photon focus

User Manual

OEM-D752E and OEM-D1024E

CMOS Sensor Module Series

MAN032 04/2012 V1.2

Contents

1 Preface

1.1 About Photonfocus

The Swiss company Photonfocus is one of the leading specialists in the development of CMOS image sensors and corresponding industrial cameras for machine vision, security & surveillance and automotive markets.
Photonfocus is dedicated to making the latest generation of CMOS technology commercially available. Active Pixel Sensor (APS) and global shutter technologies enable high speed and high dynamic range (120 dB) applications, while avoiding disadvantages like image lag, blooming and smear.
Photonfocus has proven that the image quality of modern CMOS sensors is now appropriate for demanding applications. Photonfocus' product range is complemented by custom design solutions in the area of camera electronics and CMOS image sensors.
Photonfocus is ISO 9001 certified. All products are produced with the latest techniques in order to ensure the highest degree of quality.

1.2 Contact

Photonfocus AG, Bahnhofplatz 10, CH-8853 Lachen SZ, Switzerland

Sales	Phone: +41 55 451 07 45	Email: sales@photonfocus.com
Support	Phone: +41 55 451 01 37	Email: support@photonfocus.com

Table 1.1: Photonfocus Contact

1.3 Sales Offices

Photonfocus products are available through an extensive international distribution network and through our key account managers. Details of the distributor nearest you and contacts to our key account managers can be found at www.photonfocus.com.

1.4 Further Information

For further information on the products, documentation and software updates please see our web site www.photonfocus.com or contact our distributors.

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Photonfocus can not be held responsible for any technical or typographical errors.

1.5 Legend

In this documentation the reader's attention is drawn to the following icons:

Important note

Alerts and additional information

Attention, critical warning

Notification, user guide

2

Introduction and Motivation

The OEM camera modules support user specific vision system designs and especially embedded solutions. Other than in Photonfocus cameras and board level cameras the OEM camera modules are not complete vision components. The user has to solve the interfacing to his own electronic solution to get a complete vision solution. From this target some restrictions arise. One restriction is that Photonfocus can not guarantee the correct function of the complete solution. Due to the open architecture of the OEM modules excessive support is often needed to implement the modules in advanced embedded solutions. Under defined boundary conditions Photonfocus provides this service on contract base. The OEM modules are not intended for the use in single volumes. The threshold in volume is from 100 modules and more per year. Long term contracts with the customer ensure the availability of the modules over a long period to predictable production dates.
For low volume projects please refer to our board level or camera products. These products are complete vision products that include the software. Due to the character of the board level and camera products Photonfocus can guarantee for the quality and functionality of these complete vision products.
The use of the OEM camera modules enables the use of the Photonfocus camera firmware and software. Thus the user's own vision system benefit from these concepts. Modifications in the firmware can be made on request on contract base. This applies also to modifications in the Photonfocus software. The user can set up his own software on the base of the PFRemote SDK. The Photonfocus software itself is platform independent and was already ported to different operating systems and embedded solutions.
The control of the camera modules over a low level protocol without the help of a CPU is not supported. The advanced features in Photonfocus E-series products, like LinLog and FPN correction, require complex control sequences. If user's applications require camera module control over low level commands then only products from the classic Photonfocus product range are to be considered. Please contact the Photonfocus Support for further consultance.
The idea of the OEM modules is to give the user a very easy to use environment for the own development. This is supported with the interface definition on the output of the modules. This interface definition is identically applied to all Photonfocus OEM modules and is based on the well known AIA interface definition for vision systems. The camera modules permit the direct interfacing without any background information of the camera electronic. To reach this goal the modules are sold only with digital interface. This leads to one or two PCB solutions (see Table 2.1).

Definition	OEM-D752E-40	OEM-D1024E-40	OEM-D1024E-80	OEM-D1024E-160
Number of PCBs	1	1	2	2
Sensor Module	OEM-D752E-40	OEM-D1024E-40	OEM-A1024E-80	OEM-A1024E-160
ADC Module	not required	not required	OEM-ADCE-160-12	OEM-ADCE-160-12

Table 2.1: Overview of the OEM camera modules

3

OEM Specification

3.1 Introduction

The OEM camera modules from Photonfocus are aimed at demanding applications in industrial image processing. The OEM camera modules provide an exceptionally high dynamic range of up to 120 dB at a resolution of 1024 x 1024 pixels or 752 x 582 pixels. The OEM camera modules are built around a monochrome CMOS image sensor, developed by Photonfocus. The principal advantages are:

- Extremely high image contrast achieved by LinLog technology.
- Ideal for high speed applications: global shutter, in combination with several simultaneously selectable read out windows (Multiple ROI).
- Grey scale resolution up to 12 bit.
- Low power consumption at high speeds.
- Resistance to blooming.
- The OEM camera modules are provided with a low voltage CMOS (LVCMOS) parallel data interface.
- The compact size of only or 44 x 44 mm^2 make the OEM camera module series the perfect solution for applications in which space is at a premium.

The general specification and features of the OEM camera modules are listed in the following sections.

3.2 Feature Overview

	OEM camera modules
Interfaces	Low voltage CMOS (LVCMOS), 3.3 V level
OEM Camera Module Control	PFRemote SDK
Configuration Interface	serial 9’600 baud (for -80/160 models 57.6k baud is also available)
Trigger Modes	Interface Trigger and separate Trigger I/O
Exposure Time	Defined by camera module or trigger pulse width
Features	Linear Mode / LinLog Mode / Skimming Mode
	Shading Correction (Offset and Gain)
	Grey scale resolution 12 bit / 10 bit / 8 bit
	Region of Interest (ROI) / Multiple Regions of Interest (MROI)
	Look-up table (10 to 8 bit) / Decimation
	Trigger input / Strobe output with programmable delay
	Test pattern / Image information / Status line

Table 3.1: Feature overview (see Chapter 4 for more information)

3.3 Technical Specification

	OEM-D752E	OEM-D1024E
Technology	CMOS active pixel	
Scanning system	progressive scan	
Optical format / diagonal	2/3" / 10.12 mm	1" / 15.42 mm
Resolution	752 x 582 pixels	1024 x 1024 pixels
Pixel size	10.6 μm x 10.6 μm	
Active optical area	8.0 mm x 6.2 mm	10.9 mm x 10.9 mm
Random noise	< 0.5 DN RMS @ 8 bit / gain=1	
Fixed pattern noise (FPN)	< 1 DN RMS @ 8 bit / gain=1 / offset correction on	
Dark current	2 fA / pixel @ 30°C	
Full well capacity	200 ke^-	
Spectral range	400 .. 900 nm	
Responsivity	120 x 10^3 DN / (J/m^2) @ 610 nm / 8 bit / gain=1	
Optical fill factor	35 %	
Dynamic range	up to 120 dB (with LinLog)	
Colour format	monochrome	
Characteristic curve	linear, LinLog, Skimming	
Shutter mode	global shutter	
Min. Region of Interest	1 row x 9 columns	
Grey scale Resolution	12 bit / 10 bit / 8 bit	
Digital Gain	x1 / x2 / x4	
Exposure Time	10 μs ... 0.41 s	

Table 3.2: General specification of the OEM camera modules

	OEM-D7524E-40	OEM-D1024E-40
Exposure Time Increment	25 ns	25 ns
Frame Rate (T_{int} = 10 μs)	87 fps	37 fps
Pixel Clock Frequency	40 MHz	40 MHz
Pixel Clock Cycle	25 ns	25 ns
Camera Taps	1	1
Readout mode	sequential integration	sequential integration
	and readout	and readout

Table 3.3: Model-specific parameters for the OEM-D752E-40 and for the OEM-D1024E-40 modules

	OEM-D1024E-80	OEM-D1024E-160
Exposure Time Increment	50 ns	25 ns
Frame Rate (T_{int} = 10 μs)	75 fps	150 fps
Pixel Clock Frequency	40 MHz	80 MHz
Pixel Clock Cycle	25 ns	12.5 ns
Camera Taps	2	2
Readout mode	sequential integration	sequential integration
	and readout or	and readout or
	simultaneous readout	simultaneous readout

Table 3.4: Model-specific parameters for the OEM-D1024E-80 and for the OEM-D1024E-160 modules

	OEM-D7524E-40	OEM-D1024E-40
Operating temperature	0°C ... 50°C**	0°C ... 50°C**
Camera module power supply	0.16 A @ +5 V DC (±10%)	0.16 A @ +5 V DC (±10%)
Camera module power supply	0.1 A @ +3.3 V DC (±10%)	0.1 A @ +3.3 V DC (±10%)
Camera module power supply	0.05 A @ +1.8 V DC (±10%)	0.05 A @ +1.8 V DC (±10%)
Max. power consumption	0.87 W	0.87 W
Dimensions	44 x 44 mm^2	44 x 44 mm^2
Mass	15 g	15 g
Conformity	RoHS, WEEE	RoHS, WEEE

*Table 3.5: Physical characteristics and operating ranges for the OEM-D752E-40 and for the OEM-D1024E-40 modules (** OEM modules with extended range of operating temperature on request)*

	OEM-D1024E-80	OEM-D1024E-160
Operating temperature	0°C ... 50°C**	0°C ... 50°C**
Camera module power supply	0.15 A @ +5 V DC (±10%)	0.15 A @ +5 V DC (±10%)
Camera module power supply	0.35 A @ +3.3 V DC (±10%)	0.35 A @ +3.3 V DC (±10%)
Camera module power supply	0.16 A @ +1.8 V DC (±10%)	0.16 A @ +1.8 V DC (±10%)
Max. power consumption	2.2 W	2.4 W
Dimensions	44 x 44 mm^2	44 x 44 mm^2
Mass	27 g	27 g
Conformity	RoHS, WEEE	RoHS, WEEE

*Table 3.6: Physical characteristics and operating ranges for the OEM-D1024E-80 and for the OEM-D1024E-160 modules (** OEM modules with extended range of operating temperature on request)*

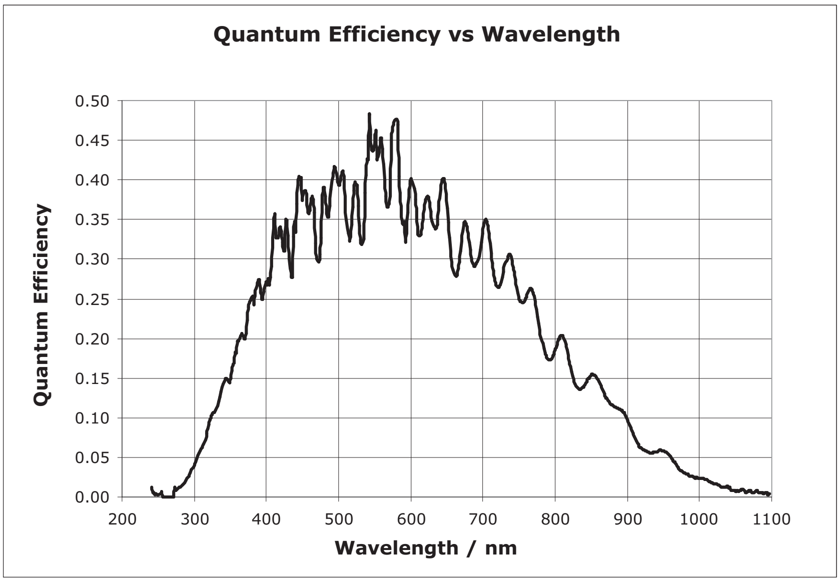

Figure 3.1: Spectral response of the A1024B Photonfocus CMOS sensor

3.4 Signal Assignment

The interface of the OEM camera modules is a parallel data interface, which follows the AIA standard. On the module connector the signals are available in a parallel format.

	OEM-D752E-40	OEM-D1024E-40	OEM-D1024E-80	OEM-D1024E-160
Pixel Clock per Tap	40 MHz	40 MHz	40 MHz	80 MHz
Number of Taps	1	1	2	2
Greyscale resolution	12 / 10 / 8 bit	12 / 10 / 8 bit	12 / 10 / 8 bit	12 / 10 / 8 bit
CC1	EXSYNC	EXSYNC	EXSYNC	EXSYNC
CC2	not used	not used	not used	not used
CC3	not used	not used	not used	not used
CC4	not used	not used	not used	not used

Table 3.7: Summary of parameters needed for interfacing

Bit	Tap 0, 8 Bit	Tap 0, 10 Bit	Tap 0, 12 Bit
0 (LSB)	A0	A0	A0
1	A1	A1	A1
2	A2	A2	A2
3	A3	A3	A3
4	A4	A4	A4
5	A5	A5	A5
6	A6	A6	A6
7 (MSB for 8 Bit Mode)	A7	A7	A7
8	-	B0	B0
9 (MSB for 10 Bit Mode)	-	B1	B1
10	-	-	B2
11 (MSB for 12 Bit Mode)	-	-	B3

Table 3.8: Port and bit assignments for the OEM-D752E-40 and for the OEM-D1024E-40 camera modules

Bit	Tap 0	Tap 1	Tap 0	Tap 1	Tap 0	Tap 1
	8 Bit	8 Bit	10 Bit	10 Bit	12 Bit	12 Bit
0 (LSB)	A0	B0	A0	C0	A0	C0
1	A1	B1	A1	C1	A1	C1
2	A2	B2	A2	C2	A2	C2
3	A3	B3	A3	C3	A3	C3
4	A4	B4	A4	C4	A4	C4
5	A5	B5	A5	C5	A5	C5
6	A6	B6	A6	C6	A6	C6
7 (MSB of 8 Bit)	A7	B7	A7	C7	A7	C7
8	-	-	B0	B4	B0	B4
9 (MSB of 10 Bit)	-	-	B1	B5	B1	B5
10	-	-	-	-	B2	B6
11 (MSB of 12 Bit)	-	-	-	-	B3	B7

Table 3.9: Port and bit assignments for the OEM-D1024E-80 and for the OEM-D1024E-160 camera modules

Name	PF CL 1.1	8 Bit	10 Bit	12 Bit
STROBE	PIXEL_CLK	STROBE	STROBE	STROBE
LVAL	LINE_VALID	LVAL	LVAL	LVAL
FVAL	FRAME_VALID	FVAL	FVAL	FVAL
DVAL	DATA_VALID	DVAL	DVAL	DVAL
SPARE	CL_SPARE	SPARE	SPARE	SPARE
PORT_A0	DATA0	A0	A0	A0
PORT_A1	DATA1	A1	A1	A1
PORT_A2	DATA2	A2	A2	A2
PORT_A3	DATA3	A3	A3	A3
PORT_A4	DATA4	A4	A4	A4
PORT_A5	DATA5	A5	A5	A5
PORT_A6	DATA6	A6	A6	A6
PORT_A7	DATA7	A7	A7	A7
PORT_B0	DATA8	B0	A8	A8
PORT_B1	DATA9	B1	A9	A9
PORT_B2	DATA10	B2	-	A10
PORT_B3	DATA11	B3	-	A11
PORT_B4	DATA12	B4	B8	B8
PORT_B5	DATA13	B5	B9	B9
PORT_B6	DATA14	B6	-	B10
PORT_B7	DATA15	B7	-	B11
PORT_C0	DATA16	-	B0	B0
PORT_C1	DATA17	-	B1	B1
PORT_C2	DATA18	-	B2	B2
PORT_C3	DATA19	-	B3	B3
PORT_C4	DATA20	-	B4	B4
PORT_C5	DATA21	-	B5	B5
PORT_C6	DATA22	-	B6	B6
PORT_C7	DATA23	-	B7	B7

Table 3.10: Configuration and port assignment of the PCB-PCB connector in Photonfocus OEM camera modules

4

Functionality

This chapter serves as an overview of the configuration modes and explains the features of the OEM camera modules. The goal is to describe what can be done with the OEM camera modules. The setup of the OEM camera modules is explained in later chapters.

4.1 Image Acquisition

4.1.1 Readout Modes

The OEM camera module series provide two different readout modes:

Sequential readout Frame time is the sum of exposure time and readout time. Exposure time of the next image can only start if the readout time of the current image is finished.

Simultaneous readout (interleave) The frame time is determined by the maximum of the exposure time or of the readout time, which ever of both is the longer one. Exposure time of the next image can start during the readout time of the current image.

Module	OEM-D752E-40	OEM-D1024E-40	OEM-D1024E-80	OEM-D1024E-160
Sequential readout	available	available	available	available
Simultaneous readout	-	-	available	available

Table 4.1: Readout mode of the OEM camera module series

The following figure illustrates the effect on the frame rate when using either the sequential readout mode or the simultaneous readout mode (interleave exposure).

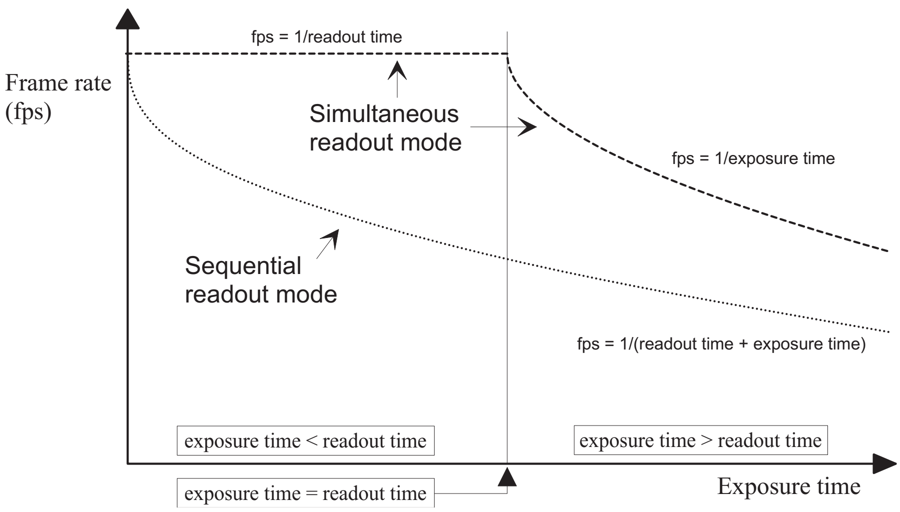

Figure 4.1: Frame rate in sequential readout mode and simultaneous readout mode

Sequential readout mode For the calculation of the frame rate only a single formula applies: frames per second equal to the invers of the sum of exposure time and readout time.

Simultaneous readout mode (exposure time < readout time) The frame rate is given by the readout time. Frames per second equal to the invers of the readout time.

Simultaneous readout mode (exposure time > readout time) The frame rate is given by the exposure time. Frames per second equal to the invers of the exposure time.

The simultaneous readout mode allows higher frame rate. However, If the exposure time strongly exceeds the readout time, then the effect on the frame rate is neglectable.

In simultaneous readout mode image output faces minor limitations. The overall linear sensor reponse is partially restricted in the lower grey scale region.

When changing readout mode from sequential to simultaneous readout mode or vice versa, new settings of the BlackLevelOffset and of the image correction are required.

Sequential readout

By default the camera modules continuously delivers images as fast as possible ("Free-running mode") in the sequential readout mode. Exposure time of the next image can only start if the readout time of the current image is finished.

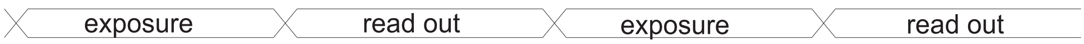

Figure 4.2: Timing in free-running sequential readout mode

When the acquisition of an image needs to be synchronised to an external event, an external trigger can be used (refer to Section 4.7 and Section 5.4). In this mode, the camera module is idle until it gets a signal to capture an image.

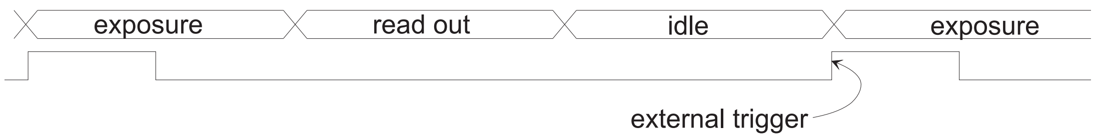

Figure 4.3: Timing in triggered sequential readout mode

Simultaneous readout (interleave exposure)

To achieve highest possible frame rates, the camera module must be set to "Free-running mode" with simultaneous readout. The camera module continuously delivers images as fast as possible. Exposure time of the next image can start during the readout time of the current image.
When the acquisition of an image needs to be synchronised to an external event, an external trigger can be used (refer to Section 4.7 and Section 5.4). In this mode, the camera module is idle until it gets a signal to capture an image.

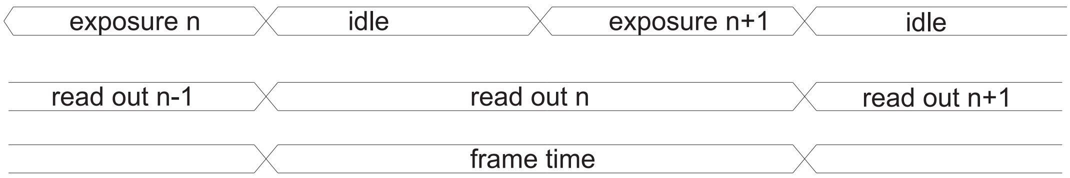

Figure 4.4: Timing in free-running simultaneous readout mode (readout time> exposure time)

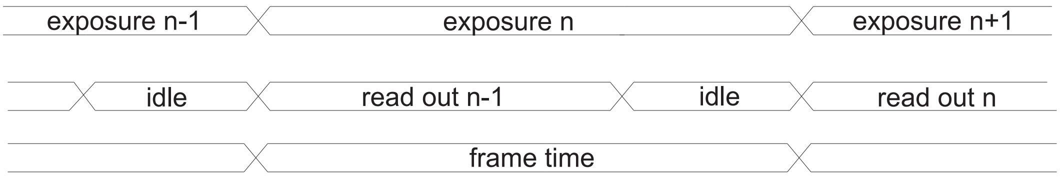

Figure 4.5: Timing in free-running simultaneous readout mode (readout time< exposure time)

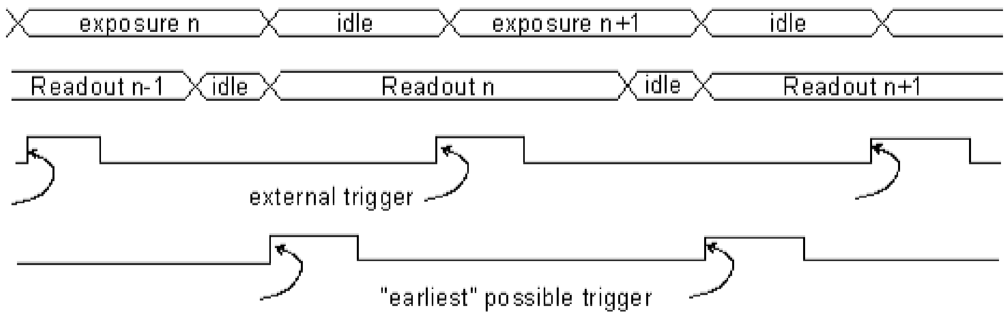

Figure 4.6: Timing in triggered simultaneous readout mode

4.1.2 Exposure Control

The exposure time defines the period during which the image sensor integrates the incoming light. Refer to Table 3.4 for the allowed exposure time range and see Section 5.4.1.

4.1.3 Maximum Frame Rate

The maximum frame rate depends on the exposure time, the readout scheme and the size of the image (see Region of Interest, Section 4.6.1). In most cases, simultaneous readout is best choice for highest framerate.

Skimming is not supported in simultaneous readout mode.

4.1.4 Constant Frame Rate (CFR)

When the CFR mode is switched on, the frame rate (number of frames per second) can be varied from almost 0 up to the maximum frame rate. Thus, fewer images can be acquired than would otherwise be possible.
When Constant Frame Rate is switched off, the camera modules deliver images as fast as possible, depending on the exposure time and the read-out time. See Section 5.3.2 for more information.

Constant Frame Rate mode (CFR) is not available together with external trigger mode.

4.2 Image Information

There are camera module properties available that give information about the acquired images, such as an image counter, average image value and the number of missed trigger signals. These properties can be queried by software. Alternatively, a status line within the image data can be switched on that contains all the available image information.

4.2.1 Counters and Average Value

Image counter The image counter provides a sequential number of every image that is output. After camera module startup, the counter counts up from 0 (counter width 24 bit). The counter can be reset by the camera module control software.

Missed trigger counter The missed trigger counter counts trigger pulses that were ignored by the camera module because they occurred within the exposure or read-out time of an image. In free-running mode it counts all incoming external triggers. (Counter width 8 bit / no wrap around).

Average image value The average image value gives the average of an image in 12 bit format (0 .. 4095 DN), regardless of the currently used grey level resolution.

4.2.2 Status Line

If enabled, the status line replaces the last row of the image with image information. It contains the properties described above and additional information:

Preamble The first parameter contains a constant value of 0x55AA00FF as a preamble in order to allow the image processing system to easily recognise the beginning of the status line.

Image counter See Section 4.2.1.

Time counter The time counter starts at 0 after camera module start, and counts real-time in units of 1 micro-second. The time counter can be reset by the software in the SDK (Counter width 32 bit).

Missed trigger counter See Section 4.2.1.

Average image value See Section 4.2.1.

Exposure cycles The exposure cycles parameter outputs the current exposure time in units of clock cycles (see Table 3.4).

Every parameter is coded into 4 pixels (LSB first) and uses the lower 8 bits of the pixel value, so that the total size of a parameter is 32 bit. The remaining pixels (24..1024) are set to 0.

The status line is also available when using an ROI. For an ROI with a width <24 pixels, the status line will be clipped.

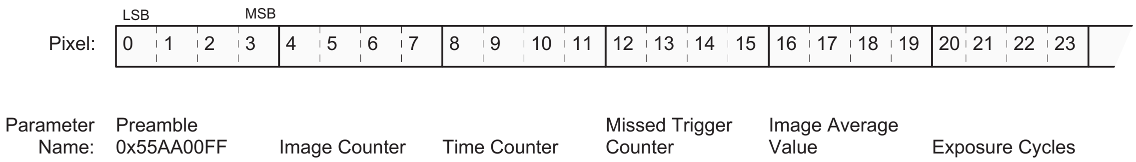

Figure 4.7: Status line parameters replace the last row of the image

4.3 Pixel Response

4.3.1 Linear Response

The camera modules offer a linear response between input light signal and output grey level. This can be modified by the use of LinLog or Skimming as described in the following sections. In addition, a linear digital gain may be applied, as follows. Please see Table 3.2 for more model-dependent information.

Gain x1, x2, x4

Gain x1, x2 and x4 are digital amplifications, which means that the digital image data are multiplied by a factor 1, 2 or 4 respectively, in the camera modules.

Black Level Adjustment

The black level is the average image value at no light intensity. It can be adjusted by the software by changing the black level offset. Thus, the overall image gets brighter or darker.

4.3.2 LinLog®

Overview

The LinLog® technology from Photonfocus allows a logarithmic compression of high light intensities inside the pixel. In contrast to the classical non-integrating logarithmic pixel, the LinLog® pixel is an integrating pixel with global shutter and the possibility to control the transition between linear and logarithmic mode.
In situations involving high intrascene contrast, a compression of the upper grey level region can be achieved with the LinLog® technology. At low intensities each pixel shows a linear response. At high intensities the response changes to logarithmic compression (see Fig. 4.8). The transition region between linear and logarithmic response can be smoothly adjusted by software and is continuously differentiable and monotonic.

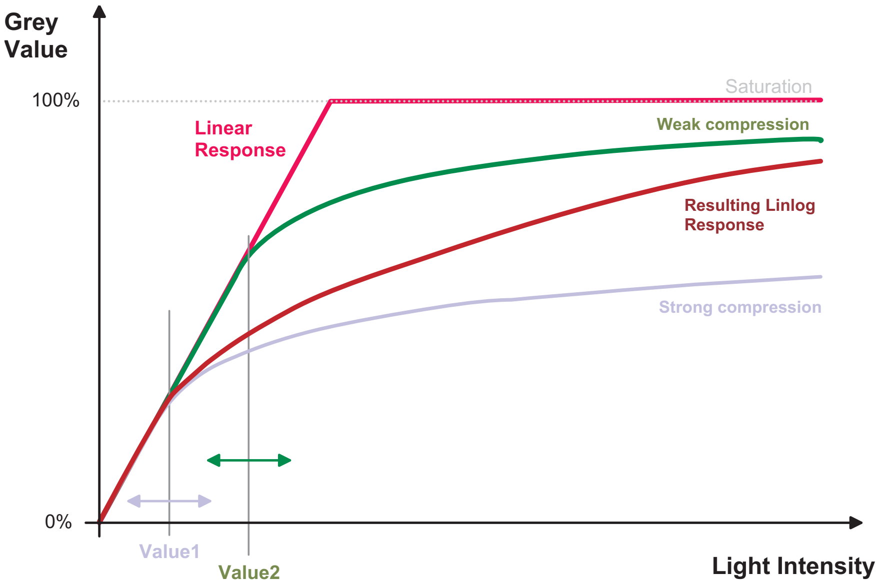

Figure 4.8: Resulting LinLog2 response curve

LinLog® is controlled by up to 4 parameters (`Time1`, `Time2`, `Value1` and `Value2`). `Value1` and `Value2` correspond to the LinLog® voltage that is applied to the sensor. The higher the parameters `Value1` and `Value2` respectively, the stronger the compression for the high light intensities. `Time1` and `Time2` are normalised to the exposure time. They can be set to a maximum value of 1000, which corresponds to the exposure time.
Examples in the following sections illustrate the LinLog® feature.

LinLog1

In the simplest way the pixels are operated with a constant LinLog® voltage which defines the knee point of the transition.This procedure has the drawback that the linear response curve changes directly to a logarithmic curve leading to a poor grey resolution in the logarithmic region (see Fig. 4.10).

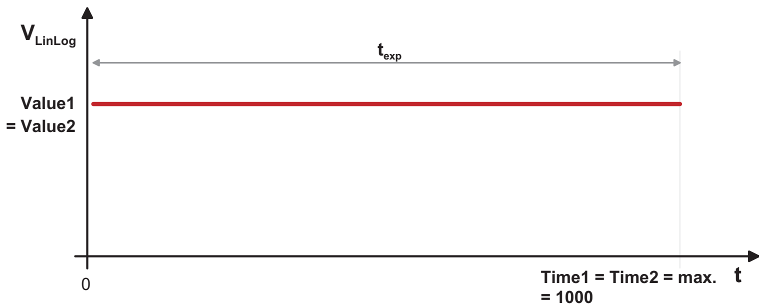

Figure 4.9: Constant LinLog voltage in the Linlog1 mode

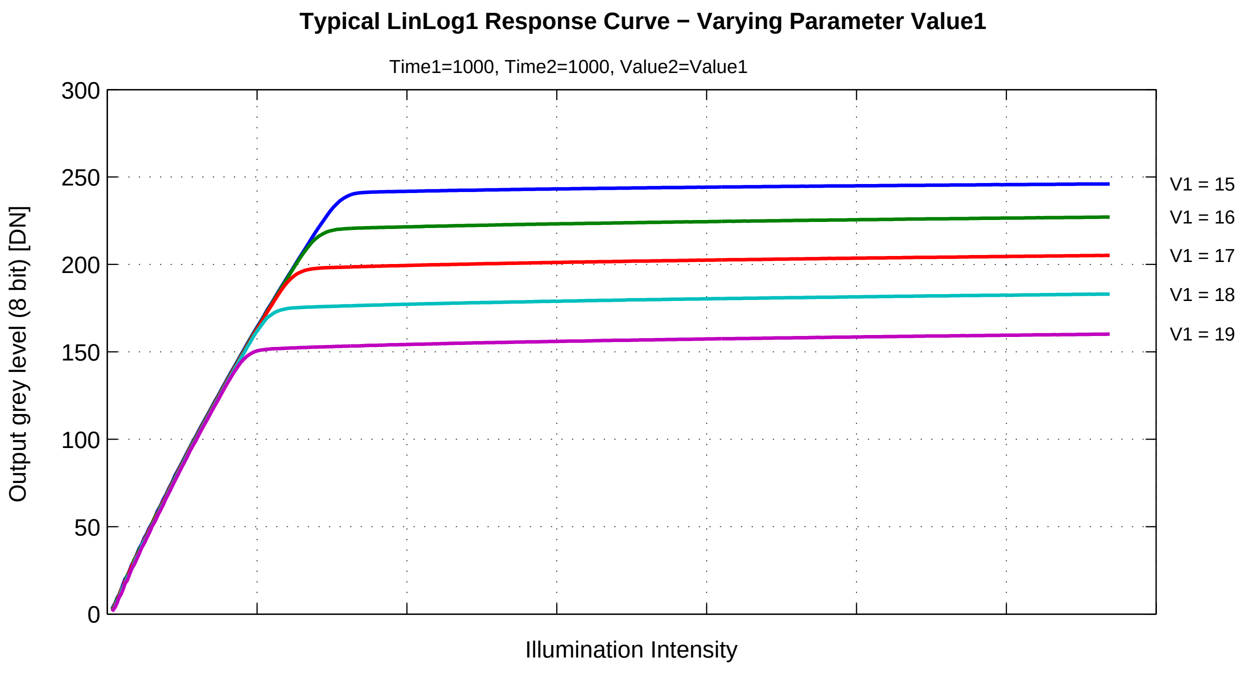

Figure 4.10: Response curve for different LinLog settings in LinLog1 mode

LinLog2

To get more grey resolution in the LinLog® mode, the LinLog2 procedure was developed. In LinLog2 mode a switching between two different logarithmic compressions occurs during the exposure time (see Fig. 4.11). The exposure starts with strong compression with a high LinLog®voltage (`Value1`). At `Time1` the LinLog®voltage is switched to a lower voltage resulting in a weaker compression. This procedure gives a LinLog®response curve with more grey resolution. Fig. 4.12 and Fig. 4.13 show how the response curve is controlled by the three parameters `Value1`, `Value2` and the LinLog®time `Time1`.

☞ Settings in LinLog2 mode, enable a fine tuning of the slope in the logarithmic region.

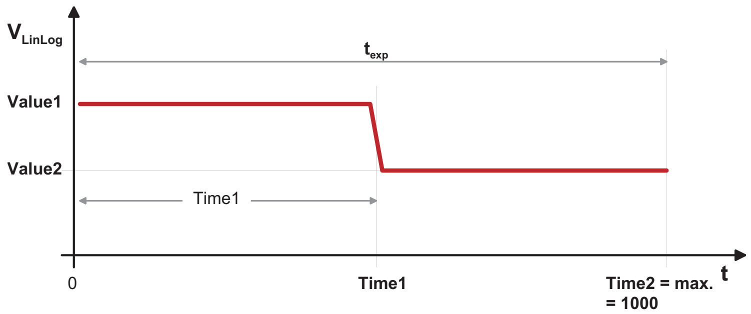

Figure 4.11: Voltage switching in the Linlog2 mode

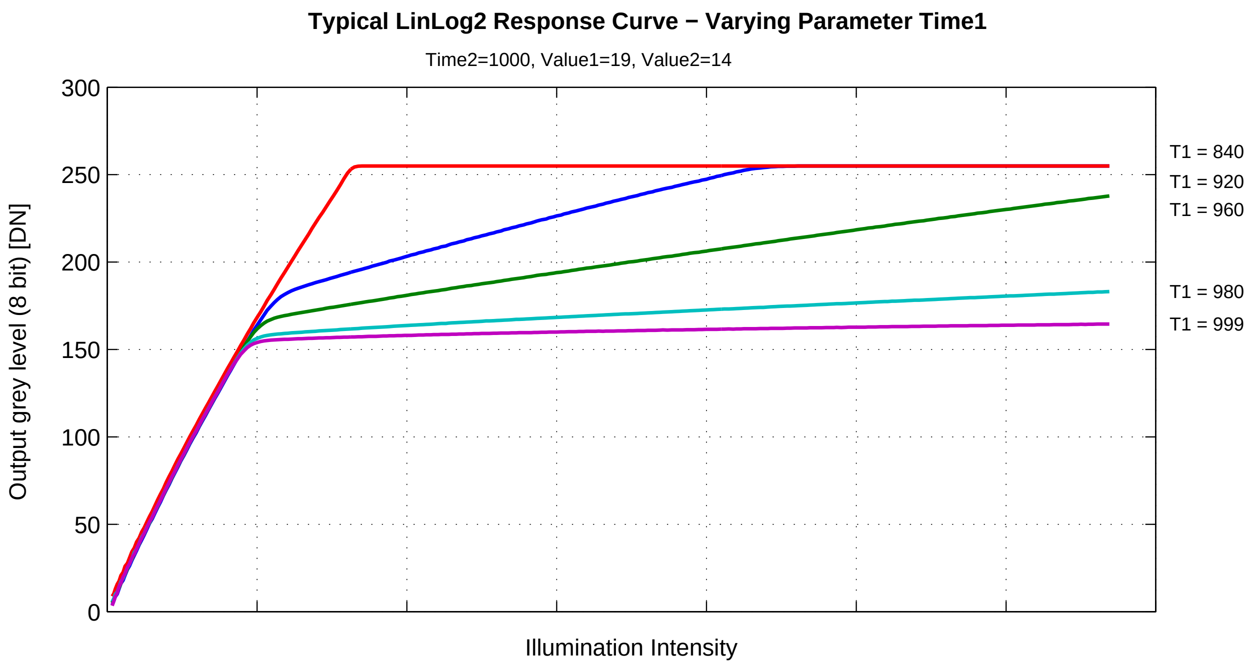

Figure 4.12: Response curve for different LinLog settings in LinLog2 mode

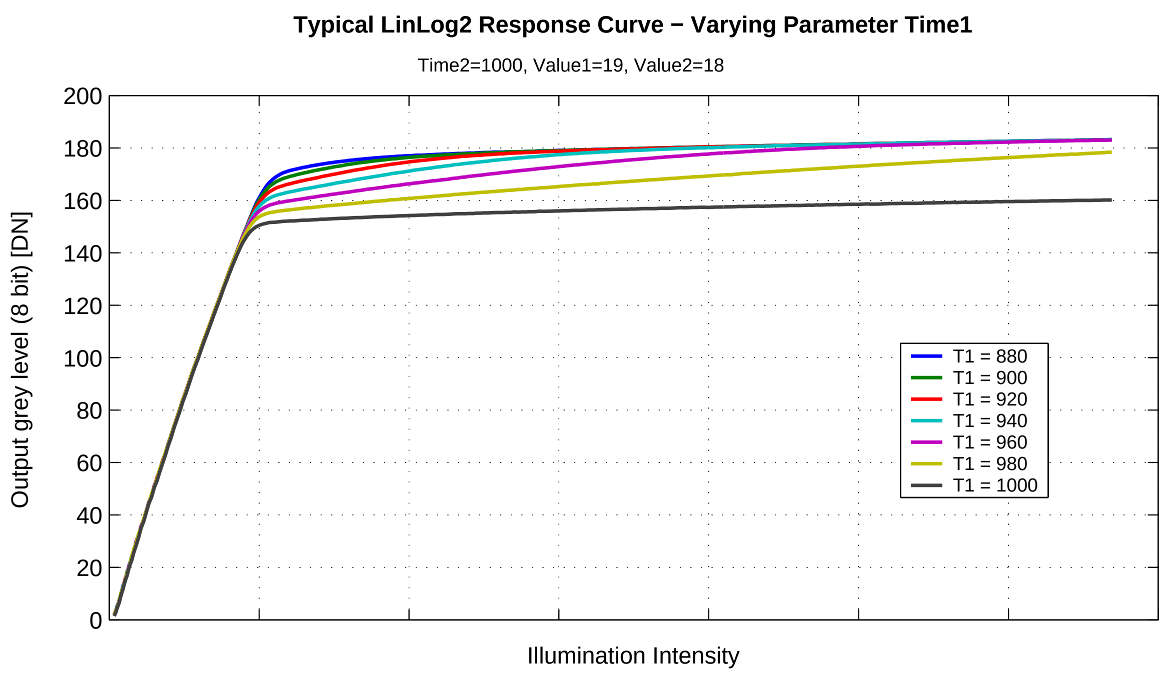

Figure 4.13: Response curve for different LinLog settings in LinLog2 mode

LinLog3

To enable more flexibility the LinLog3 mode with 4 parameters was introduced. Fig. 4.14 shows the timing diagram for the LinLog3 mode and the control parameters.

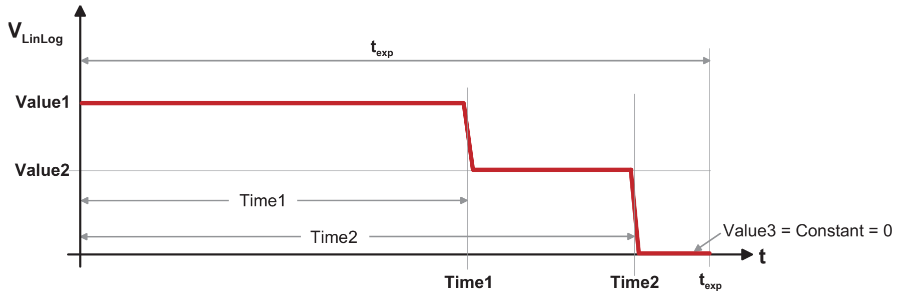

Figure 4.14: Voltage switching in the LinLog3 mode

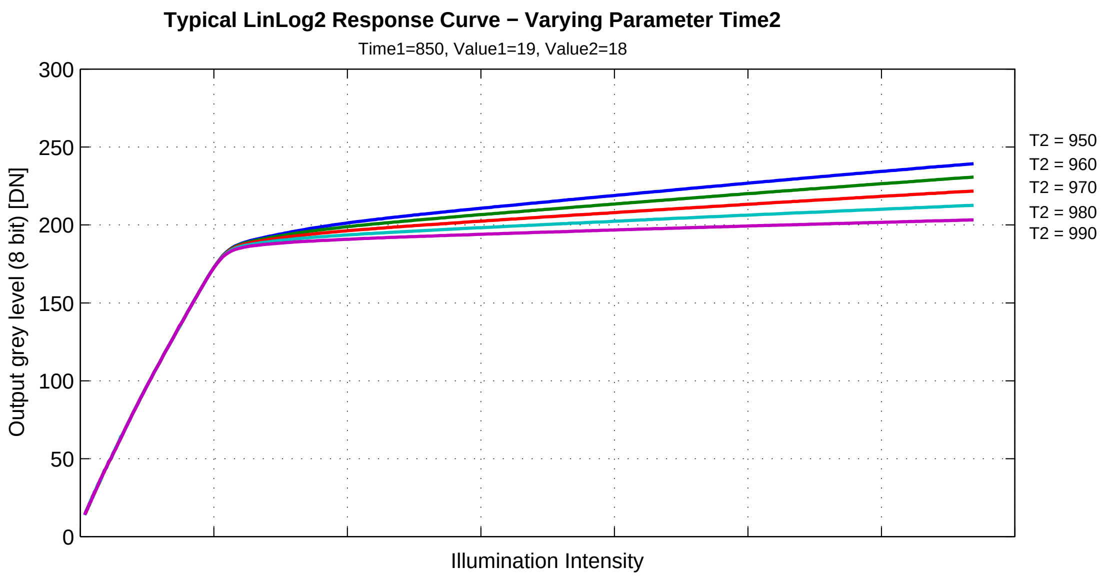

Figure 4.15: Response curve for different LinLog settings in LinLog3 mode

4.3.3 Skimming

Skimming is a Photonfocus proprietary technology to enhance detail in dark areas of an image. Skimming provides an adjustable level of in-pixel gain for low signal levels. It can be used together with LinLog®to give a smooth monotonic transfer function from high gain at low levels, through normal linear operation, to logarithmic compression for high signal levels (see Fig. 4.16). The resulting response is similar to a gamma correction.

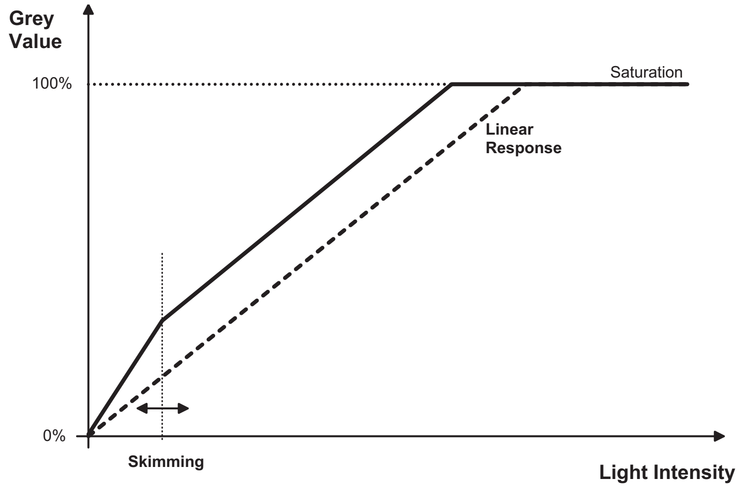

Figure 4.16: Response curve for different skimming settings

4.3.4 Grey Level Transformation (LUT)

Grey level transformation is remapping of the grey level values of an input image to new values. The look-up table (LUT) is used to convert the greyscale value of each pixel in an image into another grey value. It is typically used to implement a transfer curve for contrast expansion. The camera performs a 10-to-8-bit mapping, so that 1024 input grey levels can be mapped to 256 output grey levels. The use of the three available modes is explained in the next sections.

The output grey level resolution of the look-up table (independent of gain, gamma or user-definded mode) is always 8 bit.

There are 2 predefined functions, which generate a look-up table and transfer it to the camera. For other transfer functions the user can define his own LUT file.

Gain

The 'Gain' mode performs a digital, linear amplification (see Fig. 4.17). It is configurable in the range from 1.0 to 4.0 (e.g. 1.234).

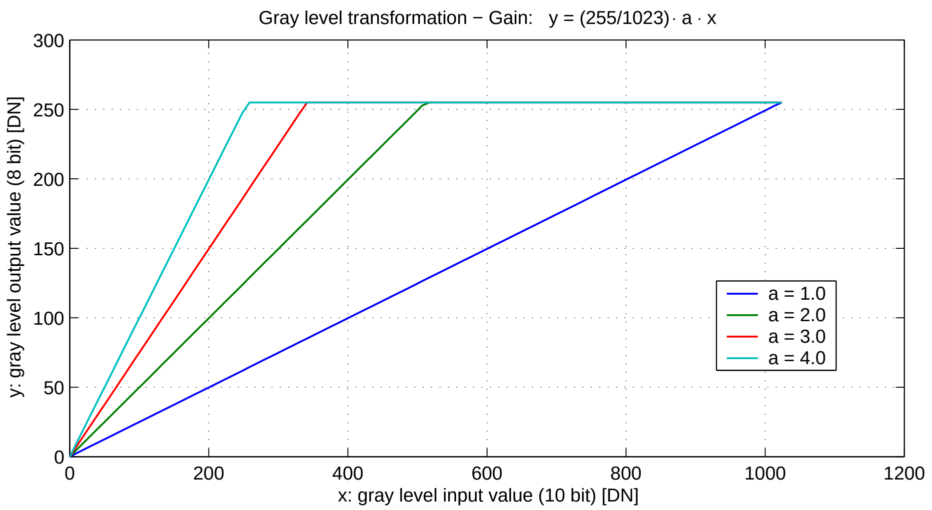

Figure 4.17: Applying a linear gain to an image

Gamma

The ’Gamma’ mode performs an exponential amplification, configurable in the range from 0.4 to 4.0. Gamma > 1.0 results in an attenuation of the image (see Fig. 4.18), gamma < 1.0 results in an amplification (see Fig. 4.19).

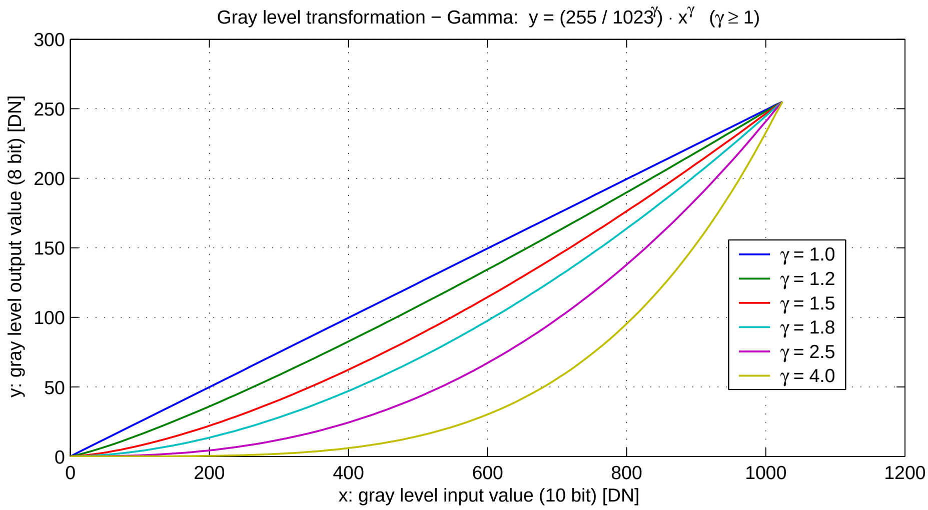

Figure 4.18: Applying gamma correction to an image (gamma > 1)

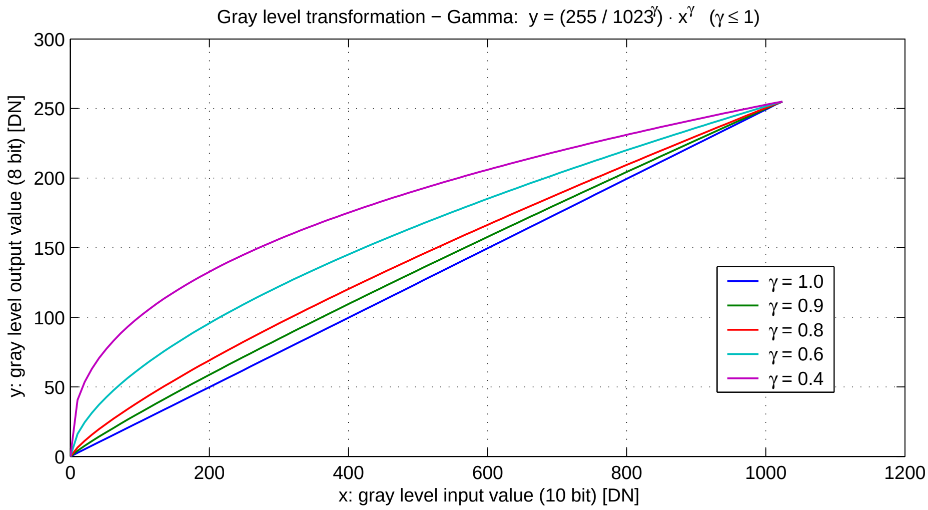

Figure 4.19: Applying gamma correction to an image (gamma < 1)

User-defined Look-up Table

In the 'User' mode, the mapping of input to output grey levels can be configured arbitrarily by the user. There is an example file in the PFRemote folder.

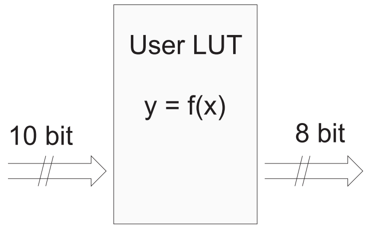

Figure 4.20: Data path through LUT

4.4 Test Images

Test images are generated in the camera FPGA, independent of the image sensor. They can be used to check the transmission path from the camera to the frame grabber. Independent from the configured grey level resolution, every possible grey level appears the same number of times in a test image. Therefore, the histogram of the received image must be flat.

A test image is a useful tool to find data transmission errors that are caused most often by a defective cable between camera and frame grabber.

The test images are optimised for the OEM-D1024E cameras due to the resolution that is a power of 2 (1024 x 1024 pixels). The test images of the OEM-D752E camera contain the first 752 x 582 pixels of the OEM-D1024E test images and therefore the histogram will not appear flat.

4.4.1 OEM-D1024E Test Images

Ramp

Depending on the configured grey level resolution, the ramp test image outputs a constant pattern with increasing grey level from the left to the right side (see Fig. 4.21).

Figure 4.21: Ramp test images: 8 bit output (left), 10 bit output (middle), 12 bit output (right)

A test image is a useful tool to find data transmission errors that are caused most often by a defective cable between camera and frame grabber.

LFSR

The LFSR (linear feedback shift register) test image outputs a constant pattern with a pseudo-random grey level sequence containing every possible grey level that is repeated for every row. In 12 bit mode only a fourth of all possible grey values appear.

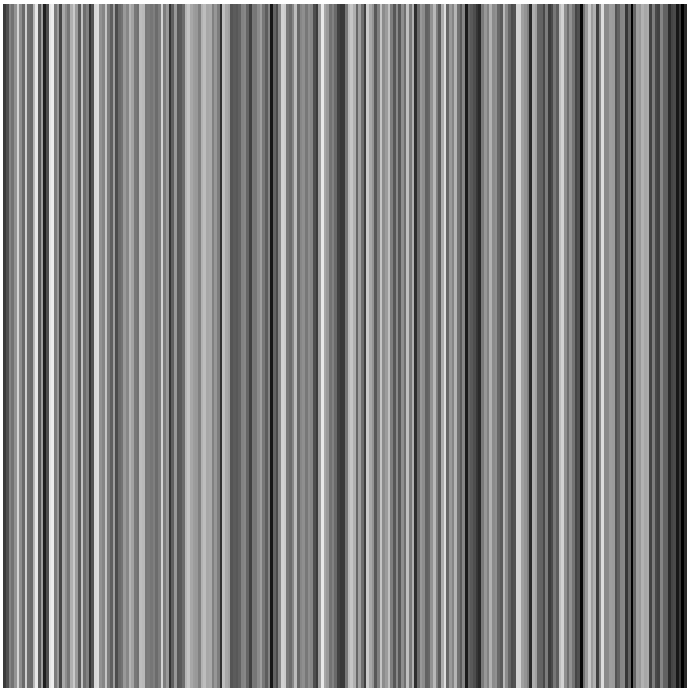

Figure 4.22: LFSR test image

Please refer to application note [AN026] for the calculation and the values of the LFSR test image.

4.4.2 OEM-D752E Test Images

Ramp

Depending on the configured grey level resolution, the ramp test image outputs a constant pattern with increasing grey level from the left to the right side (see Fig. 4.23). Table 4.2 explains the grey levels that are contained in the test images.

In the 10 bit and 12 bit test image, not every possible grey level is present in the full resolution of 752 x 582 pixels.

A test image is a useful tool to find data transmission errors that are caused most often by a defective cable between camera and frame grabber.

Test Image	Ramp Pattern
8 bit ramp image (256 DN)	582 rows with 0 .. 255 DN, 0 .. 255 DN, 0 .. 239 DN
10 bit ramp image (1024 DN)	582 rows with 0 .. 751 DN
12 bit ramp image (4096 DN)	256 rows with 0 .. 751 DN; 256 rows with 1024 .. 1775 DN; 70 rows with 2048 .. 2799 DN

Table 4.2: Grey levels in ramp test images

Figure 4.23: Ramp test images: 8 bit output (left), 10 bit output (middle), 12 bit output (right)

LFSR

The LFSR (linear feedback shift register) test image outputs a constant pattern with a 10 bit pseudo-random grey level sequence. In the 8 bit mode, the two LSBs are cut away.

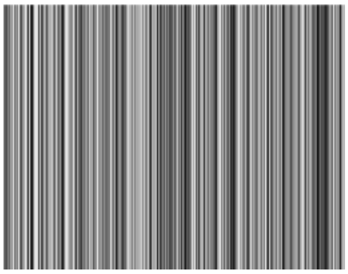

Figure 4.24: LFSR test image

Please see [AN026] for the LFSR algorithm and the output data.

4.4.3 Troubleshooting using the LFSR

To control the quality of your complete imaging system enable the LFSR mode and check the histogram. If your vision solution does not provide a real-time histogram, store the image and use a graphics software to display the histogram.
In the LFSR (linear feedback shift register) mode the camera module generates a constant test pattern containing all grey levels. If the data transmission is error free, the histogram of the received LFSR test pattern will be flat (Fig. 4.25). On the other hand, a non-flat histogram (Fig. 4.26) indicates problems, that may be caused by the interface.

The LFSR test works only for an image width of 1024, otherwise the histogram will not be flat.

The ramp test image should be used for the OEM-D752 camera and the resolution should be set to 512 x 512 pixels. This setup will result in a flat histogram.

Figure 4.25: LFSR test pattern received at the frame grabber and typical histogram for error-free data transmission

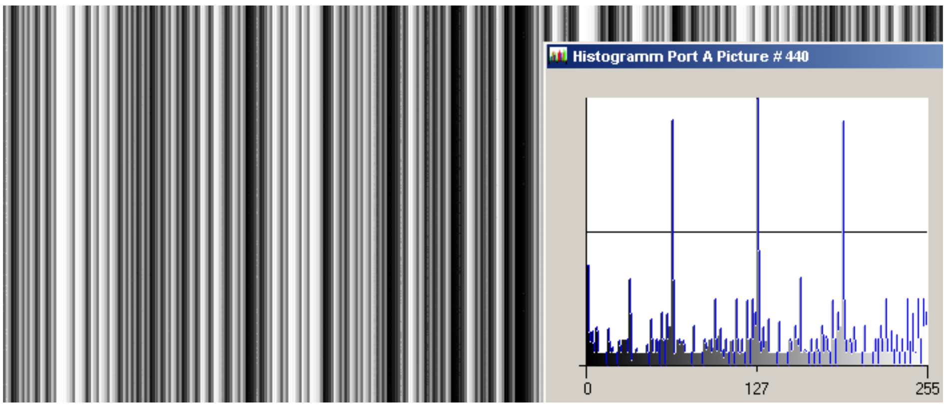

Figure 4.26: LFSR test pattern received at the frame grabber and histogram containing transmission errors

4.5 Image Correction

4.5.1 Overview

The OEM-D1024E and the OEM-D752E camera module series possess image pre-processing features, that compensate for non-uniformities caused by the sensor, the lens or the illumination. This method of improving the image quality is generally known as ’Shading Correction’ or ’Flat Field Correction’ and consists of a combination of offset correction, gain correction and pixel interpolation.

Since the correction is performed in hardware, there is no performance limitation for high frame rates.

The offset correction subtracts a configurable positive or negative value from the live image and thus reduces the fixed pattern noise of the CMOS sensor. In addition, hot pixels can be removed by interpolation. The gain correction can be used to flatten uneven illumination or to compensate shading effects of a lens. Both offset and gain correction work on a pixel-per-pixel basis, i.e. every pixel is corrected separately. For the correction, a black reference and a grey reference image are required. Then, the correction values are determined automatically in the camera module.

Do not set any reference images when gain or LUT is enabled!

Correction values of both reference images can be saved into the internal flash memory, but this overwrites the factory presets. Then the reference images that are delivered by factory cannot be restored anymore.

4.5.2 Offset Correction (FPN, Hot Pixels)

The offset correction is based on a black reference image, which is taken at no illumination (e.g. lens aperture completely closed). The black reference image contains the fixed-pattern noise of the sensor, which can be subtracted from the live images in order to minimise the static noise.

Offset correction algorithm

After configuring the camera modules with a black reference image, the camera modules are ready to apply the offset correction:

1. Determine the average value of the black reference image.
2. Subtract the black reference image from the average value.
3. Mark pixels that have a grey level higher than 1008 DN (@ 12 bit) as hot pixels.
4. Store the result in the camera module as the offset correction matrix.
5. During image acquisition, subtract the correction matrix from the acquired image and interpolate the hot pixels (see Section 4.5.2).

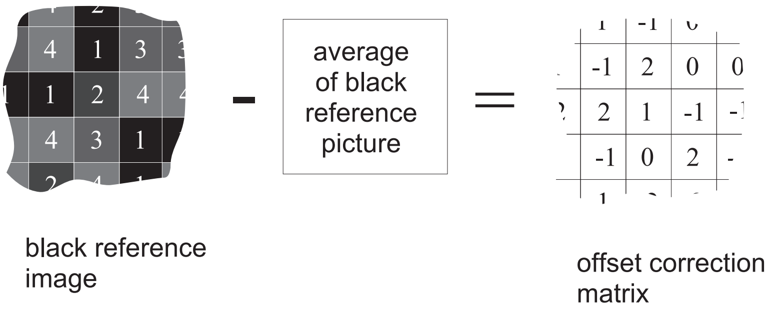

Figure 4.27: Offset correction

How to Obtain a Black Reference Image

In order to improve the image quality, the black reference image must meet certain demands.

- The black reference image must be obtained at no illumination, e.g. with lens aperture closed or closed lens opening.
- It may be necessary to adjust the black level offset of the camera modules. In the histogram of the black reference image, ideally there are no grey levels at value 0 DN after adjustment of the black level offset. All pixels that are saturated black (0 DN) will not be properly corrected (see Fig. 4.28). The peak in the histogram should be well below the hot pixel threshold of 1008 DN @ 12 bit.
- Camera module settings such as exposure time, LinLog, skimming and digital gain may influence the grey level. Therefore, for best results the camera module settings of the black reference image must be identical with the camera module settings of the image to be corrected.

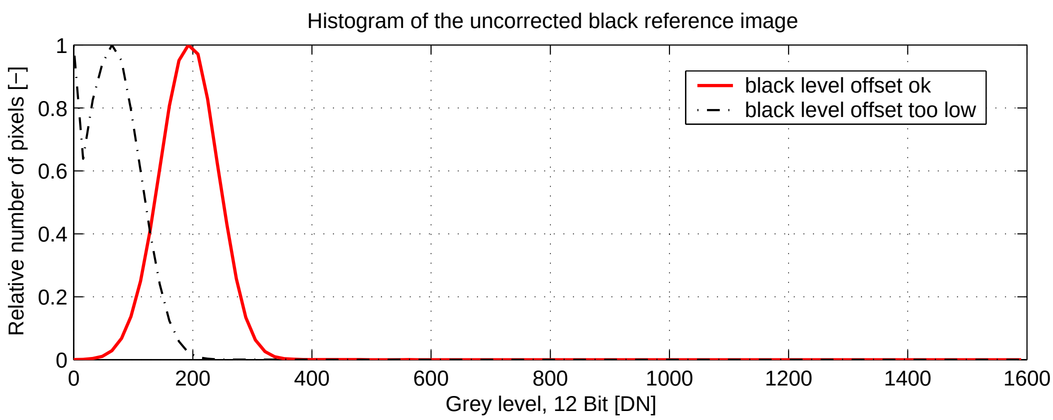

Figure 4.28: Histogram of a proper black reference image for offset correction

Hot pixel correction

Every pixel that exceeds a certain threshold in the black reference image is marked as a hot pixel. If the hot pixel correction is switched on, the camera module replaces the value of a hot pixel by an average of its neighbour pixels (see Fig. 4.29).

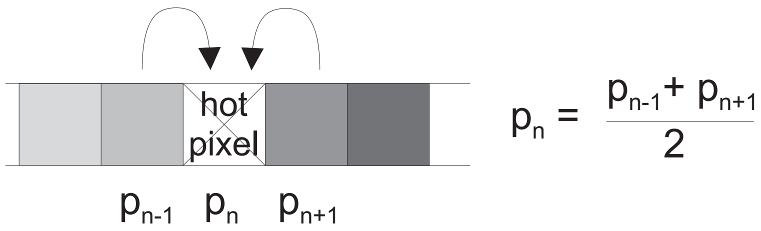

Figure 4.29: Hot pixel interpolation

4.5.3 Gain Correction

The gain correction is based on a grey reference image, which is taken at uniform illumination to give an image with a mid grey level.

Gain correction is not a trivial feature. The quality of the grey reference image is crucial for proper gain correction.

Gain correction algorithm

After configuring the camera module with a black and grey reference image, the camera module is ready to apply the gain correction:

1. Determine the average value of the grey reference image.
2. Subtract the offset correction matrix from the grey reference image.
3. Divide the average value by the offset corrected grey reference image.
4. Pixels that have a grey level bigger than a certain threshold are marked as hot pixels.
5. Store the result in the camera module as the gain correction matrix.
6. During image acquisition, multiply the gain correction matrix from the offset-corrected acquired image and interpolate the hot pixels (see Section 4.5.2).

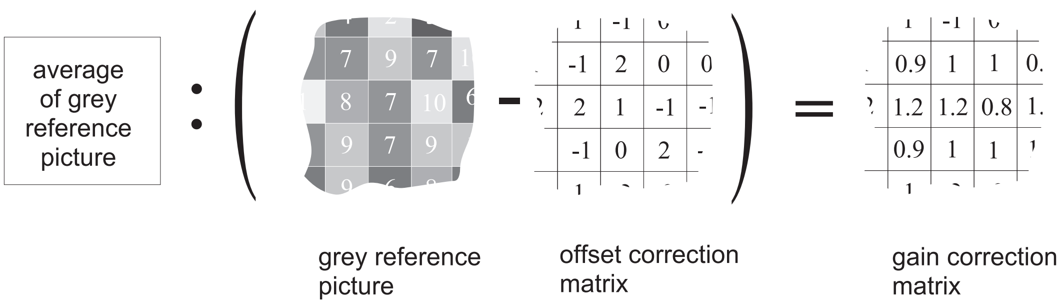

Figure 4.30: Gain Correction

Gain correction always needs an offset correction matrix, so the offset correction has to be performed before the gain correction.

How to Obtain a Grey Reference Image

In order to improve the image quality, the grey reference image must meet certain demands.

- The grey reference image must be obtained at uniform illumination.

  Use a high quality light source that delivers uniform illumination. Standard illumination will not be appropriate.

- When looking at the histogram of the grey reference image, ideally there are no grey levels at full scale (4095 DN @ 12 bit). All pixels that are saturated white will not be properly corrected (see Fig. 4.31).
- Camera module settings such as exposure time, LinLog, skimming and digital gain may influence the grey level. Therefore, the camera module settings of the grey reference image must be identical with the camera module settings of the image to be corrected.

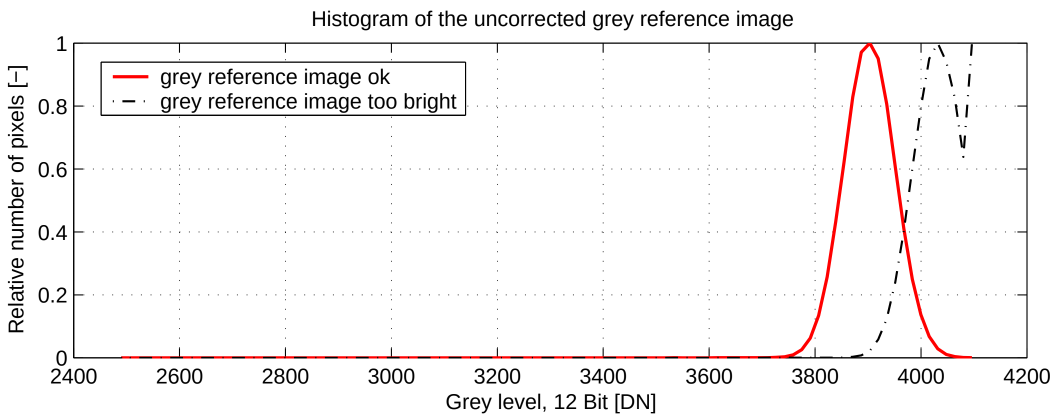

Figure 4.31: Proper grey reference image for gain correction

4.5.4 Corrected Image

Offset, gain and hot pixel correction can be switched on seperately. The following configurations are possible:

- No correction
- Offset correction only
- Offset and hot pixel correction
- Hot pixel correction only
- Offset and gain correction
- Offset, gain and hot pixel correction

In addition, the black reference image and grey reference image that are currently stored in the camera module RAM can be output.
Table 4.3 shows the maximum values of the correction matrices, i.e. the error range that the offset and gain algorithm can correct.

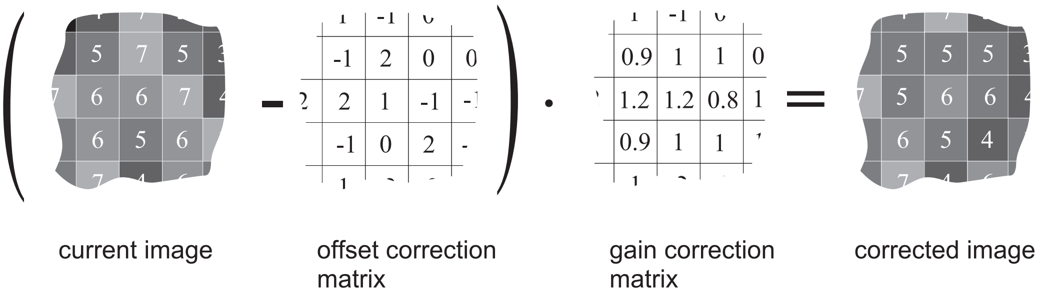

Figure 4.32: Corrected image

	minimum	maximum
Offset correction	-508 DN @ 12 bit	+508 DN @ 12 bit
Gain correction	0.42	2.67

Table 4.3: Offset and gain correction ranges

4.6 Reduction of Image Size

With Photonfocus camera modules there are several possibilities to focus on the interesting parts of an image, thus reducing the data rate and increasing the frame rate. The most commonly used feature is Region of Interest (ROI).

4.6.1 Region of Interest (ROI)

Some applications do not need full image resolution (e.g. 1024x1024 pixels). By reducing the image size to a certain region of interest (ROI), the frame rate can be drastically increased. A region of interest can be almost any rectangular window and is specified by its position within the full frame and its width and height. Fig. 4.33 gives some possible configurations for a region of interest, and Table 4.4 shows some numerical examples of how the frame rate can be increased by reducing the ROI.

☞ Both reductions in x- and y-direction result in a higher frame rate.

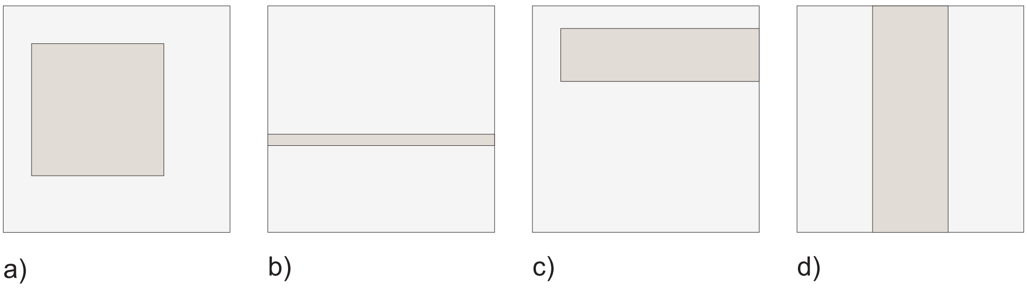

Figure 4.33: ROI configuration examples

ROI Dimension	OEM-D752E-40	OEM-D1024E-40	OEM-D1024E-80	OEM-D1024E-160
1024 x 1024	-	37 fps	74 fps	149 fps
752 x 582	87 fps	87 fps	178	356
512 x 512	149 fps	149 fps	293 fps	586 fps
256 x 256	585 fps	585 fps	1127 fps	2230 fps
128 x 128	2230 fps	2230 fps	4081 fps	7843 fps
128 x 16	15 000 fps	15 000 fps	23041 fps	37453 fps

Table 4.4: Frame rates of different ROI settings (exposure time 10 μs; correction off, CFR off, skimming off and sequential readout mode).

Exposure time	OEM-D752E-40	OEM-D1024E-40	OEM-D1024E-80	OEM-D1024E-160
10 μs	87 fps	37 fps	74 / 74 fps	149 / 148 fps
100 μs	87 fps	37 fps	74 / 74 fps	147 / 146 fps
500 μs	86 fps	37 fps	72 / 72 fps	139 / 139 fps
1 ms	82 fps	36 fps	69 / 72 fps	130 / 139 fps
2 ms	76 fps	35 fps	65 / 72 fps	115 / 140 fps
5 ms	62 fps	31 fps	54 / 72 fps	85 / 140 fps
10 ms	47 fps	27 fps	42 / 72 fps	60 / 99 fps
12 ms	43 fps	26 fps	39 / 72 fps	53 / 82 fps

Table 4.5: Frame rate of different exposure times, [sequential readout mode / simultaneous readout mode], resolution 1024x1024 pixel (correction off, CFR off and skimming off).

☞ The OEM-D752E-40 and the OEM-D1024E-40 camera modules do not support the simultaneous readout mode.

Calculation of the maximum frame rate

The frame rate mainly depends of the exposure time and readout time. The frame rate is the inverse of the frame time. In the following formulars the minimum frame time is calculated. When using CFR mode the frame time can get extended.

fps $= \frac{1}{t_{\mathrm{frame}}}$

Calculation of the frame time (sequential mode)

$$t_{\mathrm{frame}} \geq t_{\mathrm{exp}} + t_{\mathrm{ro}} + t_{\mathrm{proc}} + t_{\mathrm{RAM}}$$

Calculation of the frame time (simultaneous mode)

$$t_{\mathrm{frame}} \geq \max(t_{\mathrm{exp}} + 76\ \mu s,\ t_{\mathrm{ro}} + 476\ \mu s) + t_{\mathrm{RAM}}$$

$t_{ro} = t_{CLK}$ * (P_y * ($\frac{P_x}{taps}$ + LP) + LP)

$t_{proc} = t_{Normal}$ + t_{CFR} + t_{FPN} + t_{Skim}

$t_{RAM} = \frac{1}{128}$ * (t_{ro} + 1375 ns) - (t_{exp} + t_{proc})

When the result of t_{RAM} is negative, set it to 0.

t_{frame} frame time
t_{exp} exposure time
t_{ro} readout time
t_{proc} processing time
t_{RAM} RAM refresh time
t_{Normal} constant latency
t_{CFR} constant frame rate latency, only when CFR is enabled
t_{FPN} correction latency, only when correction is enabled
t_{Skim} skim latency, only when Skimming is enabled
t_{CLK} pixel clock
taps CameraLink taps
P_X number of pixels in x-direction
P_Y number of pixels in y-direction (+1, for MV-D1024E-80 and MV-D1024E-160)
LP line pause, constant LP = 8 for all models

	OEM-D752E-40	**OEM-D1024E-40**	**OEM-D1024E-80**	**OEM-D1024E-160**
t_{exp}	10 μs - 419 ms	10 μs - 419 ms	10 μs - 838 ms	25 μs - 419 ms
t_{Normal}	1975 ns	1975 ns	2600 ns	1300 ns
t_{CFR}	850 ns	850 ns	0	0
t_{FPN}	150 ns	150 ns	0	0
t_{Skim}	51.125 μs	51.125 μs	101.6 μs	50.8 μs
t_{CLK}	25 ns	25 ns	25 ns	12.5 ns
taps	1	1	2	2
P_Y	Window H	Window H	Window H + 1	Window H + 1

Table 4.6: Camera module specific values for frame time calculations

A calculator for calculating the maximum frame rate is available in the support area of the Photonfocus website. Please use for the calcutions the corresponding camera model.

4.6.2 Multiple Regions of Interest

The camera module series can handle up to 16 different regions of interest. This feature can be used to reduce the image data and increase the frame rate. An application example for using multiple regions of interest (MROI) is a laser triangulation system with several laser lines. The multiple ROIs are joined together and form a single image, which is transferred to the frame grabber.
An ROI is defined by its starting value in y-direction and its height. Every ROI within a MROI must be of the same width. The maximum frame rate in MROI mode depends on the number of rows and columns being read out. Overlapping ROIs are allowed. See Section 4.6.1 for information on the calculation of the maximum frame rate.

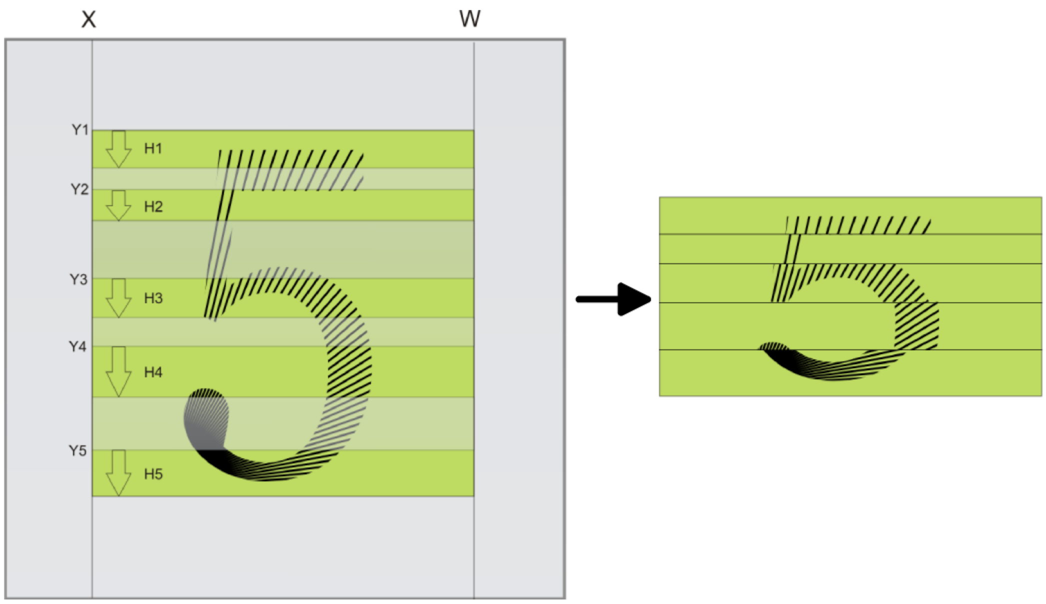

Figure 4.34: Multiple Regions of Interest with 5 ROIs

4.6.3 Decimation

Decimation reduces the number of pixels in x- and y-direction. Decimation can also be used together with ROI or MROI. Decimation in y-direction transfers every n^{th} row only and directly results in reduced read-out time and higher frame rate respectively. Decimation in x-direction transfers every pixel of a row, but uses the CameraLink `DVAL` (data valid) signal to indicate which pixels to mask (see Fig. 4.35). Therefore it cannot be used to increase the frame rate.

☞ The OEM-D1024E-80 and OEM-D1024E-160 camera modules do not support decimation in x-direction.

4.7 External Trigger

An external trigger is an event that starts an exposure. The trigger signal is either generated on the user electronic (soft-trigger) or comes from an external device such as a light barrier. If a trigger signal is applied to the camera module before the earliest time for the next trigger, this

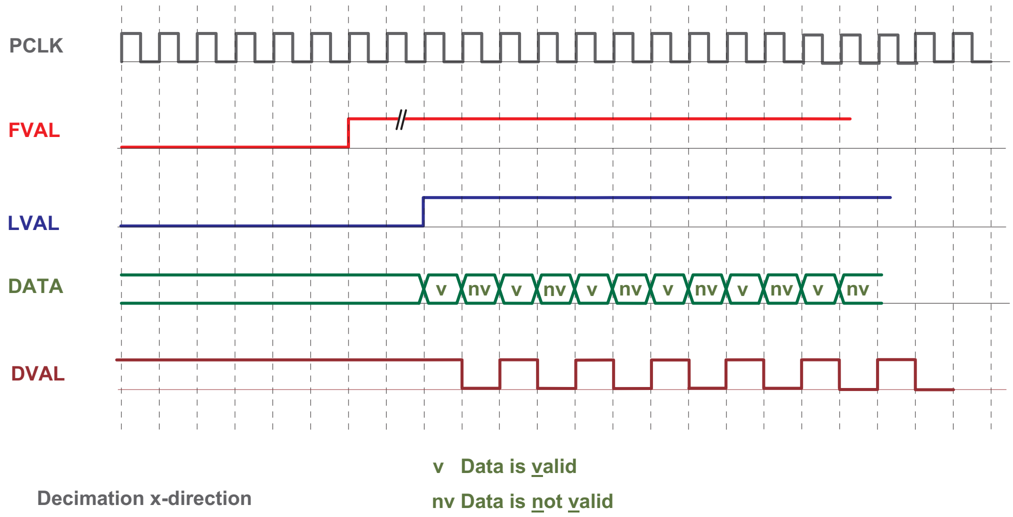

Figure 4.35: Decimation in x-direction uses the hand shake signal DVAL in the OEM-D752E-40 and in the OEM-D1024E-40 camera modules

trigger will be ignored. The camera module property `Counter.MissedTrigger` stores the number of trigger events which where ignored.

4.7.1 Trigger Source

The trigger signal can be configured to be active high or active low. One of the following trigger sources can be used:

Interface Trigger In the interface trigger mode, the trigger signal is applied to the OEM camera module by the user electronic.

I/O Trigger In the I/O trigger mode, the trigger signal is applied directly to the OEM camera module by an additional trigger signal.

4.36 serves to demonstrate two different ways to trigger the OEM camera modules. The example displays the possible input either from the CameraLink interface or from the trigger input via the opto isolated trigger.

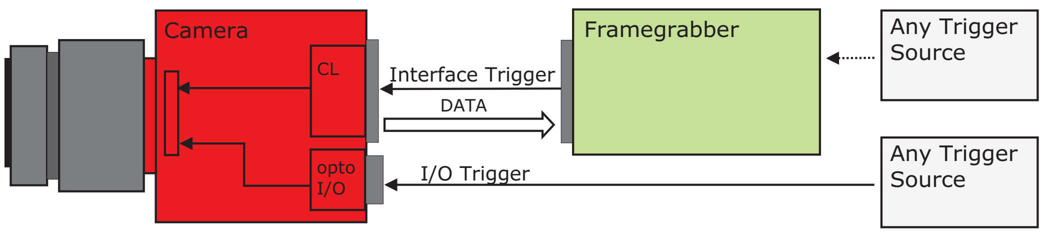

Figure 4.36: Trigger Inputs of the OEM camera modules, demonstrated here for clarity in the context of a camera vision system

4.7.2 Trigger Mode

Depending on the trigger mode, the exposure time can be determined either by the camera module or by the trigger signal itself:

Camera-module-controlled Exposure In this trigger mode the exposure time is defined by the camera module. For an active high trigger signal, the camera module starts the exposure with a positive trigger edge and stops it when the preprogrammed exposure time has elapsed. The exposure time is defined by the software.

Level-controlled Exposure In this trigger mode the exposure time is defined by the pulse width of the trigger pulse. For an active high trigger signal, the camera module starts the exposure with the positive edge of the trigger signal and stops it with the negative edge.

Figure 4.37 gives an overview over the available trigger modes. The signal `ExSync` stands for the trigger signal, which is provided either through the interface or the I/O trigger. For more information and the respective timing diagrams see Section 5.4

	Polarity Active High		**Polarity Active Low**	
	Exposure Start	**Exposure Stop**	**Exposure Start**	**Exposure Stop**
Camera controlled exposure	↑ ExSync	Camera	↓ ExSync	Camera
Level controlled exposure	↑ ExSync	↓ ExSync	↓ ExSync	↑ ExSync

↑ Rising Edge
↓ Falling Edge

Figure 4.37: Trigger Inputs of the OEM camera modules

4.7.3 Trigger Delay

Programmable delay in milliseconds between the incoming trigger edge and the start of the exposure. This feature may be required to synchronize to external strobe with the exposure of the camera module.

4.8 Strobe Output

The strobe output can be used to trigger a strobe. The strobe output can be used both in free-running and in trigger mode. There is a programmable delay available to adjust the strobe pulse to your application.

4.9 Configuration of the OEM interface

The OEM camera modules can be controlled by the user via a RS232 compatible asynchronous serial interface with LVCMOS levels. The interface is accessible via the board connectors.

5

Hardware Interface

5.1 Connectors

5.1.1 Power Supply

The OEM camera modules require several power supply voltages. The OEM camera modules meet all performance specifications using standard switching power supplies, although well-regulated linear power supplies provide optimum performance.

⚠ It is extremely important that you apply the appropriate voltages to your OEM camera module. Incorrect voltages will damage the OEM camera modules.

Table 3.5 and Table 3.6 are summarizing the supply currents and the voltages for the different supply voltages. The minimum noise level should not exceed +/- 20 mV.

5.1.2 Pinout PCB connector

The pinout of the OEM camera module PCB connector and the signal definitions are surmmarized in the following tables (see Table 5.1, Table 5.2, Table 5.3, and Table 5.4). The signal definitions are given in Section 5.2 to Section 5.4.

Pin	I/O	Name	Function
39	O	DATA19	Image data bit 19
37	O	DATA18	Image data bit 18
35	O	DATA17	Image data bit 17
33	O	DATA16	Image data bit 16
31	O	DATA15	Image data bit 15
29	O	DATA14	Image data bit 14
27	O	DATA13	Image data bit 13
25	O	DATA12	Image data bit 12
23	O	DATA11	Image data bit 11
21	O	DATA10	Image data bit 10
19	O	DATA9	Image data bit 9
17	O	DATA8	Image data bit 8
15	O	DATA7	Image data bit 7
13	O	DATA6	Image data bit 6
11	O	DATA5	Image data bit 5
9	O	DATA4	Image data bit 4
7	O	DATA3	Image data bit 3
5	O	DATA2	Image data bit 2
3	O	DATA1	Image data bit 1
1	O	DATA0	Image data bit 0

Table 5.1: Definition of the pinout of the OEM camera module PCB connector (odd row, pin 39 to 1)

Pin	I/O	Name	Function
79	PW	VDD_50	5.0 Volt power supply
77	PW	VDD_50	5.0 Volt power supply
75	PW	VDD_33	3.3 Volt power supply
73	PW	VDD_18	1.8 Volt power supply
71	O	DC_DC_CLK	Clock for DCDC power regulators (from 1.5 to 2 MHz), for fix switching frequency of 1.5 MHz, do not connect
69	O	STROBE	Special Strobe Output
67	I	TRIGGER	Special Trigger Input
65	I	CC2	External master clock
63	I	CC4	External control
61	I	CC3	External exposure control
59	I	CC1	External synchronization
57	O	CL_SPARE	CameraLink signal, do not connect
55	O	PIXEL_CLK	Pixel clock, data changes with rising edge
53	O	DATA_VALID	Data valid, indicates active data
51	O	LINE_VALID	Line valid, indicates active line
49	O	FRAME_VALID	Frame valid, indicates active frame
47	O	DATA23	Image data bit 23
45	O	DATA22	Image data bit 22
43	O	DATA21	Image data bit 21
41	O	DATA20	Image data bit 20

Table 5.2: Definition of the pinout of the OEM camera module PCB connector (odd row, pin 79 to 41)

Pin	I/O	Name	Function
40	I/O	RESERVED	reserved for future implementations, do not connect
38	PW	GND	Ground
36	O	LED_GREEN	Indicates active image data transmission (inverted FRAME_VALID)
34	PW	GND	Ground
32	O	LED_RED	Indicates active RS232 communication (LED_RED = RX and TX)
30	PW	GND	Ground
28	O	TCD	JTAG, do not connect
26	PW	GND	Ground
24	O	TMS	JTAG, do not connect
22	PW	GND	Ground
20	O	TDI	JTAG, do not connect
18	PW	GND	Ground
16	I	TDO	JTAG, do not connect
14	PW	GND	Ground
12	O	Misc_Analog	Miscellaneous analog voltage, not provided by all sensor boards, do not connect
10	PW	GND	Ground
8	O	MISC_DIGITAL	Interface reset, low active, do not connect
6	PW	GND	Ground
4	O	Global Reset	Indication of sensor board state (active...), do not connect
2	PW	GND	Ground

Table 5.3: Definition of the pinout of the OEM camera module PCB connector (even row, pin 40 to 2)

Pin	I/O	Name	Function
80	PW	VDD_50	5.0 Volt power supply
78	PW	VDD_33	3.3 Volt power supply
76	PW	VDD_33	3.3 Volt power supply
74	PW	VDD_18	1.8 Volt power supply
72	PW	GND	Ground
70	O	TX	TX RS232 interface (from camera), 3.3 V
68	I	RX	RX RS232 interface (to camera), 3.3 V
66	PW	GND	Ground
64	I/O	RESERVED	reserved for future implementations, do not connect
62	I/O	RESERVED	reserved for future implementations, do not connect
60	I/O	RESERVED	reserved for future implementations, do not connect
58	I/O	RESERVED	reserved for future implementations, do not connect
56	PW	GND	Ground
54	I/O	RESERVED	reserved for future implementations, do not connect
52	I/O	RESERVED	reserved for future implementations, do not connect
50	I/O	RESERVED	reserved for future implementations, do not connect
48	I/O	RESERVED	reserved for future implementations, do not connect
46	PW	GND	Ground
44	I/O	RESERVED	reserved for future implementations, do not connect
42	PW	GND	Ground

Table 5.4: Definition of the pinout of the OEM camera module PCB connector (even row, pin 80 to 42)

5.2 Parallel Data Interface

The interface of the OEM camera modules is a parallel data interface, which follows the AIA standard. On the module connector the signals are available in a parallel format. The AIA standard contains signals for transferring the image data, control information and the serial communication.

Data signals: Data signals contain the image data. In addition, handshaking signals such as FVAL, LVAL and DVAL are transmitted (see 5.6).

Camera module control information: Camera module control signals (CC-signals) can be defined by the user to provide certain signals to the camera module. There are 4 CC-signals available and all are inputs of the camera module. For example, the external trigger is provided by a CC-signal (see Table 5.5 for the CC-signal assignment).

CC1	EXSYNC	External Trigger. May be generated either by the frame grabber itself (software trigger) or by an external event (hardware trigger).
CC2	CTRL0	Control0. This signal is reserved for future purposes and is not used.
CC3	CTRL1	Control1. This signal is reserved for future purposes and is not used.
CC4	CTRL2	Control2. This signal is reserved for future purposes and is not used.

Table 5.5: Summary of the Camera Module Control (CC) signals as used by Photonfocus

Pixel clock: The pixel clock is generated on the camera module and is provided to the following electronics for synchronisation.

Serial communication: The camera module can be controlled by the user via a RS232 compatible asynchronous serial interface.

The user's vision system needs to be configured with the proper tap and resolution settings, otherwise the image will be distorted or not displayed with the correct aspect ratio. Refer to Section 3.4 for the parameters needed for interfacing.

5.3 Read-out Timing

5.3.1 Free running Mode

Sequential readout timing

By default, the camera module is in free running mode and delivers images without any external control signals. The sensor is operated in sequential readout mode, which means that the sensor is read out after the exposure time. Then the sensor is reset, a new exposure starts and the readout of the image information begins again. The data is output on the rising edge of the pixel clock. The signals `FRAME_VALID` (`FVAL`) and `LINE_VALID` (`LVAL`) mask valid image information. The signal `SHUTTER` indicates the active exposure period of the sensor and is shown for clarity only.

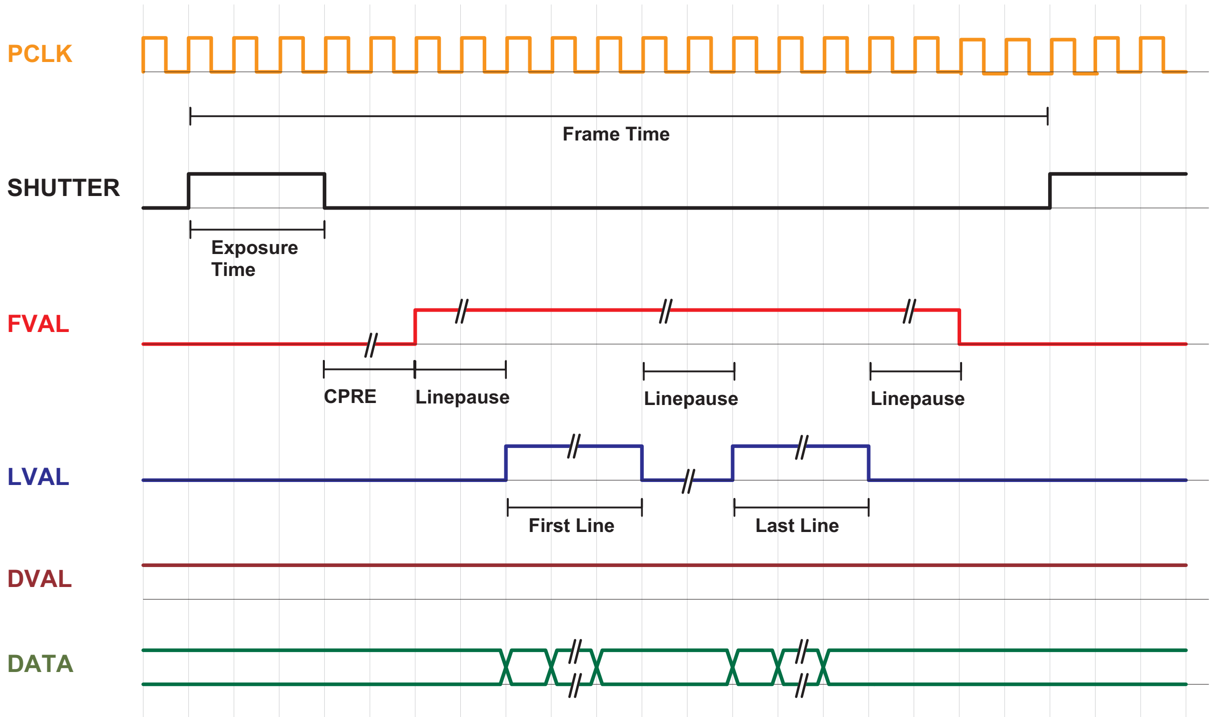

Figure 5.1: Timing diagram sequential readout mode

Simultaneous readout timing

To achieve highest possible frame rates, the camera module must be set to "Free-running mode" with simultaneous readout. The camera module continuously delivers images as fast as possible. Exposure time of the next image can start during the readout time of the current image. The data is output on the rising edge of the pixel clock. The signals `FRAME_VALID` (`FVAL`) and `LINE_VALID` (`LVAL`) mask valid image information. The signal `SHUTTER` indicates the active integration phase of the sensor and is shown for clarity only.

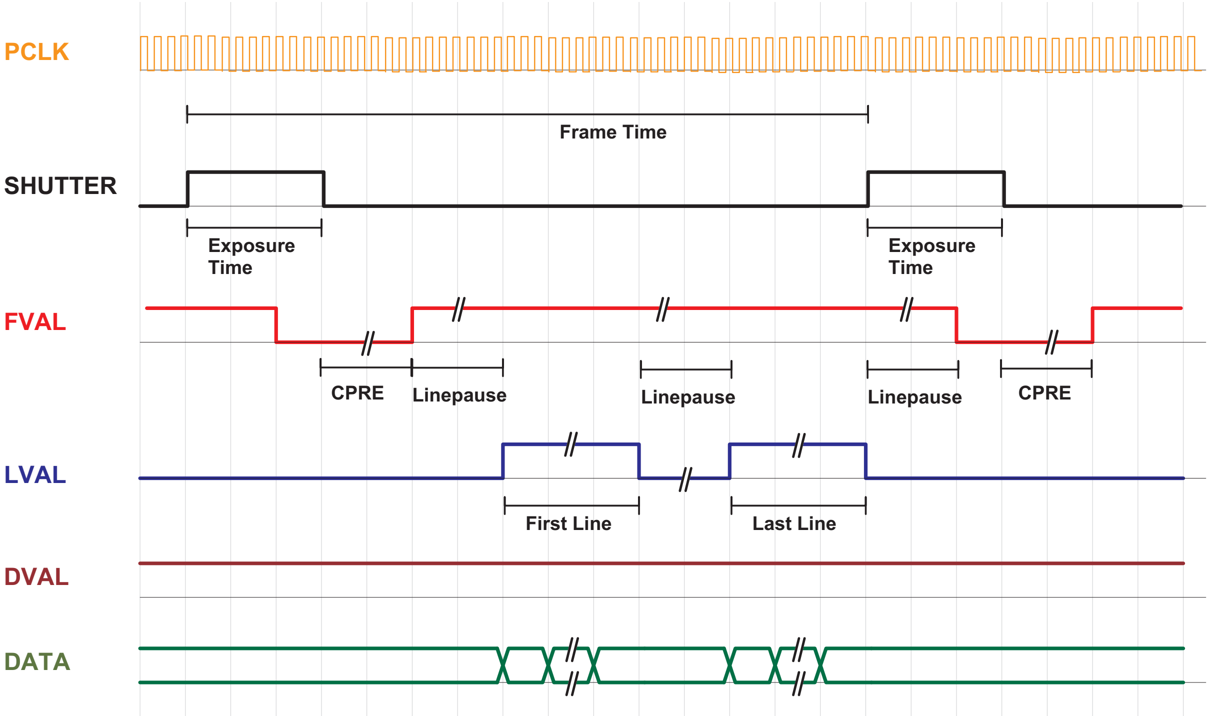

Figure 5.2: Timing diagram simultaneous readout mode (readout time > exposure time)

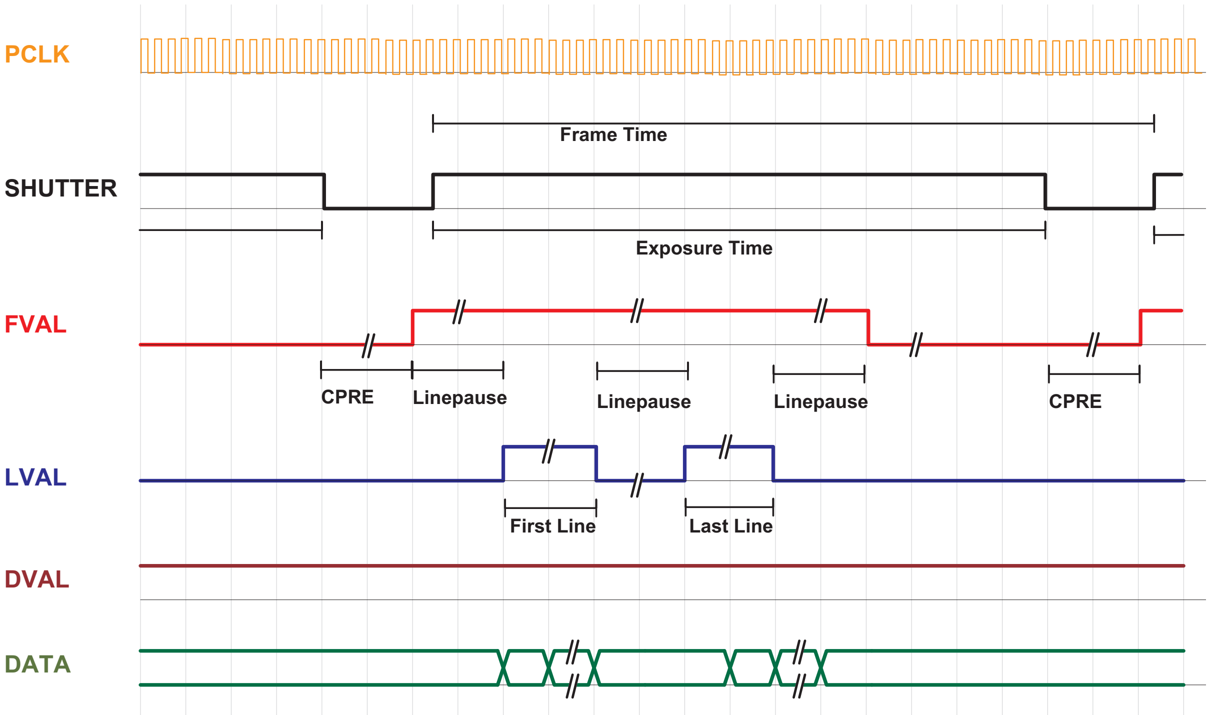

Figure 5.3: Timing diagram simultaneous readout mode (readout time < exposure time)

Frame time	Frame time is the inverse of frame rate.
Exposure time	Period during which the pixels are integrating the incoming light.
PCLK	Pixel clock on parallel data interface.
SHUTTER	Internal signal, shown only for clarity. Is 'high' during the exposure time.
FVAL (Frame Valid)	Is 'high' while the data of one whole frame are transferred.
LVAL (Line Valid)	Is 'high' while the data of one line are transferred. Example: To transfer an image with 640 x 480 pixels, there are 480 LVAL within one FVAL active high period. One LVAL lasts 640 pixel clock cycles.
DVAL (Data Valid)	Is 'high' while data are valid.
DATA	Transferred pixel values. Example: For a 100 x 100 pixel image, there are 100 values transferred within one LVAL active high period, or 100*100 values within one FVAL period.
Line pause	Delay before the first line and after every following line when reading out the image data.

Table 5.6: Explanation of control and data signals used in the timing diagram

These terms will be used also in the timing diagrams of Section 5.4.

5.3.2 Constant Frame Rate Mode (CFR)

When the camera module is in constant frame rate mode, the frame rate can be varied up to the maximum frame rate. Thus, fewer images can be acquired than determined by the frame time. When constant frame rate is switched off, the camera module outputs images with maximum speed, depending on the exposure time and the read-out time. The frame rate depends directly on the exposure time.

Constant Frame Rate mode is not available together with external trigger mode.

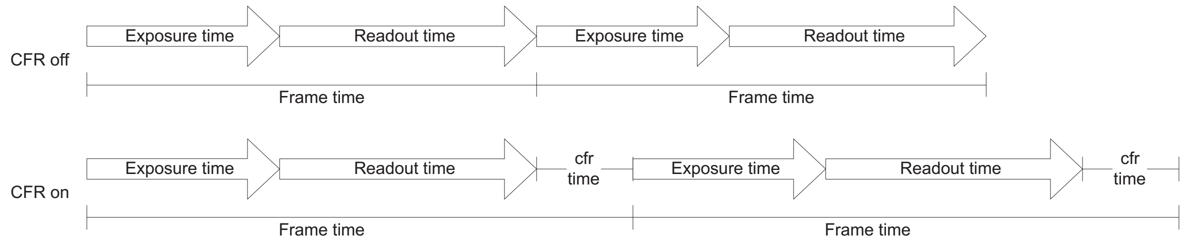

Figure 5.4: Constant Frame Rate with sequential readout mode

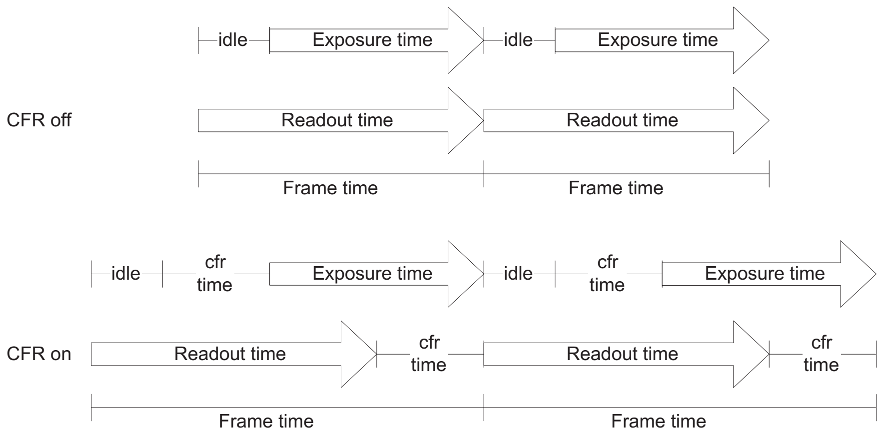

Figure 5.5: Constant Frame Rate with simultaneous readout mode (readout time > exposure time)

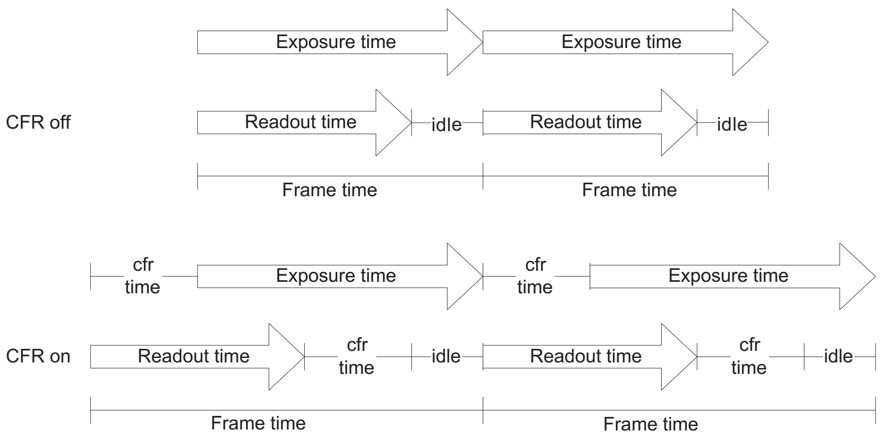

Figure 5.6: Constant Frame Rate with simultaneous readout mode (readout time < exposure time)

5.4 Trigger

5.4.1 Trigger Modes

The following sections show the timing diagram for the trigger modes. The signal ExSync denotes the trigger signal that is provided either by the interface trigger or the I/O trigger (see Section 4.7). The other signals are explained in Table 5.6.

Camera module controlled Exposure

In the camera module controlled trigger mode, the exposure is defined by the camera module and is configurable by software. For an active high trigger signal, the image acquisition begins with the rising edge of the trigger signal. The image is read out after the pre-configured exposure time. After the readout, the sensor returns to the reset state and the camera module waits for a new trigger pulse (see Fig. 5.7).
The data is output on the rising edge of the pixel clock, the handshaking signals FRAME_VALID (FVAL) and LINE_VALID (LVAL) mask valid image information. The signal SHUTTER in Fig. 5.7 indicates the active integration phase of the sensor and is shown for clarity only.

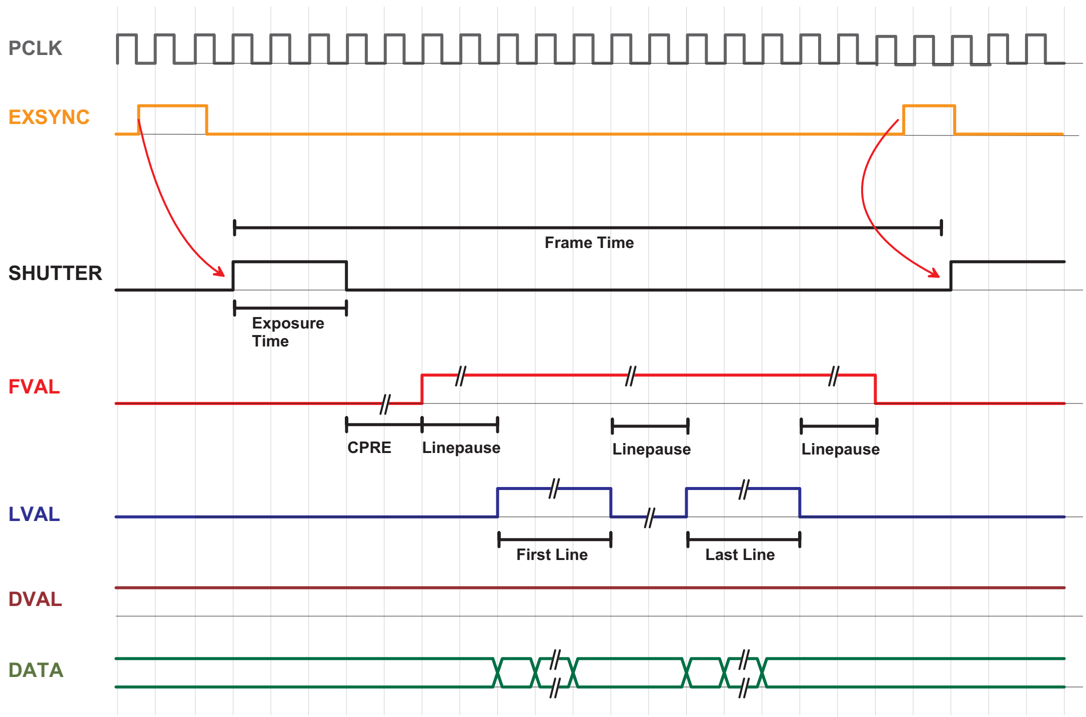

Figure 5.7: Trigger timing diagram for camera module controlled exposure

Level-controlled Exposure

In the level-controlled trigger mode, the exposure time is defined by the pulse width of the external trigger signal. For an active high trigger signal, the image acquisition begins with the rising edge and stops with the falling edge of the external trigger signal. Then the image is read out. After that, the sensor returns to the idle state and the camera module waits for a new trigger pulse (see Fig. 5.8). The data is output on the rising edge of the pixel clock, the handshaking signals `FRAME_VALID` (`FVAL`) and `LINE_VALID` (`LVAL`) mask valid image information. The signal `SHUTTER` in Fig. 5.8 indicates the active integration phase of the sensor and is shown for clarity only.

☞ Level-controlled exposure is not supported in simultaneous readout mode.

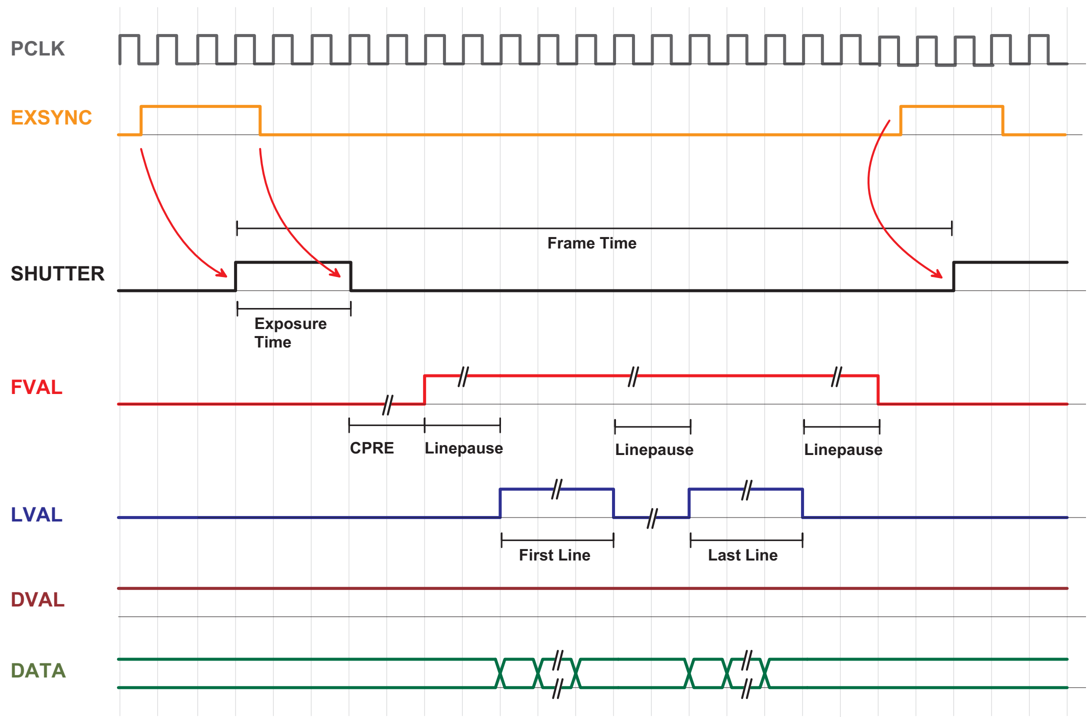

Figure 5.8: Trigger timing diagram for level controlled exposure

5.4.2 Trigger Delay

This section serves to demonstrate the possible realization of a trigger delay setup in a user's application system.

☞ For the purpose of clarity the example shown in Fig. 5.9 refers to a camera setup with CameraLink interface and CameraLink frame grabber.

The total delay between the trigger edge and the camera exposure consists of the delay in the frame grabber and the camera (Fig. 5.9). Usually, the delay in the frame grabber is relatively large to avoid accidental triggers caused by voltage spikes (see Fig. 5.10). The trigger can also be delayed by the property `Trigger.Delay`.

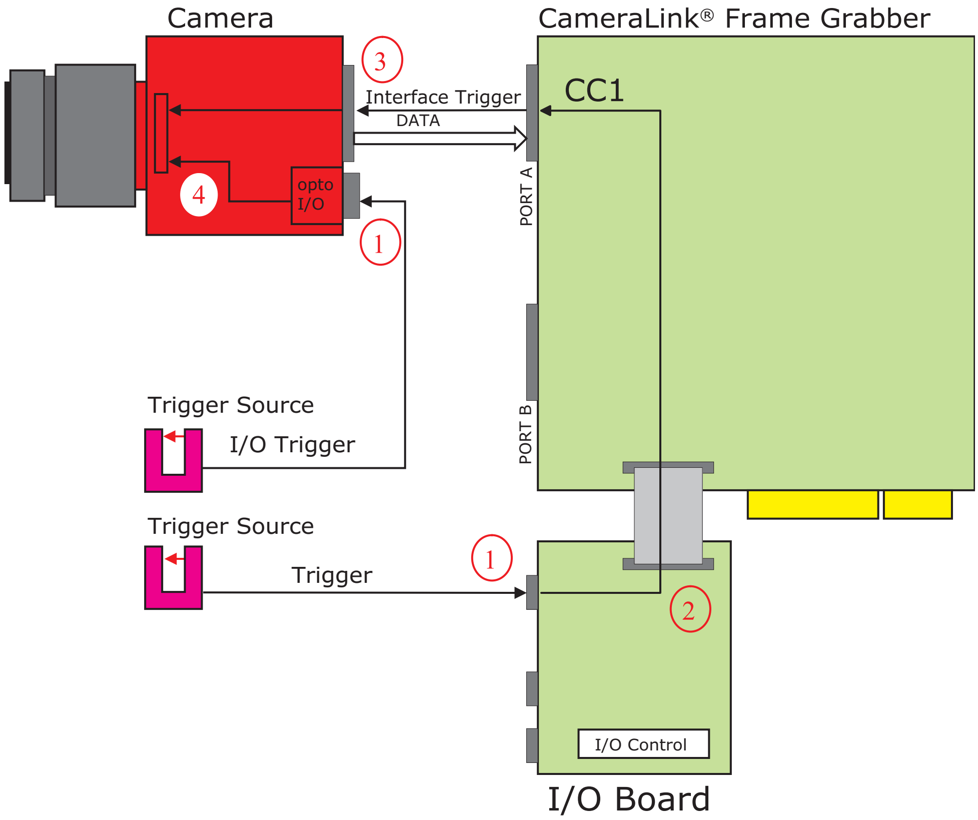

Figure 5.9: Trigger Delay visualisation from the trigger source to the camera module in a camera and frame grabber setup

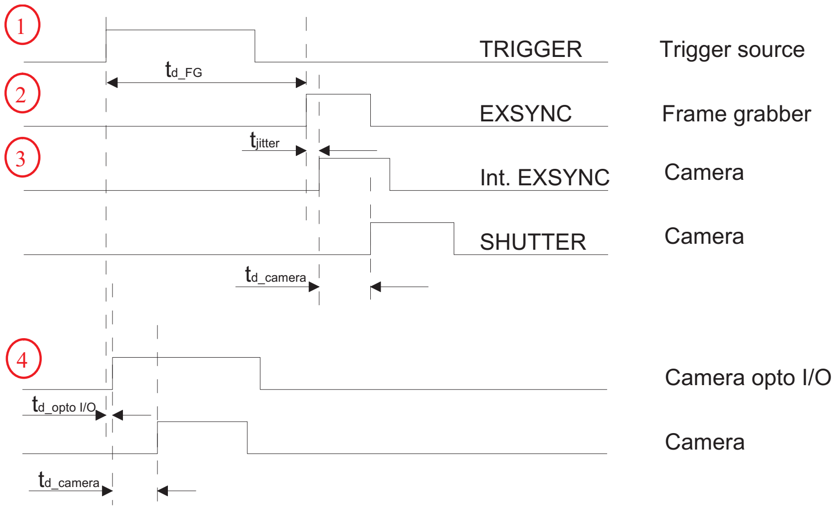

Figure 5.10: Timing Diagram for Trigger Delay

For the delay in the frame grabber, please ask your frame grabber manufacturer. The camera module delay consists of a constant trigger delay and a variable delay (jitter).

Trigger delay type	Description
t_{d-FG}	Trigger delay of the frame grabber, refer to frame grabber manual
t_{jitter}	Variable camera module trigger delay (max. 25 ns)
$t_{d-camera}$	Constant camera module trigger delay (150 ns)

Table 5.7: Trigger Delay

6

Mechanical and Optical Considerations

6.1 Mechanical Interface

The user interface is placed at the bottom of the OEM modules. This also applies for the OEM modules OEM-D1024E-80 and OEM-D1024-160, which consist of 2 PCB boards. The general mechanical data of the OEM camera modules are listed in Section 3, Table 3.5 and Table 3.6. The mechanical dimensions of the sensor modules (OEM-D752E and OEM-D1024E) are shown in Fig. 6.1. The mechanical dimensions of the ADC module are given in Fig. 6.2.
During storage and transport, the OEM camera modules should be protected against vibration, shock, moisture and dust. The original packaging protects the OEM camera modules adequately from vibration and shock during storage and transport. Please either retain this packaging for possible later use or dispose of it according to local regulations.

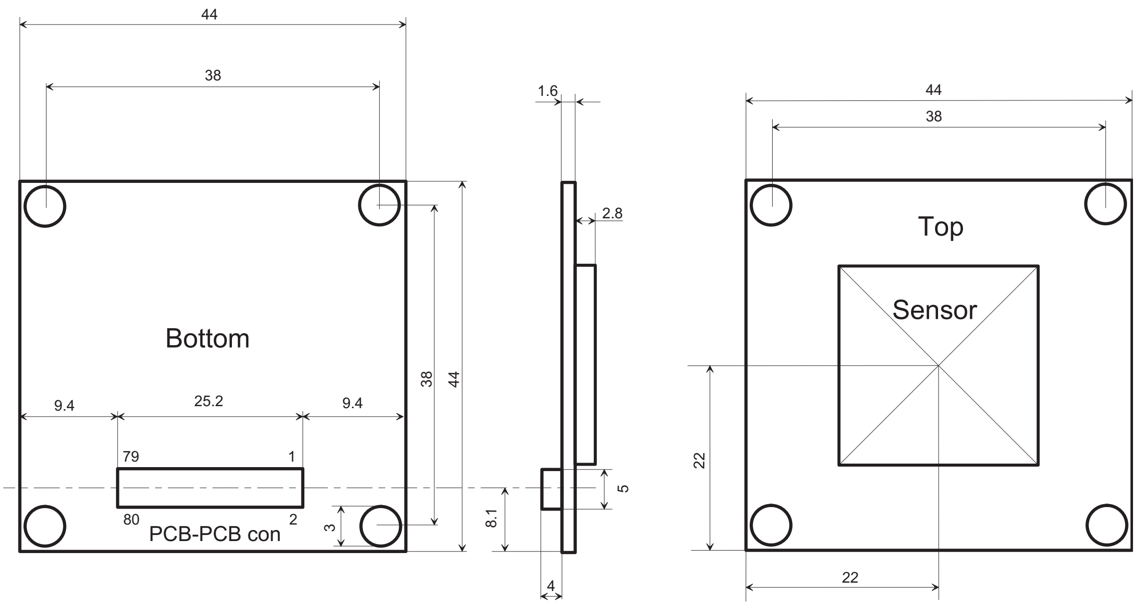

Figure 6.1: Mechanical dimensions of the OEM-D752E and of the OEM-D1024E sensor modules

The pin numbers of the PCB board-to-board connectors are indicated in Fig. 6.1 and Fig. 6.2 for clarity of pin assignment. The PCB board-to-board connectors (DF17 series, two-piece connector, stacking height 5-8 mm) are available from Hirose (www.hirose-connectors.com). Details of order number are listed in Table 6.1.

Connector type	Part Number
Header	DF17(2.0)-80DP-0.5V(51)
Receptable	DF17(4.0)-80DS-0.5V(51)

Table 6.1: Ordering details of the PCB board-to-board connectors (HRS conncetors)

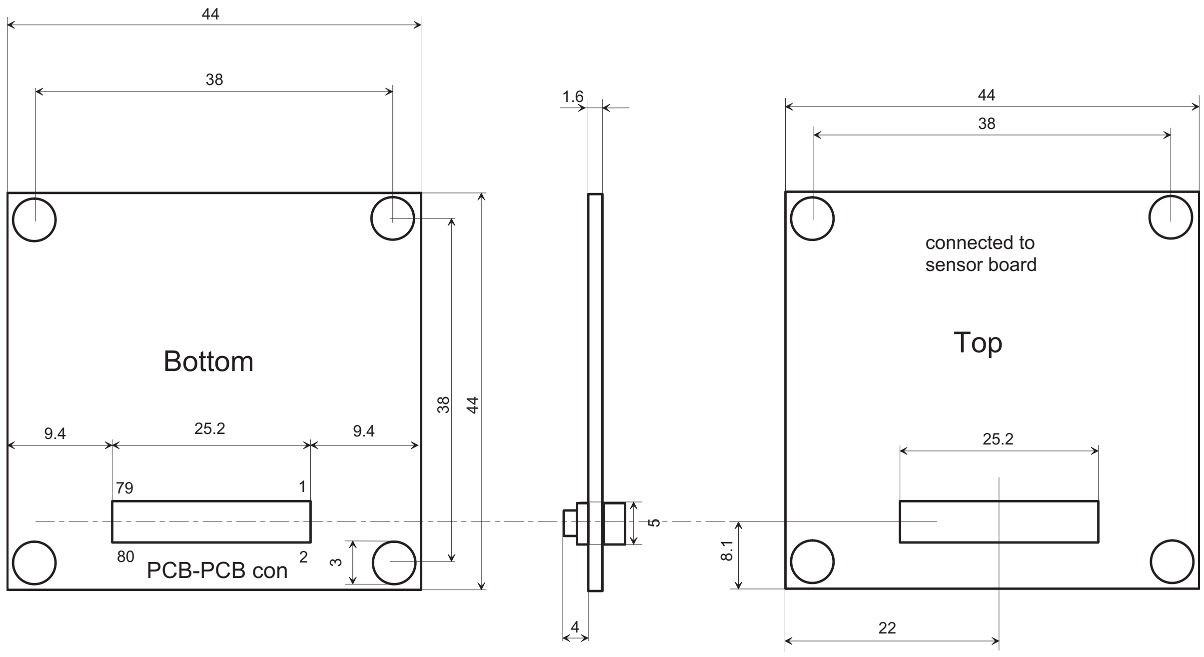

Figure 6.2: Mechanical dimensions of the OEM-ADCE-160-12 module. The top of the OEM-ADCE-160-12 module gets connected to the sensor PCB.

The outline dimensions of the A1024B sensor are displayed in Fig. 6.3. All dimensions are in mm. The optical centre of the pixel matrix is located centrally in the sensor package.
The sensor die is encapsulated using a black epoxy passivation material. The optically active area of the A1024B sensor is free of this material. The absence of a glass lid minimizes the number of elements in the optical path to the sensor.
The upper surface of the sensor is resistant to common solvents and cleaning solutions. Nevertheless, care must be taken when handling or cleaning the sensor, particularly since scratching may result. For further details on sensor cleaning, please refer to Section 6.2.

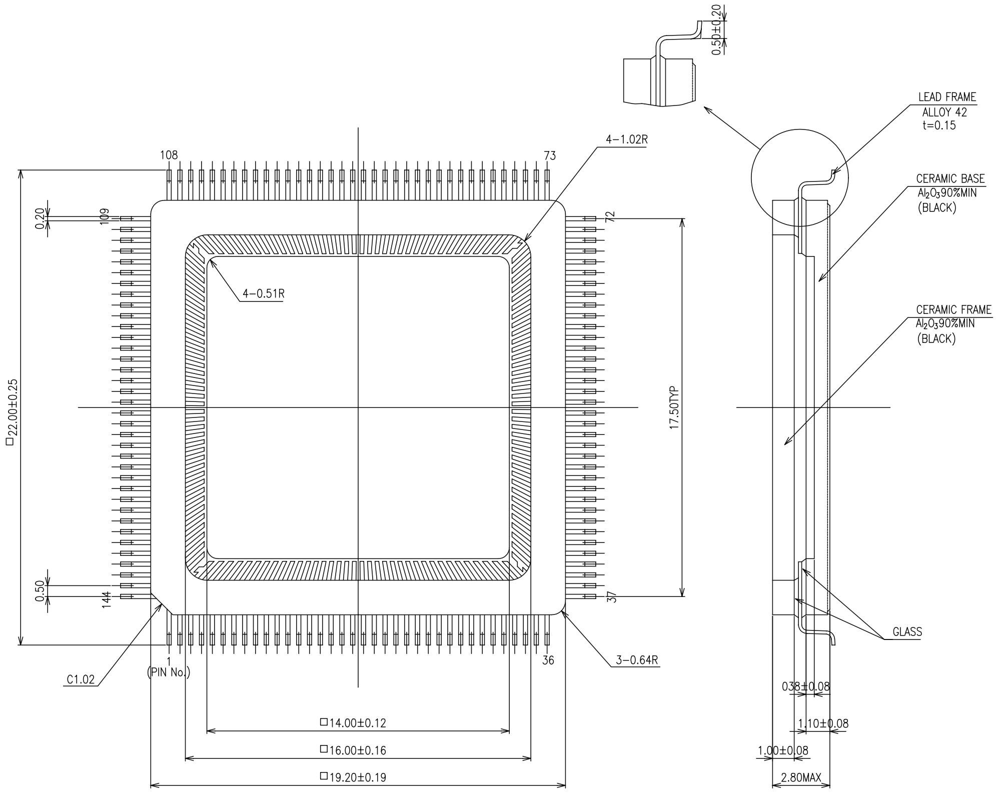

Figure 6.3: Outline dimensions of the A1024B sensor in the OEM-D752E-40 and OEM-D1024E-40 modules.

6.2 Optical Interface

6.2.1 Cleaning the Sensor

The sensor is part of the optical path and should be handled like other optical components: **with extreme care**.
Dust can obscure pixels, producing dark patches in the images captured. Dust is most visible when the illumination is collimated. Dark patches caused by dust or dirt shift position as the angle of illumination changes. Dust is normally not visible when the sensor is positioned at the exit port of an integrating sphere, where the illumination is diffuse.

1. The camera should only be cleaned in ESD-safe areas by ESD-trained personnel using wrist straps. Ideally, the sensor should be cleaned in a clean environment. Otherwise, in dusty environments, the sensor will immediately become dirty again after cleaning.
2. Use a high quality, low pressure air duster (e.g. Electrolube EAD400D, pure compressed inert gas, www.electrolube.com) to blow off loose particles. This step alone is usually sufficient to clean the sensor of the most common contaminants.

   Workshop air supply is not appropriate and may cause permanent damage to the sensor.

3. If further cleaning is required, use a suitable lens wiper or Q-Tip moistened with an appropriate cleaning fluid to wipe the sensor surface as described below. Examples of

suitable lens cleaning materials are given in Table 6.2. Cleaning materials must be ESD-safe, lint-free and free from particles that may scratch the sensor surface.

Do not use ordinary cotton buds. These do not fulfil the above requirements and permanent damage to the sensor may result.

4. Wipe the sensor carefully and slowly. First remove coarse particles and dirt from the sensor using Q-Tips soaked in 2-propanol, applying as little pressure as possible. Using a method similar to that used for cleaning optical surfaces, clean the sensor by starting at any corner of the sensor and working towards the opposite corner. Finally, repeat the procedure with methanol to remove streaks. It is imperative that no pressure be applied to the surface of the sensor or to the black globe-top material (if present) surrounding the optically active surface during the cleaning process.

Product		**Supplier**	**Remark**
EAD400D	Airduster	Electrolube, UK	www.electrolube.com
Anticon Gold 9"x 9"	Wiper	Milliken, USA	ESD safe and suitable for class 100 environments. www.milliken.com
TX4025	Wiper	Texwipe	www.texwipe.com
Transplex	Swab	Texwipe	
Small Q-Tips SWABS BB-003	Q-tips	Hans J. Michael GmbH, Germany	www.hjm-reinraum.de
Large Q-Tips SWABS CA-003	Q-tips	Hans J. Michael GmbH, Germany	
Point Slim HUBY-340	Q-tips	Hans J. Michael GmbH, Germany	
Methanol	Fluid	Johnson Matthey GmbH, Germany	Semiconductor Grade 99.9% min (Assay), Merck 12,6024, UN1230, slightly flammable and poisonous. www.alfa-chemcat.com
2-Propanol (Iso-Propanol)	Fluid	Johnson Matthey GmbH, Germany	Semiconductor Grade 99.5% min (Assay) Merck 12,5227, UN1219, slightly flammable. www.alfa-chemcat.com

Table 6.2: Recommended materials for sensor cleaning

For cleaning the sensor, Photonfocus recommends the products available from the suppliers as listed in Table 6.2.

Cleaning tools (except chemicals) can be purchased from Photonfocus directly (www.photonfocus.com).

7

Warranty

The manufacturer alone reserves the right to recognize warranty claims.

7.1 Warranty Terms

The manufacturer warrants to distributor and end customer that for a period of two years from the date of the shipment from manufacturer or distributor to end customer (the "Warranty Period") that:

- the product will substantially conform to the specifications set forth in the applicable documentation published by the manufacturer and accompanying said product, and
- the product shall be free from defects in materials and workmanship under normal use.

The distributor shall not make or pass on to any party any warranty or representation on behalf of the manufacturer other than or inconsistent with the above limited warranty set.

7.2 Warranty Claim

The above warranty does not apply to any product that has been modified or altered by any party other than manufacturer, or for any defects caused by any use of the product in a manner for which it was not designed, or by the negligence of any party other than manufacturer.

8 References

All referenced documents can be downloaded from our website at www.photonfocus.com.

CL CameraLink Specification, Rev. 1.1, January 2004

SW002 PFLib Documentation, Photonfocus, August 2005

AN001 Application Note "LinLog", Photonfocus, December 2002

AN024 Application Note "LinLog - Principle and Practical Example", Photonfocus, March 2005

AN007 Application Note "Camera Acquisition Modes", Photonfocus, March 2004

AN010 Application Note "Camera Clock Concepts", Photonfocus, July 2004

AN021 Application Note "CameraLink", Photonfocus, July 2004

AN026 Application Note "LFSR Test Images", Photonfocus, September 2005

9

Revision History

Revision	Date	Changes
1.2	April 2012	Chapter "Hardware Interface", section "Connectors"/"Pinout PCB connector": pin number of VDD_33 was wrong.
1.1	October 2010	Section Hardware Interface / Trigger / Trigger Modes / Level-controlled Exposure: corrected bug in tip: level-controlled exposure is not supported in simultaneous readout mode.
		Section Mechanical and Optical Considerations / Optical Interface / Cleaning the Sensor: updated link to supplier web page.
		Section Functionality / Test Images: added section for OEM-D752E.
1.0	August 2010	First Release
0.2	October 2007	Draft Version