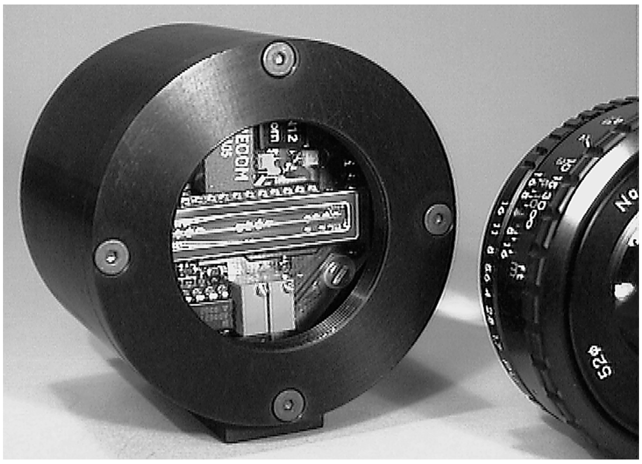
Manual

for CCD - line scan camera system CCD1000



and for CCD - line scan camera system CCD 2000

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Berlin, den 16.8.1996

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Part I Instruction Manual

1 Introduction

Our **Line-scan cameras** can be delivered with 128, 256,1024, 1728, 2048, 3456, 5000 or 7926 pixel (pixel = “picture elements”). The pixel are **set up in one line** and so you get a one-dimensional optical multi channel detector. Special area sensors are also available, which can be used as a line sensor with improved sensitivity and reduced noise. Here special binning features are possible.
The sensors, which are used mainly in copiers and fax machines, suit particularly also for all other kinds of optical measuring tasks. For example optical object recognition and tests in quality control, position-, distance- and way measurement, spectral analyses and laser beam profile diagnostics and many more.

The optic signal can be coupled directly or focused with a lens to the sensor.

The sensor is sensitive over a spectral range of 400 to 1100 nm. With sensors without window or with quartz window an expanded spectral range from 200 nm is possible.

Supplementary available are special line sensors for spectroscopy, which are sensitive in the near infrared range from 0.9 µm to 1.7 µm or to 2.5µm. These sensors have to be cooled thermo electrically to -20°C for dark noise reduction. We can deliver complete camera systems with stable cooling and a sealed case for avoiding condensation at the detectors window.
Specially coated sensors are also available which are sensitive in the X-ray range of 10 to 100 keV.

In our CCD- linescan cameras the complete sensor electronic for clock and level control is integrated, as well as an 8 bit parallel interface for data transmission. Also a 12 and 16 bit A/D- converter is possible. Data transfer rates of up to 33MHz are possible. The Software and plugs of series 1000 and series 2000 are compatible. The camera interface is compatible with our PCI- ISA or a simple parallel printer interface, whereby, however, the maximal data transmission speed is different. We offer also Interfaces with improved noise immunity (LVDS) and a fibre link interface for long distances.

Sensors with a 12 and 16 bit resolution leads indeed to a doubled data transmission time. Besides this, the noise of some sensors at room temperature are relatively high, so that an advantage of 16 bit solution will suits best with an additional available thermo electrical cooling - especially for the extended IR types.

Also a connection to non IBM compatible computers is possible, but however, 8 data lines (computer-input) and 2 handshake lines (computer-output) are required.

The CCD-control unit is only required in a setup without computer! The signals here can be observed directly with an oscilloscope. This is e.g. meaningful for adjusting lasers, where a direct control of the signal is more important than storing the data.

For running the camera with a IBM compatible computer, we suggest our comprehensive software program. This program contains the entire interface programming, also for the operation of several cameras simultaneously, as well as a graphic part for the display of the data on the screen. The program can be delivered with sourcecode (MS visual C++), so that you can make all necessary changes you need for your own application.

1.1 Sensors

The sensor reacts similar to a chemical film: the light is integrated in the sensor cells, until the read out sequence is started. The exposure time is determined by the distance between two reads and as a result the sensitivity can be increased by raising that interval.
The simplest way to use the camera is a continuous read of the line with a constant repetition rate. Here it is important to pay attention to a constant frequency, considering that the oscillation of the read-out frequency leads to an immediate oscillation of the signal.

The increasing of the sensitivity is restricted by darkness noise and read-out time of the registers.
For bright light condition a short exposure time has to be chosen. Since the deleting of the storage cells is only possible by a read of the complete line, the shortest exposure time is determined by the read sequence of one entire line.
An overexposured signal can be dimmed only with optical filters, whereby such a signal does not lead to the destruction of the sensor - unless you evaporate the chip!

For low light levels you should choose a long exposure time. According to the sensor the thermal darkness noise reaches saturation after about 5 to 50 seconds at room temperature. A cooling to -20 °C can reduce this noise about 100-1000 times.

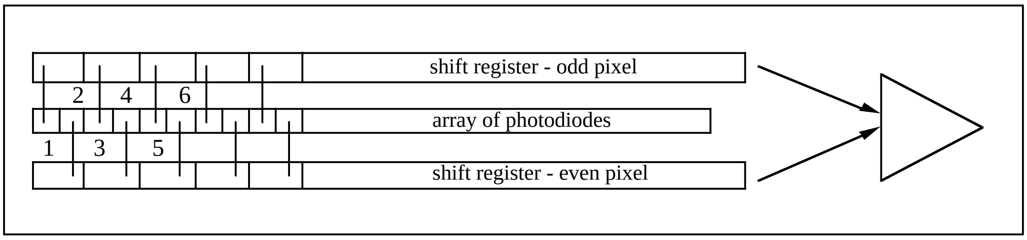
There are three main classes of sensors available:

Table 1.1: Sensor types

	Advantage	Disadvantage
CCD- sensor	price tiny pixel size	asymmetrical even/odd pixel
PDA (photo diode sensor)	good dynamic range uv-sensitive anti blooming not asymmetrical	expensive read-out at different times
FFT-sensor (full frame transfer) also called TDI (time delayed integration)	30..100 times more sensitive	expensive read-out at different times not uv-sensitive no anti blooming

a) <u>CCD line-scan sensor</u> (manufactured by Th, So)
These 'charged coupled devices' (CCD's), suit especially for opto electronic picture sensors. Picture sensors of this kind contain a sensor area assembled with photo diodes, as well as two parallel CCD-shift registers. The registers consist of side by side lying storage cells (MOS-capacitors), which can store charges through connecting to an outer voltage. Through the linkage of the individual storage cells a CCD-shift register is formed, which transports the electrons with several clocks to the output amplifier. There is one register for the even and one for the odd storage cells:

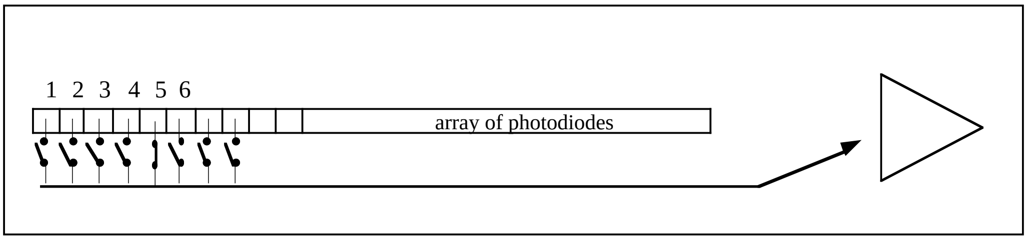
picture-1.1: CCD-sensor



After the start signal all electrons collected in the photo diode area are simultaneously submitted to the shift-registers. They were transported afterwards serial to the output. There they are translated into a voltage signal and yield to a video-signal corresponding to the exposure of the cell.
Between two read-out sequences, as well as during the transport through the shift registers, the newly arriving photons will already be integrated in the photo diode area.

b) Videoline-sensor (manufactured by Hamamatsu only applicable in series 2000)
This sensor type contains no CCD-shift registers. Instead there are switches implemented, which connects respectively one photo diode after the other to the output amplifier.

picture-1.2: Videoline-sensor



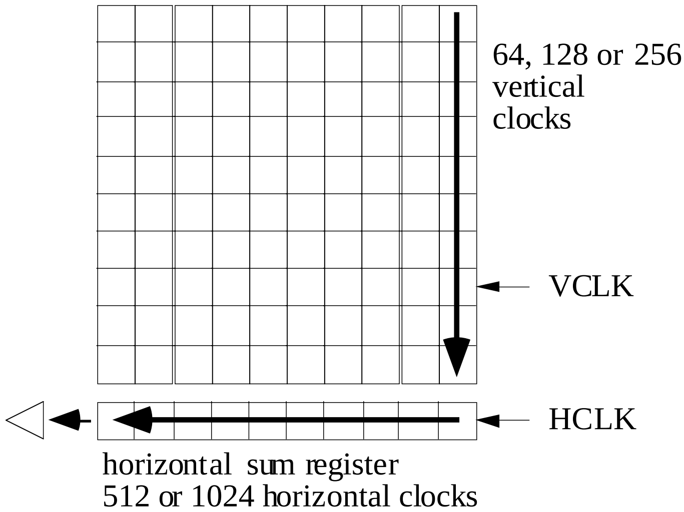
After the start signal the switch control is reseted and the diodes are connected successively to the output amplifier. Light which falls on the diodes during read-out is determined at different times, depending on the pixel number.

c) FFT-CCD-Array sensor (manufactured by Ha, Dalsa only series 2000)
This array sensor is operated like line sensors. Because of its construction the sensor reaches a higher sensitivity as standard sensors. ‘FFT’ stands for ‘full frame transfer’ (is also designated TDI).
The FFT sensor has no extra memory on the chip and therefore the entire space is filled with photosensitive cells (100% fill factor).

Also available are Interline arrays, with several standard lines on the chip, that means a complete shift register beside each line. These sensors obtain gaps between the sensor cells (fill factor 10-90%) but they can store the complete picture at a given trigger.

Like the video line sensors, the FFT's are read out at different points of time. This vertical clock phase is about 64/ 128/ 256 x 10 µs = 0.64/ 1.28/ 2.56 ms long and starts directly after calling the program procedure GetCCD.

picture-1.3: FFT-sensors



First all vertical pixels are transported to the sum register and are added there. The horizontal register is read afterwards like a line sensor. This operation mode is called 'binning mode'. The improvement of the noise reduction is √ 64, 128 or 256. The resolution of the following analog/ digital converter is now limited only through the read-out noise.
This reduces the dark noise up to 10 times with 3 different clock voltage levels (MPP: multi pinned phase).

Like the video line sensors, the dark noise of FFT sensors can be reduced with a cooler up to 1000 times.

Since these sensors use the pixel cells for storing and transferring of the data they need no extra registers on the chip. The advantage is a 100% fill factor, but the disadvantage is a need for a mechanical shutter for cw signals. Otherwise the transferred data is smeared with the new accumulated light data.
For slow pulsed signals (< data read time) the sensor can be used without a shutter.

1.2 Line-scan cameras

The camera has a M 42 mount for the connection of standard lenses. Into the camera a complete interface with A/D-converter and transfer logic for a parallel data transmission to a computer is integrated.

The cameras can be operated simple with a printer interface. For Windows complete software programs are available. Also installations at other computers are possible. Therefore an interface programming must be developed.
Each camera of series 2000 has a selectable address, that makes it possible to operate several cameras parallel.
The linescan cameras of series 1000 is exclusive designed for single-phase-CCD's of the Sony Corp. The sensors have, according to type, different middle distances from pixel to pixel (pitch). This pitch reaches from 5 µm to 14 µm. The effective sensor length can be calculated by the number of pixel multiplied with the pitch:

i.e. Sony 2048 x 14 µm = 28,672 mm.

The maximum exposure time, limited through temperature depending darkness noise, reaches at room temperature about 2 seconds according to the sensor.
The minimal exposure time corresponds to the read-out time of a complete line and can be calculated through the number of pixels and storing time for one data value:

i.e. 1800 x 2 µs = 4,1 ms.

The maximum transfer speed usually depends on the interface. This is evident through the interface limits. However with the PCI interface the sensors maximum frequency is the limiting factor:

Printer port	fmax = 200kHz
ISA Interface	fmax = 1 MHz
PCI Interface	up to fmax = 33 MHz

For the measurement of optic signals at inaccessible places a small adapter board is available, with which the sensor can be pursued outside the camera case. The circuit board is about 40 x 30 mm and available with a 0.5m long cable. This adapter board is connected with the camera case. It is not usable with highest data rates.

In addition we offer a stable micro positioner with a shielded case for these boards.

1.3 Before starting

The cameras are delivered presetted and there are no further adjustments necessary. The power supply of the camera is connected to # 12 and# 13 of the connecting cable. Our modified interface-board joins these connections to the internal supply of the computer (4.5V< U+ < 5.5V)

! Before installation the interface board you have to remove the BNC-Cinch-connectors. Otherwise the interface-board does not fit in your computer.**!**

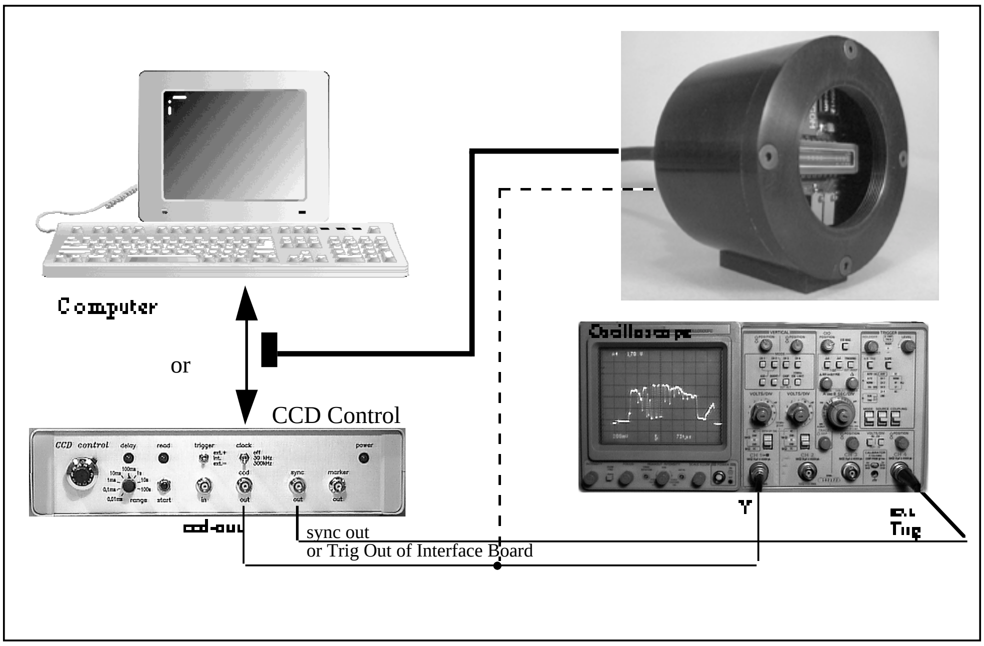
It is possible that our software must be configured to your system. You can find the installation menu in chapter-2.1.4.

To both BNC-sockets of the camera case of series 2000 an oscillograph for the examination of the signal can be connected. The BNC-socket under the LED serves the external trigger signal for the oscillograph. The BNC-socket under the DC-In socket transfers the analog video signal of the sensor. Series 1000 has only one plug for the video signal (picture-1.4).

1.4 Starting setup

After the camera was linked to the computer or to the CCD-control, the function can be examined using some simple experiments.

picture-1.4: Setup the connections



To run the camera with

Computer: Connect camera cable with interface board, turn on the computer, insert the CD and start the PC. First install the driver as shown in chapter-2.1.1. After installation and a restart our software WCCD should be used first to test the camera. You now should recognize a complete picture frame with a menu and a X and Y- Scale on the screen. If WCCD was not purchased, you will find a demo version on the CD, which has the all features but no print and save function.
You can start the measurement with F6. First the measure setup menu appears, where you can edit the exposure time and several other options. After pressing the ok button, the measure loop starts. In the picture frame the brightness distribution over the line is now repeatedly displayed. The measurement can be stopped by pressing the ESC-key (immediately) or Space key (stops after a complete measure loop is finished). Please see chapter-2.1.6 for details.

CCD control unit: Connect the camera cable to the CCD control, turn on the CCD control (switch is found on the rear). The power LED necessity flashes indicating the read cycle. The switches should be on position: trig= int, trig= +, delay= 60 ms, clock= 300 kHz. Now the LED read and delay XCK should flash in tact of the read cycle. If not, please press the start button again. With the delay XCK the exposure time can be varied. The oscilloscope should be connected, as shown in picture-1.4, with the sync out and CCD out connectors. Choose the time resolution, that exactly one read-out cycle fits on the monitor.

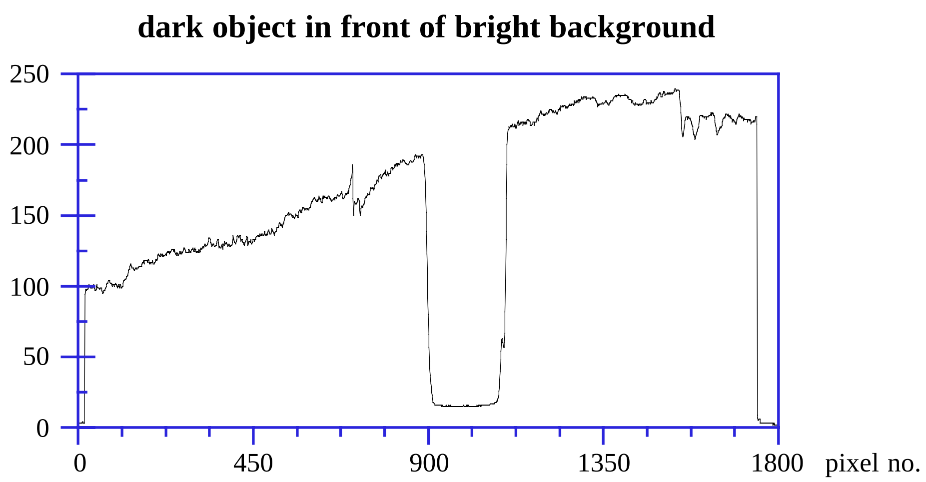
Furthermore, as shown shaded in picture-1.4, when operating the camera with a computer the video signal can be observed by an oscilloscope.

1.5 First simple experiments

As first step the following attempts may be made to get familiar with the functions:

1. Darken the camera mounting hole - now all sensor signals should be near zero.
2. If stray light falls on the sensor -all values are 255 (12 bit : 4096, 16 bit : 65000).
3. Now darken up only a part of the lens hole with your hand. You should be able to produce a brightness distribution similar to the picture-1.5 (without object in the middle). All function values between 0 and full scale must be achievable.
4. Produce stray light and perhaps change the exposure time to produce a background level at a value of about 200. Now take an object, i.e. a pen and darken carefully some of the pixels of the sensor. Move the pen over the line. It should emerge a picture similar to picture-1.5, whereby the edges are less steep in this case, because in picture-1.5 a dark object has been scanned with a lens sharply focused.

picture-1.5: Example scan of an object

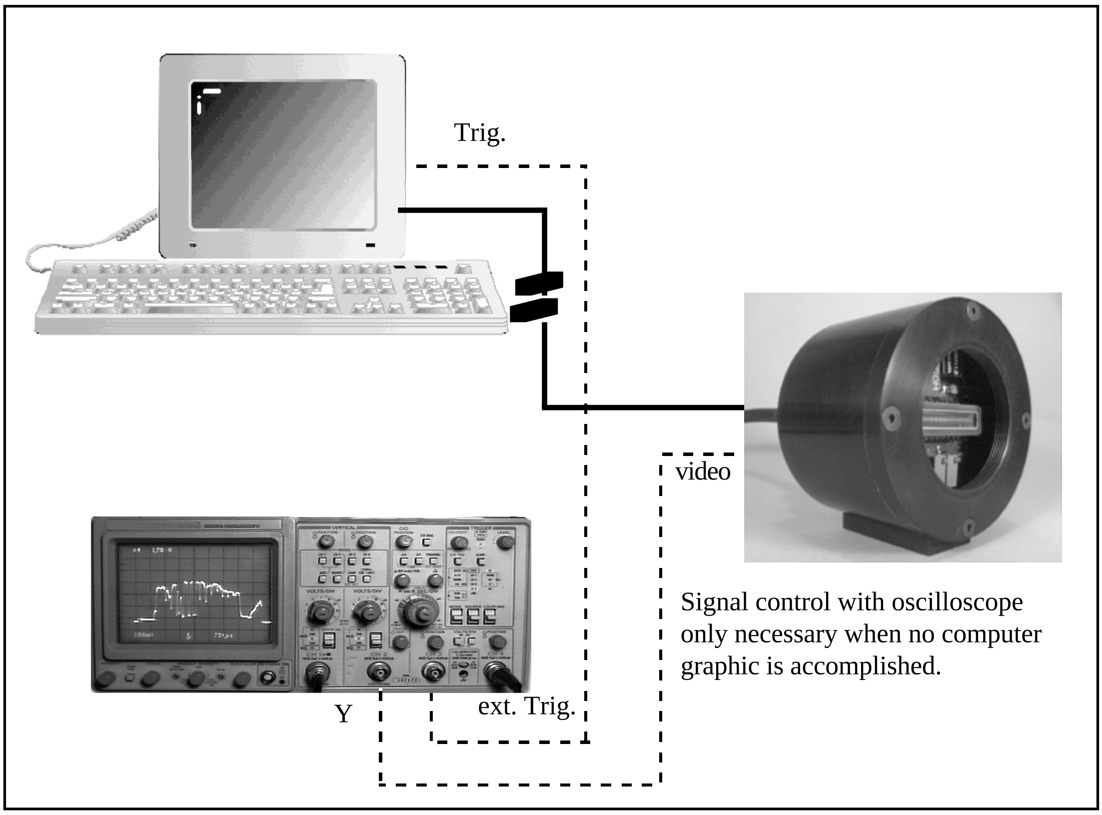


2 Operation with computer

Thanks to all the sensor and interface electronic is integrated in the camera, the programming of the computer interface is really simple. You can use a parallel standard input interface, i.e. printer interface with input capability.

For the IBM-PC compatible we offer a ISA- or PCI- interface board with additional connectors for external trigger input and output.

picture-2.1: Setup with computer



The computer can manage several cameras, which are addressable. With the Digital or Analog Distributor the cameras are operated parallel or sequentially with one interface board (chapter-4.3).

Our software manages to read, store and display the data on the screen. An on-line loop reads the data and displays it until a keystroke finishes the loop. The least measured data remains in the memory.

The DOS version: **CCD** is still interesting for high speed real time applications. Please order separate manual.
For the windows version: **WCCD** the camera drivers have to be installed in the system before use. Please see chapter-5.1.1.

2.1 Windows software ‚WCCD‘ description

The software contains already many options of an extensive measuring program. It has functions for loading and storing data, for mathematical manipulating of the data as well as for displaying, printing and analyzing data. Nevertheless not all possible applications could be considered by this program. For the purpose of special applications the source code is available. This is written in MS visual C++ and contains a frame loop, in which your own program parts could be integrated easily. This makes all thinkable processing of your data possible.

2.1.1 Installation

First you should install the board.
Switch the computer off, insert the board and switch the computer back on.
Now the drivers have to be installed.

PCI Board
When windows is starting it detects the board and asks for a driver. Just select the path where the LSCPCI.INF and LSCPCI.SYS files are located.. Restart computer

ISA Board
Start the CCDInst.exe program and select Install LSCISA1. Use the default $258 address for the board. Restart computer.

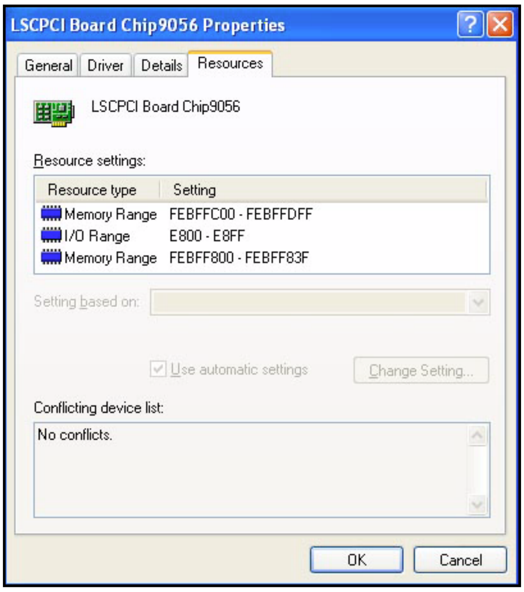
Printer Port
When using the printer port, the driver for the ISA Board has to be installed as described above (use also 258 address here!). After that the camera setup menu of WCCD must be chosen to set the interface to the appropriate printer port address (usually 378- see next chapter).

Refer to chapter-5.1.1 for more information.
Now, copy WCCD.EXE, CCDPrefs.def and Belichtung.par to your hard disk. After that start WCCD on your hard disk..

2.1.2 Correct system recognition

When the driver was found the system should have granted the resources the board needs. The correct list of the hardware device manager should look like picture-2.2. The base address may differ, but the memory ranges must be the same.

picture-2.2: mapped resources of PCI board

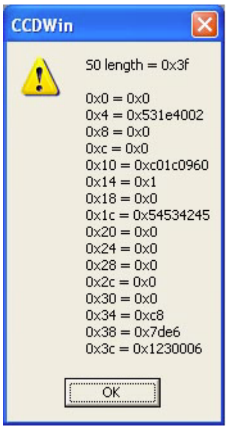


If these 3 mapped areas are not seen, a hardware problem occurred and you should remove the board. Before asking for help, please try another PC, as sometimes a problem exists in the main board of the Computer. Also flashing the newest BIOS for the main board may help here.

2.1.3 Space0

The PCI board maps several control register into the memory range of the PC. These registers are explained more deeply in chapter-4.2.4. For control of correct mapping these registers should look like picture-2.3.

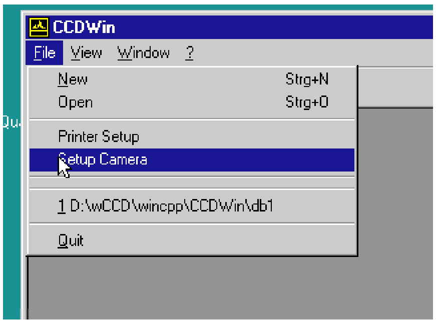
picture-2.3:



The S0 length could be 0x0f,0x1f or ox3f
The entry at 0x3c is the version of the PCI board which is also seen on the label of the board. The other values may differ.

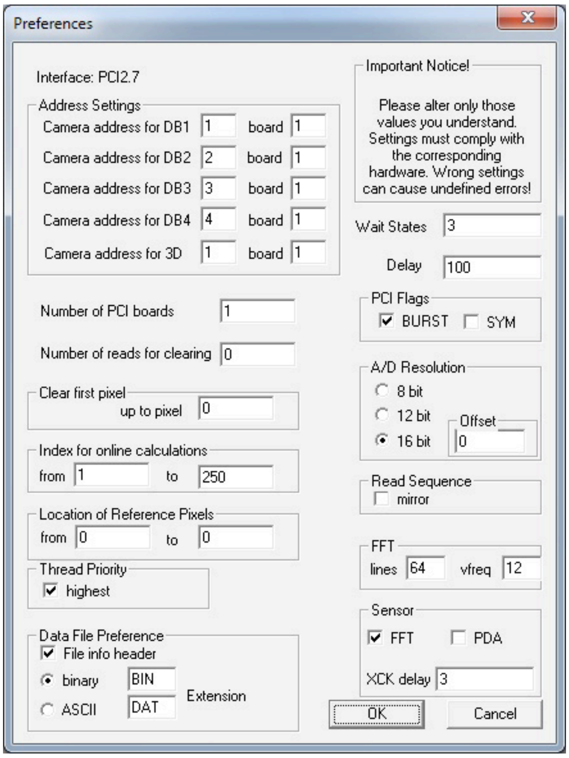
2.1.4 WCCD setup menu

If no data window is open (to get there all data windows must be closed) the main menu has an entry for the camera setup:
picture-2.4: camera setup



The values entered here depend on the hardware of the camera and align the software to the various sensor and camera types. These values must exactly correspond to the hard-ware. The values are stored in a CCDPREFS.DEF- File in the applications directory and must be entered only once.

picture-2.5: camera setup menu



The Interface could be PCI or ISA with the appended Version of the driver. In case of ISA a select box appears and can be used to switch between the ISA interface (set to ISA) or the printer port (select port address - default: 378).

In the address select field each data array can get his own camera address. This must be entered if more than one camera is used. The cameras can have addresses for parallel operation mode with a distributor (chapter-4.3.5) and if more than one interface board is used, the board no. can be entered. Default: all addresses correlate with their array index. Standard cameras do not notice this address, so the value does not matter (except for calibration of 16 bit A/Ds).

Number of cameras (1..4): The number of cameras is set here which should be read simultaneously by the software in the main loop. default = 1

The parameter wait states (0..50) delays the read operation for slower cameras. With high sensitive sensors (Ha) the noise can be reduced hereby. default: 0 wait states.

After the sensor has been overexposured, it must be cleared by several read cycles. The clear read parameter specifies how many reads should be used before a one shot measurement is started.

The resolution 8/12/16 bit must be set to the corresponding cameras internal A/D-converter. The resolution can not be switched by software!

The Online index for calculations sets the range, in which the mathematical functions are calculated. The range must be inside the pixel range.

With the Clear first pixel box the first pixel of the line can be set to zero. On some sensors these pixel have a value ≠ 0.

The refpixel index specifies the index for some sensors which have dark reference pixels. If these values are ≠ 0 the mean value in the specified range is calculated and subtracted from the actual measurement as the dark value. The range must be inside the pixel range.
Some sensors do have reference elements, which can be used for automatic determination of the ground level. With location of refpixel the position of these pixel can be specified. These pixel are darkened picture elements which shows the ground level noise in conjunction to the temperature and exposure time. With dynamically online noise subtraction enabled, the mean value of these pixel is determined and subtracted from all pixels. The position of ref-pixels can be found in Table 8.7 on page 152. In case of doubt you can check the position with the cursor. The x-position is directly given by the pixel number.

The file extension entered here is the default extension for saved data to disk.

Data format can switch between TEXT (for further processing with other software) or binary. Binary need less space on the hard disc but data is only readable from the CCD-software. The text format have CR/LF for data separation.

With the mirror read sequence Flag the data direction can be changed. That could be useful for spectrometers where the longer wavelength should be at higher pixel no.

For FFT sensors the number of vertical lines must be set here. For standard sensors this value must be 0.

The flags SYM and BURST are used to setup cameras with very high data rates (>10MHz). Detailed information is in chapter-4.2.8. In FIFO mode BURST should be set to TRUE and SYM to FALSE.

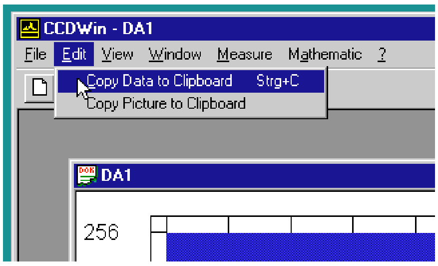
2.1.5 WCCD - Software instruction main menu

The file menu implies the file load and save as well as the print functions.
The data of the active window is loaded or saved. When using the 3D window, all data is saved in one file.

picture-2.6: file menu

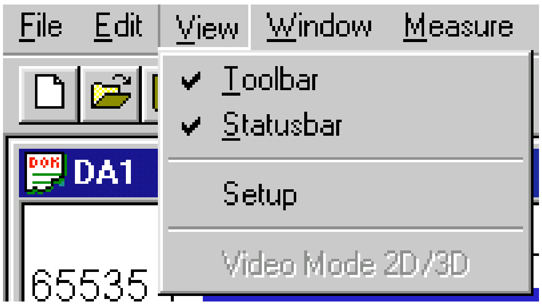
In the edit menu, data or graphic can be exported to the clipboard.
Data is exported in text format and graphic in bitmap (bmp) format.

picture-2.7: edit menu



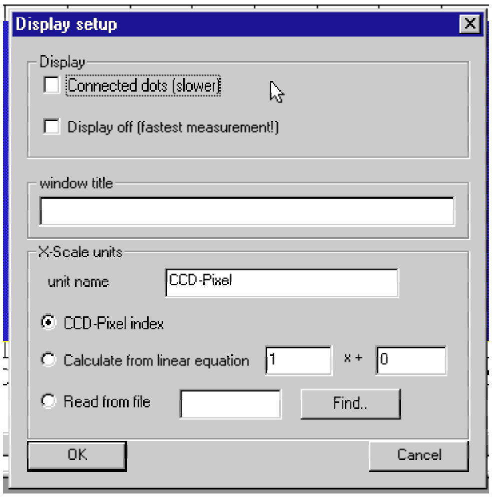
The view menu is used to setup the display window.

picture-2.8: view menu



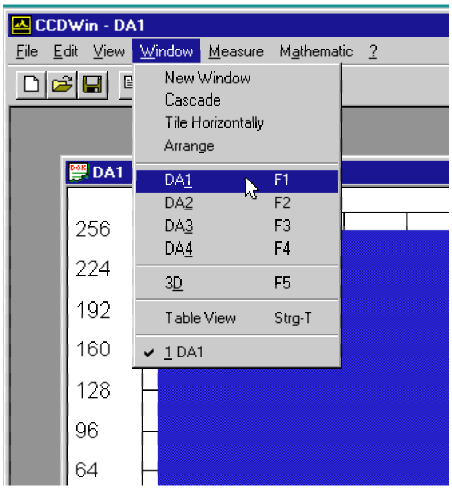
In the view setup, the x- scale parameters can be changed. The default scale is just the pixel number. Usually a linear equation is used to implement other scales.

picture-2.9: view setup menu



To start a new measurement, one of the main data windows (DA1..D4, 3D) must be opened. DA1..DA4 are just data areas for up to 4 measurements. The 3D window is intended to measure a complete block of several line scans. For FFT sensors that’s a complete area scan, for standard cameras that’s a block of line scans, which can be saved or manipulated afterwards.

picture-2.10: main data acquire window



Here some keys have a special function:

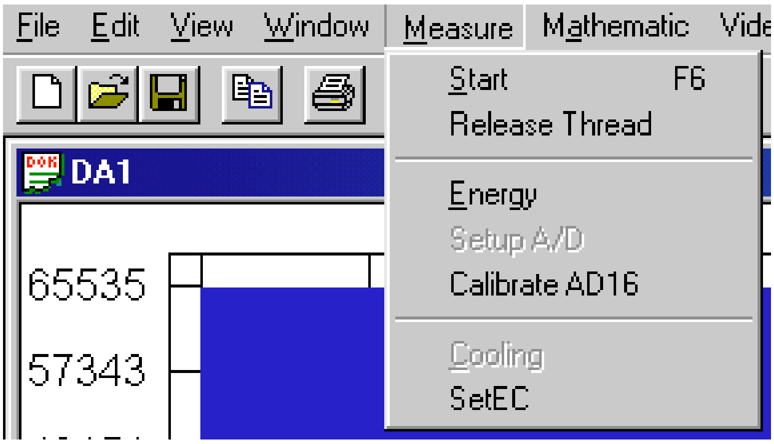
⇐ ⇒ With the help of the arrow keys you can walk through the data array in X-direction.

⇓ ⇑ With these arrow keys you can zoom the X-axis. According to the zoom factor the x- scale changes. However, in the memory always the entire line data is stored. For the correct shift the zoom factor has to begin on the left trim with pixel no. 1.

Shift ⇓ ⇑ changes the scale of the Y-axis in the power of 2. In this way data arrays can be presented also with Y-values larger then 255 (added measurements or 12 and 16 bit-values).

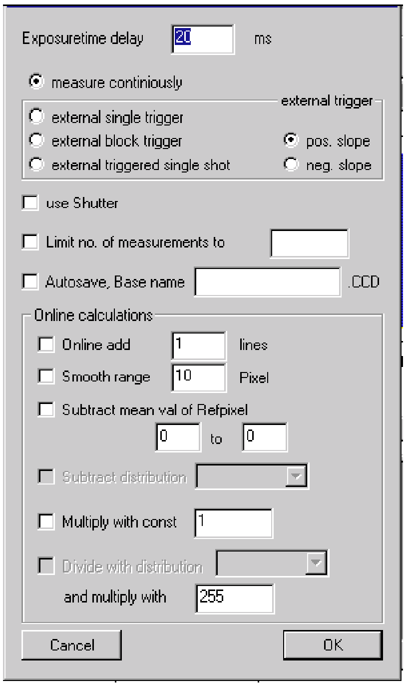
2.1.6 WCCD - Measure loop

After a data window is opened, a new measure cycle is started with the start menu item.
picture-2.11: measure menu



Also the Calibrate Functions for 16 bit A/D converters and the Cooler Control for cooled systems are located here. The SetEC menu can setup electronic controlled sensors (see chapter-2.2.8).

Start measure
Here the exposure time and the trigger modes can be altered. Also some online calculations are possible. These mathematical functions are executed directly after the data is acquired and just before the data is displayed. All online mathematics are calculated directly in memory and the original data is lost!
picture-2.12: start measure menu

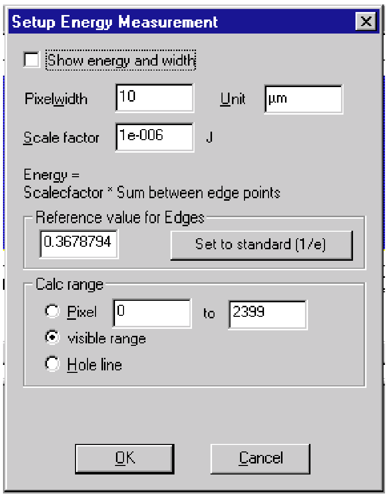


The use shutter function only apply to sensors with build in hardware shutter gate or with

an additional mechanical shutter. Here the exposure time is not the time between 2 read cycles, but the time the shutter gate is opened before the read cycle occurs.
With the auto save function automatic measurements can be realized. The data is stored with a number appended to the base name.
The trigger modes are described more in detail in chapter-2.2.
The limit no. of repeats function stops the measurement after the entered number of block reads have elapsed. Especially for 3D measurements the number of block reads can be limited. If the limit check box is not selected, only the space key will stop the block read.

If a 3D window was opened to start a block of measurements, now a new window asks for the block length.
For standard cameras the length is only limited by the amount of installed RAM. The upper limit is calculated and displayed each time the window appears.
If an FFT camera is used, the binning factor must be entered here, what limits the block length to the number of effective lines. So always the last complete picture is stored in memory, if the space key was hit.

The energy menu can be used for energy measurements of laser beams.
energy menu

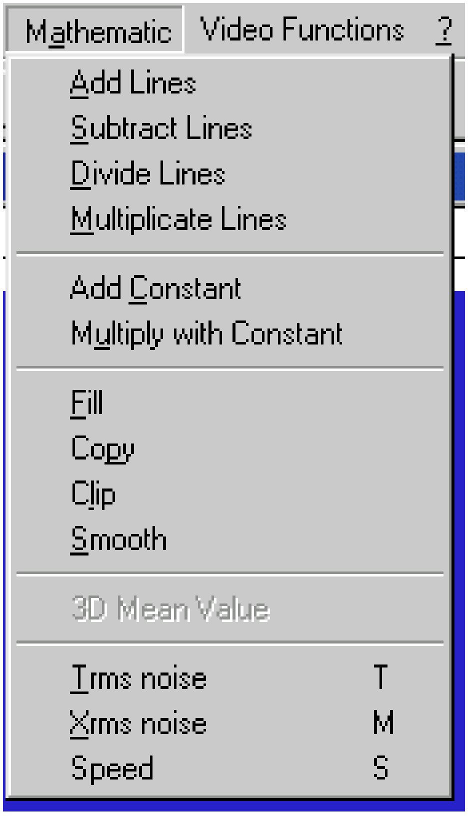


The energy option can also be used to find edges for a bright object.

2.1.7 WCCD - Mathematical menu

These functions are made for processing and manipulating the data. The four data arrays DA 1..4 can be added, subtracted, smoothed and filled. The source and destination arrays can be chosen independently, so that the original data arrays are not changed.

picture-2.13: mathematical menu



2.2 Timing sequences

The following chapters explain the functions of the start measure menu setup.

2.2.1 Internal Read Loop

When set to internal trigger the main timing generator sets the exposure time - entered by the exposure time delay value in the start measure menu. Here the shortest possible loop duration depends on the setup of several parameters.

Read Loop Scheme:
the generator starts the read sequence - set by exposure time delay which may not exceed the loop duration, or the loop becomes unstable.
if DAT is set, a delay after trigger occurs.
IF EC is set the exposure time for sensors with exposure control gate is generated
the READ time (depends on wait states for the specific sensor)
if Display is online (default) the time for a plot on the screen DISPL must expire.
- can be switched off in the view setup menu and can be found in the mathematical menu

-> timing window.
if online calculations are enabled, these calculation times have also to be added.

the WCCD program can measure online the actual timing and displays several values as tmin in the lower frame of the data window. Be sure to setup the exposure time delay higher then that value, or the loop cannot reach a stable state. If set too short, a warning will occur.

For very short exposure times the display time might limit the reachable repetition rate. In that case, the display should be switched off and a block read should be used. Therefore a new 3D window (F5) must be opened.
To disable the online display set Display off in the view setup menu.
Start the measure setup menu and enter a value for the number of lines which should be acquired in one block. Set also the limit no of measurements to 1 - means the computer stops after one block is acquired. After it is ready the scans could be displayed by moving through the block with the arrow keys.

2.2.2 External trigger

The read out sequence of the camera can be synchronized easily with an external trigger pulse. After pressing the ‘T’ key in the main menu, the internal clock generator is switched off and the read out sequence is started with the positive or the negative slope (setup of the slope with ‘+’ and ‘-’ key in the main menu) of the external signal.
The interface board has a BNC-plug for the trigger signal (maximum 30V) (see chapter-4.2).

In addition to the internal trigger mode an external block trigger mode, a single trigger mode and a single shot operation can be chosen.
The block mode starts a complete measuring cycle with the adjusted exposure time and addition cycles with one trigger.
The single trigger mode uses for each individual measurement a trigger pulse, especially when the on-line addition is active.

Since the first trigger pulse is not synchronized to the camera the first red data is rejected. The first measure signal would lead to an unsteady total signal. The camera is read by an addition of i.e. 4 signals 5 times.
The single shot mode is described in chapter-2.2.4

2.2.3 Laser pulse with long repetition rate

For some applications with repeated short term light signals the signal should not be integrated over the entire repetition rate. The ground noise grows during the long darkness period and worsens the signal noise ratio. This noise problem becomes relevant for an exposure time of more then 0.5 seconds.
Exactly this happens, if a pulsed laser is running with a long repetition rate. The laser flash has i.e.a pulse duration of 5 ns and is repeated with a frequency of 1 Hz (each second one shot).
An solution for this measuring problem is the following program loop:

Measuring loop

- repeat
- Clear camera n times (without storing to memory)
- until dead time almost run down
- wait for trigger (trigger of the laser system)
- wait exposure time (time within the laser pulse surely occurred)
- read line to memory
- until key was hit
-

Shortly before the pulse occur, the sensor integrates the light and waits the adjustable delay time. This measurement is stored with an significant shorter exposure time. Since the sensor can only be cleared read out, the delay time is used for repeatedly clearing of the sensor.

This algorithm has been realized in our control program and can be selected in the main menu with the F9 key.
The number of loops for clearing is automatically calculated by the trigger rate. If the trigger rate which has been entered is too big, only each second laser shot is sampled.
So you can get an optimal signal noise ratio.

Example:

- laser pulse with 0,1 Hz (10 s)
- light signal duration 8 ns
- light signal follows 170 ms after trigger

choose trigger rate = 10000 ms
choose exposure time= 270 ms (170 + secure factor)
read time (depends on computer) = i.e. 30 ms
The computer execute the calculated numbers of clear reads (10000-270)/ 30= 324 loops and waits then for the trigger signal. It awaits the exposure time 270 ms and reads the values.

2.2.4 Single shot mode

In some cases it might be necessary to start the read out sequence with a keystroke.
Thereby it must be considered, that the overexposured CCD sensors can only be cleared by several read out sequences. That means: if the camera has not been cleared for a long time, the memory cells are charged with electrons, and the first read out would only deliver a saturation signal.
As example a laser shot should be triggered by a keystroke and the single shot is detected by the camera (i.e. focus energy control).
For the solution of this problem following program has been realized:

If key was hit:

- clear the sensor (read camera 8 times without storing).
- create trigger signal for synchronization of the external instruments (on the

BNC Trigger Out of the interface board a low peak is generated to trigger i.e. a laser shot).

- wait the at F8 indicated delay time.
- read out camera and store values.

Instead of a key the single shot can be triggered with a TTL-signal or a remote control. Accordingly the BNC plug (Trigger In) of the interface board must be connected to the trigger source (VMax = 30V) (Chap.-4.1).

2.2.5 Noise subtraction

With the online noise subtraction 3 different corrections can be accomplished automatically:

1. Automatic subtraction of a constant value.
   The constant can be positive or negative and is subtracted after each measurement from every pixel (negative values lead to an addition).
2. Automatic subtraction of a distribution, which has been saved in one of the other data arrays previously.
   The distribution is subtracted after each measurement.
3. Automatic subtraction of the reference pixel values.
   Sensors with black reference pixel (b in Table 8.7 on page 152) can be used to correct the dark offset. The reference values are averaged after each measurement and the value is subtracted from each pixel. The position of these pixels in the line must have been entered in the setup (1./last reference pixel). If the value is zero, this function is switched off (default).

2.2.6 I/I0- Measurement for FFT- Sensor

With the FFT- sensors a special read sequence is possible: the fetching of measure and reference signal on one FFT chip. As the sensor is an area sensor, it could be used in a ‘reduced binning’ mode, so that it consists of only 2 lines. The chip is actually divided in two parts so that the upper part is summed in one data area and the lower part in a second one. The actual measurement on the upper part is read into DA=1 and the reference signal in DA=2. Afterwards the 2 scans are divided and the result can be found in DA=4. The last original measurements can still be found in DA1 and DA2.

This mode is enabled with the ‘I’ key in the main menu.

2.2.7 Parallel Read of several cameras

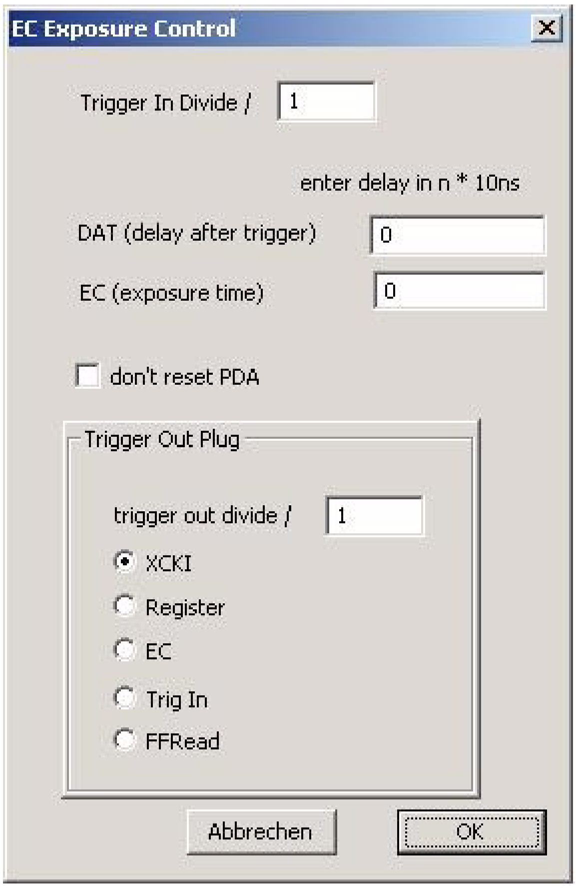
For reading 2 or more cameras in a loop the parameter „no. of parallel cams“ has to be set to the desired value (see chapter-2.1.4). In this case the GETCCD loop is called more than once. Here each data array DA1..DA4 can be set to on own address - when using a distributor -> chapter-3.2.4.2 - or when using multiple interface boards. The parameters are transferred in the order DA1, DA2 and so on.

If using the 3D- window, the highest data array is copied to the 3D memory. If i.e. „no. of parallel cams“ is set to 2, the DA2 data is copied to the 3D window and transferred to the memory block. The 3D- window can now mathematically be linked to DA1.

2.2.8 EC Control

The menu EC Control can set several bits of the DAT, the EC and the Trigger Options register. The DAT can be used with any trigger and camera, EC only for sensors with special EC control gates. (TH, Dalsa)

picture-2.14: EC Control Men



the options are more explained in chapter-4.2.4.9 to chapter-4.2.4.11
Trigger In Divide the input trigger can be divided down
Trigger Out Divide the output trigger can be divided down
DAT delay after trigger
EC exposure control - for PDAs and IL-C6 and TH78xx
don‘t reset PDA disables reset after reading for PDA sensors.

the trigger out plug of the PCI board can monitor several signals, but only one at a time.
XCKI default: high when camera is clocked
Register programmed by register CtrlA-D3
EC high during sensitive phase (shutter open)
Trig In output = trigger input -> can be used with divider to divide the freq
FFRead high when Fifo read is clocked - for testing.

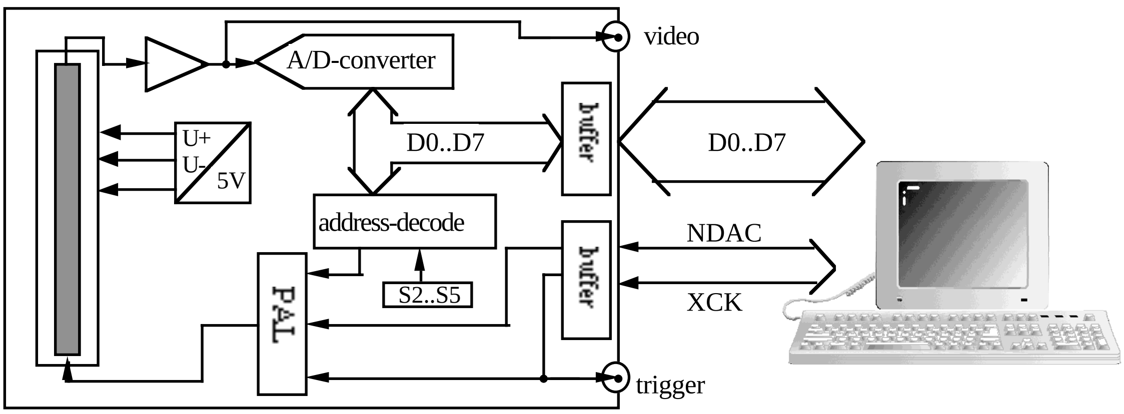
3 CCD-camera

In contrast to other CCD-cameras, this camera works with one in the camera case integrated A/D-converter and a parallel data transmission to the computer.

This has the advantage, that the data is written digitally directly to the kernel storage of the computer. Also there is no need for an additional video-A/ D-converter and memory board (frame grabber). All what is needed is a parallel interface. The additional memory board doesn’ t offer no genuine advantage, as long as the data must be reloaded for further processing to the main memory.
A further advantage is the pixel synchronous data transmission. Since one pixel is exactly transferred after the other, the digital value is always exactly related to the respective pixel number, which is not the case by the transmission of video frequency systems.
Also the frame rate can be chosen freely, there is no fixed video frequency necessary.
In addition an interface expansion for the organization of several cameras in parallel is simple to realize. The 8 data lines can be bi-directional, that means they can be used as input lines for reading of the data, as well as output lines for transmitting of addresses and commands. This is used with our distributor devices (chapter-4.3).

The camera works with a 8 bit data bus. The data of the sensor cells are transmitted value by value. The data is not stored in the camera, but directly in the computer, which acknowledges receipt of each value with a handshake signal (NDAC= no data accepted/ signal name of the IEC-bus). A second control signal (XCK='exposuretime') is active during the entire read cycle. The distance to the next following read cycle determines the exposure time.
Therefore the interface consists at least of 8 data- and 2 control lines.

All clock-signals necessary for the sensor are produced internally with the help of a pal-building block (PAL=' programmable array logic').
Also integrated is a DC/DC- converter, which produces all for the sensor necessary voltage from a single 5V-supply. This simplifies the camera supply, which can simply adapt the power supply of the computer. If this is not possible, an external supply can be used with at least 6V. The fundamental construction shows the schematic drawing picture-3.1:
picture-3.1: Schematic drawing of the camera

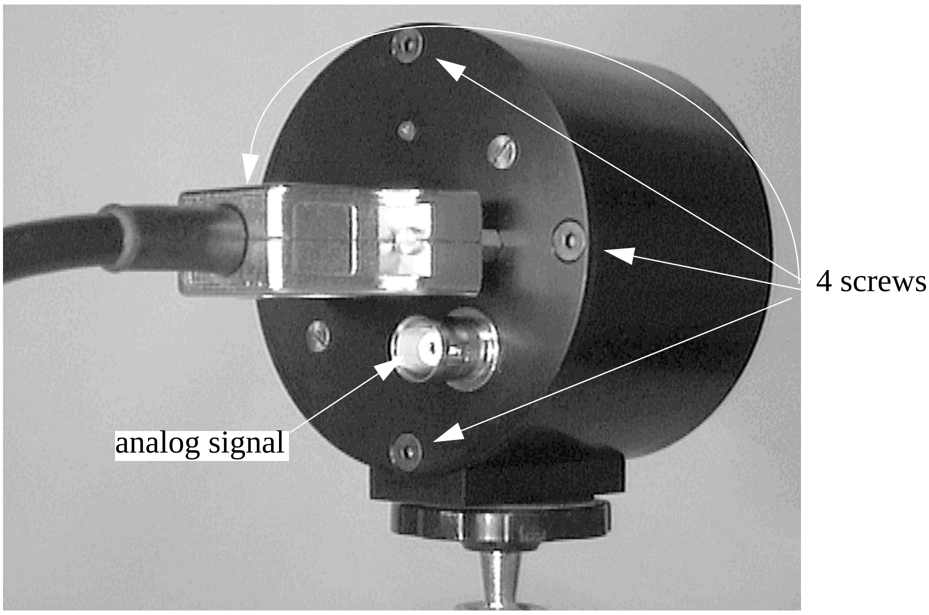


3.1 Camera Series 1000

3.1.1 Removing the case

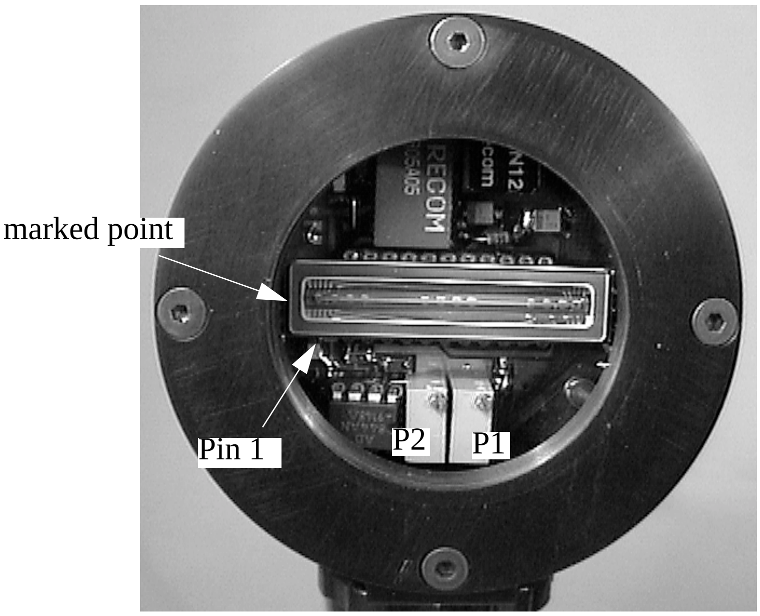
To reach the internal, you can open the camera case. As shown in the picture-3.2 the screw 1 to 4 must be removed. Now the back side can be removed. Furthermore the camera can remain operational.

picture-3.2: Opening the camera series 1010



It is not necessary to remove the cover for reaching the two adjustable potentiometers. They can be reached from the front side.

picture-3.3: Front view



3.1.2 Removing the sensor

To remove the sensor you have to open the case. The sensor can be carefully removed through alternating lever at both short sides with a screwdriver from the socket. Since the MOS-IC is sensitive against static loads, be aware of the following advises:

- Before removing disconnect the camera from the computer interface!
- Do not wear synthetic- or woolclothing as well as shoes with leading soles!
- touch a ground wire before work!
- store the sensor only in leading foam material mat!
- Before touching the IC, camera cases and mat should be touched.

When inserting the sensor attention must be paid to the orientation of the sensor. The pin number 1 lies on the side marked with a small point. This side must show to the potentiometer P1 of the upper board (compare picture-3.1.2). The sensor must be pressed firmly onto the socket and should be pressed on both sides carefully at the edges. Thereafter adjust the sensor again like described below.

3.1.3 Adjusting the sensor

Despite compensation of the electronic a disalignment of the zero line appears after turning on the camera. This effect reaches after about 15 minutes running time a stable final value. Therefore at critical measurements the camera should be given a warm up time of about 15 minutes.
After quite a time it can come however to a permanent displacement of the zero line.
In this case or after changing a sensor the camera must be readjusted.

<u>Basic adjustments</u>
There are two potentiometers in the CCD-camera (positions see picture-3.1.1):

P1 This potentiometer is for calibrating the zero level.
The sensor should not be illuminated so that the ground level could be adjusted to a value close to zero (i.e. 1...4).

P2 After assessment of the zero line the amplification of the sensor signal can be aligned newly with the help of the potentiometer P2. For this purpose, the first step is searching the saturation limit of the sensor:

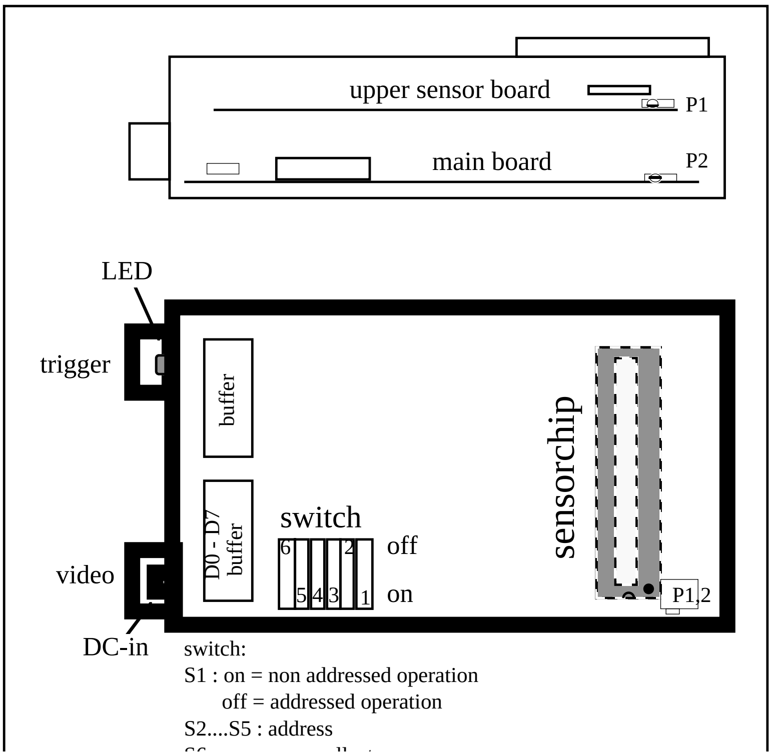
At a low overexposure of the sensor, i.e. stray light, you can turn P2 as far as the overexposure level gets under the value of 255 (12 bit: 4095). You see a plain limiting line while lowering P2. This level should fit exactly with the digitizers maximum value 255 (12 bit: 4095).
At some sensors indeed the upper area is very asymmetrically between even and odd pixel numbers, or the sensor has no more linear relationship between exposure and amplitude. The glut can lead to undefined signals simply through loads defections in neighbor cells. In these cases the saturation boundary should lie above the maximal value of 255, so that the display lies in any case in the linear sensor signal area.

In principle the sensor can be made more sensitive by raising the amplification with P2. But be aware that this adjustment lowered also the dynamic range simultaneously. Therefore the sensitivity should be better varied by extension of the exposure time.

3.2 Camera series 2000

The camera is constructed of 2 boards, whereby the upper sensor board is attached on the lower main board. The lower board contains all controls necessary for the interface, as well as the control to create the clock signals of the sensor and the A/D-converter. The upper board is fastened with three screws, whereby one of the screws sits under the sensor, thus it is achievable after removing the sensor. On this board are all controls necessary specially for the respective sensor type located. The lower board is standardized for almost all cameras. The upper board is adjusted to the respective sensor type. The sensors of different companies are not compatible. If a sensor has to be replaced, it has to be adjusted newly.

picture-3.4: Camera description series 2000



Description of the connections:

1.) Trigger:	The BNC-connector supplies a trigger--signal for synchronization of an oszillograph (high = camera read-out active / low = not active).
2.) Video:	This BNC-connector gives the direct analog signal of the sensors (approx. 1 Vpp to 50Ω).
3.) LED:	The red LED is an indicator for an active camera read-out.
4.) DC-In:	Connector for external power supply(6-9V/700 mA - center = plus).

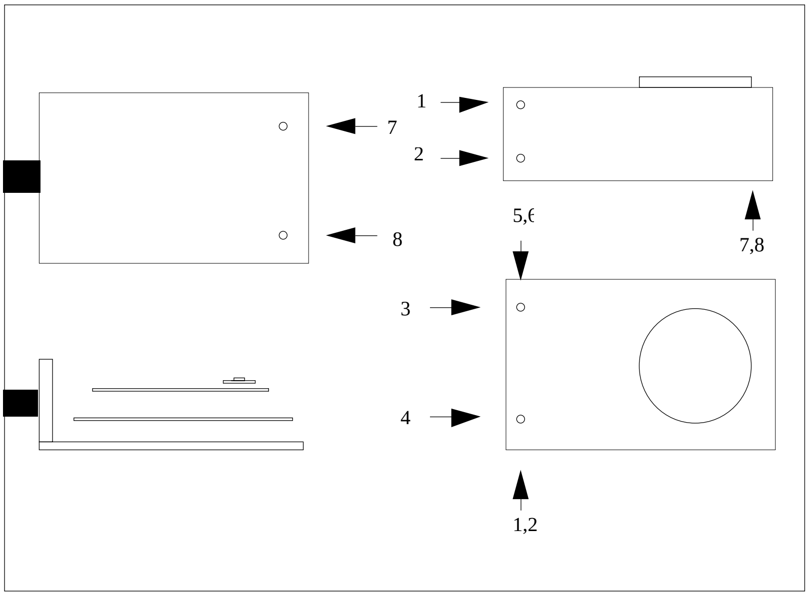
Inside the camera are 6 DIL switches, which could be reached after unmounting the side. The functions of the switches:

S1	non addressed operation / addressed operation.
S2-S5	address of camera. S2-S5 have no function during non addressed operation.
S6	n.c. (enable oversampling for 16 Bit FFT cameras)

3.2.1 Opening of the case

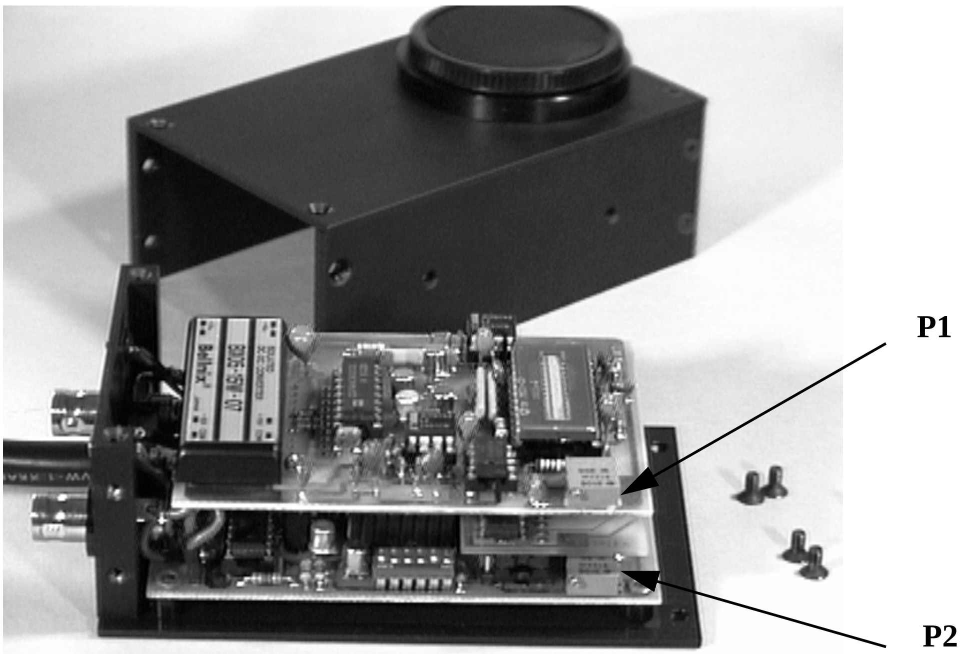
To reach the internal switches and the potentiometer of the camera, the camera case must be opened. As shown in the picture-3.3 the screw 1 to 8 must be removed. Now the cover can be removed. The camera remains furthermore operative.

picture-3.5: Opening the case



If only the switches or the two adjustable potentiometer must be reached, it suffices to remove the cover of one side only.

picture-3.6: Camera with opened case



3.2.2 Removing the sensor

To remove the sensor the case must be opened. The sensor can be removed now through alternating lever at both short sides with a screwdriver carefully from the socket. Since the **sensor is sensitive against static electrical charge**, some **care** should be taken:

- Before removing disconnect the camera from the computer interface!
- Do not wear synthetic- or woolclothing as well as shoes with leading soles!
- Touch ground wire before work and use wrist strap!
- Store the sensor only in leading foam material!
- Don‘t touch the IC pins.

When inserting the sensor attention must be paid to the orientation of the sensor. The pin number 1 lies on the side marked with a small point. This side must show to the potentiometer P1 of the upper board (compare picture-3.6). The sensor must be pressed firmly in the socket and should be pressed on both sides carefully at the edges. After installation the sensor must be adjusted newly.

3.2.3 Adjusting the sensor

Despite compensation of the electronic a disalignment of the zero line appears after turning on the camera. This effect reaches after about 15 minutes running time a stable final value. Therefore at critical measurements the camera should be given a warm up time of about 15 minutes.

After quite a time it can come however to a permanent displacement of the zero line.
In this case or after changing a sensor the camera must be readjusted.

<u>Basic adjustment</u>
There are two potentiometers in the CCD-camera (positions see picture-3.6):

P1 This potentiometer is for calibrating the zero level.
The sensor should not be illuminated so that the ground level could be adjusted to a value close to zero (i.e. 1...4).

P2 After assessment of the zero line the amplification of the sensor signal can be aligned newly with the help of the potentiometer P2. For this purpose, the saturation boundary of the sensor is searched first:

At even overexposure of the sensor, i.e.stray light, you can turn at P2 to get the overexposure level under the value of 255 (12 bit: 4095). This level should be adjusted, that it fits exactly with the digitized value 255 (12 bit: 4095).

At some sensors indeed showed at the upper area a high imbalance between even and odd pixel numbers, or the sensor has no more linear relationship between exposure and amplitude. The glut can lead simply through defections of the loads in neighbor cells to undefined signals. In these cases the saturation boundary should lie above the maximal value of 255, so that the display lies in any case in the linear sensor signal area.

In principle the sensor can be made more sensitive by raising the amplification with P2.

But by this adjustment also the dynamic range simultaneously is lowered. Therefore the sensitivity should be better varied by extension of the exposure time.

3.2.4 Camera addressable modes

The camera series 2000 can be used in 2 different modes: addressed and non addressed mode.
The addressed mode is intended for running several cameras with one computer and one interface board. Every camera has its own address which can be set on the internal DIP switches. The address is send to the data bus, before the camera read cycle starts. Only the addressed camera reacts to the XCK- cycle.
For running more then 2 cameras, the digital distributor should be used (see chapter-4.3.1). The non addressed mode is the default mode for using one camera with one computer.

3.2.4.1 Non addressed mode

The camera needs 2 handshake signals: **XCK** and **NDAC**.

1) XCK The XCK-signal ("exposure clock" / IEC-Bus = ATN) determines with the time distance to the next occurrence the exposure time.

At the beginning of the read cycle, the XCK - signal goes active. The camera is switched on (LED lightens) and all for the sensor needed signals are are initialized. All accumulated electrons are transferred to the shift register. After that transfer which lasts some micro seconds, the sensor area starts again to accumulate until the next positive slope of the XCK- signal. The signal can be seen at the BNC-plug of the camera. It stays high during the complete read time.

2) NDAC The NDAC-signal ("no data accepted") initializes the transfer of a single digital value. With every negative slope the shift register is clocked to put the next value on the data bus. After the computer got the value, the next NDAC-signal is generated.

As the NDAC signal determines the data transfer rate, it can be slowed down with the wait states variable for slower sensors.

Dil-switch settings for non addressed mode:

switch	function
S1	**on** : non addressed mode
S2..S5	no function
S6	no function

3.2.4.2 Addressed mode

In the addressed mode several cameras can be selected sequentially with one interface. Every camera has its own address which can be set by DIP switches after opening the case (see chapter-3.1.1).
Before the read sequence starts (XCK goes high), the camera address is send to the bus. Only the camera with the corresponding address is selected. The data direction of the par-

allel port is switched by the XCK signal (XCK = H = Input / XCK = L Output).

Table 3.1: switch settings for addressed mode

switch	camera Adr.1	camera Adr.2	camera Adr.3	camera Adr.4
S1	off	off	off	off
S2	off : 1	on : 0	off : 1	on : 0
S3	on : 0	off : 1	off : 1	on : 0
S4	on : 0	on : 0	on : 0	off : 1
S5	on : 0	on : 0	on : 0	on : 0
S6	off	off	off	off

3.2.4.3 Additional signals

Besides the XCK and NDAC signals some additional signals can be used for special purposes. A complete list of the camera connector can be found in chapter-8.4.2.
Function of the optional signals:

1) # **IFC** standard function:
general ‚clear‘ signal to reset the camera IFC- (“interface clear”). The signal is active low - so standard cameras put this signal ‘high’.
Function for anti blooming sensors:
sensors with anti blooming function can be cleared with that signal (see chapter-3.6).

2) **Busy** This signal (“busy” / IEC-Bus = DAV) is active during the A/D- convert phase. It goes low after the converter is ready. As the state of the art A/D-converter are very fast now (25ns) this signal is no longer used. Checking this signal would take too much time.

3) **EOS** When all pixel are transferred, the EOS- (“end of scan”) signal goes active. As the computer can easily count the values, this signal is no longer used.
The CCD control needs that signal.

3.2.4.4 IEC-Bus mode (only camera series CCD2000)

The cameras of series 2000 are IEC bus compatible. The camera is configured as a talker and the receiving computer is the listener.
This mode is similar to the addressed mode (chapter-3.2.4.2). The additional needed handshake signals are:

1) **NRFD** The NRFD- signal (“not ready for data”) can slow down the data transfer speed.

2) **DAV** The DAV- signal (“data valid”) is used to tell the listener: new data is on the bus (DAV = Busy).

3.3 A/D- converter with higher resolution

3.3.1 12 bit resolution

The cameras can also be delivered with an analog/digital converter with 12 bit resolution. The data transfer is managed by sending two bytes over the bus. The software puts the bytes together again and delivers a range of 0..4095. In the software installation menu the value must be set correctly.
Because the errors of the sensor (noise, temperature drift, pixel error) can be seen with 12 bit resolution (dynamic range approx. 1:4000), the effective resolution may be lower, according to the used sensor. The 12 bit resolution refers only to the used A/D converter.
The A/D-converter has a conversion time of 50 ns and can be used even with the fastest cameras.

3.3.2 16 bit resolution

For some cameras we even offer a 16 bit resolution. Here also the effective resolution may be lower, according to the used sensor

3.3.2.1 Converter ADC16061

The used A/D-converter has a conversion time of < 500 ns and is offered for the PDA and FFT sensors from Hamamatsu. In the software the flag (GLOBAL:H) AD16ADC has to be set to TRUE.
Because the errors of the sensor (noise, temperature drift, pixel error) can be seen with 16 bit resolution (dynamic range approx. 1:65000), the effective resolution is lower, according to the used sensor. The 16 bit resolution refers only to the used A/D converter.
Usually the dynamic range of the sensor is also reduced with its temperature. So the16 bit resolution is offered especially for cooled systems.
Important:
From time to time the 16 bit converter must be re calibrated. The calibration procedure can be started by software (function CAL16Bit in unit BOARD - see chapter-5.5.2) or is executed during the power up of the camera. For that reason the camera should be calibrated after some hours of running.
Especially when using the external power supply or the cooling unit, it is important to **switch on the computer first**.
Our Software WCCD has an extra menu entry (measure->calibrate A/D) which starts the cycle (takes about 0.5 second).
The frequency of the 16 Bit converter can be selected by the wait states in the setup menu. This value must be set according to the used sensor.

3.3.2.2 Converter AD9826

For fast cameras with sensor TC253 and IL-C6 we offer a faster converter (up to 10 MHz pclk).
This sensor has a cds- function (correlated double sampling), means it samples the pixel value and the zero reference at once and subtracts these values. This improves the read noise of fast sensors. Also the sensor has additional registers to program the amplification and the offset of the signal. Even if it has 3 channels, only the red is used here.
In the software the flag (GLOBAL:H) AD16cds has to be set to TRUE.

These functions (in module BOARD)simplify the setup of the A/D- converter:

SetAD16Default	setup the default values
SetADOff	set the offset of the Signal
SetADAmpRed	set the amplification of the A/D- converter
SetDA	set the amplification of the EM-sensor (TI)

The converter can be programmed by Software with the Function SendCommand in Unit BOARD. The registers of the converter are:

ADR	**Register**	
0	Config set to 0xD8 for 1 channel on red	
1	MUX	
2	red PGA	-> monochrome version: amplification 0...63 = 1..6 fach
3	green PGA	
4	blue PGA	
5	red Offset	->monochrome version: zero level 0..255, Bit D8=sign
6	green Offset	
7	blue Offset	

Tabelle 3.2: 16 Bit AD registers

	D7	D6	D5	D4	D3	D2	D1	D0
Config	Input range	Internal ref	3 channel	cds	clamp bias	power down	0	output mode
	1=4V 0=2V	**1=on** 0=off	**1=on** 0=off	**1=on** 0=off	**1=4V** 0=3V	1=on **0=off**	0	**0=2byte** 1=1byte
MUX	MUX	Sel	Sel	Sel				
	1=RGB 0=BGR	**1=RED** 0=off	1=green **0=off**	1=blue **0=off**	0	0	0	0

bold values = default, only config:D5 must be set to off after power on.

3.4 Special functions of Series 2000

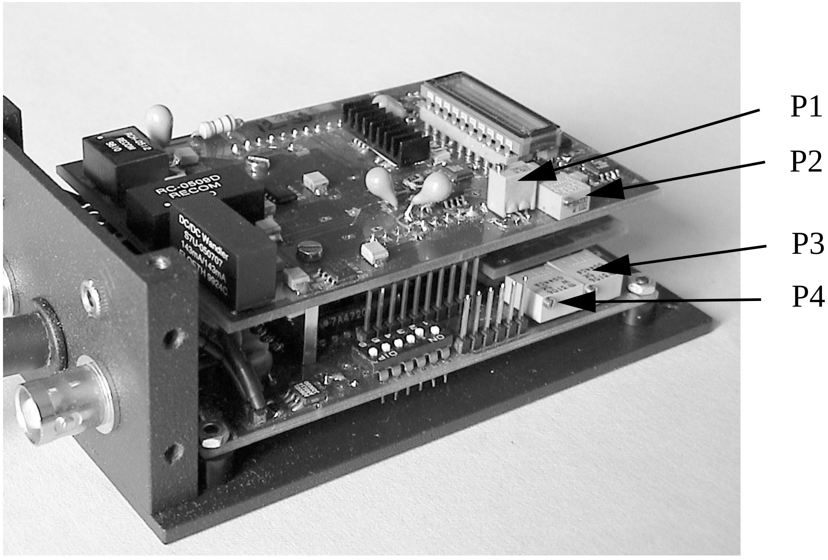
3.4.1 Addition of odd and even pixel of the Thomson sensor

The sensor TH7803 and TH7811 from Thomson have a special pixel summing mode which is enabled by a jumper. Herein the even and odd pixels are added. The jumper can be reached on the upper circuit board directly next to the sensor.
Through this the sensor gains sensitivity, but at the same time looses optical resolution.

3.4.2 Symmetry adjustment for the Thomson sensors

On the circuit boards for the sensors Th7813,14 from 'THOMSON' (Th) and some special sensors two additional potentiometers can be used to adjust the asymmetry between even and odd pixel numbers (see chapter-6.1.1).
On the upper board the potentiometer P1 can adjust the zero level for the odd pixel relative to the even pixel. The second potentiometer P2 sets the zero line for both channels. On the lower board are 2 potentiometer to adjust the amplification for each channel P3(even) and P4 (odd).

picture-3.7: Adjusting the Thomson TH7813,14



Before adjusting the sensor, the camera should have been warming up by running for at least 30 minutes. To adjust the channels, a signal near the full scale should be produced. The signals of the reference diodes at the left and right edge (near zero) shows the zero line. The signals near the full scale shows the amplificated pixel. First the zero line must be adjusted to meet the signal of the even pixel. Then the amplification for the even channel should be set to meet the odd values. The adjustments must be repeated alternative several times until both channels correspond well.

3.4.3 Switchable amplification for IR sensors from Hamamatsu

The IR sensors of Hamamatsu have a switchable integration Capacity. The value can be switched by an external gate between 0.5 pF for high gain operation and 10 pF for wider dynamic range.

The gate is controlled by the interface signal VON/OFF. To switch the amplification by software simply use the ‚V‘ or ‚v‘ key in the DOS version or click the high gain button in the windows versions start measure menu. The amplifying factor is displayed on the screen at the upper left corner if activated (*20).

3.4.4 PDA-sensor from Hamamatsu

The PDA sensors have a special gate to clear the photo diodes. This can also be used for generating a shutter open function.
Also if they are used in highest possible speed, they are not completely cleared by reading. Therefore this function can be used to reset the diodes after every read. The interface signal IFC sends a short pulse (500ns) after every read (XCK).
To set this functions the **global flag ISPDA** must be set (chapter-4.2.4.11).

3.4.5 FFT- area sensors from Hamamatsu

As the FFT sensor is an area sensor, it needs a special timing. Besides the horizontal shift clocks for one line (hclks) also vertical clocks (vclks) are needed. These clocks are generated in the PCI boards FPGA and transferred with the interface signals IFC and VON. To set the se functions the **global flag ISFFT** must be set (chapter-4.2.4.11).

3.4.5.1 Reduced binning

The FFT-sensors are area sensors (FFT= full frame transfer, see. chapter-1,2), whose vertical pixel already summed up within the chip (Binning mode). This works like a linescan sensor where each cell consists of 64, 128 or 256 vertical pixels. The averaging of the vertical pixels reduces the noise. An additional reduction of the dark signal is achieved by using different clock levels (MPP mode = multi pinned phase).
The NOFIFO version can be used to reduce the binning. Then the sensor could be used as an area sensor as well as a less sensitive sensor if the binning is only reduced. If e.g. the sum-register is saturated the charge could be spread to the next lines while binning is reduced.
At reduced binning a particular effect of the FFT sensors become clear. Refers to the data sheet the charge saturation for a single line lies about the half of the output summarizing register. (see. picture-1.3):

z.B. Sensor S7030 Full Well Capacity Vertical: 300 ke^-
Full Well Capacity Horizontal: 600 ke^-

If operated like an area sensor, the register will saturate at half of its total value. Flooded charges will be transported preferably in vertical direction. This leads to a unclear saturation signal in y-axis direction already at half total value. The exposure time or intensity have to reduce in this case. Thus it must be operated with a smaller dynamic area. As soon as two lines were summed, this effect vanish away.

Continual operation
No **shutter function** is available with FFT sensors. Thereby the camera can not be pursued at continuous signals as an area camera. Since the light signal supplies while output the following lines in vertical direction the pixels will be exposed t (see picture-1.3). This leads to a smearing of the signal in vertical direction (objects get shadows).

For continues mode a mechanical shutter or a gated image intensifier has to be used. Pulsed signals could be synchronized by software to the exposure time. The output trigger polarity can be set in the GLOBAL.H File with the Flag OUTTRIGACTLOW. The duration of the pulse is determined by the exposure time (see picture-8.8).

Noise
To reduce the read out noise the 'wait states' should be chosen that the read in is not to fast at minimum with 2,5µs (see chapter-5.1.4.2 or chapter-2.1.4).

Read out time
The read out time of the sensor is calculated with the following formula:
VZEILEN * 12 [µs] + EFFZEILEN* PIXEL* tsp [µs].

VZEILEN: number of vertical lines
EFFZEILEN: effective number of lines,
=1 with full Binning or
= VZEILEN when used as area sensor
PIXEL: horizontal pixel
tsp: storage time for one value(2,5µs). Can be set shorter, if increase of read noise can be accepted.

example
64 line sensor with 1024 pixel
full binning 64 * 12 + 1 * 1024 * 2,5 = 3.3 ms
area sensor 64 * 12 + 64 * 1024 * 2,5µs = 165 ms;

Empty pixel
If running as an area sensor please notice that the first 2 (series 7010, 11, 15) respectively 4 (Series 7030, 31) and the last 2 lines of area sensor are empty lines and give no real picture information. However, these empty lines had to be read out.

3.4.5.2 Highest speed with full binning

If the FFT sensor has to be used with the most possible repetition rate, it must be used in full binning. The time for reading one complete frame of sensor S7030-1006 is:
pclk = 2MHz, one vclk cycle =6µs, 1044 * 64 pixel
1044 * 0.5µs + 64 * 6µs = 900µs -> linerate > 1 kHz.
if the sensor is used in reduced binning with 2 areas of interest, the timing would be:
1044 * 0.5µs + 32 * 6µs +1044 * 0.5µs + 32 * 6µs = 1400µs
So to get the highest possible speed, it has to be used in full binning.

3.4.5.3 Overexposured FFT- sensor

When the sensor is overexposured, the electrons are flooding the hole sensor. The output signal jumps from 3 to 6V. This must be considered when the full scale (P2 in chapter-3.1.3) is adjusted. If the signal reaches the maxima exposure it jumps up clearly. The A/D- converters maxima should be adjusted 10% below this level.

3.4.6 Area sensor TC253

The TIs area sensor has 2 powerful special functions: binning and electron multiplication. The new electronic charge multiplying CCDs (IMPACTRON) from TI (Texas Instruments) are a good, cost effective alternative to the MCP Image Intensifiers (ICCD). The charge carrier multiplication (CCM) is achieved by an impact ionization process that occurs during repeated carrier transfers through high field regions. Here the signal could be amplified up to 100 times.

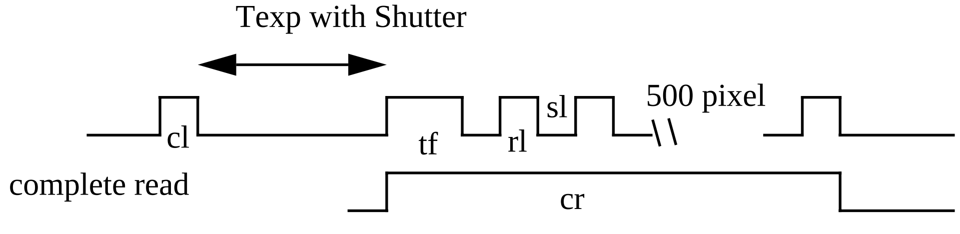
3.4.6.1 Setup for TI: TC253 sensor

On the PCI board the Jumpers J5 and J4 must be set.
The Software flags are:
_TI TRUE
_SYM FALSE
_BURST FALSE
WAITS 2
with these settings the camera is working with 8 MHz pixel clock (pclk). The timing is shown in picture-3.8

3.4.6.2 Running modes of TI: TC253 sensor

It can be run in shutter mode and in free running mode.
In shutter mode the complete sensor is cleared (cl) before an exposure sequence (Texp) is started. The exposure time can be setup to shorter times than the read cycle (cr) , but the repetition rate decreases.
In free running mode the clear- signal is not used and the exposure time is set by the distance of 2 read cycles.

picture-3.8: Read sequence of TC253 sensor



the sensor has 680 pixel (700 to read) and 500 lines.
a complete read consists of
tf: transfer the complete frame to storage area. tf = 270µs
rl: read one line to computer. rl (pclk=8MHz) = 700*125ns = 87,5µs
sl: resort line(if 16bit val has to be resorted to 8bit bmp) = 70µs (with minread example)
cr: the complete read is tf + 500*rl = 270+500*160 = 80ms
cr without resort: 270 + 500 * 90 = 45 ms

free running mode
that is also the shortest possible exposure time in free running mode.
free running mode: min exposure time = 80 ms <-> max. repetition rate = 12 Hz
without online resort: min exposure time = 45 ms <-> max. repetition rate = 22 Hz

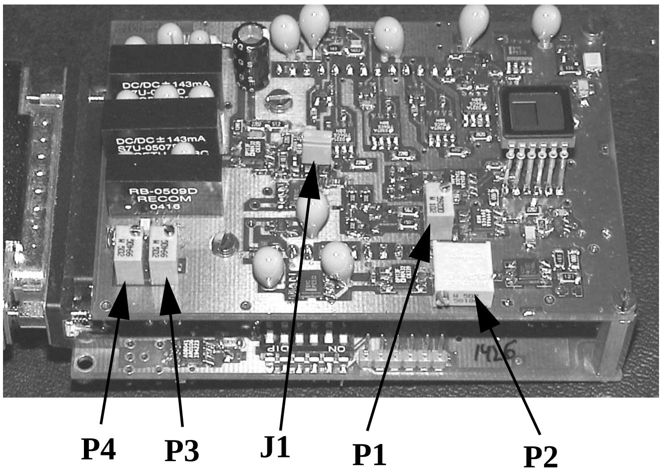
shutter mode
In the shutter mode the cl- signal is used
cl: clear the complete sensor
here the exposure time Texp is set by the distance between the cl signal and the beginning of the cr signal.
min exposure time = Texp <-> max. repetition rate = 12 Hz - 1/Texp

Binning mode
In full binning mode the horizontal clks are generated only once.
Here the sensitivity is maximal and the data rate is
cr: the complete read is = 2ms

3.4.7 Alignment TI sensor TC253

The TC253 board has 4 potentiometers and a 16bit cds A/D-converter which could be controlled by software.

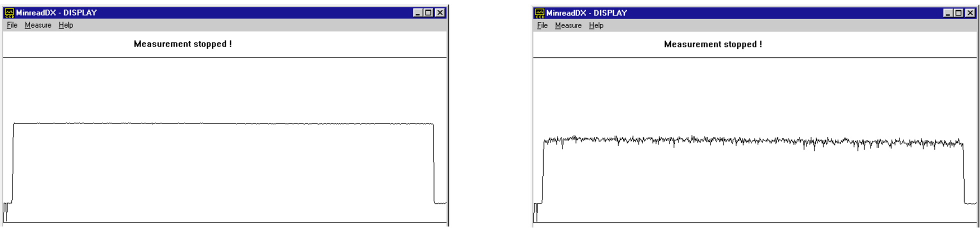
picture-3.9: TC253 pcb



P1 : anti blooming control (ODB = 6V)
P2 : video signal dc level (video signal must be between 1 to 4V DC)
P3 : fixed amplification if J1 is set left. J1 right -> amplification set by software.
P4 : minimal amplification (min. gain signal CMG = 5V)

The standard alignments should not be changed, but the anti blooming function could be changed by potentiometer P1. As the anti blooming avoids blurring of signals when the sensor gets too much light, it should be set as described here. Also the output amplitude depends on that setting. The more the sensor is resistant against overexposure, the lower the output amplitude and the less glossier the signal is.

picture-3.10: Output signal without / with anti blooming



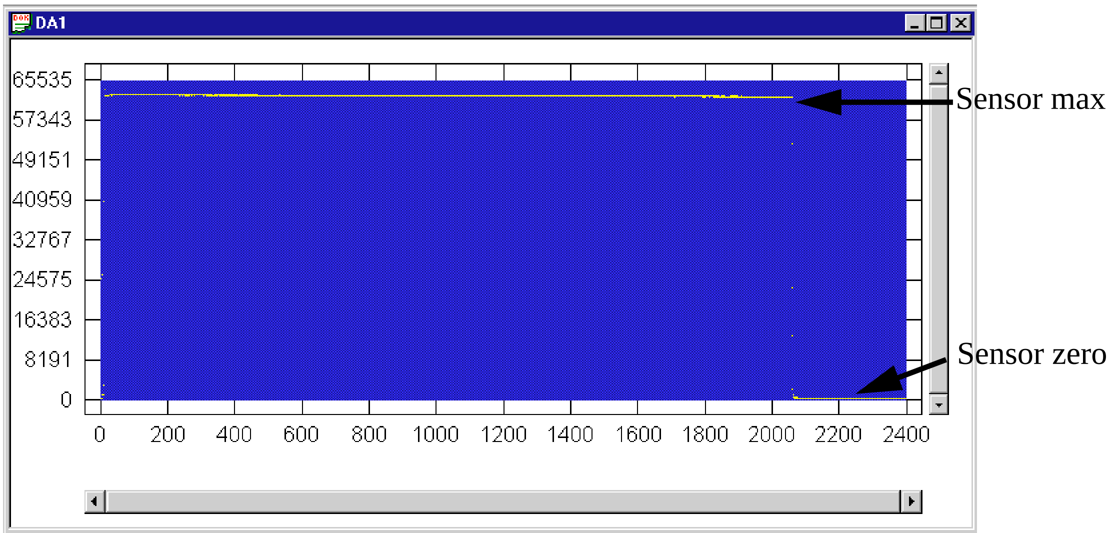
The signal shows the sensor signal with ADgain=0, ADoffset=0 and Sensorgain=0. The light signal overexposures the sensor and seen here is the saturated signal. When turning P1, the max. signal will go down, but the anti blooming function will increase and the sensor will be resistant against 100 times or 1000 times overexposure.
After aligning P1, the value of the ADgain must be newly setup by the software.
The ADoffset should be set to -255 and the ADgain must be set that even the lowest spikes of the saturated signal are not seen and beyond the max. value of 65k.
That indeed means also that noise will increase if ADgain increases.
The sensors special multiplying charge function is set by the Sensorgain value. This function is not linear (see data sheet of sensor).

3.4.8 Alignment of 16bit cds Converter

The AD9826 is a high speed 16bit converter with an adjustable amplification and offset. The cameras with this cds converter have to be setup by the software.

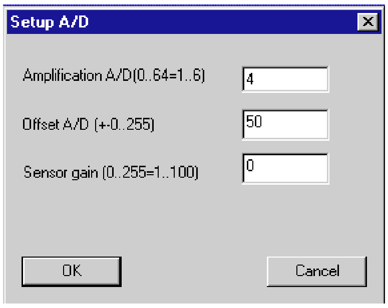
The sensor has to be illuminated slightly overexposured like in picture-3.11. Here all active pixels show their maximum value.

picture-3.11: Overexposured sensor signal



Signal with Amplification=0 and Offset=0.
The zero line and the full scale can now be adjusted. The sensors zero line should be some 100 counts above 0, that after warming up it will not move below 0.
The sensor max. line should be just behind the Maximum scale value (65535).

In the WCCD program this setup is made in the measure menu -> Setup A/D.
picture-3.12: Setup menu of WCCD



Without WCCD the software functions (in BOARD.H)
SetADAmpRed(..) and SetADOff(..) have to be used.

3.5 Shutter function

By using a special timing of the clock signals some sensors can have a shutter function. These sensors have extra gates to control the exposure EC function. So it is possible to scan moving objects, to get an exposure time shorter than the read time or to exposure several cameras at the same time.

With the CCD control or the Software or the EC control registers 3 different kinds of shutter- or ‘integration control’ function are possible. The sensor types allow the following functions:

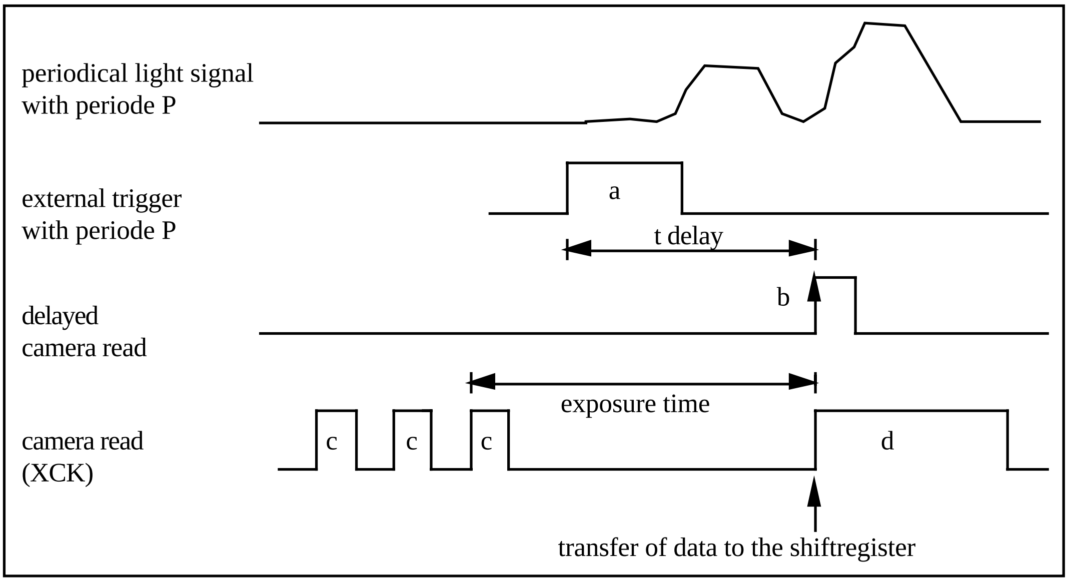
Quasi shutter function: ‘close shutter’ with CCD- sensors (Texas, Thomson).
Quasi shutter function: ‘open shutter’ with PDA- sensors (Hamamatsu).
Shutter function with Anti blooming sensor (Thomson, Sony, Dalsa IL-C6).

These functions can be programmed by software in the NoFIFO version, or they are managed by the DAT and EC register of the PCI board in the FIFO version (chapter-3.5.4).

3.5.1 Close Shutter Function with CCD-Sensors

Most CCD sensors don‘t have a signal to clear all the pixel elements at once. These sensors must be read out several times completely to be resetted. On the other hand they have a shift register to which all data is transferred at the beginning of the read out (see chapter-1.1). This transfer is similar to a close shutter function.
The read out time of the CCD has to be set exactly, to omit the following light signals. This can be done with the CCD- Control or simply by software.
picture-3.13 shows the timing:

picture-3.13: Shutter function of a CCD- sensor



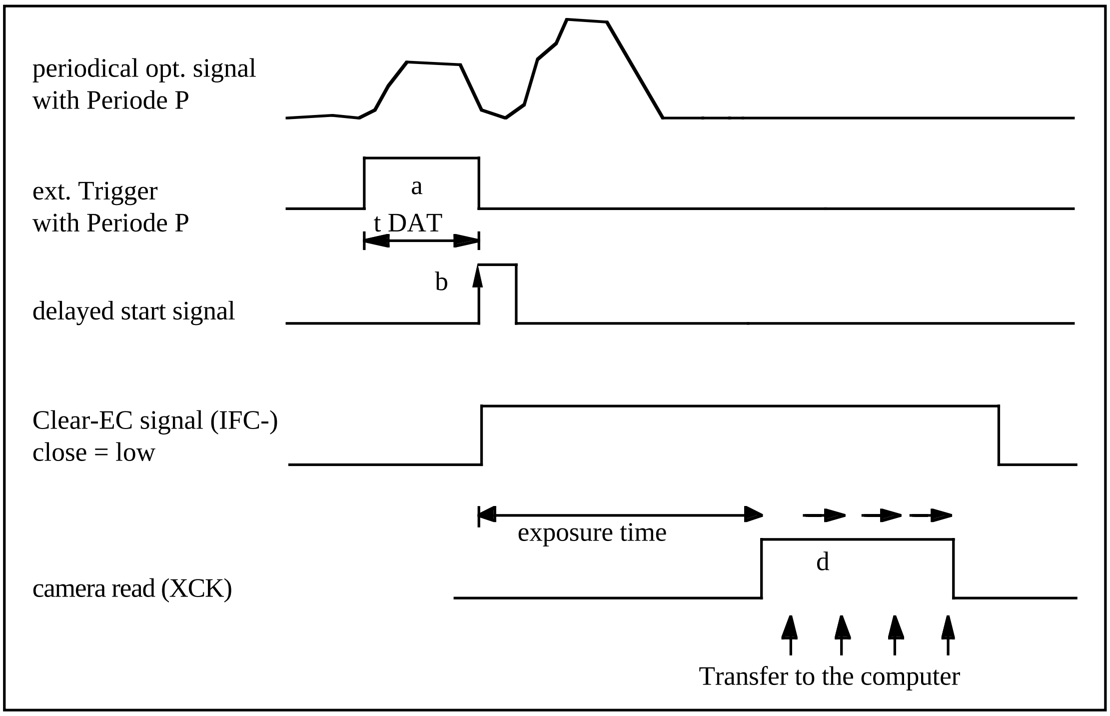
The CCD Control is triggered external and the delay of the control sets the exact transfer time b. The data is transferred to the shift register at the positive slope of b and then to the computer d.
The software must be set to external trigger and the trigger rate to the actual repetition rate

(period P $\neq$ 0). The exposure time has to be set to 0. Now the line is cleared during the wait cycles c and only the exposure time window between the last clear signal c and the read signal d is kept in memory. The signals after b are lost.

3.5.2 Function Open Shutter for PDA- Sensors (Ha)

The PDA sensors from Hamamatsu have an additional ‚clear‘ gate and can be reset directly. Usually the standard CCD- sensors must be cleared by several complete reads.
If the gate is activated, all light generated electrons are shut to ground and the sensor is blind (shutter closed). After deactivating the clear gate, all electrons are integrated in the capacitors until a complete line read occurs or a new ‚clear‘ signal resets all capacitors. The sensor is in the ‘Close Shutter’state extremely restive against overexposure.

picture-3.14: Shutter function for Hamamatsu PDA- Sensor



Because the PDA sensors have no serial register, they cannot save the analogue pixel values. The reading of the single pixel values occurs at different time (compare chapter-1.1). When using the clear function at short exposure times the different exposure time for every pixel can be seen by an increased signal level of the higher pixels. With a high pixel clock compared to the exposure time this effect is low.

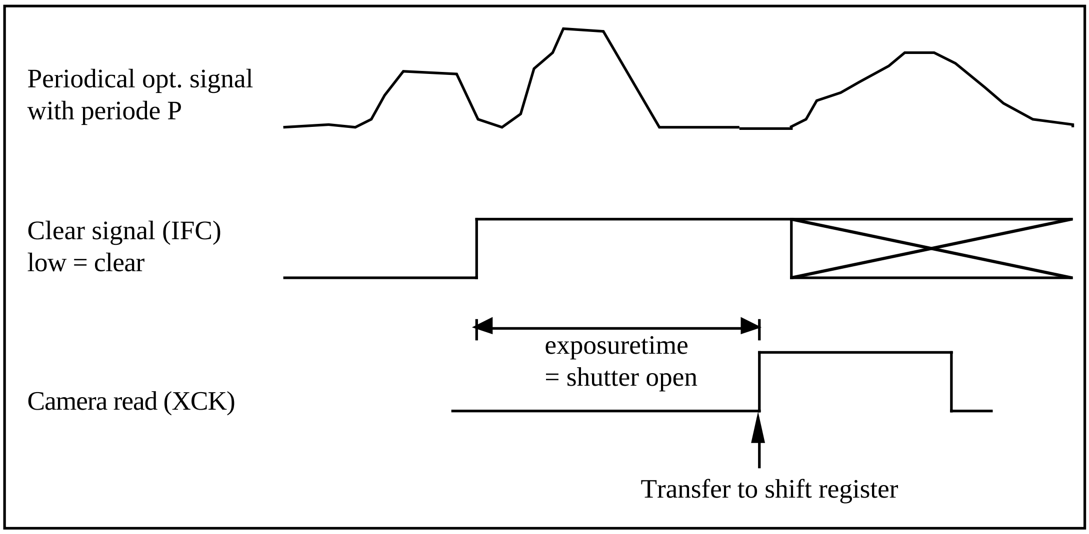
3.5.3 Shutter function with anti blooming sensor

Anti blooming sensors have also a ‚clear‘gate, where the over flooding electrons are collected (see chapter-3.6). These sensors are: IL-C6(Dalsa), CCD181 (Lo), TH7811, TH7813, TH7814 from Thomson and ILX703 from Sony. Here is an ’open shutter‘ - mode similar to the PDAs possible. Because these sensors have a CCD shift register, also the ‚close shutter‘ mode can be realized.
This electronic shutter function is accomplished with the timing shown in picture-3.15.

The software sets the IFC- Signal (low=clear) and the shutter is closed. As soon as the IFC-signal goes high, all generated electrons are accumulated. When starting the read sequence by calling GETCCD, the XCK-signal goes high and all electrons are transferred to the shift registers. After that the registers are clocked one by one to the output amplifier.

By setting the XCK and IFC signals the shutter function is possible, where even a moderate overexposure may happen.

picture-3.15: Shutter function with anti blooming sensor



This electronic shutter has 2 differences compared to a mechanical shutter:
the always closed shutter has a dark signal ≠ zero and
the overexposure light signal may not reach a specific level.

Also the ‚clear‘ signal can only reset the photo sensitive zone. The shift register can still only be cleared by several reads. Therefore here also limits the dark noise the maximal exposure time(<10 seconds), even when the ‚clear‘ signal is still active.
For avoidance of smear by moving objects and for a exact time window, these sensors are well suited.
Also when several cameras must be exposured exactly at the same time this function is very useful. The data is transferred at the same time to the shift registers and then red sequentially.

3.5.4 EC control function in FIFO mode

In FIFO mode the shutter function is managed by the EC control register. To enable the EC function in FIFO mode, the highest bit in the register (see chapter-4.2.4.10) must be set.

Table 3.3: Register for EC control

	address	bit 31	bit 30..0
DAT	S0+0x20	enable = 1	n * 10ns (n>1)
EC	S0+0x24	enable = 1	n * 10ns (n>1)

DAT delay after trigger
EC exposure control

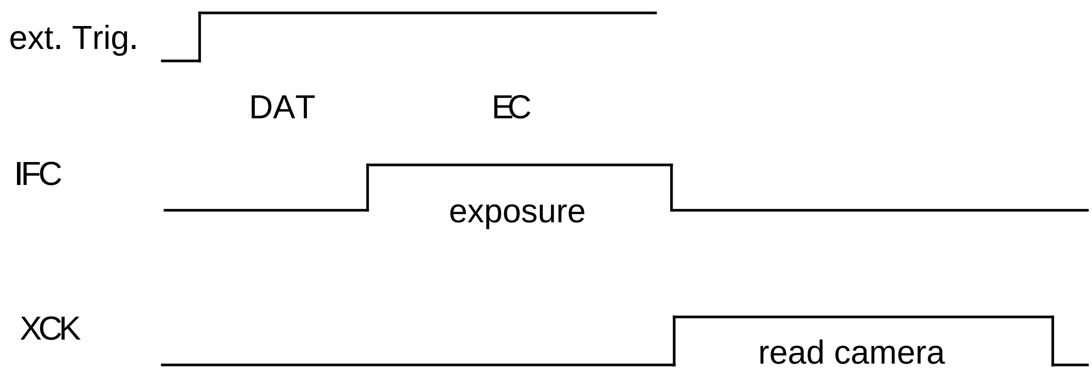
WCCD
In WCCD the values can be set in the menu -> measure -> SetEC

The call in C is: WriteLongS0(drv(=1),n,0x20);
1 < n < 2**31 = 2147483648 *10 ns -> 21 Sekunden max.

3.5.4.1 Exposure Control for Dalsa IL-C6 Sensor

The Dalsa Sensor IL-C6 has a special feature which allows the exact exposure control of the sensor, even if it has to be shorter then the read time (shutter function for open and close).

picture-3.16: Timing of exposure control for Sensor IL-C6



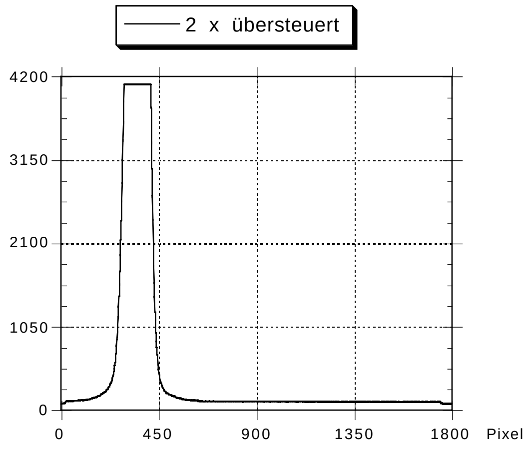
To monitor the function of the camera, the following signals should be used:
ext. Trig.: could be external trigger or internal generator (frequency setup by exposure time delay value in the start measure menu). Be sure that this value is high enough to get the measure loop DAT + EC + Display done.
DAT: register LONG8(S0+0x20) sets delay after trigger in * 10ns resolution
EC: register LONG9(S0+0x24) sets exposure time in * 10ns resolution
IFC: is available at the Trig. Out (O) connector of the PCI board if register was set to EC (see chapter-4.2.4.11).
XCK: high during the camera read (BNC plug of the camera under the green LED).

3.6 Anti blooming'-sensors

If a pixel is overexposured, the surplus electrons flow to the neighborhood elements. The area of overexposured elements gets wider. For example, if one pixel of a standard sensor is overexposured 10 times the entire sensor will be flooded with electrons. It is not possible to make any measurements outside the saturated area.

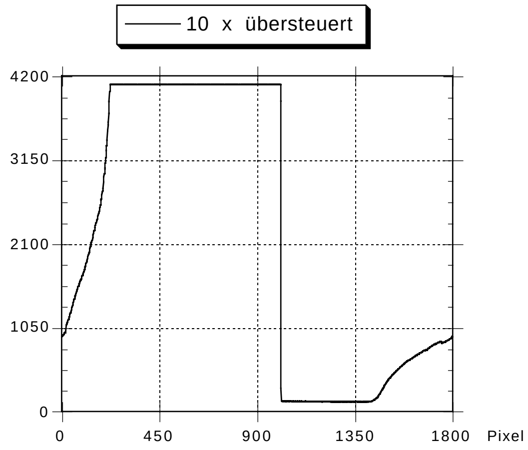
picture-3.17: 2 times overexposured

In this picture you can see a sensor signal of a laser beam. The brightness is shown on the Y- axis with 12 bit digitizing. On the x-axis the pixel number is indicated. The pixel number 400 was overexposured 2 times.



picture-3.18: 10 time overexposured

This is the same signal as picture-3.17 but 10 times overexposured. The sensor is flooded with electrons and can not be used for further measurements.



A solution for this problem is given by so called 'anti blooming'- sensors.
These sensors can be made resistant for slightly overexposures by a control voltage. This function may also be used for controlling the exposure time (shutter function).

Sensors with 'anti blooming' and shutter function

These sensors have a special gate for controlling a anti blooming voltage. The charges of the overexposured cells can pass this voltage barrier and flow into this gate. Only a local overexposure occurs and nearest neighbor cells are influenced. For example if sensor Th7811 is overexposured 100 times, only the next 15 cells will be overexposured too. This resistance to overexposure can be increase by a change of the control voltage. This leads on the other hand to a reduction of sensitivity. Thus the sensor looses also his dynamic range, which means that dark noise and pixel errors increase also by this amount.

At a certain maximum voltage all charges are shut to ground and this can be used for deleting the pixel signal ('Clear'-function or shutter close - function).

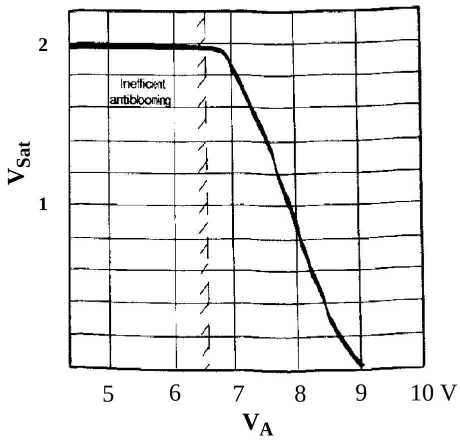
Even an anti reflex window leads to an additional widening of e.g. 20 pixel (see data sheet of Thomson, sensor Th7811).

The sensors in the following table are less sensitive against overexposure with a control voltage.

Table 3.4: Sensors with 'Anti blooming'-function

company	type	over exposure up to	reduction of V_{SAT}
Thomson	Th 7811	100 times 500 times	* 1 * 0,7
Loral	CCD 181	50 times	* 1
Hamamatsu	S39xx	100 times	* 1

picture-3.19: Anti blooming control voltage supply of Thomson sensor



copied from data sheet of Thomson.

The control voltage V_A is supplied to pin #15 of Th7811 through a resistor network. The value of these voltage has to be set by a potentiometer 7,0V.

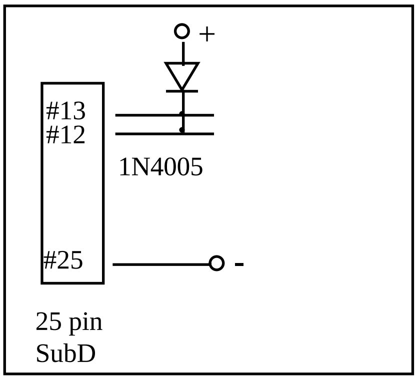
Photo diode sensor of Hamamatsu
Also PDA sensors of Hamamatsu work well when overexposured. Changing the control voltage at pin #5 > 0 V (standard set = 0V) will increase anti blooming (while a loss of sensitivity). The delete function will be controlled with the IFC- signal (see. chapter-4.3.4) by software.

4 Accessory

4.1 Operation with printer port

The camera can be operated additional with a standard printer port. The software has to be set to the address $378 (LPT1:). This address must also be the standard printer port address in the BIOS setup. Also the EPP- Mode (Rev. 1.7 or Rev. 1.9) should be selected there. All other modes do not run correctly!
If the same port is used for a printer, the camera should not be connected before the program has been started. Also disconnect the camera, before leaving the software.

With ISA or PCI- Board, the camera uses the computers +5V power supply. When using the printer port an external supply must be connected. It should be a stabilized voltage 5 to 6V with at least 400mA.
This voltage is applied at #12 and #13 of the 25 pin SubD connector:



Disadvantages of the printer port:

- 10 times slower as ISA board.
- might be incompatible with connected printer.
- The camera need an external AC-adaptor. Cameras series 2000 has a plug for external supply, cameras series 1000 need a special cable.
- Trigger functions only with limited function and special adaptor cable.
  Pin # 17 = Trigger Out, Pin #10 = Trigger In
- Functions VON/OFF and Slope are not implemented.

Win Software
The printer port interface is implemented in the ISA board driver LSCISA1. It has to be installed as described in chapter-5.1.1
Within the unit BOARD.CPP is the function: InitPPort(drvno,portadr). The parameter drvno has to be 1 and the portadr specifies the address of the printer port (usually 0x378). If this parameter is set to 0, the ISA - Interface board is selected. The portadr is not checked against validity! So please choose carefully.

4.2 PCI Interface

For fastest operation of the camera our PCI- Interface board can be used. With this board a transfer rate up to 33 MHz is possible. Since most of the sensors have a lower maximum pixel frequency (pclk), these have to be slowed down by the software (Table 4.9).

! Make sure to remove the BNC-cinch-connector before installation. The board does not fit into the computer with the attached BNC-plugs.**!**

The following special functions have been added to the 2 cinch (BNC)-connectors (picture-4.1):

- the B1 trigger input synchronizes the read out to an external event. In the programs main menu the trigger source had to be chosen with the T key as external or single shot. The trigger pulse must last at least 1 µs and must be >1.3V.
- B2 output for the synchronization of external events. That means the software can send any trigger sequence here. Usually each read sequence produces one trigger just before the read starts.

•The trigger input signal should have a maximum level of 30V!

On the interface board the 5V-supply of the computer is connected to pin #12 and #13 of the Sub D-connector for the camera. The power consumption of the camera totals about 250 mA. An automatic fuse limits the current to 1A and resets when regular current turns back.

4.2.1 Interface with and without FIFO

The PCI board can be supplied with and without a FIFO memory. The memory can de couple asynchronous accesses on the bus. As the exposure time depends on the distance of 2 read cycles, a jitter of the read sequence would lead to signal jitter.
As the Computer is usually interrupted all the time, these runtime deviations must be avoided by a FIFO or by the Software (thread programming).

with FIFO
Should be used by periodical loops if the exposure time is long (>20ms) and the pixel clock is low (<10MHz). The computer can calculate other tasks in the meantime.

<u>Advantage</u>
Asynchronous exposure and read to memory.
Windows is not interrupted.
short memory transfer even with long exposure time

<u>Disadvantage</u>
only for periodical measurements.
external events are not synchronous.

without FIFO
This mode is only possible with an real-time operating system. In windows this is accomplished by thread programming with a real-time priority class. The software controls the entire measurement process. During the measure loop other tasks and programs are stopped. Here a synchronous control of shutters, lamps or motors can be accomplished easily. Also the FFT sensors should be used in that mode, so that a free programming of

the binning mode is possible.

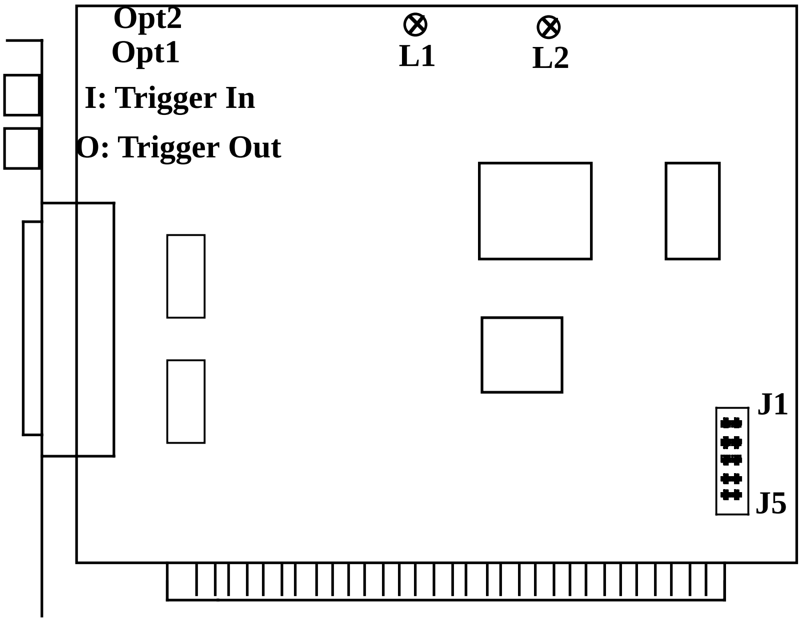
Advantage
Synchronous control of additional processes.
high data rates without disrupting.

Disadvantage
Windows does not work in the background.
Mouse and keyboard do not work.

4.2.2 Board layout

The following drawing shows the layout of the interface board.
The jumper J1..J5 implement special functions.

picture-4.1: PCI- Interface board



The LED L1 and L2 lights, when XCK is high, that means when the camera reading is in progress. It should blink the same way as the LED on the camera.

The EEPROM on the PCI- board has the following Mark:

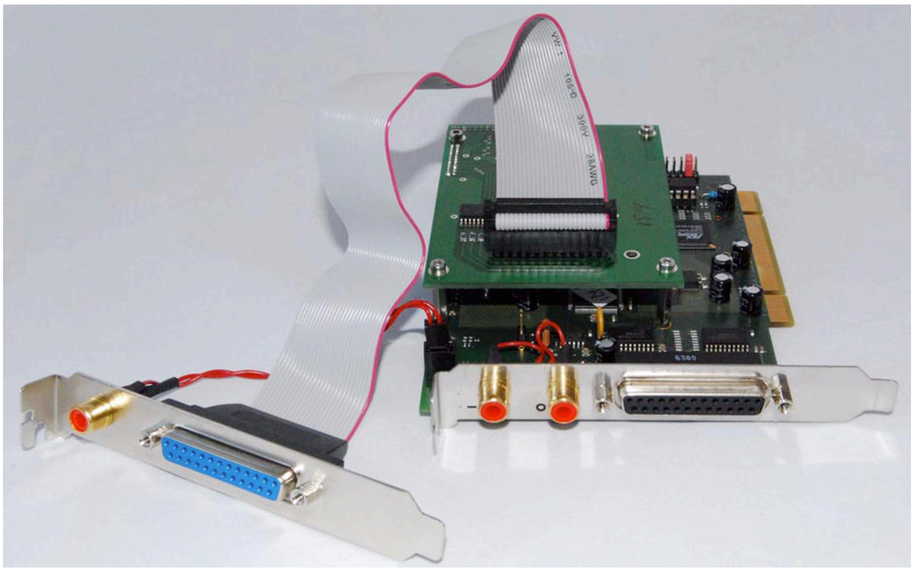
Standard version	: Xn
FIFO- Version with Interrupt	: XI

Jumper
J1: set when WRFIFO comes from external Source (EOI) -> set if fibre link is used.
J2: HI/LO swaps hi/lo bytes on 12/16bit values
J3: n.c.
J4: n.c.
J5: n.c. (was: is_FFT before 123.8, now flag ISFFT see chapter-4.2.4.11)

4.2.3 2nd channel adaptor board

For the parallel read of up to 4 cameras, an adaptor board can be mounted on the PCI Interfaceboard. Here the PCI Interface still needs only one PCI slot, but a little space is needed for the adaptor board. Also every additional camera plug needs an extra slot with a sub25 connector on the backside of the computer case.

picture-4.2: 2nd channel adaptor for a second camera



As the clocks are the same for all cameras, this system implements an exact parallel reading mechanism. The PCI bus is 32bit wide and only 8 bit are used for one camera. So max. 4 cameras can be read at once. As the 16bit values are transferred in high byte / low byte order, the data structure in memory of a 4 camera system is:

4 cam system	2 cam system
first long:	first word:
hi byte cam1	hi byte cam1
hi byte cam2	hi byte cam2
hi byte cam3	
hi byte cam4	
2nd long:	2nd word:
lo byte cam1	lo byte cam1
lo byte cam2	lo byte cam2
lo byte cam3	
lo byte cam4	

The software is responsible to resort the data afterwards. This is usually done in BORD.C in function: CallIORead(();

4.2.4 Address and function of PCI-Interface

The board maps 16 addresses in the PCI space of the computer (0..f/1f/3f). The registers can only be accessed through the driver with the functions ReadLongS0 or WriteLongS0.

Table 4.1: Address list of PCI Interface space S0

Longs in S0- range	Byte	Function
0	0	DBR
	1	0
	2	0
	3	0
1	4	CTRLA
	5	CTRLB
	6	CTRLC (Bit0=SyncTrigIn)
	7	0x53
2	8	XCKLL
	9	XCKLH
	a	XCKHL
	b	XCKMSB
3	c	XCKCNTLL
	d	XCKCNTLH
	e	XCKCNTHL
	f	XCKCNTMSB
4	0x10	PIXREG low
only	0x11	PIXREG high
FIFO	0x12	FREQREG
Version	0x13	FF_FLAGS
5	0x14	FIFOCNT
6	0x18	VCLKCTRL
7	0x1C	„EBST“
8	0x20	DAT: delay after trigger
9	0x24	EC: exposure control (shutter)
A	0x28	TOR: Trigger options register
B	0x2C	not used
C	0x30	ARRAYReg
D	0x34	DELAYREG
E	0x38	IRQREG
F	0x3C	PCI board version

DBR: read/write into the data bus register (SubD #2..9 = DB0..DB7), whereby the data direction had to be setup first with XCK=low : write, XCK=high : read

4.2.4.1 .Control Registers

Table 4.2: Register CtrlA (0x04)

0x04	D7	D6	D5	D4	D3	D2	D1	D0
Read	ETRIG	DIR TRIGIN	SLOPE	FFTrigIn	TRIG OUT	XCK	IFC	VONOFF
Write	ETRIG	-	SLOPE	FFTrigIn	TRIG OUT	XCK	IFC	VONOFF

ETRIG: set the trigger input D6 to direct(=low) or to edge triggered (=high). FF is reset by D4

SLOPE: set trigger to input slope (high = positive).

DIRTRIGIN: trigger input combined with SLOPE and ETRIG.

FFTrigIn: Trigger input for short pulses: a FF is set by Trigger input until a write D4=low resets it.. FF must be enabled by writing D4=1 and D7=1.

TRIGOUT: trigger out signal.

XCK: activate the read out of the camera data (high when reading).

IFC: global clear signal, - also used as shutter signal (clear = low=CloseShutter).

VONOFF: switchable amplifying for cooled sensors, (high-> V=1)

(is also applied for other functions - former name: DAV).

Table 4.3: Register CtrlB (0x05)

0x05	D7	D6	D5	D4	D3	D2	D1	D0
Read/ Write	F_ND SYM	F_DP	DIS_ ND	waits4	waits3	waits2	waits1	waits0

no function in FIFO version, else

F_NDSYM Flag for symmetrical ND- pulse
has to be set to 1 for pclk < 10MHz.

F_DP Double pulse- flag: produces a double pulse per read
->is high with 12 and 16 bit cameras

DIS_ND direct ND- pulse output, not used, must be set to 0.
on high sets ND- signal to low

waits0..4 wait states timer for symmetric ND- pulses
5 Bit = 31 * 66ns = 1µs max.

Table 4.4: Register CtrlC (0x06)

0x06	D7	D6	D5	D4	D3	D2	D1	D0
Read/ Write	0 -	1 -	EOI-CHB -	EOI -	BURST BURST	OPT2 OPT2	OPT1 OPT1	STRIG -

this register transfer ID- byte = 0x5351, whereby bit0 is either 0 or 1.
Bit0 is reserved for future use of internal XCK- generator.
STRIG: synchronous trigger in, Opt 1,2 optional opto couplers
BURST=1 for 33MHz data rate and in FIFO version

4.2.4.2 Register XCK (0x08)

XCK (exposure time) generator
Implemented is a 28 bit timer. The timer can be set with the XCK register and in XCK-CNT the actual value can be read. Resolution is 1µs.
A pre divider sets resolution Res_ms=1 -> 1 ms resolution; Res_ns=1 -> 100ns

Table 4.5: Resolution of the timer

28 Bit	f in MHz	res. [µs]	max [sec]	max [min]	max [h]
Res_ns=1	10	0,1	26,8	0,45	0,007
268435456	**1**	**1**	**268,44**	**4,47**	**0,07**
Res_ms=1	0,001	1000	268435,46	4473,9	74,57

The MSB of the XCK register controls the timer

Table 4.6: XCKMSB Register

0x0b	D7(31)	D6(30)	D5(29)	D4(28)	D3(27)	D2(26)	D1(25)	D0(24)
Read/ Write	F_EXT TRIG	$\overline{RS}$	Res_ms	Res_ns	XCKREG27	XCKREG26	XCKREG25	XCK-REG 24

RS resets timer, must be =1 for free running.

F_EXT TRIG external Trigger (Cinch plugB1), if 1. Each positive slope (or negative -> slope in CTRLA) starts a read sequence.

RS reset Timer, must be = 1 for starting the timer.

RES_MS Timer base = 1 ms
RES_NS Timer base = 100 ns

4.2.4.3 Register XCKCNT (0x0c)

here the timer state of the XCK timer can be read (28bit). example: the XCK reg is set to 1000 - that’s 1ms. So XCKCNT counts from 0..1000 and is resetted again.

4.2.4.4 Register PIXREG (0x10)

here the amount of bytes to transfer has to be entered. The register is type „word“ (bit 15:0). With 12/16 bit = 2 * PIXEL and with 8 bit = PIXEL

4.2.4.5 Register FREQREG (0x12)

0x12	D7(23)	D6(22)	D5(21)	D4(20)	D3(19)	D2(18)	D1(17)	D0(16)
Read/ Write	RS_FF	SWTrig	XCK delay2	XCK delay1	XCK delay0	FREQ2	FREQ1	FREQ0

FREQ ND clock frequency. val 0..6 (7 = off) ; frequency of FIFO write
0 = 33 MHz, 1 = 16 MHz, 2 = 8 MHz, 3 = 4 MHz, 4 = 2 MHz
XCK delay Delay between camera on (XCK high slope) and start of ND clocks .
must be > 900ns for most sensors.
= 100ns + 400 * delay ns; delay = 2 -> 900 ns.
SWTrig starts write to FIFO sequence by software (is ored to timer).
RS_FF reset the FIFO.

4.2.4.6 RegisterFF_FLAGS (0x13)

0x13	D7(31)	D6(30)	D5(29)	D4(28)	D3(27)	D2(26)	D1(25)	D0(24)
Read	VALID	EF	FF	XCKI	OVFL	-	-	-

VALID TRUE, if one or more complete lines in the FIFO.
EF TRUE, if FIFO is empty.
FF TRUE, if FIFO is full (the standard FIFO has 8kByte).
XCKI TRUE, if write to FIFO is active.
OVFL is set with FF=TRUE and keeps it until RS_FF.

4.2.4.7 Register FIFOCNT (0x14)

0x14	D7	D6	D5	D4	D3	D2	D1	D0
Read	WRCNT7	WRCNT6	WRCNT5	WRCNT4	WRCNT3	WRCNT2	WRCNT1	WRCNT0

The „write to FIFO“ Register (bit7:0) counts the complete lines written to the FIFO. When the timer was startet, the counter is incremented with every line written to the FIFO. The DMA read of the FIFO decrements the counter. The Flag: FF_FLAGS:VALID is high if WRCNT>0.
This counter counts the read- and write cycles up to 255 independent of the capacity of the FIFO itself (FIFO default 32kByte)!
With FREQREG:RS_FF the WRCNT is set to 0,

4.2.4.8 Vertical Control Register VCLKCTRL (0x18)

Register VCLKCNT (0x18) - word
This value (bit11:0) sets the number of vlks generated before the read of the horizontal register is started. This is the number of vertical lines for an area Sensor (FFT) - must be zero for line sensors! Value is 12bit = 0..4095.

Register VCLKFREQ (0x1b)
This value (bit31:24) sets the frequency for the vertical clocks, which usually has to be much lower then the horizontal clock frequency. Value set in 400ns steps +200.

val=0-> vclk = off, val=1 -> vclk = 600ns, val=2-> vclk = 1µs, val=7-> vclk = 3µs
value is 8bit = 0..255.

4.2.4.9 Delay After Trigger Register DAT (0x20)

The integration control DAT = delay after trigger function can be used to add a delay after an external trigger occurs. DAT works in FIFO and in no FIFO versions,

DAT: delay after trigger (bit 31 = enable, bit 0..30 = val * 10ns).
can be used in all trigger modes.
must be 0 if not used.

4.2.4.10 Exposure- Control Register EC (0x24)

EC only in FIFO versions and only with specific sensors.

EC: exposure control (bit 31 = enable, bit 0..30 = val * 10ns).
only for sensors with ec function (shutter) , not for FFTs.
must be 0 if not used - if 0 IFC Signal is controlled by CtrlA:D1

4.2.4.11 Trigger Options Register TOR (0x28)

This 30 bit register enables several trigger input and output options and sets the IFC signal to PDA or FFT.

Trigger Options Register TOR (msb)

0x28	D31	D30	D29	D28	D27	D26	D25	D24
Read/ Write	TO_REG	EC	TIN	FFXCK	DAT	no_PDA RS	ISPDA	ISFFT

TOCNT (D23:16): trigger Out divider (bit 7 = enable, bit 0..6 = freq divider).
value = divider - 1
TICNT (D7:D0) : trigger In divider (bit 7 = enable, bit 0..6 = freq divider).
value = divider - 1

ISFFT high if FFT sensor (set IFC to generate vertical clks ENND)
ISPDA high if PDA sensor (set IFC to special EC control signal)
no_PDA RS In high speed mode (2MHz) the PDA is not completely cleared through read out. Therefore in default mode (bit = 0) a 500ns pulse is send via IFC to clear the diodes after read is done. To disable that pulse, set bit to 1.

The **O- output of the PCI board** can be switched (only one of these bit should be high)
all zero Signal is XCK - high if camera is reading
TO_REG Signal is programmable trough CtrlA-D3
EC Signal is high during sensor is sampling (shutter open).
TIN Signal is Trigger In - can be used in conjunction with TOCNT to divide trigger in frequency.
FFXCK Signal is high during read of Fifo - for test purposes.
DAT Signal is high during DAT (delay after trigger) sequence

4.2.4.12 Register ArrayReg (0x30)

This register implies the number of lines for the Andanta area sensor. The highest bit (31) is not only the enable signal, it is also used to synchronize the frames. If the bit is zero, the internal linecounter is reset. Therefore the bit must be set to zero, then to 1 and then the timer can be startet - not before! Otherwise the linecounter does not start correctly with line 1.

4.2.4.13 Register DELAYREG (0x34)

DELAY: delay (0..0x3ff).
Adds a delay to the write to FIFO Signal.
This register can be used to delay the write to FIFO signal relative to the data signal. Here the cable length can be compensated and the data can be red when it is in a stable and undistorted state. This leads sometimes to a better noise performance (default val = 0x100).

4.2.4.14 Register IRQREG (0x38)

Here 2 registers are implemented for the optional use with interrupt.

Register IRQLAT (0x38)
counts (bit 15:0) the time after read of FIFO starts in units of 25ns.

Register IRQCNT (0x0A)
Count (byte) is incremented when one line was completely written to FIFO.

4.2.5 Interrupt

The PCI- board has an optional interrupt (INTA - B, C, and D can be used by Jumper). The interrupt function is only implemented in the FIFO- version. For the internal interrupt (LINT) the number of complete lines in the FIFO are used (counts to 7). As long as not all lines are read the interrupt is pending.

The interrupt can be programmed by the INTCSR register of the PLX9056 chip. With WriteLongIOPort(1,0x900,0x68); it is active and is instead of 0x900 the value 0 used, the interrupt is stopped.

Important **INTCSR** register (0x68h) bits - for a complete list see manual of PLX 9056
valid are bit 0..31
#8 PCI Interrupt enable
#11 local interrupt enable (LINT)
#15 Flag: LINT is active
#18 DMA channel0 int enable
#21 Flag: DMA channel0 is active

The DMA interrupt is programmed by the **DMAMODE0** register (0x80h)
#10 enables int when done (DMA is ready)
#17 routes DMA channel0 int to PCI int when = 1
The EEPROM (XI-marker) has additional values InterruptLine: FE and InterruptPin: 01.

4.2.5.1 ID of Interface board

For Identification of the PCI board these registers can be used:
In the PCI- Configuration space the Vendor and SubVendor values:

Table 4.7: Vendor and SubVendor ID of the PCI- Board

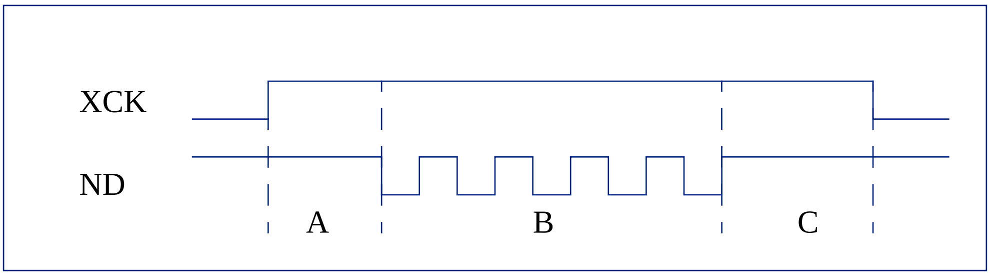
	Vendor	Device	VendSubSys	VendSubID
Offset	0	2	0x2c	0x2e
ID	10B5	9056	4553	7401

ID Registers
In the S0 space are some type long registers with fixed values:
S0+0x04: value should start with 0x535n.
S0+0x1c has the „EBST“ value
S0+0x3c major and minor version of interface board

4.2.6 Burst mode in different operating systems

In the so called burst mode, highest data rates are possible. Here the PCI-bus frequency of 33 MHz can be used. Anyway, the different operating systems are leading to different over all reading times.

picture-4.3: Read time in burst mode



The reading sequence has 3 phases. Windows operating systems must start a initialisation (A) before they can start the burst mode (B). After the burst read (B) an additional memory move from driver buffer to application buffer(C) must be executed. Additional interrupts occur during the DMA phase. This leads to a effective data rate of about 42ns / value, instead of 30ns / value, which can be reached with DOS.

Table 4.8: read times in burst mode (33MHz)

OS	A [µs] initial	B [µs] (2400Pixel)	C [µs] move data	over all[µs]
DOS	0	72	30	102
Win98/ME	4	100	32	136
Winxp	10	100	68	178

All measurements with 8 bit camera.

4.2.7 PCI- board timer

The XCK timer is a 28 bit counter, which is reset when the XCK- registers count value is reached. The actual count value can be red in the XCKCNT- register. To start the counter, the $\overline{RS}$- flag: D6 of XCKMSB must be set to high. The count pulse input comes from a quartz generator with 1 µs resolution. With the Res_ms flag it can be switched to 1ms resolution or to 100ns resolution with the Res_ns flag.
Two timing functions can be realized:

4.2.7.1 Micro second timer

This simple method is used in our software.
The XCK register is set to the maximal value = 0x0fffffff.
The RS- flag is set to high and the software checks continuously the XCKCNT register for reaching the needed delay time.
This function can also be realized with the precision timer of windows (see chapter-5.1.9.1). The windows timer also works for the ISA- and printer port interface.

4.2.7.2 Hardware timer for the trigger function

Within the Interface board a timer is integrated to compensate jitter in runtime.

Two software functions might be hardware synchronized to the timer:

Function WaitTrigger -> see Unit BOARD.
This function can be called with the flag sync=true. In this case the function triggers to the high signal of the SyncTrigIn = bit0 at CtrlC register. This input is the output of timer, which might be started external or internal (flag bit7 of CTRLB register). Afterwards the time of the register XCKREG is awaited. The actual count state can be red at register XCKLL up to XCKMSB.
If sync=false, the wait trigger is set to the external trigger signal at DirTrigIn = bit6 of CtrlA register. The timer is not discerned any more.

Also Function PGETCCD can be synchronized to the timer. In this case a call instead of function, read‘fkt=1, the function: ‚sync. read‘fkt=4 is used. When jumping to the routine GETCCD the read function waits until the syncTrigIn Flag is changed to high. Also a key press terminates this wait loop.
If function fkt=1 the camera is red immediately.

4.2.8 Settings for several cameras

When using the PCI board the connecting cable should have a maximum length of 5m (3m for vhs = 33 MHz camera series). The clock frequency is setup by some constants by the software. That is Wait States in WCCD (see picture-2.5) and WAITS in UNIT BOARD.

4.2.8.1 Settings for No_FIFO version

For several cameras different wait states have to be inserted.
Table 4.9: ‚Wait states of PCI- board for different sensors

waits	pclk 8 bit sym ns / MHz	for sensors	pclk 8 bit asym ns / MHz	pclk 12 bit sym ns / MHz	for sensors	pclk 12 bit asym ns / MHz
0	90 / 11	ILX 506	60	(150)		120 / 8,3
1	150 / 6,7	ILX 503, 703, 505,	90	270 / 3,7	ILX 503, 703, 505, 514, 506	180 / 5,6
2	210 / 4,8	ILX 514	120	390 / 2,6	ILX 511	240 / 4,2
3	270 / 3,7		150	510 / 2	TH7803	300 / 3,3
4	330 / 3		180	630 / 1,6		
5	390 / 2,6	ILX 511 TH7803				
7				1 µs / 1	all Ha	
0x0F	1 µs / 1	all Ha		1,9 µs / 0,5		
..						
0x1F	1,9 µs		990	3,9µs		2 µs

Two additional software flags are used for **highest possible speed**:

BURST = FALSE, SYM = TRUE standard configuration for table Table 4.9
BURST = FALSE, SYM = FALSE for 16 MHz data rate, waits=0
BURST = TRUE, SYM = FALSE for 33 MHz data rate, waits=0

For highest speed 8 bit cameras (hhs-series with thomson TH7813 and 7814) can use 33 MHz data rate.

Most cameras of series 1000hs may run with 1wait state. Standard cameras must be set at least to 4 waits states.
The camera of series 2010 with all sensors of Hamamatsu are not recommended for high data rates. The dark noise raise with the data rate. Therefore these sensors should operate with maximum wait states (0x1f) or with the ISA- interface board. The PCI- board bear no advantage in this application.
To evaluate the minimal possible wait cycles the wait states should be selected quite large, and than start the software with the signal described in chapter-1.4. If cycles are chosen to small the signal is wrong or extreme overlaid by dark noise. The cycles have to be raised until the signal is clear.

4.2.8.2 Settings for FIFO version

The Fifo version has a separate hardware timer which clocks the write to FIFO signals. Here the wait states value in WCCD, FREQ in CCDExamp determines the frequency for that clock, where this signal (ND) transfers one byte at a time. As a word transfer needs 2 bytes, the pixel clock of a 16 or 12 bit Camera is half that frequency.

Table 4.10: wait states for FIFO version

waits	0	1	2	3	4
ND clock	33 MHz	16MHz	8 MHz	4 MHz	2 MHz
pclk@16bit	16 MHz	8 MHz	4 MHz	2 MHz	1 MHz

The WAITS value represents the read from FIFO value and should be zero, as the read can be done with maximum burst speed on the PCI bus. Therefore also BURST should be TRUE and SYm does not matter here.

4.2.9 Register of Interface chips 9056

The PCI- board operates with a interface chip Typ 9056 made by PLX. The most important register for software of DMA controllers are listed below. The program of these register are built in the Unit Board (Function InitDMA) and should not be changed.

Table 4.11: Register of PCI- DMA Controllers

Address	Function
0x80	DMA mode reg = 0x843
0x84	phys. PCI Address - described by driver
0x88	Local Address = 0x0
0x8c	Transfer Byte Count = (PIXEL*4)
0x90	DMA descriptor = 0x08 (read mode)
0xA8	Com/Stat register = 03 (start transfer)

4.2.10 Jitter of the PCI- board

The jitter of the read loop is measured with the CCDExamp software. Hereby the thread was programmed with the highest priority and a Sleep(0) statement (refer to chapter-5.1.9.2). In internal trigger mode the precise timer was used and set to 30ms. The exact repetition rate is measured here. At external trigger mode the jitter is measured referred to the trigger input.

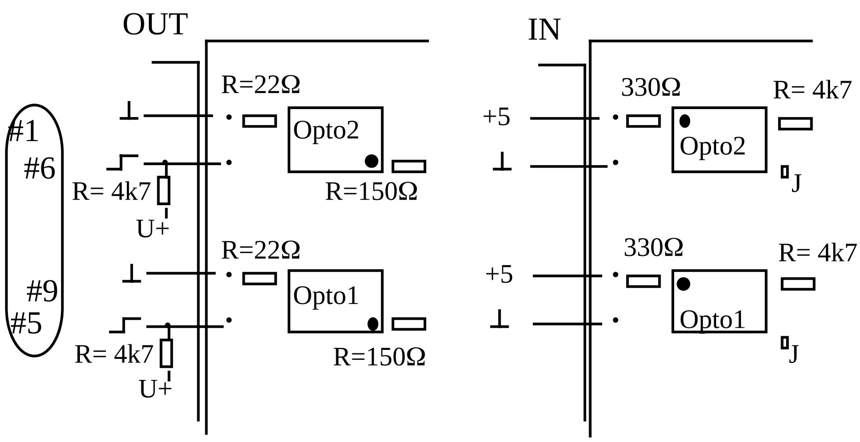
Table 4.12: Jitter of PCI board

	DOS	W98	Winxp	DOS	W98	Winxp
	10ms XCK	10ms XCK	10ms XCK	ext. Trigger	ext. Trigger	ext. Trigger
	µs rms(max)	µs rms(max)	µs rms(max)	µs rms(max)	µs rms(max)	µs rms(max)
Jitter	±1,8 (3,6)	±4 (50)	±2,5(320)	±1,2 (3,6)	±3 (42)	±16(250)
Delay				14	17	60

4.2.11 Additional trigger in- and output with opto- coupler

The PCI board can be delivered with two optional trigger in- or outputs, which are coupled with an opto coupler. The coupler type Infineon SFH6156-2 can handle up to U+ = 70V(R=4k7 @U+=5V).

picture-4.4: Opto coupler connections of PCI board

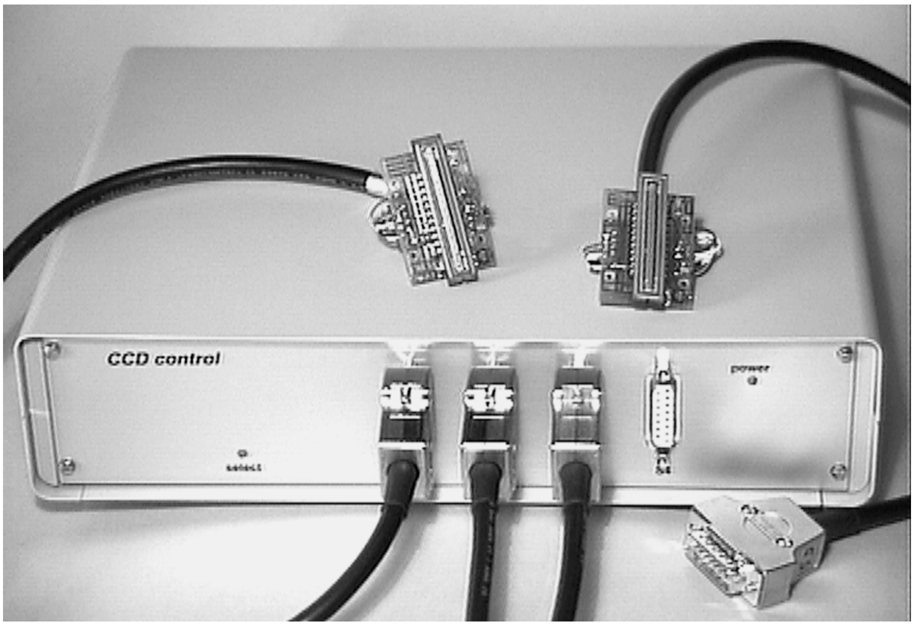


The functions SetOpto(ch) and RsetOpto(ch) in the unit BOARD can switch the level on and off; GetOpto(ch) reads the sate if Input (CtrlC register). Default is Opto1=OUT / Opto2=IN.

4.3 Distributor

To run up to 4 cameras with one interface board, a distributor can be used. Especially when all cameras have to be exposured parallel the distributor must be used. When using several interfaces, only a sequenced read is possible. The parallel exposure is accomplished with a special clocking of the sensors(chapter-4.3.5).

picture-4.5: Analog Distributor



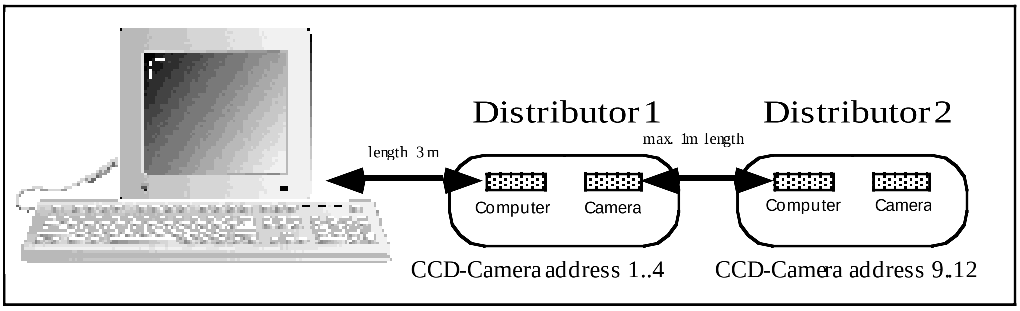
Two types of distributors can be delivered:

digital distributor: manages control of up to 4 cameras.

analog distributor: manages control of up to 4 Adaptor boards(chapter-4.4.1).

For managing more then 4 cameras, two distributors can be used. At the backside of the case are two 25 pin SubD- plugs: Computer and Camera. The additional distributor is connected with the:'Camera' plug of the first one.

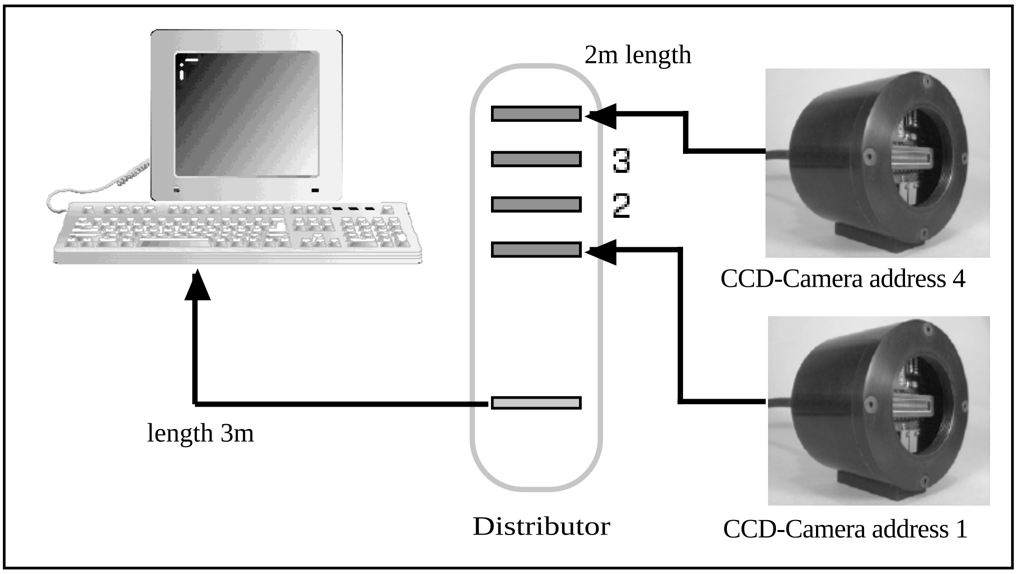
picture-4.6: Parallel mode of two distributors



4.3.1 Digital Distributor

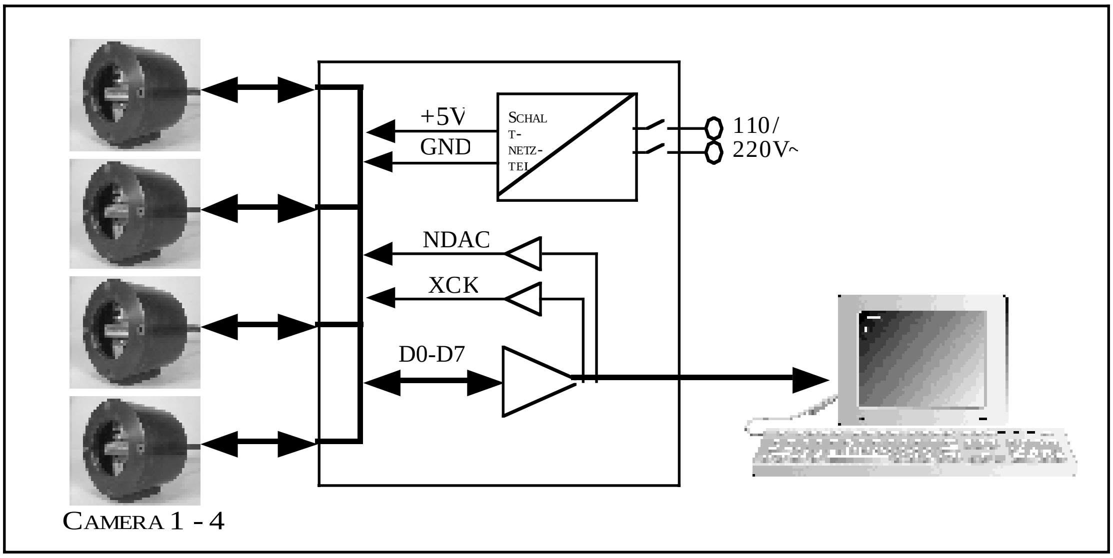
Similar to the IEC-Bus the data bus can send an address on the bus. So all cameras get an own address (1..15), which is put on the bus before the read cycle is started. Only the selected camera is activated (flashing LED). So it is possible to run up to 15 addressed cameras with one interface board.

picture-4.7: Setup with distributor



Our Software and one distributor can handle up to 4 cameras. The distributor implies a cable driver and an own power supply.
The cameras have a 2,5 m cable. The connection to the computer is 3 m.
The Software is written, that each data array DA1..4 can have its own camera address. In the setup menu the addresses for each DA can be selected (chapter-2.1.4).

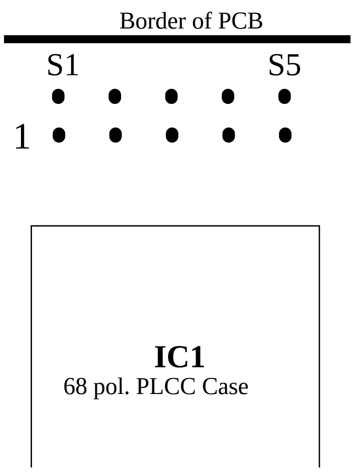
picture-4.8: Setup for the digital distributor



The power supply is: 5V / @ <3A = max. 15W.
The maximum pixel clock with the distributor is 4,5 MHz (2 wait states).

The exposure mode of the distributor has to be set with a Jumper on the main board (picture-4.9):
parallel or sequence exposure

picture-4.9: Jumper on the digital distributor board



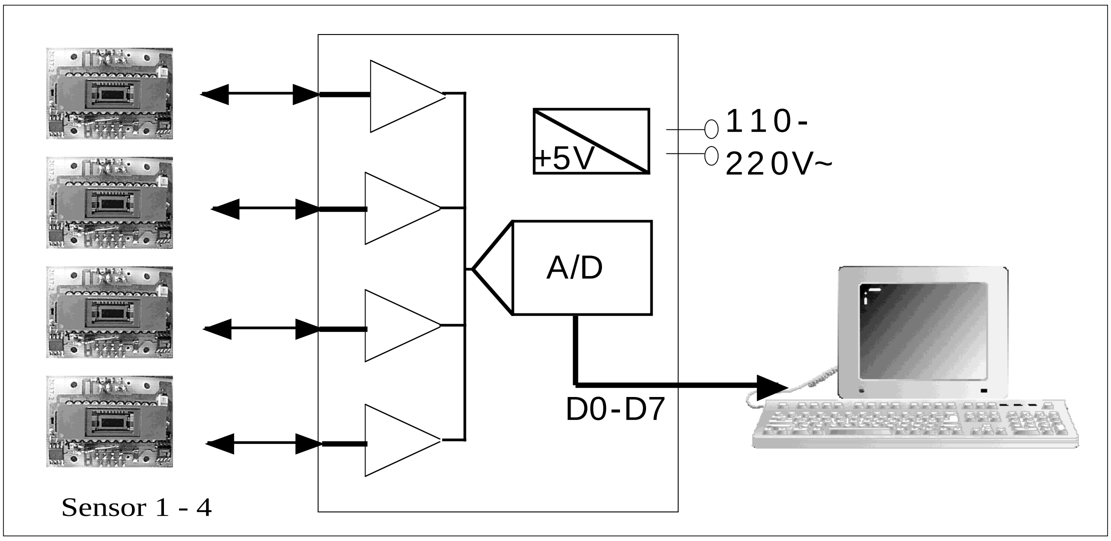
S1 open: select address: 1..4.
S1 set: select address: 9..12.
S2 open: cameras are exposured parallel.
S2 set: cameras are exposured in a sequence.
S3 nc
S3 nc
S4 open: normal operation
S4 set: Reset (only for testing)
S5: nc (no function)

The functions of S2 are explained in detail in chapter-4.3.3 and following.

4.3.2 Analog Distributor

The Analog Distributor consists of 4 selectable amplifier, one Analog/ Digital- converter and driver for the digital interface. The Analog / Digital- converter has an 8 bit interface. For 12 bit the high and low byte is transferred sequentially.

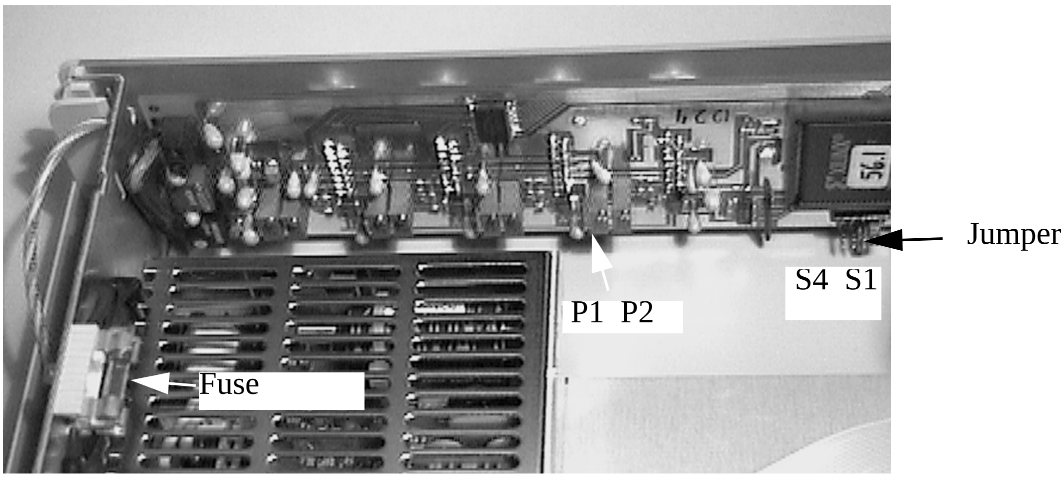
picture-4.10: Setup of Analog Distributor



Important: **Don‘t un/plug the sensor board when the CCD Control is turned on!**

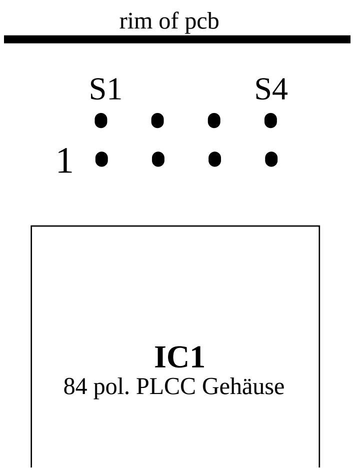
If the adaptor board was connected by mistake a protection fuse could brake. The fuse is inside the CCD Control and can be reached after opening the case(picture-4.11). If it is broken, the +5V supply is disconnected and the ‘power’ LED does not light.
The fuse is a F0,8A.

picture-4.11: opened Analog Distributor



Functions of Jumper field:

picture-4.12: Jumper field of pcb 2068



S1 open: select address: 1..4.
S1 set: select address: 9..12.
S2 open: cameras are exposured parallel.
S2 set: cameras are exposured in a sequence.
S3 open: no pixel pairing
S3 set: pixel pairing
S4 open: Sensor ILX506
S4 set: Sensor ILX503, 511

pixel pairing: adding even and odd pixel,
leads to a doubled signal and divides pixel number by 2.

Every sensor must be adjusted with the potentiometer P1 (offset) and P2 (amplification) as described in chapter-3.1.3 and chapter-3.2.3. The sensors vary (especially the offset) and must be realigned after changing the channel.

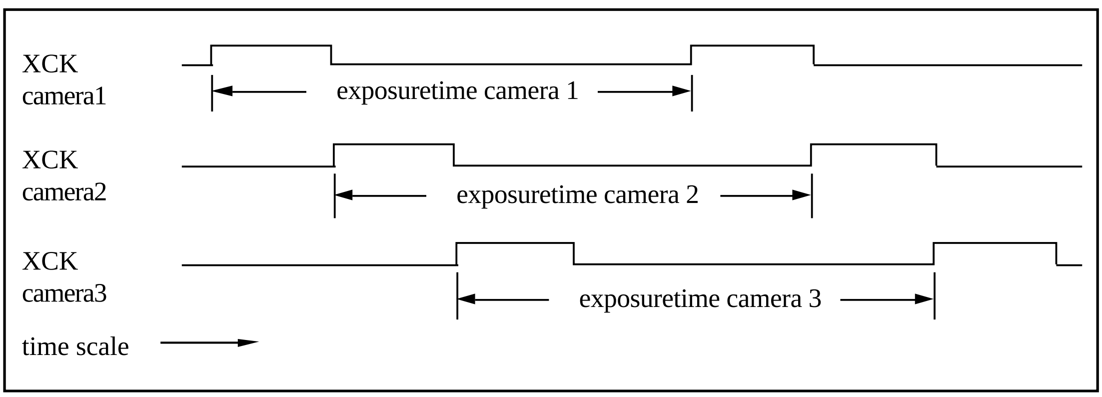
4.3.3 Sequence exposure

Set Jumper S2 on pcb 2061/2068. In the setup menu of the software the sequence exposure mode must be entered (no. of cameras = 1).

The cameras are selected one by one with their address. Only one camera is selected at a time (only one LED is illuminated). Every plug of the distributor has its associated address. The address is 1..4 or 9..12 if S1 is set.

The software selects the camera by calling GETCCD with the address as a parameter. The standard software correlates the address with the data array number 1..4. A parallel exposure at the same time is not possible in this mode. The minimum exposure time is limited by the read time of all cameras. This mode is similar to a setup with several interface boards.

picture-4.13: Sequence exposure mode



4.3.4 Parallel exposure mode of shutter cameras

In this mode the Jumper S2 on pcb 2062 may not be set. In the software setup the parallel mode must be set (no. of parallel exposured cameras >1).

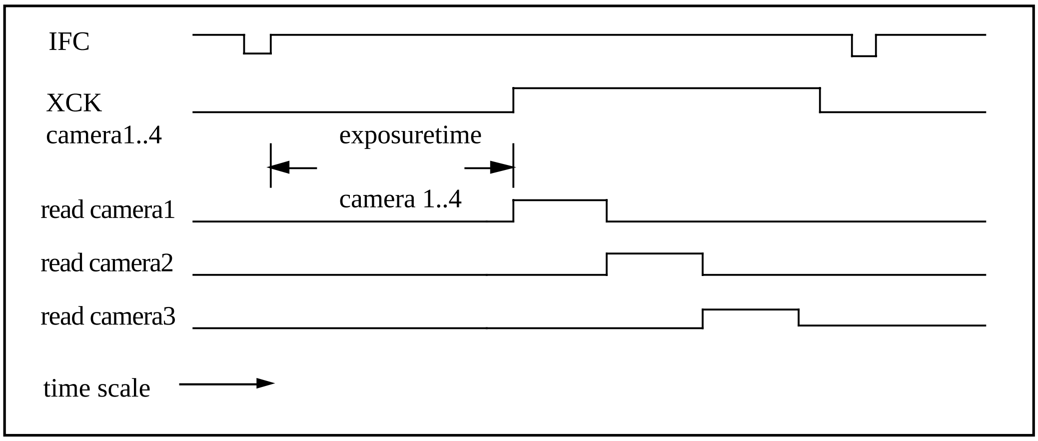
In this mode all connected cameras can be exposured exactly at the same time. The cameras are switched on parallel and the read will follow one by one sequentially. At the beginning of the read cycle (XCK = high) all generated electrons are transferred to the CCD shift registers. From there they are transferred one after the other to the computer. This function is only available for CCD sensors and not for the PDAs and FFTs , which have no registers.

The software algorithm looks as follows:

IFC low	CloseShutter;
IFC high	OpenShutter;
delay exposure time	Delay(exposuretime)
Read 1.camera	GetCCD(..1,1);
Read 2. camera	GetCCD(..2,2);
Read n. camera	GetCCD(.. n,n);
repeat loop	

The timing shows picture-4.14.

picture-4.14: time scaleParallel exposure mode of shutter cameras



The procedures CloseShutter and OpenShutter must also be used for sensors without shutter function if the distributor is used. In that case they reset the distributor.

4.3.5 Parallel exposure of standard cameras

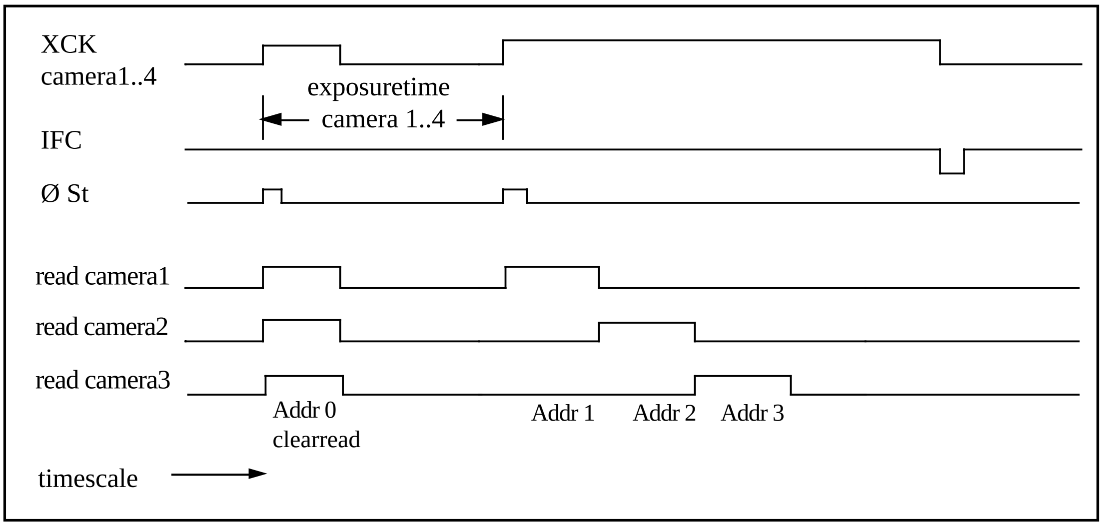
Cameras without shutter function must be cleared by several read cycles after they have been over exposured. Therefore the distributor uses camera ZAdr=0. When calling GETCD with address 0, all cameras are selected at the same time and the CCD-register are clocked simultaneously. The data is not written to memory. The FKT parameter must be set to FKT=0 (chapter-5.1.4.3).
Additional in the setup Setup the parallel mode must be selected (no. of parallel exposured cameras >1).

The software looks like that:

GetCCD (..,-1,0,1);	Clear read of all cameras (up to 10 times)
Delay(BelZeit);	wait exposure time
GetCCD(..,1,1,1);	Read data of camera1 in DA1 : start XCK sequence
GetCCD(..,1,2,2);	Read data of camera2 in DA2
GetCCD(..,1,3,3);	Read data of camera3 in DA3
CloseShutter;	IFC low Peak: reset sequence
OpenShutter;	
repeat	

This generates the following timing:

picture-4.15: Parallel exposure mode of standard cameras



XCK : enable camera; is here equal for all cameras.
IFC: is used to generate the end of a sequence. For shutter cameras the function is shown in chapter-4.3.4.
ø St : sensor intern transfer signal to the shift register.
read camera is the time during the NDAC signal is active (picture-7.6 and picture-8.10).

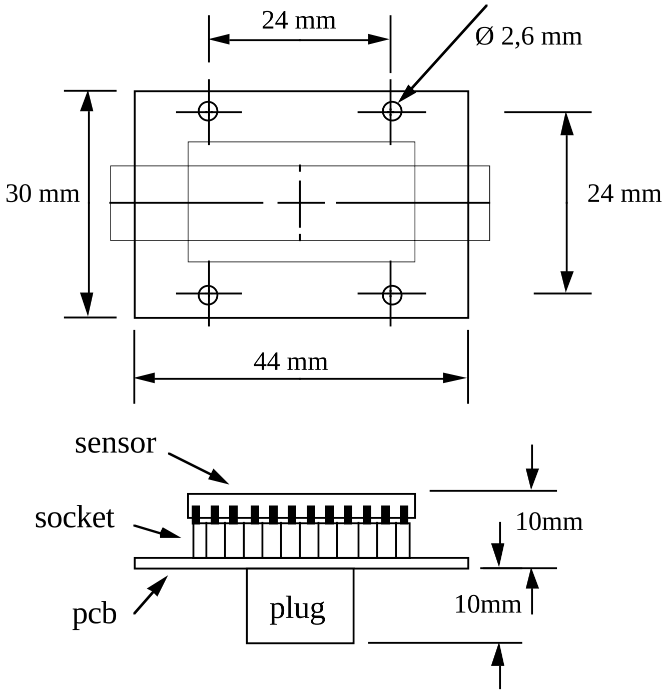
Please notice for parallel mode with S2=not set:
When using our software up to 4 sensors can be exposured simultaneously. In the setup the parameter no. of parallel exposured cameras must be > 1 (chapter-2.1.4). Is this value = 1 , the clear function of chapter-4.3.5 (Adr=0) will not be executed. For a correct reset of the distributor, the **shutter function must be enabled**!

4.4 External sensor

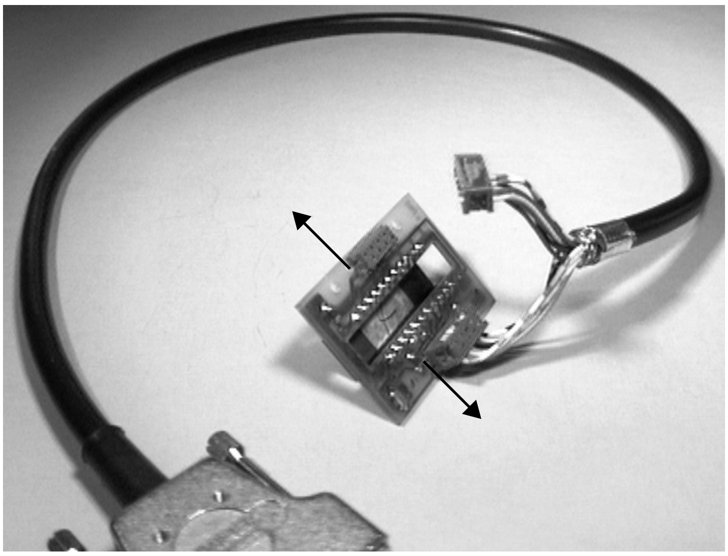
With our optional adaptor board it is possible to use the sensor outside the camera case. This board is only available for slow scan cameras (pclk < 4 MHz).

4.4.1 Adaptor board

The size of the adaptor board is shown in picture-4.16. The cable length is 0,5 m.
picture-4.16: Size of adaptor board



picture-4.17: Connection of adaptor board

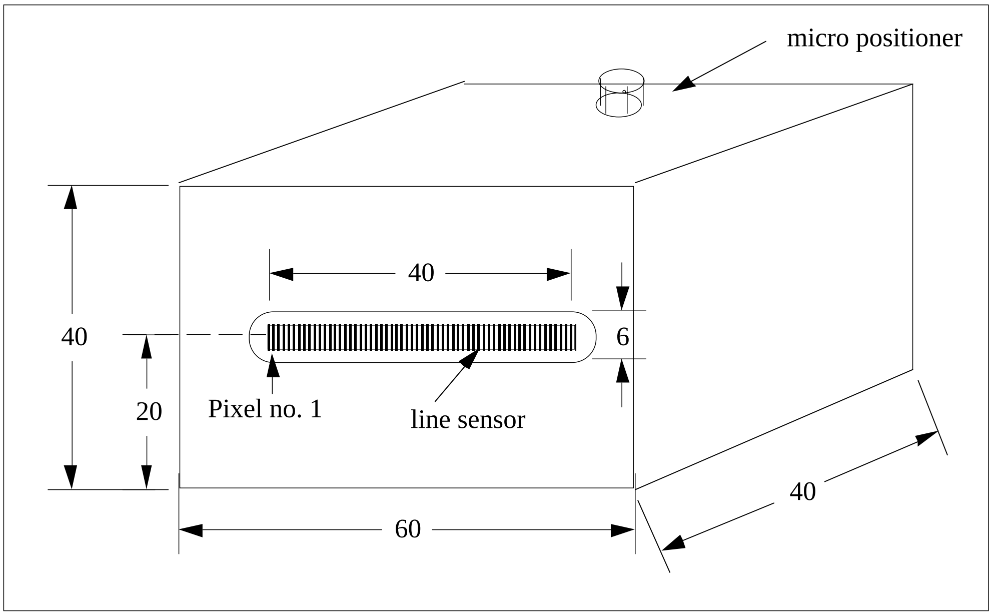


The plugs must be connected so that the wires leave outside.

4.4.2 Micro positioner case

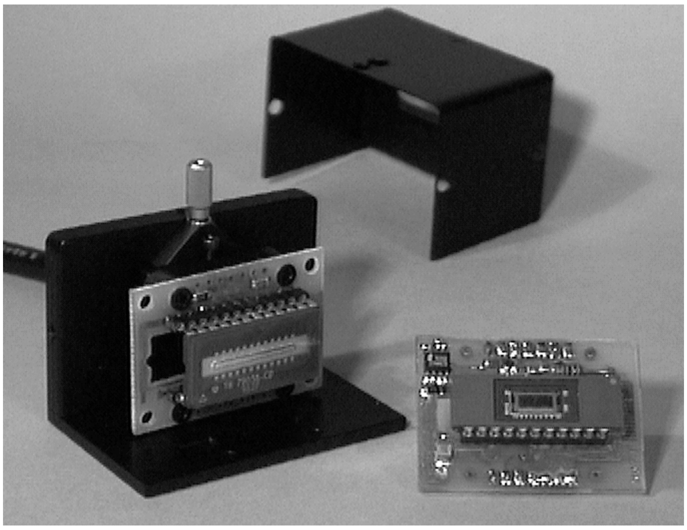
Additional we offer a shielded case with a stable micro positioner for adjusting the sensors horizontal position.
The size is shown in picture-4.18.

picture-4.18: Adaptor case (size in mm)



The horizontal position is adjustable 20 ± 2 mm above the ground plate.
The cable length is 0,5 m.

picture-4.19: Case and adaptor board

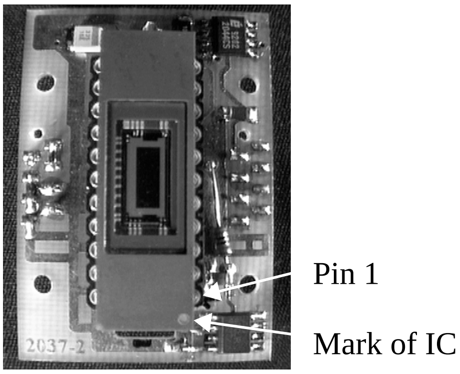


4.4.3 Removing the sensor

To use the sensor outside the camera, the sensor must be removed and set into the adaptors socket.
The best way to do this is:
1. Switch off computer and unplug camera.
2. Open camera (chapter-3.1.1 and chapter-3.2.1) and remove sensor carefully, as described in chapter-3.1.2 and chapter-3.2.2.
3. Open micro positioner case and put sensor in the socket. Best use cotton gloves and press the sensor at the outer ends. Avoid touching the window.

Important: Mark of the IC must correspond to the sockets mark!

picture-4.20: Sensor position on adaptor board



4. The sensor can now be adjusted and fastened on the mount. After that the case must be closed.
5. Additional the 8 pin operational amplifier on the upper camera pcb must be removed from the socket.
6. The Sub-D adaptor pcb must be pushed in the sockets of the sensor and the operational amplifier. Both sides of the case should be removed.
   Important: please check the correct sitting of the connector.

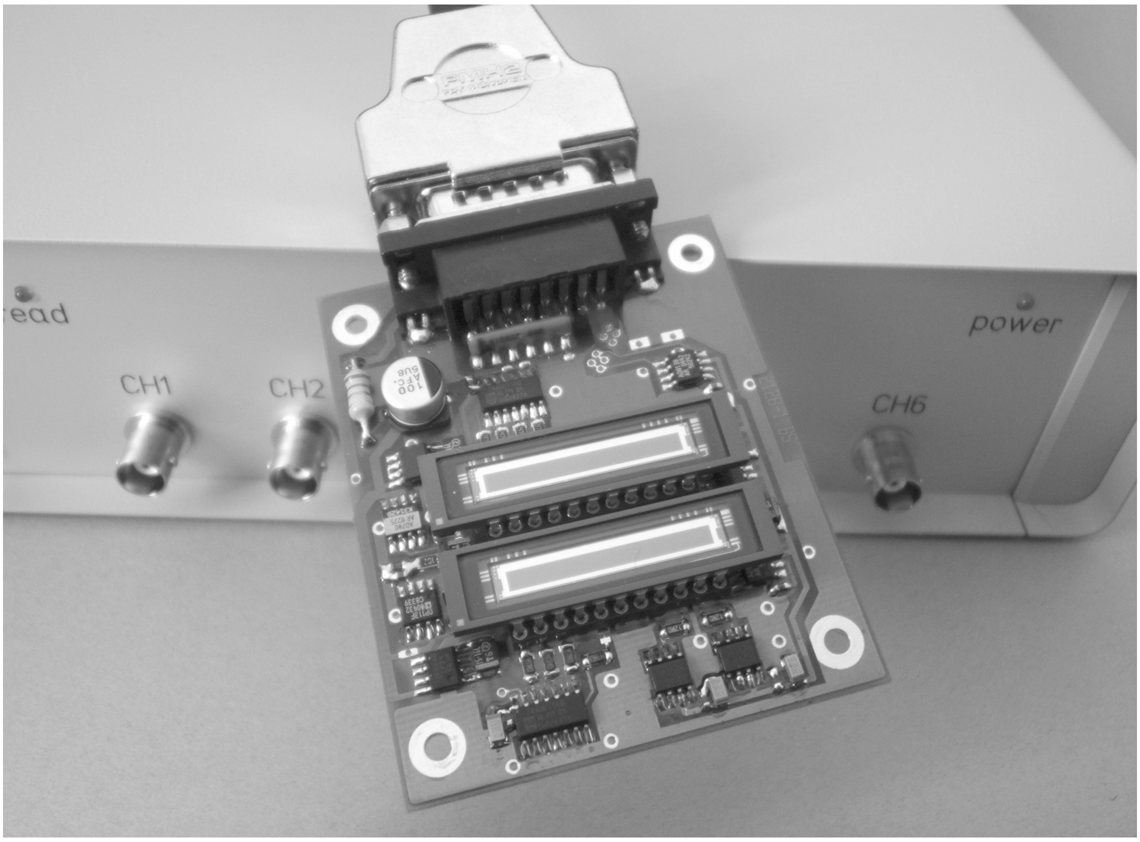
Please be aware:
Some sensors are extremely sensitive against electrostatic charge!
A simple touch of a pin can destroy the sensor. Especially sensitive are the sensors from Hamamatsu:
FFT series
IR series

With these sensors no guaranty is possible against unqualified handling.
The sensor should not be removed from the board. As long as the sensor sits in its socket it is protected by special diodes.

4.5 Double line sensor board

Our double line sensor board is intended for use in a I/I0 spectrometer systems. Both lines are sampling exactly at the same time. Therefore the PCI board must be used with a special adaptor board for the 2nd channel.

picture-4.21: Double Line Control Unit



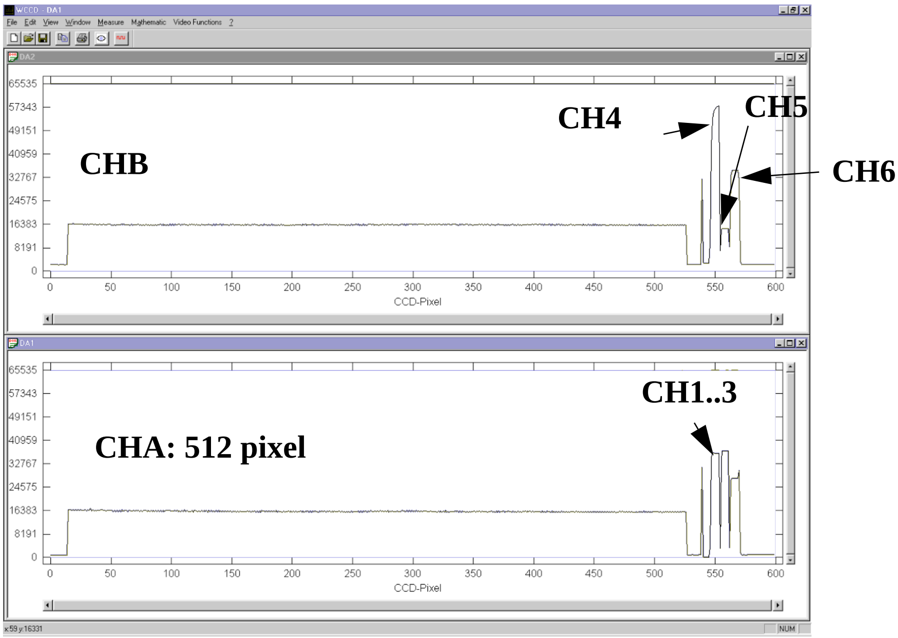
At the rear of the control unit 2 connections has to be made:
25 pol. Computer has to be connected to the PCI boards main connector (under the cinch plugs) / 25 pol. Camera has to be connected to the adaptor boards connector.

The Software reads the 32bit PCI bus data as an array of ULONGs where the low word is CHA and the high word is CHB.

An additional BNC plug at the rear shows the read timing XCK (is high during read cycle - the low high transition shows the read start time.

The control has 6 additional inputs which can be used for intensity control with additional photo diodes. The inputs are integrated and the signal is red right after the PDA read is complete (3 signals in array CHA and 3 signals in array CHB, see picture-4.22).
At the high low transition of the XCK signal (end of read) the Integrators perform their reset.

picture-4.22: Screenshot of 2 line Scan

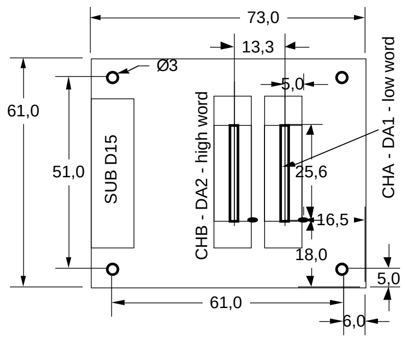


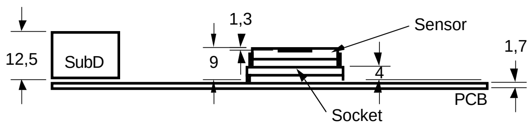
Specification of CCD control with 2 Sensors

Sensor Series S390x - 512
pclk = 2MHz
read time (600 pixel / 4 waits) = 400µs
max. rep. rate = 2.5 kHz

Pin CCD Control = 8W

Size of Double Line Sensor Board





4.6 Image intensifier

Series 2000 cameras can be coupled with an image intensifier. These MCP based tubes can amplify the intensity up to 100000 times. The MCP (MCP = 'multi channel plate') is of the 2. generation, with 18 or 25 mm diameter. With the supply voltage of the MCP, the amplification can be adjusted.

picture-4.23: Camera with image intensifier

2 different systems with sensors from Hamamatsu are available:
18 mm tube with 12,5 mm long sensor S3924-512
25 mm tube with 25 mm long sensor S3924-1024
The sensors have a special fiber plate window (consists of a bundle of 3µm single fibers), for coupling to the screen of the image intensifier which has also a fiber plate. With this fiber coupling up to 70% of the screen light is coupled to the sensor. By using standard optics only 5% of the light reaches the sensor.
25 mm systems are more expensive but have less noise and a better dynamic range.

Before using the system, please read the safety instructions in chapter-4.6.6**!**

4.6.1 Running instructions

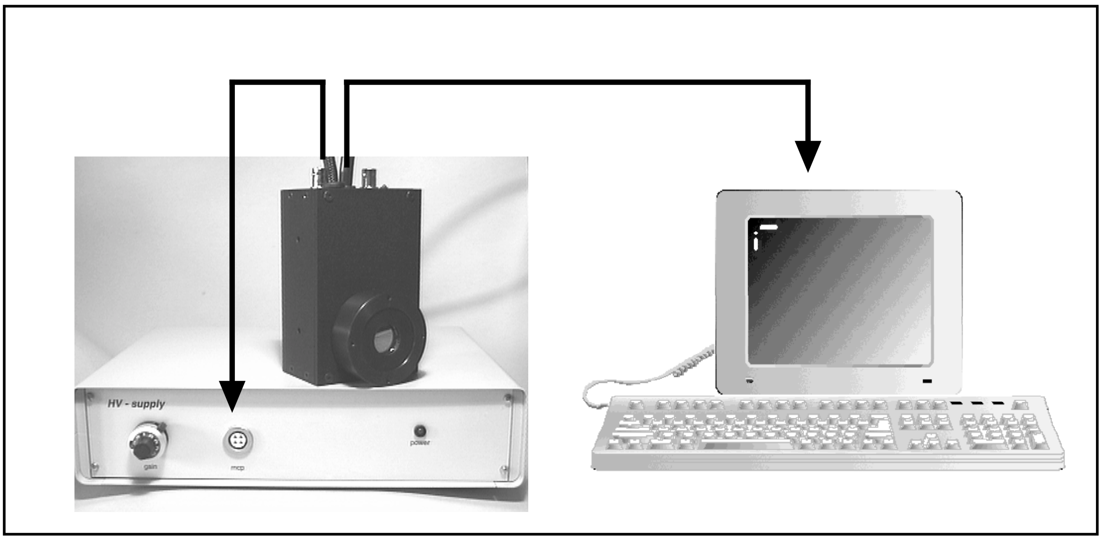
When using the system in cw mode, the integration time of the camera should be set by the software pretty high so that the image intensifiers amplification can be chosen low. That would increase the life time of the tube. Also the signal- noise ratio would be extended because the decay of the screen smooth the signal.

For that reason the exposure time should be set up first, before the amplification is raised slowly until the signal is seen.
With the highest amplification the noise of the photocathode can be seen.

4.6.2 Setup

Because the image intensifier is electrically separated from the camera the trigger cable has to be connected to the interface board (Trigger Out) and the supply cable to the HV supply.

picture-4.24: Setup with image intensifier



Before using the system, please read the safety instructions in chapter-4.6.6!

4.6.3 Choosing the right intensifier

We use MCP- image intensifier from Proxitronic and DEP. The so called near focus intensifier use single- or double MCP's.

In principle the cameras can be intensified up to 100.000 times. Hereby also other options must be considered:

* Choice of 4 Photocathode materials

Table 4.13: Photocathode material

	Spectral range [nm]	Dark signal [el/cm2/sec]	Sensitivity [µA/lm]	
S25-Pk	165 - 850	1000	350	standard
S20-Pk	165 - 750	100	200	
Bialkali-Pk	165 - 550	10	60	
RbTe-Pk	165 - 300	3		uv

* To adopt the sensors to the screen, 2 materials are possible. The sensors S3924 best sensitivity is at 600nm. With a resolution of 1% = 0,01 = 1/100 ≈ 7 Bit the maximal repetition rate is fmax.

Table 4.14: Screen material

	Maximum [nm]	efficiency (600nm) [W/W]	Decay 90 auf 10% [ms]	Decay 10 auf 1% [ms]	f_{max} [Hz]
P20	517	$7\ 10^{-4}$	4	55	17
P46	513	$4\ 10^{-5}$	0,3	0,09	3000

* The resolution (MTF = modulation transfer function) is worse for double-MCP's.

Table 4.15: Resolution

	MTF bei 20 lp/mm	max.amplification [lm/lm]	max.amplification [el/el]
single-MCP	30%	$3\ 10^{5}$	$5\ 10^{3}$
double-MCP	20%	10^{7}	$3\ 10^{5}$

2 control devices are available:

The **HV supply** which is always needed. It generates all voltages and also the adjustable amplification.

Optional **MCP Delay generator**
Because the tube is gatable, a pulse generator can be used to reach very short exposure times, even shorter then the camera read time.
The standard version has a minimal gate duration of 100ns. Optional a 5ns generator is possible.

4.6.4 MCP Delay

The MCP Delay combines the HV supply circuit board with the delay circuit board for gated mcp operation. In this case the Cathode voltage is switched between +12V (shutter closed) and -180V (shutter open). The timing for that gate can be triggered and adjusted by the build in delay generator. The monitor out can be used to control the timing of the gate. The real HV switch has a constant delay to the monitor out (sd) of 300ns.

picture-4.25: MCP Delay pulses

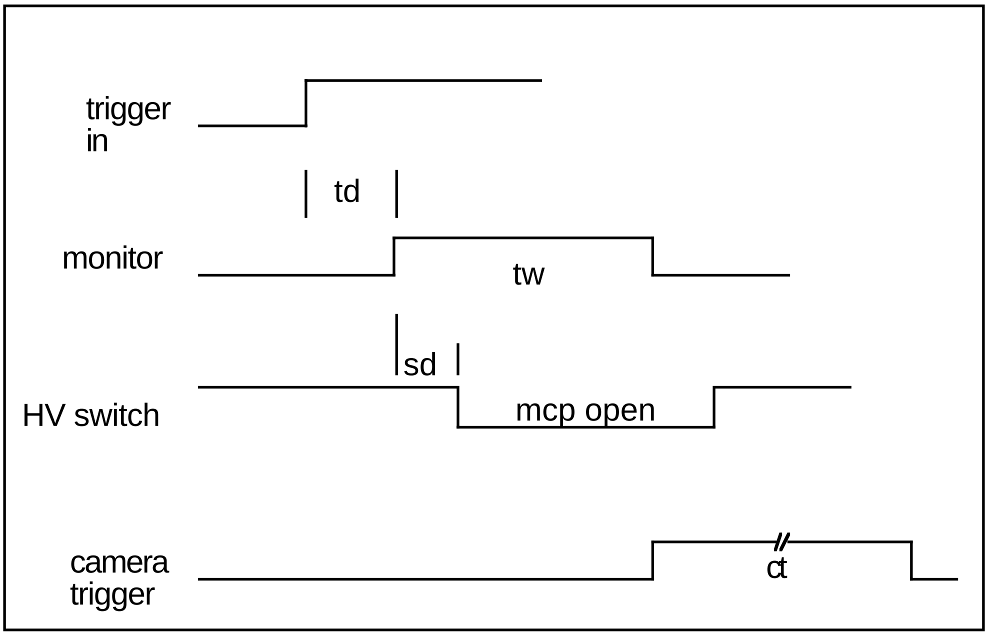


Table 4.16: Timing specifications of the Delay Generator

	delay direct td	delay delayed td	width direct tw	width delayed tw	switch delay sd	camera trigger ct
tmin [ns]	140	240	130	290	290	450 µs
tmax [s]	-	10	-	10	-	

The delay can be used in 2 modes:
<u>External Trigger mode</u>
An external event triggers the delay generator, the Computer is also set to external trigger and its PCI boards I plug is connected to the camera trigger out plug of the delay.
<u>Computer trigger mode</u>
The computer is set to internal trigger and the shutter function is enabled. The O plug of the computers PCI board is connected to the trigger in of the mcp delay. The gate switch is set to direct, so that the software can control the pulswidth.

4.6.5 Technical Data

Power HV Supply: max. 5W
Power MCP Delay: max. 8W

Table 4.17: Data image intensifier type BV2562QX100N

max. Q.E.	14,9	
max. gain	3340	W/W
resolution	32	lp / mm
min. Gate	100	ns
min. input diameter	25	mm
cathode voltage VK	-200	V
anode voltage VA referred to VMCP	5500	V
VMCP	0-800	V

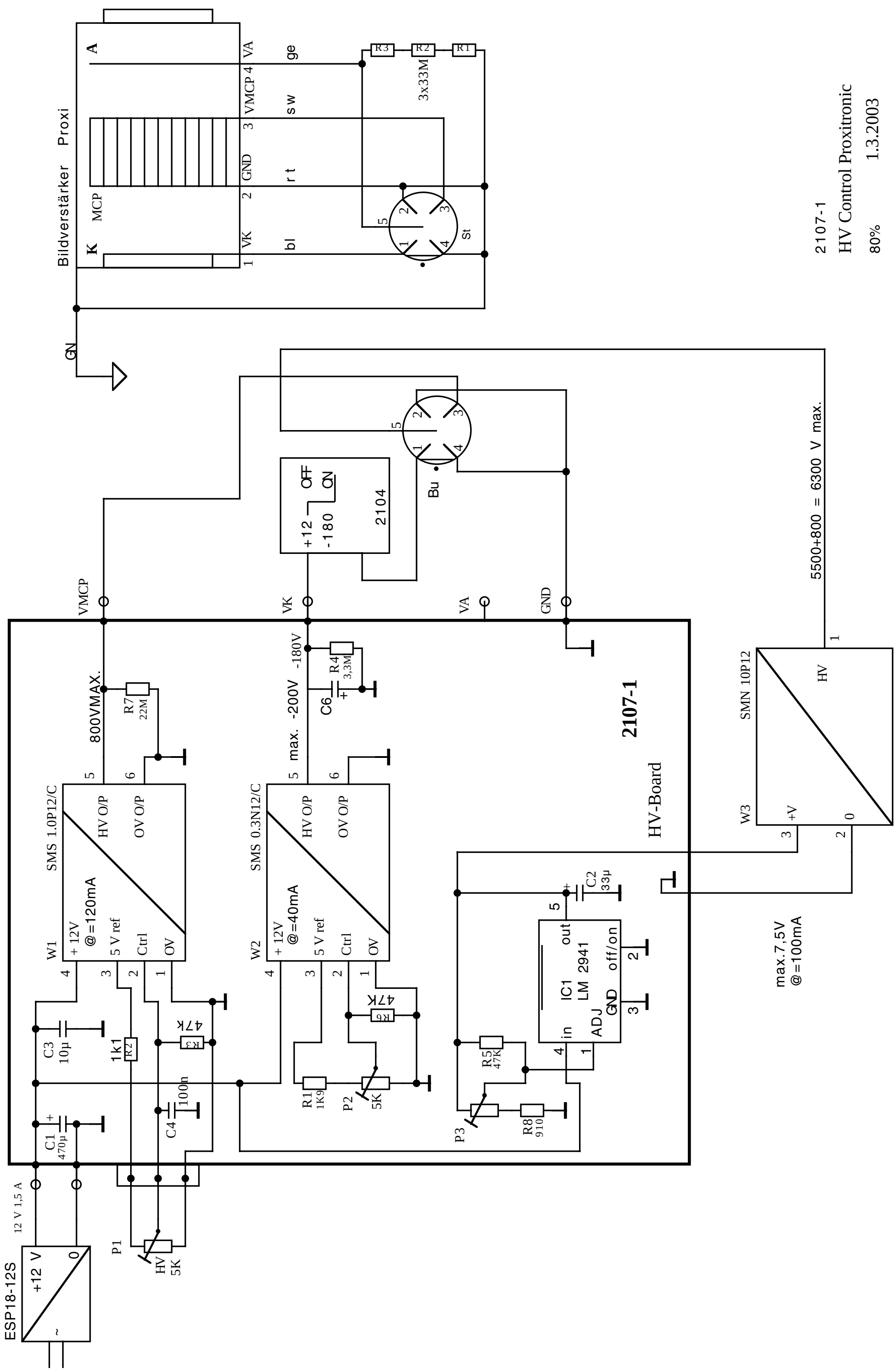
4.6.6 Safety instructions

Avoid bright light on cathode when device is powered!
Don‘t illuminate with direct sun light or Laser!
To avoid strong current with bright light, the amplification should be set to minimum before power on. Then it should be raised carefully.
Overexposure reduces the life time of the tube.
Avoid bright light also if not in use. The photocathode should be covered for safety.
Only use grounded cable: Euro- power plug.

The image intensifier works with high voltages.
Never work on the image intensifier or the HV supply if power is supplied!
Risk of electric arcs and electrical shock which can cause death, serve personal injury or substantial property damage. High voltages and components storing a very substantial amount of energy are present in this power supply during normal operation. However, these are inaccessible, improper handling may result in an electric shock or serious burns.
Do not open the case until at least 5 minutes after it has been disconnected from the mains on all poles.
The HV supply may be opened only by trained personnel.

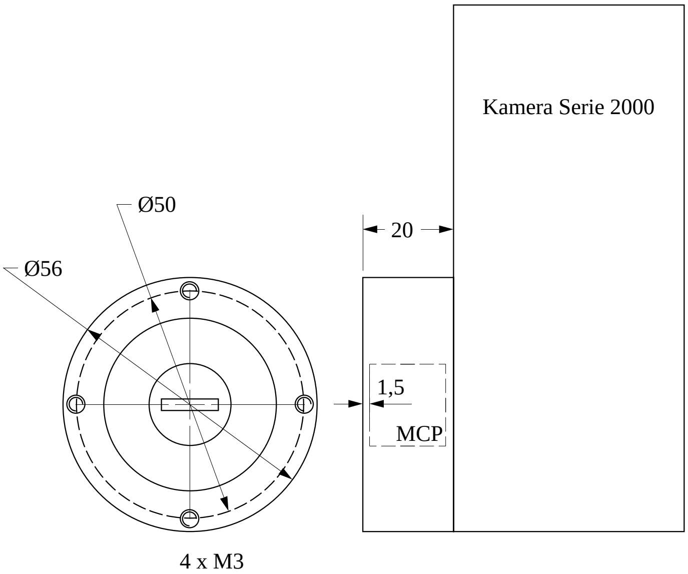
4.6.7 HV supply

picture-4.26: Schematic of HV supply



4.6.8 Dimensions

picture-4.27: Dimensions of image intensified camera



Part II Technical Manual

5 Software description

To use the CCD linescan camera as flexible as possible, it is necessary to have the ability to insert own parts to the program. Therefore the source code of the program is offered for easy adopting own routines.

Package 1: Camera driver
The package includes the driver to attach the camera to own application programs and a demo software for utilizing the driver. An own module: BOARD.* sets the functions of the interface board: external trigger and shutter function. This package is made for users, who want to write own applications. With this no work has to be done for interface or driver software.

Package 2: picture recognition ‘Toolbox’
Special routines for picture recognition, as well as for graphic display on the screen are available in a separately sold 'Toolbox' program. This is a collection of routines which should be selected by the user for his very special measurement problems.
16 or 32 bit camera drivers are include in this package.
The functions are described in the toolbox manual.

Package 3: Comfortable measurement software ‘WCCD‘
The offered software includes many functions of a basic measurement software. This should be sufficient for a lot of measurement problems.
The functions of WCCD are described in detail in chapter-2.1.

Additionally each package can be delivered for older operating systems:
DOS Win95/98/Me with LSCISA1.VXD driver or LSCPCI1.VXD
and
WIN WinNT4/2000/xp/vista/7 with 32 bit protected System driver LSCPCI.SYS.

The following chapters turns to programmers, who are already familiar with the programming language C. These descriptions are not suitable as an introduction to the programming languages itself.

5.1 Win- Version

For a lot of applications, i.e. in the quality control, where special measuring tasks must be processed, the control program ‘WCCD.C’ might be adopted if purchased with source code.

For example the camera signal has to be evaluated and a decision, good / bad has to be made. In this case the brightness signal on the line is not of interest. Instead statistical data should be displayed on the screen, i.e. amount of the examined objects etc.
The WCCD control program can be very helpful to start the development of own picture recognition software.

The source code can be used while developing own routines, lets say as a starting point for an own measuring program.

The most important part is the driver call for the CCD camera: GETCCD for the no FIFO version and CallIORead or ReadFifo for the version with a FIFO.
These functions generate all necessary clock signals and reads the pixel values in a data array what has had to be allocated before the call..

The driver program is available in 4 versions:

PCBV4_4 16 bit ASM- version for DOS and Windows 3,1version
PCBW1_0 32 bit ASM- version for Windows95/98
LSCISA/PCI1VXD- driver in 32 bit for Win and
LSCISA/PCISYS- driver in 32 bit for ‘protected mode’ WinNT/2000/xp/vista.

The call of the driver from the different environments is described in the following chapters. Example programs which call the driver are included on the CD.

The call of the drivers from different environments is described in the following chapters. Linking demo-software and drivers are included in the following files:

CCDEXAMPdemo software for linking the driver, runs in NT and Win

5.1.1 Installation

For installation of the drivers and the entries in the registry, the file LSCPCI.INF can be used, which is part of the driver software package. The installation procedure in windows is as follows:

1 switch off computer
2 install interface board in the computer
3 start windows
4 usually the new hardware wizard is started automatically
select -> next
5 select -> search for suitable driver (recommended)

select -> next

6 choose search location where the *.inf and *.sys file was copied or the original CD

7 the wizard should now install everything needed

8 restart the computer

Now you can test the driver with the program WCCD, which is explained in chapter-1.5
When you look at the system control panel you should find in
->hardware -> device manager ->LSCPCIBoards-> LSCPCIBoard an entry:
drivers are installed.
In the lower field a ->use this device (enable) entry must be found.

5.1.1.1 program CCDInst[1]

The installation software will be delivered inclusive source code and may be used as an example for your own installation software. Also you may use simply the functions of the software to install your camera driver.
A list of the installed board addresses can be displayed (Prefs), a new driver can be installed (Install) or a installed driver can be removed (Deinstall).

When starting CCDInst, the original driver LSCISA1.SYS, LSCPCI1.SYS, LSCISA1.VXD or LSCPCI1.VXD must be in the same folder as the file CCDInst.EXE. Then the driver will be copied into the system folder.
At deinstallation each operation the install process made, is removed. Also the driver LSCISA/PCIn.* in system folder will be deleted!

When installing the ISA- board the hardware coded address of the interface board is needed. The default value is 258. The input and display is interpreted as a hex code writing. Also the addresses 358, 250 and 350 can be entered, but they must correspond to the jumper settings of the board. After restarting windows, these addresses are confirmed by the windows startmanager.If these addresses are already used from other boards an error message occurs: Service failed. The jumper settings must be replaced and another address has to be entered.
The software is executable under Win and WinNT. It switches automatically between the operation systems. The current OS is easy to find in the source code with flags IS_NT and IS_Win.

5.1.1.2 Installation of multiple interface boards

The driver LSCPCI Version >=2 can handle the installation of multiple interface boards. Here the numbering scheme of the board numbers (1..4) is accomplished by the computer and it is not predictable which board will get what number. Therefore the program CCDExamp must be used to find out which number selects which board. The board number is set by the constant DRV located in BOARD.H. If you set this to 1 and execute the program you can see which camera is working. If you set the constant to 2, you should see the next interface which is selected.
In the WCCD program the board no. can be set in the File->Camera setup menu (which

1. for older systems, not for winxp and later

is only accessible when all windows are closed).

older operating systems (LSCPCI Version <2)
In the ASM- version the address of the interface board is a parameter of function GETC-CD, Therefore multiple boards can be selected.
Under WinNT this selection is not possible. When calling CreateFile a handle to the driver is returned. This handle manages the further access to the boards data registers.

The address of the board is inserted inside the registry with the installation software. It is possible to operate up to 4 interface boards with the driver LSCISA/PCI1, LSCISA/PCI2 LSCISA/PCI3 and LSCISA/PCI4. The drivers are alike but the names are different. Each driver gets a fixed address in the registry. With this method each board can be installed or de installed independently. In case of operation with one board, it is sufficient to install the driver LSCISA/PCI1.
Correspondingly the installation software functions for further interface boards are written modular and can be deleted easily if you need.

5.1.2 Deinstallation

To deinstall the driver, the device manager can be used. Go to the system control panel ->hardware -> device manager ->LSCPCIBoards-> LSCPCIBoard entry and look for the driver->deinstall button. After that switch off the computer and remove the PCI board.

5.1.3 Camera driver

The driver package can be delivered in 2 versions for the ISA- and the PCI Board
(the printer port driver is part of the ISA board driver):

System driver
Win95/98/Me with driver LSCISA/PCI1.VXD
and WinNT4/2000/xp/vista with 32 bit protected System driver LSCISA/PCI.SYS.

Included in each package is a demo software ‘CCDEXAMP’. This source code example shows the call of the driver. This simple demo software might be used for the test of the camera and for driver installation.

The system driver package for older systems includes an additional installation software ‘CCDInst’. This program can be used to simple install the drivers. The source code is also included, so own installation needs can be adopted easily.

5.1.3.1 VXD driver LSCISA

The driver LSCISA1.VXD is written to make the software, which is written for WinNT, also executable for Win95/98 without changes. The drivers interface work exactly like described for WinNT.
In WinNT the call to hardware via In / Out statements is not allowed. Here the call of the driver is managed with the File I/O mechanism. The functions CreateFile, DeviceIoControl and CloseHandle are used to transfer data to the interface. This mechanism may also be used in Win.
An installation like in WinNT with our software CCDInst is not absolutely necessary, the driver can load dynamically. For this purpose the LSCISA1.VXD file has to be in the

same folder as the called EXE- software. If the hardware address of the interface board must be changed the software CCDInst must be used to install the driver statically. In the registry a key under
HKEY_LOCAL_MACHINE\System\CurrentControlSet\Services\vxd\LSCISA1
is entered. Here the new hardware address may be entered. The driver is copied to the system file.
The software CCDInst recognizes automatically the operating system and fits all differences automatically.
When calling the dynamic driver, the function CreateFile must have the name of the driver with the extension.vxd ! - When calling the statistic driver, this extension is optional.

5.1.3.2 SYS driver LSCISA

WinNT is an operating system running in protected mode. Simple I/O-access, as used in ASM driver, is not allowed here. Similar to the access of files, the hardware is attached with the functions for File I/O: CreateFile, DeviceIoControl or ReadFile and CloseHandle. To use this functions, the driver:

LSCISA1.SYS

must be installed within the system. Additional an entry in the registry has to be made.

5.1.3.3 Installation of driver LSCISA1.SYS

Two entries must be made to install the driver.

1. The driver LSCISA1.SYS must be copied into the system file:
   WINNT\SYSTEM32\DRIVERS.
2. Within the registry the entry has to be like following:
   Type REG_DWORD=0x1
   Start REG_DWORD=0x2
   Group REG_SZ=Extended Base
   ErrorControl REG_DWORD=0x1
   under the key:
   HKEY_LOCAL_MACHINE\System\CurrentControlSet\Services\LSCISA1.
   Additionally a sub key \Parameters has to be generate under:
   IoPortAddress REG_DWORD=0x258
   IoPortCount REG_DWORD=0x4.

After installation or deinstallation a reset has to be confirmed.
After reset a further sub key will be set up by the system: \Enum, which must be deleted at deinstallation as well.
This installation might be done on the one hand with the help of the system software accessory: REGEDT32 by yourself, or with our installation software: CCDInst, which generates the above mentioned settings.

5.1.3.4 VXD driver LSCPCI

The driver LSCPCI1.VXD was written to make software which has been written for

WinNT also executable without changes in Win. So your application is independent of the operating system.

The access to hardware with in/out statements is not allowed under WinNT. Instead execution is similar to the file access with the functions CreateFile, DeviceIoControl and CloseHandle. This mechanism can be used also under Win. The access is described in chapter-5.1.4.

5.1.3.5 Installation of the driver LSCPCI1.VXD

The installation can be made easily with the program CCDInst.
Alternatively all settings might be made with regedit:

1. The driver LSCPCI1.VXD must be copied into the system folder:
   WINDOWS\SYSTEM\.
2. In the registry the settings:
   Start REG_DWORD=0x0
   StaticVxD REG_SZ LSCPCI1
   under the key:
   HKEY_LOCAL_MACHINE\System\CurrentControlSet\Services\vxd\LSCPCI1
   must be completed.
   Additionally a sub-key \Parameters must be generated for registration under:
   VenDevID REG_DWORD=0x10b59080
   SubVenDevID REG_DWORD=0x45537401
   MaxDMABufLength REG_DWORD=32000.
   MaxBufLength is the maximum buffer width of the DMA transfer buffer in byte.

When calling the dynamic driver, the function CreateFile must have the name of the driver with the extension.vxd ! - When calling the statistic driver, this extension is optional.

Plug&Play manager
When starting the computer with the installed PCI board, the Plug and Play Manager asks for a driver. Within this after an automatic search you simply choose under various components the category not supported device. After this the P&P manager reads within the vxd- driver the required data.

5.1.3.6 SYS driver LSCPCI

For use of the PCI-board the driver: LSCPCI1.SYS
must has been installed within the system with the help of the LSCPCI.INF file which handles all necessary entries.

5.1.3.7 Installation of driver LSCPCI.SYS

Two entries in the registry have to be made:

1. The driver LSCPCI1.SYS must be copied to the system file:
   WINDOWS(WINNT)\SYSTEM32\DRIVERS.
2. Within the registry the setting:
   Type REG_DWORD=0x1 //Service_Kernel_Driver
   Start REG_DWORD=0x2 //load by service controller

Group REG_SZ=PCI Configuration//instead of extended base
ErrorControl REG_DWORD=0x1
under the key:
HKEY_LOCAL_MACHINE\System\CurrentControlSet\Services\LSCPCI1
must be entered.
Additionally a sub-key \Parameters must be generated with entries:
VenDevID REG_DWORD=0x10b59080
SubVenDevID REG_DWORD=0x45537401
MaxDMABufLength REG_DWORD=32000
MaxBufLength is the maximum buffer width of the DMA transfer buffer in byte.

After installation or deinstallation a reset has to be made.

After reset a further sub key will be set up from system manager: \Enum . In case of deinstallation this key must be deleted as well.

This installation can be done with the acessory\REGEDT32 , or with our installation software: CCDInst, or just the *.INF file.

5.1.4 Calling the driver

The easiest way is to use the unit Board of the CCDExamp folder. Here all calls to the driver are made and a set of functions can be used to initialize the Interface and to manipulate the control registers. The most important function is GETCCD or CallIORead and ReadFifo, which is used to read the camera data.

5.1.4.1 UNIT BOARD

The unit BOARD includes all routines which set registers on the interface board. Here the particular assembler code software (OBJ- file) or driver software (VXD or SYS file) is called.

<u>Procedures and Function of UNIT BOARD</u>

Initialization routine for Win version (must be called once at program start)

CCDDrvInit	open driver
CCDDrvExit	close driver
InitBoard	initialize the interface board

setup transfer

SetBoardVars	see chapter-5.1.4.2 - can be called several times

read camera data

GETCCD	see chapter-5.1.4.3

Miscellaneous Interface functions

AboutDrv	read driver version and ID-Byte of board
ClrRead	clear camera register after overexposure

ClrShCam	clear for shutter camera
HighSlope	set external trigger to positive slope
LowSlope	set external trigger to negative slope
OutTrigHigh	set trigger out to high
OutTrigLow	set trigger out to low
OutTrigPulse	outputs a 'PulseWidth' long pulse at the trigger output plug.
Waittrigger	wait until raising or falling slope at trigger input
OpenShutter	switch off shutter function[2]
CloseShutter	switch on shutter function[3]
V_On	turn to higher amplification[3]
V_Off	turn off higher amplification[4]
CAL16Bit	starts calibration of 16 bit A/D-converter

Not interrupt driven special functions for low Jitter

ReadKeyPort	read PS2 keyboard directly
ActMouse	turns mouse function on
DeactMouse	turns mouse function off

5.1.4.2 Function SetBoardVars

This function sets the transfer parameter for the Interface and DMA, if PCI.
The definition is:
SetBoardVars(UINT drvno, BOOL sym, BOOL burst, ULONG pixel, ULONG waits, ULONG flag816, ULONG pportadr)

The function must be called once to setup the transfer but can be called more then once if a parameter must be changed.

drvno	no. of interface board, usually = 1
sym	only PCI: symmetrical pulses, see chapter-4.2.8
burst	only PCI: highest data rate, see chapter-4.2.8
pixel	number of pixel to read
waits	waitstates for transfer see Table 4.9
flag816	resolution of A/D- converter (2=8bit, 1=12&16bit)
pportadr	only ISA: address of printer port - 0 if ISA Interface
pclk	only sync: pixelclock for camera write to FIFO - see ccdexamp.h
xckdelay	only sync: delay for charge transfer -> see ccdexamp.h

5.1.4.3 Calling GETCCD

The main procedure to read the camera data is GETCCD, which has the following parameters:

GETCCD(UINT drvno, PULONG dioden, ULONG fftlines, long fkt, ULONG zadr);

---

2. Only cameras with hardware shutter function.
3. Only cooled camera systems series 2000.

drvno no. of interface board, usually = 1
dioden the array address (here: DIODEN)
fftlines number of vertical lines for FFT- Sensors (or lines to sum, if binning), fftlines is set to zero for standard sensors!
fkt =

-1 This function clears the line registers. The camera is clocked but the data is not stored. This read clears the sensors registers. After an overexposure or if the sensor was not used for a longer time, the storage cells are saturated and must be cleared by repeated reads. The amount of clear read cycles differ from sensor to sensor. There might be up to 10 cycles necessary.

0 Sets the data of the data array (DA) to zero. That means Dioden[1.. pixel]= 0. The clock signals are not generated.

1 Normal read operation. Reads the data and stores the values to the array dioden.

2 The new data is added to the data already located in memory - in real time! Please note, when displaying the data on the screen, the values of a 12 bit array are bigger than 255 and the Y-resolution for the display function must be changed.
5 test data is written to memory array (const. val 100).

zadr
1..16: Address of the line camera at the bus. To be able to manage up to 16 cameras in the addressed mode, the address of the camera must be entered here. Addressed mode is only available for camera series 2000 or for the digital distributor. For the standard camera series 1000 this variable has no function.

5.1.4.4 Driver call details

The driver is called similar to file I/O. The demo software CCDEXAMP.C shows the exact call parameters in the module BOARD.C .
The software should use the following functions:
handle=CreateFile(“\\\\.\\LSCPCI1, ..) once at the beginning of the program -> opens the driver
DeviceIoControl(handle, Function, ..) for each access to the interface board
or ReadFile(handle,Buffer,sizeof(Buffer)) for each DMA transfer
CloseHandle(handle) once when program is terminated-> closes the driver

The **DeviceIoControl** function uses the following definitions:
Function=

IOCTL_SetBoard : initialized the interface and returns an error code.
Call only once at program start.

IOCTL_GetVersion : gets the driver version (0x1n1; or 1n2..1n4 for the driver LSCPCI2..4); n: sub-version-number

IOCTL_ReadByteS0 : read one byte from register range of the interface board

IOCTL_GetCCD : passes parameters to the driver and starts the data transfer

IOCTL_ReadLongS0 : read a long from register range of the interface board

IOCTL_ReadLongIORunReg : read long from 9080 register (exclusively PCI)

IOCTL_ReadKey: read keyboard port directly without interrupt

IOCTL_SetFct: special functions: InitPCI, Act/deact mouse

IOCTL_WriteByteS0 : write a byte to the register range of the interface board

IOCTL_WriteLongIORunReg : write long to 9080 register (exclusively PCI)

IOCTL_WriteLongS0 : write long to the register range of the board

The function ReadFile(..) is the same as function GetCC, but no parameter is passed to the driver.

The simplest way to test the driver is done with the demo software CCDEXAMP within the function AboutDrv ( ):

CreateFile("\\\\.\\LSCPCI1",..);find and load driver

DeviceIoControl(hDlg, IOCTL_GetVersion,..);get version =101

PCI: DeviceIoControl(hDlg, IOCTL_ReadLongS0,4..);= "S" = 0x535nnnnn = board found, n: don't care

ISA: DeviceIoControl(hDlg, IOCTL_ReadByteS0,4..);= "S" = 0x53 = board found

If these functions execute without error, the board is installed correctly.

5.1.5 ASM Version of GETCCD for Win

The camera read procedure GETCCD can also be delivered in a OBJ version for W95/98/Me operating system. Here the driver could be omitted. This file is only available on demand.

The ASM driver software is available in 5 OBJ versions:

PCBP1	16 bit version in DOS and Win 3.1 for printer port
PCBPW1	32 bit version in Win for printer port
PCBV4_4	16 bit version for DOS and Windows 3.1 for ISA interface board
PCBW1_1	ASM32 bit version for Win with Microsoft linker COFF format
PCBB1_0	32 bit version for Win with Borland linker OMF format

5.1.5.1 Linking of OBJ driver to 32Bit C++ (Win)

The operating system Win is something special because here all driver versions are able to operate. The optimized assembler camera driver for Win is ASM32 version. In Win it is possible to run the software with 32 bit and there are no problems with 'protected mode' mechanism of WinNT. Win is the optimized surrounding for hardware close software. The access to I/O- Addresses are allowed here in contrary to WinNT and therefore uncomplicated.
But to make software compatible for Win, though they are written for WinNT, the VXD-driver was written. The call of the DeviceIoControl mechanism of 'protected mode' sys-

tem WinNT is in the VXD- driver forwarded to the ASM32 driver.

The 32bit version of the driver is written for C language. The definition is:

```
external void _GETCCD(void* Off, unsigned long up_dn, unsigned long fourmax,
        unsigned long V_Clks, unsigned long Flag816, unsigned long Waitsta,
        unsigned long CCDPort, unsigned long FKT, unsigned long Zadr,
        unsigned long DataB);
```

The call is simple:
_GETCCD(&Dioden,up_dn, fourmax,vclks, flag816, waits, portadr, 0, 0, datab);

The array Dioden is declared in the 32bit version as follows:
pixel = 1800 /* sensor with 1800 pixel*/
unsigned long Dioden [4] [pixel]; /* when using 4 line buffers*/

Each data value is a 32bit type, which enables the online addition of
$2^{32} = 16 * 10^6$ - 8 bit values or
$2^{20} = 1 * 10^6$ - 12 bit values.
The camera driver PCBW1_0.OBJ must be linked to the project.
You can find the driver in the folder ASM32\C.

5.1.5.2 Specials of Borland C

To link the Borland compiler the ASM- File must have the OMF format. Additionally the Inp and Outp - statements are not defined (used in the Unit BOARD to read the register of the interface board). Therefore these functions are declared inside the ASM driver. The driver PCBB1_0.OBJ can be delivered on demand.

5.1.6 Reading camera data with a DLL

To adopt the functions of the unit BOARD to other programming languages a DLL can be used.

5.1.6.1 “LWLSCDLL“

The DLL: LWLSCDLL.DLL can be found in sub-folder \ Release and enables the call of the camera driver functions from other software.
Each function of the unit BOARD can be called with the following definition:

```
BOOL DLLCCDDrvInit();
void DLLCCDDrvExit();
BOOL DLLInitBoard(..); // for parameters see SetBoardVars at chapter-5.1.4.2.
UCHAR DLLReadBytePort(ULONG PortOff);
void DLLWriteBytePort(char DataByte, ULONG PortOff);
void DLLGETCCD(PULONG dioden, ULONG pixel,
            ULONG vclks, long fkt,ULONG zadr,ULONG db);
int DLLAboutDrv();
void DLLHighSlope();
```



```
void DLLLowSlope();
void DLLOutTrigHigh();
void DLLOutTrigLow();
void DLLOutTrigPulse(ULONG PulseWidth);
void DLLWaitTrigger(BOOL ExtTrigFlag,BOOL *SpaceKey, BOOL *EscapeKey);
void DLLOpenShutter();
void DLLCloseShutter();
void DLLVOn();
void DLLVOff();
UCHAR DLLReadKeyPort(ULONG PortOff);
```

The DLL module wraps the functions defined in the module ‘Board.c’ (see chapter-5.1.4.1).
An enhancement for Win/NT versions is implemented in the following functions:

DLLCCDDrvInit	must be called once at beginning of the program
DLLCCDDrvExit	must be called once at the end of the program
DLLCCDInitBoard	must be called at least once at beginning of the program sym=TRUE, waits see Table 4.9 on page 59 and flag816=2 for 8bit / =1 for 12 or 16 bit.
DLLReadBytePort	read byte of register (offset ISA 0..3 / PCI 0..ff)
DLLWriteBytePort	writes byte in register (offset ISA 0..3 / PCI 0..ff)
DLLAboutDrv	proofs weather driver and board is available and reads ID-byte
DLLGETCCD	complete call of read CCD data routine
DLLReadKeyPort	reads keyboard OEM scan code direct, not with interrupt
DLLClrRead	clears camera by ClrCount reads, but does not keep data
DLLClrShCam	clears shutter camera
DLLCal16Bit	starts calibration cycle for 16bit cameras.

The compiler was set up for _stdcall and multithreaded DLL. If you need another interface, the source must be rebuild with the new compiler settings. These settings are especially useful for linking the drivers to Labview. The File LWLSC.DEF is necessary for the correct build and may not be omitted!

5.1.6.2 Linkage of DLL

The driver and the board must be initialized before using the interface from your own software.

The called software should at least look like this example:

```
DLLCCDDrvInit(1);    // searching the driver
DLLInitBoard(..)     // initialized the board see chapter-5.1.4.2
```

For simple testing here the called functions are:

```
        DLLOutTrigHigh(1);
        DLLOutTrigLow(1);

DLLCCDDrvExit();
```

This signal can easily be controlled with an oscilloscope connected to the trigger out plug of the Interface board.

5.1.6.3 Different compiled DLLs

To adopt the DLL to different sensors, there are some global flags (defined in LWLSC.H)
#define _FIFO TRUE   // TRUE if used for FIFO version
#define _HA_IR FALSE// must be true for IR sensor, set also resort
#define _HA_IRSingleCH FALSE// TRUE if IR Sensor has 256 pixel, FALSE if 512
#define _IR2 FALSE// must be true for 2 parallel IR sensors
#define _TI FALSE// must be true for TI TC253 sensor
#define _IS_C4350 FALSE // must be TRUE for C4350 adapter
#define _PARALLEL FALSE//TRUE for 2 Interface Boards
#define _RESORT FALSE // resort array for PCI board with 2 cameras or IR
#define _PPORT FALSE//TRUE if used on printer port
#define _OPTSTATE FALSE //decrement pixel if shutter state input with OPTO1 is used with old board 2105
#define _COOLER FALSE//TRUE if PC manages the cooler

#define _HWCH2 TRUE// TRUE if 2 cam data bytes are packet in one word (2cams parallel read with adaptor board)
#define _FFADC TRUE//TRUE for FIFO and ADC16061

When delivered, the values for this camera are setup as needed. If some of these values must be changed, the DLL must be recompiled again. The new generated file in release/ LSCDLL.DLL must be copied to the folder where the new version is needed.

5.1.7 Using Labview

To link the camera to Labview we recommend to use the DLL: LWLSC.DLL.

The delivered examples show how Labview can use the driver LSCISA1.SYS LSCPCI.SYS, LSCPCI.SYS or *.VXD . **The driver had to be installed** correctly before use (see chapter-5.1.1) - even when using the printer port: the printer port is implemented within the LSCISA driver (see chapter-4.1).

LWLSCDLL.DLL is called within Labview as external library. Several examples and software demos *.vi are applied:

The low level functions of the PCI board are stored as “vi’s“ in the sub folder Board.vis. They might be called from the own software and should not be moved. Also the DLL LWLSCDLL.DLL must be in that sub folder. As the DLL exists in several versions, ISA (is also the printer port version) and different PCI versions, the correct DLL has to be copied to the board.vis folder. The type of DLL can be examined with the property function of windows. As the DLL Source is also part of the driver package, the different PCI Versions can be examined by reading the Source code.

5.1.7.1 Example vis

As explained in chapter-4.2.1 the examples are different for the FIFO and no_FIFO version. Also it makes a difference wether 2 cameras are read parallel. Here the data array must be defined different (array of word instead array of bytes).
The concept is: the program leaves labview and jumps into the DLL to execute the tasks more accurately. After the data is acquired the processor comes back and the data can be recalculated and displayed by labview.
A more sophisticated solution is shown in GetRing, where a task is started in the background and runs parallel to labview and other programs.
The DLL with commented source code (MS visual C) is part of the driver package and can be used for own enhancements and for reference (Source is commented).

noFIFO
The noFIFO version reads camera with function GETCCD in a loop.
The time between 2 reads (2 calls of GETCCD) is the exposure time - so a wait function is needed. This waiting must be accomplished by software, but here the system timer can be used to achieve better performance. As the wait function of labview is not good enough, the DLL is used to call the system timer.

FIFO
The FIFO version has a build in hardware timer, which is programmed by registers of the PCI board. Here the data is written constant to the FIFO and the software must poll the FIFO before it overflows.

simple DDL calls

Abouttest	Open driver and show Version (1.5) and ID Byte =$53 (5350 with PCI). Before calling any sub VIs (located in BOARD.vis), Init-> InitDrv + InitBrd must have been called, otherwise an Error message appears! After your call ExitDrv must be used. Wrap your call as shown here.
GET	Reads camera data. In free running a loop with not very constant exposure time is executed. The function GETCCD is called and the time between 2 calls is the exposure time. This distance must be as constant as possible, as a Jitter here leads to fluctuations in the signal. Main jitter here comes from display function.
GETTRY	uses Routine GETCCD. To measure in a loop it must be called continuously. - exposure time not very constant -> should be controlled by Scope looking for XCK signal (BNC under the green LED).
TrigTest	Waits for Trigger event and generates a Trigger Output Pulse. Can be stopped with the space key.

get constant exposure time by using the system timer (via DLL call)

GETconst	implements a constant loop in labview. The windows system timer is used to sync the loop to a constant exposure time (called in LwlscDLL, see source). The display could interrupt the loop quite often, so it should be disabled at least for some time to get a constant loop. - shows some interrupts (depending on system).

complex calls for stable exposure time

concept: stable burst measure

a loop of measurements is started in a very high thread priority.
When finished the control is passed back to labview.

Loop	implements a very constant measure loop outside labview, reads a complete block of nos scans, during block read, the thread is highest -> runs modal and disables mouse, after reading all scans are transferred to labview and displayed transparent on one graph. This graph keeps all scans in memory! (don't save with nos too big). runs on single and multi core PCs.
Loopsel	implements a very constant measure loop outside labview -reads a complete block of nos scans, during block read, the thread is highest -> runs modal and disables mouse, after read the slider can select the scan which is displayed - first hit run, then hit arm/clear and then read. For a new block of scans press stop then arm and then read again. - runs on single and multi core PCs.

concept: background thread

a high priority thread is started in the background to fetch the data.One core is completely busy for that task. The other cores can handle windows and the display tasks.

GetRing	(runs on multi core PCs only!) A ring buffer is set up in memory to get the data independent in the background. The display thread and labview tasks are running with standard priority. Both processes run independent and communicate with global Flags of the DLL. **Be sure to stop the task, or camera will keep on going!**

misc. functions

SetTemp	only for cooled cameras. Sets the desired temperature level. 0 = off.

double line systems

GetTry2D	Shows how to split the data array if two 12/16 bit cameras are used parallel.
GetTry4to8	Shows how to split the data array if up to four 8 bit cameras are used parallel.

5.1.8 Demo software CCDExample

This source code example shows the direct call of the driver.
The software performs a loop, which reads the camera data continuously and displays the data in a simple display window. After pressing the ESC-key the loop is immediately ter-

minated. With enabled online addition (const AddRep>1) the space key terminates the online loop after all calculating is made.
There are slight differences for the specialities of the respective operation systems. The adoption is shown in the source code within the unit BOARD.

If the example starts without error message, all needed drivers were found. The value for the version message is 1n1, 1n2, 1n3, 1n4 for the respective camera drivers LSCISA/PCI 1, 2, 3, and 4. n is the actual version.
After that the control register should read the value 0x53 for ISA or 0x535x for PCI (direct read of ID byte on the interface board).
If these messages appear without error, the driver and the board is found correctly.

The software consists of several modules

CCDExamp	windows main for window
CCDUnit	measure loops and reading sequence
BOARD	functions for setting the interface, see chapter-5.1.4.1
CCDCtrl	driver definitions

5.1.9 Constant exposure time

The 32bit systems Win and WinNT are capable of working with large data arrays. Therefore the definition of the data array is not limited and can be enlarged to all the installed memory RAM. The XMS interface is not needed any more.

The problem with the modern operation systems is indeed, that the reading loops are not as constant as the DOS versions. The excessive interrupt usage of multitasking and networking leads to a jitter in the delay time routine. The concept of the read loop:

```
Repeat
    Delay (exposure time);
    GETCCD();
    Display;
until end;
```

is not working very well.

Even with the precision timer of the Win / NT API function: QueryPerformanceCounter(), this problem is not solved. The precision timer is a system clock with 64bit resolution. It shows the already elapsed time, since the start of windows. although the timer runs very constantly, the reading function of the API can be interrupted.

5.1.9.1 Constant read loop with precision timer

By changing the algorithm a better constant for the read loop can be achieved:

```
start time = QueryPerformanceCounter;
repeat
    wait until (start time+exposure time=QueryPerformanceCounter) is reached;
    start time = QueryPerformanceCounter;
```

```
        GETCCD();
        display;
    until end;
```

The Counter has different ticks on different operation systems. Therefore this function must be calibrated by calling the API function: QueryPerformancFrequency. Please look at the Source code of the CCDExample for details.
As long as the computer has not too many additional tasks and the delay is > 0, the error of the delay loop is better 40 µs.

Another approach is the usage of the multithreading functions. When starting the GETCCD function as a single thread with high priority, the delay can be realized by the sleep function. This function gives access of the processor to other threads until the time out elapsed and does not loose the ownership during wait time.

5.1.9.2 Read loop as ‘Thread’

A very comfortable method for a constant read loop is the ‘Thread’. Here the measure loop will be started as a sub function of the main program whereby the focus of the processor can be set with the command SetThreadPriority(..). When the priority is higher than that of other running software, this part of the application can not be interrupted by others. It is possible to set levels form 1..39, whereby normal user applications get level 8.

The exact call is described in CCDEXAMP in the function Contimess, part of CCDUNIT.

If you give a high priority to the measure loop (THREAD_PRIORITY_TIME_CRITICAL), this can lead to interrupted other tasks, for example mouse query, network reply, etc.Indeed you can give the highest priority to the measure loop, so that no other task could be handled. Similar to a computer game, the routine will be executed in real time and if the measurement is finished, the control is passed back to Windows.

Additionally it is possible with the sleep- function to give the control back to other processes while waiting for long exposure times (>20ms). If the wait time of the sleep- function elapses, the measure loop awakes. The sleep function uses the ‘TimeSlicer’ mechanism of Windows. The hereby reached maximum precision is around 20ms. This value can be changed to a maximum precision of 1 ms.

<u>Function ‘measuresleep’ in module Contimess</u>
The‘sleep’- function can be evaluated with our demo software CCDEXAMP. If the variable delayms in the file CCDEXAMP.H is set to 0, the software will not give the control back, that means you can‘t switch to other applications anymore.

<u>Function ‘measure’ in module Contimess</u>
The measure routine combines the precision timer and the thread mechanism.
The highest precision of the read loop is achieved within this loop.
Additional the Sleep(0) statement should be used within that loop. The reason is, that after calling the other threads could be served during the wait count of the timer. If you omit that statement, after some time the other threads gain control and interrupt the measure

loop for a longer time.

For example the jitter of the function ‘measure’ with an delayms = 10 is measured with a AMD 1200MHz computer (see chapter-4.2.10).

with W98:
highest Thread_ Priority (level = 39)
maximum Jitter with precision timer and Sleep(0): 50µs.

with WinNT:
highest Thread_ Priority (level = 31)
maximum Jitter with precision timer and Sleep(0): 90µs.

with W2000
highest Thread_ Priority (level = 31)
maximum Jitter with precision timer and Sleep(0): 320µs.

Faster computer are better.

5.1.9.3 Multiprocessor Systems

With the multi core systems the moving of the camera data to the main RAM can be achieved even more convenient. One processor can be programmed to work in high priority to poll the FIFO for new lines and if there are one or more - to copy this data to the RAM. This loop is executed from one processor in highest priority. The other processor(s) execute the standard windows tasks and the rest of the application in normal priority. This solution is intended for high data rate cameras (33MHz) and short exposure times (<1ms). Here is the danger that some lines are lost because of the overflow of the FIFO.
The standard WCCD program is made for a single processor system where windows and the mouse is switched off during the measure loop.
With this implementation, shown in the Ex2CoFifo example, the program can run under normal windows conditions. Please have a look at the source code for details.

5.2 Common software definitions

5.2.1 Data organization

The camera data is stored in an array declared as:
PASCAL:Dioden: ARRAY[1..ZMAX,1..PIXEL] of WORD
C: ULONG DIODEN [zmax][pixel];
The array type is usually ULONG for WINDOWS and WORD for DOS

whereby pixel = amount of pixel and zmax = amount of data arrays or lines (here=4; could be omitted if only one line is used.).
The definitions are written in the header file or in UNIT GLOBAL.

The values for PIXEL is chosen a bit larger than the actual amount of pixel elements, because additional to the picture elements the reference, dark signal and isolation elements have also to be read. (see Table 8.7 on page 152). We recommend to take the next higher value which is dividable through 600. The calculation of the 600 horizontal displayed pixel elements is much simpler (VGA resolution).

Table 5.1: Const. PIXEL for different line sensors

pixel elements	128	256	512	1024	1728	2048	2592	3456	5000
PIXEL	200	300	600	1200	1800	2400	3000	3600	5400

with ZMAX the number of arrays or lines is determined (usually ZMAX = 4). Please notice that certain 16 bit compiler limits the length of data array. You need for one line of 3600 values and 4 memory arrays: 3600 * 4 * 2(integer) = 28,8 k byte only for this data array. If there is enough memory the array might become bigger -> Win versions use array of type ULONG (i.e. 56 k byte).

The values are saved to disc the same way they are displayed on screen in the in-output menu (F8). They are saved in a text file with the following algorithm:

```
i:=0
WRITELN(FILE,Kopf : STRING[80])
REPEAT
        WRITE(FILE,i:6)
        for j:=1 TO 10 DO
                WRITE(FILE,DIODEN[I+J]:6)
        i := i+10
        WRITELN
UNTIL i >= max
WRITELN(FILE,i:6,' values')
```

Within the 16bit version all values are declared in the word range 0...65000.
In the 32bit version all values are allowed in the ULONG range 0...4 $*10^9$.

5.2.2 Alternative X-Scale

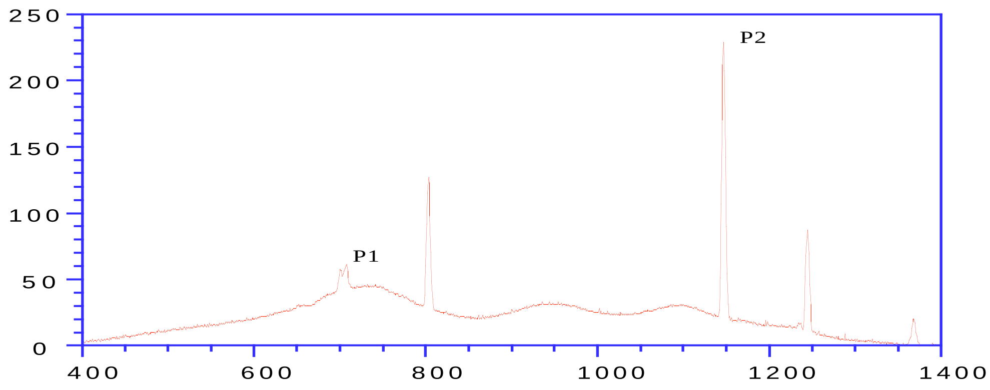
The standard X-scale is the pixel number (pixel= picture element). In some cases it is more comfortable, to display an alternative scale. For example a scale for measuring a distance or a wavelength can be indicated.

When starting the program the standard pixel scale is displayed. With shift F5 key (CCD) or in the view menu -> setup (WCCD) an alternative scale can be calculated. The scale can be switched with the F5 key.

The scale is calculated with the equation:
y:= m * x + b .
y is the new scale value and x is the pixel index.

Example: calibrate scale
A wavelength scale for a spectrometer is needed. The numbers m and b must be determined with several measurements of known wavelengths.

picture-5.1: Mercury lines of a fluorescent lamp



Two lines can be determined:

> yellow double line P1 (pixel 705 / 578 nm) and
> blue line P2 (pixel 1150 / 435.8 nm).

Calculating leads to m = -0.32 and b = 804.
With further lines P3 (pixel 805 / 546 nm) and P4 (pixel 1380 / 365 nm) the parameters can be calculated more precisely by regression.
The parameters m & b can be entered in the software to use the new scale.
Please keep in mind that the values are not examined by the program. Even wrong or absurd values are indicated.

5.3 Toolbox program

The Toolbox offers a collection of evaluation functions for different applications. It is available in PASCAL or C.

Toolbox procedures:

Procedure DetermineRuntime	determines the different run times of computers
Procedure ReadCCD	read of camera data
Procedure Subtr. Offset	subtracts noise signal
Function MeanVal	average value for a number of pixels
Procedure FindMax	determines maximum point position
Procedure Smooth	smooths data array
Procedure RelGaussPower	finds maxima and $1/e^2$ edge points of Gaussian distribution
Procedure AutoExposure	finds optimal exposure time
Function Edge	finds edges; forms weighted means over edge distributions
Procedure Display	generates freely positioning plot windows (slower than ASM routine: Displ)
Procedure Set XScale	set scale for free defined plot windows

Please seeToolbox manual for a complete description.

5.4 Data rate

The maximal data rate is limited by several factors. Also it must be considered: the faster the sensor is clocked, the more light you need. The sensors sensitivity depends on the exposuretime.

Limits of the camera
The maximal data rate of the camera series 2010 and series 1000 is approximately: 3MHz or 300ns per byte. The series 2000 has the max. data rate: 200 kHz or 5 µs per byte.
The high speed series 1000hs and 2010hs can have data rates up to 10 MHz or 100ns per byte. The hhs series can have data rates up to 33MHz.

Limits of the Interface
The ISA- Interface has a max. data rate of 1 MHz.
The PCI- Interface has a max. data rate of 33 MHz.

Limits of the sensor
Additional the max. pixel clock (pclk) of the sensor limits the data rate. This value can be found in the technical reference part.

The lowest value limits the speed.

Example:
The sensor Sony ILX505 has a max. pclk of 5MHz. With camera series 1000hs/8bit and

the PCI- board the read out can have 5 MHz. Die PCI- Interface must be used with 1 wait-state. The same camera can reach 1 MHz at the ISA- bus.

Example2:
The sensor Hamamatsu S3924 has a max. pclk of 500kHz. It does not matter wether you use the ISA or PCI board, the sensor may not be clocked faster than that. So the PCI Interface has no advantage here. The 12bit camera with ISA- board can have 1MHz data rate, which leads to a pixel clock of 500 kHz.

The shortest possible exposure time the program can reach is:
data rate (T_{SP}) * number of pixel + display time (T_{DISP}) of 600 points to screen.

T_{XCK} (N=1000): exposure time for a 8 bit camera with 1000 pixel.
The display time is measured for DOS, which is fastest, windows is much slower.
With 12 bit transfer the TSP has to be multiplied with 2.
Faster computer are not better! Limitation is the ISA Bus.
On the PCI bus the limit is 33MHz for the data rate.

The real timing is determined at the program at start-up. The calculated loop duration for the measure loop (F6) is calculated and displayed as the minimal exposure time. The data rate can be lowered by entering wait states in the installation menu.

For low light level signals the sensitivity of the linescan camera can be increased simply by increasing the exposure time TXCK.

5.5 Software adoption for special sensors

5.5.1 Software adoption for Ha IR- Sensors

The IR sensors from Hamamatsu need a special software adoption. The special clocking needs a 4 * _PIXEL array size and a resort of the array afterwards (function: resort()). Only every 4. pixel is valid.
In our Software (Unit „GLOBAL“) these conditions are integrated. Also the 256 pixel sensor differs from the sensor with 512 pixel.

The following Flags are used to control the Software:

_IR	TRUE for all Ha IR- Sensors, FALSE for Ha Detector Head C806x
_IRSingleCH	TRUE for all Ha IR- Sensors with 256 Pixel, FALSE for 512 Pixel
_IS_C8060	TRUE for Detector Head C806x

_RESORT	TRUE for all Sensors, which have to be resorted. These are the Ha- IR Sensors and Sensors which are red in parallel with our PCI- Interface for up to 4 cameras. This Function is used in Module „BOARD“.
_PPORT	TRUE if used with the printer port.

The IR- Sensors of series G92xx have a switchable amplification (approx. factor 20). To use this the flags:

_VSWITCHABLE TRUE
_FACTOR 20
have to be set.
The flag HIAMP or in WCCD the check box high gain (measure menu) can be used to switch the amplification.

additional setup for the IR G92xx series is:

BURST = FALSE
SYM = TRUE
WAITS = 5 with PCI- Interface or =0 with printer port.

5.5.2 Calibration for 16 bit A/D- converter ADC16061

The ADC16061 is a low speed (2MHZ) low noise converter.
After some time the 16 bit A/D converter must be re calibrated. For that purpose the procedure CAL16Bit can be found in the unit BOARD. Here this function is implemented by just calling GETCCD with setting the highest bit of the parameter zadr. For calibrating the camera with address 1, zadr must be set to 0x81.
In that case the address of the dip switches must also have been set properly to 1!

5.5.3 Software adoption for IR Sensors with control unit C8060

The IR sensors from Hamamatsu need a special software adoption.
In our Software the global flag _IS_C8060 TRUE sets the right functions.

The IR sensors have a build in clock generator. The clock is max. 4MHz,
so the PCI boards wait states must be set to -> 3 waits.
The sensor uses the clock divided by 8 to generate a data rate of 500kHz

For simple hardware implementation the data array must have 4 times the standard size.
If a 12 bit A/D converter is used, and 2 cameras (CH1 and CH2) are handled in parallel the array structure is as follows:

Array for IR sensors

dummy (usually = 0)
dummy
CH2 dummy
CH1 dummy
CH2 pixel1
CH1 pixel1
CH2 dummy
CH1 dummy
CH2 pixel2
CH1 pixel2
..

In the unit BOARD -> GetCCD the array is sorted to a standard structure:

CH1 pixel1
CH1 pixel2
CH1 pixel3
..
CH1 pixeln
CH2 pixel1
CH2 pixel2
CH2 pixel3
..
CH2 pixeln

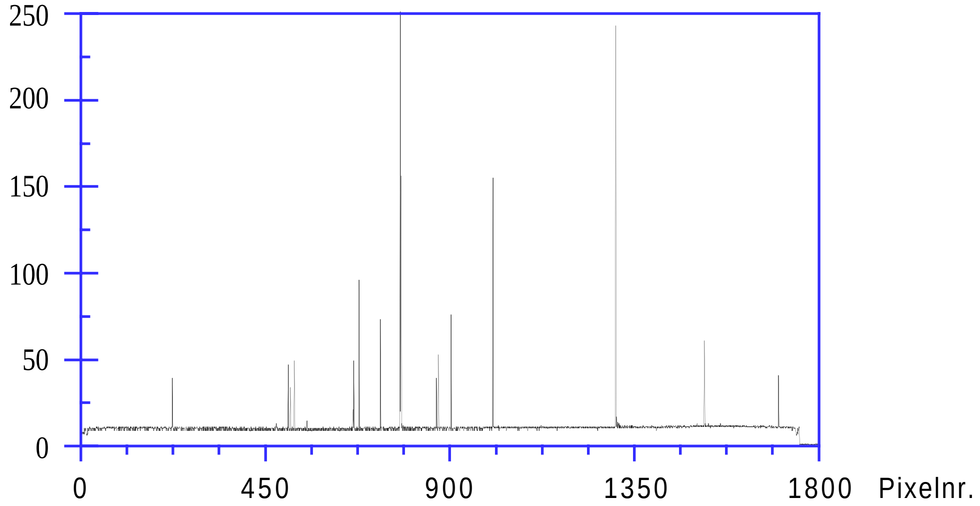
GETCCD must have a 10 time bigger array for saving the data. After calling the array must be resorted, because not all values are valid. Some are sampled in the slope or overshoot region. These values should be omitted.

6 Specialties of CCD sensors

6.1 Bad pixel elements

CCD chips might have single bad pixels according to the manufacturing process. This is, however, a systematic deviation. It depends only on the exposure time and appears always at the same diode number. That makes it easy to correct the pixel value if necessary by software.
Also with scattering light it is recommended to scan with a reference signal and the subtraction afterwards. Picture 8.1 shows a signal of a measurement of a sensor with more than 20 bad pixels. The exposure time had been 1 sec. in this case.

picture-6.1: pixel errors

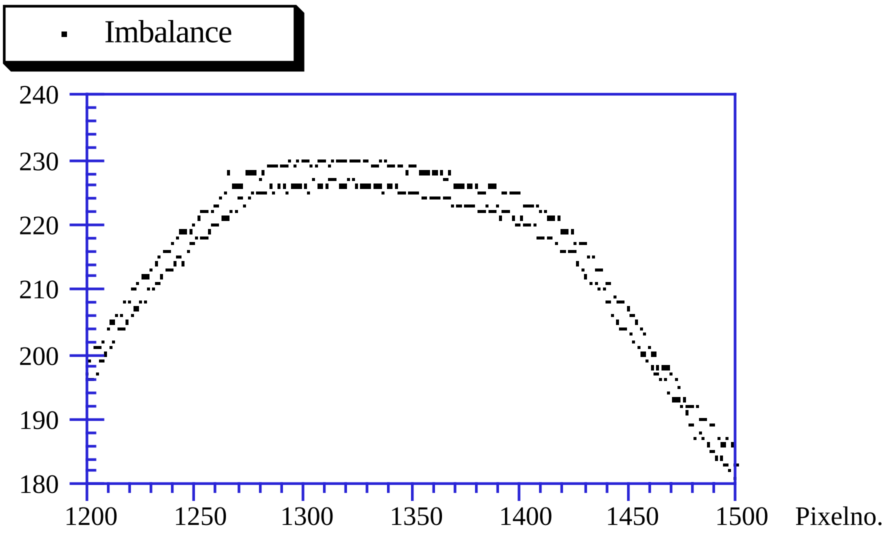


On the x-axis the pixel number is indicated (this particular sensor has 1728 pixel). On the y-axis the level of digitalization is shown (8 bit = 0..255). The value 255 is due to the saturation voltage of the sensor.

6.1.1 Asymmetry of pixel (imbalance)

Because of the asymmetric construction of the sensor - two different shift register are lying on each side of the sensor area. (see. chapter-1.1) - the lines of Texas Instruments and Thomson has an **offset between** the signal of the shift register for **odd and even pixel numbers**.
A slight asymmetry of the register produce a different signal. Though this error again is systematically and the decline dependent to the sensor maximum 5 points in the range 0...255 (5/255 = 2%), a correction of this error could be managed with the software (picture-6.2 shows the enlarged drawn effect). But, however, if light come from one side, this effect is even worse. This could be avoided by a reduced aperture. Especially if a lens is used this asymmetry will be reduced.

picture-6.2: imbalance of pixel



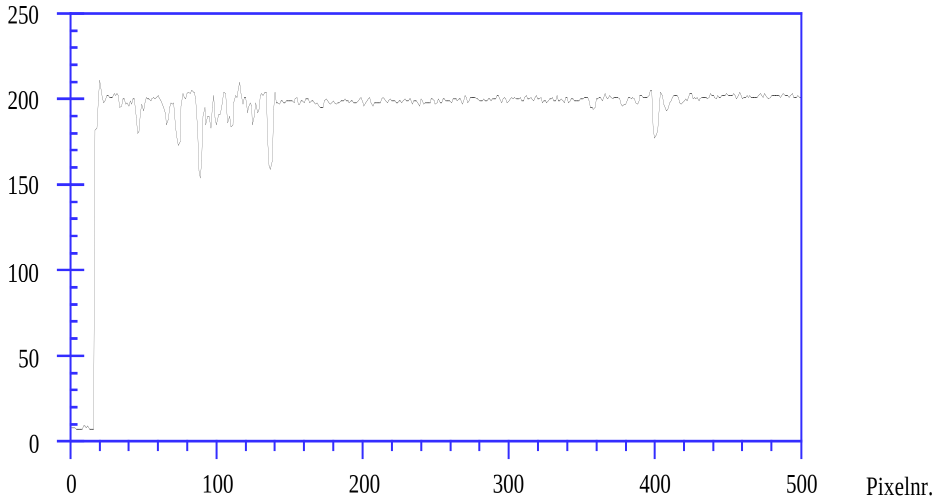
This error is especially a problem with sensors of **Texas Instruments**, however, could be from sensor to sensor quite different. As well as the anti blooming sensors Th7811 of Thomson do have this effect the more the resistant against over exposure is increased.

Sensors of	Thomson:	Effect at 12 bit resolution visible.
	Sony:	Effect at 12 bit resolution visible.
		Sensors with only one shift register: no asymmetry
	Hamamatsu:	no asymmetry

6.2 Dust on the window

With a spot light source it is possible to detect a signal caused by modulation structures on the measurement signal, which are caused by dust.

picture-6.3: Modulation caused by dust



These signals do not change their position if the camera is moved.

Because of this the sensor should be cleaned regularly with a special clearance paper.

6.3 Sensors without window

The window appropriate to the protection from dust on the sensor can lead at measurements with monochromatic light to interference phenomena, which falsify the measurements.

Besides the standard windows limit the spectral sensitivity in the UV region, since the standard window of the sensors (BK7) is not transparent underneath 400 nm. According to the sensor the following differences occur:

- Conditionally through their construction particularly the TI-sensors are very well sensitive to 200nm, if the window is removed.
- The Th-sensors TH7813 and TH7814 are well sensitive in the uv region and can be delivered without window.
- The Ha-sensors are delivered with standard quartz windows and expanded UV-sensitivity.
- One So-sensor (ILX511) can be delivered without window and with special coating.

To avoid the interference- and UV-problems, some sensors without windows (o.F.), that means with a standard removable window, can be delivered. The window is fastened with a tape. To remove the tape, the cover of the camera should be disassembled (chapter-3.2.1).

Two modes of operation are possible:

- You can take off the window and close the cameras M42 mount with the included body cap. The sensor is dust protected after each measurement again. For measurements in the lab this is the simplest solution.
- For measurements in harsh dusty industry environment it is advisable instead, to order a sensor with a specialized window, which is firmly positioned. For the interference problem the window can be covered with an anti reflex coating.
  For the expansion of the spectral range, quartz glass windows should be used. We can deliver quartz windows with and without coating on inquiry.

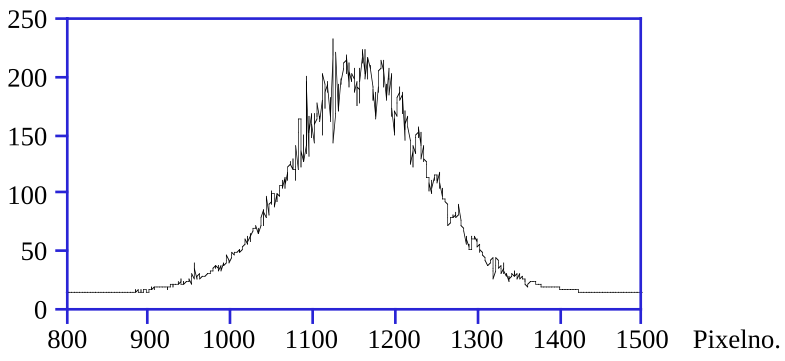
When sticking the window it must be paid attention to the humidity of the air! Otherwise condensation could happen on the inside of the sensor window.

IMPORTANT!
No guarantee for problems, which are caused through mechanical damage of a sensor without window!

6.3.1 Avoidance of interference with sensors without window

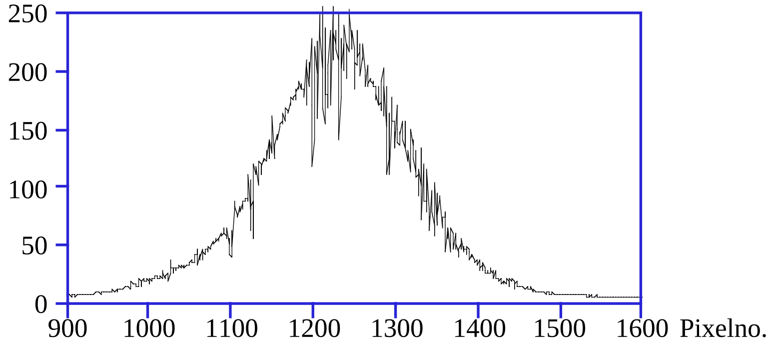
The measurement with coherent light is influenced by the window in front of the sensor which should protect the pixel of dust and mechanical damage. The window leads to interference. As an example tree measurements are shown of a He-Ne-laser beam profile, two taken with window and one without window.
Two modulations occur within the measurement signal: one is determined through the thickness of the window, the other through the distance of the lower rim of window to the highly reflectance surface of the chip. (picture-6.4).

picture-6.4: HeNe-Laser beam profile, sensor with window



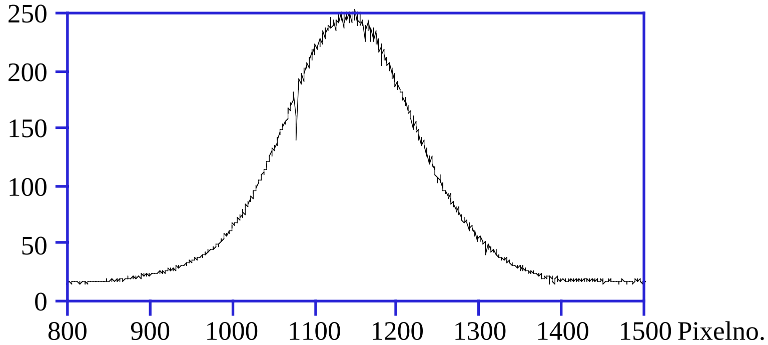
The modulation can be reduces by an angel within the light beam, however, this does not avoid the short wave beam (picture-6.5).

picture-6.5: HeNe-Laser beam profile, sensor angled



A picture without interferences can only be taken if the window was removed (picture-6.6).

picture-6.6: HeNe-Laser beam profile, sensor without window



A further advantage of using sensors without window could be the enlarged spectral range. The sensor itself could be sensitive down to 200 nm, but the window in front of the sensor selects the light only down to 400nm (depend also on sensor).

But be aware of the higher sensitivity of a sensor without window against dust and mechanical damage. In the example measurement (picture-6.6) a grain of dust is located at pixel number 1100 and eclipse the sensor at these pixel. These coverages might be disposed by a light blow but though a heavy expiration can destroy the tiny bonding connection. For laboratory measurements the window can be removed before each measurement. For measurement task in rough surrounding the window should be especially coated for the used wavelength.

Please ask for windows with special coating or quartz-windows for enlarged spectral range measurements.

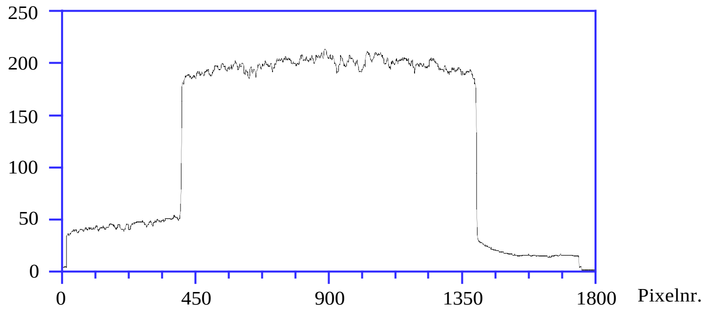
Attention please!
No guarantee for damaged sensors without window due to mechanical damages.

6.4 Working with a lens

The camera has an M42-mount for the connection of standard lenses. Thereby object control or measurement tasks are conceivable simply to realize.

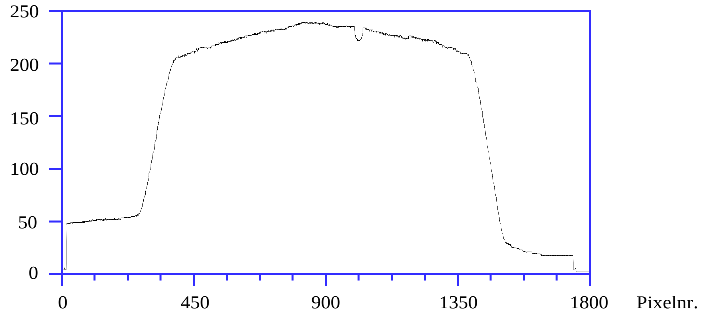
Since the sensor is assembled 12 mm under the upper edge of the camera case, the lens must be pursued with an extension tube by about 30 mm.

picture-6.7: Bright object, correct focused



picture-6.7 shows the measurement of a bright object in front of a dark background. At sharply focused lens the contrast passages of the edges are exact to recognize. A width measurement is easily possibly after prior calibration of the lens. These edges extends over approx. 5 pixel.

picture-6.8: Bright object, wrong focused



An unclear focused edge shows picture-6.8. The contrast passages are smooth and extend over approx. 100 pixel.

A good contrast relationship is always requirement for a good measurement. Therefore most important is the lighting of the object. The program calculation of the edges is essentially simpler with good contrast.
The adjustment of the sensitivity can be made either by raising the exposure-time or by reducing the aperture of the lens.

6.4.1 Selecting the focal length

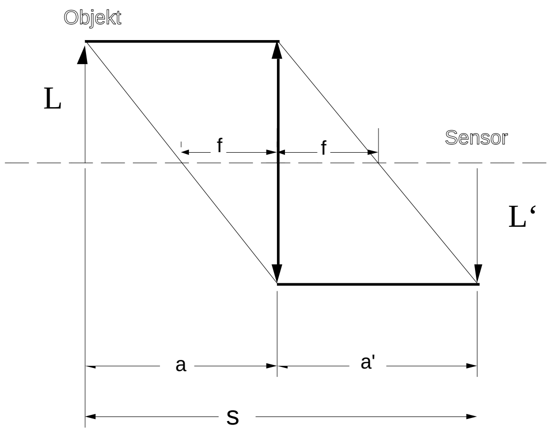
The following formulae can be used to determine the focal length of the lens for scanning an object with the CCD-line scan camera:

i) $s = a + a'$ s= distance from object to the sensor
a= distance lens - object, a' = distance lens - sensor

ii) $1/f = 1/a + 1/a'$ = focal length

iii) $ß = a'/a = L' / L$ ß << 1 reduction
ß >> 1 enlargement

picture-6.9: Schematic lens geometry



<u>example</u>

A quad 1 x 1 x 1 m should be scanned by a camera with 1024 pixel. The scanned range is 1m. With 1024 points is the theoretical resolution: 1 m/1024 = 0.98 mm.
The length of the sensor is 13 µm x 1024 pixel ≈ 13.3 mm. The required enlargement is

$ß = L' / L = 0.0133 / 1 = 0.0133.$

If the camera, should be installed in a distance from 3m (s= 3m)

$s = 3m = a + a'$ therefore $\underline{a' = 3 - a}$

inserted in iii) , whereby the above calculated enlargement ß = 0.0133 is inserted:

$ß = a'/a = L'/L$ and therefore follows $a'= 0.0133 \times a$

$0.0133 \times a = 3 - a$ and thus $\underline{= 2.96 \text{ m}; a'= 0.04 \text{ m}}$

For a focal length calculated from ii):

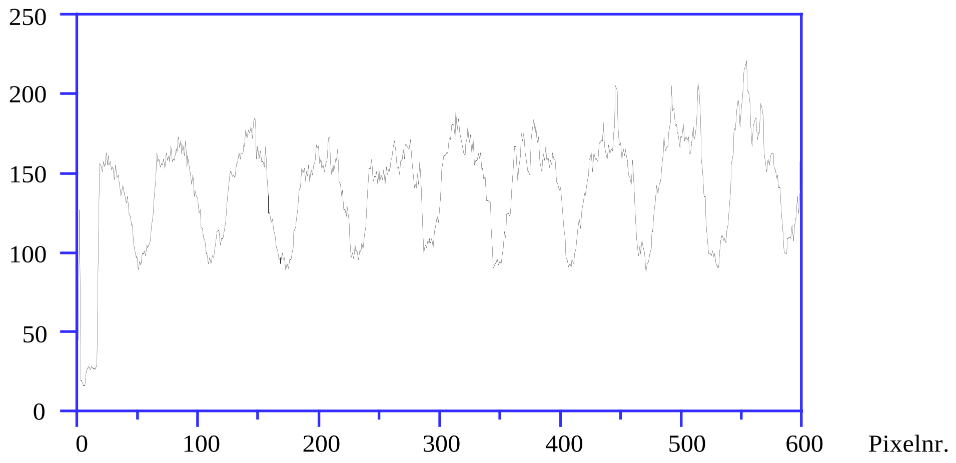
$\underline{f} = a \times a'/ s = 2.96 \times 0.04 / 3 = \underline{40mm}$

This calculation is thought as example for the estimation of the focal length. Aberrations of the lens, as well as inaccuracies through bad contrast relationships have remained in-considerate.

6.4.2 Calibration of the lens

A simple method, to calibrate an unknown lens, is measuring the scale of a calliper with known distance marks.
In the picture-6.10 the scale of a calliper has been scanned. The dark scale strokes on the metallic surface are clear to recognize.

picture-6.10: Scan of a milli meter scale



With the here used lens 1 mm correspond to about 50 pixel (distance between 2 minima).
Conversely 1 pixel corresponds to 1mm / 50 = 0.02 mm = 20 µm.
The used sensor has a pixel width of ≈ 11 µm (TC104: 10.7 µm), so:

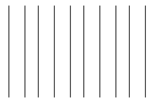
ß = 11 µm / 20 µm ≈ 1 : 2 reduction.

Also possible aberrations of the lens, i.e. non linearity along the line, can be measured and corrected with a look up table afterwards.

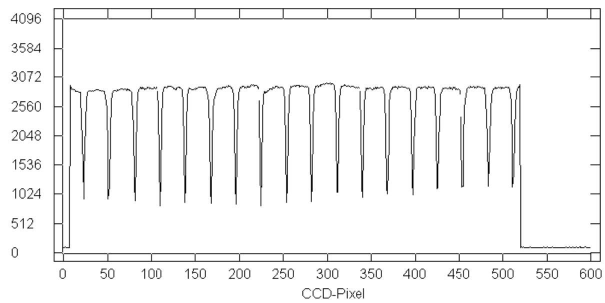
6.4.3 Hints for adjusting the focus with magnification

Usually the lens is used in a reduction setup: for instance a 2m object is scanned by a 25mm sensor. Here the focus is adjusted by the focus ring on the lens.
In case of an enlargement or an 1:1 mapping, the focus must be adjusted by changing the distance to the object. The focus ring does not matter much and should be set to ∞ in this case.

Here a line pattern like this should be used
picture-6.11: Test line pattern



and the sharp scan should look like that:
picture-6.12: Scan of line pattern

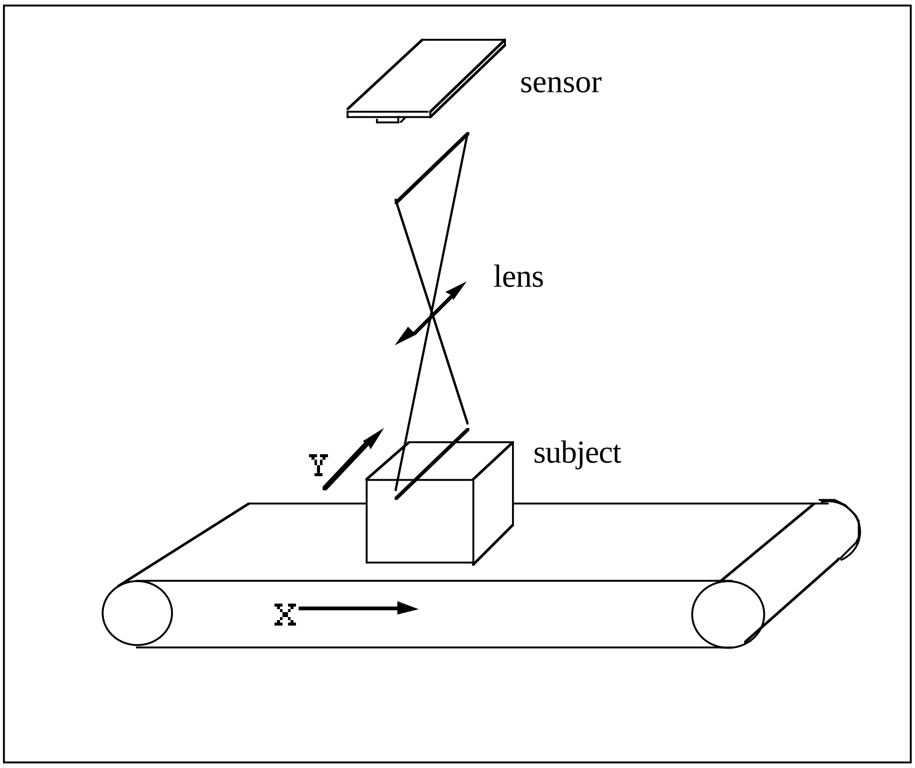


The focus adjustment is achieved only by changing the distance between the object and the camera with mounted tube and lens.

6.5 Measurement of objects in motion

For measurements of objects in motion it might necessary to reach high process velocity. As an example calculation here a piece which should be measured moves with the velocity v. Its apparent should be studied. For this measurement a line scan camera is highly appropriate because, similar to a photocopier, the object moves in one direction. Here the object is scanned by the camera while moving under the sensor. In principle this resembles a image scan of the object. The information is generated line by line.

picture-6.13: Measurement of an object in motion



Usually the lens is calculated by the needed resolution of Y (see chapter-6.4)

The data rate limits the resolution in X direction. The minimal exposure time is set by the time to read and calculate the data.

$T_{XCK} = N^* T_{SP} + T_{DISP} + T_{Mat}$.

hereby:

T_{XCK}:	exposure time of sensor
N :	number of pixel
T_{SP} :	time for reading the data
T_{DISP}:	display time - could sometimes be omitted
T_{Mat} :	time for own calculations e.g. edge detection

During this time the object moves the distance X:

$$X = v * T_{XCK}$$

Example calculation:

N=1000 Diodes, v=0,1m/s, T_{Mat} = 0 (depends application and computer)
T_{SP} = 1µs, T_{DISP} = 1ms

T_{XCK} = 1000 * 0,001 + 1= 2 ms.

X = 0,1 * 0,002 = 0,0002 m or 0,2 mm.

6.6 Partly read out of sensor line

If it is not necessary to read out the hole pixel amount of the sensor, the read in time could be reduce. For this you only **read out a part of the sensor** and delete the not used pixel. For example at a read in time of 1µs/pixel a 2000 pixel line is read out in 2 ms. If only 600 pixel of the line are used, the read out is completed within 600µs.

Therefor that the unused pixel do not produce a signal, these must be deleted.
This can be accomplished for Ha-diodes lines (Series S39xx) with the ‚delete gate‘ (IFC-signal).

CCD-sensors with shutter function (ILX703, CCD181, Th7811) can be delete with the IFC-signal.
Standard sensors clear the shift register only by reading all pixel. If the read out is not completed, the signals of the new measurement will be added to the foregoing measurement:

If for example a 2400 pixel sensor is divided into 4 parts of 600 pixel,

A	B	C	D

leads at a continues read out and continues light exposition to a sum signal of

$$A(t) + B(t-1) + C(t-2) + D(t-3).$$

If the parts ACD were covered the signal of these areas were set to zero the above mentioned example will only obtain the signal of B(t-1).

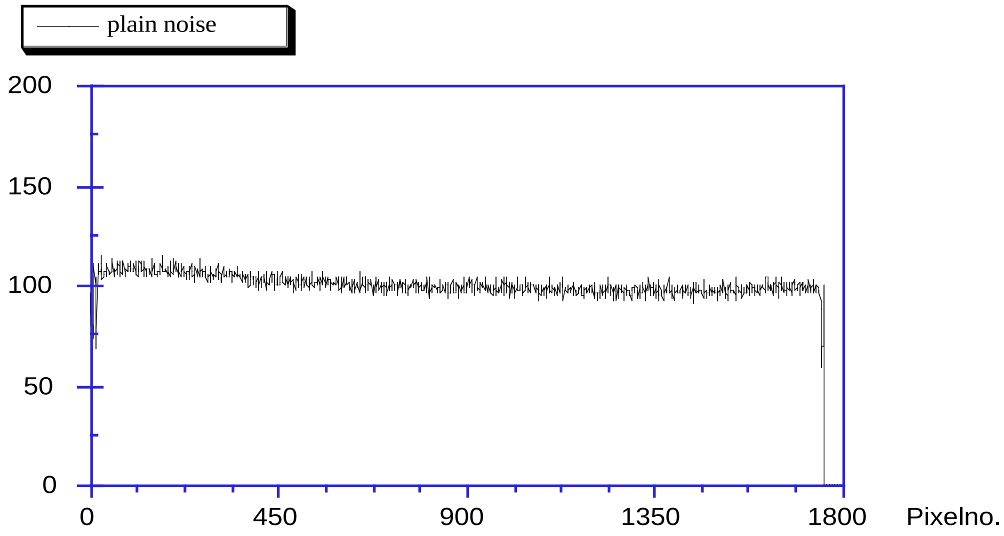
The variable PIXEL within the software (module GLOBAL or module CCDEFS) will be set in this case to = 600.

The zero signal in this operation mode is four times higher as in normal operation. However this does not mean much at this short read in time.

6.7 Noise

It is possible to observe the noise on a continual output signal. Particularly at high exposures time (»1 second) these effects are remarkable:

picture-6.14: Dark noise at long exposure time



Since the charge is not only generated by light but also by temperature noise the maximal integration time (or sensitivity) is limited by this dark noise. This increase with higher exposure time and thus decreases the signal noise ratio. The value when the dark signal will reach the saturation can be roughly estimated with the following e-function for maximal exposure time (values 80 and 0,07 for TI sensor):

e.g. $T_{\cdot xck}^{max} = 80 * e^{-0,07 * T}$[sec] (T in ^{0} C).

e.g. this line is saturated at: operating temperature max. exposure time

operating temperature	max. exposure time
40 ^{0} C	10 sec
20 ^{0} C	20 sec.
10 ^{0} C	40 sec.

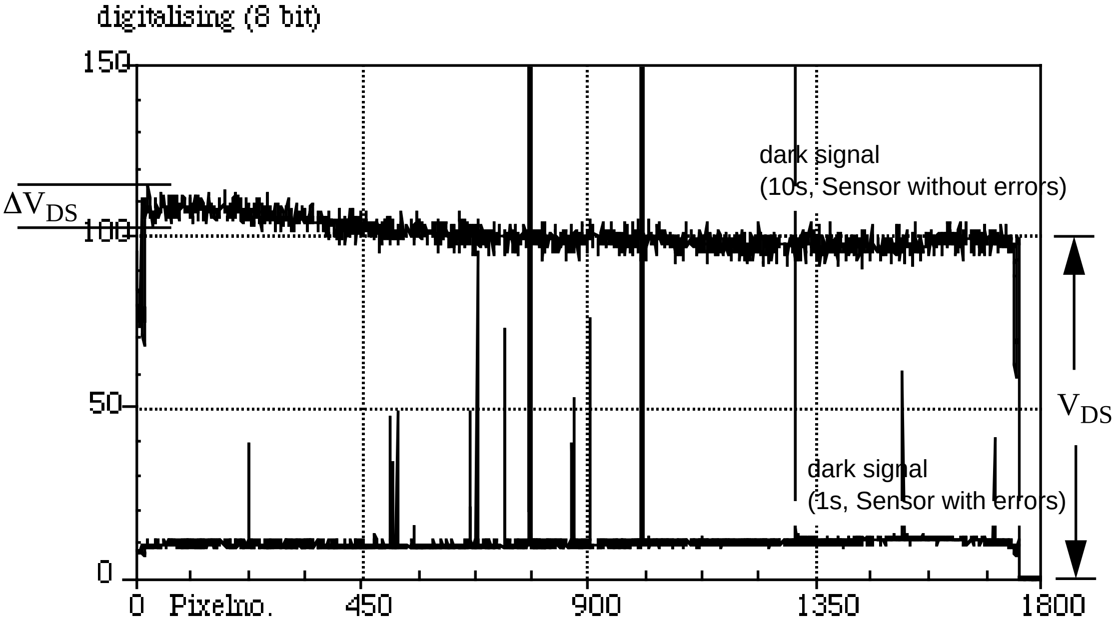
Dependent on the production process the CCD-line sometimes differ with their characteristics. The dark current noise may be individually lower than noted here as example. The constants 80 and 0,07 are determine for one sensor empirically and had to be ascertain again for every single sensor. Even within the sensor type these values may vary.
Hence the sensor is warming up while running, the exposure time should be shortened instead of decreasing the light with filters. If you are measuring short signals with slow repetitions rate we recommend for a better signal noise ratio our software which deletes the CCD line while waiting. (see chapter-2.2.3).

For applications with exposures time higher than 1 sec. a thermo-electric cooling can be delivered for most sensors.

6.7.1 Dark noise

The output signal involves a dark signal which is summed to the measured signal. This dark signal can be measured with a covered sensor. It is especially related to the exposure time and to the temperature.

picture-6.15: Noise fractions of video signal



The dark signal can be divided into two fractions.

1 **Read out noise (ΔV_{DS})** (or Johnson noise), caused by resistor- and amplifier noise but also by clock signals of the shift register. You may notice the variation of the peak to peak signal caused by noise.

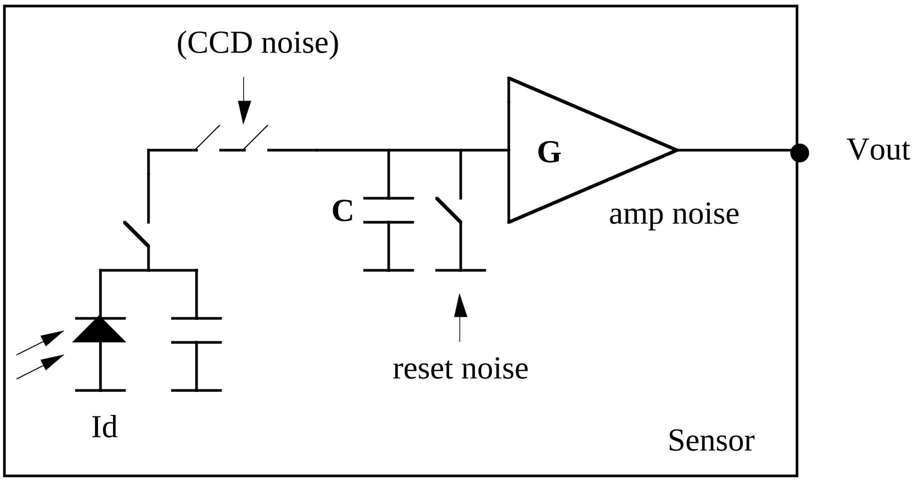
2 **Dark current noise (V_{DS})** (or shot noise), caused by temperature generated electrons in the accumulating zone of the sensor. This noise causes a permanent increase of the zero level (if time is increased). When the saturation is reached, the maximal possible exposure time elapsed.

Some of these noise signals are indicated in the data sheets. However, the quite diverse notes and units of each manufacturer makes it difficult to compare different sensors.
In the following you will find mostly the data of Thomson and Hamamatsu.

6.7.2 Definitions

For a simple evaluation of the noise effect as well as to compare different sensors the principal scheme of the sensor is shown in the next drawing.

picture-6.16: Principle structure of sensors



The charge of photo diodes are gathered in a single capacitor and are transferred either to a CCD register (CCD- Sensors: Th, TI, So) or to a capacitor **C** (diode array type: Ha, EG&G), where the charge is converted to a voltage. This voltage will be enforced by the factor **G** (normally <=1) and this leads to the voltage at output **Vout**.

The charge Q will be integrated time related into the diode array: $Q = I \cdot t$

afterwards transported to the capacitor C and changed into voltage: $V = \frac{Q}{C}$

The output buffer amplifies the signal by factor G: $Vout = G \cdot V$

For simple calculation the two factors G and C might be summarized by a effective capacitor C*:

$$\boldsymbol{Vout} = G \cdot \frac{Q}{C} = \frac{\boldsymbol{Q}}{\boldsymbol{C^*}} \qquad \text{with} \qquad C^* = \frac{C}{G}$$

Additional the charge can be expressed as a multiply of the elementary charge e :

$$Q = n \cdot e^- \qquad \text{with} \qquad e^- = 1,60 \cdot 10^{-19} [Cb]$$

and also the change of charge by C into voltage can given by the ‘conversion’ factor k:

$$V = \frac{Q}{C} = \frac{n \cdot e^-}{C} = n \cdot k \qquad \text{with} \qquad k = \frac{e^-}{C}$$

6.7.3 Dark current comparison between Ha - Th sensors

To compare two sensors, the technical data (25 °C) of Th7803 (CCD-Sensor) and Ha S3924 (PDA- sensors) are taken from the data sheets

Table 6.1: Noise data of different manufacturers

Th7803		Ha S3924	- 1024
V_{DS}	500 µV (at 10ms)	I_d	200 fA
k	1,6 µV/e^-	C_{ph} [1]	9 pF
	n.d.	Q_{Sat}	22,5 pCb
V_{Sat}	2 V	V_{Sat} [2]	0,61 V
ΔV_{DS}	0,35 μV_{rms}		n.d.
$A[10^{-6}cm^2]$	1,3	$A[10^{-6}cm^2]$	500

n.d.: no data
[1] Cph is the capacity of the photo diode and not equal to C.
[2] VSat and C is dependent to the number of pixel (here: value of 1024 pixel sensors).

See formula in the above chapter to calculate the missing values to compare the sensor specifications:

Table 6.2: calculated data for comparison of dark noise

Th7803		Ha S3924	- 1024
$C^* = \frac{e^-}{k}$	0,10 pF	$C^* = \frac{Q_{Sat}}{V_{Sat}}$	37 pF
$I_d = \frac{C^* \cdot V_{DS}}{t}$	5,0 fA	$V_{DS} = \frac{I_d \cdot 10ms}{37pF}$	45 µV (at 10 ms)
$\frac{I_d}{A}\left[\frac{nA}{cm^2}\right]$	3,8	$\frac{I_d}{A}\left[\frac{nA}{cm^2}\right]$	0,4
$DR(10ms) = \frac{V_{Sat}}{V_{DS}}$	$\frac{2}{0,0005} = 4000$	$DR(10ms) = \frac{V_{Sat}}{V_{DS}}$	$\frac{0,61}{0,000045} = 13500$
$t_{max^3} = \frac{V_{Sat} \cdot 10ms}{V_{DS}}$	40 s	$t_{max} = \frac{Q_{Sat}}{I_d}$	112,5 s

[3] After t_{max} the noise reached saturation.

6.7.4 Read out noise

The read out noise is caused by all kinds of disturbance and clock signals. Also amplifier noise and resistor noise is a source.
Especially the CCD sensors - in contrary to the PDAs - have a pretty high amount of clock noise, caused by the additional signals of the CCD register.

The read noise is the limiting factor for high sensitivity at short exposure times. This noise is often noted as the dynamic range DR. It is approximately between 1/1000 to 1/6000 of the saturation.
Two values in the data sheets are common: ‘ptp= peak to peak’ and ‘rms= root mean square’. Here the values can be converted approximately with the factor ptp = 5 * rms.

Example: data sheet FFT- Sensor Ha S7030: R_{rms} = 8e, E_{Sat}=600ke
DR = 600k / 8 = 75k this is equivalent to 16 bit = 2^{16} = 64k
but related to R_{ptp} = 40e results DR = 15K of approx. 14 bit

a measurement with	14 bit resolution equivalent to measurement values of ± 1 bit noise
	15 bit resolution equivalent to ± 2 bit
and	16 bit resolution equivalent to ± 4 bit

This PDAs noise factor is seldom noted, because it is less than the dark noise. In extreme (cooled sensor and increased amplification) this factor is also the maximum amplification limiting factor (see chapter-6.10.2).

6.7.5 Noise Theory

Theoretically the reset noise depends on the temperature:

$$VrmsResetnoise \sim \sqrt{\left(\frac{kT}{C}\right)}$$

The detector size A is hided in the capacity C ~ A.

The dark current I_D is integrated within the capacity C and produce a exposure time related dark signal. At longer exposure times the signal reaches the saturation limit and the sensor cell is flooded, therefore no further measurement is possible.

Theoretically this noise is also temperature dependant:

$$I_D(T) = I_D(T_0) \cdot e^{\left(\frac{-\alpha q}{2K}\right)\left(\frac{1}{T_0} - \frac{1}{T}\right)}$$

In our measurement the function is calculated with a e-function in the range from +20˚C down to -20˚C (chapter-6.11.1).

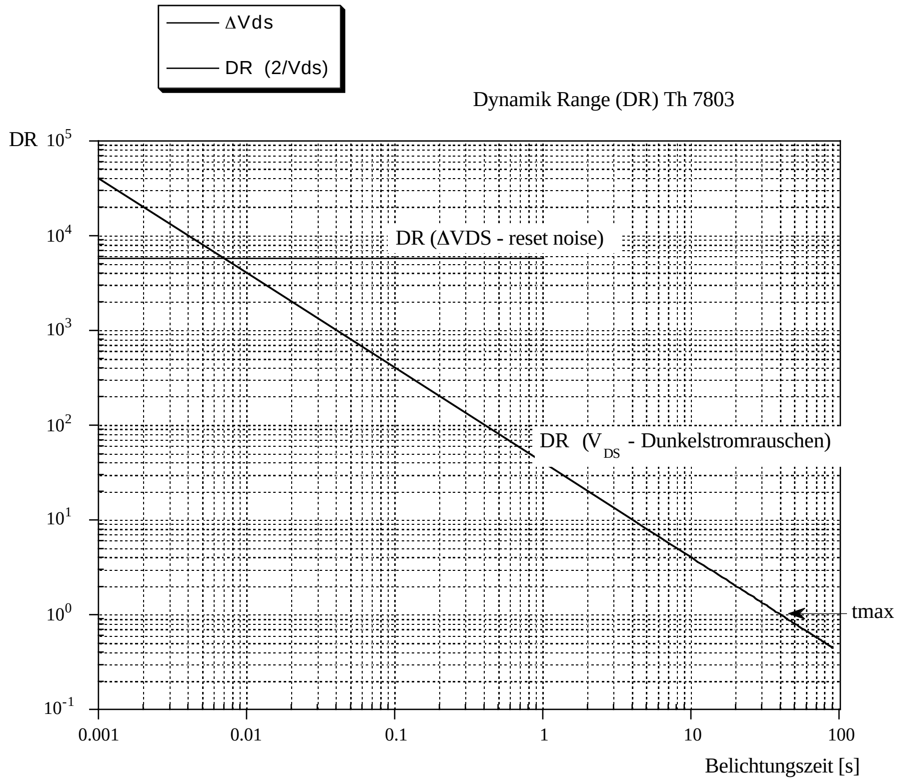
$$V_{DS} \sim e^{(1)/(KT)}$$

The detector size A is included with $Id \sim \sqrt{A}$.

6.8 Dynamic range

The dark current noise is limited by the usable dynamic range.

At longer exposure time the raising ground level leads to a permanent decreasing of the dynamic range, until the sensor is flooded, which means that the dark noise reached the saturation of the sensor and no further measurement is possible.
The dynamic range is related to the dark noise: DR = V_{SAT} / V_{DS}
picture-6.17: dynamic range of Th7803



At short exposure time the dynamic range of the sensor is limited by the read noise. This dynamic range is shown in the data sheet of CCD-sensors, for example Th7803:DR = V_{SAT} / ΔV_{DS} = 2 / 0,00035 ≈ 6000: 1.

The real dynamic of the camera is of course limited by the A/D-converter and is at 12 bit approx. DR_W = 2000: 1 (8 bit at 128: 1; the lowest bit is the error of the converter). The effective dynamic for a fixed exposure time is decreased by the growing dark signal:

DR_{eff} = (1-1/DR) * DR_W or DR_{eff} = (1-ß t) * DR_W.

The exposure time tmax after the chip is flooded, can be seen in the diagram picture-6.17 DR = 1 = 10^0 (here: 40 s).

6.9 Quantum efficiency

Because the sensors turn photons into electrons, we can enter the quantum efficiency which is a count of effectiveness for this change:

$$QE = \frac{\text{number of generated electrons}}{\text{number of received photons}}$$

The energy of photons are wavelength dependent

$$E = h \cdot \nu \qquad \text{or} \qquad E = \frac{h \cdot c}{\lambda} = \frac{1243}{\lambda}$$

with the units

E : Photon energy [1 eV = 1,6 x 10^{-19} J]
λ : wavelength in [nm]
S : radiant sensitivity in [A/W = Cb / J]

the result is

$$QE = E \cdot S = \frac{1243}{\lambda} \cdot S$$

By use of data from Thomson (Th 7803) the conversion factor k=1,6 $\cdot 10^{-6}$ V/e^- and the detector area A = 1,30 $\cdot$ 10^{-6} cm^2 is to be regarded.

$$QE = E \cdot \frac{R}{A \cdot k} = \frac{20 \cdot 10^{-11}}{\lambda} \cdot \frac{R}{A \cdot k}$$

with

R: responsivity [V/ µJ / cm^2]
E : Photon Energy [µJ]

The values are taken from the data sheets of Thomson (Th7803) and Hamamatsu (Ha:S3924):

Table 6.3: Quantum efficiency of different sensors

λ [nm]	S(Ha) [A/W]	QE[%] (Ha)	R(Th) [V/µJ/cm^2]	QE[%] (Th)
1000	0,05	6	0,9	8,6
800	0,215	33	4	48
700	0,29	52	5	68
600	0,32	66	4	64
500	0,26	65	3	57
400	0,16	50	2,1	50
200	0,05	31	0	0

6.10 Sensitivity

The comparison of sensors is difficult when different units are used.
The sensors are lighted with different light sources and sample charge Q or current I after a certain integration time. Because of different spectral dispersions of the light sources, different sensor specific base values comes up. Also the sensors itself have different sensitivity (see schemes in chapter chapter-8.2). Additionally technical as well as physical units were used:

Beam achievement Ø[W]	light current Ø[lm]
Beam power E [W/m^2]	light intensity E [lx = lm/m^2]
Beam H [Ws/m^2]	exposure H [lxs]

in the data sheets H are often noted as saturation exposure E_{Sat} [µJ/cm^2].

The infra red parts of light source were eclipsed with filters to adjust the spectral line of the light source to the sensors.

For example used light source:
Thomson: light by Tungsten (2854 K) with IR cut off filter BG38 (Schott)
here 1 µJ/cm^2 = 3,5 lxs
Hamamatsu: CIE standard light source “A”
here 1 µJ/cm^2 = 20 lxs

With the help of this conversion values the sensors can be compared theoretically.

A simple way to compare the sensitivity is the following:

The often in data sheets given photo electric sensitivity, which is **area independent**:

$$S = \frac{I}{\phi} \qquad \left[\frac{A}{W} = \frac{Cb}{J}\right]$$

or the sometimes given **area dependent** responsivity R

$$R^* = S \cdot A\left[\frac{A}{W}(cm^2)\right] \quad \text{or} \quad R^* = \frac{R \cdot 1,6 \cdot 10^7}{k}$$

$$\text{with} \quad R = \left[\frac{V}{\mu J/(cm^2)}\right] \quad \text{and} \quad k = \left[\frac{\mu V}{e^-}\right]$$

It is possible to compare the sensitivity for example at the maximum spectral curve of sensitivity.

If another spectral area is of interest, take the respectively sensitivity from the diagram (chapter-8.2).

A conversion with Q_{SAT} is also possible:

with $S\left[\frac{A}{W} = \frac{Cb}{J}\right]$ and $S \cdot A = \frac{Q_{Sat}}{E_{Sat}} = R^*$

results $E_{Sat} = \frac{Q_{Sat}}{S \cdot A} = \frac{Q_{Sat}}{R^*}$

6.10.1 Comparison of different sensors

Table 6.4: Sensitivity of sensors different manufacturers

	Th7803	Th 7831	TC 103	Ha S3924	Ha S3923
$A[10^{-6}cm^2]$	1,3	5,07	1,61	500	100
E_{SAT}	0,45 µJ/cm^2	0,11 µJ/cm^2		220 mlxs	220 mlxs
$R\left[\frac{V}{\mu J/(cm^2)}\right]$	5(650nm)	32(650nm)	5 (700nm)		
$S\left[\frac{A}{W}\right]$			0,45	0,32 A/W	0,32 A/W
$Q_{SAT}[pCb]$				22,5	4,5
$V_{SAT}[V]$	2	2	1	0,6	0,2

Table 6.5: Calculation for the maximum of the spectral sensitivity

	Th7803	Th 7831	TC 103	Ha S3924	Ha S3923
$K = \frac{e^-}{C}$	1,6 µV/e-	1,4 µV/e-		*0,0043 µV/e$^-$*	*0,01 µV/e$^-$*
$S = \frac{R \cdot e^-}{k \cdot A}$	*0,38 A/W*	*0,72 A/W*	0,45 A/W	0,32 A/W	0,32 A/W
$R = \frac{S \cdot A \cdot k}{e^-}$	5 V/µJ/cm^2	32V/µJ/cm^2	5V/µJ/cm^2	*4,3V/µJ/cm^2*	*1,4V/µJ/cm^2*
$E_{Sat} = \frac{V_{Sat}}{R}$	*0,4µJ/cm^2*	*0,06µJ/cm^2*	*0,2µJ/cm^2*	*0,14µJ/cm^2*	*0,14µJ/cm^2*
$E_{ges} = E_{Sat} \cdot A$	*0,52pJ*	*0,32pJ*	*0,32pJ*	*70pJ*	*14pJ*
$Q_{Sat} = S \cdot E_{ges}$	*0,2 pCb*	*0,23 pCb*	*0,15 pCb*	*22,3 pCb*	*4,5 pCb*

values in italic are calculated, others are taken from the data sheets.

6.10.2 Limits of resolution

The output current of our CCD line scan camera is amplified before digital converted. It is adjusted to the dynamic range of the A/D-converter which means nothing else as that always the saturation of the sensor V_{Sat} is amplified to the maximum input of the converter (2,5V) (at 8 bit: 255 or at 12 bit: 4095).

The amplification of the video signals is in principle free of choice. If the amplification is high the camera is very sensitive which means even at low intensity the output signal is immense. In comparison to this at low amplification the camera seemed to be less sensetive.
Also the sensors have different intern amplification or capacity, which can be compared by responsivity.
A comparison of responsivity data only tells us that a certain light energy (energy per cm^2) a certain signal will be reached.
For example if we compare Th7803 R=5 V/µJ/cm^2 and the Ha S3924 R=4,3 V/µJ/cm^2 you see that they have almost the same values. If exposed to the same light, both show the same sensitivity (not mentioned different spectral sensitivity dispersions) and thus though the active area of the Ha- sensors is 500 times bigger:
The reason therefore is a much lower intern amplification k (C much bigger) of the Ha-sensors.

Because at amplification the noise part is increased as well, the read noise limited the maximum possible sensitivity. Therefore the determination of noise equivalent energy (NEE: 'noise equivalent energy') is the simplest way to get the resolution limits.
Therefore the saturation energy is divided through the dynamic range and the result is the noise equivalent energy. Herein commonly the mean values are taken (rms. = 'root mean square').

Comparison of some sensors:
TI sensor: TC103 with 2048 diodes (Pixel: 12,7x12,7 µm)

E_{SAT}	=	350	nJ / cm^2
Dyn. Range rms.	=	5000:1	
E_{MIN} (rms)	=	70	pJ / cm^2

Th sensor: TH 7803(Z) with 1728 diodes (10x13 µm)

E_{SAT}	=	450	nJ / cm^2
Dyn. Range ptp.	=	6000:1	
E_{MIN} (rms)	=	75	pJ / cm^2

Sensor TH 7831(Z) for spectrometry with 1728 diodes (13x39 µm)

E_{SAT}	=	110	nJ / cm^2
Dyn. Range rms	=	6000:1	
E_{MIN} (rms)	=	18	pJ / cm^2

Enlarged sensor of Ha: S3924 with 1024 diodes (20x2500 µm)

E_{SAT}	=	330	nJ / cm^2
Dyn. Range rms	=	better than 25000 : 1[1]	

1. value respective. ptp- noise.

E_{MIN} (rms) = 13 pJ / cm^2

Spectrometry sensor of RFT: L172C (23x480 µm)
E_{SAT} = 6 nJ / cm^2
Dyn. Range rms = 5000 : 1
E_{MIN} (rms) = 1 pJ / cm^2

All values are taken from data sheets, whereby typical values were chosen not those which were guaranteed at minimum for room temperature (25 ^{0} C)!

Not considered is the detector area within this reflections. There will be an advantage of enlarged area sensors at optical construction with abbreviation. For example if the scanned slit in a spectrometer is bigger than the detector area, the light energy which did not hit the detector will not be changed to electrons. This energy will not be lost when a sensor with larger pixels was used.

6.10.3 Increase of sensitivity

The simplest method of increase the sensitivity is to increase the exposure time. This has the same effect as increasing the amplification, but has the advantage that the dynamic range of the sensor is completely used by the variation of the exposure time.

The dark current limits the maximum exposure time (t_{max}) and therefore the sensitivity. With cooling of the sensor this noise will be reduced a lot.

If you measure short single shot signals which occur only once (pulsed signals) the sensitivity can not be increased by the exposure time. Here the camera must get more sensitive through the increasing of the amplification. The limiting factor is here the read out noise and the dark noise. The read out noise will not be reduced by cooling adequately.
Cooled sensors do have a switchable amplification or 16 bit A/D.

For disadvantage we have to name that the in this stage highly sensitive camera is that the upper linear area of the sensor (area between saturation of A/D-converter and saturation of the sensor) can not be used. The total dynamic range of the sensor is decreased.
So the 16 bit solution is the better one.

6.11 Temperature influence

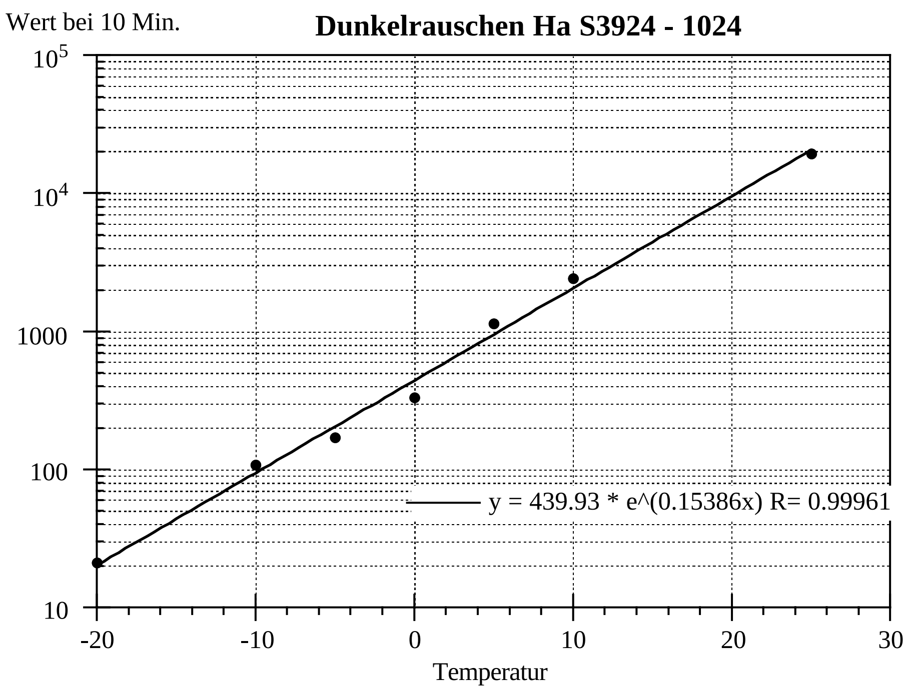
6.11.1 Dark noise measurement of Ha S3924

The values were sampled with 12 bit and $Q_{Sat}\text{bzw.}V_{Sat} \cong 4096$.

Table 6.6: Measurement of dark current with Ha S3924-1024.

Temp[°C]	zero line	exp.-time [s]	noise value	value-zero	value [10 m]
25	12	60	1958	1946	19460
10	70	60	312	242	2420
5	93	600	1228	1135	1135
0	110	600	444	334	334
-5	133	600	303	170	170
-10	149	600	257	108	108
-20	189	600	210	21	21

picture-6.18: Temperature dependency of **dark current for Ha S3924**



This diagram shows a temperature dependency of the dark current:
Factor 10 each 16 °C or with cooling at -20°C the dark current decrease to appro. 1000 compared to room temperature.

7 Technical Specifications Series 1000

7.1 Camera specifications

Power:	5V/max 250 mA
Dimensions:	72 x 54 (Ø x L in mm)
Weight:	approx. 280 g
min. data transfer rate (Series 1000):	200 ns / value
max. data transfer rate:	only limited by dark noise

The camera has an M42 connector for standard lenses. The sensor is mounted 12 mm below the connector.
The Camera cable length is 2,5m.

7.2 Sensor specifications

7.2.1 Standard sensors

The cameras are available with CCD-line scan sensors from Sony (So):

Sensor ILX 551/751 (503/703) with 2048pixel (So)

active length:	28,7 mm
pixel size:	14 x 14 μm^2
max. exposure time:	approx. 2 sec. (25°C)
Dyn. Range$_{ptp.}$:	6000:1
Response:	40 V/lx s
E_{SAT}:	0,045 lx s
V_{SAT}:	1,8 V
Pclk	6,7 MHz

Sensor ILX 505with 2592 pixel (So)

active length:	28,5 mm
pixel size:	11 x 11 μm^2
max. exposure time:	2 sec. (25°C)
Dyn. Range$_{ptp.}$:	5000:1
Response:	21 V/lx s
E_{SAT}:	0,085 lx s
V_{SAT}:	1,8 V
Pclk	6,7 MHz

Sensor ILX 506 with 5000 pixel (So)	
active length:	35 mm
pixel size:	7 x 7 μm^2
max. exposure time:	1 sec. (25°C)
Dyn. $Range_{ptp.}$:	5000 : 1
Response:	10,8 V/lx s
E_{SAT}:	0,14 lx s
V_{SAT}:	1,5 V
Pclk	10 MHz

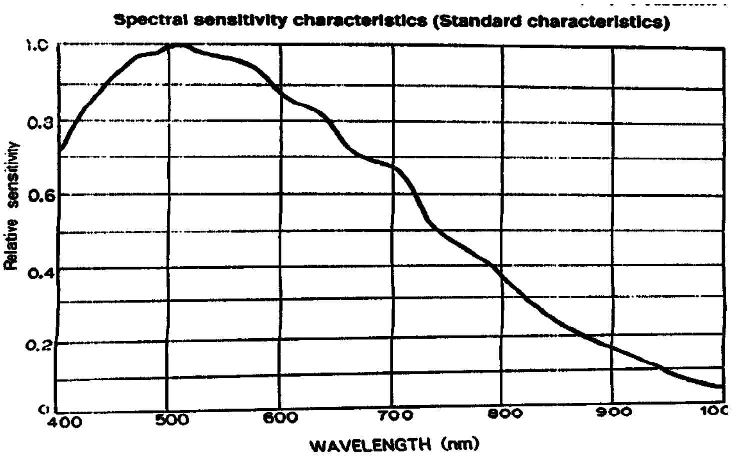
Sensor ILX 511 with 2048 pixel (So)	
active length:	28,7 mm
pixel size:	14 x 200 μm^2
max. exposure time:	2 sec. (25°C)
Dyn. $Range_{ptp.}$:	270 : 1
Response:	200 V/lx s
E_{SAT}:	0,004 lx s
V_{SAT}:	0,8 V
Pclk	2,5 MHz

Sensor ILX 553 with 5150 pixel (So)	
active length:	36 mm
pixel size:	7 x 7 μm^2
max. exposure time:	1 sec. (25°C)
Dyn. $Range_{ptp.}$:	6000:1
Response:	15 V/lx s
E_{SAT}:	0,14 lx s
V_{SAT}:	2 V
Pclk	16 MHz

7.3 Spectral sensitivity

Spectral sensitivity of the sensors mentioned above leads to the following distribution:

picture-7.1: spectral sensitivity of So- sensors ILX 501 (lin- Scale)

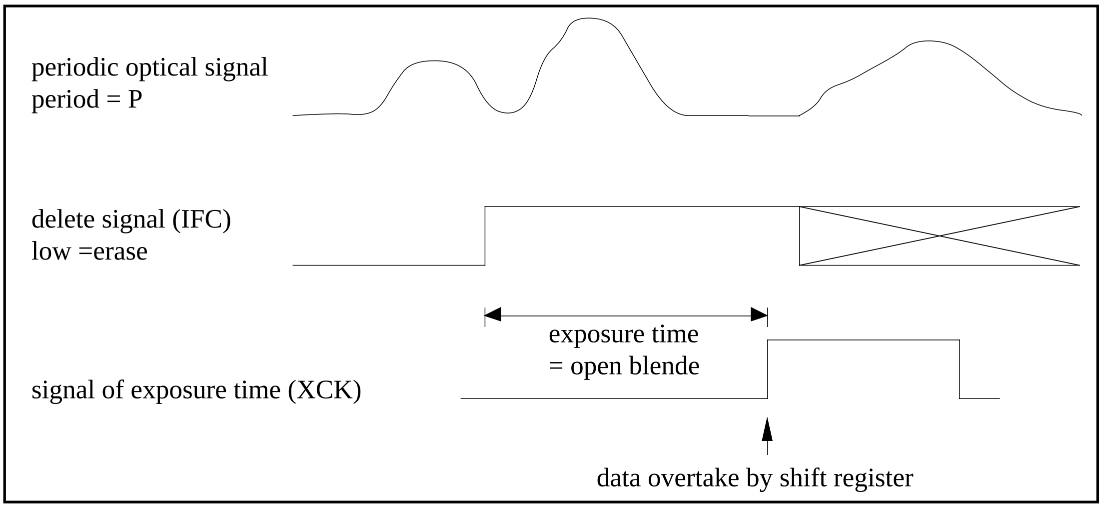


7.4 Shutter sensor ILX703/751

This sensor includes a erase function which clears the pixels. Therewith a shutter function can be realized. The exposure time can be determined as short as needed or the shutter can be closed totally. In this case it is easy to detect the dark noise.

The shutter operation mode is executed with the help of the CCD-control or the control program according to picture-7,2. In assistance to the IFC- signal (low=delete) the shutter will be held closed. As soon as the IFC-signal changed to high, light is accumulated at the sensor area. With the activating of the Xck-signal (appeal of GETCCD) the collected loads will submit to the shift-registers and then slowly red out.
Through exact access of the signals XCK and IFC the shutter function will be possible. This function guarantees a safety against overexposure.

picture-7.2: Shutter function with anti blooming sensor

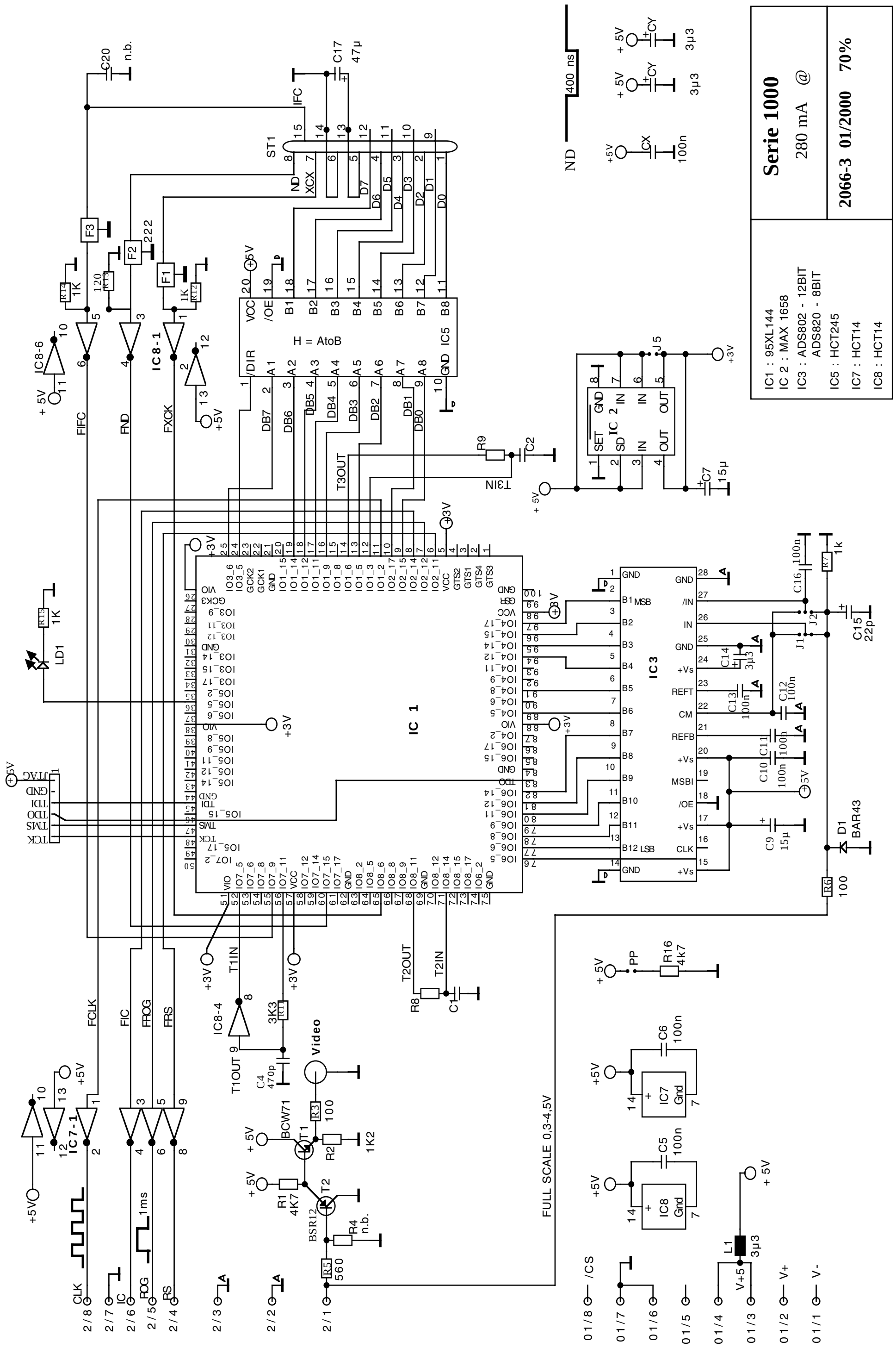


The signals IFC and XCK can be generated either with the CCD-control unit or through the control software.

However, you can not compare this function with a mechanical shutter. Even a closed electronically shutter will show a ground signal ≠ zero, nor is it able to avoid over exposure.

For prevention of floating loads to neighbor pixels while detecting objects in motion and to realize a time zone this sensor is well suited. This function will be very helpful even if several cameras are exposed at the same time, to guarantee a identical time related exposure. The data of the numerous cameras can be transferred hence successively to the computer.

7.5 Main board camera series1000



7.6 Signal connections series 1000

Table 7.1: Signal connections camera series 1000

camera (15 pol.)	color	Function	IBM (25 pol.)
1	w/or	D1	2
2	w/ge	D3	4
3	bl	D5	6
4	gr	D7	8
5	or	+5V	13
6	w/rt	GND	18
7	br	XCK	16
8	w/br	NDAC	1
9	w/gn	D2	3
10	gn	D4	5
11	li	D6	7
12	w	D8	9
13	rt	+5V	12
14	sw/w	GND	25
15	ge	IFC	14
14	sw	GND	24

C A U T I O N : Plus 5V at pin#12 and #13, Minus at Pin #25 and #18.
The device will be destroyed with power over 7 V at Pin #12 and #13 !

Signalbeschreibung

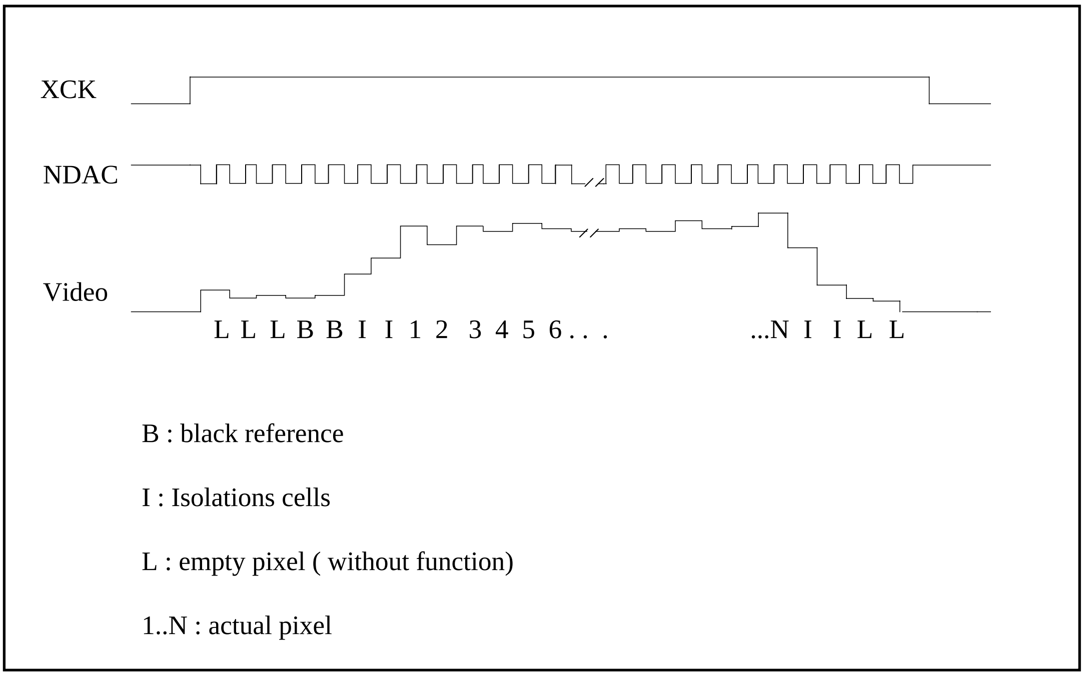
D0..D7	8 bit data bus.
XCK	'exposure time' - signal: high= read cycle to / low= quit read out cycle.
NDAC	'pixel clock' - signal: the negative slope starts the converting for the next pixel.
IFC	optional shutter signal (only ILX 703): high = shutter open / low = shutter closed. If not in use: set to high.
GND	Ground for current and logic.
+5V	Current for camera @ 200mA.

7.7 Signals

7.7.1 Video signal

The video signal output of the line sensor can be obtained at the video BNC-plug of the camera.

picture-7.3: Video signal



The video signal contains beside the real signal of the picture elements (pixel 1..N) black reference elements (B). This can be used to determine the dark noise level. These elements are darkened pixel elements and lie in the beginning and in the end of the line. The signal of these elements corresponds to that of a picture element without light, however, with darkness intoxication and is therefore dependent on the exposure-time.

Table 7.2: Reference and isolation pixel

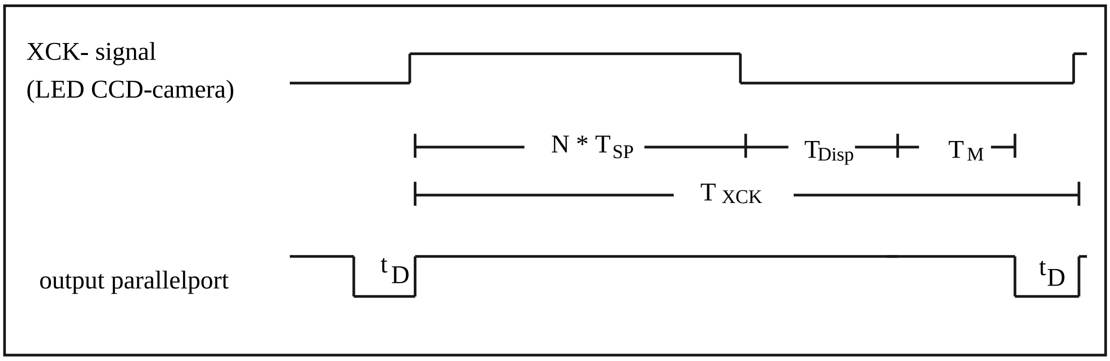
Sensor	L	B	I	Pixel	I	L	all in all
ILX 50X	20	18	2	N	-	6	N+46
ILX 506	18	10	2	5000	6	5	5041

Abbreviation: L: empty pixel, B: black pixel (dark reference), I: isolation pixel, N amount of pixel: picture element, W: white reference; all sensors from Sony,
all: amount of pixel, which were maximal read out.
The diagram is leads to the right to higher pixel numbers.

7.7.2 Standard trigger signal

The BNC- plug located near the LED of the CCD camera delivers a trigger signal for synchronizing an oscilloscope. In addition the signal contains some further timing information:

picture-7.4: Trigger out camera and interface board



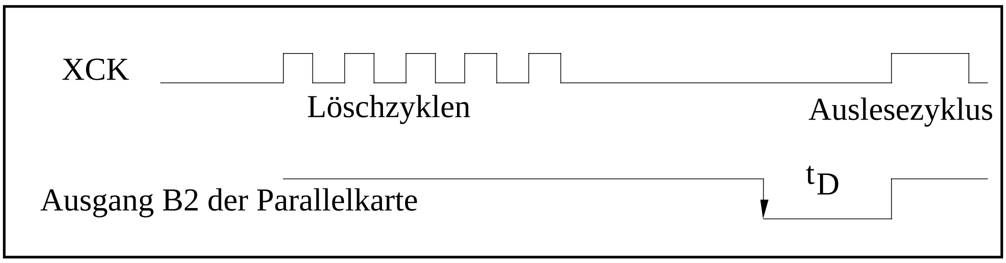
T_{XCK}:exposure time
N: number of pixel
T_{SP}: transfer time of one pixel
T_{Disp}:display time
T_M: time for own calculation
t_D: adjustable delay time (through software) for longer exposure of the line.

The exposure time T_{XCK} will be determined by the software. The evaluated value is shown under F8 in the measurement menu. Here the delay time can be extended $t_D \neq 0$.

7.7.3 Single Shot trigger signal

At the operation mode ‘single shot’ (see chapter-2.2.4) this output can be used for triggering other events.

picture-7.5: Trigger out while single shot mode



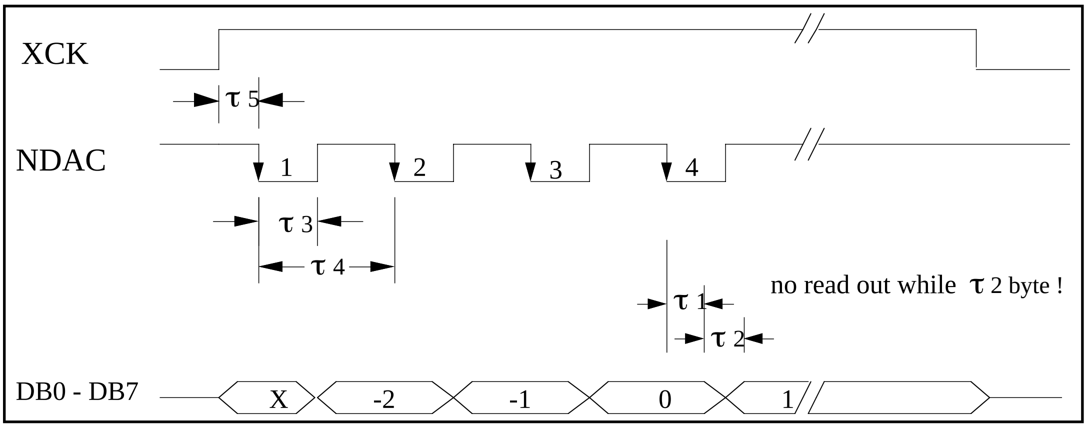
To start a measurement the negative slope of the signal can be used.
This signal can also be programmed by the software in polarity and time.

7.7.4 Camera timing

The program produce two control signals for the CCD-camera:

XCK	high = camera on	low = camera off
NDAC	negative slope starts A/D-converter	
IFC	high = standard mode	low = reset or integration control

picture-7.6: Clocks for camera control



The converter works in the ‘pipeline’- process, that means at the data bus lie the result with time delay. After 4 clocks the first result without time delay is at the data bus. Discharge the first 4 read out values.

The algorithm for the software control:

read data bus
creates negative pulse NDAC
repeat loop

With 8 bit resolution a negative slope is generated on each reading access. With 12 (16) bit the high and low byte is transferred and is set together by the program again. Here each second slope starts a new convert process.
The reading of the values on the data bus (D0..D7) may not occur during τ_2.

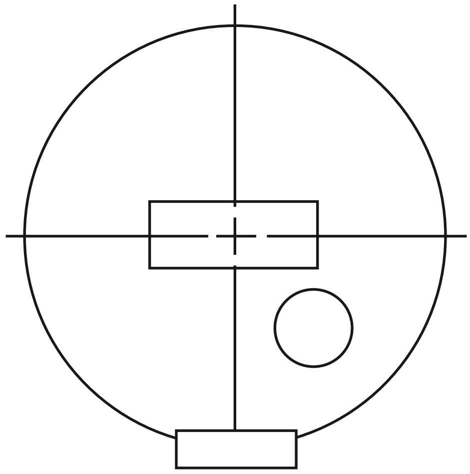
Table 7.3: timing characteristics

	t_{min}	$t_{(10MHz)}$	t
τ_1		70	100 ns
τ_2		20	50 ns
τ_3	>15 ns	50 ns	500 ns
τ_4	>30 ns	100 ns	1 µs
τ_5	> 1 µs	> 1 µs	9 µs

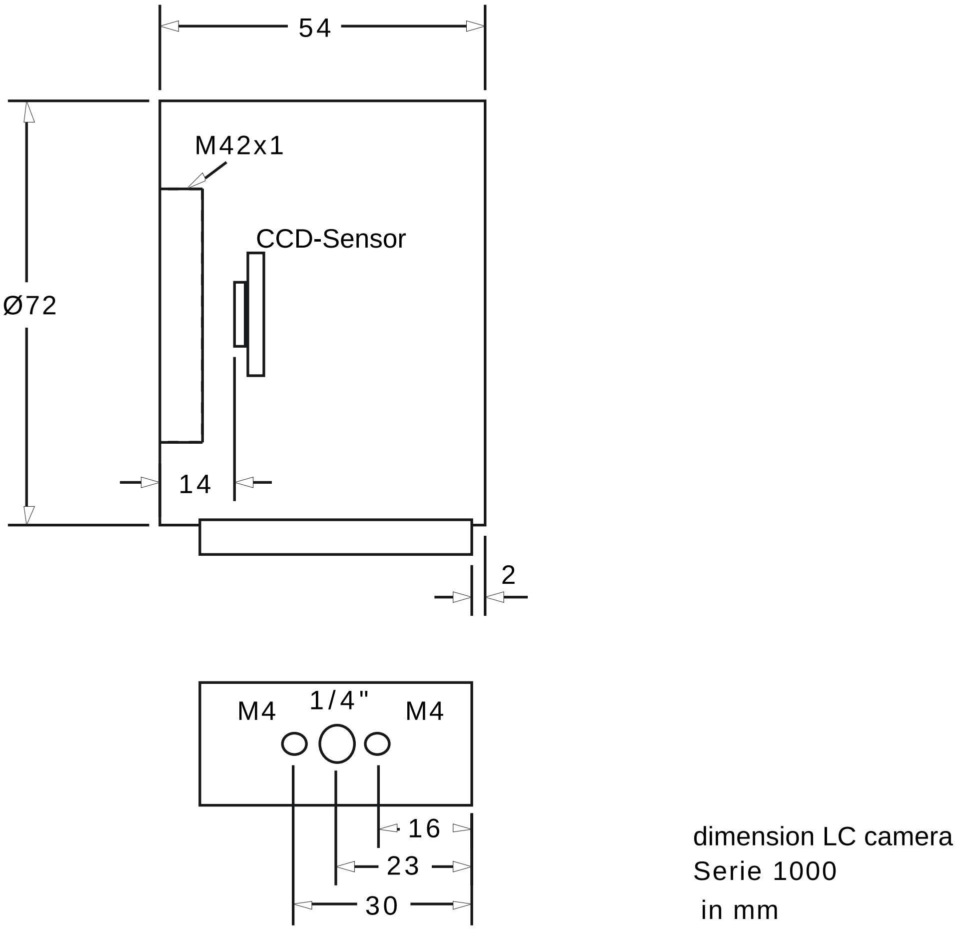
7.8 Dimension

picture-7.7: Dimension of the camera series1000

back view



side view



8 Technical Specifications Series 2000

8.1 Camera specifications

Power:	5V/max 700 mA
Dimensions:	116 x 74 x 44 (L x W x H in mm)
Weight:	approx. 500 g
min. data transfer rate (Series 2000):	5 µs / byte
min. data transfer rate (Series 2010):	300 ns / byte
min. data transfer rate (Series 2010hs):	100 ns / byte
min. data transfer rate (Series 2010hhs):	30 ns / byte
max. data transfer rate:	only limited by dark noise

The camera has an M42 connector for standard lenses. The sensor is mounted 12 mm below the connector.
The Camera cable length is 2,5 m.

8.2 Sensor specifications

8.2.1 Standard sensors

The cameras are available with CCD-line scan sensors from Texas Instruments (TI),Thomson (Th), Hamamatsu (Ha), Sony (So), Toshiba(To) or Loral / formerly Fairchild (Lo):

Sensor TH 7803A(Z) with 1728 Pixel (Th)

active length:	17,3 mm
max. exposure time:	approx. 5 sec. (25°C)
pixel size:	10 x 13 μm^2
Dyn. $Range_{ptp.}$:	1200:1 (6000:1_{rms})
Response:	5 V/($\mu J/cm^2$)
E_{SAT}:	450 nJ/cm^2
k	1,6 µV/e-
spectral range:	ca. 0,4 - 1,1 µm with window
Pclk	2 MHz.

active length:	35 mm
max. exposure time:	approx. 1 sec. (25°C)
pixel size:	4.7 x 4.7 μm^2
Dyn. $Range_{rms.}$:	1800:1
Response:	15 V/lxs
E_{SAT}:	0.12 lxs
spectral range:	ca. 0,4 - 1,1 µm with window
Pclk	25 * 2 MHz.

8.2.2 Antiblooming sensors

Antiblooming sensor TH 7811 A(Z) with 1728 diodes (Th)

active length:	22,5 mm
max. exposure time:	approx. 3 sec.
pixel size:	13 x 13 μm^2
Dyn. Range$_{ptp.}$:	1200:1 (6000:1$_{rms}$)
Response:	6 V/($\mu J/cm^2$)
E_{SAT}:	330 nJ/cm^2
spectral range:	ca. 0,4 - 1,1 µm with window; o.F.
Pclk	2 MHz.

Antibloomingand Shutter sensor TH 7813 with 1024 diodes (Th)

active length:	10,3 mm
max. exposure time:	approx. 0,5 sec.
pixel size:	10 x 10 μm^2
Dyn. Range$_{ptp.}$:	6000:1$_{rms}$
Response:	10 V/($\mu J/cm^2$)
E_{SAT}:	330 nJ/cm^2
spectral range:	ca. 0,2 - 1 µm with quartz window
Pclk	25 * 2 MHz.

Antiblooming and Shutter sensor TH 7814 with 2048 diodes (Th)

active length:	20,5 mm
max. exposure time:	approx. 0,5 sec.
pixel size:	10 x 10 μm^2
Dyn. Range$_{ptp.}$:	6000:1$_{rms}$
Response:	10 V/($\mu J/cm^2$)
E_{SAT}:	330 nJ/cm^2
spectral range:	ca. 0,2 - 1 µm with quartz window
Pclk	25 * 2 MHz.

Antiblooming and Shutter sensor DALSA IL-C6 with 2048 diodes

active length:	26,6 mm
max. exposure time:	approx. 0,1 sec.
pixel size:	13 x 500 μm^2
Dyn. Range$_{ptp.}$:	6000:1$_{rms}$
Response:	360 V/($\mu J/cm^2$)
E_{SAT}:	7 nJ/cm^2
spectral range:	ca. 0,4 - 1 µm
Pclk	25 * 2 MHz.

Antiblooming, Shutter and EMCCD Area sensor TI TC253

active area:	656x496 pixel / 4,85x3,7 mm
max. exposure time:	approx. 1 sec at max. gain / 60s ec gain=1
pixel size:	7,4 x 7,4 μm^2
Dyn. Range$_{ptp.}$:	2000:1$_{rms}$
Response:	290 V/(lx s) / gain = x30
spectral range:	ca. 0,4 - 1 µm / 0,2 - 1µm window removed
Pclk	hor.:12 MHz / vert.: 3 MHz.

8.2.3 PDA photo diode arrays

large area sensors S3903 with 1024 diodes (Ha)

active length:	25,6 mm (25 µm pitch)
max. exposure time:	approx. 50 sec (doubles every 5° C) *
pixel size :	20 x 500 µm^2
Dyn. Range$_{ptp:}$	1400 : 1 (7000 : 1$_{rms}$)
Response:	ca. 4 V/(µJ /cm^2)
spectral range:	ca. 0,2 - 1µm with quartz windows
Pclk / linerate	2 MHz / 2 KHz

large area sensors for very long exposure times S3904 with 1024 diodes (Ha)

active length :	25,6 mm (25 µm pitch)
max. exposure time:	approx. 50 sec (doubles every 5° C) *
pixel size:	20 x 2500 µm^2
Dyn. Range$_{ptp}$	6000 : 1 (30000 : 1$_{rms}$)
Response:	ca. 4 V/(µJ /cm^2)
spectral range:	ca. 0,2 - 1µm with quartz windows
Pclk / linerate	2 MHz / 2 KHz

Table 8.1: Elektro - optical specifications for Hamamatsu sensors

	S 3901	S3902	S3903	S3904
size	50 x 2500 µ	50 x 500 µ	25 x 500 µ	25 x 2500 µ
pixel	128 256 512	128 256 512	256 512 1024	256 512 1024 2048
noise current	0,2 pA	0,08 pA	0,04 pA	0,1 pA
C_{photo}	20 pF	4 pF	2 pF	10 pF
Q_{Sat}	50 pC	10 pC	5 pC	25 pC
E_{Sat}	180 mlx s	180 mlx s	180 mlx s	180 mlx s
V_{Sat} [mV]	1350 1300 1100	900 670 460	420 280 160	1050 820 570
max. non-uniformity	±3 %	±3 %	±3 %	±3 %

* The specs refer to room temperature (25° C). With a peltier cooling the dark noise can be reduced drastically. The sensitivity is enlarged by the factor of the pixel area.

8.2.4 CCD- array sensors (FFT = full frame transfer)

pixel size:	24 x 24 µm^2
max. exposure time (25° C):	ca. 1 sec (doubles all 5° C) *
Dyn. Range$_{ptp}$	3000 : 1 (15000 : 1$_{rms}$)
Response:	120 V/(µJ /cm^2)
spectral range (back / front):	0,2/0,4 - 1100 µm
V_{Sat}	960 mV
k	1,2 µV/e
max. non-uniformity	±10%
Pclk(max.)	1 MHz

Table 8.2: Geometry of FFT sensor

S7030, S7031. S7032	current pixel (H x V)	area (H x V) mm^2	total pixel (H x V)	S7010, S7011, S7015	current pixel (H x V)	area (H x V) mm^2	total pixel (H x V)
0906	512 x 58	12,29 x 1,39	532 x 64	0906	512 x 60	12,29 x 1,44	532 x 64
0907	512 x 122	12,29 x 2,93	532 x 128	0907	512 x 124	12,29 x 2,98	532 x 128
0908	512 x 250	12,29 x 6,00	532 x 256	0908	512 x 252	12,29 x 6,05	532 x 256
1006	1024 x58	24,58 x 1,39	1044 x 64	1006	1024 x60	24,58 x 1,44	1044 x 64
1007	1024 x 122	24,58 x 2,93	1044 x 128	1007	1024 x 124	24,58 x 2,98	1044 x 128
1008	1024 x 250	24,58 x 6,00	1044 x 256	1008	1024 x 252	24,58 x 6,05	1044 x 256
S9840	2048 x 14	28,672 x 0,196	2080 x 20				

Series S7030 is without Peltier element.
Series S7031 has one Peltier element for cooling down to -20ºC and sealed case.
Series 7032 has two Peltier elements for cooling down to -40ºC.

Special sensor **S9840** with 2048 x 14 active pixel

active area:	28,672 x 0,196mm
max. exposure time:	approx. 5 sec.
pixel size:	14 x 14µm^2 / 20 lines
Dyn. Range$_{ptp.}$:	5200:1$_{rms}$
V_{Sat}	300 mV
k	4 µV/e
Pclk(standard / max.)	2 / 5 MHz.

8.2.5 IR- Sensors Hamamatsu G92xx

Infrared sensor series G92xx with 256 or 512 InGaAs-diodes (Ha)
the G9208 is only available as cooled version, max. cool temperature -30 degrees C.

Table 8.3: Geometry of IR sensors G92xx

type	pixel	pitch µm	size HxV µm	spectral range µm
G9201-256	256	50	50 x 250	0.9 to 1.67
G9202-512	512	25	25 x 250	0.9 to 1.67
G9203-256	256	50	50 x 500	0.9 to 1.67
G9204-512	512	25	25 x 500	0.9 to 1.67
G9208-256W	256	50	50 x 250	0.9 to 2.55

Series 9201-4	no defective pixel
Series 9211-14	max. 1% defective pixel
Series 9208	max. 5% defective pixel
Series R	non cooled
Series S	cooled
Series D	non cooled, max. 5% defective pixel

VSat	3.2 V
QSat low/high cap	1.5 / 30 pC (cap is switchable)
Pclk max.	0.5 MHz
PRNU G9201-4	± 5%
PRNU G9208	±10%

darknoise

Id typ. (25ºC) G9201	2 pA
Id typ. (25ºC) G9202	1 pA
Id typ. (25ºC) G9203	4 pA
Id typ. (25ºC) G9204	1 pA
Id typ. (-20ºC) G9208	500 pA

tmax (+25ºC) G920x	50 sec
tmax (-10ºC) G920x	160 sec
tmax (+25ºC) G9208	5 ms
tmax (-20ºC) G9208	50 ms

tmax is the time where the dark noise reaches 2/5 of maximum.

read noise low cap (trms measured values over 400 scans)
G9203 trms = 3 -> DR=64k/3 = 20000
G9208 trms = 8 -> DR=64k/8 = 8000

trms = noise of a single darkened pixel in counts of a 16bit converter = 0..64k

8.2.6 IR- Sensors Hamamatsu G11608

Infrared sensor series G11608 with 256 or 512 InGaAs-diodes (Ha)
the G11608 is only available as not cooled version.

.

Table 8.4: Geometry of IR sensors G11608

type	pixel	pitch µm	size HxV µm	active size HxV µm	spectral range µm
G11608-256	256	50	50 x 500	30 x 500	0.5 to 1.7
G11608-512	512	25	25 x 500	10 x 500	0.5 to 1.7

Series 11608 max. 1% defective pixel

VSat	1.8 V
k low/high cap	16 / 160 nV/e- (cap is switchable: 1/10 pF)
Pclk max.	1 MHz

darknoise
Id typ. (25ºC) G11608 5 pA

read noise low cap (trms measured values over 400 scans)
G11608: trms = 5 -> DR=64k/5 = 13000

trms = noise of a single darkened pixel in counts of a 16bit converter = 64k

8.2.7 IR- Sensors Goodrich Sensor Unlimited

Infrared sensor series SU with 256, 512 or 1024 InGaAs-diodes (Go)
only cooled versions available, max. cool temperature -15 degrees C.
vertical pixel size (vps) of 25 or 50 µm on demand.

Table 8.5: Geometry of IR sensors

type	pixel	pitch µm	vertical size vps µm	spectral range (std) µm	spectral range (ext) µm
SU256LSB	256	50	250 or 500	0.9 to 1.67	1 to 2.2
SU512LDB	512	25	250 or 500	0.9 to 1.67	1 to 2.2
SU512LSE	512	50	250 or 500	0.9 to 1.67	1 to 2.2
SU1024LE	1024	25	250 or 500	0.9 to 1.67	1 to 2.2

Series LSB & LDB std	no defective pixel
Series LSB & LDB ext	max. 2% defective pixel
Series LSE std	max. 5 defective pixel
Series LSE ext	max. 10 defective pixel
Series LE std	max. 10 defective pixel
Series LE ext	max. 20 defective pixel
VSat	2.7 V
QSat low/high cap	0.8 / 20.8 pC (cap is switchable)
Pclk max.	2 MHz
PRNU	±10%
darknoise	
Id typ. vps = 250 ext	12500 pA
Id typ. vps = 500 std	5 pA

read noise low cap (trms measured values over 400 scans)
256LSB std = 3 -> DR=64k/3 = 20000
512LSE ext = 8 -> DR=64k/8 = 8000

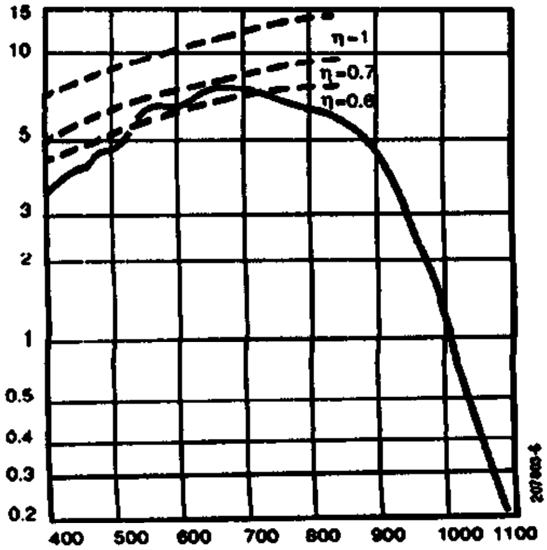
trms = noise of a single darkened pixel in counts of a 16bit converter = 64k

8.3 Spectral response

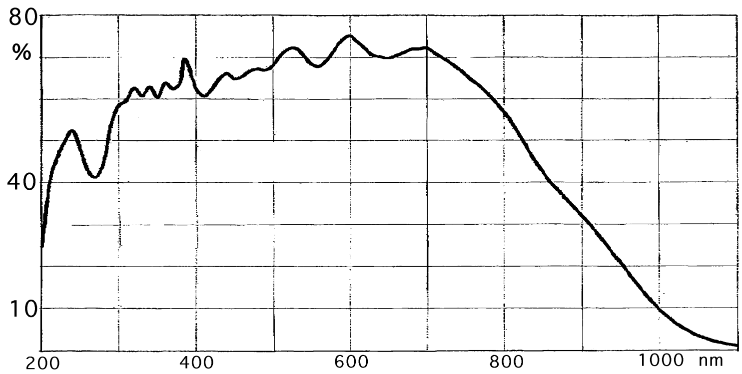
8.3.1 Standard sensors

The spectral sensitivity of the sensors corresponds to following distributions (copied from the data sheets of the respective manufacturer):

picture-8.1: Spectral response of Thomson Th7803 (log- Scale)

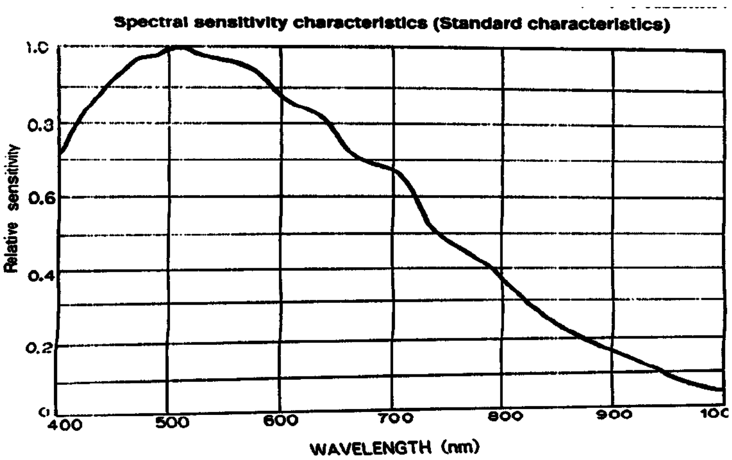


TH 7813/14 ACC typical quantum effectivity

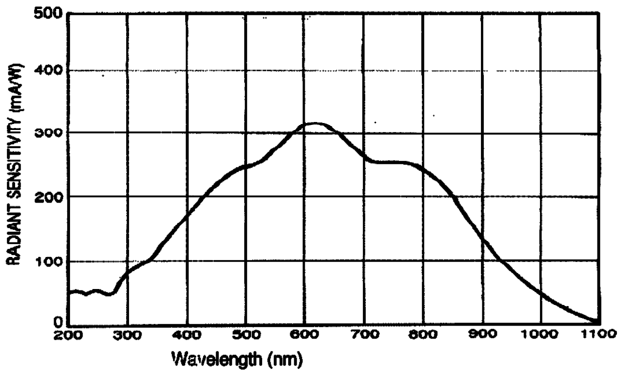


Measurement typical for sensor without window or quarz window.

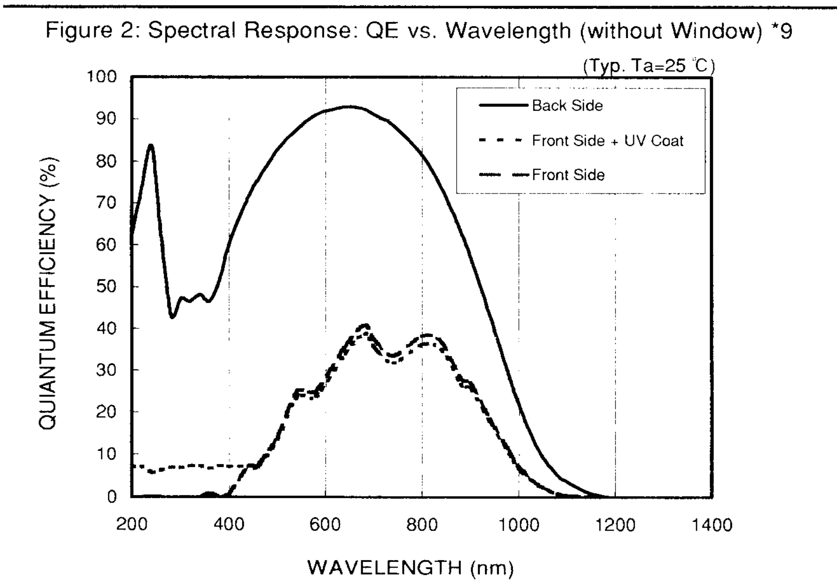
picture-8.2: Spectral response of Sony ILX 501 (lin- Scale)



picture-8.3: Spectral response of the Ha- sensors S3924 (lin- Scale)

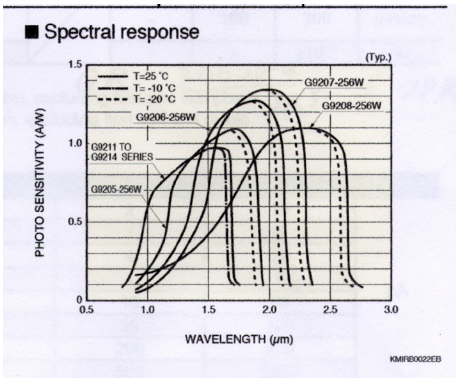


Spectral response of the Ha- Sensor FFT type (lin- Scale)

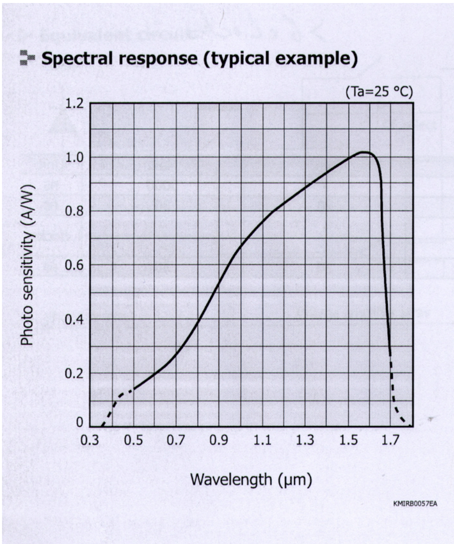


Infrared sensors (IR)

picture-8.4: Spectral response of the Ha- sensor G92xx



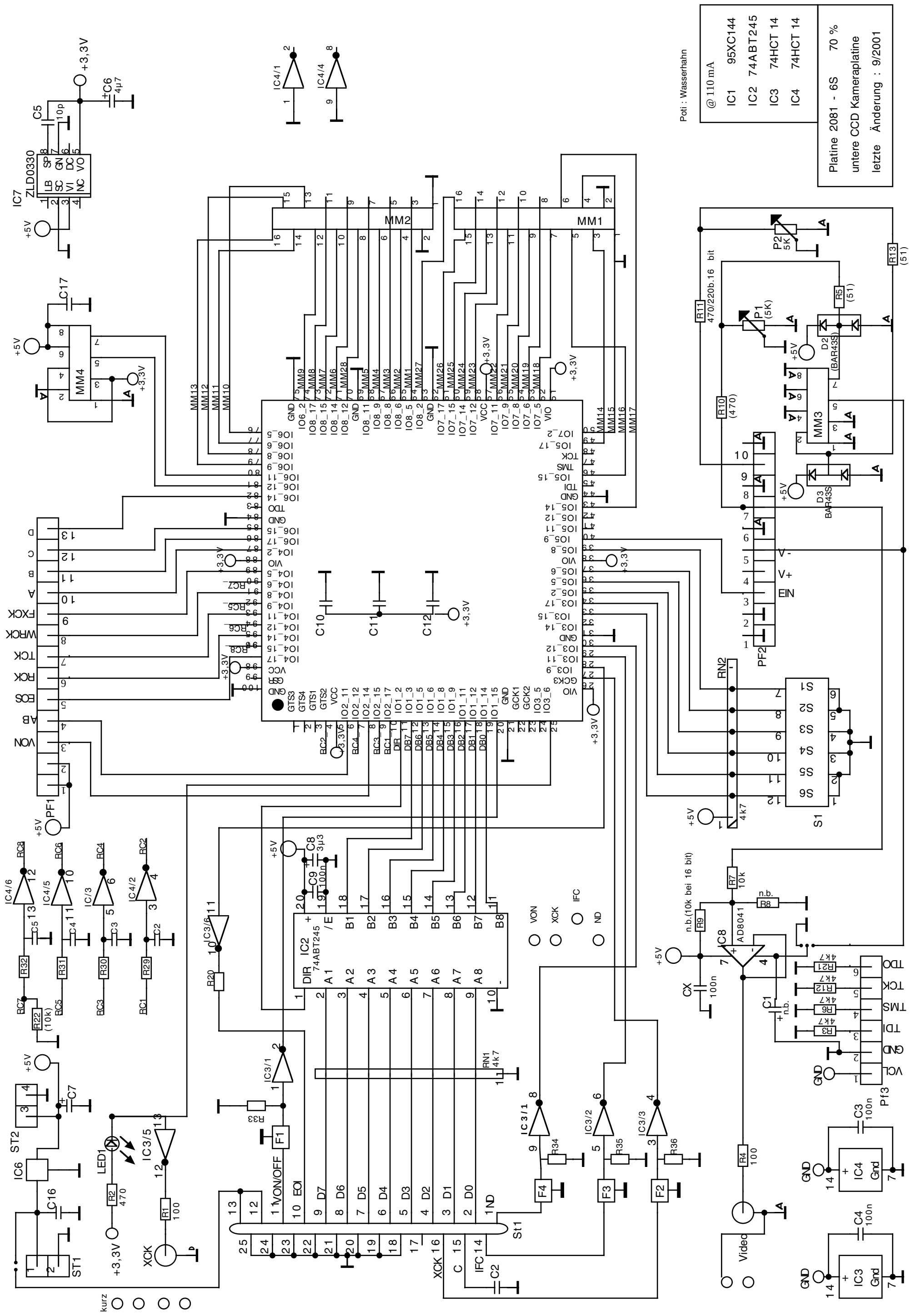
picture-8.5: Spectral response of the Ha- sensor G11608



8.4 Circuit diagram

8.4.1 Camera Series 2000

picture-8.6: Circuit diagram of the main board Series 2000



8.4.2 Signal connections series 2000

Table 8.6: Signal connections series 2000

Function	Color	Pin	CCD Control
IFC	br	#14	-
NDAC	br/or	#1	#1 CLK
VON/OFF	br/gn	#11	-
EOI	br/ge	#10	#10 EOI
XCK	br/schw	#16	#16 XCK
ext.Trig.	-	#17	-
GND(C)	w	#18	#18 GND
GND	bl	#19	#19 GND
GND	gn	#20	#20 GND
GND	li	#21	#21 GND
GND	gra	#22	#22 GND
GND	br/bl	#23	#23 GND
GND	w/gra	#24	#24 GND
GND S	sw	#25	#25 GND
+5V	ge	#12	#12 +5V
+5V	rt	#13	#13 +5V
D0	w/bl	#2	#2 D0
D1	w/li	#3	#3 D1
D2	w/gn	#4	#4 D2
D3	w/ge	#5	#5 D3
D4	w/or	#6	#6 D4
D5	w/rt	#7	#7 D5
D6	br/gra	#8	#8 D6
D7	br/li	#9	#9 D7

C A U T I O N: Plus 5V at pin # 12 and # 13 is connected by the interface board to the internal supply of the computer.

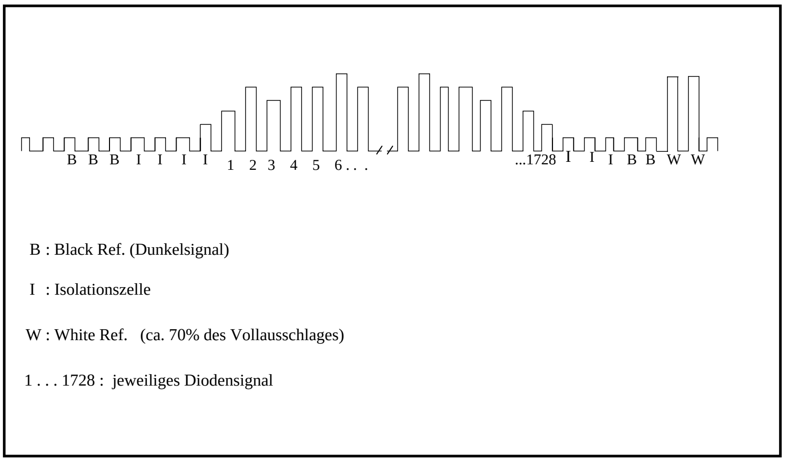
The device will be destroyed with power over 7 V at Pin #12 and #13 !

8.5 Signals

8.5.1 Video signal

The video signal output of the line sensor can be obtained at the video BNC-plug of the camera.

picture-8.7: Video signal



Beside the active pixel signal it contains additional black reference elements, which can be used for measuring the dark noise level. These elements are darkened picture elements and are positioned at the beginning and in the end of the line. The signal of these elements corresponds to that of a picture element without light.

.

Table 8.7: Reference- and isolation Pixel

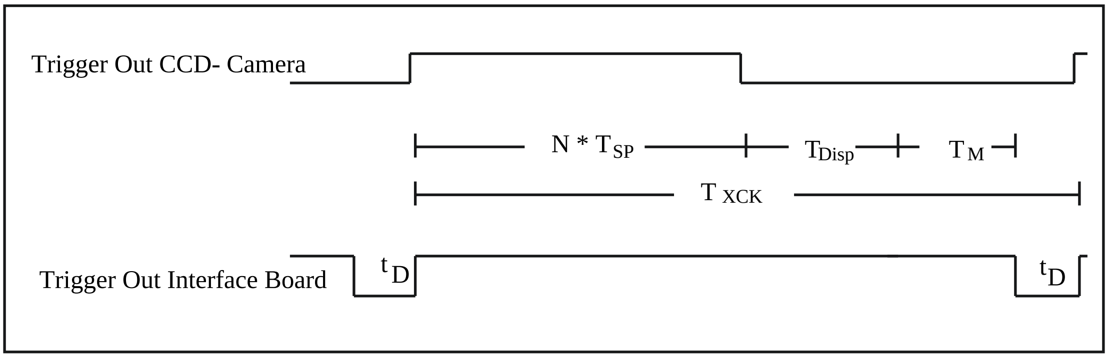
sensor	L	B	I	pixel	I	B	L	W	total
TI	11	4	4	N	4	4	4	2	N+33
Th	8	4	4	N	4	4	2	-	N+26
Ha	2	-	-	N	-	-	2	-	N+4
Lo	4	8	8	N	2	-	-	-	N+22
So	18	10	2	5000	-	-	5	-	5035

Abbreviations L: empty pixel, B: black reference pixel, I: isolation pixel, N number of pixel: picture elements, W: white reference; TI: Texas Instruments, Th: Thomson, Ha: Hamamatsu, So: Sony, total: number of pixel, which should be read at minimum.
The index counts from left to right with increasing pixel numbers.

8.5.2 Standard trigger signal

The BNC- plug located near the LED of the CCD camera delivers a trigger signal for synchronizing an oscilloscope. In addition the signal contains some further timing information:

picture-8.8: Trigger Out of camera and interface board



T_{XCK} :exposure time
N: number of pixel
T_{SP}: transfer time of one pixel
T_{Disp}:displaytime
T_M: time for own calculation

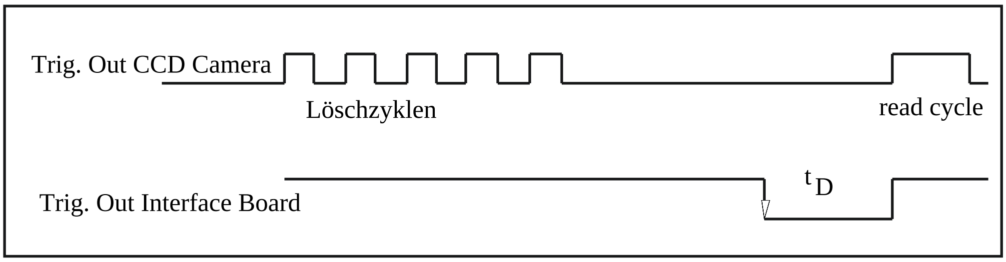
t_D: adjustable delay time for long exposure.

The exposure time T_{XCK} will be determined by the software. The evaluated value is shown under F8 in the measurement menu. Here the delay time can be extended $t_D \neq 0$.

8.5.3 Single Shot trigger signal

At the operation mode ‘single shot’ (see chapter-2.2.4) this output can be used for triggering other events.

picture-8.9: Trigger Out in Single Shot Mode



The negative slope of the signal can be used for the triggering of an external event. This signal can be programmed freely in the control program.

8.5.4 Camera timing

The program generates 3 clock signals for the CCD- Camera:

XCK	high = camera on	low = camera off
NDAC	negative slope started A/D-converter (initialized by read(Port))	
IFC	high = standard mode	low = reset or integration control

picture-8.10: Clocks for camera control

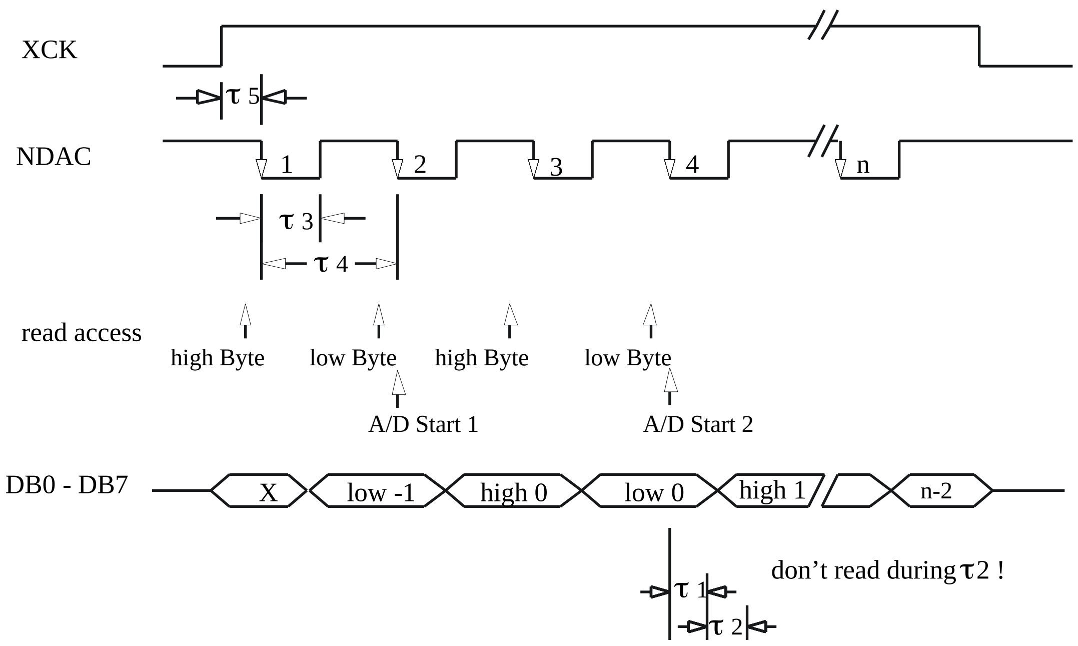


Table 8.8: Switching characteristics

	standard t_{min}	standard t	6 MHz @12 bit	33 MHz @ 8 bit
τ_1		100 ns	65 ns	15 ns
τ_2		200 ns	10 ns	10 ns
τ_3	>300 ns	500 ns	40 ns	15 ns
τ_4	>700 ns	1 µs	80 ns	30 ns
τ_5	> 1 µs	9 µs	1 µs	1 µs

In the **addressed camera operation** the address of the selected camera is send to the data bus before XCK goes high.

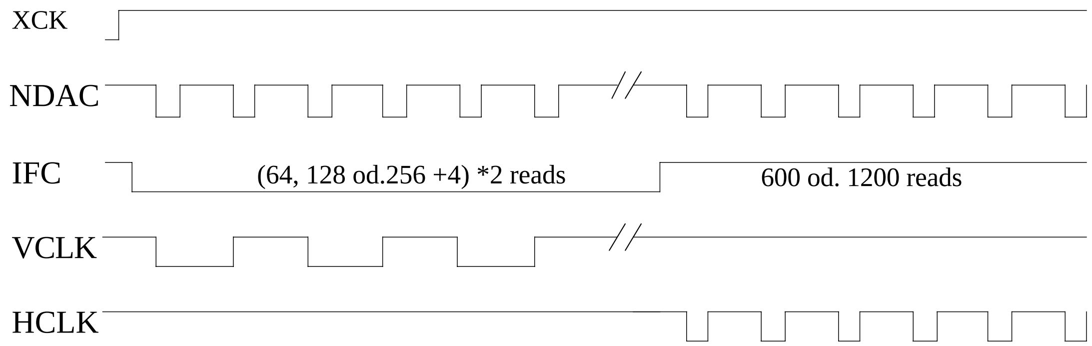
With 8 bit resolution a negative slope is generated on each reading access. With 12 (16) bit the high and low byte is transferred and is set together by the program again. Here each second slope starts a new convert process.

The reading of the values on the data bus (D0..D7) may not occur during τ_2.

8.5.5 Clocks of the FFT- sensors

For the FFT-sensors the signals for the vertical clock must be produced additionally. Like the standard cameras the NDAC-pulse triggers the clock automatically with each read access on the data bus address. The distinction between vertical and horizontal clock is determined with the IFC-signal.

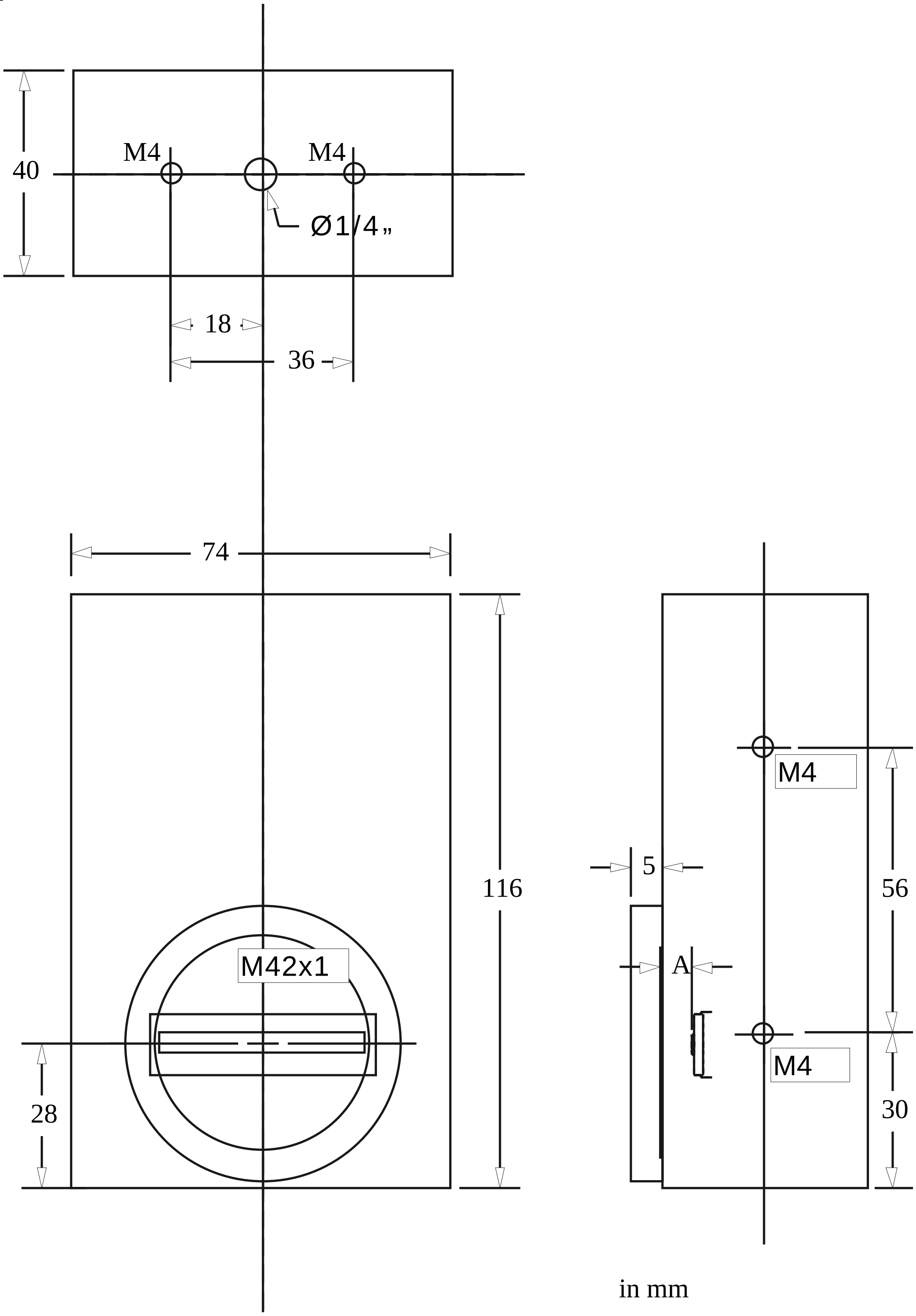
picture-8.11: Clocks for FFT- sensors



The sensor signals VCLK and HCLK were produced internally with the signals NDAC and IFC.

8.6 Dimensions of camera series 2000

picture-8.12: Camera case dimensions

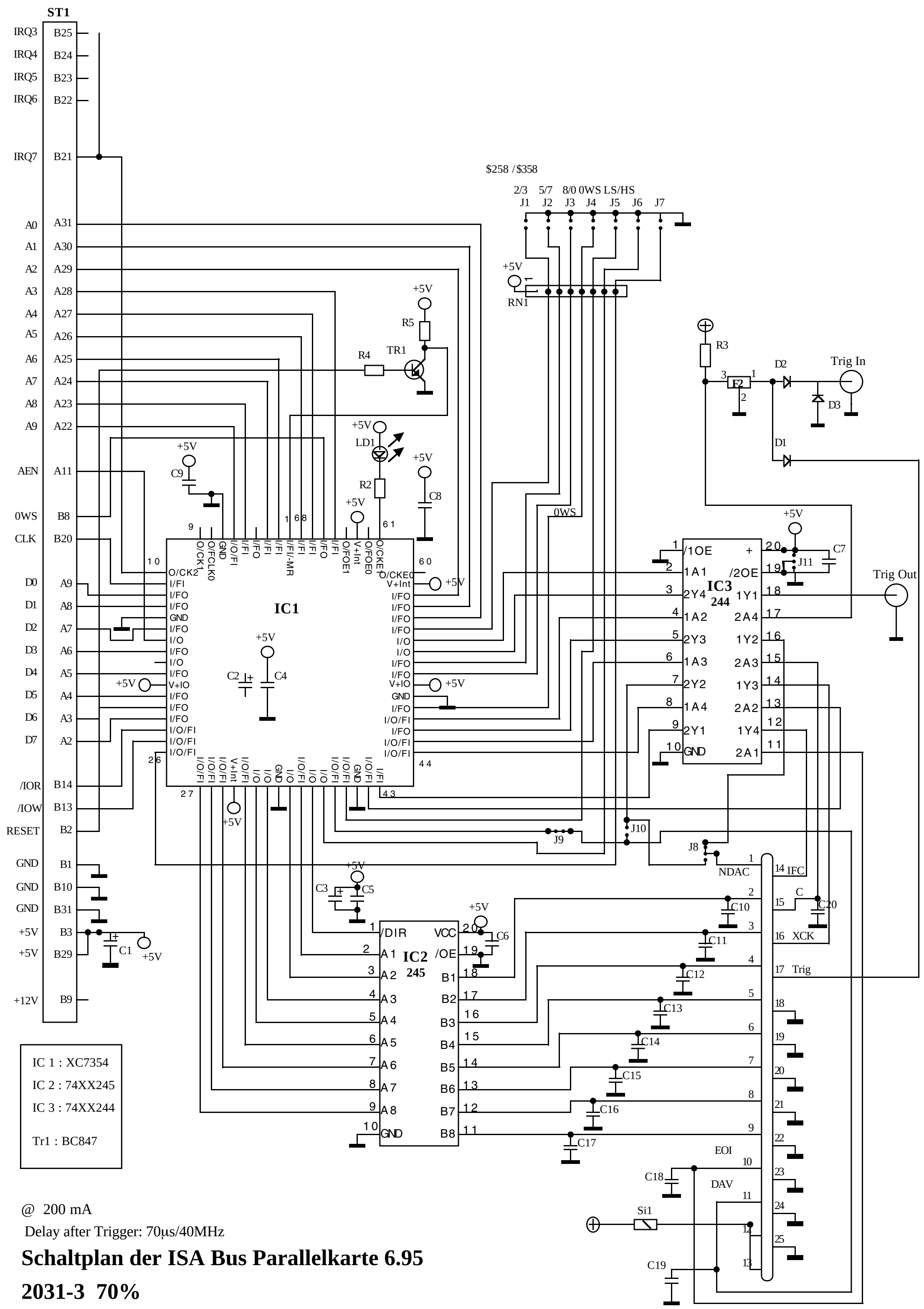


Length A: standard A = 9mm; IR-sensor A = 7mm
Distance window - sensor: standard 1-2mm; IR- sensor 2.55mm

9 Technical Specifications

9.1 ISA Interface board

picture-9.1: Circuit diagram of the ISA interface board



9.2 PCI interface board

picture-9.2: Circuit diagram of the PCI interface board

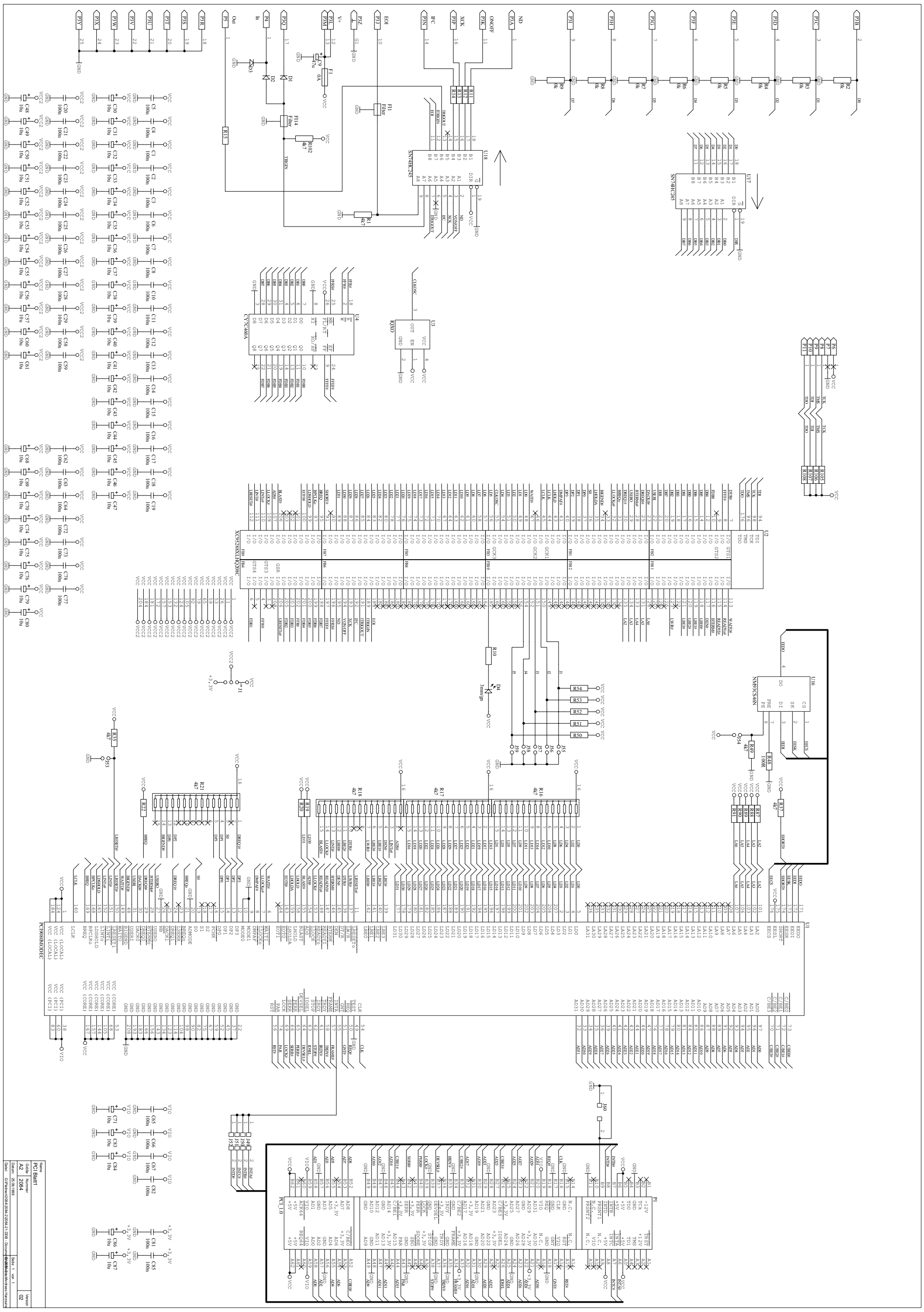


Table 9.1: Pinning of PCI- Interface

Pin	Function	Direction
#1	NDAC	O
#2	D0	I/O
#3	D1	I/O
#4	D2	I/O
#5	D3	I/O
#6	D4	I/O
#7	D5	I/O
#8	D6	I/O
#9	D7	I/O
#10	EOI	I
#11	VON/OFF	O
#12	+5V	Si 750mA
#13	+5V	
#14	IFC	O
#15	-	
#16	XCK	O
#17	ext.Trig.	
#18	GND(C)	
#19	GND	
#20	GND	
#21	GND	
#22	GND	
#23	GND	
#24	GND	
#25	GND S	

The +5V supply current is limited to 750mA by a fuse with automatic reset. Pin #12 and #13 are connected.
All signals have TTL level.
GND(C)=case gnd, GND S=shield

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