

SK2048U3SH

Monochrome Line Scan Camera

2048 pixels $14 \times 14 \mu\text{m}^2$, line frequency up to 14 kHz

Line scan camera with large dynamic range and 14.3 kHz maximum line rate, anti blooming and integration control.

CCD

monochrome
Spectral range

USB 3.0

Instruction Manual



Sample Configuration

- 1** CCD line scan camera
SK2048U3SH
mounted with
- 2** Mounting bracket SK5105
- 3** Clamping claws SK5101
- 4** Focus adapter FA22R-40 (two-piece),
facilitates adjustment of any rotation angle
- 5** Enlarging lens Apo-Rodagon N 4.0/80





Please read the following sections of this Instruction Manual before unpacking, assembly or use of the Line Camera System:

The safety warnings on this page

Introduction to the system, page 4

Installation and Setup, page 6

Keep this Instruction Manual in a safe place for future reference.

Safety Warnings



► Electricity Warning

Assembly and initial operation of the line scan camera must be carried out under dry conditions.

Do not operate the camera if you notice any condensation or moisture in order to avoid danger of a short circuit or static discharge!



Line scan cameras are mostly used in combination with a motion device such as a translation stage, a conveyor or a rotational drive, as well as with high intensity light sources.

For assembly close down these devices whenever possible. Beyond that, please consider the following warnings:



► Mechanics Warning

Ensure that the motion device and the scan way is free to move and that no obstacles are in the way.

Do not place any part of the body in the way of moving parts!



► Risk of High Power Lighting

According to the application, laser or high power LED light sources might be used. These can affect your eyesight temporarily or even cause permanent damage to the eyes or skin.

Do not look directly into the light beam!

How to Use this Instruction Manual	2
Safety Warnings	2
Contents	3
1 Introduction	4
1.1 Intended Purpose and Overview	4
1.2 System Setup at a Glance	4
1.3 SK2048U3SH Line Scan Camera - Specifications	5
2 Installation and Setup	6
2.1 Mechanical Installation: Dimensions, Mounting Options, and Heat Dissipation	6
2.2 Electrical Installation: Connections and I/O Signals	7
2.3 USB3 Connections and SkLineScan Software Installation	8
SkLineScan Installation and Automatic Camera Driver Installation	8
SkLineScan Start-up	8
Camera Setup	8
Initial Function Test	9
3 Camera Control and Performing a Scan	10
3.1 Software: SkLineScan	10
Function Overview: SkLineScan Toolbar	10
Visualization of the Sensor Output	11
3.2 Adjustments for Optimum Scan Results	12
Lens Focussing	12
Sensor Alignment	13
Gain/Offset Adjustment	13
Shading Correction	14
Optimum brightness adjustment, Integration Time	16
Synchronization of the Image Acquisition with the Feed Rate of the Object	17
4 Advanced Camera Control Functions	18
4.1 Camera Control by Commands	18
Set Commands	19
Request Commands	19
Synchronization Modes	20
4.2 Advanced Synchronization Control	22
Advanced Trigger Functions and Sync Control Register (SCR) Settings	22
Example Timing Diagrams	23
5 Sensor Information	24
Glossary	26
Disposal of Waste of Electrical and Electronic Equipment (WEEE)	28
Warranty	29
EC Declaration of Conformity	30
Accessories	32

1 Introduction

1.1 Intended Purpose and Overview

The SK line scan camera series is designed for a wide range of vision and inspection applications in industrial and scientific environments. The SK2048U3SH is highly portable and the robustly attached dedicated connections enable external synchronization of the camera and the output of data to the USB 3.0 port of the computer.

The USB 3.0 connection supplies power to the camera and the camera is hot-pluggable, providing the greatest degree of flexibility and mobility. The computer does not require a grabber board, allowing a laptop to be used when space or weight restrictions are also at a premium.

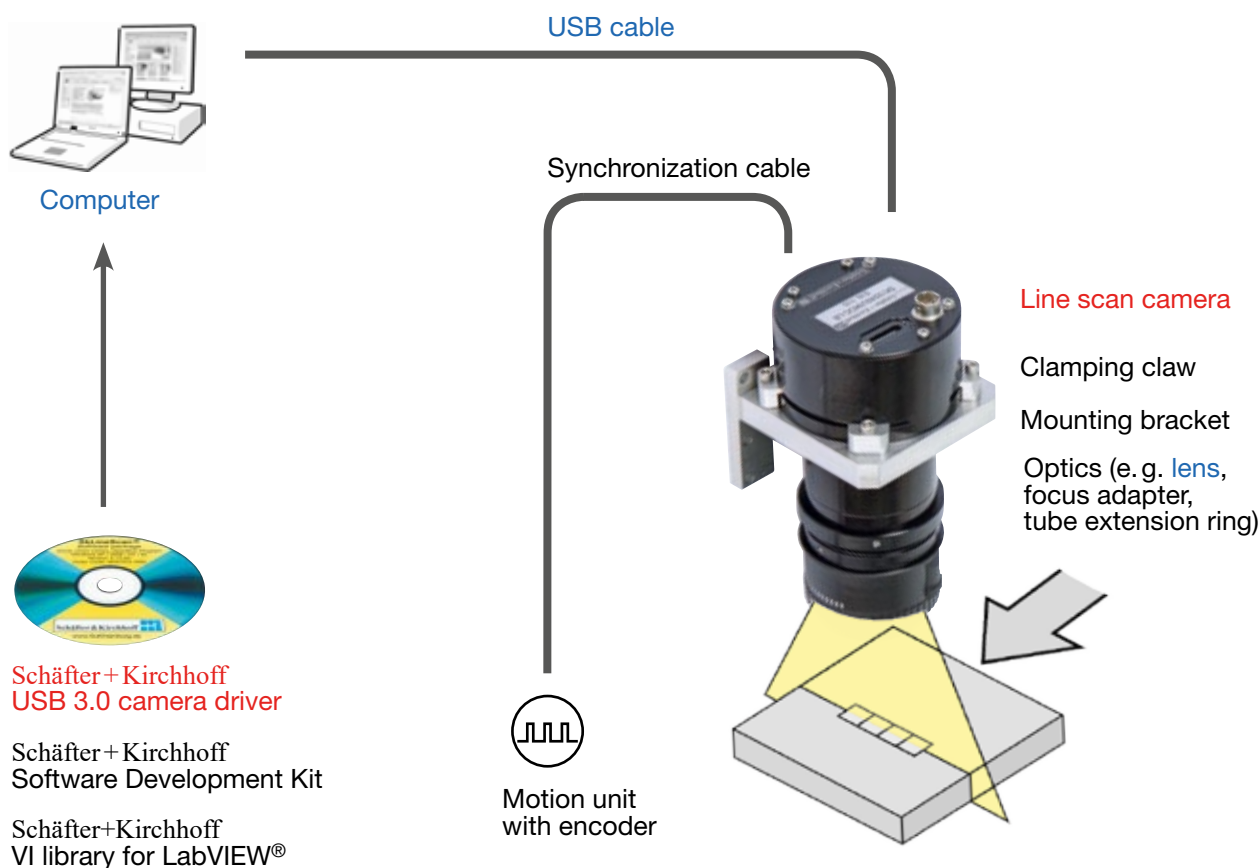
Once the camera driver and the SkLineScan® program have been loaded from the SK91USB3-WIN CD then the camera can be parameterized. The parameters, such as integration time, synchronization mode or shading correction, are permanently stored in the camera even after a power-down or disconnection from the PC.

The oscilloscope display in the SkLineScan® program can be used to adjust the focus and aperture settings, for evaluating field-flattening of the lens and for orientation of the illumination and the sensor, see **3.1 Software: SkLineScan (p. 10)**.

1.2 System Setup at a Glance

red: SK2048U3SH scope of delivery
blue: accessories for minimum system configuration
black: optional accessories

For accessory order details see *Accessories (p. 32)*.



1.3 SK2048U3SH Line Scan Camera - Specifications

Sensor category	CCD Monochrome Sensor
Sensor type	S12551-2048
Pixel number	2048
Pixel size (width x length)	14 x 14 µm ²
Pixel spacing	14 µm
Active sensor length	28.7 mm
Anti blooming	yes
Integration control	yes
Shading correction	yes
Threshold detection	yes
Line synchronization modes	Line Start, Exposure Start, Exposure Active
Frame synchronization	yes
Pixel frequency ²⁾	30 / 15 MHz
Maximum line frequency ¹⁾	14 / 7 kHz
Integration time	0.01 ... 20 ms
Dynamic range	1:2500 (rms)
Spectral range	200 ... 1000 nm
Video signal	monochrome 8/12 Bit digital
Interface	USB 3.0
Voltage	USB (600 mA)
Power consumption ²⁾	3 W @30 MHz
Casing	Ø65 mm x 54 mm (Case type AT2)
Objective mount	M40x0.75
Flange focal length	19.5 mm
Weight	0.2 kg
Admissible casing temperature	+5 ... +45°C
Camera control firmware rev.	1.25 (SkRevisionNumber)

- 1) This camera is USB 2.0 downward compatible with the following limitation:
When connected to a USB 2.0 interface, the pixel data transfer rate is limited to 20 MByte/s and the line frequency is limited accordingly.
- 2) The maximum power supplied by an USB 3.0 interface is 4.5 Watt and by an USB 2.0 interface it is 2.5 Watt. For an external 5VDC power supply unit see section **Accessories**.
The specified power is valid for the maximum pixel frequency.

The camera must be mounted thermally coupled so that the acceptable casing temperature is not exceeded during operation. Therefore applies to the thermal resistance of the bracket or heat sink:

$$R_{thHS} \leq \frac{\theta_{amb} - \theta_{casing}}{P_{camera}}$$

where

R_{thHS} [K/W] = thermal resistance of the bracket or heat sink

θ_{amb} [°C] = ambient temperature

θ_{casing} [°C] = temperature of the camera casing (not to be confused with the internal camera temperature that is queried and output with the request command I32)

P_{camera} [W] = camera power consumption

2 Installation and Setup

2.1 Mechanical Installation: Dimensions, Mounting Options, and Heat Dissipation

Mounting Options

When mounting the camera, pay attention to the following:

- Mechanical stability to avoid vibrations.
- Good thermal coupling for cooling the housing. The power consumption and the maximum housing temperature of the camera are specified in section **1.4 - Specifications**.

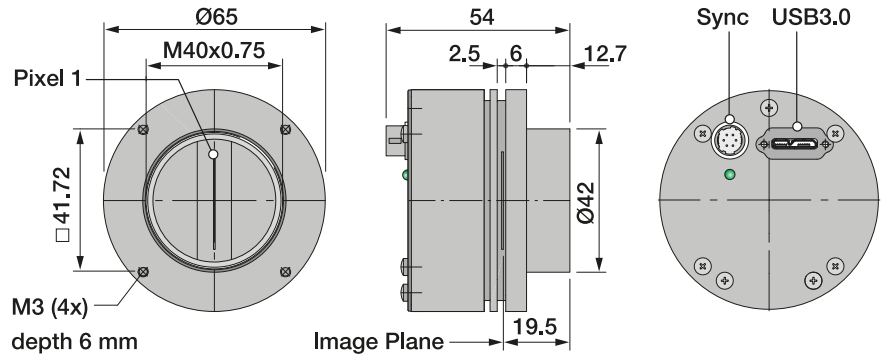
The best fixing point of the camera is the collar for the mounting bracket SK5105 (available as an accessory). Four threaded holes M3x6.5 mm provide further options for customized brackets.

The length and weight of the optics might be beyond the capability of the standard mounting bracket SK5105. For this purpose, a second mounting bracket type SK5105-2 to hold the tube extension ring(s) is more appropriate.

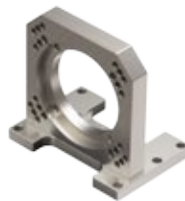
Optics Handling

- If the camera and the optics are ordered as a kit, the components are pre-assembled and shipped as one unit. Keep the protective cap on the lens until the mechanical installation is finished.
- If you must expose the sensor or lens surface, ensure the environment is as dust-free as possible.
- Gently blow off loose particles using clean compressed air.
- The sensor and lens surfaces can be cleaned with a soft tissue moistened with water or a water-based glass cleaner.

Casing type AT2

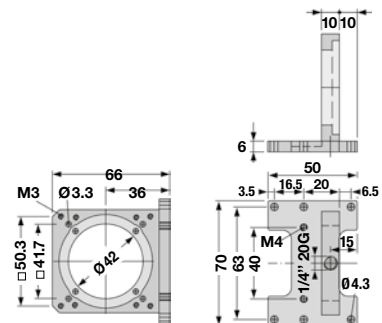


Mounting bracket SK5105



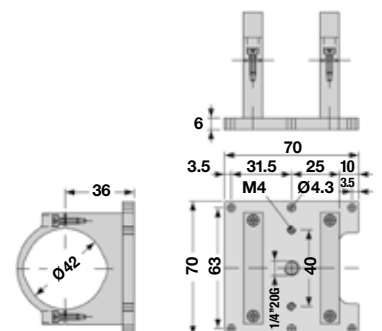
Clamping set SK5101

Set of 4 pcs. clamping claws incl. hex socket screws (EN ISO 4762-M3x12)



Mounting system SK5105-2

for cameras with a tube extension > 52 mm



2.2 Electrical Installation: Connections and I/O Signals

- The USB3.0 interface provides data transfer, camera control and power supply capabilities to the SK2048U3SH line scan camera. If you want to operate the camera in Free Run (SK Mode 0) trigger mode the USB3.0 cable is the only connection you have to make.
- For any kind of synchronized operation, the external trigger signal(s) must be wired to socket **2**. A frame-synchronization signal and two separate line-synchronization signals can be handled. The various trigger modes are described fully in section *Synchronization of the Image Acquisition with the Feed Rate of the Object* (p. 17)

All Schäfter+Kirchhoff USB3.0 line scan cameras can be operated with a USB2.0 interface. Note that there might be limitations in terms of the maximum data transfer rate. The details for your camera can be found in section **1.3 Line Scan Camera - Specifications** (p. 5).

If the power consumption of the camera exceeds 4.5 Watt (USB3.0) or 2.5 Watt (USB2.0), then connect an external source to socket **2**.

1

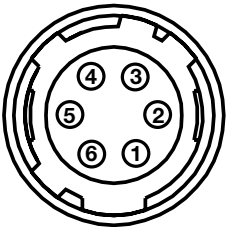
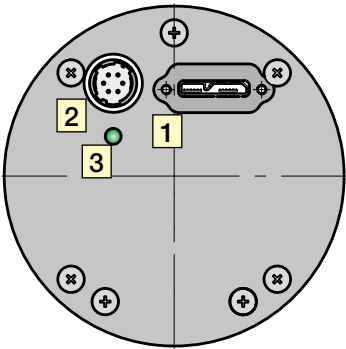
Data and power

USB 3.0 socket type μ B with threaded holes for locking screws
Power: 3 W @30 MHz

2

Synchronization

Socket: Hirose series 10A, male 6-pin



Pin	Signal	Pin	Signal
1	Line Sync B	4	NC
2	NC	5	Line Sync A
3	Frame Sync	6	GND

Line Sync A/B and Frame Sync: TTL levels

3

Status indicator

- off no power, check the USB link for a fault.
- red power on
- green power on, firmware is loaded, camera is ready

Accessories (see also *Accessories* (p. 32)):

USB3.0 cable SK9020.x

For connecting socket **1** with the PC or USB hub.

Cable length:

- 1.0m SK9020.1
- 3.0m SK9020.3 (standard)



External synchronization cable SK9026.x

Use this cable to feed external synchronization signals into socket **2**.

Connectors:

- Hirose plug HR10A, female 6 pin (camera side)
- Phoenix 6 pin connector incl. terminal block

Cable length:

- 3.0m SK9026.3
- 5.0m SK9026.5



2.3 USB3 Connections and SkLineScan Software Installation

This section is a quick reference for installing the **SkLineScan** adjustment and configuration software and to set up the USB3 camera driver. SkLineScan and the SkLineScan manual is provided for download on the Schäfter+Kirchhoff website under <http://www.sukhamburg.com/support.html>. It is also part of the fee-based software development kit **SK91USB3-WIN**.

Step 1: Install **SkLineScan**. The setup program will automatically install the Schäfter+Kirchhoff USB3 Line Scan Camera Driver.

Step 2: Plug in the USB3 connection cable to the camera. if appropriate switch on the external power supply.

Step 3: Start the **SkLineScan** program.

SkLineScan Installation and Automatic Camera Driver Installation

Prior to the installation, power on the PC (not the camera) and unpack the downloaded zip-file to a temporary folder. Alternatively, if your installation medium is a CD, insert the disk to the drive.

The autostart function may launch the setup program automatically from CD. Otherwise, look for one of these installation files:

SkLineScan-USB3-Win_x64.msi
SkLineScan-USB3-Win_x86.msi

SK91USB3-Win_x64.msi
SK91USB3-Win_x86.msi

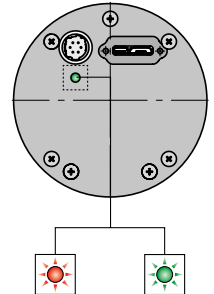
Then start the applicable installation file manually. This will set up the Schäfter+Kirchhoff **SkLineScan** camera control and adjustment tool as well as the USB3 Line Scan Camera Driver.

SkLineScan Start-up

- Start SkLineScan.
- A start-up dialog box pops up and displays the connected camera(s) that have been automatically detected. It also indicates the active USB standard. The optimum performance is provided by USB 3.0.
- The camera LED changes from red to green color light.



Desktop Icon

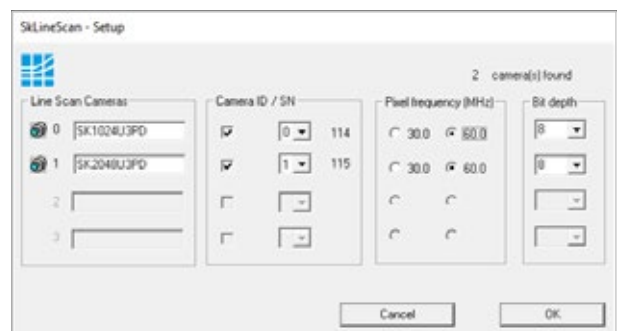


Camera Setup

Use the Setup dialog for

- activating/deactivating a connected USB3 camera (activated device is ticked)
- changing the pixel frequency
- setting the bit depth of the video signal to 8 or 12-bit

In USB 2.0 mode the lower pixel frequency and 8-bit video signal is recommended

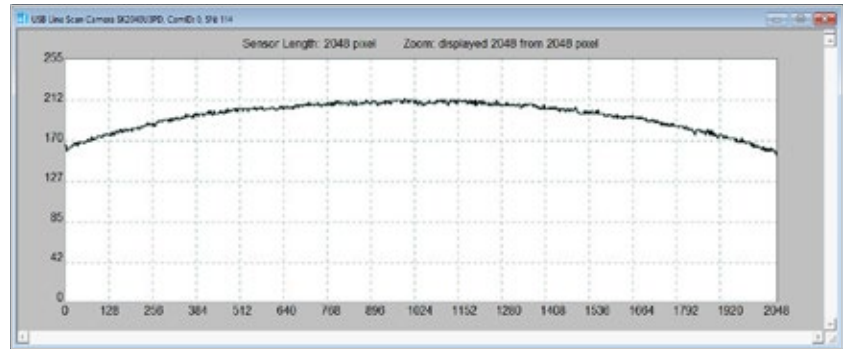


SkLineScan Setup dialog

■ Initial Function Test

- Quit the SkLineScan startup dialog box.
- Select "OK" in the SkLineScan start-up dialog.

The Signal Window showing the current brightness versus the pixel number indicates the correct installation.



3 Camera Control and Performing a Scan

3.1 Software: SkLineScan

This section is a brief introduction to the SkLineScan adjustment and configuration software. A more detailed description is provided in the separate SkLineScan manual. The pdf is included in the SkLineScan installation package or is available for download from the Schäfter+Kirchhoff website under <http://www.sukhamburg.com/supporte.html>.

Detailed instructions on how to obtain optimal image data and use the data with the Schäfter+Kirchhoff software package can be found in the **SkLineScan Software Manual**.

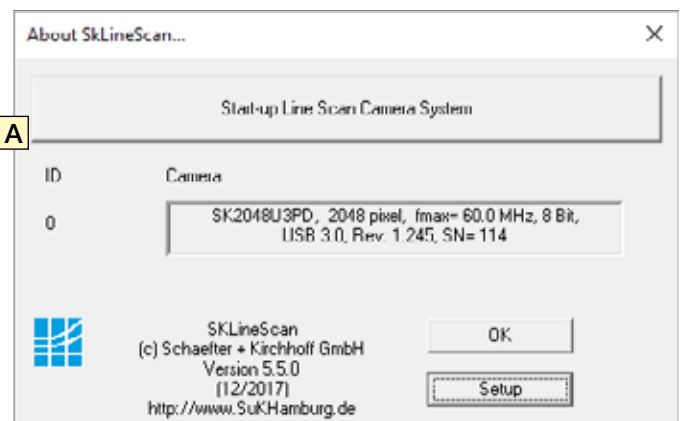
The most common functions of the line scan camera can be controlled by menu items and dialog boxes.

In the "Camera Gain / Offset Control" dialog there is a command line for entering further control commands.

Click on the desktop icon to start the **SkLineScan** program.

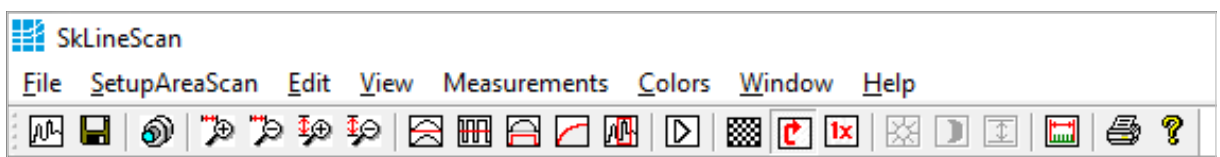
The SkLineScan program recognizes the connected line scan cameras automatically. The identified cameras are shown in the start-up dialog **A**.

If the SK2048U3SH camera is identified correctly, confirm with "OK". The "Signal window" graphically showing the intensity signals of the sensor pixels (oscilloscope display) will open. It is responsive in real-time and the zoom function can be used to highlight an area of interest. The oscilloscope display is ideally suited for parameterizing the camera, for evaluating object illumination, for focussing the image or for aligning the line scan camera correctly.



SkLineScan: Start-up dialog

■ Function Overview: SkLineScan Toolbar



SkLineScan: Toolbar



New line scan. All open "Signal window" windows will be closed. [F2]



"Camera Control" dialog for parameter settings: integration time, line frequency, synchronization mode, thresholding



Zooming in and out



New line scan. "Area Scan" windows will be closed, "Signal window" windows will remain open. [F2]



Threshold mode in new binary signal window.



"Shading Correction" dialog to adjust the white balance [Alt+s]



"Gain/Offset Control" dialog, also for commands input [Shif+F4]



New area scan

■ Visualization of the Sensor Output

• Signal Window / Oscilloscope Display

The signal window plots the digitalized brightness profile as signal intensity (y-axis) versus the sensor length (x-axis) at a high refresh rate. The scaling of the y-axis depends on the resolution of the A/D converter: The scale range is from 0 to 255 for 8-bits and from 0 to 4095 for 12-bits. The scaling of the x-axis corresponds with the number of pixels in the line sensor.



Line scan in Signal Window: brightness vs. pixel number

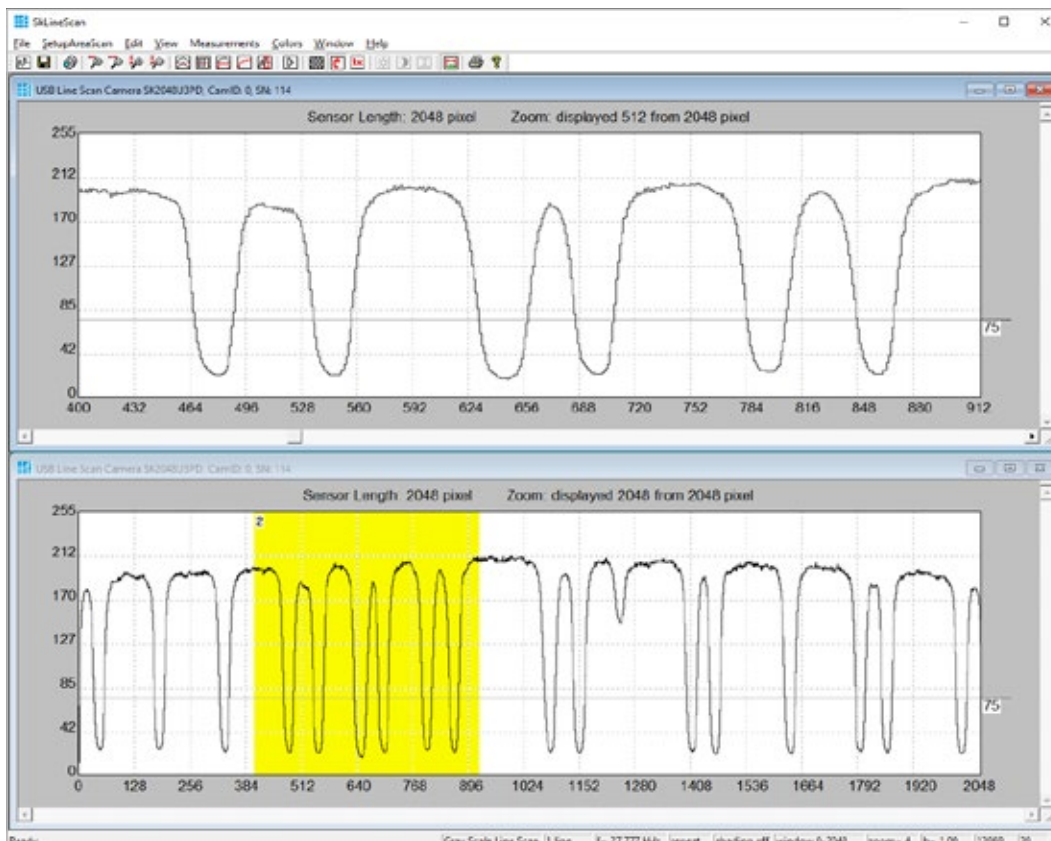
• Zoom Function



With a high number of sensor pixels, details are lost due to the limited number of display pixels. With the zoom function you select a part of the sensor for the detailed display. The possible magnification ranges up to the representation of the intensity signal of individual pixels.

• Window Split Function

The signal window can be divided horizontally into two areas. Use the slider **B** at the top of the vertical scroll bar. If you then use the zoom function in one frame, the selected section in the other frame will be highlighted in yellow.



Line scan in split signal window: The upper frame shows an enlarged section of the lower frame.

3.2 Adjustments for Optimum Scan Results

Prior to a scan, the following adjustments and parameter settings should be considered for optimum scan signals:

- Lens focussing
- Sensor alignment
- Gain/Offset
- Shading correction
- Integration time
- Synchronization of the sensor exposure and the object surface velocity, trigger mode options.

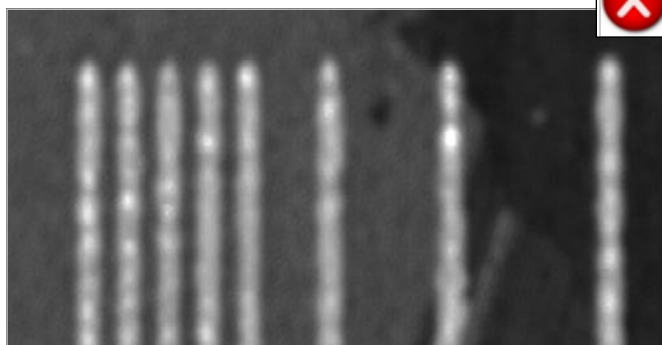
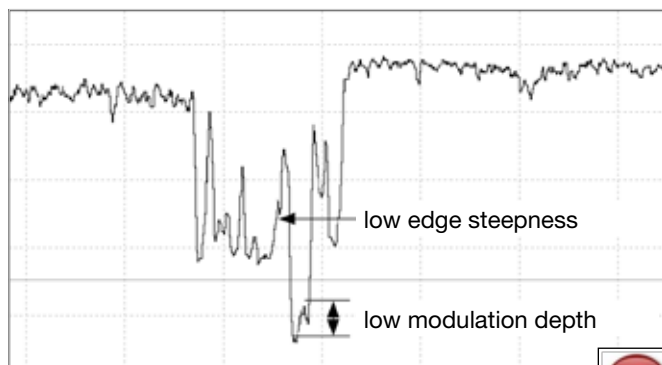
Start with the signal window / oscilloscope display. Any changes in the optical system or camera parameters are displayed in real-time when using an open dialog box.

■ Lens Focussing

The real time Signal Window facilitates the effective focussing of the line scan camera system, even for two-dimensional measurement tasks. For determining the correct focus, the edge steepness at dark-bright transitions and the modulation of the line scan signal are the most important factors.

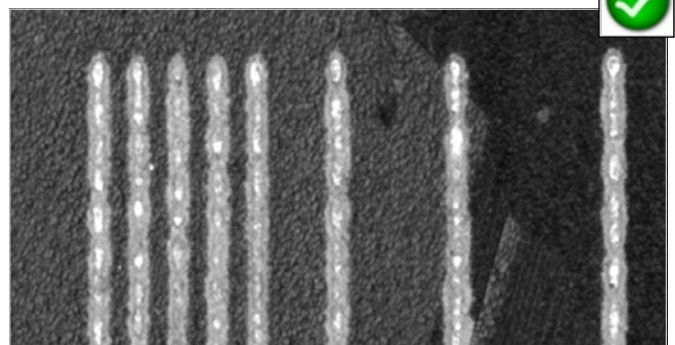
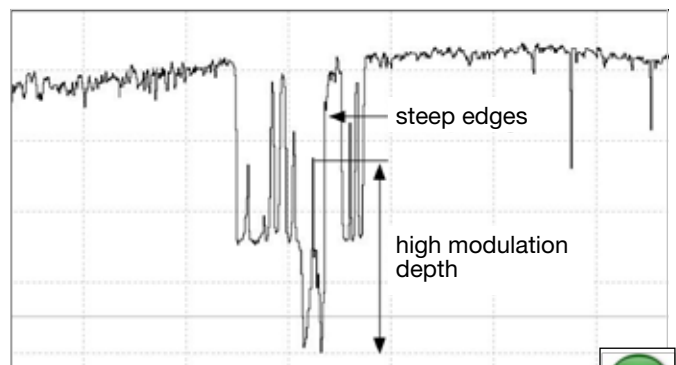
Adjust the focus with the aperture fully open to limit the depth of field and enhance the effects of changing the working distance.

If the sensor is overloaded when the aperture is fully open, the easiest way to reduce the signal amplitude is to shorten the integration time, as described in section *Optimum brightness adjustment, Integration Time (p. 16)*.



Out-of-focus:

- Low edge steepness
- Signal peaks are blurred
- High spatial frequencies with low modulation depth

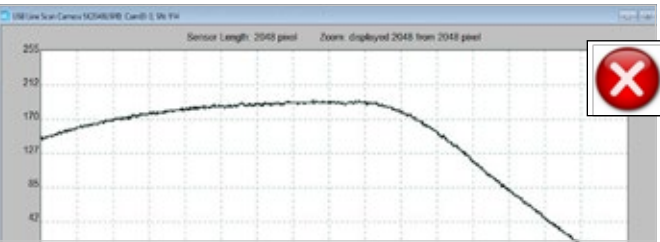


Optimum focus:

- Dark-bright transitions with steep edges
- Large modulation in the signal peaks
- High spatial frequencies with high modulation depth

■ Sensor Alignment

If you are using a linear light source, check the alignment of the light source and sensor before shading correction, as rotating the line sensor will result in asymmetric vignetting.



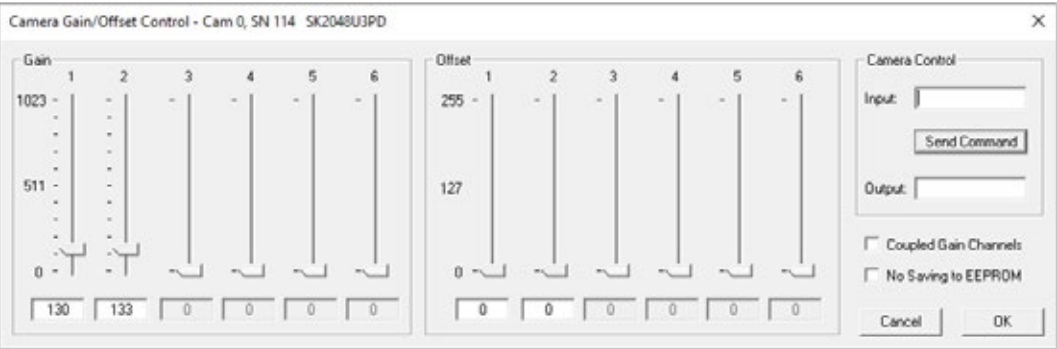
Sensor and line lighting slightly twisted in relation to each other, asymmetric vignetting



Sensor and line lighting aligned in parallel, symmetric vignetting

■ Gain/Offset Adjustment

The cameras are supplied with factory-set gain/offset. Open the "Gain/Offset Control" dialog to adjust these settings.



Gain/Offset Control dialog

The gain/offset dialog contains up to 6 sliders for altering gain and offset. The number of active sliders depends on the individual number of adjustable gain/offset channels of the camera. If "Coupled Gain Channels" is checked, all channels are set synchronously with one slider.

Enter commands for advanced software functions in the 'Camera Control' field (see page 10).

Adjustment principle

1. Offset

To adjust the zero baseline of the video signal, totally block the incident light and enter "00" (volts) for channel 1.

For a two- or multi-channel sensor, minimize any differences between the channels by adjusting the other Offset sliders.

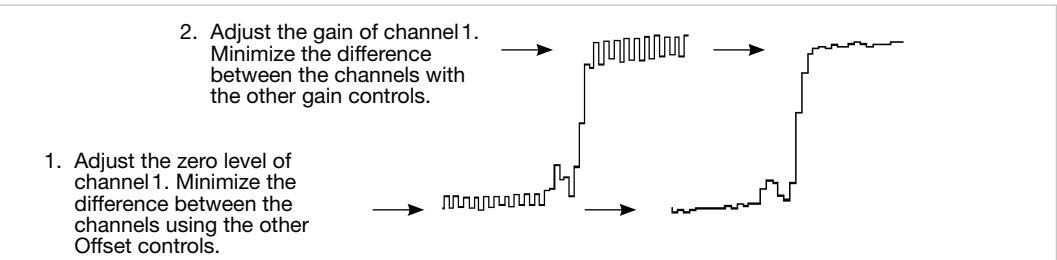
A slight signal noise should be visible in the zero baseline.

2. Gain

Illuminate the sensor with a slight overexposure in order to identify the amplitude clipping. Use the Gain slider "1" to adjust the maximum output voltage.

For a two- or multi-channel sensor, minimize any differences between the channels by adjusting the other Gain sliders.

For the full 8-bit resolution of the camera, the maximum output voltage is set to 255 and for 12-bit is set to 4095.



Offset and gain adjustment for more than one gain/offset channel

■ Shading Correction

Shading correction compensates for non-uniform illumination, lens vignetting as well as any differences in pixel sensitivity. For this purpose, there is a memory area in the line scan camera (Shading Correction Memory SCM) that contains the scaling factor for the white reference for each pixel. Subsequent scans are normalised with these correction factors, provided that automatic shading correction is switched on.

With the SkLineScan software you can generate these scaling factors in two different ways, a) via the n-fold acquisition of a homogeneous reference signal, e.g. a white sheet of paper or b) via the theoretical calculation of the lens vignetting based on the focal length and the magnification. If possible, method a) is to be preferred, as it usually provides the better correction result.

a) Determine scaling factors based on the acquisition of a homogeneous reference signal

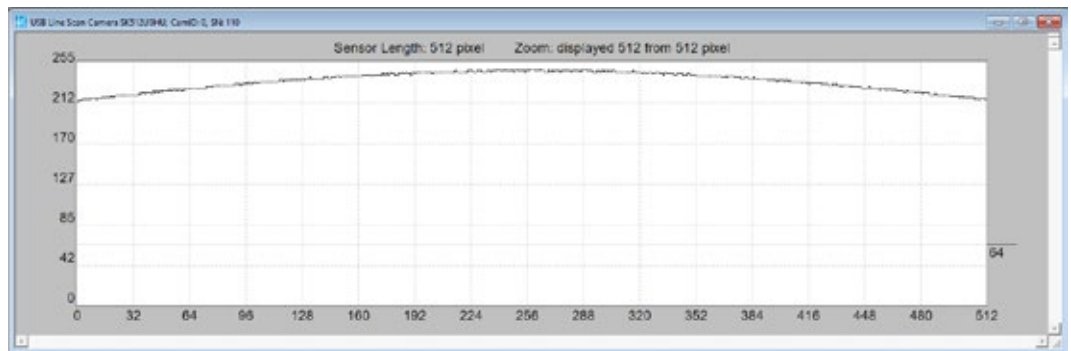


Fig. 1 Prerequisite for shading correction: imaging of a uniformly bright surface

- Make sure to carry out the shading correction at 12-bit resolution if you want to operate the camera with this resolution later.
- The signal of a white homogeneous background is used as a reference. Adjust the lighting or exposure time so that the brightest pixels almost reach the maximum possible intensity but do not overdrive the sensor.
- Record a 2-dimensional scan ("Area Scan Function" [F3]). The set number of lines determines the set of values for averaging. To suppress influences of the surface structure, move the imaged object during the image acquisition.
- When the scan is complete, open the Shading Correction dialogue (Alt+s) and make the settings for the scaling range:

The automatic shading correction is applied to detected brightness values in the range "**Minimum**" to 100%.

"**Scale to**" is the target value for scaling that is identical for all pixels, so as a result a uniform intensity of this value is output.

The entry 0% for "**Scale to**" causes the maximum value in the recorded reference signal to be used as the target value.

A typical suitable value for "**Minimum**" is 20%.

Recorded pixels whose brightness is below "**Minimum**" are not corrected. At 8-bit resolution, this is all pixels with less than $255 \cdot 20\% = 51$ brightness value, at 12-bit correspondingly $4095 \cdot 20\% = 819$.

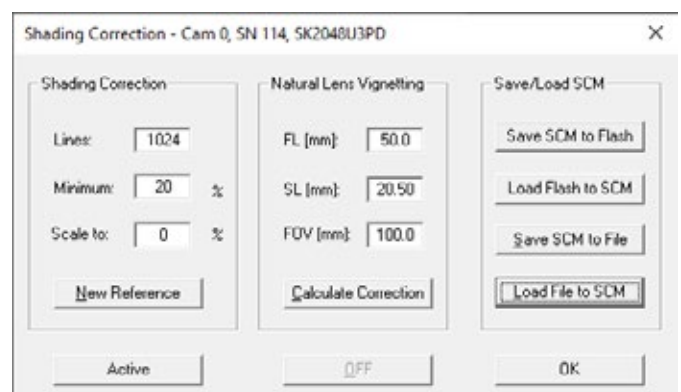


Fig. 2 Shading Correction dialog

- Click on the "**New Reference**" button to calculate the correction data and store it in the volatile SCM memory.

b) Calculate scaling factors based on the theoretical lens vignetting

- Open the "Shading Correction" dialogue (Alt+s) and enter the following values in the middle column "Natural Lens Vignetting":

FL [mm] lens focal length in mm
SL [mm] sensor length of the camera in mm
FOV [mm] Field of View in mm

- Click on the "**Calculate Correction**" button to calculate the correction data and store it in the volatile SCM memory.

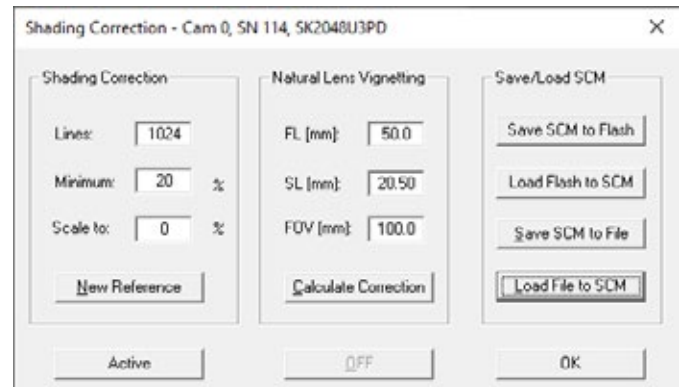


Fig. 3 Shading Correction dialog

Saving or loading shading correction data

Use the four buttons **Save SCM to Flash** / **Load Flash to SCM** / **Save SCM to File** / **Load File to SCM** in the right box to copy the shading correction data between different memory areas.

The Shading Correction Memory (SCM) is accessed during operation. It is fast, but loses the information when the camera is switched off. The flash memory inside the camera serves as a backup. When the camera is switched on, the data is automatically copied to the SCM.

Once the reference signal is copied from the shading correction memory (SCM) to the camera flash memory it will persist even after a power down.

On a re-start, this data will be restored from the flash memory back to the SCM.

The current shading correction status - active or not active - is also retained after power down.

Activating and deactivating the shading correction function

ACTIVATE Activate shading correction with the reference signal stored in the SCM.

OFF Switch off Shading Correction. The shading correction data will not be loaded from the flash memory into the SCM the next time the camera is started - even if the SCM data was previously stored in the flash memory.

Load File to SCM A stored reference signal file is loaded into the SCM of the camera. Shading correction is then active.

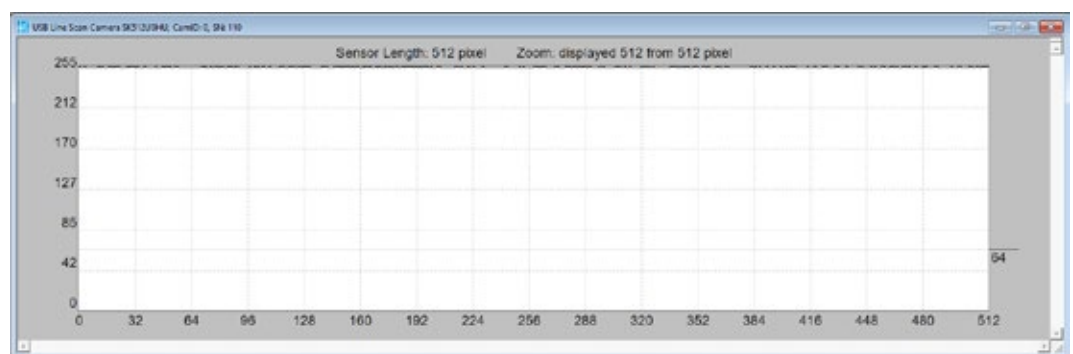
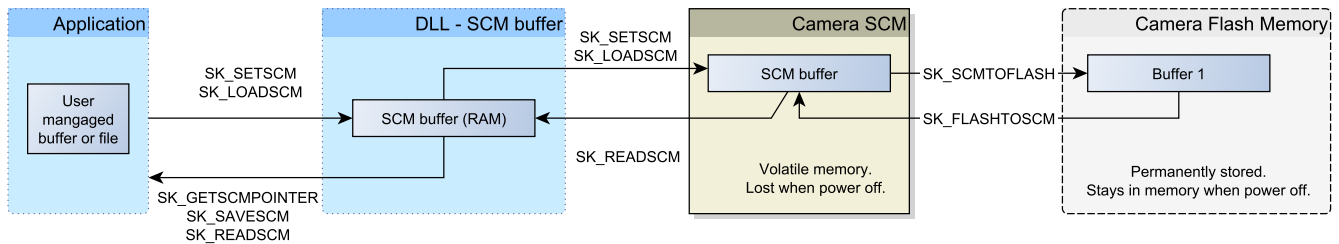


Fig. 4 Line scan signal with a homogeneous intensity at 255 (8 bit, Maximum 100%) after shading correction

Shading Correction Memories and API Functions

As an alternative to the user dialog, a new shading correction reference signal can also be generated using API (Application Programming Interface) functions. The relationship between the memory locations and the related API functions are shown in the following figure. The API functions are included in the SK91USB3-WIN software package. For more information, refer to the *SK91USB3-WIN manual*.



Structure of the shading correction memories (SCM) and the related API functions for memory handling

■ Optimum brightness adjustment, Integration Time

The brightness distribution of the line signal is influenced not only by the integration time, but also by the illumination and the aperture setting. It should be noted that the aperture setting affects the depth of field and thus the overall quality of the image.

The line signal is optimal if the signal from the brightest area of the object corresponds to 95% of the maximum output value. At 8-bit digitizing depth, 256 brightness levels are available, at 12-bit 4096. In this setting, optimum signal sensitivity is achieved and overexposure or even blooming is avoided.

Open the **Camera Control** dialog.

Menu **Edit -> Operation Parameters** or **[F4]**

- The integration time can be set by two vertical sliders or two input fields in the section **Integration Time** of this dialog. The left slider is for coarser the right for finer adjustments.
- The current line frequency is displayed in the **Line Frequency** status field.
- For cameras with integration control function (shutter), it is possible to shorten the integration time without increasing the line frequency. This integration control mode is activated as soon as the maximum line frequency of the camera is reached by shortening the integration time or by checking **Decoupl. LF** and thus the integration time is decoupled from the line frequency.

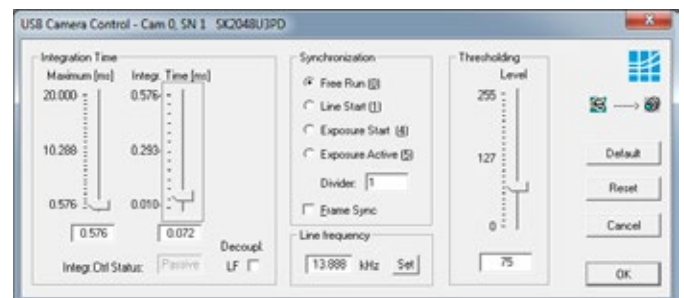
The **Default** button sets the integration time to the minimum exposure period that is determined from the maximum line frequency.

Reset restores the start values.

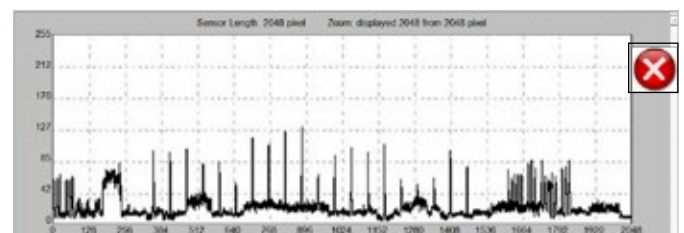
Cancel closes the dialog without changes.

OK stores the integration time values and closes the dialog.

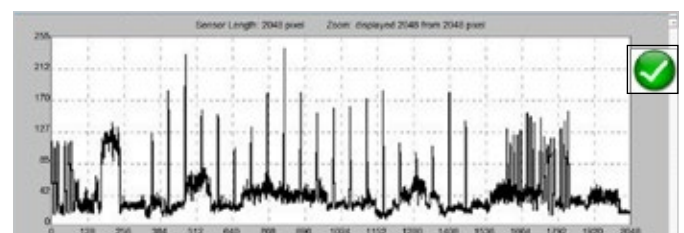
For synchronization settings, see section *Synchronization of the Image Acquisition with the Feed Rate of the Object* (p. 17).



SkLineScan Camera Control dialog



A camera signal with insufficient level: The integration time is too short, since only about 50% of the gray levels are used.



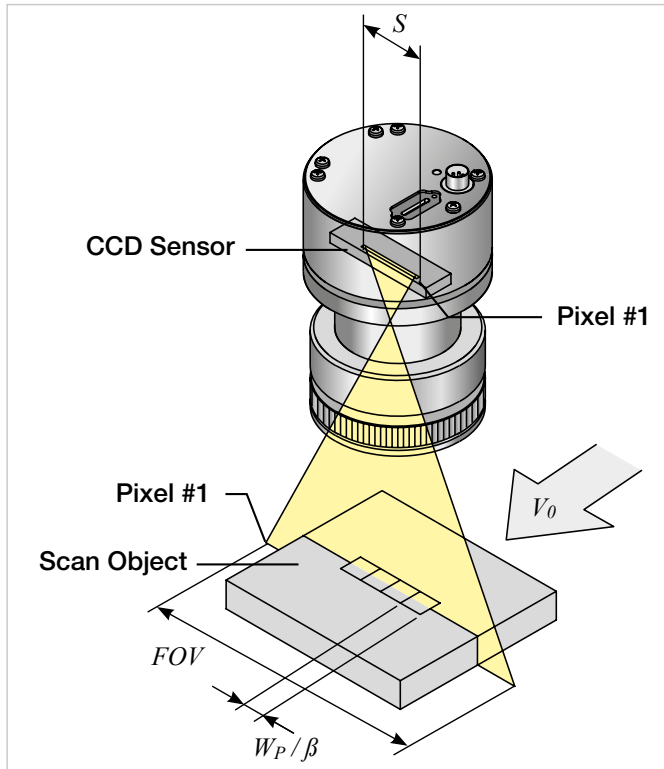
Optimized level of the camera signal after increasing the integration time by a factor of 4 to 95 % of the available scale.

■ Synchronization of the Image Acquisition with the Feed Rate of the Object

A line scan camera produces a two-dimensional image by moving either the object or the camera. The direction of the translation movement must be orthogonal to the sensor axis of the line scan camera.

In order to obtain an image with the correct aspect ratio, a line synchronous feed is required. With RGB color sensors, the color sequence of the individual sensor lines must also be taken into account when processing the sensor data. The software development kits from Schäfter+Kirchhoff contain easy-to-use functions for this purpose.

If the object speed is variable or the accuracy requirements are high, external synchronization is required. The various synchronization modes are described in the next section.



The optimal scan speed for a given line frequency is calculated as follows:

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

If the scanning speed is fixed, the line frequency must be adjusted accordingly in order to obtain the correct aspect ratio in the image:

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

V_O	=	object scan velocity
W_P	=	pixel width
f_L	=	line frequency
S	=	sensor length
FOV	=	field of view
β	=	magnification factor
	=	S / FOV

Example 1:

Calculating the scan velocity for a given field of view and a given line frequency:

Pixel width	=	14 μm
Line frequency	=	14 kHz
S	=	28.7 mm
FOV	=	50 mm

$$V_O = \frac{14 \mu\text{m} \cdot 14 \text{ kHz}}{(28.7 \text{ mm} / 50 \text{ mm})} = 341 \text{ mm/s}$$

Example 2:

Calculating the line frequency for a given field of view and object scan velocity:

Pixel width	=	14 μm
Scan velocity	=	300 mm/s
S	=	28.7 mm
FOV	=	50 mm

$$f_L = \frac{300 \text{ mm/s} \cdot (28.7 \text{ mm} / 50 \text{ mm})}{14 \mu\text{m}} = 12.3 \text{ kHz}$$

4 Advanced Camera Control Functions

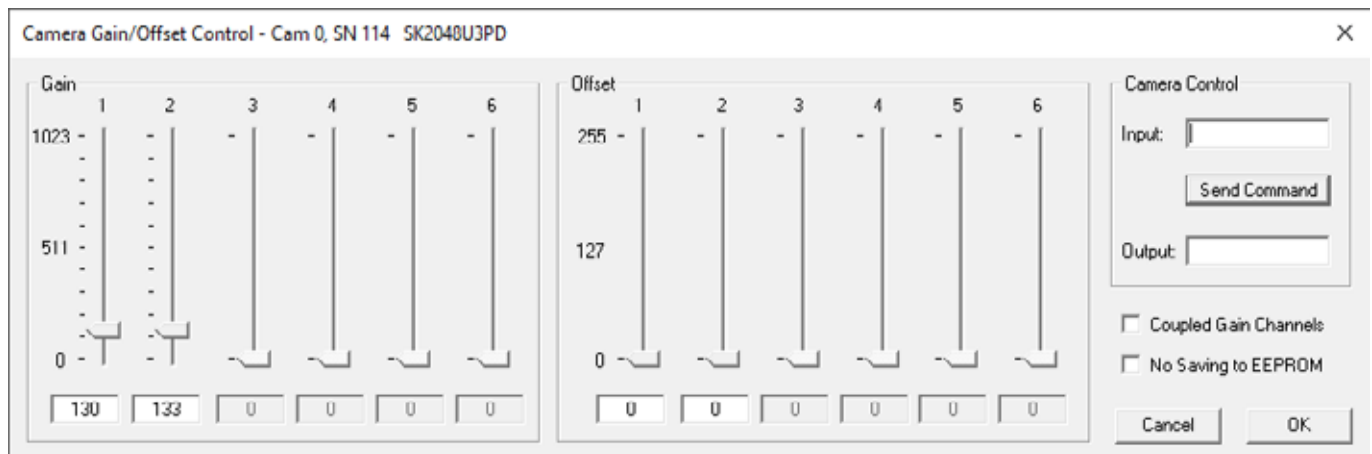
4.1 Camera Control by Commands

In addition to user dialog inputs, the SkLineScan software also provides the option to adjust camera settings, such as gain, offset, trigger modes, by sending control commands directly.

Similarly, current parameters, as well as specific product information, can be read from the camera using the request commands. All set and request commands are listed in the tables below.

- The commands are entered in the 'Input' field in the 'Camera Control' section of the "Camera Gain/Offset Control" user dialog, [Shift+F4].
- In the 'Output' field, either the acknowledgement of the set commands (0=OK, 1=not OK) or the return values of the request commands are output.

The parameter settings are stored in the non-volatile flash memory of the camera and are available after a rapid start-up, even after a complete shut down or loss of power.



Gain/Offset Control dialog: Camera Control input and output in the right section

■ Set Commands

Set Operation	Description
Goooo<CR>	gain 1 setting 0-24 dB
Oppp<CR>	offset 1 setting
F8<CR>	output format: 8 bit output data
F12<CR>	output format: 12 bit output data
C30<CR>	camera clock: 30 MHz data rate
C15<CR>	camera clock: 15 MHz data rate
T0<CR>	test pattern off / SCM off
T1<CR>	test pattern on (turns off with power off)
T2<CR>	shading correction on
T3<CR>	auto program Shading Correction / SCM on
T4<CR>	copy flash memory 1 to SCM
T5<CR>	save SCM to flash memory 1
T6<CR>	video out = SCM data
T7<CR>	copy Flash Memory 2 to LUT Memory
T8<CR>	save LUT Memory to Flash Memory 2
T9<CR>	output data = LUT data
M0<CR>	line trigger mode0: free run (no triggering) at selected line rate
M1<CR>	line trigger mode1: extern trigger, next line
M2<CR>	line trigger mode0: free run (no triggering) at maximum line rate
M4<CR>	line trigger mode4: external triggering and restart
M5<CR>	line trigger mode5: extern SOS, all lines
Mx+8	frame trigger external, start on falling edge
Mx+16	frame trigger external, active low
Axxxx<CR>	SCM address (Axxxx = A0-A2047) or LUTM (Axxxx = A32768-A36863)
Dxxxx<CR>	SCM memory data (xxxx = 0-4095), increment memory address counter
Eyyyyy<CR>	frames / multiframe (yyyyy = 0-32767)
EFyyyyy<CR>	external frame trigger delay (yyyyy = 0-32767 lines)
Nyyyyy<CR>	lines / frame (yyyyy = 1-32767)
Vyyyyy<CR>	extern sync divider (yyyyy = 1-32767)
Ypppp<CR>	set sync control (ppp = 0-4095)
Wyyyyy<CR>	line clock frequency (yyyyy = 50-14000) [Hz]
WLyyyyy<CR>	Window Pixel length (yyyyy = 1-Line length)
WFyyyyy<CR>	Window First Pixel (yyyyy = 1-Line length)
Xyyyyy<CR>	exposure time (yyyyy = 10-20000) [μs]

SDXT<CR>	enable DXT (decoupling of line clock frequency and exposure time)
RDXT<CR>	disable DXT (decoupling of line clock frequency and exposure time)
SLUT<CR>	enable LUT
RLUT<CR>	disable LUT
SNES<CR>	enable NES (no EEPROM save)
RNES<CR>	disable NES (no EEPROM save)
RESET<CR>	reset Memory to manufacturer default

■ Request Commands

Request	Return	Description
K<CR>	SK2048U3SH	returns SK type number
R<CR>	Rev. 1.25	returns Revision number
S<CR>	SNr00163	returns Serial number
I<CR>	SK2048U3SH Rev. 1.25 SNr00163	camera identification readout
I1<CR>	VCC: yyyyy	returns VCC (1=10mV)
I2<CR>	VDD: yyyyy	returns VDD (1=10mV)
I3<CR>	moo: yyyyy	returns mode of operation
I4<CR>	CLo: yyyyy	returns camera clock low frequency (MHz)
I5<CR>	CHi: yyyyy	returns camera clock high frequency (MHz)
I6<CR>	Ga: yyyyy	returns gain 1
I8<CR>	Of: yyyyy	returns offset 1
I14<CR>	THL: yyyyy	returns threshold level
I19<CR>	Tab: yyyyy	returns number of video channels
I20<CR>	CLK: yyyyy	returns selected clock frequency (MHz)
I21<CR>	ODF: yyyyy	returns selected output data format
I22<CR>	TRM: yyyyy	returns selected trigger mode
I23<CR>	SCO: yyyyy	returns shading corr. on/off
I24<CR>	Exp: yyyyy	returns exposure time
I25<CR>	miX: yyyyy	returns min. exposure time (μs)
I26<CR>	LCK: yyyyy	returns line frequency (Hz)
I27<CR>	maZ: yyyyy	returns max. line frequency (Hz)
I28<CR>	TSc: yyyyy	returns Sync Divider
I29<CR>	SyC: yyyyy	returns Sync Control
I30<CR>	Lin: yyyyy	returns Lines/Frame
I31<CR>	DXT: yyyyy	returns DXT on/off
I32<CR>	Tmp: yyyyy	returns Video Board Temper.
I33<CR>	FSD: yyyyy	returns Frame Trigger Delay
I36<CR>	WPL: yyyyy	returns Window Pixel Length
I37<CR>	WFP: yyyyy	returns Window First Pixel
I38<CR>	LUT: yyyyy	returns LUT on/off
I39<CR>	KST: yyyyy	returns Status

LUT: Lookup Table
 SCM: Shading Correction Memory
 SOS: Start of Scan

Range of values:
 oooo = 0 ... 1023
 ppp = 0 ... 255
 xxxx = 4 digits integer value as ASCII
 yyyyy = 5 digits integer value as ASCII

Acknowledgement for all set commands:
 0 = OK, 1 = not OK

■ Synchronization Modes

The synchronization mode determines the exact timing of the exposure. Synchronization can either be performed internally or triggered by an external source, e.g. an encoder signal.

There are two different synchronization functions that can be applied together or individually:

1. Line synchronization:

The falling edge of a TTL signal at the LINE SYNC A input triggers each individual exposure of the sensor line by line.

The SK2048U3SH line scan camera enables extended synchronization control by means of a second trigger input LINE SYNC B. A detailed description can be found under **Advanced Synchronization Control, S. 22**.

2. Frame synchronization:

The recording of a set of lines (frame) representing a two-dimensional image is started by the falling edge of a TTL signal at the FRAME SYNC input.

Free Run / SK Mode 0

The acquisition of each line is synchronized internally (free-running) and the next scan is started automatically after completion of the previous line scan. The line frequency is determined by the programmed value.

LineStart / SK Mode 1

After an external trigger pulse, the currently exposed line is read out at the next internal line clock. The start and duration of the exposure are controlled internally by the camera and are not affected by the trigger pulse. The exposure time is programmable. The line frequency is determined by the frequency of the trigger signal.

Limitations: The period of the trigger signal must be longer than the exposure time used. Between the external trigger signal and the internally generated line clock, jitter occurs in the range of the exposure time.

ExposureStart / SK Mode 4 (only available when camera supports integration control)

A new exposure is started exactly at the point in time of the external trigger pulse. The exposure time is determined by the programmed value. The exposed line is read out after the exposure time has elapsed. The frequency of the trigger signal determines the line frequency.

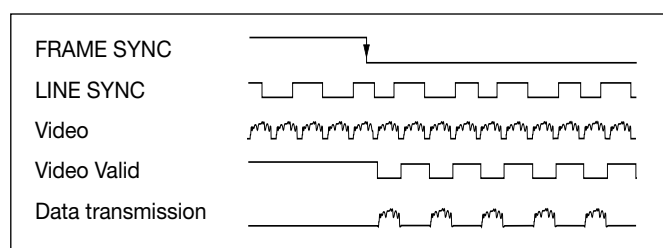
Restriction: The period duration of the trigger signal must be longer than the exposure time used.

ExposureActive / SK extSOS (Mode 5)

The exposure time and the line frequency are controlled by the external trigger signal. This affects both the start of a new exposure (Start of Scan-Pulse, SOS) and the readout of the previously exposed line.

FrameTrigger / SK FrameSync

The camera suppresses the data transfer until a falling edge of a TTL signal occurs at the FRAME SYNC input. This starts the acquisition of a 2D area scan. The number of image lines must be programmed in advance. Any of the available line synchronization modes can be used for the individual line scans.



Combined frame and line synchronization

-

The diagram illustrates the internal architecture of a CCD camera system. It features a central CCD sensor block on the left, which outputs pixel clock, SOS, and discharge signals. The system is controlled by an Oscillator and an Exposure Time block. A Clock Select block routes the pixel clock to various components. A Pixel Counter block generates a DVAL signal and a pixel address. A Sync Select block, controlled by the Exposure Time block, routes signals to a Region of Interest (ROI) block and the Output Format Select block. The Advanced Sync Control block manages synchronization signals, including Line Sync A, Line Sync B, and various Sync C signals (SyC 2, SyC 3...7, SyC A, SyC B, SyC 0,1). A Sync Divider block provides a trigger signal. The Output Format Select block receives signals from the ROI block and the Advanced Sync Control block, and outputs CCLK and Camera Interface signals. The system also includes an AD Converter, Shading Corr. block, and Look Up Table (LUT) for video processing.

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4.2 Advanced Synchronization Control

The basic synchronization function makes use of the trigger input LINE SYNC A. The trigger mode is determined by the settings in the 'Camera Control' dialog, e.g. LineStart (1) or ExposureStart (4).

Advanced trigger functions are provided by combining LINE SYNC A with a second trigger input LINE SYNC B. The operation mode is controlled by the entries in the **Sync Control Register (SCR)**.

Control commands to write to or to read from the Sync Control Register:

Yppp<CR> set SCR with ppp = 0...255 (decimal)
Return value: 0 = OK; 1 = not OK

I29<CR> return sync control
Return value: SyC:yyyyy (5-digits integer value as ASCII)

Example:

Y232
ppp = 232(dec) = 11101000(bin)
new SCR value: 11101000 → **E**

Advanced Trigger Functions and Sync Control Register (SCR) Settings

- Basic synchronization function, 'Camera Control' dialog settings are valid → **A**
- Detection of direction → **B**, **C**, **D**, **E**
- Trigger pulses are valid only in one direction, trigger pulses in the other direction are ignored → **B**
- Trigger on 4 edges → **D**, **E**
- Suppression of jitter in the encoder signal, programmable hysteresis for trigger control → **E**

Sync Control Register (SCR)	SyC7	SyC6	SyC5	SyC4	SyC3	SyC2	SyC1	SyC0
default	x	x	x	x	x	x	0	0
pixel #1 data = external trigger input states	x	x	x	x	x	x	0	1
pixel #1 data = Linecounter (8 bit)	x	x	x	x	x	x	1	0
pixel #1, #2 data = ext. trigger states (3 bit) + line counter (13 bit)	x	x	x	x	x	x	1	1
ExSOS and Sync at LINE SYNC A (Mode5)	x	x	x	x	x	0	x	x
ExSOS at LINE SYNC B, Sync at LINE SYNC A (Mode5)	x	x	x	x	x	1	x	x
Jitter Hysteresis off	x	x	x	0	0	x	x	x
Jitter Hysteresis 4	x	x	x	0	1	x	x	x
Jitter Hysteresis 16	x	x	x	1	0	x	x	x
Jitter Hysteresis 64	x	x	x	1	1	x	x	x
Sync 1x Enable	x	x	0	x	x	x	x	x
Sync 4x Enable	x	x	1	x	x	x	x	x
Sync up Enable / down disable	x	0	x	x	x	x	x	x
Sync up/down Enable	x	1	x	x	x	x	x	x
Sync Ctrl. Disable, SyC3...SyC6 without function	0	x	x	x	x	x	x	x
Sync Control Enable	1	x	x	x	x	x	x	x
	128	64	32	16	8	4	2	1

For diagnostic purposes, the present state of external trigger inputs (LINE SYNC A, LINE SYNC B, FRAME SYNC) or the internal line counter can be output instead of pixel #1 and/or pixel #2 data.

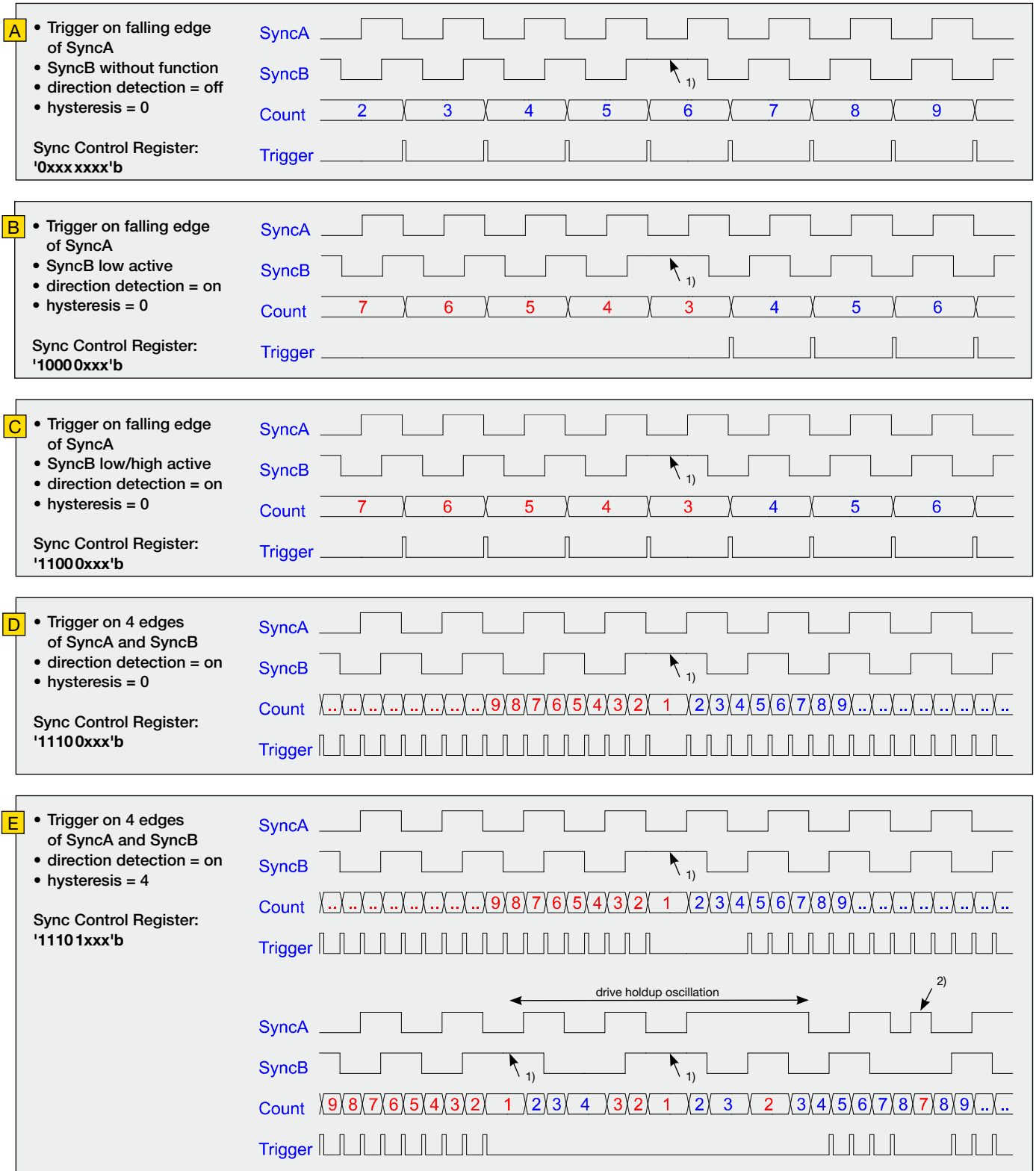
SCR	Pixel #1 Data (lowByte)	Pixel #2 Data (lowByte)
xxxxxx00	intensity	intensity
xxxxxx01	D7 = FRAME SYNC D6 = LINE SYNC A D5 = LINE SYNC B D4 ... D0 = 0	intensity
xxxxxx10	internal line counter (8 bit)	intensity
xxxxxx11	D7 = FRAME SYNC D6 = LINE SYNC A D5 = LINE SYNC B D4 ... D0 = line counter (bit 12 ... 8)	internal line counter (bit 7 ... 0)

Example Timing Diagrams

Annotations:

- SyncA = LINE SYNC A (external line synchronization input, I/O connector)
 SyncB = LINE SYNC B (external line synchronization input, I/O connector)
 Count = internal counter
 Trigger = Generated trigger pulses from the Trigger Control stage. The signal goes to the Trigger Divider stage inside the camera. For setting the divider, use the Vyyyyy<CR> command or the 'Divider' input field in the **4.1 Camera Control by Commands (p. 20)**.

- 1) direction changed
 2) glitch



5 Sensor Information

Manufacturer: Hamamatsu

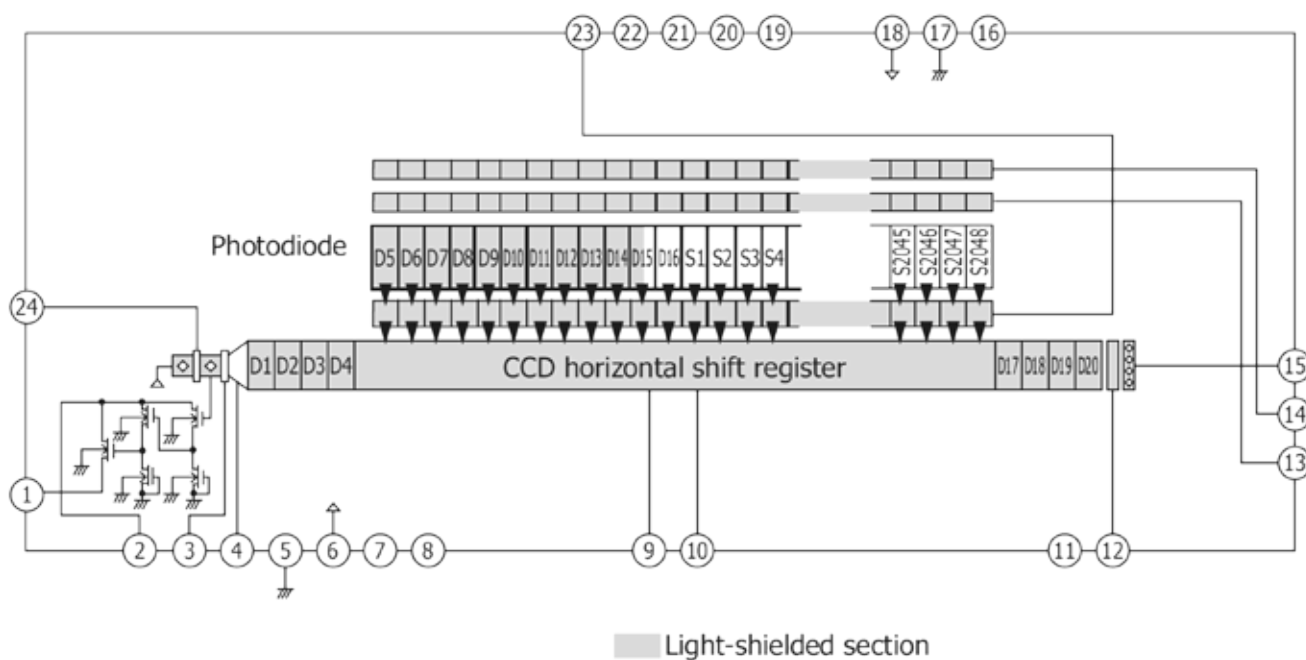
Type: S12551-2048

Data source: Hamamatsu CCD linear image sensor S12551-2048
Cat. No. KMPD1147E04 Oct. 2016 DN

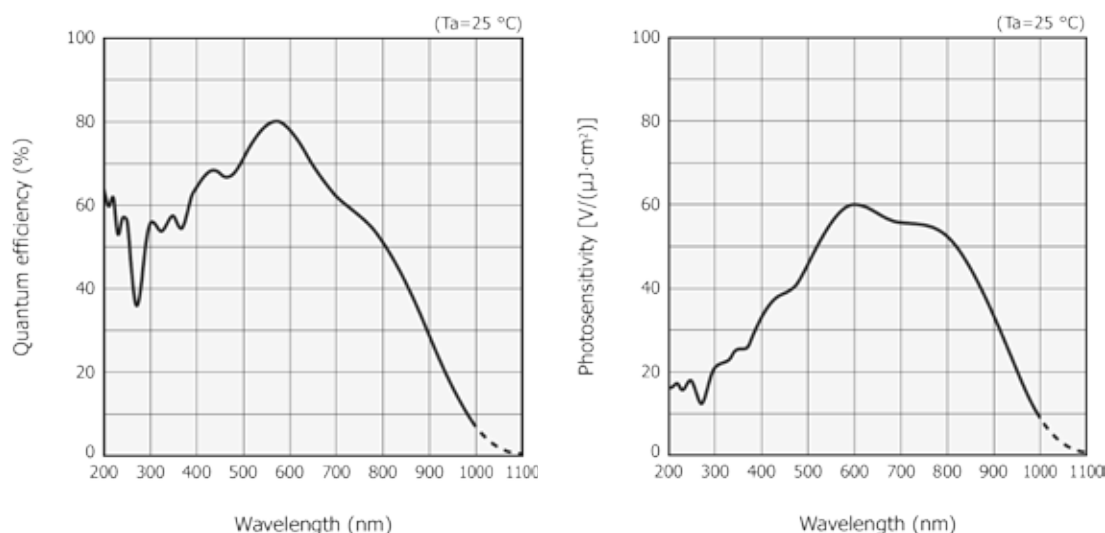
a) Features

- 2048 pixels, pixel size: $14 \times 14 \mu\text{m}$
- High CCD node sensitivity: $13 \mu\text{V}/\text{e}^-$ typ.
- Readout speed: 40 MHz max.
- Anti-blooming function
- Built-in electronic shutter

b) Device Structure (conceptual drawing)

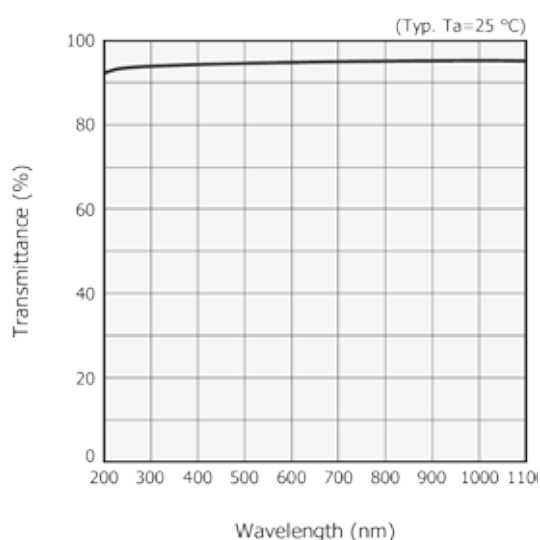


c) Spectral Response (without window, typical example)



Spectral response with quartz glass is decreased according to the spectral transmittance characteristics of window material.

d) Spectral Transmittance Characteristics of Window Material



e) Electrical and Optical Characteristics (Ta = 25°C)

Parameter	Symbol	Min.	Typ.	Max.	Unit
Saturation output voltage	Vsat	-	Fw × CE	-	V
Full well capacity	Fw	70	100	-	ke ⁻
Conversion efficiency	CE	11	13	15	μV/e ⁻
Dark current (maximum of all effective pixels)	ID max	-	15	75	e ⁻ /pixel/ms
Readout noise ^{*7}	Nread	-	40	60	e ⁻ rms
Dynamic range ^{*8}	Drange	1167	2500	-	-
Spectral response range	λ	-	200 to 1000	-	nm
Photoresponse nonuniformity ^{*9 *10}	PRNU	-	±3	±10	%
Image lag ^{*9}	Lag	-	0.1	1	%

^{*6}: Dark current is reduced to half for every 5 to 7 °C decrease in temperature.

^{*7}: Readout frequency 40 MHz

^{*8}: Dynamic range = Full well capacity / Readout noise

^{*9}: Measured at one-half of the saturation output (full well capacity) using LED light (peak emission wavelength: 470 nm)

^{*10}: Photoresponse nonuniformity = $\frac{\text{Fixed pattern noise (peak to peak)}}{\text{Signal}} \times 100 [\%]$

Blooming

If by overexposure too many charge carriers are produced in one or several photosensitive elements (pixels) of the line sensor, the transport register is „flooded“ with charge carriers, and also the following register bins are charged over the saturation limit. This spreading of a local overexposure along a line is called „blooming“. In the resulting video signal an overexposed area includes too many pixels. In that area the geometric mapping between image and object is not correct.

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.

Exposure period

is the illumination cycle of a line scan sensor. It is the → **integration time** plus the additional time to complete the read-out of the accumulated charges and the output procedure. While the charges from a finished line scan are being read out, the next line scan is being exposed. The exposure period is a function of the pixel number and the → **pixel frequency**. The minimum exposure period of a particular line scan camera determines the maximum → **line frequency** that is declared in the specifications.

Integration control

Cameras with integration control are capable of curtailing the → **integration time** within an → **exposure period**. This performs an action equivalent to a shutter mechanism.

Integration time

The light-sensitive elements of the photoelectric sensor accumulate the charge that is generated by the incident light. The duration of this charge accumulation is called the integration time. Longer integration times increase the intensity of the line scan signal, assuming constant illumination conditions. The complete read-out of accumulated charges and output procedure determines the minimum → **exposure period**.

Line frequency, line scan frequency

is the reciprocal value of the → **exposure period**. The maximum line frequency is a key criterion for line scan sensors as this is the limiting factor for the scan velocity.

Optical resolution

Two elements of a line scan camera determine the optical resolution of the system: first, the pixel configuration of the line sensor and, secondly, the optical resolution of

the lens. The worst value is the determining value. In a phased set-up, both are within the same range.

The optical resolution of the line sensor is primarily determined by the number of pixels and secondarily by their size and spacing, the inter-pixel distance. Currently available line scan cameras have up to 12 000 pixels, ranging from 4 to 14 µm in size and spacing, for sensors up to 56 mm in length and line scan frequencies up to 83 kHz.

During a scanning run, the effective resolution perpendicular to the sensor orientation is determined by the velocity of the scan and by the → **line frequency**

Pixel frequency

The pixel frequency for an individual sensor is the rate of charge transfer from pixel to pixel and its ultimate conversion into a signal.

Region of Interest

A freely programmable window (region of interest, ROI) can be applied to the line sensor so that only the pixel information within the ROI can reach the memory.

By only illuminating these ranges, data volume and data processing is accelerated for both line and area scan acquisitions.

Constraint: the ROI memory allocation must be divisible by 8.

Shading correction

→ **Shading Correction**, section 3.2

SCM

Shading Correction Memory,

→ **Shading Correction Memories and API Functions**, section 3.2

Sol (Start of Integration)

In addition to → **SoS**, cameras with → **Integration Control** function generate an internal Sol-signal that initiates the integration period.

SoS (Start of Scan)

is an internally generated trigger signal for sequential control of the camera. The signal is induced either by an internal counter or by an external line synchronization signal, depending on the selected line synchronization mode.

→ **Synchronization**

→ **Advanced Synchronization Control**, section 4.2

SkLineScan

is the software application from Schäfter + Kirchhoff for controlling and adjusting the line scan cameras,

→ **Software: SkLineScan**, section 3.1

Synchronization

To obtain a proportional image with the correct aspect ratio, a line synchronous transport with the laterally correct pixel assignment is required. The → **Line frequency** and constant object velocity have to be compatible with each other.

For more accurate requirements or with a variable object velocity, external synchronization is necessary.

→ **Synchronization of the Imaging Procedure and the Object Scan Velocity**, section 3.2

Thresholding (monochrome cameras only)

The thresholding process generates a binary signal from the gray scale data, with values below the threshold yielding 0 and those above yielding 1. Only the pixel addresses of the location and threshold transition (from high→low or low→high) are transmitted, reducing data throughput.

Thresholding is particularly appropriate for measuring widths or edge positions, by simply masking the required pixel addresses.

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Contact service@sukhambug.de to receive a return form or or download it at <https://www.sukhamburg.com/documents/RMA-en.pdf>

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An EU Declaration of Conformity has been issued for this product.

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We the Manufacturer

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Herewith declare that:

Product Description:	Line Scan Camera		
Product Family Name:	Line Scan Cameras with USB 3.0 Interface		
Product Types:	SK512U3SH	SK1024U3HU	SK2048U3HA
	SK512U3HU	SK2048U3SH	SK4096U3HW
	SK1024U3HA	SK2048U3JR	SK7500U3TF-XB
	SK1024U3SH	SK2048U3HW	SK16200U3TOC
	SK1024U3HV	SK2048U3HU	SK22800U3JRC-XC

are produced in accordance with the following:

2011/65/EU	Restriction of Hazardous Substances Directive (RoHS)	2011
2014/30/EU	Directive on the harmonisation of the laws of the Member States relating to electromagnetic compatibility	2014

Following harmonized standards applied:

DIN EN 61326-1	Electrical equipment for measurement, control and laboratory use - EMC requirements – Class A	2022
DIN EN 55011	Industrial, scientific and medical equipment - Radio-frequency disturbance characteristics - Limits and methods of measurement	2022
DIN EN 61010-1	Safety requirements for electrical equipment for measurement, control and laboratory use	2020

I hereby declare that the equipment named has been designed to comply with the relevant sections of the above referenced specifications, and complies with all applicable Essential Requirements of the Directives.

Hamburg, 6 Dec. 2022
Place, Date

U. Oechsner
Managing Director, Dr. Ulrich Oechsner

Software



SK91USB3-WIN

Order Code

SDK from *Schäfter + Kirchhoff* including the **SKLineScan** operating program, as well as API, C++ class library and examples.

Operating systems:
Windows 7 / 8.1 / 10 / 11 - x64 and x86



Software

SK91USB3-LX

Order Code

SDK from *Schäfter + Kirchhoff* including the **SKLineScan** operating program, as well as libraries and examples.

Operating systems:
Linux kernel 3.13 or higher

Accessories



USB 3.0 cable SK9020.x

Camera connector: USB 3.0 plug, type micro-B, with safety lock screws

PC connector: USB 3.0 plug, type A (also fits into a USB 2.0 type A socket)

SK9020.x

Order Code

1 = 1 m cable length

3 = 3 m cable length (standard)



External synchronization cable SK9026...

for line scan cameras with USB 3.0 interface.

Shielded cable with Hirose plug HR10A, female 6 pin (camera side), and Phoenix 4 pin connector incl. terminal block.

SK9026.x

Order Code

cable length 3 / 5 m
Other lengths on request



USB 3.0 active extension cable USB3.EXT.A2A...

Hybrid cable (copper/fiber), power supply by another USB-connection, cable length up to 100m on request.

Connectors:
USB 3.0 plug and socket, with locking screws

USB3.EXT.A2Ax

Order Code

20 = 20 m cable length
30 = 30 m
50 = 50 m

other lengths up to 100 m on request



Adapter cable for sync signals CAB-AD Sync-BNC-1

BNC/SMA (3x) to Line Scan Camera Synchronization Cable SK9016/SK9024/SK9026.

Shielded cable, length 0.25 m

Connectors:
1x Phoenix 4-pin connector
3x SMA plug (Line Sync A, Line Sync B, Frame Sync)
3x adapter SMA socket (outside threading) to BNC-plug

CAB-AD Sync-BNC-1

Order Code

M1 Mounting Bracket SK5105



Order Code
SK5105

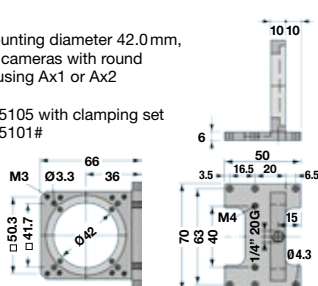
Mounting diameter 42.0 mm,
for cameras with round
housing Ax1 or Ax2

SK5105 with clamping set
SK5101#

MC Clamping Set SK5101



Order Code
SK5101

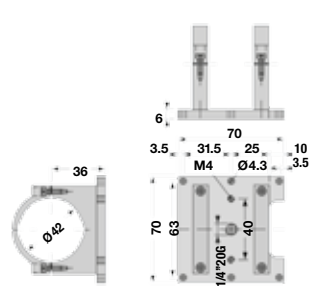


M3 Mounting System SK5105-2



Order Code
SK5105-2

For camera configurations
with tube length > 55 mm
using extension rings **ZR**



FA1 Focus adapter FA22...



FA22-x

Order Code

42 = M42 x 1

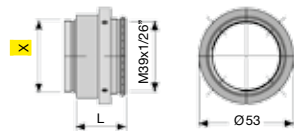
40 = M40 x 0.75

39 = M39 x 1/26"

32 = M32 x 0.75

C = C-Mount

length L: 22 ... 32 mm



FA2 Focus adapter L-Mount (M39x1/26" Leica)

any rotation angle adjustable (V-groove)
attachment thread M40x0.75, male



FA22R-40

Order Code

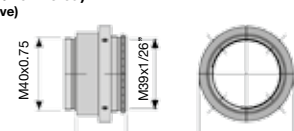
length L: 28 ... 38 mm



FA22RL-40

Order Code

length L: 35 ... 45 mm



ZR Extension rings L-Mount (M39x1/26" Leica)

attachment threads M39x1/26" male/female



ZR 10

Order Code

10 = Length 10 mm

15 = Length 15 mm

20 = Length 20 mm

50 = Length 50 mm

