CCD Line Scan Camera Digital b/w SK 7500 DTO

7500 Pixels, 7 x 7 µm, 40 MHz Pixel Frequency

1 **CCD Line Scan Camera SK 7500 DTO**
mounting:
2 Modular Focal Adapter
3 Magnification Lens

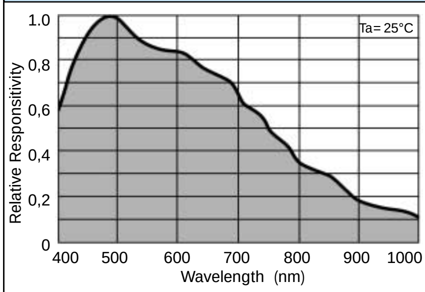
Characteristics

- digital camera, 8 bit resolution
- very light-sensitive
- line frequency up to 5.2 kHz
- low noise
- high dynamic range
- LVDS interface
- low power consumption
- housing (WxHxD) 82mm x 82mm x 95mm

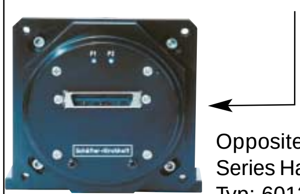
Performance Specifications

Camera Type:	SK 7500 DTO
Order Code	
Physical Characteristics	
Sensor:	CCD linear
	Type TCD 1703 AC
Pixel Number:	7500
Pixel Size:	7 µm x 7 µm
Pixel Distance:	7 µm
Line Width:	7 µm
Active Length:	52.5 mm
Lens thread:	M39 x 1/26"
Operating Ranges	
Pixel Frequency:	maximum 40 MHz
Line Frequency:	maximum 5.2 kHz
	minimum 0.05 kHz
Integration Time:	minimum 0.192 ms
	maximum 20 ms
Dynamic Range:	1 : 750 (rms)
Spectral Range:	400 - 900 nm

Typical Spectral Responsitivity



Input Control Signals	
	Master Clock
	StartOfScan (SOS)
Output Signals	
Video Signal:	8 Bit digital
Interface:	LVDS
Power Supply	
Voltage:	+5 V, +15 V, -15 V
Power Consumption:	3,5 W
Connector	
Mini Centronics	36 pin-male



Opposite connector:
Series Harting Bellows
Typ: 6013 036 5100

Others:	
Operating Temp.:	+ 5°C ... + 45 °
Size (W x H x D):	82mm x 82mm x 95mm
Weight:	0.7 kg

Accessories (optional)

Lenses

- high resolution **Enlarging and Macro Lenses**

Extension rings

Extention ring:
ZR-L25
ZR-L60
ZR-L87

Filters

attenuate diffuse and stray light using LED- and laser diode illumination (edge filters) and reflective light (polarisation filters).

Connecting Cabel SK9019 for Digital CCD Line Scan Cameras of Camera Series XSD, DPD, DPT, DJR, DJRC etc.
36-pin shielded cabel for camera and video signals. Standard: 3m cabel length, one- or double-sided with Centronics connectors (female, 36-pin).

SK9019.3 FF Order Code

FF = Connector double-sided (female)
F = Connector one-sided (female)
3 = 3 m (standard cabel length)
5 = 5 m cabel length
x = Cabel length coustom made

PC-Interface SK 9192 D
Digital CCD Line Scan Camera Interface
PCI-Bus, preprocessing on-board:
Shading correction : white balance
Windowing . . . : data reduction
Thresholding . . : binarisation
external synchronisation (LineSync, FrameSync)

Software **SK91PCI-WIN** *
SK91PCI-LX **

System Software **SKLineScan®**, Drivers, DLLs, Class Libraries for C++
Operating Systems:
* Windows XP/2000/NT, ** Linux

Content **Page**

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1. Technical Specifications of the DTO-Camera

Camera Model	SK 7500 DJR	SK 7500 DTO	SK 7926 DJR
CCD sensor	ILX 532 A	TCD 1703 AC	ILX 508
Number of pixels	7500	7500	7926
Pixel size	7 µm x 7 µm	7 µm x 7 µm	7 µm x 7 µm
Sensor width	7 µm	7 µm	7 µm
Pixel distance	7 µm	7 µm	7 µm
Active length	52.5 mm	52.5 mm	55.5 mm
PRNU *Photo Response Non Uniformity*	[3]	[3]	[3]
Anti-Blooming	no	ano	no
Integration Control	no	no	no
CDS [1]	no	no	no
Pixel frequency max	40 MHz	40 MHz	10 MHz
Min. integration time	0.192 ms	0.192 ms	0.8 ms
Max. integration time	20 ms [2]	20 ms	20 ms [2]
Max. line frequency	5.2 kHz	5.2 kHz	1.26 kHz
Min. line frequency	0.05 kHz	0.05 kHz	0.05 kHz
Dynamic range	1 : 500 (rms)	1 : 750 (rms)	1 : 500 (rms)
Spectral range	400 - 900 nm	400 - 900 nm	400 - 900 nm
Video signal	8 Bit digital	8 Bit digital	8 Bit digital
Interface	LVDS	LVDS	LVDS
Voltage supply	+5V, +15V, -15V	+5V, +15V, -15V	+5V, +12V, -12V
Power consumption	3W	3.5W	2W
Lens connection	M39 x 1/26”	M39 x 1/26”	M39 x 1/26”
Housing (W x H x D)	82 mm x 82 mm x 95 mm	82mm x 82mm x 95mm	82 mm x 82 mm x 95 mm
Weight	0.7 kg	0.7 kg	0.7 kg
Temperature range	+5°C ... +45°C	+5°C ... +45°C	+5°C ... +45°C

[1] CDS = Correlated Double Sampling. Noise reduction technology, increase of photosensitivity.
[2] Longer exposure times are possible, but the signal-to-noise ratio will be reduced.
[3] For further sensor specifications obtain the details of the sensor manufacturer. See the datasheet at the end.

2. Handling details of the line scan cameras

Attention:
Before the line scan camera is atached to or detached from the power supply make sure the power supply is switched off.
Otherwise, a permanent damage of the line scan camera device is risked.

To prevent damage due to heat accumulation and keep the temperature of the camera below 45°C, a sufficient air circulation around the camera housing has to be ensured.

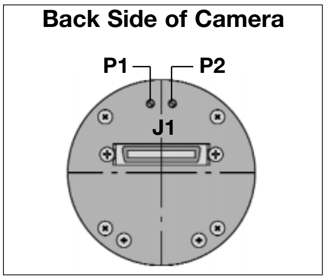
To start operation the required voltages, the Master-Clock- and StartOfScan-Signals using a 36-pin Centronics Miniature Connector have to be applied to the camera.

The camera is shiped aligned and set to default settings in gain and offset. Extensive modifications of the gain/offset-parameter can lead to a decrease in signal quality.

A successful application of the line scan camera is based upon a careful adjustment of the whole optical system. Attention should be paid to the arrangement of the illumination, the aperture setting, the focussing range of the lens, as well as the orientation of the sensor axis to the scanning direction.

Recommendation:
Using the **SK9192D** PC-Interface and the **SkLineScan®** software by **Schäfter+Kirchhoff** the camera is ready for operation immediately. The oscilloscopical display of the line scan camera signal including the zoom-function and the online parameter setting of the camera is a valuable tool while arranging the optical system setup. The hardware preprocessing on the Interface board (Shading Correction, Windowing, Thresholding) enables recording and evaluation with maximum line frequency. Furthermore, the comfortable methods of the class libraries for C++ support the development of user software.

3. Connection and Control Signals



J1 = Mini Centronics 36pin-male, P1 = Gain even, P2 = Gain odd

Voltage Supply

+ 5 V	± 5%	ca. 150 mA	(5 MHz Clock)
		ca. 360 mA	(40 MHz Clock)
-12 V to -15 V	± 5%	ca. 30 mA	
+15 V	± 5%	ca. 65 mA	

Pin out

Miniature Centronics 36 pin Connector (male)

	Signal	Pin	Pin	Signal		
	GND	18	36	GND		
(+5V)	VCC	17	35	VCC		(+5V)
	GND	16	34	D7	- out	
(+5V)	VCC	15	33	D7	+ out	
	CCLK - out	14	32	D6	- out	
	CCLK + out	13	31	D6	+ out	
	LVAL - out	12	30	D5	- out	
	LVAL + out	11	29	D5	+ out	
	SOS - in	10	28	D4	- out	
	SOS + in	9	27	D4	+ out	
	MCLK - in	8	26	D3	- out	
	MCLK + in	7	25	D3	+ out	
	GND	6	24	D2	- out	
(-12V/-15V)	VEE	5	23	D2	+ out	
(+15V)	VDD	4	22	D1	- out	
(+15V)	VDD	3	21	D1	+ out	
	GND	2	20	DO	- out	
	Analog Video A out (Test purpose only)	1	19	DO	+ out	

Digital Control Inputs

Input Control Signals:

The Low Voltage Differential input Signals (LVDS) are converted into TTL conform signals inside of the CCD camera.

The camera uses only the control signals "Clock" (MCLK) and "Start Of Scan" (SOS) for operation. The camera electronic responds to the rising signal edges that should be ‘sharp’ and free from noise.

The frequency of the "Start of Scan" signal determines the total count of line scans per second. On the rising edge of this signal all the accumulated charges inside the pixels will be tranferred to the analog shift register of the sensor. The shift register (transport register) will be read out with the ‘Clock’ signal.

The ‘Clock’ signal frequency gives the read-out rate for single pixel informations of the linear sensor. This is just the rate of the video output signal of the camera. Every rising edge of ‘Clock’ transfers the next following pixel’s charges to the video output amplifier.

The ‘Clock’ and the ‘SOS’ signals need not to be syncronized. The ‘Clock’ frequency should be set to a sufficient large number to ensure enough ‘Clock’ pulses to read out the line sensor completely between two successive ‘SOS’ signals. The SK 7500 DTO-Camera needs 7680 ‘Clock’ signals to read out a line scan completely. Generally, transferring a larger number of ‘Clock’ pulses as needed is unproblematic and usual.

MCLK: Master-Clock in: determines the pixel transport frequency, maximum 40 MHz. Low voltage differential input.

SOS: Start of Scan: 30 ns minimum pulslength. Differential input.

The frequency of the ‘SOS’ signal determines the line frequency readout of the camera.

The charges of the sensor are accumulated while the ‘SOS’ signal is low. This way the length of the ‘low’ period can be used to effectively control the actual integration time at a fixed or rapidly changing line frequency.

The rising edge of the ‘SOS’ signal initiates the readout operation and the charges are transferred into the onchip analog shift register.

Output Signals:

‘Clock’ and ‘Start of Scan’ signals are echoed at the camera output to monitor system timings. These signals, like the input ‘Clock’ and ‘Start of Scan’ signals, are ‘Low Voltage Differential signals’ (LVDS).

CCLK: Camera-Clock out / Low Voltage Differential driver.

LVAL: Line Valid / Differential driver. A ‘High’-level shows the availability of valid pixel data at the AD-converter output. The signal ‘LVAL’ contains a ‘CLT’ pulse at the beginning of the line, necessary to synchronize **Schäfter+Kirchhoff** - Interface boards.

D0-D7: 8 bit digital video output (8 x Low Voltage Differential driver LVDS) D0=LSB, D7=MSB

4. Exposure and Integration Control

Exposure:

The light sensitive elements of the sensor store the charge which are generated by the incident light during the exposure cycle. This accumulated charge is then converted into voltage. These values are a measure for the incident light intensity on each pixel.

The process of integration starts with the falling edge of the ‘StartOfScan’ (SOS)-signal. While the SOS-signal is ‘Low’, charge is accumulated. With the rising edge of the SOS-signal the exposure is concluded. The SOS-signal level stays a short time on ‘High’, before the next falling edge triggers the next exposure cycle.

Exposure time:

The exposure time of a single line scan t_B is the time interval of adjacent positive edges of the ‘StartOfScan’ (SOS)-signal. The time period of this interval (pixel clock) is determined by the minimum number of necessary pulses to read the accumulated charge into the shift register of the line scan sensor.

The sum of the pixel clock pulses results from the number of pixels **N** plus sensor dependent passive pixel clock pulses N_P. The camera SK7500DTO needs 180 pixel clock pulses. The read out frequency is determined by the pixel frequency (MCLK). The exposure time t_B of a camera calculates:

$$t_B = \frac{(N + N_P)}{f_P}$$

The line frequency is given by:

$$f_L = 1/ t_B$$

Example:	SK 7500 DTO, SK 9192D 40 MHz pixel frequency
	$t_B =$ (7500 + 180) / 40 MHz $t_B =$ 0.192 ms $f_L =$ 40 MHz / (7500 + 180) $f_L =$ 5.2 kHz

5. Generating an Image – Scan a Surface

A two-dimensional image is generated by moving the object or the camera. The direction of the movement needs to be orthogonal to the sensor axis of the CCD line scan camera.
To optain a propotional image with correct aspect ratios a line synchronous transport and a laterally correct pixel assignment is required.

$$V_O = \frac{W_P \cdot \beta}{t_B}$$

V_O	=	Object rate
W_P	=	Pixel width
β	=	Magnification
t_B	=	Exposure time

- **Exposure time:** Time interval between successive ”SOS“ signals.
- **Integration time:** Duration of the actual charge accumulation during the exposure time.
- **Integration Control:** for CCD line scan cameras it is possible to program shorter integration times within the actual exposure time (Shutter operation).

Integration Control (SK 2048 DJRI - Camera):

In the default setting of the camera the SOS signal between two exposure cycles shows ‘High’ only at very few pixel clock pulses. The Integration time and the exposure time are virtually of the same length.

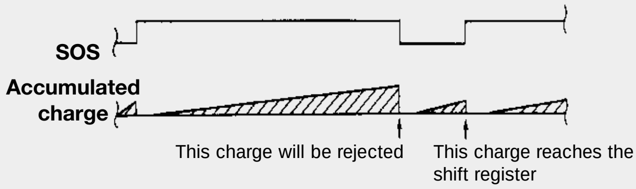
The Integration Control function allows the extention of the ‘High’-level condition in the SOS signal about a specified number of pixel clock pulses. The start of the accumulation of charge during an exposure cycle is thus delayed.

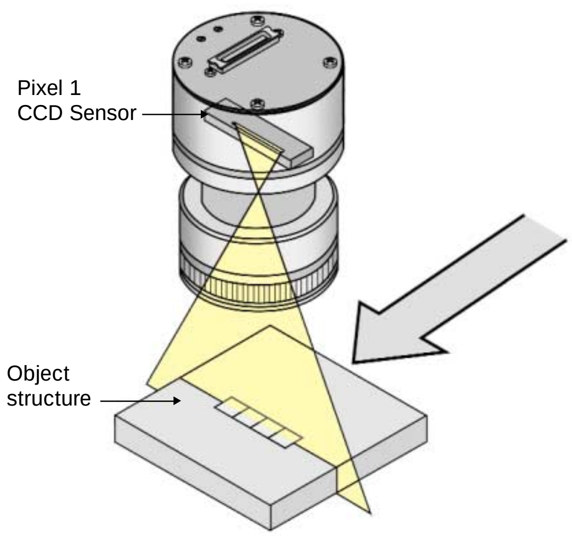
The integration time t_A is shortened to the difference of during one exposure period necessary pixel clock pulses ($N + N_P$) and the specified number of clock pulses for the extension of the ‘High’-level condition in the SOS signal (**SOSL**).

The line scan frequency is not influenced by the Integration Control function.

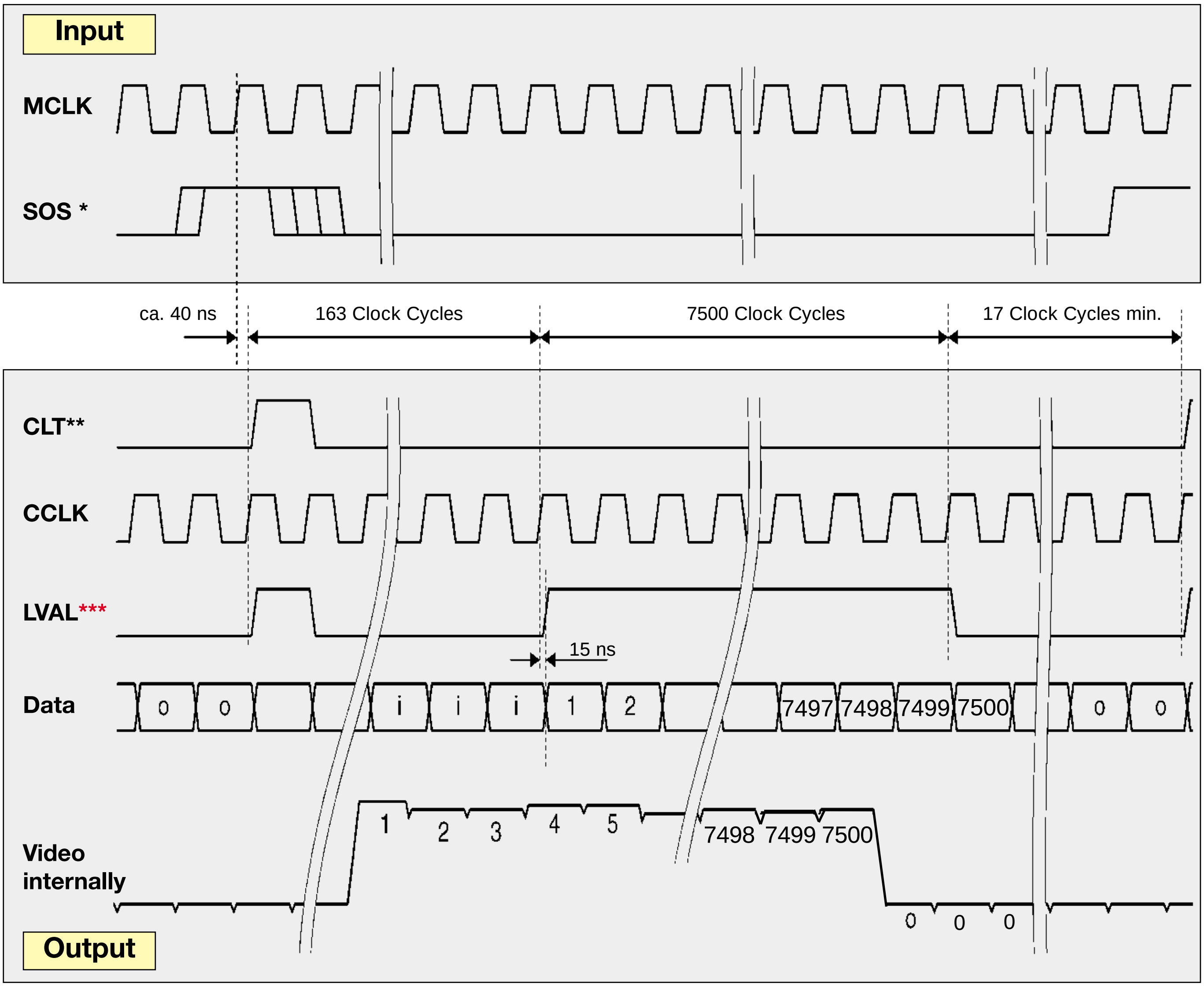
$$t_A = \frac{(N + N_P) - SOSL}{f_P}$$

Mode of operation of the Integration Control function





6. Timing - Diagram



* The rising edge of 'SOS' should not occur within a range of 3 to 25 ns before leading edge of 'MCLK'.

** CLT = Camera Line Transfer (internal line scan camera Signal)

*** The signal 'LVAL' contains a 'CLT' pulse at the line beginning, which is required for the synchronisation of the **Schäfter+Kirchhoff** Interface boards.

If requested, the CCD line scan camera is available without 'CLT' pulse at the line beginning of the 'LVAL'. Order Code SK 7500 DTO-3

The pixels determining the black level value are the 7th to the 103th before pixel no. 1.

i = Isolation pixels

o = Overclocking

7. Anti Blooming

Blooming

Extended illumination of saturated pixels, which are not able to accumulate further charge due to long exposure, leads to charge overflow into adjacent pixels. This effect is called **blooming**. Blooming causes a corruption of the geometrical allocation of image and object in the line signal.

CCD line scan cameras with **anti-blooming** sensors direct the abundant charge to a ”drain gate”. Charge overflow into adjacent, less illuminated pixels is prevented. Depending on pixel frequency and spectral range, overexposure up to factor of 50 can thus be handled.

The CCD line scan cameras of the DJR-series do not contain anti-blooming sensors. Nevertheless, they are prevented from overexposure due to a special design. DJR-cameras can be densed to a factor of 3.8, without blooming the sensor.

Figure [1] shows the line scan signal of a SK2048DJRI-camera with increased illumination in the center. For a better visualisation of the blooming effect the saturation voltage of the sensor V_{SAT} was reduced to roughly 90% of the maximum ADC-voltage. Thus, even with overexposure the maximum of 255 of the 8-bit digitized signal intensity will not be reached. In the central section the sensor is on the verge of saturation.

The marked region from figure [1] is zoomed in figure [2]. Here, the integration time $\mathbf{t_A}$ amounts to 0.634 ms.

In figure [3] the integration time was increased to $\mathbf{t_A}$ 2.419 ms. Only from this point on the sensor starts to bloom. The signal edge is displaced slightly to the right, caused by excessive charge congesting the adjacent pixels.

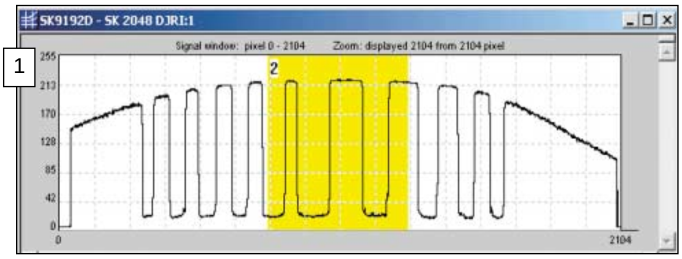
Even longer integration times result in an intolerable deformations of the signal structures. In figure [4] the integration time was set to $\mathbf{t_A}$ 3.38 ms, corresponding in an overexposure of a factor of 5.3.

Figure [5] shows a phenomenon at extreme overexposure of CCD line scan cameras. The large charge excess of the preceding scan leads in the shown sample to an overload of the pixels at the beginning of the line. In this area the pixels determining the dark level are located. These pixels are used as a reference for the offset control. The large dark level intensity induces a reduction of the total signal intensity. Under these conditions more light generates a smaller signal intensity at the camera output.

In case of a very small output signal at operation start up of the CCD line scan camera, an extreme overexposure can be the reason.

Consider:

CCD line scan cameras including anti-blooming sensors can be densed to a factor of 50 before showing any effect of blooming.

1


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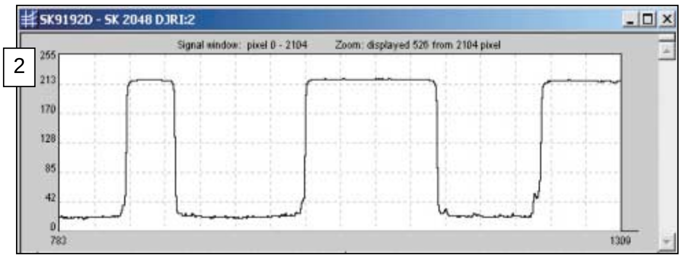

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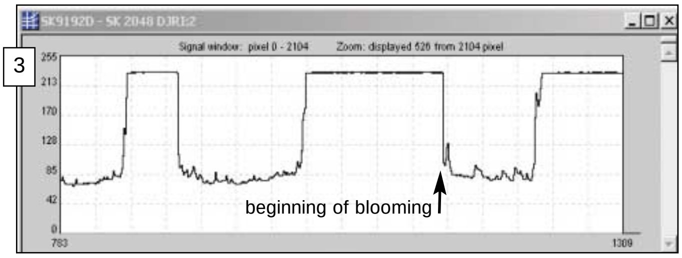

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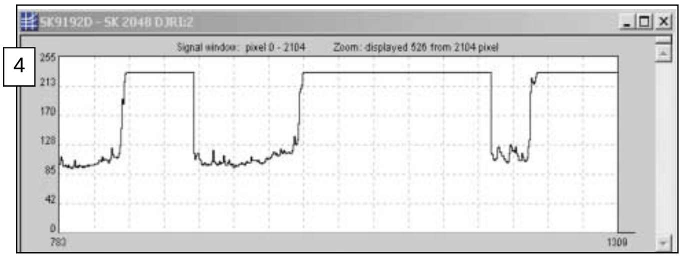

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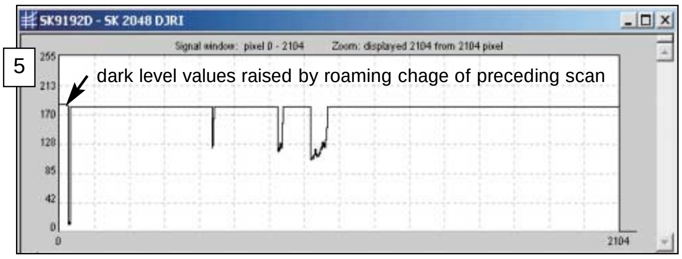


Oscilloscopic display of line scan signals (barcode illuminated with incident light), SK 2048 DJRI

[1] CCD line scan signal with increased illumination in the center and sharp rising signal edges.

[2] Zoomed detail from the center of the CCD line scan signal in [1], integration time $\mathbf{t_A}$ = 0.634 ms

[3] Extended integration time $\mathbf{t_A}$ = 2.419 ms. The signal edge is displaced slightly to the right. At an overexposure of a factor of 3.8 the sensor starts to bloom.

[4] Overexposure caused by an increased integration time results in signal deformations for sensors without anti-blooming technology.

[5] Charge by extreme overexposure penetrate the following scan and cause an overload of the black level pixel values. The offset control unit of the camera is disturbed and the CCD line scan camera supplies a reduced signal.

8. Gain / Offset - Settings

The CCD line scan camera SK 7500 DTO containes two shift registers. The video signal is split into two channels, one attends the even, the other on the odd pixel numbers. With this camera the setting of the gain is thus always a matter of multiple steps:

1. Employing the aperture wide open and sufficient illumination, adjust the odd pixel numbers using the trimmer P1 to the maximum output voltage reasonable.

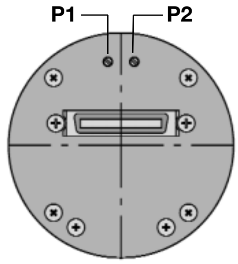
2. Use trimmer P2 to adjust the eaven pixel numbers to the intensity of the odd pixels as good as possible.

Changing the pixel frequency significantly can require a repetition of this balancing procedure.

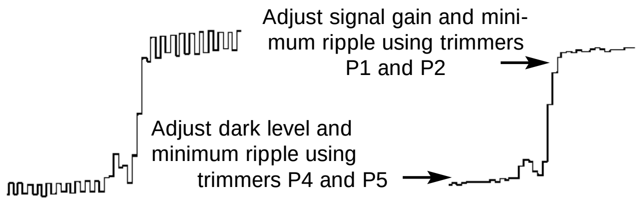
The maximum output voltage is set at 40 MHz pixel frequency to ca. 2.5 Volts (‘FF’ Digital) per default.

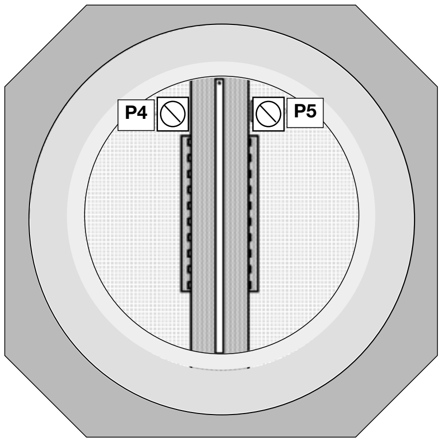
If necessary, the eaven and the odd dark level signals can be adjusted aswell. Shade off all light incident on the line scan camera and adjust the levels of the pixels using the trimmers P4 and P5 situated on the frontside of the board to 0 Volts.

Camera backside



To adjust the gain-setting of the eaven and odd pixel numbers the camera does not need to be opened. The trimmers for balancing are accessible from the outside.





Camera board, sensor side

9. References and Warranty

Although this manual has been reviewed carefully for technical accuracy, errors are possible. The reader is kindly asked to contact us, if errors are suspected.

The indicated circuits, descriptions and tables are not warranted to be free from rights of third parties.

With the statements in the technical descriptions only assembly groups are specified. Characteristics as well as the suitability for a particular purpose is not guaranteed.

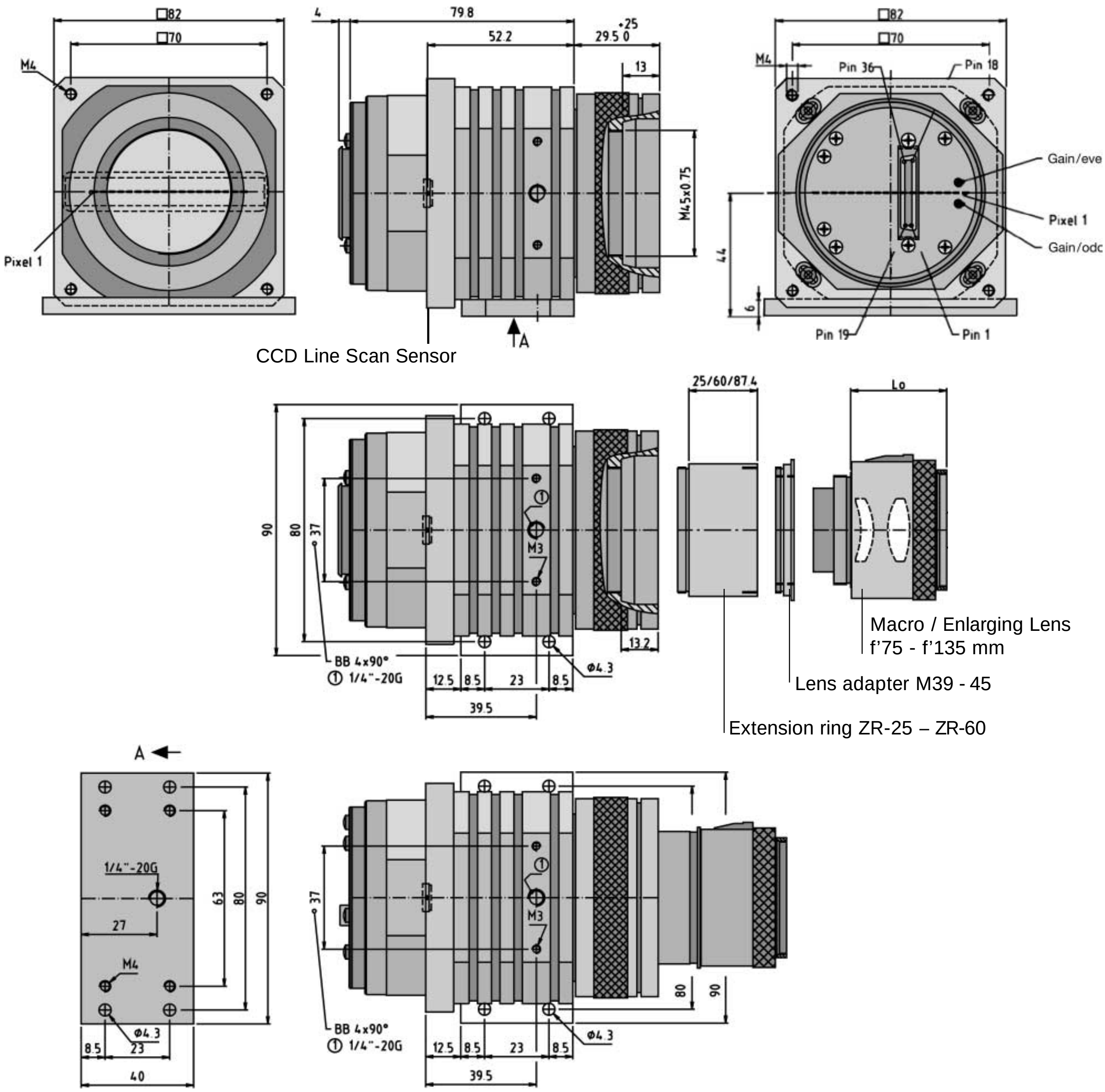
The warranty period for the CCD line scan camera is 24 months. The warranty ends with inappropriate actions.

EC-Declaration of Conformity

This product meets the requirement of the EC directive 89/336/E.E.G. The requirements of DIN EN 61326 are fullfilled.

10. Dimension Drawings

Mounting plate / mountable on eachside



Mounting plate /
mountable on eachside

1 CCD line scan camera SK7500DTO 2 Lens
3 Lens adapter M39-45 4 Extension ring ZR-L25
5 CCD line scan camera assembled including a lens, a lens adapter and an extension ring.

11. Lenses and selection criteria

Lens selection criteria and assembly

Enlargement- and macrolenses exhibit a high image quality (70 Lp/mm) in the specified range of magnification (s. table 1). A focussing mechanism as provided by CCTV- and photolenses does not exist. The necessary lens extension is obtained using the modular focus of the line scan camera and one or more extension rings ZR-L25.

The image magnification is the major criterion for the lens selection. Hereupon the necessary modular focus extension and extension rings are calculated from the focussing range f and the flange focal length s'A∞ of the selected lens, the flange back distance sK, and the magnification β (see example).

The lens adapter M39-45 is classified as a part of the camera and included in delivery. Lenses and extension rings ZR-L25 have to be ordered separately.

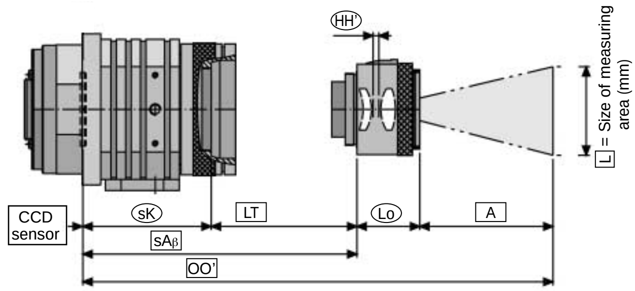
Table 1

Enlarging lenses / Order Code	Focussing lens f' = mm	Aperture number k	Working aperture	Resolution max. (µm)	CCD sensor length max. (mm)	Ideal image magnification β	Range of magnification β	Flange focal length s'A∞ (mm)	Distance of principal points – HH' (mm)	length of lens Lo (mm)	Lens thread	Outer diameter Ø (mm) filter thread	OO' = distance of CCD line to measuring area (L)	A = distance of lens to measuring area	Tube length LT at optimum imaging	Extension ring 25 mm Order Code ZR-L25	Total focussing extension (mm)
Apo-Rodagon-N 4,0/80	82,5	4	X	7	85	10x	4 – 15	77,0	-2,8	30,8	M39 x 1/26"	Ø 54 mm – M 40,5 x 0,5	995	879	16,3	–	12,3
			X														
Apo-Rodagon-N 4,0/105	105	4	X	7	90	6x	4 – 15	99,1	-3.0	36,3			851	698	47,5	1x	19,0
Apo-Rodagon D1x	75,1	4	X	7	85	1x	0,8 – 1,2	61,6	-14,8	34,3			286	115	67,7	2x	14,7
Apo-Rodagon D2x	74,6	4,5	X	7	85	2x	1,2 – 2,5	72,1	-2,2	30,4			334	194	40,4	1x	11,9
Apo-Rodagon D	120	5,6	X	7	150	2x	0,5 – 3	112,9	-2,98	30,7			537	333	103,9	4x	1,9

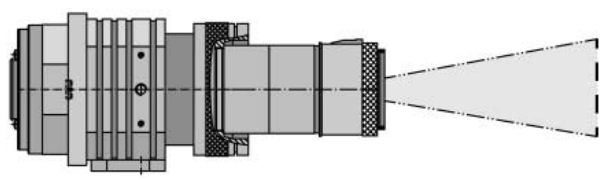
These data refer to the ideal image magnification

System parameters and calculation values

- f = Lens focal length (mm)
- β = Magnification : β = L/S
- OO' = Distance between measuring area and CCD line scan sensor. OO' = (β+1/β+2) f +HH' (mm)
- L = Size of measuring area (mm)
- S = Sensor lengths (mm)
  - S = 52,5 mm of SK7500DJR
  - S = 55,5 mm of SK7926DJR
- HH' = Distance of principal points of the lens. HH' can be positive or negative (s.Table). Preserve the sign when adding distances!
- sA∞ = Flange focal length for images of indefinitly distant objects.
- Δs' = Lens extension for close up and macro images: Δs'=f / β
- sAβ = Flange focal length for magnification β : sAβ = sA∞ + Δs'
- sK = Flange back distance for CCD sensor: sK = 69 mm of SK7500DJR
- LT = Tube length, calculated using LT = sAβ - sK, realized by extension of the modular focus (0-25 mm), lens adapter M39-45 (4 mm) and (if necessary) one or more extension rings ZR-25 (24.5 mm)
- Lo = Length of the lens
- A = Distance between lens and measuring area



Configuration with Apo-Rodagon D1x for β = 1 (+ 2x ZR-L25, OO' = 286 mm)

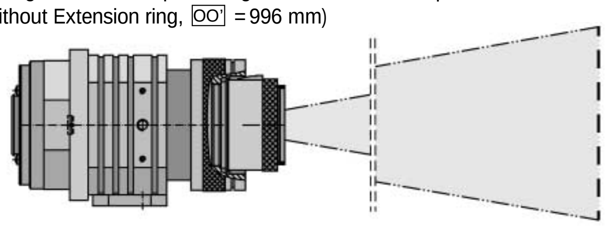


Example for Apo-Rodagon-N 4.0/80 at β = 4 measuring area L = 210 mm

- f = 82.5 (Lens focal length mm)
- β = 4 (Magnification)
- sA∞ = 77 (Flange focal length for images of indefinitly distant objects)
- HH' = 2.78 (Distance of principal points)
- sK = 69 mm (Flange back distance for CCD sensor)
- OO' = (β+1/β+2) f + HH' = (4+1/4+2) 82.5 mm - 2.78 mm= 512.8 mm
- Δs' = f /β = 82.5 mm / 4 = 20.6 mm
- sAβ = sA∞ + Δs' = 97.6 mm
- LT = sAβ - sK = 97.6 mm - 69 mm = 28.6 mm

Realized using:	Modular focus extension	24.6 mm
	Lens adapter M39-45	4.0 mm
	Sum	28.6 mm = LT

Configuration with Apo-Rodagon N 1:4/80 mm for β = 10 (without Extension ring, OO' = 996 mm)

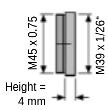


Lens adapter

M39-45 Best.-Code

M39 x 1/26 – M45 x 0.75

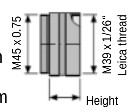
included in delivery



Extension rings

ZR-L25 Best.-Code

- 25 = height 24.5 mm
- 60 = height 60 mm
- 87.5 = height 87.5 mm



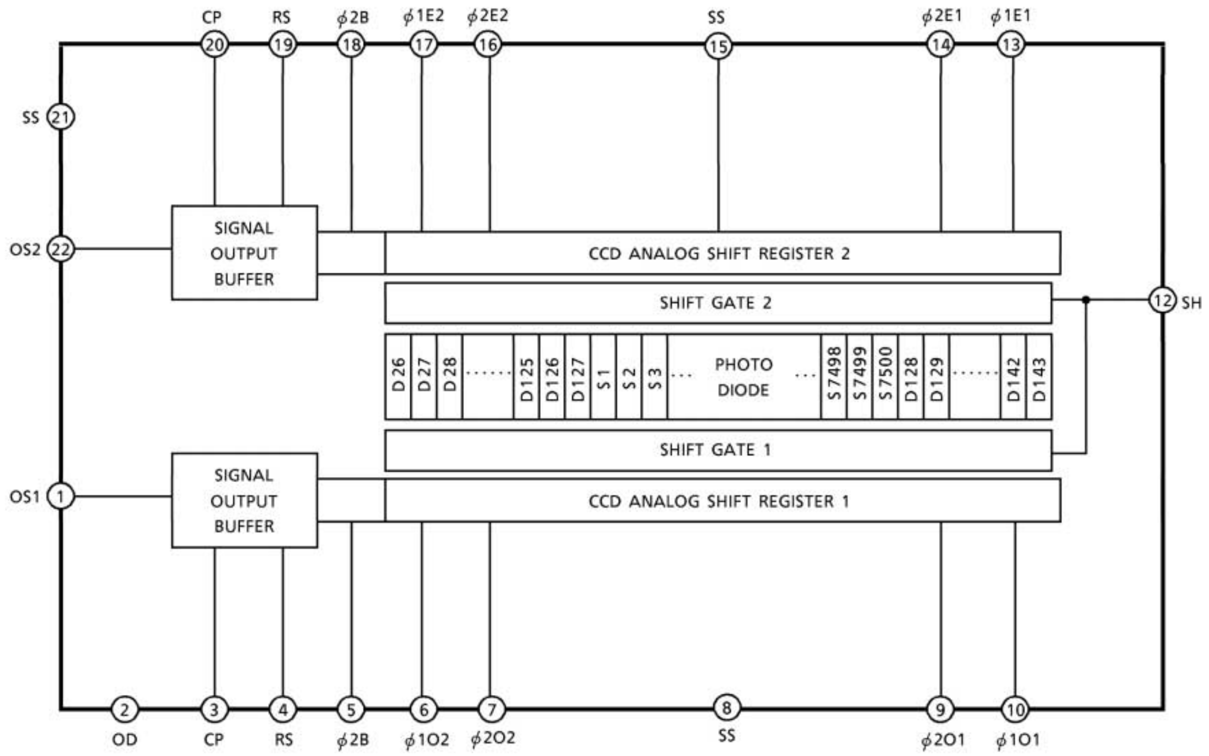
12. Sensor Data

Manufacturer: Toshiba®

Type: TCD 1703 AC

Data: Toshiba® – CCD Linear Sensor – DataSheet

CIRCUIT DIAGRAM



OPTICAL / ELECTRICAL CHARACTERISTICS

(Ta = 25°C, V_{OD} = 12V, $V_\phi = V_{SH} = V_{RS} = V_{CP}$ = 5V (PULSE), f_ϕ = 1MHz, t_{INT} (INTEGRATION TIME) = 10ms, LIGHT SOURCE = DAYLIGHT FLUORESCENT LAMP, LOAD RESISTANCE = 100kΩ)

CHARACTERISTIC	SYMBOL	MIN.	TYP.	MAX.	UNIT	NOTE
Sensitivity	R	12	15	18	V / lx·s	
Photo Response Non Uniformity	PRNU	—	3	10	%	(Note 2)
	PRNU (3)	—	6	12	mV	(Note 8)
Saturation Output Voltage	V_{SAT}	1.5	2.0	—	V	(Note 3)
Saturation Exposure	SE	0.08	0.13	—	lx·s	(Note 4)
Dark Signal Voltage	V_{DRK}	—	1.2	3	mV	(Note 5)
Dark Signal Non Uniformity	DSNU	—	2.5	4	mV	(Note 5)
DC Power Dissipation	P_D	—	350	400	mW	
Total Transfer Efficiency	TTE	92	98	—	%	
Output Impedance	Z_O	—	0.2	1	kΩ	
Dynamic Range	DR	—	1660	—	—	(Note 6)
DC Signal Output Voltage	V_{OS1}	4.0	5.5	7.0	V	(Note 7)
	V_{OS2}	4.0	5.5	7.0		
DC Differential Error Voltage	$\|V_{OS1}-V_{OS2}\|$	—	—	300	mV	
Random Noise	ND_σ	—	1.0	—	mV	(Note 9)

(Note 2) Measured at 50% of SE (Typ.)

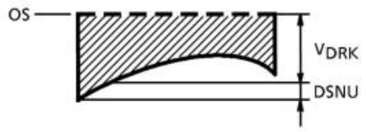
Definition of PRNU : $PRNU = \frac{\Delta\chi}{\overline{\chi}} \times 100\ (\%)$

Where $\overline{\chi}$ is average of total signal outputs and $\Delta\chi$ is maximum deviation from $\overline{\chi}$ under uniform illumination. (Channel 1)
In the case of 3750 elements (Channel 2), the condition is the same as above too.

(Note 3) V_{SAT} is defined as minimum saturation output voltage of all effective pixels.

(Note 4) Definition of SE : $SE = \frac{V_{SAT}}{R}$ (lx·s)

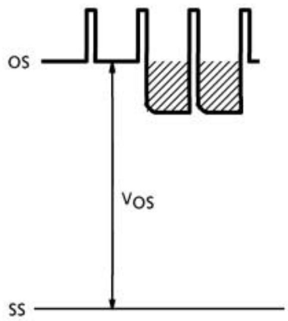
(Note 5) V_{DRK} is defined as average dark signal voltage of all effective pixels.
DSNU is defined as different voltage between V_{DRK} and V_{MDK} when V_{MDK} is maximum dark signal voltage.



(Note 6) Definition of DR : $DR = \frac{V_{SAT}}{V_{DRK}}$

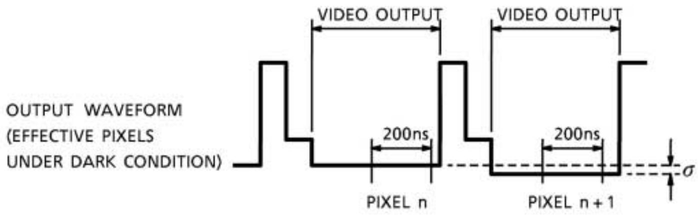
V_{DRK} is proportional to t_{INT} (Integration Time).
So the shorter t_{INT} condition makes wider DR values.

(Note 7) DC signal output voltage and DC compensation output voltage are defined as follows:



(Note 8) PRNU (3) is defined as maximum voltage with next pixel, where measured 5% of SE (Typ.)

(Note 9) Random noise is defined as the standard deviation (sigma) of the output level difference between two adjacent effective pixels under no illumination (i.e. dark condition) calculated by the following procedure.



1) Two adjacent pixels (pixel n and n + 1) in one reading are fixed as measurement points.
2) Each of the output levels at video output periods averaged over 200 nanosecond period to get Vn and Vn + 1.
3) Vn + 1 is subtracted from Vn to get ΔV.

   $\Delta V = Vn - Vn + 1$

4) The standard deviation of ΔV is calculated after procedure 2) and 3) are repeated 30 times (30 readings).

$$\overline{\Delta V} = \frac{1}{30} \sum_{i=1}^{30} |\Delta Vi| \qquad \sigma = \sqrt{\frac{1}{30} \sum_{i=1}^{30} (|\Delta Vi| - \overline{\Delta V})^2}$$

5) Procedure 2), 3) and 4) are repeated 10 times to get 10 sigma values.

$$\overline{\sigma} = \frac{1}{10} \sum_{j=1}^{10} \sigma j$$

6) $\overline{\sigma}$ value calculated using the above procedure is observed $\sqrt{2}$ times larger than that measured relative to the ground level. So we specify the random noise as follows.

$$\text{Random noise} = \frac{1}{\sqrt{2}} \overline{\sigma}$$