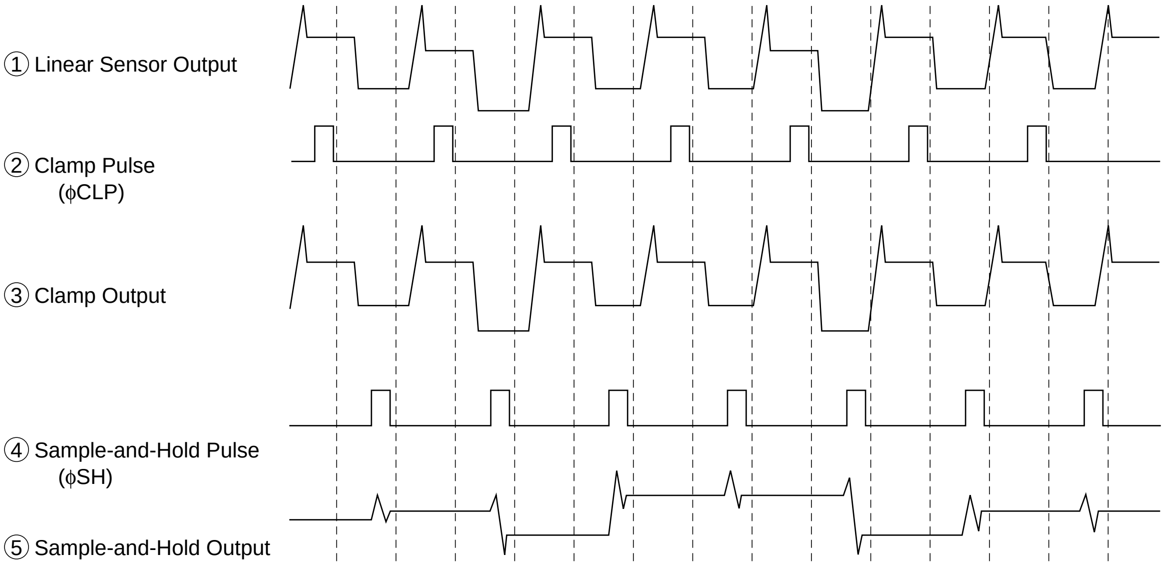


Fig. 4-9

(c) Effects Noise suppression

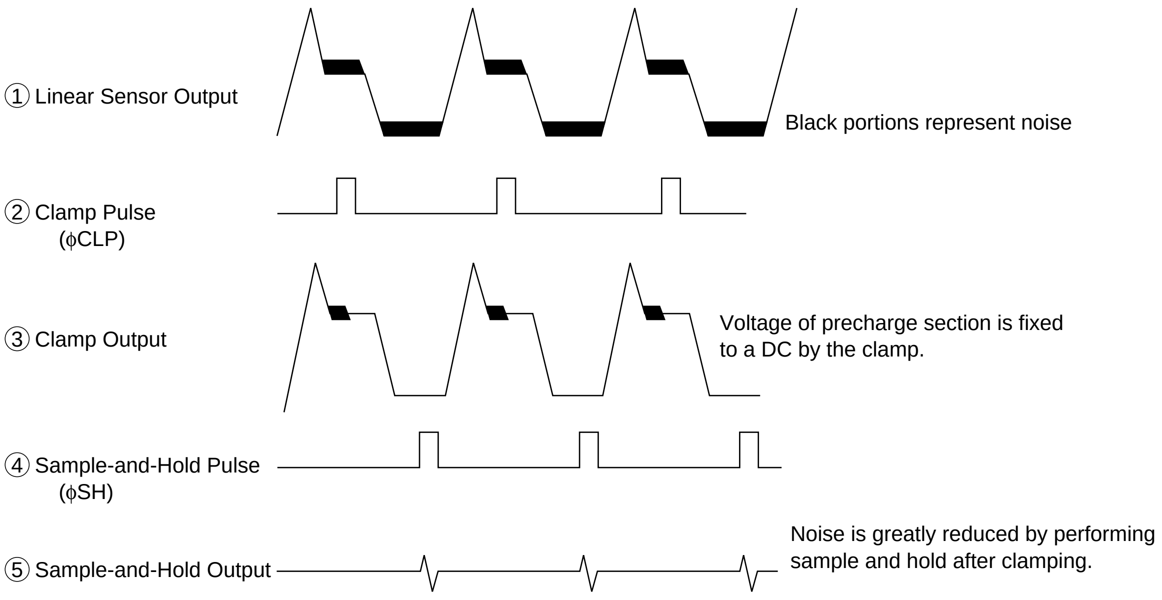


Fig. 4-10

2) Subtraction method

(a) Circuit configuration

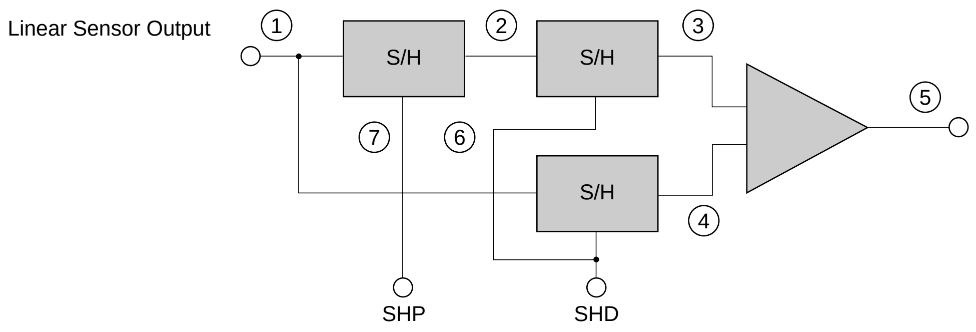


Fig. 4-11

(b) Timing

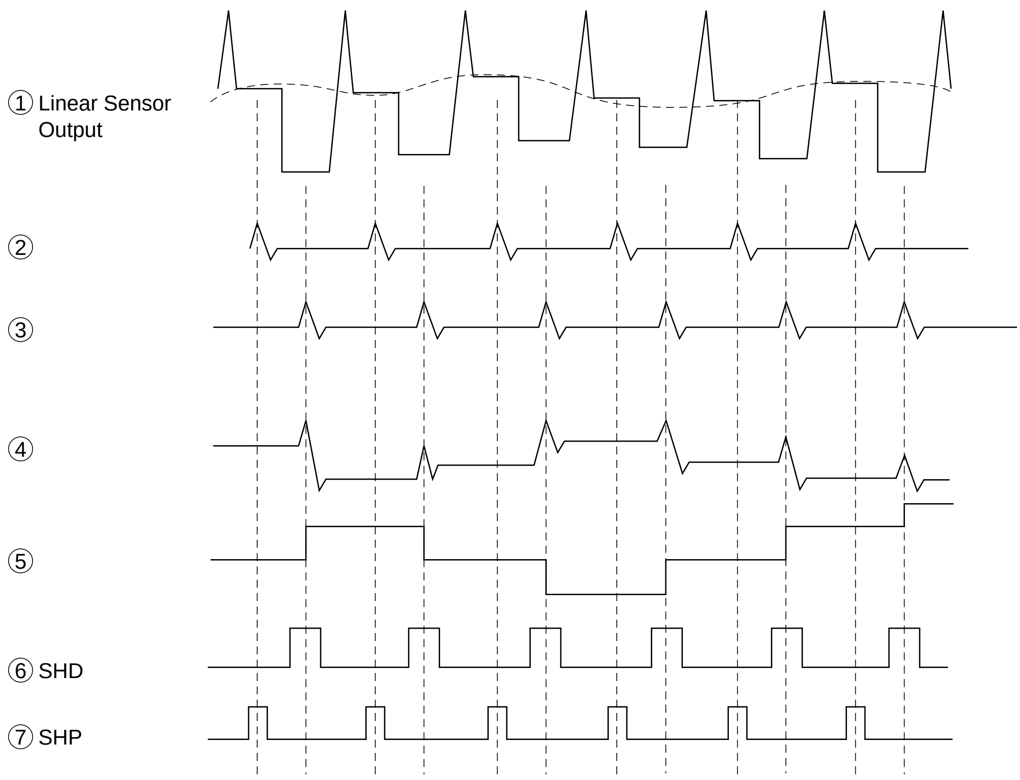


Fig. 4-12

(c) Effects

(1) Noise suppression

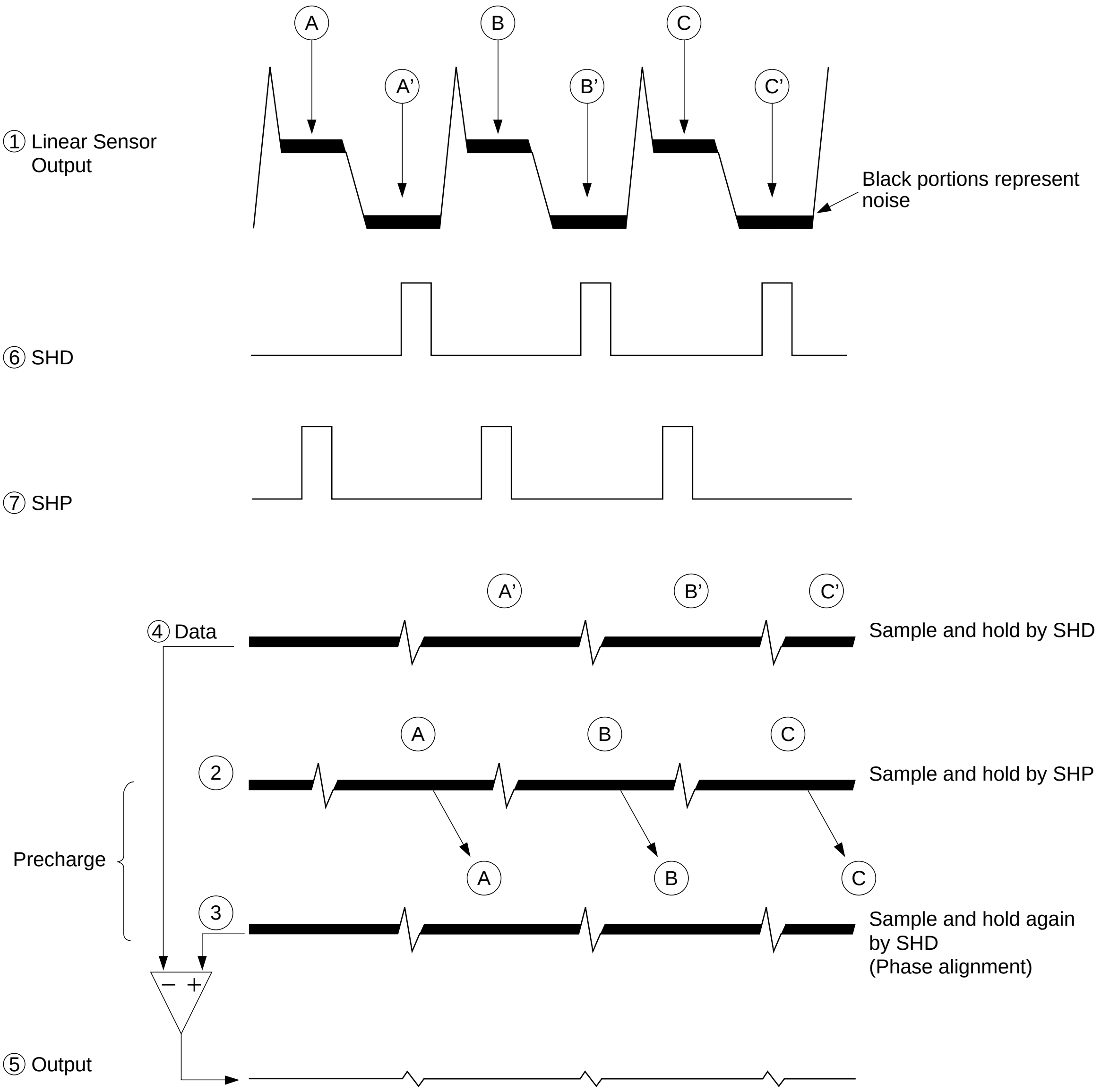


Fig. 4-13

As noises Ⓐ and Ⓐ', Ⓑ and Ⓑ', Ⓒ and Ⓒ', respectively, have strong correlations, they can be suppressed by cancelling out each other when putting through an amplifier in phase after sample and hold.

(2) Reduction of sample-and-hold pulse feed-through

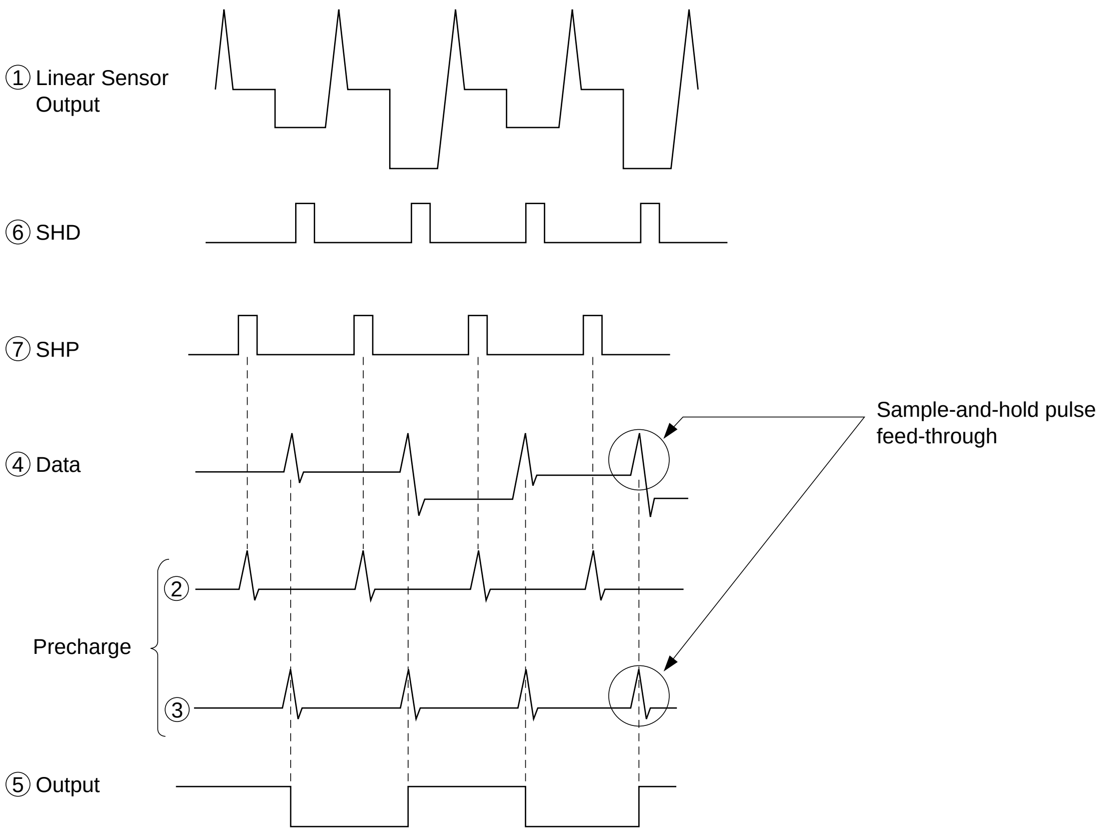


Fig. 4-14

Feed-through of those sample-and-hold pulses will be reduced by using the differential because the feed-through occurs similarly whether the precharge or data sections is sampled and held.

4-8. Compensation of Even/Odd Black Level DC Difference

Although the ILX506 and ILX508A offer improved even/odd black level DC difference (abbreviated to "ΔV") through their internal circuitry, ΔV increases as the frequency gets higher.
However, because ΔV does not depend on the signal level, the following method of signal processing is recommended even when the DC level difference is large.

Method 1)
The even pixel signal is processed as the difference between even pixel black levels, and the odd pixel signal is processed as the difference between odd pixel black levels.
Method 2)
Using the output of effective pixels under the shading conditions as the reference, eliminate the difference for each pixel when the signal is output.

4-9. V_{GG} Pin

The bias voltage output of linear sensor internal output circuit is delivered to the V_{GG} pin. It is recommended that the V_{GG} pin should be connected to GND via a capacitor to stabilize the operation. If the V_{GG} pin is connected directly to GND or subjected to bias voltage, the output circuit operating point changes, which results in abnormal operation.