SOLID STATE DIVISION

TECHNICAL INFORMATION

Characteristics and use of back-thinned TDI-CCD

HAMAMATSU

Table of contents

1. TDI (Time Delay Integration) mode 3

2. Features of HAMAMATSU back-thinned TDI-CCD 5

    2-1 High sensitivity (UV to near IR) 5

    2-2 High-speed line rate with multi-port structure 6

    2-3 Anti-blooming function 6

3. Timing chart 7

4. Output circuit structure 9

5. Driver circuit 10

6. Electrostatic and surge measures 11

Characteristics and use of back-thinned TDI-CCD

TDI-CCD captures clear, bright images even under low-light-level conditions during high-speed imaging. During TDI mode, the CCD captures an image of a moving object while transferring integrated signal charges synchronously with the object movement. This operation mode dramatically boosts sensitivity to high levels even when capturing fast moving objects. Our new TDI-CCD uses a back-thinned structure to achieve even higher quantum efficiency over a wide spectral range from the UV to the near IR region (200 to 1100 nm).

1. TDI (Time Delay Integration) mode

In CCD operation, a signal charge is accumulated in a potential well separate from other wells. The change is transferred from one well to another towards the output section, like a packet, without being mixed with other individually separated charges. TDI mode utilizes this CCD charge transfer principle. TDI mode is an effective method for detecting a low light levels and for imaging a moving object or for imaging a still object with the CCD sensor in motion.

Normally, an image focused on the CCD sensor is detected as a signal charge corresponding to the position of each pixel. This means that the image must stay at the same position on the CCD sensor during the charge integration time. If for some reason the image position shifts, the image S/N deteriorates.

When an object is moving, the image always becomes smeary or cannot be recognized at all, though it is possible to capture an image momentarily.

In contrast, TDI mode has the unique feature of being able to capture clear images of moving objects.

In FFT-CCD, signal charges in each line are vertically transferred during charge readout. TDI mode synchronizes this vertical transfer timing with the movement of the object, so that signal charges are integrated a number of times equal to the number of vertical stages of the CCD pixels.

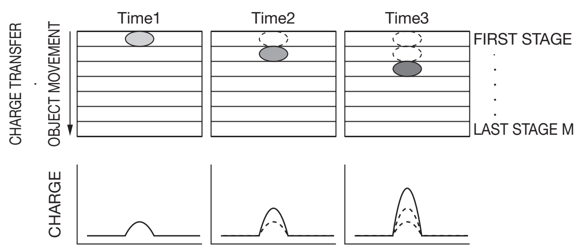
In TDI mode, the signal charges must be transferred in the same direction at the same speed as those of the object to be imaged. These speeds are expressed by the following equation:

$$v = f \times d \cdots\cdots\cdots\cdots (1)$$

v : Object speeds, Charge transfer speed
f : Vertical transfer frequency
d : Pixel size

In figure 1-1, when the first stage charge is transferred to the second stage, an additional charge is produced in the second stage by photoelectric conversion and accumulated. When this operation is continuously repeated until reaching the last stage M (the number of vertical stages), a signal charge which is M times greater than the initial charge is accumulated. This shows that TDI mode can enhance sensitivity up to M times higher than ordinary linear image sensors. (In S10200-02, S10201-04, S10202-08, and S10202-16, there are 128 stages, which gives them 128 times the sensitivity of conventional linear image sensors.) Since the signal charge on each line is output from the CCD horizontal shift register, a two-dimensional image can be continuously acquired. TDI mode also improves sensitivity variations compared to frame mode operation.

[Figure 1-1] Schematic diagram showing integrated exposure by TDI mode



TDI-CCD is ideal for capturing images of fast moving or rotating objects, and is thus widely used in line scan cameras for industrial robots, etc.

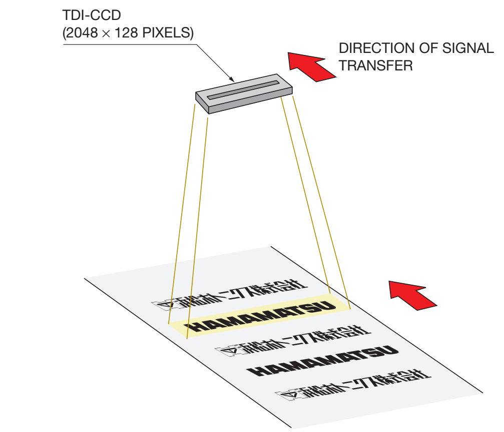
The following examples show how images of a fast moving or fast rotating object can be captured with a TDI-CCD. There is a difference between imaging in frame mode and TDI mode.

[Table 1-1] Selection guide

Type No.	Pixel size (μm)	Number of total pixels (H) × (V)	Number of effective pixels (H) × (V)	Number of ports	Pixel rate (MHz/port)	Line rate (kHz)	Vertical transfer
S10200-02	12 × 12	1040 × 128	1024 × 128	2	30	50	Bidirectional
S10201-04		2080 × 128	2048 × 128	4			
S10202-08		4160 × 128	4096 × 128	8			
S10202-16		4224 × 128	4096 × 128	16		100	

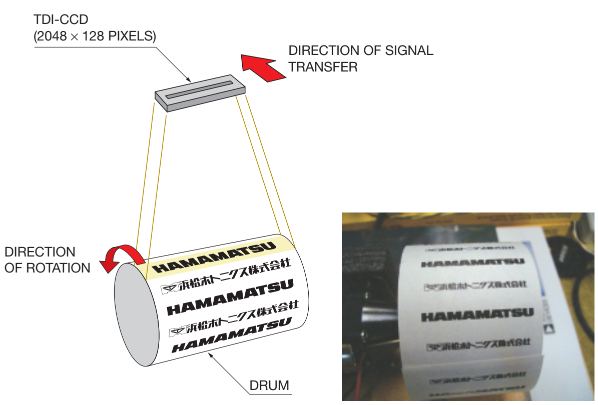
[Figure 1-2] Capturing image examples in TDI mode

(a) Fast moving object



KMPDC0266EA

(b) Fast rotating object



KMPDC0267EA

Frame mode imaging

When the drum is in idle, a clear image with no blurring is obtained as shown in ①. However, when the drum is rotating, the frame mode image is blurred as shown in ②. Although shortening the shutter time allows capturing an unblurred image, the image becomes dark as shown in ③.

① When drum is in idle:

② When drum is rotating:

③ When drum is rotating (with shutter time reduced):

TDI mode imaging

In TDI mode, signals are transferred in the same direction and at the same speed as the rotating drum, so a continuous image with no blurring is obtained as shown in ④.

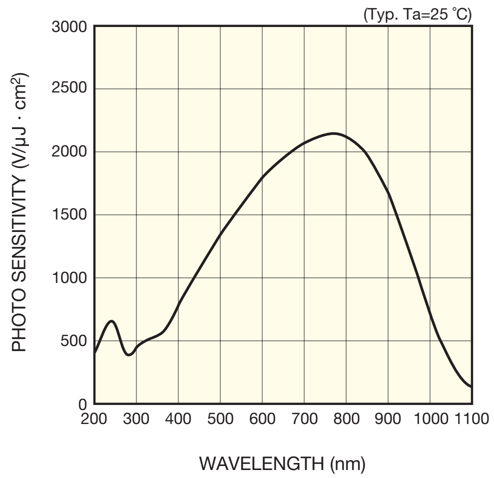
④ Continuous image when drum is rotating

2. Features of HAMAMATSU back-thinned TDI-CCD

2-1 High sensitivity (UV to near IR)

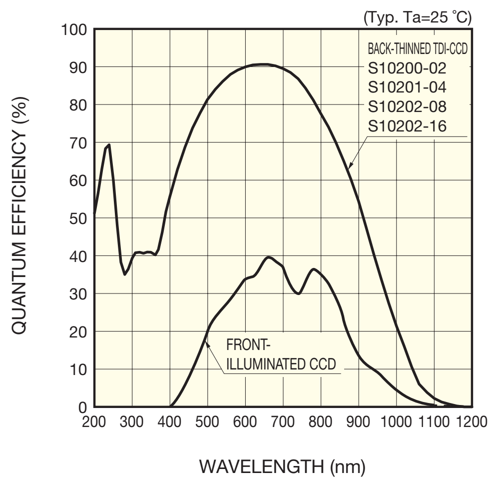
The back-thinned (back-illuminated) structure of HAMAMATSU TDI-CCD ensures higher sensitivity in the UV through the near IR region.

[Figure 2-1] Spectral response



KMPDB0268EA

[Figure 2-2] Quantum efficiency vs. wavelength



KMPDB0269EA

■ The structure of back-thinned CCD

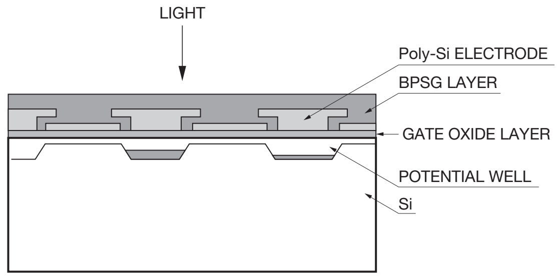
Conventional CCDs are designed to allow light in from the side on which the image pattern is formed. This type of CCD is called a front-illuminated CCD.

With front-illuminated CCDs, the photosensitive area is the front of the Si substrate, where the BPSG layer, poly-Si electrode and gate oxide layer, etc. are stacked, and light is largely reflected and absorbed there [Figure 2-3 (a)]. Because of this, the quantum efficiency is limited to about 40 % of the visible region, and the sensor cannot detect the ultraviolet region. The back-thinned CCD was developed to resolve this problem [1].

With back-thinned CCDs, the BPSG layer, poly-Si electrode and gate oxide layer are in the front of the Si substrate. But the CCDs are designed to allow light to enter from the rear of the Si substrate [Figure 2-3 (b)]. This is why the back-thinned CCD has a high quantum efficiency in wide spectral range.

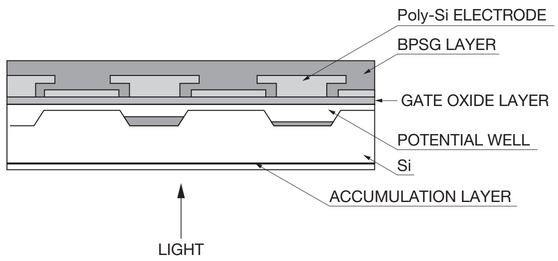
[Figure 2-3] CCD structure side view

(a) Front-illuminated CCD



KMPDC0179EB

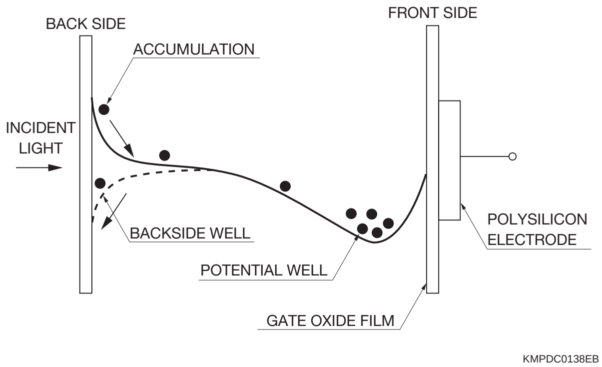
(b) back-thinned CCD



KMPDC0180EB

In the fabrication of back-thinned CCD, it is essential to thin the Si substrate and activate the photosensitive area. The photosensitive area is activated by forming an internal potential (accumulation) so that signal charges generated near the backside surface are smoothly carried to the CCD potential wells without recombining [2,3]. The internal potential state under accumulation is shown in Figure 2-4.

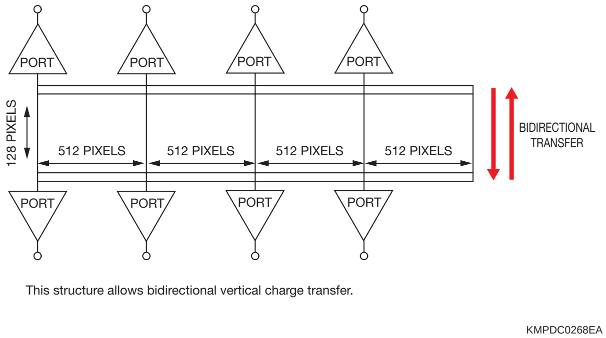
[Figure 2-4] Internal potential of back-thinned CCD



2-2 High-speed line rate with multi-port structure

The back-thinned TDI-CCD has multiple amps to allow continuous imaging of a sample moving at high speed, and a high-speed line rate is achieved through parallel readout of the image. The pixel rate is 30 MHz/port, and the line rate is 50 kHz for S10200-02, S10201-04, S10202-08, and 100 kHz for S10202-16. In addition, the vertical shift register transfer speed is typically 1 MHz, and the sensor is capable of bidirectional transfer.

[Figure 2-5] Sensor structure
[Example: S10201-04, 2048 (H) × 128 (V) pixels, 4 ports on each side × 2 (bidirectional transfer)]



2-3 Anti-blooming function

When the light intensity is too high for the image sensor, the saturation charge for a single pixel is exceeded and the excess charge bleeds over into the adjoining pixels. This phenomenon is called “blooming.” Back-thinned TDI-CCD applies overflow drain voltage and overflow gate voltage to control blooming even if the pixel is overloaded by 1000 times the saturation charge.

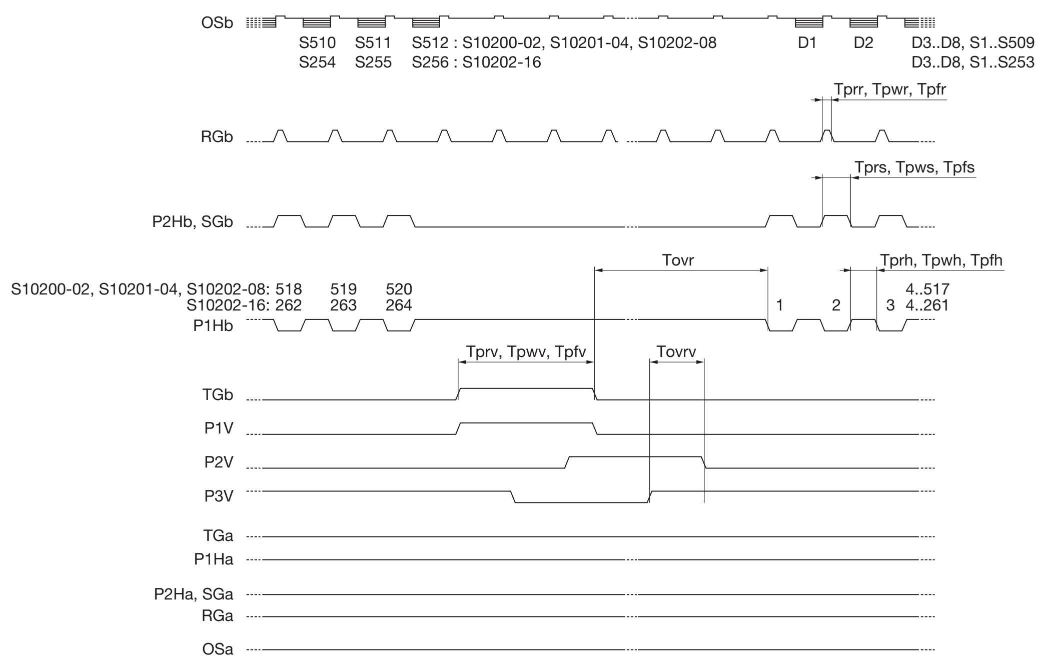
However, care must be taken with the applied voltage, which, if too high, will lower the saturation charge. In addition, it is strongly recommend that the overflow drain voltage and overflow gate voltage conform with the typical value of the operational conditions specified in the datasheet.

3. Timing chart

Figure 3-1 shows the timing chart for the back-thinned TDI-CCD operation.

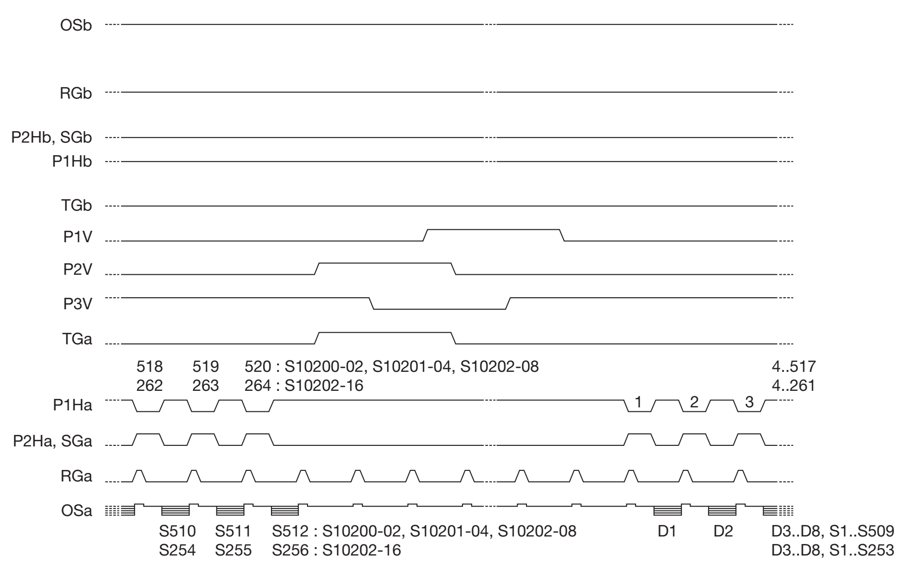
[Figure 3-1] Timing chart

(a) B port side readout



KMPDC0253EB

(b) A port side readout

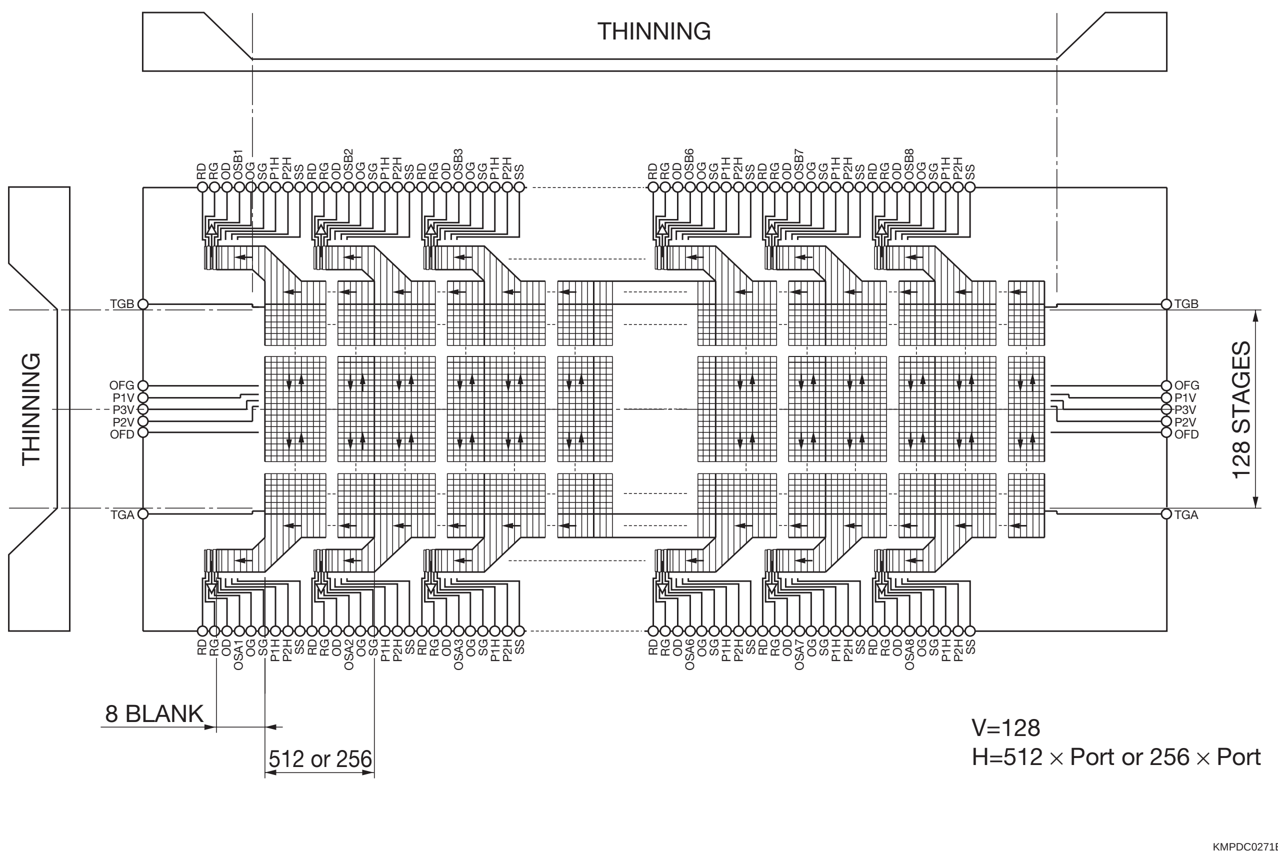


KMPDC0254EB

Parameter		Symbol	Min.	Typ.	Max.	Unit
P1V, 2, 3V, TG	Pulse width	Tpwv	120	770	-	ns
	Rise and fall time	Tprv, Tpfv	2	10	-	ns
	Overlap time	Tovrv	30	300	-	ns
P1H, P2H	Pulse width *1	Tpwh	12.5	16.5	-	ns
	Rise and fall time *1	Tprh, Tpfh	3	6	-	ns
	Duty ratio *1	-	-	50	-	%
SG	Pulse width	Tpws	12.5	16.5	-	ns
	Rise and fall time	Tprs, Tpfs	2	4	-	ns
	Duty ratio	-	-	50	-	%
RG	Pulse width	Tpwr	5	6	-	ns
	Rise and fall time	Tprr, Tpfr	1	2	-	ns
TG - P1H	Overlap time	Tovr	30	1000	-	ns

*1: Symmetrical clock pulses should be overlapped at 50 % of maximum pulse amplitude.

[Figure 3-2] Device structure (Conceptual chip drawing of top view)



4. Output circuit structure

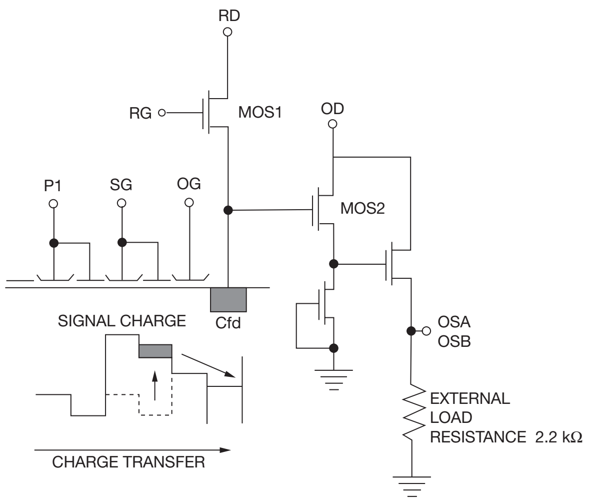
Back-thinned TDI-CCD output stages have an on-chip MOS-FET charge-to-voltage converter called a floating diffusion amplifier (FDA). A signal charge is guided by the Cfd capacitance, and the charge-to-voltage conversion occurs according to the following formula.

Vfd = Signal charge/Cfd ············ (2)

Vfd: Output voltage

This voltage is impedance-converted through a two-stage source follower circuit (gain < 1), and is output as OSA and OSB. The external load resistance (2.2 kΩ) in Figure 4-1 is not included, and must be attached externally.

[Figure 4-1] Output section of a CCD with FDA



KMPDC0043EB

5. Driver circuit

The TDI camera C10000 series is useful in a wide range of imaging applications that require both high speed and high sensitivity, including in-line monitoring and inspection.

■ TDI camera C10000 series

[Table 5-1] Specifications (TDI)

Parameter	C10000-301	C10000-401
Pixel number	1024 (H) × 128 (V)	2048 (H) × 128 (V)
Device structure	Back-thinned type	
Pixel size	12 µm (H) × 12 µm (V)	
Effective area	12.29 mm (H) × 1.536 mm (V)	24.58 mm (H) × 1.536 mm (V)
TDI transfer direction	Bi direction	
Readout mode	TDI readout mode or Frame readout mode *2	
TDI output channel	2 ports (512 × 2)	4 ports (512 × 4)
Anti-blooming	Lateral overflow drain (× 100)	
TDI pixel clock rate	30 MHz	
TDI line rate	0.45 kHz to 50 kHz	
Full-well capacity (Typ.)	100000 electrons	
Readout noise (Typ.)	130 electrons rms	
Dynamic range (Typ.)	770 : 1	
A/D converter	12-bit / 8-bit *3	
Image processing	Real-time shading correction with internal DSP	
Lens mount	C-mount	F-mount
Interface	Base configuration	
Camera output clock	60 MHz	
Camera output channel	1 port (1024 × 1)	2 ports (1024 × 2)
TDI line rate control	Internal setting by serial command *4 External trigger	
Analog enhancement gain	0 dB to 14 dB	
Power / Power consumption	DC +12 V, 20 V·A	
Camera control	Serial control in Camera link	

*2: Frame readout mode is useful for easy focusing, but it is not suitable for measurement.
Please consult with our sales office for details.
*3: Selectable by serial command.
*4: Internal TDI line rate can be set in 33 ns steps.

6. Electrostatic and surge measures

CCD area image sensors may be damaged or deteriorate if subjected to static electricity and voltage surges. Take the following precautions to avoid trouble.

(1) Handling precautions

Take measures to protect against static electric charges when taking the CCD out of a conductive container. Install a conductive sheet (1 MΩ to 100 MΩ) on the workbench and floor with grounding.
Persons handling the CCD should wear anti-static work clothes including gloves and shoes and should always use a grounding wrist strap. [The wrist strap attached to the body should always have a protective resistor (about 1 MΩ) and be connected to ground. Failure to use a protective resistor is extremely dangerous since leakage current may cause electrical shocks.]
Always be sure to ground the soldering iron so it does not apply leakage voltage to components being soldered.
Keep the CCD away from materials carrying electrical charges (insulators such as plastic or vinyl, PC display monitors and keyboards, etc.). Just bringing the CCD near these materials might destroy it due to picking up stray inductive electrical charges.

(2) Precautions during use

Measurement devices used with CCD image sensors must be properly grounded so no surges are applied by a leakage voltage. Do not to allow a voltage higher than the maximum rating (from measurement device, etc.) to be applied to CCD image sensors. (This tends to occur during ON/OFF switching of power sources, so use caution.) If there is the possibility of a voltage surge, insert a filter (made up of a resistor or capacitor) to protect the CCD image sensors.
When installing the CCD image sensor into the socket, be extremely careful to avoid reverse insertion, wrong insertion and terminal pin shorting.
Do not connect or disconnect any power supply line or output line connector during operation.

(3) Precautions for carrying or shipping

When carrying or reshipping a CCD image sensor, place it on a conductive foam by inserting the lead pins into the foam (for shorting lead pins) and then put it in a conductive container. The PC board to mount the CCD image sensor should also be put in a conductive container. Avoid using plastic or styrofoam packages as they may generate static electricity by vibration during shipping, causing breakdown or deterioration.

(4) Precautions for storage

When storing a CCD image sensor, place it on a conductive foam by inserting the lead pins into the foam (for shorting lead pins) and then put it in a conductive container. The PC board to mount the CCD image sensor should also be put in a conductive container. Avoid using plastic or styrofoam packages as they may generate static electricity by vibration during shipping, causing breakdown or deterioration.
Avoid placing equipment that may generate high voltage or high magnetic fields near image sensors.

It is not always necessary to provide all the electrostatic and surge measures stated above. Implement these measures according to the amount of damage that could occur.

References

1: Masaharu Muramatsu, Hiroshi Akahori, Katsumi Shibayama, Syunsuke Nakamura and Koei Yamamoto, Hamamatsu Photonics K. K., Solid State Division: "Greater than 90 % QE in Visible Spectrum Perceptible from UV to near IR Hamamatsu Thinned Back Illuminated CCD's", SPIE, Solid State Sensor Arrays: Developments and Applications, 3019 (1997), P2

2: M. P. Lesser, Steward Observatory, University of Arizona: "Chemical/Mechanical Thinning Results", SPIE, New Methods in Microscopy and Low Light Imaging, 1161 (1989), P98

3: James Janesick, Tom Elliott, Taher Daud, Jim McCarthy, Jet Propulsion Laboratory California Institute of Technology, Morley Blouke, Tektronix. Inc.,: "Backside charging of the CCD", SPIE, Solid State Imaging Arrays, 570 (1985), P46

HAMAMATSU PHOTONICS K.K., Solid State Division
1126-1 Ichino-cho, Higashi-ku, Hamamatsu City, 435-8558 Japan, Telephone: (81) 53-434-3311, Fax: (81) 53-434-5184, www.hamamatsu.com
U.S.A.: Hamamatsu Corporation: 360 Foothill Road, P.O.Box 6910, Bridgewater, N.J. 08807-0910, U.S.A., Telephone: (1) 908-231-0960, Fax: (1) 908-231-1218
Germany: Hamamatsu Photonics Deutschland GmbH: Arzbergerstr. 10, D-82211 Herrsching am Ammersee, Germany, Telephone: (49) 08152-3750, Fax: (49) 08152-2658
France: Hamamatsu Photonics France S.A.R.L.: 19, Rue du Saule Trapu, Parc du Moulin de Massy, 91882 Massy Cedex, France, Telephone: 33-(1) 69 53 71 00, Fax: 33-(1) 69 53 71 10
United Kingdom: Hamamatsu Photonics UK Limited: 2 Howard Court, 10 Tewin Road, Welwyn Garden City, Hertfordshire AL7 1BW, United Kingdom, Telephone: (44) 1707-294888, Fax: (44) 1707-325777
North Europe: Hamamatsu Photonics Norden AB: Smidesvägen 12, SE-171 41 Solna, Sweden, Telephone: (46) 8-509-031-00, Fax: (46) 8-509-031-01
Italy: Hamamatsu Photonics Italia S.R.L.: Strada della Moia, 1/E, 20020 Arese, (Milano), Italy, Telephone: (39) 02-935-81-733, Fax: (39) 02-935-81-741

Cat. No. KMPD9004E01
Apr. 2007