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Advanced High-Speed
Digital CCD Line Camera
CCD-S3600-D(-UV)

**High-Sensitivity Linear CCD Array with 3648 Pixels, 16-bit ADC,
32 MB DDR2 RAM, USB 2.0, Trigger Input & Output**

Acquisition & Viewer Software for Windows is now included for FREE!
No LabVIEW license required to run this software.

LabVIEW and **C++** Drivers & Example Applications Included

WHQL Certified Drivers for **Windows 10** / 8.1 / 8.0 / 7 / Vista / XP,
Drivers for Linux, Mac OS X & Other OS

OPERATING MANUAL

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Preface

Thank you very much for purchasing this product. This manual contains information for proper installation and operation. Please read it carefully as well as all additional documentation included before installing and operating the device. In order to obtain optimum performance from this product please follow the instructions. Please note that some photographs or screenshots may slightly differ from your specific product.

Please keep the whole documentation for your records.

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For further information regarding the software included please refer to the README files included with the software.

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1. Getting Started

⚠	**This product is a precision instrument and must be handled with extreme care. Do not drop and do not expose to electrostatic discharges, mechanical shock or rapid temperature changes.**

⚠	**Carefully read the accompanying documentation before installing and operating the device.** **ALPHALAS GmbH is not responsible for any damages to the delivered products or any injury to persons sustained as a result of improper installation or improper usage. If you have any questions regarding installation and operation, please contact us.**

1. Before unpacking the product, inspect the **packaging** for damages due to transportation. If there are any visible damages notify immediately the shipping company and ALPHALAS GmbH. Also check the status of any shock and/or tilt indicators if such indicators are attached. The shipping carrier is responsible for damage in transit.

2. **Do not open the packing box immediately if there is an outside temperature below 15°C (59°F) or if the temperature difference inside/outside is more than 5°C (9°F). In this case let the equipment thermally equalize for at least 24 hours, in order to avoid water condensation.**

3. To avoid damage, **carefully** cut and remove wrapping materials. Remove dumping foam and air bags.

4. **Inspect the equipment** immediately after opening the packaging for mechanical damages, moisture and other visible defects. Notify the shipping company and ALPHALAS GmbH immediately of potential problems.

5. **Save the original packing boxes and packing material.** They will be required if it becomes necessary to reship the equipment for service or repair.

⚠	**Troubleshooting inside the device is prohibited and will void any warranty and support. The device is provided with security labels and can be opened only in ALPHALAS GmbH's production facilities.** **If you cannot solve a problem, please contact the customer service.**

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2.   Quick Installation Instructions

It is extremely easy to install and use our device in any version of Windows:

1. **Plug the CCD device into the USB port**
   Windows will automatically recognize and install the correct certified USB driver. There is no need for manual USB driver installations.

2. **Install the desired software**

   - **Standalone Acquisition & Viewer Software** (no LabVIEW license required):
     Simply launch the Acquisition & Viewer Software installer from the included installation media. The installer already includes the required LabVIEW Run-Time Engine; no additional installation is required.

   - **For LabVIEW developers**:
     The device includes free LabVIEW drivers & applications compatible with ALL versions of LabVIEW since v8.6. If you are a LabVIEW developer simply copy the contents of the included **ALPHALAS CCD S Series** folder into your LabVIEW's **instr.lib** folder. Launch LabVIEW, open the included LabVIEW project and enjoy all ready to use applications or modify them as required to suit your needs.

For more details please refer to other parts of this manual and the readme files on your installation media.

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3. The CCD-S3600-D(-UV): Introduction & Features

3.1. Overview of the CCD Line Camera

The CCD-S3600-D(-UV) is a complete and easy to use high-speed digital CCD line scan camera system with many advanced features. These powerful and unique features include:

- high-sensitivity linear CCD sensor array with 3648 active pixels
- spectral range from 320 nm to 1100 nm or 200 nm to 1100 nm with UV option
- integration time programmable from 10 µs to 1 minute in very precise 1 µs steps (note: to prevent the accumulation of noise in the sensor, always use the shortest possible integration times that are suitable for your application)
- 16-bit precise high-speed analog-to-digital converter (ADC)
- 32 MB high-speed DDR2 RAM for data storage & data buffering
- high-speed USB 2.0 interface
- state-of-the-art FPGA controller optimized for true high-speed parallel operation in hardware
- high-speed electronics
- trigger input & trigger output (with programmable offset) for synchronization from & to external devices (e.g. pulsed lasers), gold-plated SMB connectors
- maximum frame rate of 269.5 frames per second
- multiple modes of operation & precise control
- onboard data storage mode & direct data streaming mode

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- capturing of an unlimited number of subsequent frames with no missing frames at the highest frame rate (only limited by the storage device used)
- many advanced features (e.g. hardware dark correction)
- very compact, lightweight and flexible hardware
- easy plug & play operation and full software control
- no need for an external power supply (powered through the USB cable)
- no need for additional components (no frame grabbers and no data acquisition boards required)
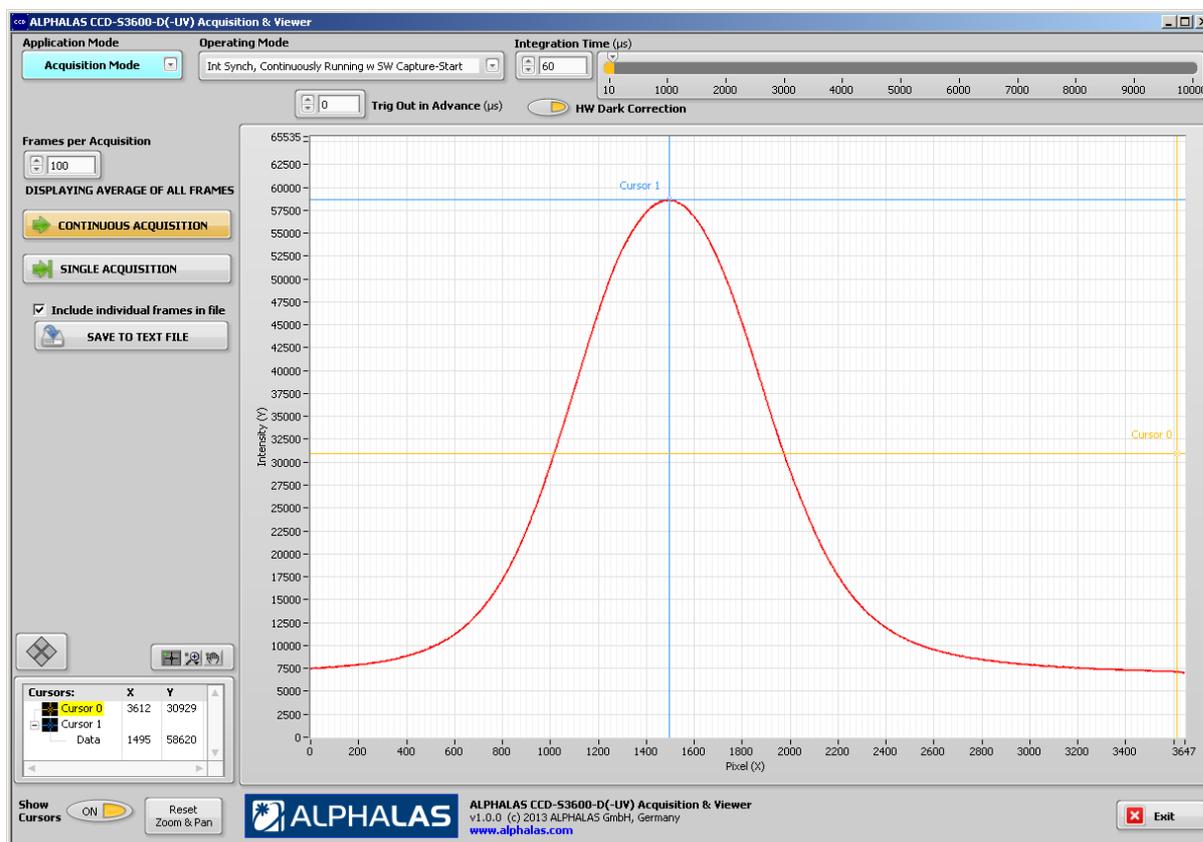
- programmable from many programming languages & software development platforms for unlimited post-processing possibilities
- multi-OS support: Windows, Linux, Mac OS, etc.
- free & ready-to-use LabVIEW drivers, fully-functional GUI applications and examples supporting LabVIEW for Windows, Linux and Mac OS X
- free USB drivers from FTDI supporting all major hardware platforms and operating systems: Windows, Linux, Mac OS X, etc.
- fully automated driver installation on operating systems like Windows allowing true plug & play without any need for manual driver installation, because the certified USB driver is already included in these OS
- **NEW: free, easy & ready to use Acquisition & Viewer Software for Windows** (does NOT require a LabVIEW license)

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- free C++ source cross-platform code demonstrating the device in use; for Microsoft Visual C++ for Windows as well as GCC for Linux, Mac OS X, etc.
- free high-level USB interfacing libraries from FTDI for Windows (.dll), Linux (.so), Mac OS X (.dylib), etc.
- ideal for science, research, education & OEM applications
- ideal for mobile / notebook / laptop as well as desktop use

3.2. Fields of Application

Fields of application for the CCD-S3600-D(-UV) include but are not limited to various science & research areas (e.g. physics, chemistry, biology, biomedicine, medicine), lasers, optics, photonics, spectroscopy, measurements (e.g. light, fluorescence, M², beam profile, single-shot autocorrelators), imaging, data acquisition, machine vision, monitoring, process control, OEM applications (e.g. industrial) and education. The device represents a cost-effective solution for the above applications. Please note that the device is *not* intended for use on human beings and must *not* be used in critical applications. Always observe the applicable safety requirements, especially when working with devices like lasers.

The CCD camera is suitable for desktop applications as well as notebook / laptop and mobile measurement applications. It can be used to capture images at a high optical resolution in 1-D and even in 2-D (by parallel moving of the CCD or the light source).

3.3. Ease of Use vs. Advanced Features

We have designed the CCD-S3600-D(-UV) to combine ease of use with unique and powerful advanced features. The device can be used by both types of customers:
- **novice users** who need to simply acquire light intensity data
- **advanced users and experts** who want to "squeeze out" each of the unique powerful features of the CCD device

3.3.1. Ease of Use for the Novice User

If you are a **novice user** you will probably just want to acquire light intensity data. In this case it is only required to set up the integration time, i.e. for how long the sensor will collect light during a scan. And that's all you need to start with data acquisition. Optionally, you may also want to choose how many scans you want to collect. There is no need to understand all details of CCD operation or the advanced operating modes in order to use the device for such basic tasks. You can just leave all advanced settings at their default values. Immediately get started with the **free, easy & ready to use Acquisition & Viewer Software for Windows** (does NOT require a LabVIEW license). If you would like to start developing your own application, a good starting point are the included LabVIEW and C++ examples and applications.

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3.3.2. Unique & Powerful Features for the Advanced User

If you are an **advanced user** you will probably want to make use of all advanced features of the device. Those features include:

- **Five CCD operating modes**: Three internally synchronized modes with software capture start, hardware capture start, hardware capture enable; a special single shot mode and an external synchronization mode
- Integration time and other timing parameters can be set in very precise **1 µs steps**
- The **external trigger** input can be used to trigger a complete acquisition or to trigger the capture of single frames selectively
- In **external synchronization** mode the external trigger input is used to synchronize all frames and to define their integration time
- Automatic **hardware dark correction** can be enabled if desired
- The device can give feedback through the trigger output when the next integration period will exactly begin (even a couple of µs in advance if desired); this way the user can **trigger external devices from the CCD**
- The trigger input and the trigger output can be even used in combination to trigger the CCD from an external source and use the CCD trigger output to trigger another external device (e.g. pulsed laser) at the same time. This **dual-triggering** setup is extremely powerful and unique and allows the user to capture very short pulses at short integration times. Complex synchronization schemes can be easily achieved.
- An **unlimited number of subsequent frames** can be streamed directly to the hard drive of the host computer; this is needed if the large onboard frame storage of 32 MB (4599 frames) is not enough for your needs

If you are an expert, you will be probably also interested in how the device works "under the hood", e.g. how the integration time defines frame duration and frame rate. Or maybe you want to program the device yourself from your favorite programming language? For all of those advanced use cases you will find useful information and hints in the next chapters of this manual. Also refer to the free LabVIEW and C++ applications included with the camera for working examples.

3.4. Features of the CCD Line Camera

The main hardware components of the CCD-S3600-D(-UV) line scan camera are (see also Figure 3-1):

- CCD (charge-coupled device) sensor with 3648 active pixels
- Main CCD controller FPGA
- 16-bit precise analog-to-digital converter (ADC)
- Large 32 MB DDR2 onboard memory for data storage / buffering
- USB 2.0 controller for the PC interface
- Trigger input and trigger output

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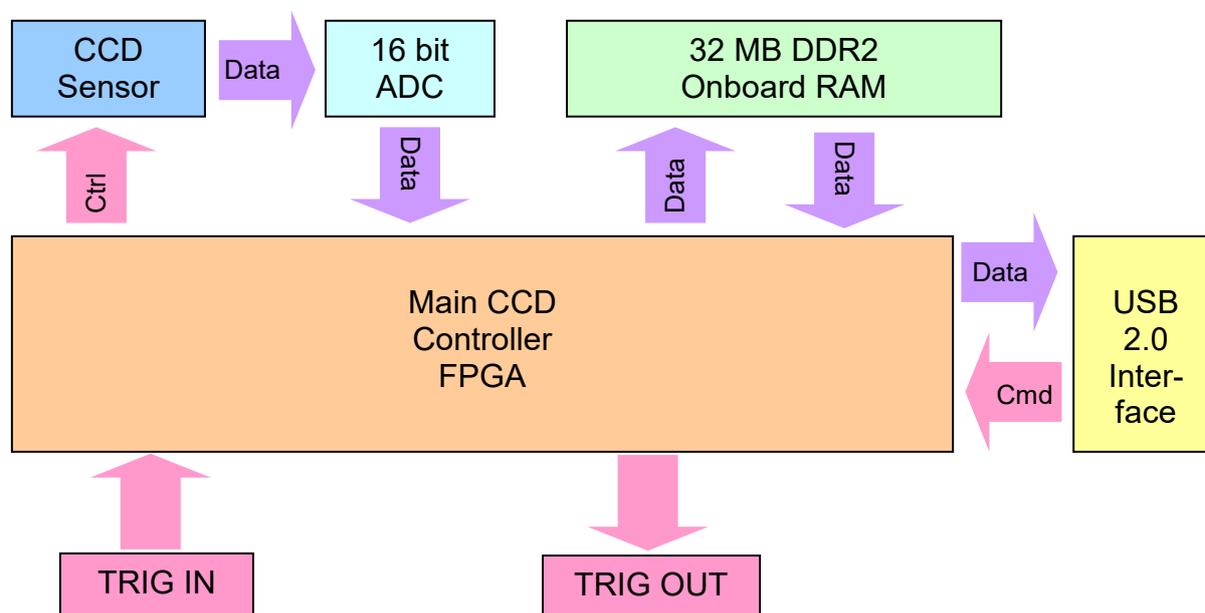
Figure 3-1: Simplified Block Diagram of the CCD-S3600-D(-UV)

The CCD-S3600-D(-UV) features a **high-sensitivity linear CCD sensor** array with a large number of pixels (3648 active pixels), high optical resolution, wide spectral range from 320 nm to 1100 nm or 200 nm to 1100 nm with UV option as well as wide dynamic range.

The whole CCD line camera is controlled by an **advanced hardware controller** implemented in state-of-the-art FPGA technology, optimized for true high-speed parallel operation in hardware. FPGA technology has many benefits over microcontroller-based solutions used by other companies.

Sensor data is sampled using a high-end fast **analog-to-digital converter (ADC)** with precise **16-bit resolution** delivering 65536 possible intensity values for each CCD pixel.

For maximum flexibility, all parameters are **fully programmable** at runtime through software commands.

The **integration time** can be set in very precise 1 microsecond (µs) = 0.001 millisecond (ms) steps and it is programmable in the extremely wide range from 10 µs to one minute. This range applies to internal as well as external synchronization. In internal synchronization mode the internal timing module of the camera specifies the integration time. In external synchronization mode the external trigger signal provided by the user determines the integration time.
To prevent the accumulation of noise in the sensor, always use the shortest possible integration times that are suitable for your application.

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The device features **high frame rates** of up to 269.5 Hz with no missing frames. As with all CCD sensors, the actual frame rate depends on the set integration time. There are two data storage modes: In the default mode, the device uses the large **32 MB DDR2 RAM for onboard storage** of up to 4599 frames during an acquisition; these frames can be fetched later by the host PC. The second mode is unique and allows the device to **stream an unlimited number of frames directly to the host PC**. This can continue for an unlimited amount of time, at the highest frame rate and again *without* any missing frames, being only limited by the storage device used. In addition, this sophisticated technology uses the **32 MB DDR2 RAM to buffer frames** for up to 17 seconds (at the highest frame rate), before the host PC fetches that data. This enables reliable data streaming, even if the PC operating system becomes busy for some time. The extremely large 32 MB of high-speed RAM and the streaming mode are unique features that allow the user to capture an unlimited amount of subsequent frames back-to-back with no missing frames. In contrast, other manufactures offer just a few KB of RAM for frame storage on their devices.

The CCD line camera features **five different main operating modes** allowing internal or external frame synchronization, as well as internal or external triggering. Each of the five operating modes can be used together with onboard data storage mode as well as advanced data streaming mode.

The SMB **trigger input** (gold-plated) can be used to trigger or to synchronize the CCD line camera from external devices. Depending on the selected operating mode, the trigger input is the acquisition start signal, the selective frame capture enable signal, the single shot trigger or the external synchronization signal.

The SMB **trigger output** (gold-plated) can be used to trigger or synchronize external devices from the CCD line camera (with 500 ns resolution). In most operating modes, this signal indicates to the user when the integration period in a frame actually begins.

A **trig out before integration offset** can be also programmed to let external devices "know" in advance, when integration will actually start. The trigger output can be even used in combination with the trigger input in order to trigger external devices and to solve complex synchronization tasks between the CCD and other devices.

The automatic **onboard hardware dark correction** makes use of the optical black pixels of the sensor and features temperature adaptability. It can be turned on or off at any time as required by the user.

Although the CCD-S3600-D(-UV) includes so many advanced features, it is **very compact** and **lightweight**. Only **modern highly-integrated, high-speed, low-power hardware components** from industry leading manufacturers have been implemented. The device contains **no moving parts**.

No external power supply is needed; power is provided **through the USB cable** for true single-cable plug & play operation. This makes the CCD camera ideal for mobile and notebook applications.
The high-speed **USB 2.0** (480 Mbit/s) interface connects the CCD-S3600-D(-UV) to the host computer. The USB controller is a dual-channel high-speed USB 2.0 chip from the industry leader FTDI (www.ftdichip.com).

Multi-OS support is a key feature in today's rapidly changing computer environments. For maximum compatibility at the USB level, the CCD camera uses the **original FTDI D2XX USB drivers** which are available free of charge and support **all major operating systems** including future Microsoft **Windows** versions as well as **Linux**, Apple's **Mac OS X** and Microsoft's **Windows CE**. Both, **64-bit and 32-bit** operating systems are supported. Windows drivers also feature Windows Hardware Quality Labs (**WHQL**) certification. On operating systems like Windows the driver is provided by the OS through Windows Update and installation is done **automatically by the OS without the need for manual driver installation** allowing true plug & play operation. The company FTDI is constantly updating the drivers to support new operating systems. For an updated list of operating systems compatible with the latest FTDI drivers, please see the FTDI web site (www.ftdichip.com).

The CCD-S3600-D(-UV) can be programmed and controlled through various programming languages and software development platforms like **LabVIEW, Visual C++, GCC C++, C++ Builder, C#, Delphi, Visual Basic, Java, LabWindows/CVI, Perl, Python**, etc. Because of this large variety of programming languages and platforms, ALPHALAS cannot support all of them directly, but customers can always refer to the provided LabVIEW and C++ examples as well as the multiple programming examples and documentation on the FTDI web site for more information on their favorite programming language and platform.

Fully functional LabVIEW drivers, GUI applications and examples are included with the CCD-S3600-D(-UV) free of charge. The LabVIEW drivers have been developed according to the National Instruments driver guidelines. LabVIEW versions 8.6 and later are supported; for older versions please contact ALPHALAS. LabVIEW for Windows, Linux and Mac OS X is supported. The applications and examples include full data acquisition and data streaming applications. Additional examples demonstrate Gaussian fit, FWHM, 3D graph visualization, etc. Even examples for simultaneous acquisition with multiple line cameras connected to the same host computer are included for free.

Fully functional free C++ source code is provided, demonstrating the CCD-S3600-D(-UV) in use. A complete project for **Microsoft Visual C++** for Windows is included. This project is also compatible with the free Express edition of Visual C++. The *same* C++ source code can be also compiled directly with **GCC** (GNU Compiler Collection) for Linux, Mac OS X, etc. This application demonstrates that cross-platform development and access to the CCD device is possible.

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The FTDI D2XX USB drivers include free **high-level USB interfacing libraries** for Windows (.dll), Linux (.so), Mac OS X (.dylib), etc. Communication to the onboard USB 2.0 controller can be established through simple **library function calls**. The driver's library interface hides all complex details of low-level USB communication (e.g. endpoints, descriptors, synchronization, etc.).

The CCD line camera is ideally suited for **OEM applications**. On the one hand, this is achieved by the compact and flexible hardware. On the other hand, this is achieved by the underlying flexible and open software development concept. Many companies modify USB drivers just to make their devices show up with a customized manufacturer's name. In contrast, ALPHALAS does *not* modify the original FTDI USB drivers. The benefit is that the device uses the standard widely used and certified drivers with the standard FTDI VID (vendor ID) & PID (product ID) and consequently ensures compatibility with all operating systems and programming languages supported by the driver **out of the box**. The customer also benefits from **all future free driver updates** and **new operating system support** from the industry leader FTDI. An additional benefit is that the device can be interfaced and programmed directly through all supported programming languages. It is not tied to some proprietary software package as this is the case with other manufacturers. This distinctive flexibility makes the CCD-S3600-D(-UV) ideally suited for research and OEM applications in diverse IT environments and also guarantees compatibility with future operating systems, hardware and software platforms.

Unlimited post-processing possibilities can be applied to the acquired data when using additional software packages like LabVIEW, MATLAB, Origin, Mathcad, etc. Instead of limiting the possibilities to a manufacturer's proprietary software package, this approach guarantees maximum flexibility for the customer's application and is especially important for research and OEM applications: Captured data can be processed by the user's own application without limitations. Post-processing can include **averaging, binning, accumulation, reference subtraction (all with floating point accuracy), noise removal, smoothing, function fitting and peak finding can be applied, data can be reviewed, zoomed in or out, printed, exported, converted to graphics, etc**. On a powerful PC with lots of memory much better post-processing can be performed than in hardware on the CCD camera itself. Data can be simply stored after acquisition and can be loaded later for further processing. Post-processing functionality is limited only by the capabilities of the user's software package. Any custom function can be applied to the acquired data.

The **signal-to-noise (SNR) can be improved (i.e. increased) by averaging multiple subsequent scans**. The SNR improves by the square root of the number of averaged scans. For example, the SNR improves by a factor of 10 when 100 scans are averaged. Averaging has been already built into the LabVIEW drivers and can be used if desired.

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Please note that SNR will decrease with longer integration times, such behavior is normal for any CCD sensor. To prevent the accumulation of noise in the sensor, always use the shortest possible integration times that are suitable for your application.

SNR will improve with lower ambient temperatures.

Multiple CCD line cameras are supported on a single host computer. This allows the user to connect more than one device and acquire data from all devices simultaneously. An example application for LabVIEW is provided.

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4. Specifications

4.1. Detailed Specifications

Please note: All specifications are typical at 25 °C unless otherwise stated. All specifications in this manual are subject to change without notice. No responsibility for typing or printing errors. All trademarks are the property of their respective owners.

Parameters	Specifications	Notes
Sensor Type	High-Sensitivity Linear CCD Array	Large number of pixels, high optical resolution and wide spectral ranges.
Active Sensor Pixels	3648 pixels	
Total Sensor Pixels	3694 pixels	Include optical black (light shielded) pixels and dummy pixels.
Size of Sensor Pixels (W x H)	8 µm x 200 µm	The sensor features vertically elongated pixels for high sensitivity.
Active Length of Sensor	3648 x 8 µm = 29.184 mm	
Spectral Range (typ.)	• 200 nm - 1100 nm with UV option • 320 nm - 1100 nm without UV option	The UV option must be ordered explicitly.
Dynamic Range (typ.)	1000 : 1	
Signal-to-Noise Ratio without Averaging (typ. for short integration times)	300 : 1	Can be greatly increased by signal averaging. To prevent the accumulation of noise in the sensor, always use the shortest possible integration times that are suitable for your application.
Sensitivity (V/(lx*s)) (typ.)	160	High sensitivity CCD sensor.
Integration Time (T_{int})	10 µs – 1 minute, programmable in precise 1 µs (0.001 ms) steps	The integration time is controllable in an extremely wide range and in very precise steps. The same wide range is also usable with external synchronization triggering. To prevent the accumulation of noise in the sensor, always use the shortest possible integration times that are suitable for your application.
Frame Rate	Max. 269.5 Hz (frames/s) constant frame rate, corresponds to a minimum frame duration of 3710 µs (3.71 ms)	The frame rate depends on the set integration time. In streaming mode a constant frame rate without any missing frames can be achieved for an **unlimited** time.
Sensor Readout Time	3710 µs (3.71 ms)	This time is specified by the sensor.
Sensor Modes	Shutter Mode for T_{int} < 3710 µs Non-Shutter Mode for T_{int} ≥ 3710 µs	The CCD camera **automatically** uses the correct sensor mode.
Trigger Input	Yes	External devices can trigger the CCD.
Trigger Output	Yes	The CCD can trigger external devices.

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Analog-to-Digital Converter (ADC)	16-bit ADC	Industry-leading ADC, high-speed, high-precision, low-noise, low-power
Bits per Pixel	16 bits / pixel	
Saturation Levels per Pixel	65536	
Pixel Output Speed	1 MHz (1 µs / pixel)	
Readout Data Rate: Sensor to internal RAM	2 MBytes / s	
On-Board Memory	256 Mbits (32 MBytes) High-Speed DDR2 RAM @ 266 MHz	The extremely large high-end DDR2 RAM runs at 266 MHz and is used for onboard data storage as well as for buffering in data streaming mode.
Data Acquisition Modes	• **Onboard data storage** mode (PC can fetch data later when free) • **Data Streaming** Mode (PC fetches data immediately, number of frames is not limited by the onboard RAM)	The **unique data streaming mode** allows the user to stream an unlimited amount of data to the PC at the highest frame rate without any missed frames. The only constraint is the data storage device (e.g. PC hard drive).
Onboard Data Storage	Up to 4599 frames can be captured, before fetching any of them.	The CCD can store up to 4599 frames onboard (approx. 17 s at the highest frame rate), before the PC fetches them. For <u>unlimited</u> number of captured frames see data streaming mode.
Data Streaming	<u>Unlimited</u> number of frames can be streamed to the PC in this mode. The large RAM is used as a FIFO frame buffer.	This mode allows capturing of an <u>unlimited</u> number of frames in real-time and streaming them directly to the PC's hard drive. The onboard RAM is used as a big buffer in this mode.
Continuous Frame Capture at Highest Frame Rate without Any Missing Frames	• <u>UNLIMITED</u> number of frames & capture time in data streaming mode • 4599 frames in onboard storage mode	Unique streaming technology with 32 MB RAM can buffer up to 17 s at the highest frame rate. This allows the PC to fetch the data on time.
Trigger Types	**Internal** & **External** Triggering	Can be also used in combination.
Main Operating Modes	**Five main operating modes:** 1. Internally synchronized, continuously running, with software capture start 2. Internally synchronized, continuously running, with hardware capture start 3. Internally synchronized, continuously running, with hardware capture enable 4. Single-shot with external hardware trigger (sensor is kept clean & ready), usable for T_{int} up to 500 µs 5. Externally synchronized, continuously running, with software capture start	Each operating mode is usable in onboard data storage mode as well as data streaming mode

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External Trigger Input	Yes, gold-plated SMB connector. Used in the different operating modes as capture start, capture enable, single-shot trigger or synchronization trigger.	TTL, max. + 5 V (rising edge). Note: To be able to also capture short signals, the input signals are stretched by ~ 50 ns. The minimum trigger pulse width is ~ 8 ns.
External Trigger Output	Yes, gold-plated SMB connector. Used for synchronization of external devices. In most operating modes this signal indicates when the integration in a frame actually begins. In external synchronization mode this signal indicates when the integration in a frame ends.	TTL, + 5 V (rising edge). This signal is high for 500 ns. This means that external devices can be triggered with a resolution of 0.5 μs when triggering on the rising or falling edge. Trigger output be enabled / disabled by the user since firmware A1.10.
User-Definable Offset for Trigger Output Before Integration Starts	Yes, for short integration times when the sensor is in shutter mode. Programmable at runtime in the range from 0 μs to 1849 μs.	Very useful for exact synchronization of external devices (e.g. pulsed lasers).
Main CCD Controller Hardware	Industry-leading Xilinx FPGA for precise concurrent hardware control	
Full Programmability	Yes, all parameters are fully programmable at runtime through software commands.	
Onboard Signal Conditioning	Yes	
Onboard Dark Correction in Hardware	Yes, with temperature adaptability.	Can be activated by the user at any time.
PC Interface	High-Speed USB 2.0 (480 Mb/s)	USB Type B Connector on device side.
Onboard USB 2.0 Hardware	Industry-leading FTDI dual-channel high-speed USB 2.0 controller with FIFO buffers	
USB Bus Powered	Yes, no external power supply required.	Ideal for mobile & notebook applications.
Package Features	Very compact, no moving parts.	Ideal for mobile & notebook applications.
Plug & Play	Yes, plug & play operation.	Ideal for mobile & notebook applications.
OEM	Yes, ideal for OEM applications.	Very compact. Uses standard FTDI drivers & libraries. Multi-OS support.
USB Drivers & Libraries Included	Yes, **FREE**! Original FTDI drivers & libraries for high-level USB interfacing from multiple programming languages for Windows (.dll), Linux (.so) and Mac OS X (.dylib). WHQL certified.	FTDI D2XX drivers support all major operating systems & are constantly updated. Application software can access the USB device through simple high-level library function calls. No need to handle any low-level details of USB operation.
LabVIEW Drivers, GUI Applications & Examples Included	Yes, **FREE**! For LabVIEW 8.6 and later. Support LabVIEW for Windows, Linux and Mac OS. Compliant with NI driver guidelines.	Drivers, GUI applications and examples for data acquisition, data streaming, Gaussian fit, FWHM, 3D graph visualization, etc.
C++ Examples	Yes, **FREE**! Visual C++ project & GCC C++ files. Source code can be compiled under Windows, Linux and Mac OS X.	Well-commended source code demonstrates cross-platform access to the CCD device. Visual C++ Express is also supported.

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Post-Processing Possibilities with Additional Software Packages	**Unlimited**, using your favorite software package, e.g. LabVIEW, MATLAB, Origin, Mathcad, etc.	The captured data can be further processed using floating point accuracy (averaging, binning, accumulation, reference subtraction), noise can be removed, data can be reviewed, printed, exported, etc. This functionality is defined by the capabilities of your software package.
Programming Languages for Programming and Controlling the CCD	LabVIEW, Visual C++, GCC C++, C++ Builder, C#, Delphi, Visual Basic, Java, LabWindows/CVI, Perl, Python, etc.	The large variety of languages is not directly supported by ALPHALAS. Please refer to the programming examples on the FTDI web site (www.ftdichip.com) for more information.
Operating Systems Supported by the FTDI Device Driver	Microsoft **Windows** (8.x, 7, Vista, XP, Server, etc.), **Linux** (e.g. Ubuntu, openSUSE, Debian, etc.), Apple **Mac OS** X, Microsoft Windows CE 4.2-5.2 & CE 6.0. **32-bit & 64-bit OS are supported.**	Windows Hardware Quality Labs (WHQL) certification. Fully automatic driver installation on plug-in through Windows Update. For an updated list of new operating systems compatible with the FTDI drivers, please see the FTDI web site (www.ftdichip.com).
Multi-Camera Support	Yes, multiple CCD line cameras are supported on the same host computer.	This allows the user to connect more than one CCD line camera and acquire data from all devices simultaneously. A LabVIEW example application is provided.
Visual Indicators	Power LED, Error LED	The Error LED will signal an internal buffer overflow in data streaming mode.
Host PC Hardware Requirements	Modern PC or Notebook (e.g. Intel Core CPU), 2 GB of RAM or more, USB 2.0, enough hard drive space if data streaming will be used.	The device should also run without problems on slower hardware.
Power-Up Time (Typ.)	< 1 s	
Operating Temperature	0°C to 40°C (non-condensing)	Lower temperatures may reduce sensor noise.
Storage Temperature	-20°C to 60°C	
Relative Humidity	0% to 80%, non-condensing	
Physical Dimensions (W x H x D)	~ 90 x 25 x 105 mm See mechanical drawing.	Very compact size.
Weight	~ 165 g	Very lightweight.

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4.2.   Spectral Sensitivity

Normalized Spectral Sensitivity (Typ.) (T_a = 25°C)
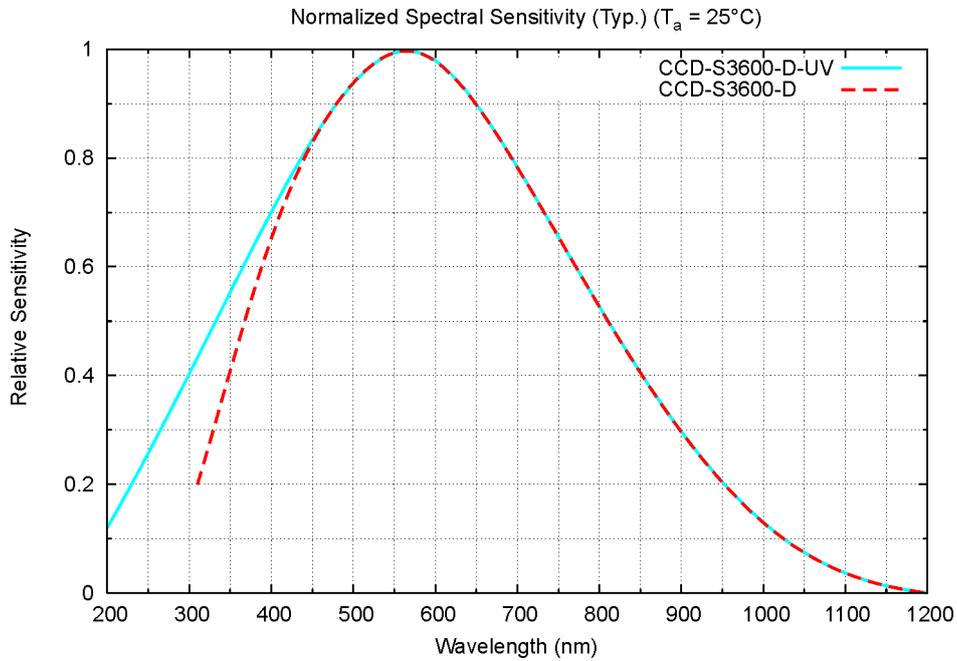
Figure 4-1: Spectral Sensitivity Chart

4.3.   Connectors and Indicators on the Rear Panel

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4.4. Mechanical Drawing

RevNo	Revision note	All dimensions are in mm	Date	Signature	Checked

USB Type B Connector

Mounting Holes Ø3mm

SMB Connectors

12.5

25

80

90

2.5

104.5

109.5

69,1

Itemref	Quantity	Title/Name, designation, material, dimension etc		Article No./Reference	
Drawn by JK		Checked by	Approved by - date	File name	Date 27.09. 2011	Scale

NO PART OF THIS DRAWING MAY BE REPRODUCED OR TRANSMITTED IN ANY FORM OR BY ANY MEANS INCLUDING PHOTOCOPYING OR RECORDING WITHOUT THE PRIOR WRITTEN PERMISSION OF ALPHALAS GMBH

Digital CCD Line Camera with USB 2.0 Interface
Model: CCD-S3600-D(-UV)

ALPHALAS GmbH
Göttingen, Germany

| Edition 1.2 | Sheet 1/1 |

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5. Description of Operation

5.1. Overview of CCD Operation

5.1.1. Collecting Light & Data Flow in the CCD-S3600-D(-UV)

The CCD line sensor contains a photoactive region which is a linear array of individual pixels. These pixels are sensitive to light and accumulate electric charges which are proportional to the light intensity and the light exposure time. Those charges are converted to digital light intensity values through the analog-to-digital converter (ADC). As soon as an acquisition has been initiated by the host PC, the acquired data is stored in onboard RAM and finally sent to the PC through USB (see Figure 5-1).
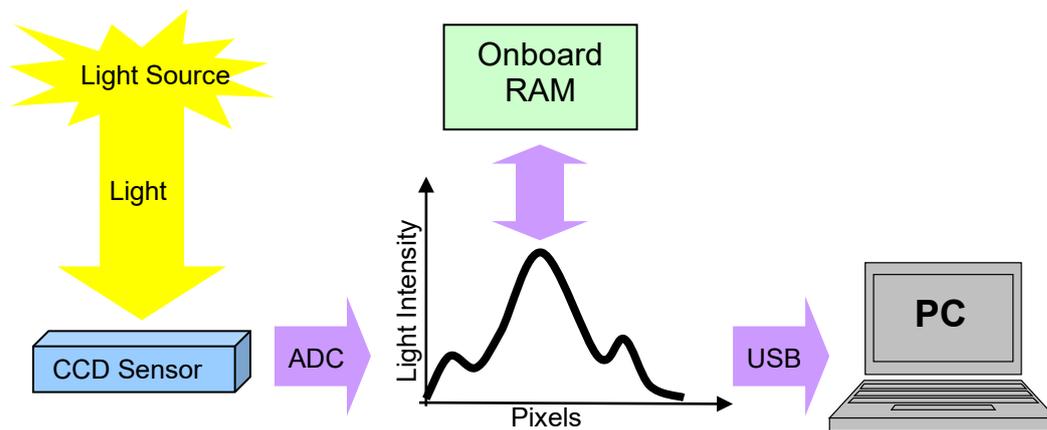
Figure 5-1: CCD Collecting Light and CCD Data Flow

5.1.2. Sensor Pixels

The CCD sensor consists of a large number of optical active pixels which collect usable light intensity information. The 3648 optical active pixels are situated in the *middle* of the sensor. At the beginning and at the end of the CCD sensor there is a small amount of dummy pixels. Most of the dummy pixels do not deliver usable information; only the optical black (light-shielded) pixels are used as a reference for dark correction. See Figure 5-2.

32 dummy pixels, including 13 optical black (light-shielded) pixels

3648 OPTICAL ACTIVE PIXELS: The intensity values of these pixels represent the usable data from the CCD. The first active pixel is designated as pixel 0, the last active pixel is designated as pixel 3647.

14 dummy pixels

3648 Active CCD Sensor Pixels

Pixel 0

Pixel 3647

Total Number of CCD Sensor Pixels (Active + Dummy) = 3694

Figure 5-2: Pixels on the CCD Sensor

5.1.3. Exposure to Light and Integration Time

When the CCD sensor is exposed to light, this light causes each pixel to act as an accumulator of electric charge proportional to the light intensity and the time of exposure at that pixel (see Figure 5-3).

Light Source

Light Intensity

Pixels

3648 Active CCD Sensor Pixels
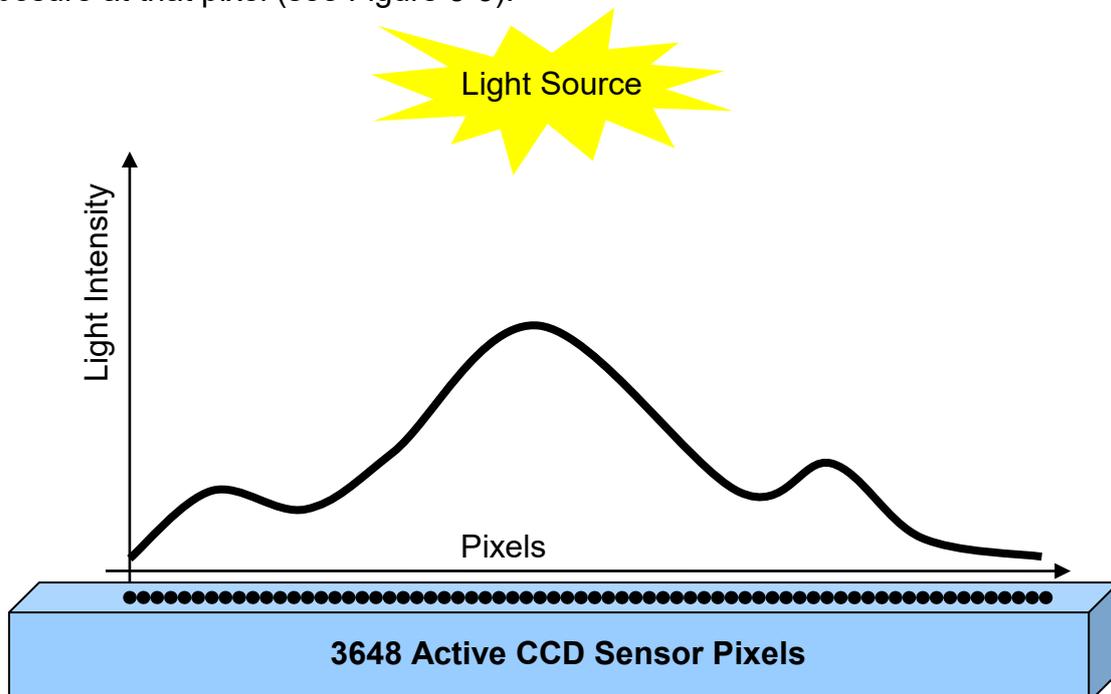
Figure 5-3: CCD Sensor Collecting Light

The converted into voltage light intensity values from each active pixel are then converted to digital data and sent to the PC. One set of light intensity data is often described as a **frame**, scan or readout.

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As mentioned above, the voltage equivalent of the collected light also depends on the **time of exposure** to light. In order to define for how long the pixels of the CCD sensor will be exposed to light and accumulate charges, the **integration time** (T_{int}) must be specified.

Integration Time (T_{int}):
The integration time defines (in µs) for how long the sensor accumulates charges during a frame when exposed to light.

For very high integration times the pixels may collect too much light, become overexposed and saturated; they will then contain maximum digital intensity values (see Figure 5-4).
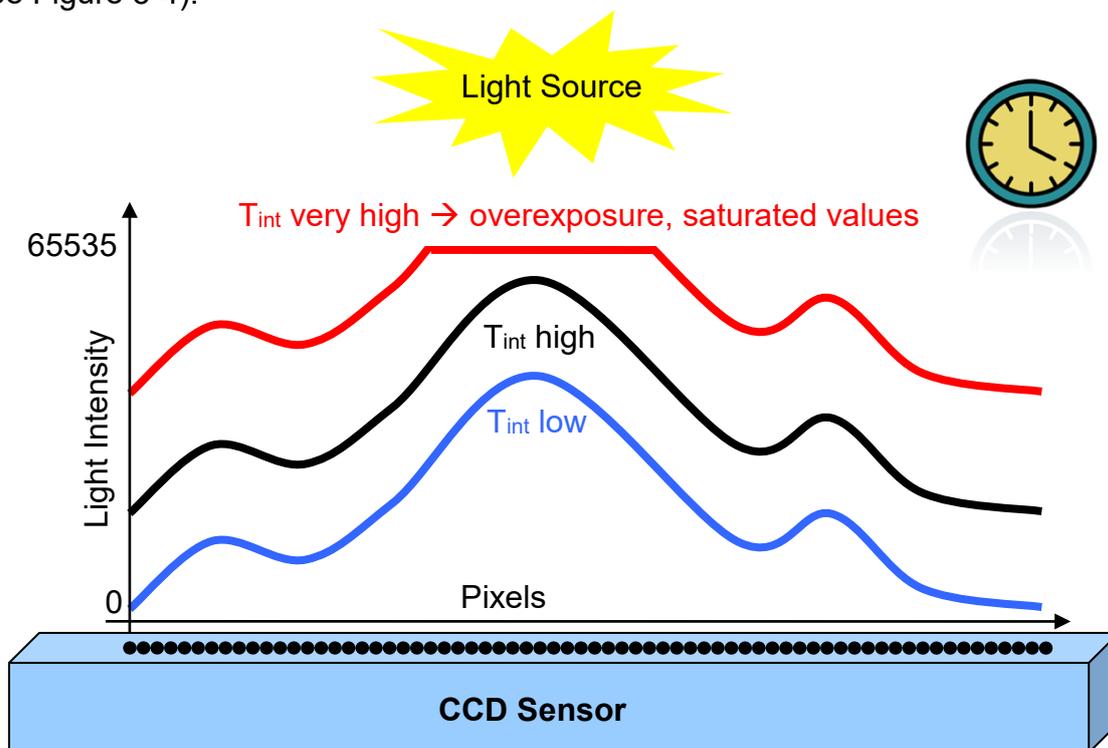
Figure 5-4: Integration Time and Overexposure

Overexposure should be avoided. If the sensor becomes overexposed, it may deliver incorrect intensity data, also in regions that are not overexposed. This is because excess charges from over-saturated pixels may propagate into adjacent pixels (blooming) or even the next frames. Therefore, make sure that the signal level stays below approx. 85% of the full digital range, i.e. 85% from 65535 ≈ 55705.

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5.1.4. Attenuation of Light

The CCD camera has been calibrated to work with the shortest possible integration times (down to 10 µs). This means that the CCD sensor will quickly become saturated when longer integration times are used. However, this is no big problem as light can be attenuated before it reaches the sensor.

This **attenuation** can be achieved by using an **optical filter** or a **polarizer** in case the light source is polarized. In the latter case, a combination of a **polarizer and a half wave plate** can be also used. This method offers the advantage of continuous adjustment of the light intensity from zero to maximum.
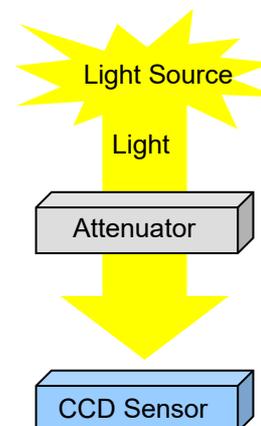
Figure 5-5: Light Attenuation

5.1.5. Damage Threshold of the CCD Sensor

Especially when working with powerful laser sources, care must be taken to prevent damage to the CCD sensor. Unfortunately, the manufacturers of CCD sensors do not provide exact data about damage thresholds. However, one thing is clear:

> **The sensor will become saturated far earlier then the damage threshold is reached.**

Therefore, the following rules should be followed:

> **Never shoot directly with a laser onto the sensitive area of the CCD.**
>
> **The best way to work safely with the sensor is to start with a strong attenuation of the light source and gradually decrease it until a good signal is achieved.**
>
> **Remember that increasing the integration time may lead to earlier saturation of the signal.**

From a general point of view, power of more than 1 W/cm^2 CW and pulse energy of 0.1 µJ/cm^2 (at 10 ns) must be avoided. But as stated before, with these values the sensor will be already heavily oversaturated.

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5.1.6. Integration Time vs Sensor Noise

To prevent the accumulation of noise in the sensor, always use the shortest possible integration times that are suitable for your application. For example, with a pulsed laser if an integration time of 50 µs is sufficient to catch the laser pulse in a frame, do not use longer integration times, as they would just increase the noise.

5.1.7. Sensor Temperature

All CCD sensors are sensitive to temperature. Lower ambient temperatures will reduce noise. Especially for long-term measurements the device should be connected for approximately 10 minutes before starting the measurement and the ambient temperature should be kept constant during the measurement.

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5.1.8. Frames, Sensor Readout and Continuously Running Frame Integration

So far, we have considered only the **integration** of a *single* frame (also called scan or readout). Charges proportional to the light intensity as well as to the exposure time have been collected in the sensor as soon as the integration of that frame is complete; but these charges *still* have *not* been read out from the sensor. This sensor readout has to be done *after* integration of the current frame has finished. As soon as the integration for one such **frame is complete**, the **charges from all pixels** are first **transferred at once into a transmission region** on the sensor – the **analog shift register**. From there, the sensor will output them one by one and they can be sampled by the analog-to-digital converter (ADC), then stored in onboard RAM as digital values and finally transferred to the PC (again refer to Figure 3-1 and Figure 5-1).

Typically, the CCD operates in such a way that it does **not** integrate single frames only and does **not** have to "wait" for them to be read out before starting a new frame. Instead, it **continuously** integrates frames back-to-back. While the charges from the previous frame are being read out, the CCD-S3600-D(-UV) can already integrate the next frame, i.e. the sensor again starts to collect light. This has the advantage that the pixel charges collected during the **last** frame can be read out from the sensor and saved while the **next frame** is being integrated **in parallel**. This allows continuous acquisition of multiple frames back-to-back with **no dead time between frames**. See Figure 5-6.
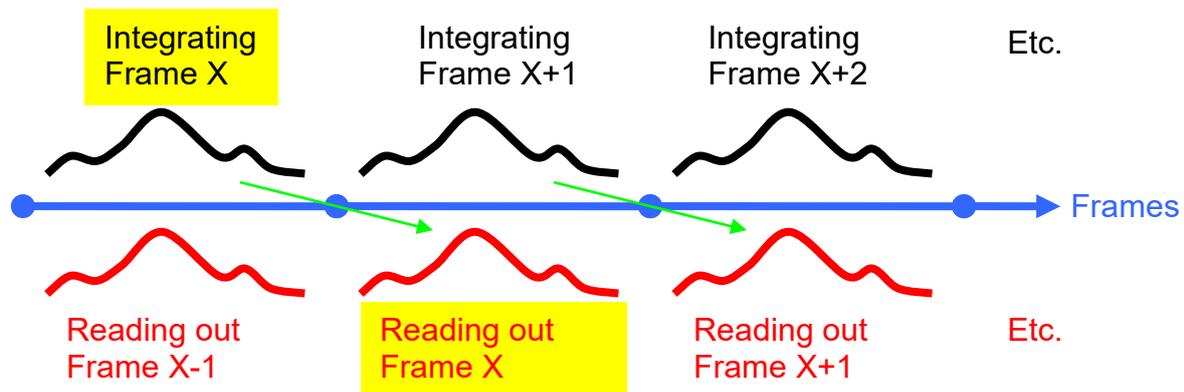
Figure 5-6: Continuous Frame Integration and Readout in Parallel

This **continuously running frame integration** starts immediately as soon as the CCD device has been powered up or has been reconfigured with new parameters. The device begins to continuously integrate frames back-to-back and without stopping. This operation is already in progress even before an acquisition has been initiated (i.e. before frame capture starts). During each frame, the CCD sensor is collecting light for the same amount of time, which is defined by the **integration time** parameter. All frames have the same duration. There is no gap between frames – as soon as a frame finishes, the next frame immediately starts and so on.

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Please note that data from those continuously running frames will be **only then stored for further use**, if an acquisition has been started, otherwise that data is simply discarded.

In detail, the following happens between two frames:

1. As soon as the **exposure for the current frame has finished**, the **exposure for the next frame immediately begins.** The sensor again starts to collect light.
2. **At the same time (at the start of the new frame), the individual pixel charges collected during the *previous* frame are immediately transferred at once into the transmission region** of the sensor and now start being **shifted out on a one-by-one (pixel by pixel) basis** from the analog shift register. This process is called **reading out the sensor**. Each shifted out pixel charge goes through an amplifier circuit and is converted into a voltage. This voltage is then converted through the ADC (analog-to-digital converter) to digital data which represents the light intensity value for the individual pixel. **If an acquisition has been started by the host PC, the digital data is captured and immediately stored into internal device memory; otherwise it is simply discarded.** After the acquisition has finished, the digital data can be fetched from the internal device memory and transferred to the host PC.

This means that the **readout of a previous frame overlaps with the exposure of a new frame**. Readout takes some time because it includes sampling the voltage of each <u>individual</u> pixel. The required total sensor readout time is proportional to the number of pixels and equals **3710 µs** (3.71 ms) for the CCD-S3600-D(-UV). This readout time is defined by the sensor hardware.

Sensor Readout Time ($T_{readout}$):

The sensor read out time is the time required to read out all collected pixel charges from the last frame. It is constant and defined by the CCD sensor used. For the CCD-S3600-D(-UV) this time is 3710 µs (3.71 ms).

5.1.9. Integration Time vs. Readout Time

As previously described, because of the continuously running frame integration of the CCD, **during each frame two things happen at the same time**:

1. The **integration** of the **current** frame takes place and the user-specified **integration time** defines for how long the sensor will collect light during that frame and therefore obviously, **how long the frame will last**.
2. The **readout** of the **previous** frame takes place. The sensor readout time is defined by the sensor hardware and is 3710 µs (3.71 ms).

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Because of the fact that the readout of all pixel values from the previous frame takes place **while** the new frame is being exposed to light, **the frame duration cannot be below the readout time** of the sensor. Because of this readout time restriction of 3.71 ms, it is obvious that **a frame cannot be shorter than 3710 µs (3.71 ms)**. Otherwise the sensor would not be able to readout all pixel charges from the previous frame. **It is important to understand that a full readout must be done after each frame in order to clean the sensor for the next frame**. This means that even if the user does not need the data from a frame, the readout still **must** be done after each frame, in order to clear the analog shift register from the accumulated charges and ensure that it is empty for the next frame. This will make sure that the **sensor is clean** for light exposure in the new frame and does not contain charges from the previous frame.

Sensor Readout Time Restriction:

A frame cannot be shorter than the sensor readout time of 3710 µs (3.71 ms).

This restriction would normally imply that the integration time also cannot be set below the readout time of 3710 µs. Fortunately, the CCD-S3600-D(-UV) device uses an advanced CCD sensor, allowing **integration times down to 10 µs**. This is achieved by using the special **shutter mode** of the sensor which will be described shortly. But first, the normal **non-shutter** mode will be described.

5.1.10.   Non-Shutter Mode vs. Shutter Mode

Non-Shutter Mode

This mode is used whenever the **integration time is equal to or greater than the sensor readout time** of 3710 µs. In this case, the frame readout time restriction does not pose a problem and the **frame duration always equals the integration time**. As soon as a frame starts, integration starts. See Figure 5-7.

Integration Time **≥** Sensor Readout Time of 3710 µs

Sensor Readout Time of 3710 µs

Frame Duration = Integration Time
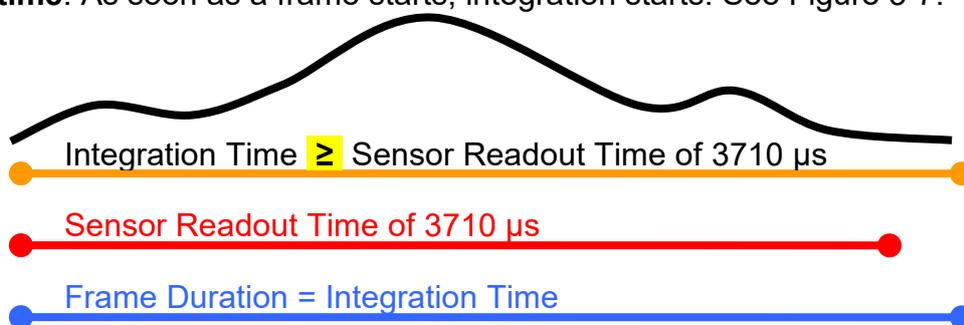
Figure 5-7: Frames with Integration Time ≥ Readout Time : Non-Shutter Mode

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Shutter Mode

The next question is what happens if the integration time is set to a value **below** the sensor readout time of 3710 µs? In this case the device will automatically drive the sensor in the special **shutter mode**. This is again required by the sensor hardware:

Integration Times Below the Readout Time:

When the integration time is set to be shorter than the sensor readout time of 3710 µs (3.71 ms), the integration time will be <u>repeated</u> multiple times in a frame, until the frame time becomes equal to or greater than the sensor readout time. The frame duration then equals that least multiple of the integration time.

<mark>Very important: In shutter mode <u>only the last part of the frame is used for integration.</u></mark> Only the last integration time period in the frame will take effect because the shutter will clear all previously collected charges whenever a *new* integration time period starts during a frame. Therefore, although a frame starts, actual integration takes place only in the last part of this frame.
It is very important to keep this in mind when working with integration times < 3710 µs.

Shutter mode is shown in Figure 5-8.

In shutter mode the integration time is repeated **M times** during a frame, until the frame time becomes equal to or greater than the sensor readout time of 3710 µs. Here M = 3.
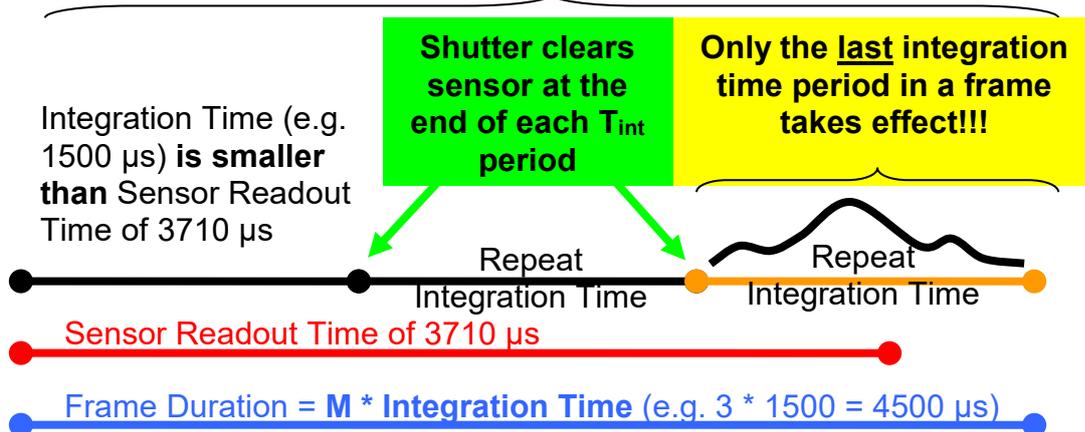
Figure 5-8: Frames with Integration Time < Readout Time : Shutter Mode

Again, in shutter mode **only the last part of the frame is used for integration**; this way **integration times <u>below the sensor readout time</u> can be achieved, but the minimum frame duration is *still* the sensor readout time**.

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When working with pulsed lasers, the laser pulse should appear immediately when the actual integration begins, i.e. at the beginning of the last integration time period <u>in the last part of the frame</u>. This gives the most accurate results. The trigger output feature of the CCD-S3600-D(-UV) can be used to trigger the laser as described in details in the next chapters.

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5.1.11. Integration Time vs. Frame Rate

The **integration time** will influence:
1. **how long a single frame** will last
2. the **frame rate**

The frame rate (or line scan frequency) is inversely proportional to the integration time.

In **non-shutter mode** ($T_{int} \geq 3710$ µs):
The frame duration equals the integration time.
The **frame rate** equals **1/T_{int}**.

In **shutter mode** ($T_{int} < 3710$ µs):
The frame duration equals the least multiple M of the integration time, where
$M * T_{int} \geq T_{readout}$.
$T_{readout}$ is the constant readout time of the sensor and equals 3710 µs.
The **frame rate** equals **1/(M*T_{int})**.

The following table lists some **frame rates** that can be achieved for different **integration times** with the CCD-S3600-D-(UV):

Integration Time T_{int} (µs)	T_{int} Period is Repeated in Frame (times)	Resulting Frame Duration (µs)	Resulting Frame Rate (Hz)
$T_{int} < T_{readout}$ → **Shutter Mode**			
10	371	3710	~ 269.5
50	75	3750	~ 266.7
100	38	3800	~ 263.2
500	8	4000	250
1000	4	4000	250
2000	2	4000	250
$T_{int} \geq T_{readout}$ → **Non-Shutter Mode**			
3710 and above	**1**	**= T_{int}**	**= (1 / T_{int}) * 10⁶**

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5.1.12.   Integration Time with Internal vs. External Synchronization Mode

There are two ways to define the integration time:

Internal Synchronization: T_{int} is set in software

The first is when using **internal synchronization**. In this mode the user sets the integration time through a <u>software command</u> and this value is used by the internal timing module of the device to automatically define the exposure period as well as when a frame will start and when it will end. Internal synchronization is used in most CCD operating modes described later in chapter 5.3.

External Synchronization: T_{int} is set through the external trigger input

The second option to define the integration time is **external synchronization**. In this mode an <u>external synchronization pulse</u> with a constant period must be applied to the trigger input of the device and the time between external trigger pulses will determine the integration time as well as when a frame starts and when it ends. External synchronization is used only in the "externally synchronized operating mode" described later in chapter 5.3.

So far we have described what frames are, how the integration time parameter defines the exposure to light during a frame and how the sensor is read out. Next we will describe further details of CCD operation.

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5.2.   Configuration and Acquisition

Whenever the CCD device is powered up, it starts in its default configuration. The default configuration presets the device to factory default modes and parameters. For example, the default integration time is preset to 5000 μs.

In most operating modes, the CCD immediately starts to integrate frames back-to-back and therefore enters continuously running frame integration. The first frame of that sequence is an **initial dummy frame** during which any old charges are read out from the sensor but the data is simply discarded. The data collected during the initial dummy frame is also discarded when it is read out during the next frame. Data collected during the frame **after the initial dummy frame** as well as **during the next frames** is valid and can be captured and stored into the internal memory of the device. But note that capture & store takes place only if an **acquisition** has been started. See Figure 5-9.
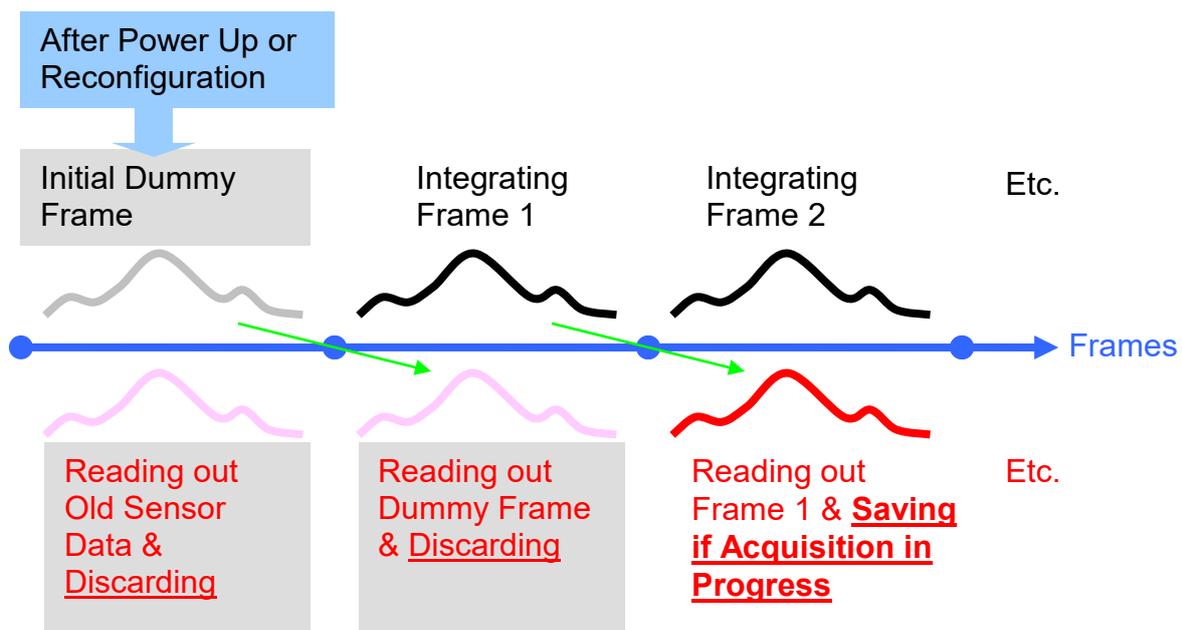
Figure 5-9: Initial Dummy Frame after Power Up or Reconfiguration

> **Although the CCD is continuously running and integrating frames, as long as there is <u>no</u> acquisition in progress, any read out frame data is discarded instead of being stored or transferred to the PC.**

As long as there is **no** acquisition in progress, the CCD will accept commands from the USB interface. Such commands can be configuration commands, commands to initiate an acquisition, etc.

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5.2.1. Configuring the CCD Camera

While there is no acquisition in progress, the device can be reconfigured by sending configuration commands from the host PC to the device via USB. The LabVIEW drivers and the C++ examples use these commands.

Configuration commands set the CCD parameters or modes to new values. The following commands are available:

- Set integration time (in µs)
- Set frames (scans) per acquisition → use for onboard storage mode (1 to 4599 frames)
- Set CCD operating mode → five different modes (described in the next chapters)
- Set trig out before integration offset (in µs)
- Enable or disable the external trigger output (new feature added in firmware A1.10)
- Enable or disable hardware dark correction
- Include dummy pixels in readouts → this advanced command is normally not used

These configuration commands will be described later in details.

Whenever a *valid* configuration command is received, it will first reset the CCD, apply the new parameter, interrupt the current frame and start integrating new frames with the newly defined parameter by entering continuously running frame integration. The first new frame is a new initial dummy frame. During that initial dummy frame the device will readout any old sensor data and discard it. The data read out from the initial dummy frame is also readout and discarded during the next frame. Data read out during further frames will be stored if an acquisition is in progress. Again refer to Figure 5-9.

As a reply to a successful configuration command the device will return an **ACK** (acknowledgement) byte to the host PC via USB. After executing that command, the device will again start accepting new commands.

If an **invalid command** is received, this command will be simply **ignored** and will not influence current CCD operation. The device will respond with a **NACK** (not acknowledged) byte reply to the host PC via USB.

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5.2.2. Initiating Acquisition in Different Data Modes

After having configured the device, the user must send a special *initiate acquisition* command to the device in order to initiate an acquisition. This is required in order to capture frames. However, in most modes, **initiating** an acquisition does <u>not</u> immediately start the acquisition. I.e. the actual capturing of frames requires an additional hardware trigger from the external trigger input in those modes. The detailed behavior depends on the selected operating mode and will be described later.

The *initiate acquisition* command is sent from the host PC to the CCD device via USB. There are actually two different commands that will initiate an acquisition, depending on the data mode the user wants to use:

- **Initiate acquisition in <u>onboard data storage mode</u>**
- **Initiate acquisition in <u>data streaming mode</u>**

Onboard Data Storage Mode (Default)

The default "onboard data storage mode" will be sufficient for most applications. In this mode the device will store the captured frames into **onboard memory**. They can be fetched later by the host PC. As soon as acquisition starts, the device will capture the **set number of frames (scans) per acquisition** into onboard RAM. As soon as this has been done, **acquisition will finish <u>automatically</u>** and the device will send all captured frames to the host PC which is now responsible for fetching the data through USB. In this mode the number of required frames is set from 1 to 4599 through the correspondent parameter and is limited by the onboard RAM to 4599 frames (which is a very large value and will be sufficient in most cases).

Data Streaming Mode (Advanced)

In this mode the device will **immediately stream** any captured data to the host PC. The data rate is very high and it is therefore not recommended to view the acquired data in real time. Instead, all saved frames can be viewed later from the hard drive of the host PC. There is no frame limit in this mode and data can be streamed without missing any frame. As soon as acquisition starts, the device will always **<u>ignore</u> the set number of frames (scans) per acquisition**. Instead it will stream any captured frames immediately to the host PC until the device **receives** the ***stop acquisition and data streaming* command** (or actually any other command) from the host PC. After receiving the stop command the device will capture one more frame and then stop acquisition. During streaming, the onboard RAM is used as a big FIFO frame buffer that prevents data overflow during capture. If there are any frames left in the buffer after acquisition is stopped, they will be still streamed to the PC.

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Finishing Acquisition

In *both* data modes, after the final captured frame in the acquisition, the CCD will always do a **last readout-only frame**, during which the data from that last valid captured frame will be readout and stored. After that, the CCD will continue integrating new frames. These new frames will be always read out from the sensor but the data will be simply discarded until the next acquisition has been started. See Figure 5-10.
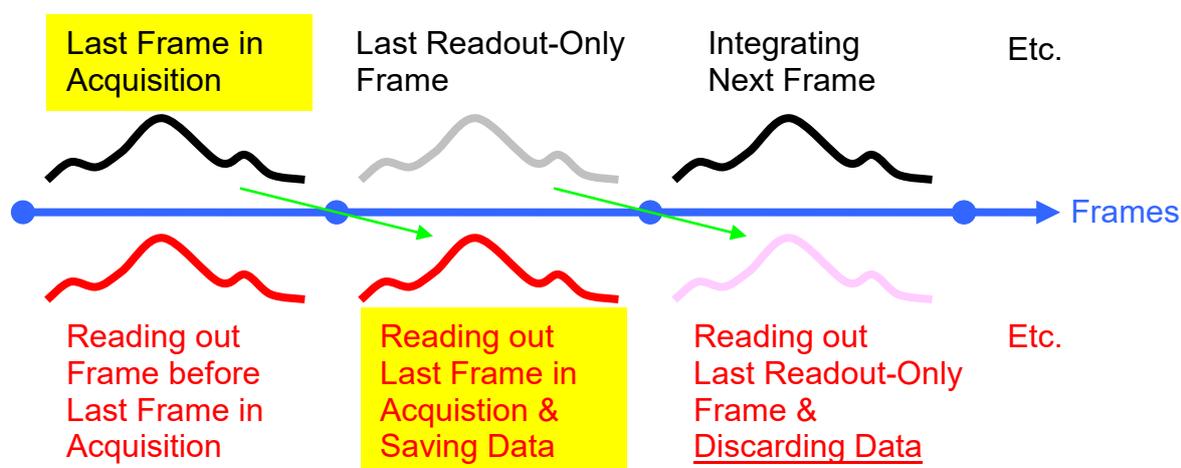
Figure 5-10: Finishing the Acquisition and Last Readout-Only Frame

Note: While acquisition is in progress the CCD will not accept new commands until the acquisition has finished.

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5.3.   CCD Operating Modes

In the last subchapter we discussed how an acquisition is initiated and when it finishes, depending on the data mode selected, i.e. onboard data storage mode vs. data streaming mode.

Initiating an acquisition is always required before frame capturing can start, but it only means that the CCD becomes *ready* for capturing and storing frames. Though, it does **not automatically mean that the device will immediately start to capture and store frames**. In most modes a second hardware trigger is required for that. *When* capture will actually occur, is defined by one of the five CCD operating modes.

> After an acquisition has been initiated, the selected **CCD operating mode** will determine, **if** and **when** a frame will be actually captured and stored. It will determine **what** will **trigger** a capture. A capture can be triggered by software or by hardware.

The following operating modes are available on the CCD-S3600-D(-UV):

- **Internally synchronized, continuously running, with <u>software</u> capture start**
- **Internally synchronized, continuously running, with <u>hardware</u> capture start**
- **Internally synchronized, continuously running, with <u>hardware</u> capture enable**
- **<u>Single-shot</u>, clean & ready with external <u>hardware</u> trigger**
- **<u>Externally</u> synchronized, continuously running, with <u>software</u> capture start**

> In all **internally** synchronized modes as well as the **single shot** mode the device uses its **internal timing** generator and the programmable integration time set by the user in order to generate frames.
>
> In contrast, in **externally** synchronized mode the **external synchronization** signal will define the integration time and the frame duration.
>
> In the **internally** synchronized modes as well as in **externally** synchronized mode the CCD enters **continuously running** operation and already starts integrating frames. These frames are still not captured until an acquisition has been initiated and actually started by the software or hardware trigger used in the corresponding mode.
>
> In contrast, in **single shot** mode the sensor is kept clean and ready but does **not** enter continuously running frame integration. Instead, it always waits for the hardware trigger to start integrating a frame.

Next, the five modes will be described in details.

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5.3.1. Internally Synchronized, Continuously Running with Software Capture Start

This is the default and the simplest operating mode. In this mode **no external trigger** is required. **Acquisition starts** immediately as soon as the **initiate acquisition** command arrives.

In this mode the frame duration and synchronization is defined by the *internal* CCD controller clock and the set integration time. The CCD is in continuously running operation and integrates frames back-to-back, no frames are skipped.

Frame capturing starts **immediately** as soon as the **initiate acquisition command** arrives from the host PC via USB. The first captured frame is the frame that is currently being integrated when the initiate acquisition command arrives. No external trigger signal is used in this mode; therefore the capture start is software-defined. See Figure 5-11.
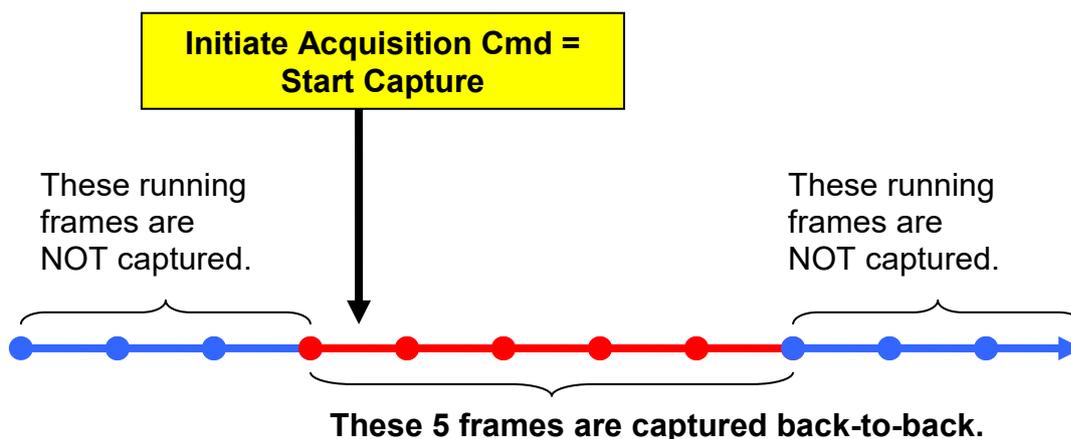
Note: In this example the user has set 5 frames (scans) per acquisition.

Figure 5-11: Internally Synchronized, Continuously Running with Software Capture Start

In **onboard data storage mode**, as soon as the acquisition is initiated, the preset **number of frames (scans) per acquisition** are captured back-to-back. As soon as this is done, the acquisition will finish automatically.

In **data streaming mode**, as soon as the acquisition is initiated, the CCD starts capturing frames back-to-back and streaming them to the host PC. This will continue until the **stop acquisition and data streaming command** arrives from the PC.

In both data modes, integrated frames are read out and saved in the next frame as described in the previous chapters. In order to save the last frame, an additional readout-only frame is used.

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5.3.2. Internally Synchronized, Continuously Running with Hardware Capture Start (Rising Edge Triggering)

This operating mode is very similar to the previously described operating mode, but allows the user to start the *actual capture* as soon as a **rising edge** appears on the external trigger input. All subsequent frames are then captured back-to-back, no frames are skipped.

In this mode the frame duration and synchronization is defined by the internal CCD controller clock and the set integration time. The CCD is in continuously running operation and integrates frames back-to-back.

Frame capturing does **not** start immediately when the initiate acquisition command arrives from the host PC via USB. Instead, the CCD will be ready and wait **until a rising edge appears on the external trigger input** during a frame. Therefore, the capture start is hardware-defined. The first captured frame is the frame that is currently being integrated when the trigger edge arrives. See Figure 5-12.
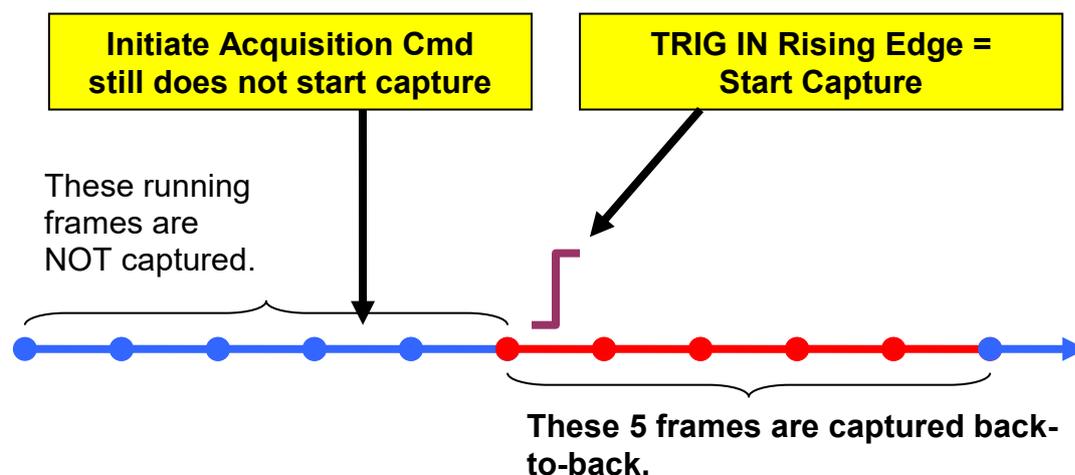
Note: In this example the user has set 5 frames (scans) per acquisition.

Figure 5-12: Internally Synchronized, Continuously Running with HW Capture Start

In **onboard data storage mode**, as soon as the **trigger edge** arrives, the preset **number of frames (scans) per acquisition** are captured back-to-back. As soon as this is done, the acquisition will finish automatically. The trigger input is ignored until the end of the current acquisition.

In **data streaming mode**, as soon as the trigger edge arrives, the CCD starts capturing frames back-to-back and streaming them to the host PC. This will continue until the **stop acquisition and data streaming command** arrives from the PC. The trigger input is ignored until the end of this acquisition.

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In both data modes, integrated frames are read out and saved in the next frame as described in the previous chapters. In order to save the last frame, an additional readout-only frame is used.

Please note that **edge** triggering is used here, not level triggering. The CCD will wait for a rising edge on the trigger input signal.

If the CCD device does not receive a trigger input signal, the control software (e.g. LabVIEW) will appear frozen. If your device appears frozen, you may want to disconnect the device from the USB port of the host PC. This should make the software report a connection error and exit the waiting loop.

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5.3.3. Internally Synchronized, Continuously Running with Hardware Capture ENABLE (High Level Triggering)

This operating mode allows the user to select **which** frames will be actually captured by using a high level on the external trigger input. Only frames during which this external signal is **high** will be captured. Therefore captured frames do not have to be back-to-back, i.e. frames can be skipped intentionally.

In this mode the frame duration and synchronization are defined by the internal CCD controller clock and the set integration time. The CCD is in continuously running operation and integrates frames back-to-back.

Frame capturing does **not** start immediately when the initiate acquisition command arrives from the host PC via USB. Instead, the CCD will be ready and wait until a **high level** on the external trigger input appears. Therefore, the capture start is hardware-defined. The first captured frame is the frame that is currently being integrated when the high level on the trigger input is detected. **In this mode the trigger level is used to <u>select</u> which frames need to be captured = capture enable.** The captured frames do not have to be back-to-back. **Only subsequent frames during which the external trigger input signal is high will be captured.** Therefore, the external trigger signal is still being evaluated after having started capturing. See Figure 5-13.
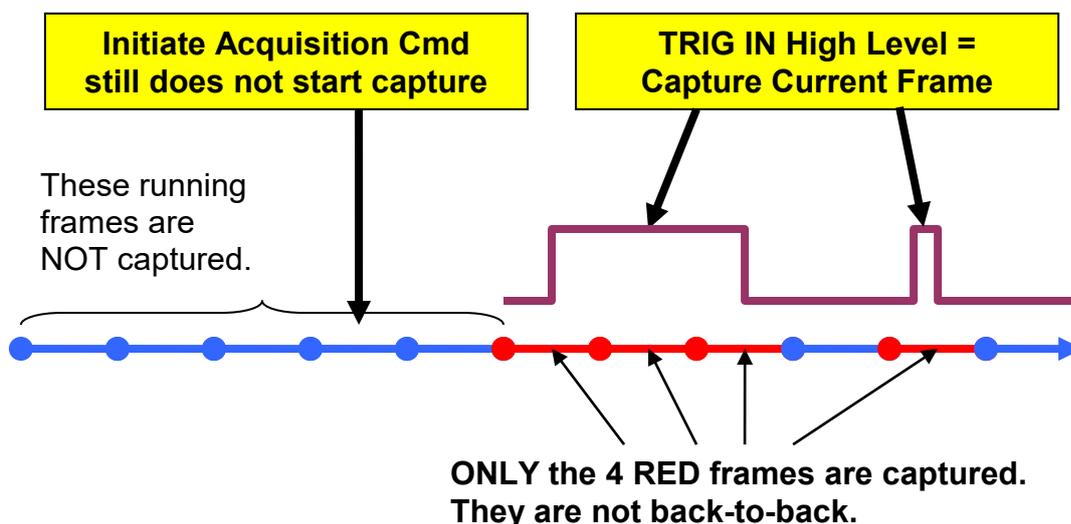
Note: In this example the user has set 4 frames (scans) per acquisition.

Figure 5-13: Internally Synchronized, Continuously Running with HW Capture ENABLE

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In **onboard data storage mode**, whenever a high level is detected on the external trigger input, the current frame will be captured, until the preset **number of frames (scans) per acquisition** have been all captured (this does not have to be back-to-back). As soon as this number of frames has been reached, the acquisition will finish automatically. The trigger input will be watched for a high level until the end of the current acquisition.

In **data streaming mode**, as soon as a high level on the external trigger input is detected, the CCD will capture the current frame and stream it to the host PC. This will continue until the **stop acquisition and data streaming command** arrives from the PC. The trigger input will be watched for a high level until the end of the current acquisition.

In both data modes, integrated frames are read out and saved in the next frame as described in the previous chapters. In order to save the last frame, an additional readout-only frame is used.

Please note that **level** triggering is used here, not edge triggering. The CCD will watch for a high level on the trigger input signal.

If the CCD device does not receive a trigger input signal, the control software (e.g. LabVIEW) will appear frozen. If your device appears frozen, you may want to disconnect the device from the USB port of the host PC. This should make the software report a connection error and exit the waiting loop.

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5.3.4. Single Shot, Clean & Ready with External Hardware Trigger (Rising Edge Triggering), Use for $T_{int} ≤ 500$ µs Only

This advanced operating mode allows the user to start a **new** frame as soon as an external **trigger rising edge** arrives. This behavior is different from the modes described so far, because it does **not use continuously running** frames. Instead, the device **keeps the sensor clean** by using the shutter. It does not initiate frames and does not collect charges, until the trigger arrives. Please note that this special mode requires integration times < 500 µs and the sensor is operated in shutter mode - therefore **only the last part of the frame is used for integration** (see Shutter Mode in Chapter 5.1.10 and Figure 5-8 as a reminder).

When the trigger edge arrives, a **single frame** will be initiated with the integration time preset by the user. After that frame, the sensor is readout and the data is captured and stored. Then the sensor returns back to the **clean & ready** state waiting for the **next** frame trigger. Because of the readout phase and the clean & ready state between frames, **captured frames cannot be back-to-back**.

This unique single shot mode makes use of some very special properties of the CCD sensor. The trigger *input* can be used in combination with the trigger *output* to synchronize external devices. This is very useful for applications with pulsed lasers. Please refer to chapter 5.5.2 for detailed information on this topic.

As soon as the device is set to this mode, instead of continuously integrating frames, the following happens: After power up or reconfiguration, the device reads out the sensor first in order to clean it from previous charges (this takes 3710 µs and is comparable to the initial dummy frame in other modes). The device then enters the so called "clean & ready" state. In this state the CCD sensor does not collect charges but is **kept clean and ready** for the integration of the next single shot frame. This **single shot frame** is triggered as soon as a **rising edge** appears on the external hardware trigger input. *After* the integration of the single shot frame has finished, the device will **read out** the charges collected during that single shot frame (this takes again 3710 µs) and then the device again enters the **clean & ready** state to wait for the next trigger.

Because of the special sensor behavior used in order to keep the sensor clean, this mode can be used **only for integration times ≤ 500 µs**. Please note that for such $T_{int} ≤ 500$ µs, the sensor will use shutter mode and the **integration will take place during the last T_{int} period of the frame!**

==Very important: In shutter mode== ==only the last part of the frame is used for integration.== (See Shutter Mode in Chapter 5.1.10 and Figure 5-8 as a reminder.)

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This mode is especially useful for applications with pulsed lasers. It allows the user to observe very short laser pulses by setting a very short integration time. Because the CCD sensor is kept clean between subsequent shots, the lasers may have a very low repetition rate or may be even single shot. The laser pulse should appear at the beginning of the integration period, in the last part of the frame. In order to achieve this, the CCD can be triggered by an external frequency generator while the CCD trigger output will trigger the laser, exactly before the integration period begins. A pre-integration trigger out offset can be also specified. For further information please refer to chapter 5.5 where the trigger output is described in details.

If integration times longer than 500 µs are specified in this mode, the captured light intensity values may become too low. For $T_{int} \leq 500$ µs the error is typically < 0.1%.

In this mode the frame duration and the integration period are defined by the **internal** CCD controller clock and the set integration time. However, the CCD is **not** in continuously running operation and will only integrate a single frame, as soon as the trigger arrives. Then it will clean the sensor first. Therefore, it will never capture frames back-to-back in contrast to the other operating modes.

Frame capturing does **not** start immediately when the initiate acquisition command arrives from the host PC via USB. Instead, the CCD will be ready and wait until a **rising edge** on the external trigger input appears while the sensor is in the clean & ready state. Then it will start the single shot frame that will be captured. Therefore, the capture start is hardware-defined. See Figure 5-14.
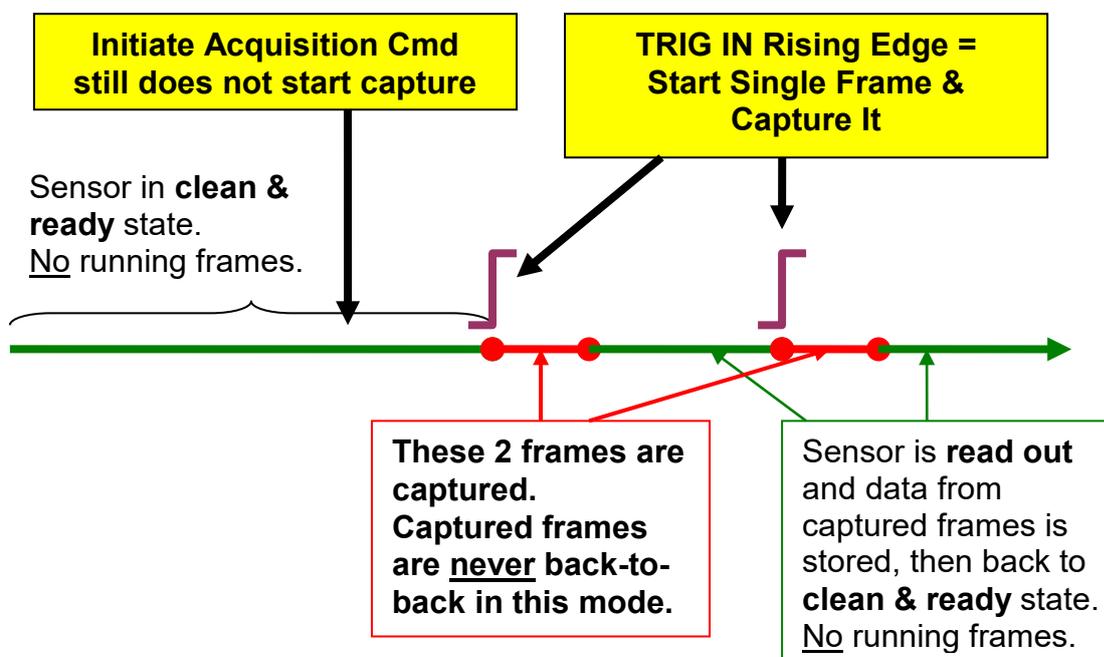
Note: In this example the user has set 2 frames (scans) per acquisition.

Figure 5-14: Single Shot, Clean & Ready with External Hardware Trigger

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The external trigger signal will be *ignored* while the device is *integrating* the frame and afterwards *reading* out the sensor. **Because of the "read out only" phase, there is a <u>dead time</u> of 3710 µs after each captured frame** in this mode. As soon as the device has reentered clean & ready state, the next trigger can capture the next frame if an acquisition is in progress. Therefore, in contrast to other modes, this mode limits the maximum possible frame rate to 269.5 / 2 ≈ **134 fps** and a trigger rate from single shot up to **134 Hz** can be applied.

In **onboard data storage mode**, as soon as the trigger edge arrives, a single frame will be started and captured, until the set **number of frames (scans) per acquisition** have been all captured (not back-to-back here). As soon as the device has returned to the clean & ready state, the trigger input will be watched for the next rising edge until the end of the current acquisition. As soon as the preset number of frames has been reached, the acquisition will finish automatically.

In **data streaming mode**, as soon as the trigger edge arrives, the CCD will start and capture a single frame and stream it to the host PC. The trigger input will be watched for the next rising edge until the end of this acquisition, whenever the device has returned to the clean & ready state. This will continue until the **stop acquisition and data streaming command** arrives from the PC.

In both data modes, the single integrated frames are read out and saved during the sensor readout-only phase of 3710 µs after those frames. The frame data is also stored into RAM during that phase.

Please note that **edge** triggering is used in this mode, not level triggering. The CCD will wait for a rising edge on the trigger input signal.

If the CCD device does not receive a trigger input signal, the control software (e.g. LabVIEW) will appear frozen. If your device appears frozen, you may want to disconnect the device from the USB port of the host PC. This should make the software report a connection error and exit the waiting loop.

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5.3.5. Externally Synchronized, Continuously Running with Software Capture Start

All operating modes described so far used internal synchronization. In those modes the user entered an integration time and this value was used by the internal timing module of the device to automatically define the exposure period as well as when a frame will start and when it will end. In contrast, *this* mode uses **external synchronization**.

An external trigger pulse **with a constant period** is applied to the trigger input of the device and the time between external trigger rising edges will determine the integration time period as well as when a frame starts and when it ends. **It is important to make sure that the external synchronization trigger edges arrive continuously and with a constant period on TRIG IN before initiating an acquisition**. The minimum time between rising edges is 10 µs (= minimum integration time). The resulting integration time resolution is 1 µs. The signal does not need to have an even duty cycle of 50%.

The integration time set by the user is completely ignored in this mode.

Besides the fact that this mode uses external synchronization, it is very similar to the default *internally synchronized, continuously running, with software capture start* mode. Acquisition starts **immediately** as soon as the *initiate acquisition* command arrives (software capture start). It is important to note, that in this mode the external signal applied to the trigger input is only used for continuous frame **synchronization**; it is **not** used to trigger specific frames.

In this mode the **integration time** as well as the **frame duration, frame synchronization and frame rate** are defined by the **rising edges** on the *external* trigger input. Actually the device will use special hardware algorithms to watch the time interval between the rising edges. If the time interval is ≥ 3710 µs the device will work in non-shutter mode and the next rising edge will always start a new frame. If the time interval is < 3710 µs then the device will switch to shutter mode and multiple integration time periods will be repeated until the minimum frame duration of 3710 µs (= $T_{readout}$) has been reached. See chapter 5.1.10 as a reminder regarding shutter mode.

In this operating mode the CCD is in continuously running operation and integrates frames back-to-back.

Assumed that the external synchronization trigger is already running continuously as described above, frame capturing will start **immediately** as soon as the *initiate acquisition* **command** arrives from the host PC via USB. The first captured frame is the frame that is currently being integrated when the initiate acquisition command arrives. **No** external trigger signal is used to *start* capture in this mode; therefore the capture start is software-defined. See Figure 5-15.

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Initiate Acquisition Cmd = Start Capture

Note: In this example the user has set 5 frames (scans) per acquisition.

These running frames are NOT captured.

These 5 frames are captured back-to-back.

These running frames are NOT captured.

External synchronization: Rising edges on TRIG IN define the integration time as well as frame duration, frame synchronization and frame rate. Here: Non-shutter mode.

Figure 5-15: Externally Synchronized, Continuously Running with Software Capture Start

Shutter mode details are shown in Figure 5-16. **Here the period between the rising edges of the external signal will define the integration time period**. The expired frame time is calculated on the fly and a new frame starts as soon as the expired frame time becomes equal to or greater than the sensor readout time.

In shutter mode the integration time is repeated **M times** during a frame, until the frame time becomes equal to or greater than the sensor readout time of 3710 µs.

Integration Time < Sensor Readout Time of 3710 µs (e.g. 1500 µs)

SHUTTER

Only last integration time in frame takes effect!

Repeat Integration Time

Repeat Integration Time

Sensor Readout Time of 3710 µs

Frame Duration = M * Integration Time (e.g. 3 * 1500 = 4500 µs)
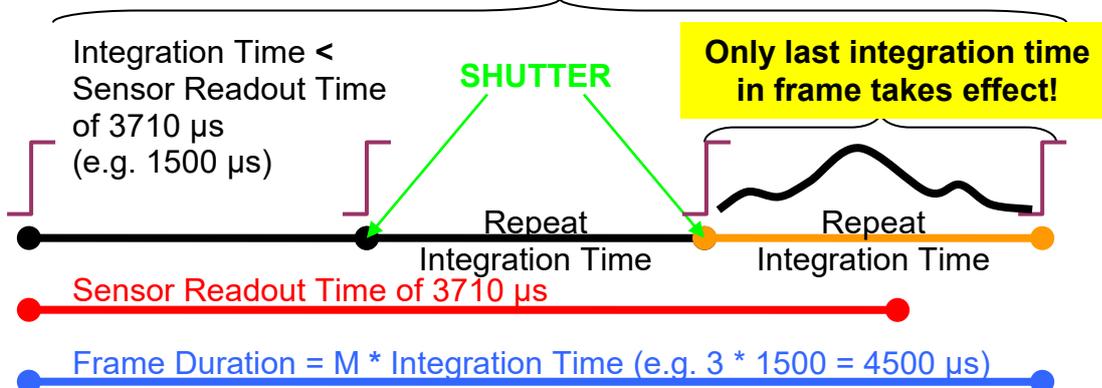
Figure 5-16: A Single Frame in Shutter Mode with External Synchronization

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> **Please note that in shutter mode the <u>frame rate</u> does <u>not</u> equal the <u>synchronization trigger rate</u> any more. Multiple synchronization trigger edges occur during a single frame.** Again refer to Figure 5-16.

In **onboard data storage mode**, as soon as the acquisition is initiated, the set **number of frames (scans) per acquisition** are captured back-to-back, assuming that the external synchronization trigger edges arrive continuously from the external trigger source. As soon as this is done, the acquisition will finish automatically.

In **data streaming mode**, as soon as the acquisition is initiated, the CCD starts capturing frames back-to-back and streaming them to the host PC. This will continue until the **stop acquisition and data streaming command** arrives from the PC.

In both data modes, integrated frames are read out and saved in the next frame as described in the previous chapters. In order to save the last frame, a final readout-only frame is needed.

If the CCD device does not receive a trigger input signal, the control software (e.g. LabVIEW) will appear frozen. If your device appears frozen, you may want to disconnect the device from the USB port of the host PC. This should make the software report a connection error and exit the waiting loop.

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5.4. Trigger Input to the CCD

Four of the five CCD operating modes described in chapter 5.3 require the use of the external trigger input. The purpose of the trigger input signal depends on the mode and is shown in **bold** below:

- Internally synchronized, continuously running, with **hardware capture start**
- Internally synchronized, continuously running, with **hardware capture enable**
- Single-shot, clean & ready with **external hardware trigger**
- **Externally synchronized**, continuously running, with software capture start

So the trigger will be used either as the capture start, the capture enable, the single-shot trigger or the synchronization trigger in these modes.

Connecting the trigger input

Connect an appropriate cable to the TRIG IN SMB connector on the CCD device. The external trigger signal must be **max. +5 V, TTL (rising edge)**. Most CCD operating modes are **rising edge triggered**, only the *internally synchronized, continuously running, with hardware capture enable* mode is **level** triggered (*not* edge triggered).

Minimum trigger input pulse width

The minimum trigger pulse width is ~ 8 ns. To be able to capture short signals, all input signals are stretched in hardware by ~ 50 ns at + 5 V (and by less than 50 ns for voltages below + 5 V).

The trigger input can be also used in combination with the trigger output to synchronize external devices like pulsed lasers to the CCD. This unique **dual-triggering** technique is described in details in **chapter 5.5**.

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5.5. Trigger Output from the CCD

The CCD-S3600-D(-UV) features a **trigger output**. This signal can be used **to trigger external devices** *from* the CCD. Synchronization to the exact internal integration period of the CCD is possible. Important applications are for example the recording of optical events from pulsed lasers and emanation of lock-in features.

Connect an appropriate cable to the TRIG OUT SMB connector on the CCD device. **The trigger output is + 5 V, TTL (rising edge).** The trigger output signal pulse stays at high level for **500 ns**. If the external device is triggered on rising and falling edge, a trig out precision of 500 ns can be achieved.

In most CCD operating modes the trigger output signal **indicates when integration actually *starts* in each frame** (this is at the end of the frame for very short integration times). Note regarding "external synchronization mode": Due to the different behavior in "external synchronization mode", in that special mode the trigger output indicates when integration has actually *finished* for a frame.

A unique **dual-triggering** scheme that uses the external **trigger input** to the CCD **in combination** with the **trigger output** from the CCD can be also applied: In this case the CCD will be triggered from an external source (e.g. frequency generator) that will define when the frames start, while the trigger *output* from the CCD will be used at the same time to trigger an external device (e.g. a laser) **exactly when integration begins** *inside* each of these frames. This is especially important for lasers with short pulses, where very short integration times are needed and integration starts in the last part of a frame (shutter mode of the CCD sensor is used). Dual-triggering guarantees exact timing in this special case. The possibility to additionally specify a "trig out offset" from the integration start makes this solution truly unique on the market. For detailed information on this topic please refer to chapter 5.5.2.

Important notes regarding the external trigger output:

Trigger output behavior on device plug in

Caution must be exercised when the CCD device is **plugged into the USB port** of the host computer. At this point it gets **initialized** and loads its initial configuration. **The trigger output signal may go high or glitch for a moment during this first initialization phase and so called "false triggers" may appear on the output.** This is expected behavior in all firmware versions. If external devices triggered from the CCD are sensitive to such glitches, it is important to **make sure that they do not get triggered during this initial plug in phase**. This can be achieved e.g. by simply disconnecting the trigger output cable from the device.

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Trigger output behavior during device reconfiguration

During device **reconfiguration**, i.e. whenever the user sends commands to set the integration time, number of scans, or any other parameter, the timing logic of the device gets **reset internally** and running frames get "out of synch" for a moment. This is expected behavior and may cause **glitches or spurious trigger signals to appear on the trigger output**.

If such glitches represent a problem for external devices that are being triggered from the CCD, it is important to **make sure that such devices do not get triggered during the device reconfiguration phase**. For the old firmware A1.00 this can be achieved by disconnecting the trigger out cable from the device. In firmware A1.10 a new advanced trigger output control feature has been introduced:

New trigger output control feature since firmware A1.10:
In order to additionally **protect external devices from glitches** ("false triggers") appearing on the trigger output **during reconfiguration**, a new trigger output control has been added in firmware version A1.10 to the device. In contrast to the old firmware A1.00 where the trigger output was constantly enabled, **the trigger output will now be <u>disabled</u> by default** after plug in and can be enabled by the user as required. The user can then configure the device parameters without having to worry about glitches.

When configuration of all device parameters is complete, the **user can finally enable the trigger output if required**, i.e. just before initiating an acquisition. This can be done by simply sending the new *trigger output enable* command to the device (see chapter 5.6.1).

After the **acquisition is complete and all data has been fetched by the host PC** the device is ready to accept new commands and the user may again **disable** the trigger output in order to stop triggering the external devices. This is done by simply sending the *command to disable the trigger output* (see chapter 5.6.1).
Note: After acquisition of the specified number of frames is complete, the device immediately starts sending all captured data to the PC. This data <u>must be then fetched</u> by the host PC. Before the acquired data has been fetched, the device <u>cannot process further commands</u>. Any further commands will be accepted <u>after</u> data has been fetched which may take a few seconds because of the large internal storage of the device. E.g. turning the trigger output off will take effect with some <u>delay</u> after the actual acquisition has finished and the trigger output will still be active during this time. Just keep this in mind.

If for some reason the user needs to continue triggering the external devices from the CCD even after acquisition of the captured data is complete he can simply skip leave the trigger enabled.

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If the user needs to **reconfigure some device parameter between acquisitions**, he can do so by again disabling the trigger output (see chapter 5.6.1), then sending the new configuration commands and parameters, and finally reenabling the trigger output (see chapter 5.6.1). Again, this technique prevents glitches on the trigger output during the reconfiguration phase.

This new trigger output control has been also added to the LabVIEW and C++ demo applications coming with the CCD camera.

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5.5.1. Trigger Output = "Integration Start" in Most CCD Modes

In the following **CCD operating modes** the trigger output signals **when** the **integration actually <u>starts</u>** in a frame:

- **Internally synchronized, continuously running, with software capture start**
- **Internally synchronized, continuously running, with hardware capture start**
- **Internally synchronized, continuously running, with hardware capture enable**
- **Single-shot, clean & ready with external hardware trigger**

a) "Integration Start" Output in <u>Non-Shutter Mode</u>: Offset cannot be used

In non-shutter mode (i.e. $T_{int} \geq 3710$ µs) the trigger output (TRIG OUT) will always fire **at the beginning of the frame**, at the point in time when the actual integration period begins.

> The user definable **trig out before integration offset** is **ignored** in non-shutter mode and the offset is always 0 µs (otherwise the offset trig out signal would have to appear during the previous frame). See Figure 5-17.

Trig Out at Integration Start in Non-Shutter Mode ($T_{int} \geq 3710$ µs). Offset cannot be used and is ignored.

Integration Time ≥ Sensor Readout Time of 3710 µs

Frame Duration = Integration Time

Figure 5-17: Trig Out at Integration Start in Non-Shutter Mode

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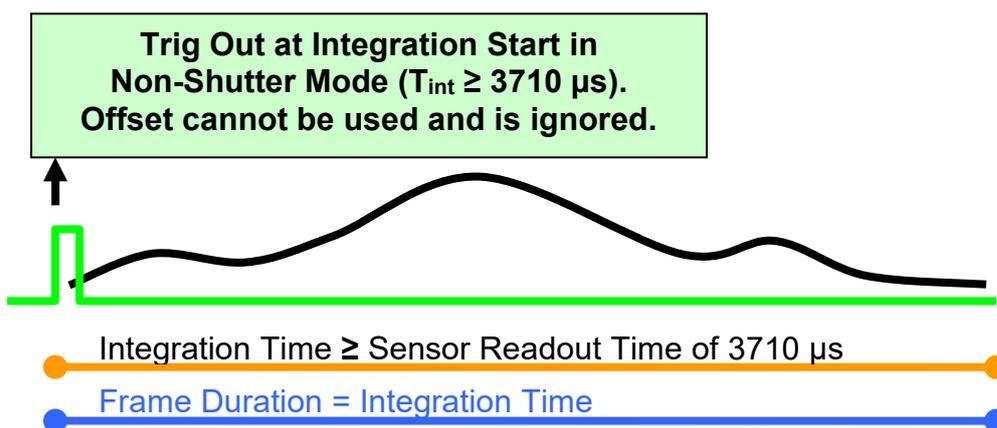
b) "Integration Start" Output in <u>Shutter Mode</u>: Offset can be used

In shutter mode (i.e. T_{int} < 3710 µs) the trigger output (TRIG OUT) will fire **at the beginning of the <u>effective integration period</u> in the frame**, i.e. the last repetition of the integration time in the frame (NOT at the beginning of the frame). See also chapter 5.1.10 as a reminder on how shutter mode works.

The user definable **trig out before integration offset** can be used in this mode. The trig out offset before integration start can be specified in the range between **0 µs (= no pre-integration offset)** and **1849 µs (= max. possible pre-integration offset)**.

For an example with **0 µs offset** before integration start (i.e. no offset) see Figure 5-18.
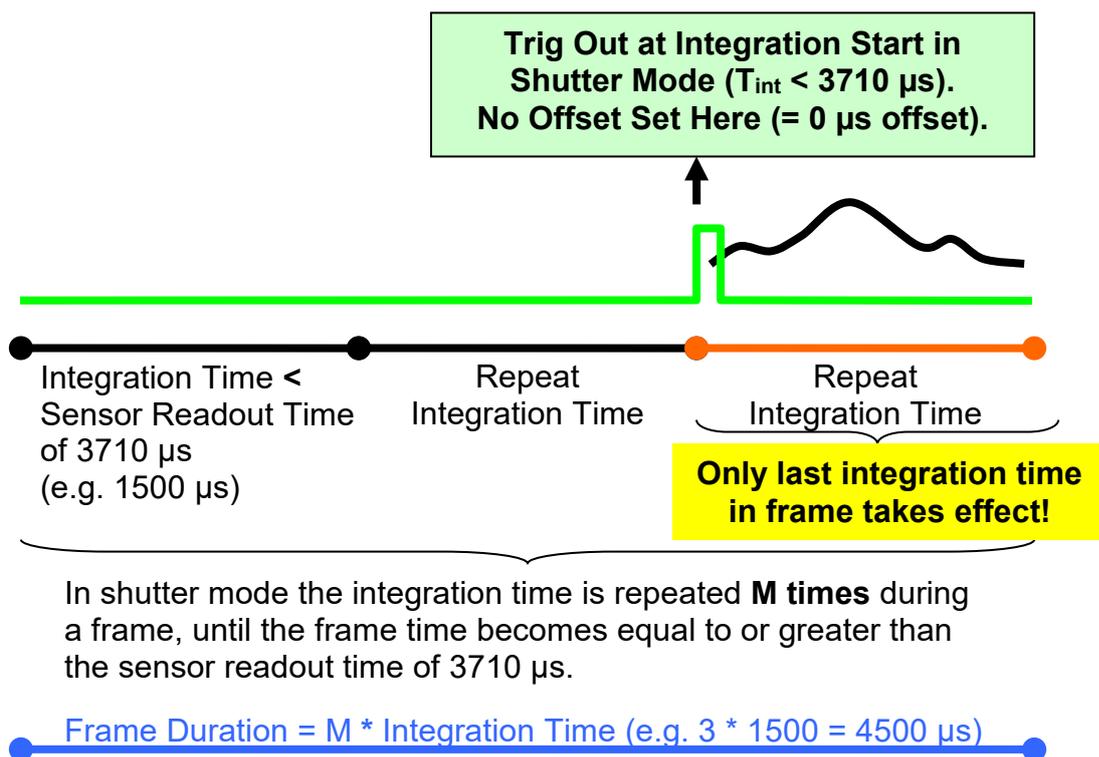
Figure 5-18: Trig Out at Integration Start in Shutter Mode (No Offset)

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For an example **with an offset** before integration start see Figure 5-19. In this figure the offset can be set in the range from **1 µs to 1849 µs**.
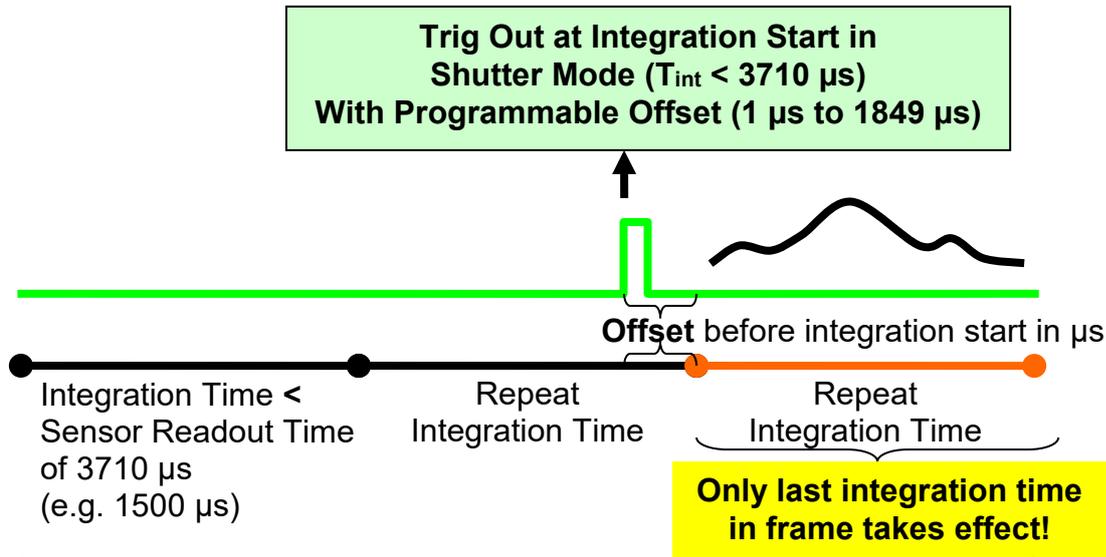
Figure 5-19: Trig Out at Integration Start in Shutter Mode with Offset

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5.5.2. Dual-Triggering with Pulsed Lasers (Including an Application Example)

Dual-triggering represents an extremely powerful and unique approach that can be used in applications with pulsed lasers. Important applications are for example the recording of optical events from pulsed lasers and emanation of lock-in features.

Let's assume that the following user requirements need to be met:

- Capture **very short laser pulses** (e.g. couple of nanoseconds or shorter)
- The laser may have a **low repetition rate** or even be **single shot** (any repetition rate from single shot up to 134 Hz is possible)
- Keep **noise as low as possible**, the shortest possible integration time (e.g. 10 µs) has to be used

To meat the user requirements we will investigate two different approaches. First, we will look at a sub-optimal approach and will later find a better solution using the dual-triggering technique.

A simple but sub-optimal solution because of noise

A very basic approach would be to simply use one of the "internally synchronized" modes of the CCD camera (refer for example to chapter 5.3.1). These modes would give continuously running frames which are integrated back to back. The pulsed laser would be then **simply triggered from the trigger output of the CCD camera at the beginning of each of these frames**.

While this approach would be ok for achieving the highest possible repetition rate, the approach has a **drawback** for low repetition rates. To achieve **low repetition rates** this would require the user to choose a **low frame rate** which will in turn require the user to set a **very long integration time** for each frame. This will add a lot of **noise** during the integration because one would have to integrate multiple milliseconds per frame in order to catch a laser pulse of a few nanoseconds. Therefore, this solution is **not** optimal for observing short laser pulses.

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## A better solution for lowest noise: Dual-Triggering
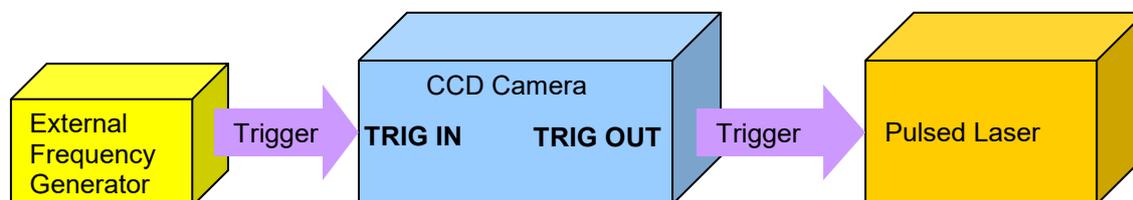
Figure 5-20: Dual-Triggering with Pulsed Laser (Overview)

The dual-triggering approach uses the trigger input and the trigger output of the CCD camera in combination. In this case the CCD will be triggered from an external source (e.g. frequency generator) that will define when the frames start, while the trigger *output* from the CCD will be used at the same time to trigger an external device (e.g. a laser) **exactly when integration begins** *inside* each of these frames. This is especially important for lasers with short pulses, where very short integration times are needed and integration starts in the last part of a frame (shutter mode of the CCD sensor is used). Dual-triggering guarantees exact timing in this special case. The possibility to additionally specify a "trig out offset" from the integration start makes this solution truly unique on the market.

Dual-triggering can be implemented as follows in the example:
- An **external frequency generator** is required to specify the repetition rate of the pulsed laser. Repetition rates of **up to 134 Hz** can be used. Connect the frequency generator to the **trigger input** of the CCD camera. The generator's trigger pulses will **define the repetition rate** of the laser indirectly by defining when new frames on the CCD camera will start. The CCD camera must be set to the mode *"Single-shot, clean & ready with external hardware trigger"*.
- Connect the **trigger output** of the CCD camera to the **pulsed laser**. As soon as new frames are started by the trigger input (see above), the CCD will perform the integration at the correct moment in each frame. For short integration times the **integration period will begin at the end of each frame**. This **exact point in time** will be signaled through the **trigger output** which will also **trigger the laser** at this moment. This means that the repetition rate applied from the frequency generator on the trigger input of the CCD will be always **replicated** at the trigger output of the CCD with a short delay (the time in each frame before the actual integration takes place).
- Set the CCD camera to the operating mode "**Single-shot, clean & ready with external hardware trigger**".
- Set the shortest possible **integration time** required to catch the laser pulse (e.g. 10 µs). Please note that if the laser has jitter you may need to increase the integration time a bit to be able to catch the pulse (e.g. from 10 µs to 50 µs). However note that single shot mode is designed to work with integration

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times below 500 µs. Using integration times that are higher than actually required will also add more noise.

- A **pre-integration start offset for the trigger output** can be also specified (up to 1849 µs in advance). This may be required if the laser must be **triggered in advance** in order to make the pulse appear as soon as integration starts. Refer to chapter 5.5.1.
- A **number of frames (scans) per acquisition** must be specified if the user is not using the advanced data streaming mode.

The main idea in this dual-triggering approach is to use the CCD camera mode "**Single-shot, clean & ready with external hardware trigger**" (see chapter 5.3.4). In this mode the CCD camera does **not** integrate frames continuously but instead keeps the sensor clean & ready for a new frame. It waits for the **external trigger that will define the repetition rate**. As soon as an external trigger edge arrives, a new frame starts and integration takes place at the end of this frame with the specified integration time which can be set as short as possible. At the exact point in time when the integration period begins in a frame, the **trigger output** of the CCD camera will **trigger the pulsed laser**. After finishing the frame, the sensor is read out which takes 3710 µs. This delay (dead time) normally does not pose a problem for lasers that do not require very high repetition rates. Repetition rates of **up to 134 Hz** can be used. After the sensor readout is complete, the CCD camera reenters the clean & ready state and waits for the next trigger to trigger the next frame and correspondingly the next laser pulse.

Please also refer to Figure 5-21 for an overview and Figure 5-22 for a detailed view of a single frame.
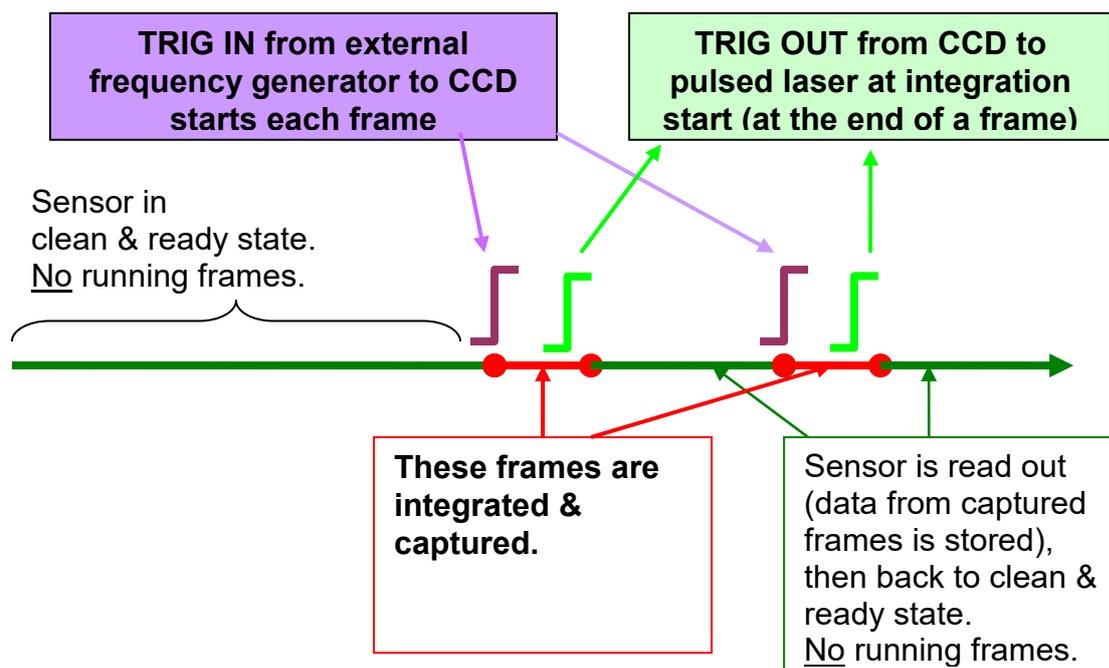
Figure 5-21: Dual-Triggering Example with a Pulsed Laser (Overview)

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TRIG IN from external frequency generator to CCD = frame start

TRIG OUT to laser at <u>integration start</u> (i.e. at the end of each frame). Single shot mode: T_{int} < 500 μs. Shutter is used. The trigger output offset before integration start can be set from 0 μs to 1849 μs.

Offset before integration start in μs

Integration Time < Sensor Readout Time of 3710 μs (e.g. 10 μs)

Repeat Integration Time Multiple Times

Last Repeat Integration Time

Only last integration time in frame takes effect!

In shutter mode the integration time is repeated **M times** during a frame, until the frame time becomes equal to or greater than the sensor readout time of 3710 μs.

Frame Duration = M * Integration Time (e.g. 371 * 10 μs = 3710 μs)

Figure 5-22: Dual-Triggering Example with a Pulsed Laser (Single Frame in Detail)

Next, a practical example with a pulsed laser is described.

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APPLICATION EXAMPLE:
Long-Term Frequency Stability Analysis of a Pulsed Laser

In this example, the frequency stability and the longitudinal mode content of a single-frequency diode-pumped Q-switched laser was conveniently monitored and analyzed by means of a combination of a Fabry-Perot interferometer and the CCD-S3600-D line camera. The laser used in this experiment was the PULSELAS-P-1064-100-SF (manufactured by ALPHALAS GmbH) delivering 1 mJ pulses with 3 ns pulse duration (FWHM) in single-frequency mode and operating at a repetition rate of 100 Hz.

The laser output was frequency-doubled to 532 nm, not only for the convenience to work with visible light, but also to allow high-sensitivity detection of weaker additional longitudinal modes [1]. The Fabry-Perot interferometer (FPI) had a free spectral range of 50 GHz (~ 47 pm at 532 nm).

The experimental setup is shown in Figure 5-23.
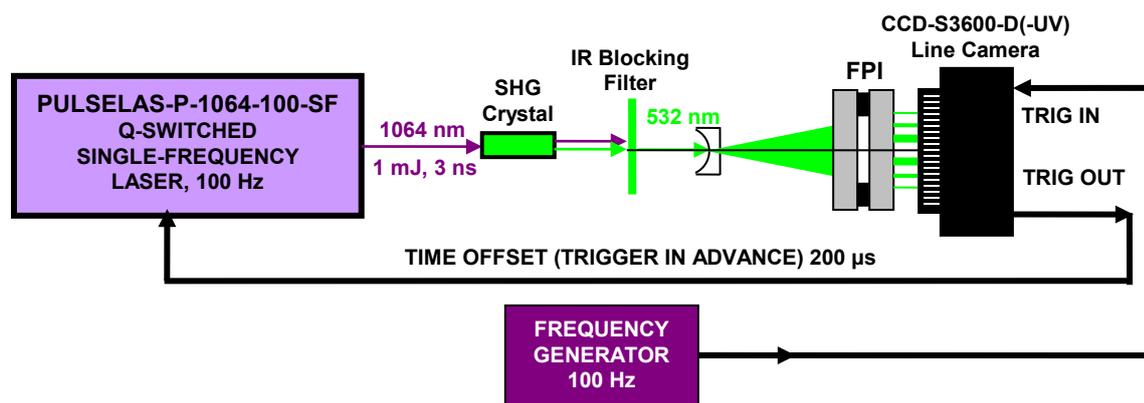
Figure 5-23: Experimental Setup for Long-Term Frequency Stability Analysis of a Pulsed Laser

The CCD camera was set to "single-shot" operating mode. It was triggered from a frequency generator at 100 Hz. Its trigger output in turn was used to trigger the pulsed laser. This resulted in the same repetition rate of 100 Hz, but the laser could be triggered always exactly at the moment when integration begins in the CCD. Thus, the shortest possible integration times could be used and noise was reduced to a minimum.

Because this particular laser fires with a delay of approximately 200 µs after having received a trigger signal, another unique feature of the CCD-S3600-D line camera to generate trigger in advance was also used.

In addition, because a jitter of about 30 µs was typical for this particular laser, a slightly increased integration time of 50 µs was set. Thus, the shots could be captured in spite of the jitter. Without jitter, one could have set the shortest possible integration time of 10 µs.
The following CCD camera settings were used:

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- **CCD operating mode**: "**Single-shot, clean & ready with external hardware trigger**"
- **Integration Time**: 50 µs (because of the jitter specific for that laser)
- **Trig Out before Integration**: 200 µs (this is the pre-integration start offset for the trigger output to trigger the laser in advance, also specific for that laser)
- **Scans per Acquisition**: 3024 (this is the number of captured frames required by the user). It is worth mentioning that CCD-S3600-D(-UV) line cameras allow to capture up to 4599 shots in standard onboard data storage mode. In the advanced streaming mode, the number of captured frames can be much higher and is only limited by the capacity of the hard drive of the user's computer.

The line camera was able to capture the Fabry-Perot interference pattern for each laser shot. In Figure 5-24 below, 3024 shots were recorded. Clearly visible is the transition feature at the beginning of the recording after turning on the laser, where the laser frequency is still unstable. All recorded data was captured and conveniently visualized in a LabVIEW 3-D plot. Please refer to the LabVIEW example applications included with the CCD camera.
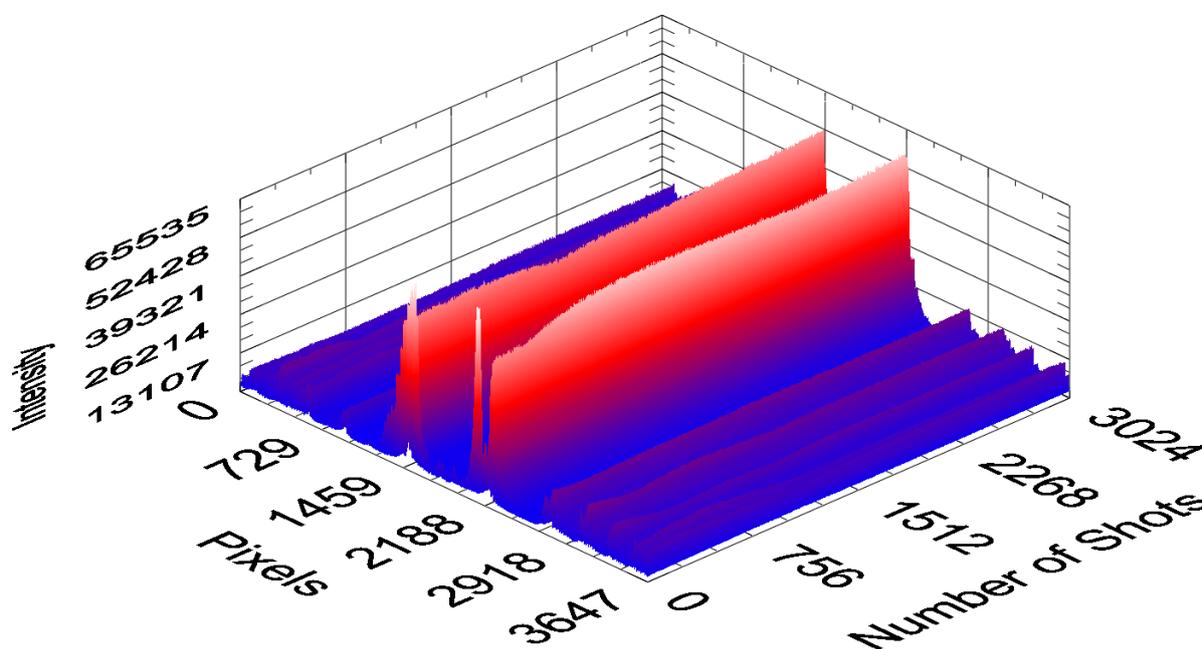
Figure 5-24: Record of the Fabry-Perot Interference Pattern Evolution

Another recorded data set is shown in a second run that clearly demonstrates the slight change of the laser frequency (best visible through the spacing change for the most inner maxima of the interference pattern) during the warm-up stage (see Figure 5-25).
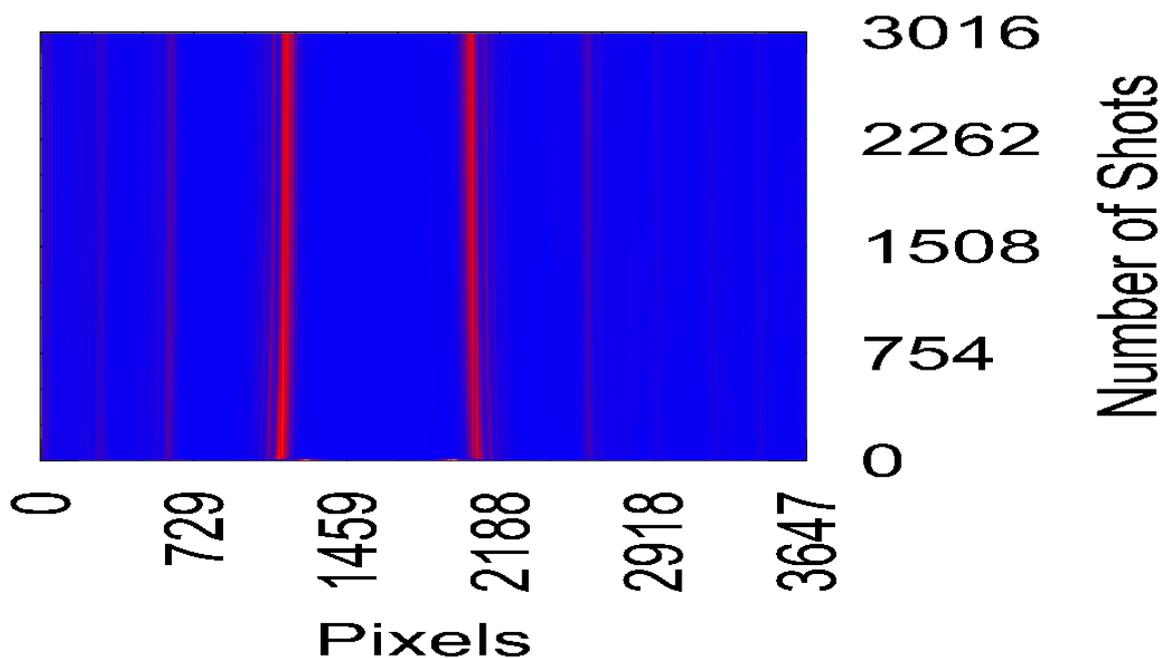
Figure 5-25: Laser Frequency Drift as Function of Time (Number of Shots)

Reference:

[1]. K. A. Stankov and I.Y.Milev, **Use of a vacuum-planar photodiode to drive an electro-optic Q-switch directly**, APPLIED OPTICS, Vol. 30, No. 36 , (1991) p. 5250

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5.5.3. Other External Synchronization Applications with Dual-Triggering

In the following **CCD operating modes** the **trigger output** (TRIG OUT) may be used to **synchronize** an external device or system that will then assert the **trigger input** (TRIG IN) as **hardware capture start / enable** signal to start or enable capture in the current frame:

- **Internally synchronized, continuously running, with hardware capture start**
- **Internally synchronized, continuously running, with hardware capture enable**

This can be useful to **capture only very specific events** that are synchronized to the trigger output from the CCD. See Figure 5-26.
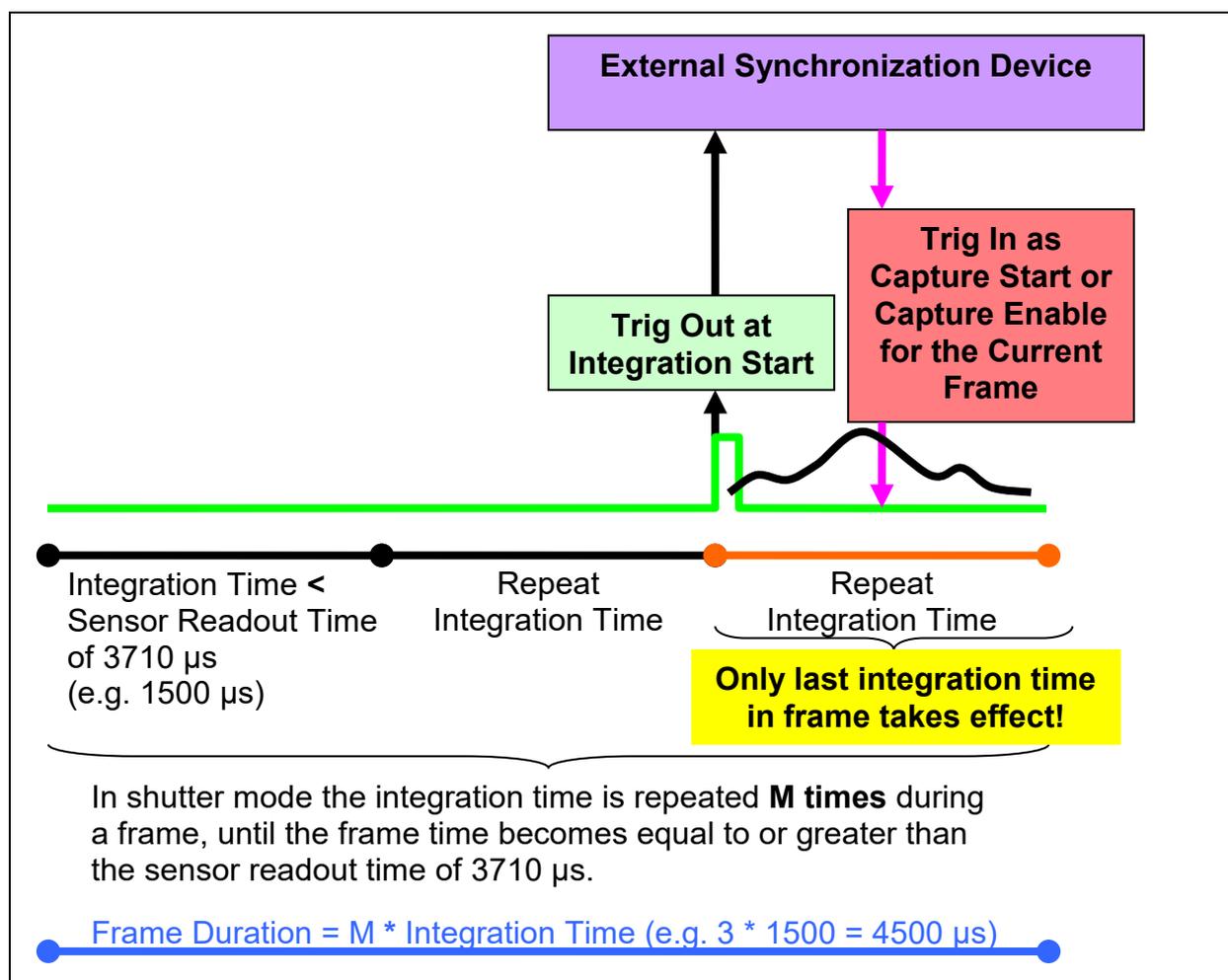
Figure 5-26: Trig Out at Integration Start used Together with Trig In

In order to **capture the current frame**, one can assert TRIG IN **right after** the TRIG OUT rising edge. The assertion of TRIG IN must happen **at least 5 µs before the integration period expires**. This is required because of the way how the sensor integrates frames. For example, if the integration time is set to the absolute minimum

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of 10 µs (shutter mode used and integration takes place in the last 10 µs of the frame) and TRIG OUT uses no trig out offset, the TRIG IN should be asserted in less than 5 µs after the TRIG OUT rising edge in order to start capture / enable capture in the **current** frame.

5.5.4. Trigger Output = "Integration End" in Externally Synchronized Mode

In contrast to the CCD operating modes described so far, in the **externally synchronized, continuously running, with software capture start** mode the trigger output signals **when** the **integration actually ends** in a frame (not when it starts).

This different behavior is due to the fact that the integration time and frame duration are **not known in advance** in this mode; they are defined during runtime by the external synchronization trigger input signal. Actually, there is **no difference if non-shutter mode or shutter mode is used here**. See Figure 5-27 for non-shutter mode and Figure 5-28 for shutter mode. An **offset cannot be defined**.
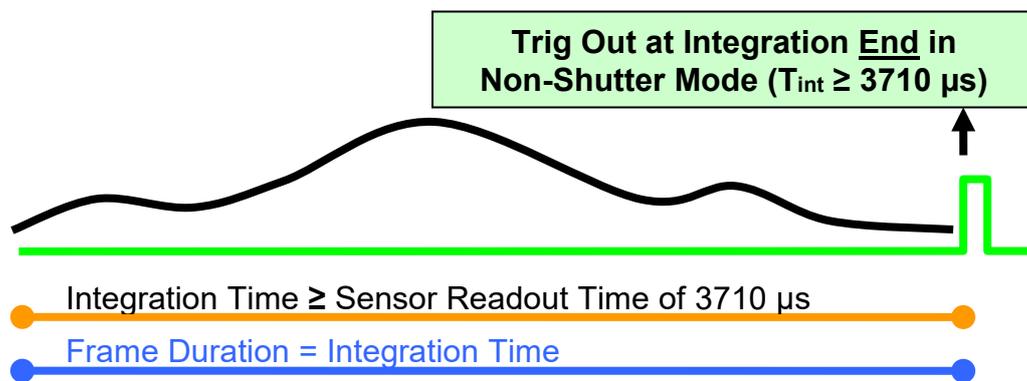
Figure 5-27: Trig Out at Integration End in Ext. Synch. Mode (Non-Shutter Mode)

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Trig Out at Integration **End** in Shutter Mode (T_{int} < 3710 µs)

Integration Time < Sensor Readout Time of 3710 µs (e.g. 1500 µs)

Repeat Integration Time

Repeat Integration Time

Only last integration time in frame takes effect!

In shutter mode the integration time is repeated **M times** during a frame, until the frame time becomes equal to or greater than the sensor readout time of 3710 µs.

Frame Duration = M * Integration Time (e.g. 3 * 1500 = 4500 µs)

Figure 5-28: Trig Out at Integration End in Ext. Synch. Mode (Shutter Mode)

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5.6.   Detailed Description of Commands and Programming

This chapter includes a detailed description of the CCD commands with the required data values and their default values. It also includes information on programming the device. This is useful if you want to program the device yourself.

Device communication details (required for low-level programming): Before communicating with the device, **port B** of the FTDI USB controller must be setup for communication via the D2XX driver. Please refer to the FTDI D2XX Programmer's Guide on the FTDI web site (www.ftdichip.com) for general information on interfacing the FT2232H USB chip. CCD commands to the device are sent via USB as single **command bytes, immediately followed by the corresponding data bytes** in the **binary** (not ASCII) format. The required number of data bytes will depend on the command. The device follows the "command – response" pattern and will always send a reply to the host PC. For some commands the reply will be an acknowledgement **ACK** (hex: 0x06) for valid commands and data; or a non-acknowledgement **NACK** (hex: 0x15) for invalid commands (e.g. unknown command) or for invalid data (e.g. data out of range). For acquisition commands the reply will be a **sequence of bytes representing the returned pixel data** values. For other device query commands the reply will contain values consisting of multiple bytes (e.g. the serial number). **All data is sent and received most significant bit (MSB) first, followed by the least significant bits (LSBs)**.

5.6.1. Configuration Commands

Set Integration Time Command

This command sets the integration time in microseconds (µs). The valid range is from 10 µs to 60 s.
For integration times from 10 µs to 3709 µs the sensor operates in shutter mode. For integration times equal to or above 3710 µs the sensor operates in non-shutter mode.
Important notes:
In single shot mode the integration time should be set to ≤ 500 µs.
The integration time setting will be ignored in external synchronization trigger mode because the external trigger period will define the integration time in that mode.

Unit: microseconds (µs)
Valid range: 10 µs – 60 000 000 µs

Default: 5000 µs = 5 ms

Command byte (hex): 0xC1
Data: 32-bit unsigned integer (4 bytes), MSB first
Reply from device: ACK (0x06) or NACK (0x15)

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Set Number of Frames (Scans, Readouts) Per Acquisition Command

This command sets how many frames will be captured in one acquisition. This setting applies to onboard data storage mode only. The maximum possible number of frames per acquisition is limited by the internal RAM of the device to 4599 (or 4541 if the user has chosen to include the dummy pixels in the readouts).

Important note: This setting will be ignored in the advanced data streaming mode because the number of frames is not limited in that mode and acquisition will continue until it is manually stopped.

Unit: N/A
Valid range: 1 – 4599   (4541 if dummy pixels are included in readouts)

Default: 1

Command byte (hex): 0xC2
Data: 32-bit unsigned integer (4 bytes), MSB first
Reply from device: ACK (0x06) or NACK (0x15)

Set CCD Operating Mode Command

This command sets the operating mode of the CCD. The five operating modes define the behavior of the device (external or internal synchronization, trigger types, etc.). The available operating modes are:

- **0: Internally synchronized, continuously running, with <u>software</u> capture start**
- **1: Internally synchronized, continuously running, with <u>hardware</u> capture start**
- **2: Internally synchronized, continuously running, with <u>hardware</u> capture enable**
- **3: <u>Single-shot</u>, clean & ready with external <u>hardware</u> trigger**
- **4: <u>Externally</u> synchronized, continuously running, with <u>software</u> capture start**

Unit: N/A
Valid range: 0 – 4 (please note that the first mode is number 0)

Default: 0 (Internally synchronized, continuously running, with software capture start)

Command byte (hex): 0xC3
Data: 8-bit unsigned integer (1 byte), MSB first
Reply from device: ACK (0x06) or NACK (0x15)

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Set Trig Out Before Integration Offset Command

This command sets the trig out offset prior to integration start in microseconds (µs). This offset can be used to indicate in advance that the integration will begin shortly but it is applicable **only when the sensor is in shutter mode (i.e. T_{int} < 3710 µs)** and applies **only to the following four operating modes**:

- Internally synchronized, continuously running, with software capture start
- Internally synchronized, continuously running, with hardware capture start
- Internally synchronized, continuously running, with hardware capture enable
- Single-shot, clean & ready with external hardware trigger

Important notes:
In the above operating modes when the sensor is in non-shutter mode this setting will be ignored as the integration begins at the start of a new frame and the offset is always 0 µs.
In external synchronization mode this setting is also ignored as the trig out signal has a different meaning and indicates when integration has finished (not when it has started).

Unit: microseconds (µs)
Valid range: 0 µs – 1849 µs

Default: 0 µs (= no offset)

Command byte (hex): 0xC4
Data: 32-bit unsigned integer (4 bytes), MSB first
Reply from device: ACK (0x06) or NACK (0x15)

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Enable Trigger Output Command *(Available since FW A1.10)*

Since firmware A1.10 the trigger output has been disabled by default (set to 0) after device initialization and should stay disabled during device configuration. This is to prevent glitches from appearing on the trigger output. This feature has been implemented in favor of additional protection of external devices connected to the trigger output. The user can enable the trigger output before initiating the acquisition as required. See also **chapter 5.5**.

After having configured all other device parameters, this command can be sent with parameter 1 = enabled in order to reenable the trigger output.

Important note: Please note that this option will be ignored on older devices (FW A1.00). Trigger output is always *enabled* on those devices.

Unit: N/A
Valid range: 0 or 1 (0 = disabled, 1 = enabled)

Default: 0 (= disabled)

Command byte (hex): 0xE1
Data: 8-bit unsigned integer (1 byte), MSB first
Reply from device: ACK (0x06) or NACK (0x15)

Set Hardware Dark Correction Command

This command turns the hardware dark correction of the device on or off. If this option is enabled (1) the optically black pixels at the beginning of the sensor will be used to automatically compute the average dark level for each frame in real time in hardware. This level will be then subtracted from the current signal level for all active pixels of that frame.

Important note: This setting will be ignored if the dummy pixels are set to be included in the readouts.

Unit: N/A
Valid range: 0 or 1 (0 = disabled, 1 = enabled)

Default: 0 (= disabled)

Command byte (hex): 0xC5
Data: 8-bit unsigned integer (1 byte), MSB first
Reply from device: ACK (0x06) or NACK (0x15)

Include Dummy Pixels in Readouts Command

This advanced command is normally not used. We recommend leaving this setting disabled. This advanced setting defines if the dummy pixels of the CCD sensor will be included in readouts. Because most of these pixels do not contain any useful information this setting should be normally left disabled. If disabled, only the active pixels of the CCD are included in readouts, which is the default.

Important note: If this setting is enabled, the Hardware Dark Correction setting will be always disabled.

Unit: N/A
Valid range: 0 or 1 (0 = disabled, 1 = enabled)

Default: 0 (= disabled)

Command byte (hex): 0xC9
Data: 8-bit unsigned integer (1 byte), MSB first
Reply from device: ACK (0x06) or NACK (0x15)

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5.6.2. Acquisition Commands

After having configured the device to the desired operating mode and parameters, one can initiate an acquisition by using the commands described below.

Initiate Acquisition in Onboard Data Storage Mode Command
(acquisition will auto-stop after capturing the preset number of frames)

This command initiates an acquisition for the preset number of frames (scans). Up to 4599 captured frames can be set to be stored in onboard RAM. Acquisition will auto-stop after capturing the preset number of frames; no explicit stop command is required.

Important notes: After acquisition of the specified number of frames is complete, the device immediately starts sending all captured data to the PC. This data must be then fetched by the host PC. Before the acquired data has been fetched, the device cannot process further commands. Any further commands will be accepted after data has been fetched which may take a few seconds because of the large internal storage of the device. E.g. turning the trigger output off will take effect with some delay after the actual acquisition has finished and the trigger output will still be active during this time. Just keep this in mind.

Command byte (hex): 0xC6
Data: N/A
Reply from device: When acquisition of the specified number of frames has finished, the device will return all pixel data values from all captured frames. Each frame consists of 3648 pixel data values (or 3694 pixel data values if the dummy pixels are included). Each data value is 16 bits (2 bytes), MSB first.

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Initiate Acquisition in Data Streaming Mode and Stream Data Until Manually Stopped Command (does not use the preset number of frames)

This command initiates an acquisition in data streaming mode. In this mode the device will immediately stream any captured data to the host PC. There is no frame limit. The only limit is the storage device used (please also observe the maximum file size allowed by the underlying file system used on your storage device). In this advanced mode the configured number of frames (scans) per acquisition is completely ignored. Instead, the acquisition of triggered scans will continue until it is manually stopped by sending the **Stop Acquisition and Data Streaming** command (described below). After receiving the stop command, the device will capture one more frame and then stop acquisition. During streaming, the onboard RAM is used as a big FIFO frame buffer and prevents data overflow during capture.
During acquisition, acquired data will be continuously streamed to the PC and each scan must be fetched in time. The device features advanced buffering technology allowing the PC to fetch the data without buffer overflows. Nevertheless, the user must make sure that data is fetched as soon as possible and written to disk. Because in streaming mode the constant data rate is very high, it is not recommended to attempt to view the streaming data in real time. Instead, write the data to disk and view it later.

Programming logic tips: As described, <u>during</u> streaming one should periodically fetch captured frames. As soon as acquisition has been <u>stopped</u> by calling the *Stop Acquisition and Data Streaming* command, it is not sure if there are more scans to arrive that have to be fetched. If there are frames left in the buffer after acquisition is stopped, they will be still streamed to the PC. Therefore, the incoming device buffer should be checked for pending data even after acquisition has been stopped; if there is such data, it should be fetched. If there is no data in the buffer *for a longer time*, the last streaming data has been already fetched and the acquisition is complete.

The FIFO RAM buffer is very large and should be able to buffer data without overflowing if the data is regularly fetched by the host PC. Nevertheless, if the buffer should overflow for some reason, this will be indicated by the red error LED on the device. In this case, streaming will be aborted. Please disconnect and reconnect the device from USB in order to reset it in case of this error.

Programming in data streaming mode is recommended for advanced users only. If you are using LabVIEW, please look at the included data streaming applications for more information.

Command byte (hex): 0xC7
Data: N/A
Reply from device: Acquired pixel data values will be immediately and continuously *streamed* to the host PC during acquisition. After acquisition has been stopped, if there is still data in the frame buffer, it will be also streamed to the PC. Each frame

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consists of 3648 pixel data values (or 3694 pixel data values if the dummy pixels are included). Each data value is 16 bits (2 bytes), MSB first.

Stop Acquisition and Data Streaming Command

This command stops the current acquisition and streaming in data streaming mode. In this advanced mode the configured number of scans per acquisition is completely ignored. Instead, the acquisition of triggered scans will continue until it is manually stopped by sending this command.

As soon as we have stopped acquisition by sending this command, we are not sure if there are more scans to arrive that have to be fetched. Therefore, we should continue to check for pending data in the incoming device buffer. If there is more data to be fetched, we can then fetch the scans. If there is no data in the buffer for *a longer time*, the last streaming data has been already fetched and the acquisition is complete.

Programming in data streaming mode is recommended for advanced users only. If you use LabVIEW, please look at the included data streaming applications for more information.

Command byte (hex): 0xC8
Data: N/A
Reply from device: The device will stream the last data left in the buffer.

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5.6.3. Other Commands

Query Device Serial Number Command

This command queries the 64-bit (8-byte) serial number of the device.

Command byte (hex): 0xD1
Data: N/A
Reply from device: 64-bit unsigned integer (8 bytes), MSB first.

Query Device Hardware and Firmware Signature Command

This command queries the 64-bit (8-byte) hardware & firmware signature of the device.

Command byte (hex): 0xD2
Data: N/A
Reply from device: 64-bit unsigned integer (8 bytes), MSB first.

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5.7.   Time Needed to Acquire, Fetch & Display Frames (Measured in LabVIEW)

The time needed to initiate an acquisition from the host PC, capture all frames back-to-back, fetch those frames to the host PC and finally display them in a LabVIEW graph depends on multiple factors, including the hardware and speed of the host PC.

We have done some measurements with LabVIEW 8.6 and Windows XP on an Intel Core2Duo CPU notebook which is considered a low-end configuration. The results may vary depending on the hardware and software running on the host PC. They are for information purposes only.

When acquiring **single frames** (one scan per acquisition) with $T_{int} = T_{readout} = 3.71$ ms, fetching these frames and **displaying** them in a LabVIEW graph we measured a total acquisition-to-acquisition delay of ~ 13 ms. This corresponds to an acquisition, fetch & display rate of ~ 77 Hz.

When acquiring the **maximum number of 4599 frames** that can be stored at once in onboard RAM (4599 scans per acquisition) with $T_{int} = T_{readout} = 3.71$ ms, fetching these frames, **averaging and displaying** them in a LabVIEW graph we measured a total acquisition-to-acquisition delay of ~ 26200 ms. This corresponds to ~ 5.7 ms for each frame.

Again, the values above are for information purposes only and will depend on the configuration of the host PC.

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6. Connecting the CCD & Installing the USB Drivers

> ⚠️ **Please carefully read the following instructions, BEFORE connecting the device to the computer.**

The CCD device has to be connected to a spare **USB 2.0 port** on your computer using an appropriate USB 2.0 cable. The cable must have a type B plug on the CCD side. Most host computers require a type A plug on the host side. Depending on your operating system, the driver installation will vary as described below.

6.1. Microsoft Windows

> **Microsoft Windows operating systems will indicate that new hardware has been found and will either install the driver without any user intervention or ask the user to confirm that the OS should search for the driver in the Windows Update database and will then install it automatically.**

Microsoft Windows OS already have the required WHQL certified D2XX FTDI drivers in their database and are able to install them automatically. Therefore, in most cases installation is extremely easy and will complete within seconds.

On device plug-in a message will pop up in the task bar indicating that a new ALPHALAS CCD-S3600-D(-UV) device has been found. The driver will be either installed without any user intervention (this is typical for Windows 7 and later) or a wizard will indicate that new hardware has been found and ask if the OS should connect to Windows Update to search for the appropriate driver (this is typical for Windows Vista and Windows XP). The user should confirm and let the OS download and install the driver automatically.

Please note that the found new hardware wizard may pop up multiple times, because modern FTDI devices have multiple ports and use multiple drivers. Confirm the installation prompts until all drivers have been installed. The OS may need some time to find the drivers, download and install them. Please be patient and do not unplug the device until the drivers have been installed completely.

If the drivers have been installed correctly, two USB devices called **USB Serial Converter A** and **USB Serial Converter B** should have appeared in the Windows Device Manager under Universal Serial Bus Controllers. These devices represent both ports (A and B) of the dual-port FT2232H chip. In the advanced properties of these devices the "Load VCP" option should remain *unchecked*, which means that the driver will use the faster D2XX mode instead of the slower virtual com port (VCP) mode of the combined drivers.

For further information please refer to http://www.ftdichip.com/FTDrivers.htm.

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6.2.   Linux, Mac OS X, etc.

The CCD-S3600-D(-UV) uses the **FT2232H chip** from FTDI. The recommended USB drivers for this chip are the direct **D2XX** drivers, *not* the VCP (virtual COM port) drivers. The D2XX drivers are faster and the recommended choice for this high-speed chip. They are accessed through a special API. The LabVIEW applications included with the CCD device use these D2XX drivers.

As described previously, the latest Microsoft Windows OS should be able to install the appropriate drivers automatically. This is the easiest and recommended way to install the drivers in Windows OS. If you are using a different operating system like Linux or Mac OS or want to install or update your driver manually, please visit the FTDI website. At http://www.ftdichip.com/Drivers/D2XX.htm you can find the appropriate drivers for the FT2232H chip and for your specific OS. You should use the D2XX drivers for fastest performance and compatibility with the examples. Please read the driver installation instructions for your OS. On the FTDI website you can also find detailed troubleshooting instructions. Please note that ALPHALAS is not able to provide support for all operating systems supported by the drivers.

6.2.1. Linux

Please note that on many modern **Linux** distributions (e.g. Ubuntu, openSUSE, etc.) FTDI drivers are already included with the kernel and will be loaded automatically as soon as the device is plugged in. However, the drivers that are loaded by default are *not* **the fast D2XX** drivers but the slower virtual com port (VCP) drivers which present the device to the OS as an emulated com port. The VCP drivers are not compatible with the D2XX API used in the examples. Therefore you should manually **install the fast D2XX Linux drivers** from http://www.ftdichip.com/Drivers/D2XX.htm. For installation details please refer to the Linux ReadMe files at that webpage.

Before you can use the D2XX drivers you must always **unload** the VCP drivers that have been automatically loaded by the kernel. This has to be done every time the device is plugged in. You can check if the VCP drivers have been loaded by entering **dmesg | grep FTDI**. If there are messages containing *ftdi_sio*, then the VCP drivers have been loaded and *need to be unloaded* first as root user or by running sudo: **sudo rmmod ftdi_sio** and **sudo rmmod usbserial**.

Another important thing is that the FTDI library makes use of libusb. In order to get access to a USB device you have to **run all programs that access the USB device as a root user** or by using **sudo**. For LabVIEW this means starting it like this: **sudo ./labview**

Instead of using sudo as described above, you may also change the permissions by a udev rule like described here:
http://code.google.com/p/picusb/wiki/libusb_and_udev
The device's VID is 0x0403 and the PID is 0x6010.

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6.2.2. Mac OS X

For **Mac OS X** installation notes please refer to the Mac OS X ReadMe files at
http://www.ftdichip.com/Drivers/D2XX.htm. Make sure that you install the drivers
compatible with your Mac OS X version.

If you are **only using LabVIEW for Mac** to access the CCD camera you may skip
the installation for the USB drivers because LabVIEW for Mac accesses the device
through a Mac OS X framework instead of using the driver libraries directly. Please
refer to chapter 8.1.3 for detailed information.

6.2.3. Other OS

For **other operating systems** or **manual driver installation** instructions please
refer to http://www.ftdichip.com/Drivers/D2XX.htm.

6.2.4. libftdi – An Alternative to D2XX

In addition to the closed source FTDI D2XX drivers & API, an **open source**
alternative API called **libftdi** also exists. Libftdi works with Linux, Windows, MacOS X
and BSD variants because it is based on the libusb driver. The user should be able
to use this API, however ALPHALAS has not tested it and cannot provide support.
The libftdi API is different from the D2XX API. For further details please refer to
http://www.intra2net.com/en/developer/libftdi/.

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7. Acquisition & Viewer Software for Windows

7.1. Overview
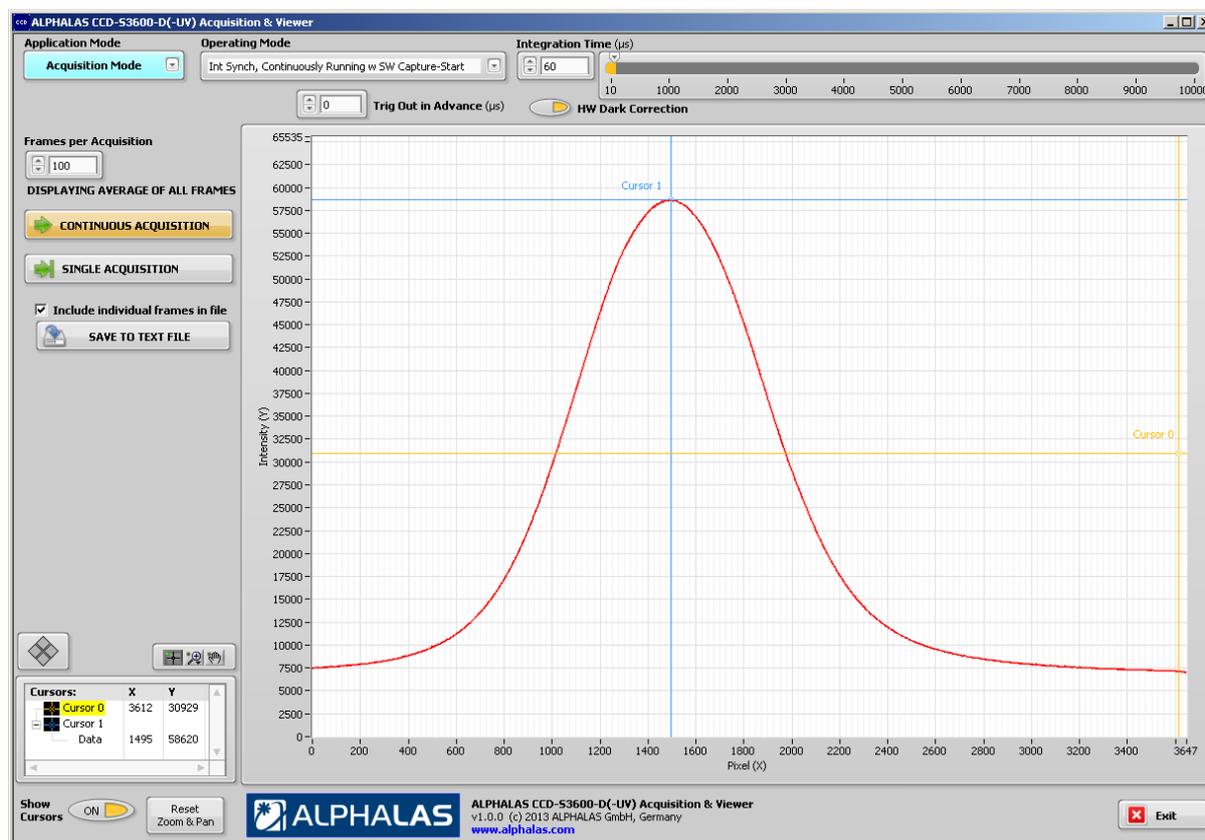
Figure 7-1: Acquisition & Viewer Software

The Acquisition & Viewer Software for Windows is now included for free. The software is easy to use and does NOT require a LabVIEW license to run.

7.1.1. Acquisition Mode

- Easily control the CCD camera and all settings: operating modes (incl. all trigger modes), integration times, frames per acquisition, HW dark correction, trig out in advance
- Easily acquire CCD data: continuous acquisition mode & single acquisition mode
- Easily save CCD data: average of all frames + all individual frames, all acquisition parameters and device settings are also saved in the versatile text file format for easy access from any other software (e.g. Microsoft Excel, text editors, mathematical software, etc.)

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7.1.2. Viewer Mode

- Easily load & view saved data
- View average & individual frames from any acquisition; saved acquisition parameters are also displayed

7.1.3. Tools Included in the Software

- Zoom & panning, cursors (free & snapping)
- Direct export of acquired data as image files, to clipboard or to Microsoft Excel

7.2. Installation

In order to install the Acquisition & Viewer Software for Windows please complete the following steps:

1. **Make sure that the device drivers are installed**

   Please plug in the CCD camera and let your Windows OS install all drivers. The device drivers must be installed properly in order to run the software.

2. **Run the Executable Installer**

   Please run setup.exe and follow the steps in order to install the Acquisition & Viewer Software for Windows.

   Note: The installer already includes the required LabVIEW Run-Time Engine; no manual installation is required.

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8. LabVIEW Drivers & GUI Applications

> ⚠ **Please carefully read the following instructions, BEFORE installing the LabVIEW drivers.**

8.1.   Installing the LabVIEW Drivers

8.1.1. Instructions for All Operating Systems

In order to use the LabVIEW drivers, first make sure that the required FTDI D2XX USB drivers have been installed properly as described in chapter 6. In the latest Windows versions this happens automatically.

The ALPHALAS LabVIEW drivers are located in the "**ALPHALAS CCD S Series**" subfolder of the "**LabVIEW Drivers and Apps**" folder provided to the customer via e-mail download link, on a USB stick or in a similar way.

32 bit LabVIEW:
In "**LabVIEW Drivers and Apps**" you will find one subfolder with the (older) driver supporting only 32 bit versions of LabVIEW (since v8.6). The "classic" 32 bit versions of LabVIEW run fine on 64 bit Windows 10 and National Instruments even recommends using them, also for compatibility with existing 32 bit LabVIEW libraries and some 32 bit only LabVIEW features. In order to support older as well as newer LabVIEW versions, the driver has been created with LabVIEW 8.6 but it is also compatible with the latest 32 bit versions of LabVIEW.

64 bit LabVIEW:
On the other hand, we noticed that some customers now install the true 64 bit version of LabVIEW and therefore we now added driver support for this version under Windows. Therefore, you will find a second folder with this newer driver that adds support for 64 bit LabVIEW. The new driver works with LabVIEW 2017 and later for Windows. It actually supports the 64 bit as well as the 32 bit versions of LabVIEW for Windows and can therefore be used on any of these. The 64 bit driver calls the 64 bit FTDI driver DLL. *Please note that the 64 bit version of LabVIEW may not support some of the 32 bit only features of LabVIEW like ActiveX based 3D graphs.*

Copying the 32 bit -or- 64 bit LabVIEW driver to your LabVIEW directory:
In order to install the LabVIEW driver, simply copy the complete "**ALPHALAS CCD S Series**" subfolder including *all* of its contents into your LabVIEW "**instr.lib**" folder. This LabVIEW folder contains all instrument driver folders and is located in your main LabVIEW directory.

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Example for **LabVIEW 2021** (English version) on Windows 10 **64-bit**: If you have installed LabVIEW into its **default** installation location:

- o If you have installed the **32-bit version of LabVIEW**, your "instr.lib" folder would be the following :
  "C:\Program Files (x86)\National Instruments\LabVIEW 2017\instr.lib"
- o If you have installed the **64-bit version of LabVIEW** your "instr.lib" folder would be the following :
  "C:\Program Files\National Instruments\LabVIEW 2017\instr.lib"

The driver VIs will be automatically recompiled by the newer LabVIEW versions in the background when used for the first time and may prompt the user to save them for the newer LabVIEW version.

You may also do a manual mass compile of the driver and VIs for your LabVIEW version by opening the **ALPHALAS CCD S Series.lvproj** project file that you can find in the **…\instr.lib\ALPHALAS CCD S Series** folder, then right-clicking on the main project item and selecting **Mass Compile…** from the pop-up menu.

By default the LabVIEW driver is ready to be used with **Microsoft Windows**. For additional information on using the driver in LabVIEW for **Linux** please refer to chapter 8.1.2. For additional information on using the driver in LabVIEW for **Mac OS X** please refer to chapter 8.1.3.

8.1.2. Special Instructions for LabVIEW for Linux

If you are using LabVIEW for Linux first make sure that the FTDI D2XX Linux USB drivers have been installed as described in chapter 6.2.1. Also make sure that ftdi_sio and usbserial have been removed from the active modules via rmmod as described in that chapter.

Make sure that you have copied the LabVIEW driver to your instr.lib folder as described in chapter 8.1.1. While the LabVIEW for Windows driver uses FTDI's *d2xx.dll* for Windows, the LabVIEW for Linux driver uses **libftd2xx.so** instead. For this reason you have to *replace* the folder **FTDI D2XX Functions** which contains the Windows files by default and is located in
Your LabVIEW Folder/instr.lib /ALPHALAS CCD S Series/Private
with the corresponding folder containing the *Linux* files by doing the following:

1. Shut down LabVIEW for Linux.
2. Rename the existing **FTDI D2XX Functions** folder to **Windows FTDI D2XX Functions**
3. Rename the **Linux FTDI D2XX Functions** folder to **FTDI D2XX Functions**

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Now the FTDI D2XX Functions folder contains the required Linux files and the LabVIEW drivers are ready for use with Linux.

Another important thing is that the FTDI library makes use of libusb. In order to get access to a USB device you have to **run all programs that access the USB device as a root user** or by using **sudo**. For LabVIEW this means starting it like this:
sudo ./labview

Instead of using sudo as described above, you may also change the permissions by a udev rule like described here:
http://code.google.com/p/picusb/wiki/libusb_and_udev
The device's VID is 0x0403 and the PID is 0x6010.

8.1.3. Special Instructions for LabVIEW for Mac OS

Make sure that you have copied the LabVIEW drivers to your instr.lib folder as described in chapter 8.1.1.

It is important to note that LabVIEW for Mac versions prior to 2011 are not able to use the dynamic shared libraries (*.dylib) included in the FTDI D2XX Mac OS X drivers directly. Therefore, a special framework had to be created. After having installed the LabVIEW driver as described in chapter 8.1.1 you can find this framework in *Your LabVIEW Folder/***instr.lib/ALPHALAS CCD S Series/Private/Framework for Mac OS X for FTDI D2XX**
directory. Please also refer to the README file in that folder. In order to install the driver framework, please do the following:
1. First copy the libftd2xx.framework.zip contained in this folder to your Mac desktop (do NOT unzip it in Microsoft Windows because important properties of the files will get lost!).
2. Unzip the libftd2xx.framework.zip file on your Mac by double clicking it. It should be now extracted into a libftd2xx.framework folder.
3. Copy this complete libftd2xx.framework folder to the existing /Library/Frameworks folder on your Mac.
4. You should now have a /Library/Frameworks/libftd2xx.framework folder.

While the LabVIEW for Windows driver uses FTDI's *d2xx.dll* for Windows, the LabVIEW for Mac OS X driver uses the **libftd2xx.framework** instead. For this reason you have to *replace* the folder **FTDI D2XX Functions** which contains the Windows files by default and is located in
*Your LabVIEW Folder/***instr.lib /ALPHALAS CCD S Series/Private**
with the corresponding folder containing the Mac files by doing the following:

1. Shut down LabVIEW for Mac.
2. Rename the existing **FTDI D2XX Functions** folder to **Windows FTDI D2XX Functions**

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3. Rename the **Mac FTDI D2XX Functions** folder to **FTDI D2XX Functions**

Now the FTDI D2XX Functions folder contains the required Mac files and the LabVIEW drivers are ready for use with your Mac.

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8.2. Using the LabVIEW Drivers

After having installed the LabVIEW drivers as described in chapter 8.1, please restart LabVIEW.

If the installation is successful you should be able to access the "**ALPHALAS CCD S Series**" instrument driver VIs through the palette menu:

1. Go to the block diagram of any VI and right-click to open the "**Functions Palette**".

2. In the "Functions Palette" you should be able to locate the driver VIs under "**Instrument I/O >> Instrument Drivers >> ALPHALAS CCD S Series**".

The main palette icon of ALPHALAS CCD S Series looks like this .

The palette contents are shown in Figure 8-1.
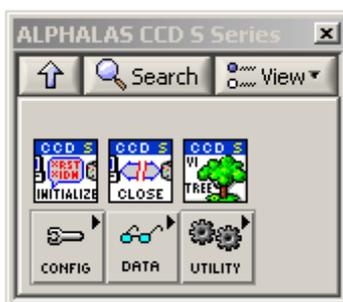
Figure 8-1: The LabVIEW Driver in the Functions Palette

The driver structure is shown in the "VI Tree VI" in Figure 8-2:

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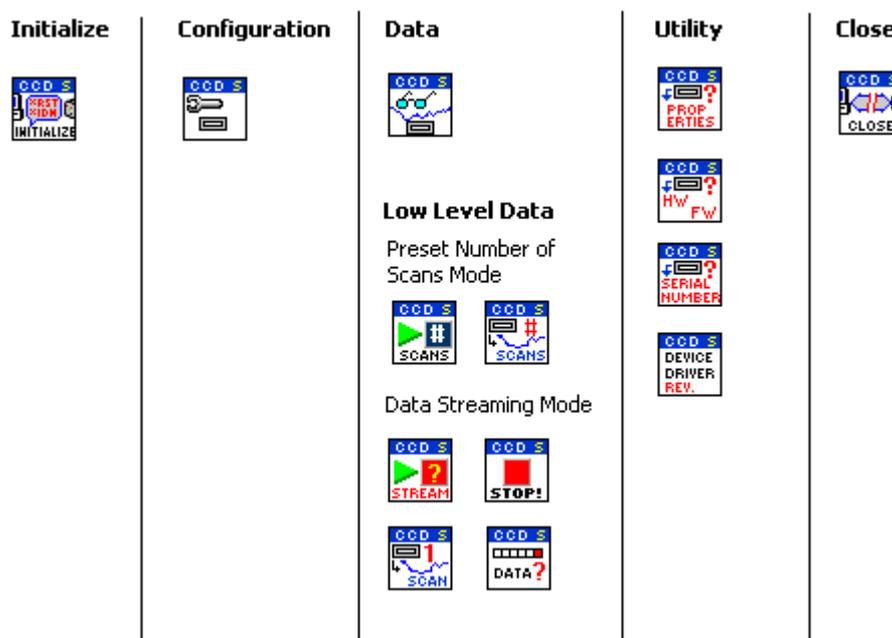
Figure 8-2: The LabVIEW Driver Structure Shown in the VI Tree VI

- The driver contains the common "Initialize VI" and "Close VI".
- The CCD device can be configured using the "Configure Acquisition VI".
- Making an acquisition of the number of scans set by the user and finally fetching all data can be done by using the high-level "Acquire Preset Number of Scans and Fetch Data VI". The low-level data VIs can be used for finer control of the device in *preset number of scans* mode or in the more advanced *data streaming* mode.
- The utility VIs can be used to query the device properties, the device hardware and firmware, the device serial number and the driver revision.

All driver VIs are well documented. Please use the LabVIEW Context Help to access the documentation.

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8.3.   LabVIEW Examples & GUI Application VIs

Fully-functional LabVIEW GUI application VIs are included with the device. All drivers and VIs are modern project-style, designed for plug&play operation. The VIs include well-commented block diagrams, front panels and context help and are built according to the National Instruments LabVIEW development guidelines.

LabVIEW applications & examples include:

- Single Acquisition VI
- Single Acquisition to File VI
- Acquisition Loop VI
- Acquisition Loop with Runtime-Changeable Parameters VI
- 3D Realtime Graph (Active X Version) VI
- 3D Realtime Graph (Native Version) VI
- Data Streaming to File VI
- View Data from File VI
- View Data from File in 3D Graph VIs (multiple variations)
- Gaussian Fit Loop VI
- Acquisition Loop with Save and Load and Full-Width Half-Maximum Calculation VI
- Acquisition Loop with Multiple CCD Cameras VI
- Device Information VI
- Speed Test VI

All application VIs and driver VIs contain documentation and comments.

All driver VIs and applications are contained in a single LabVIEW project.

Please open the "**ALPHALAS CCD S Series.lvproj**" project file in your "**instr.lib\ALPHALAS CCD S Series**" folder in your main LabVIEW directory. The application & example VIs, are in the folder "**Examples**". See Figure 8-3.

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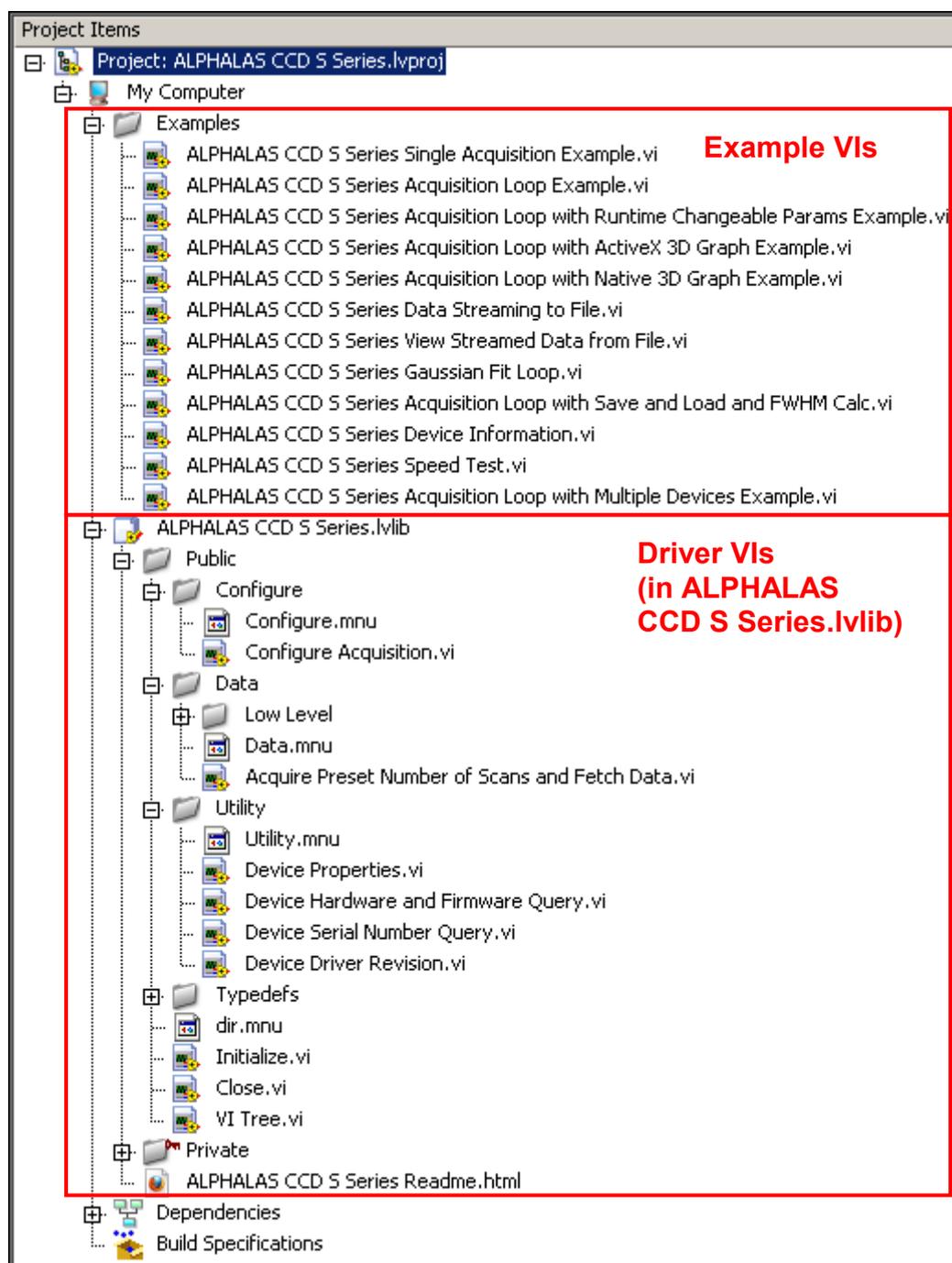
Figure 8-3: The LabVIEW Project Containing the Example VIs

Before running any example VIs you need to have the CCD device connected to the computer and the USB drivers as well as the LabVIEW drivers installed, as described in the previous sections of this manual.

Make sure that you have set all parameters to valid values before running the example applications. To read the documentation of the example Vis, please use the LabVIEW Context Help and see the comments on the front panels and block diagrams. Please note that different LabVIEW versions on different OS may display front panel fonts in different sizes; this is expected behavior of LabVIEW.

In the following figures screenshots of some of the example VIs are shown. For further information please refer to the front panel comments as well as the block diagrams of the VIs.
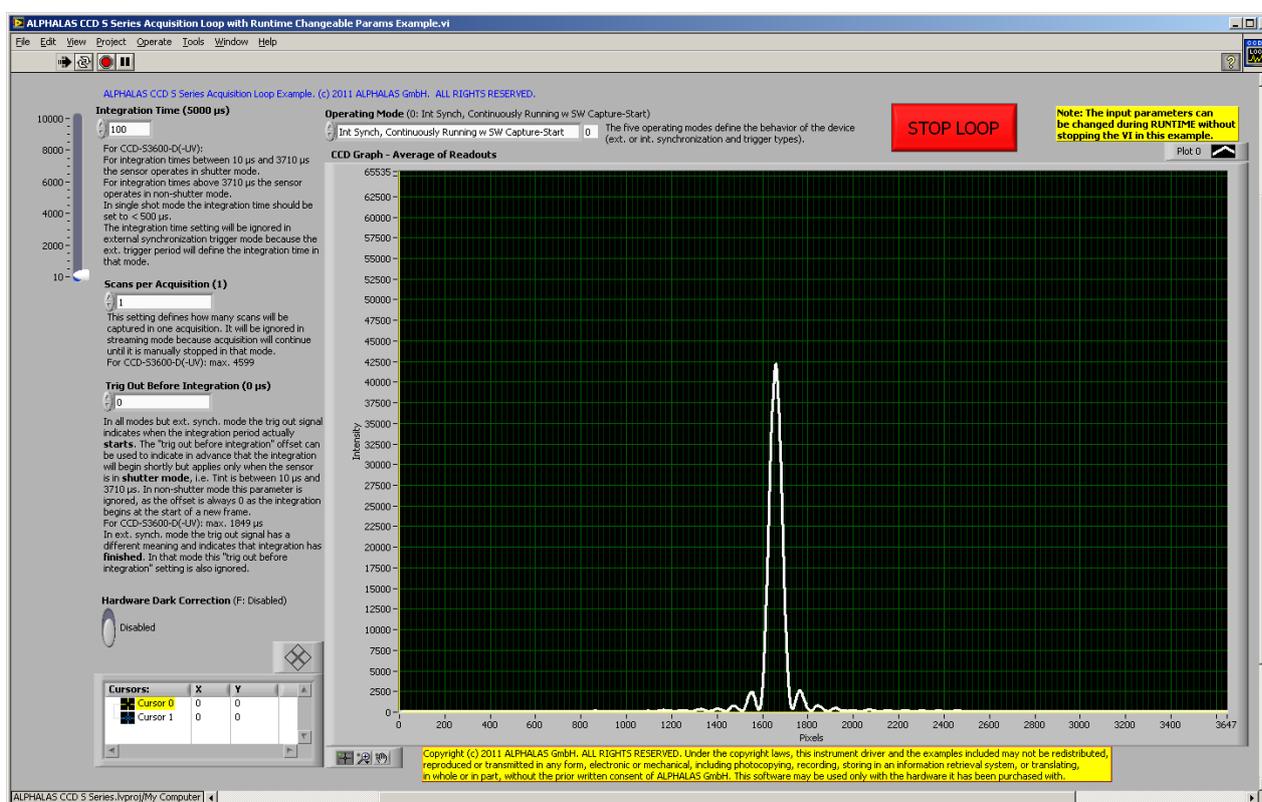

*Figure 8-4: Acquisition Loop with Runtime Changeable Parameters VI*

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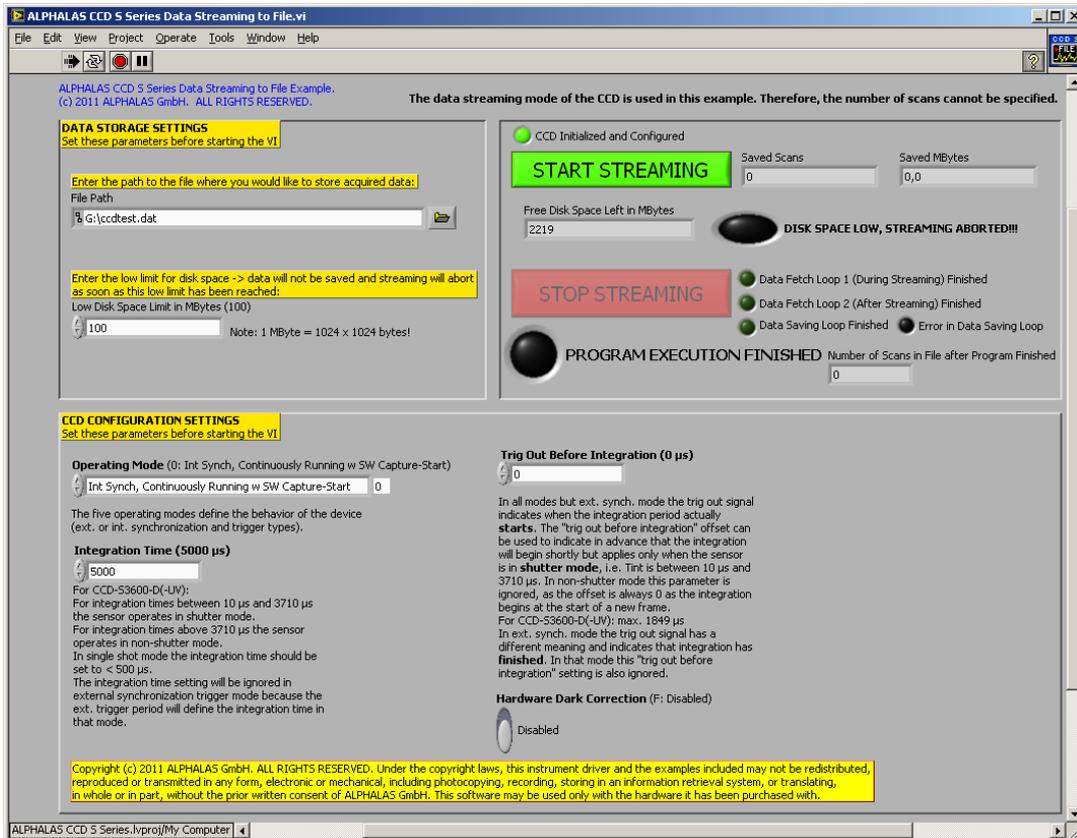
Figure 8-5: Data Streaming to File VI
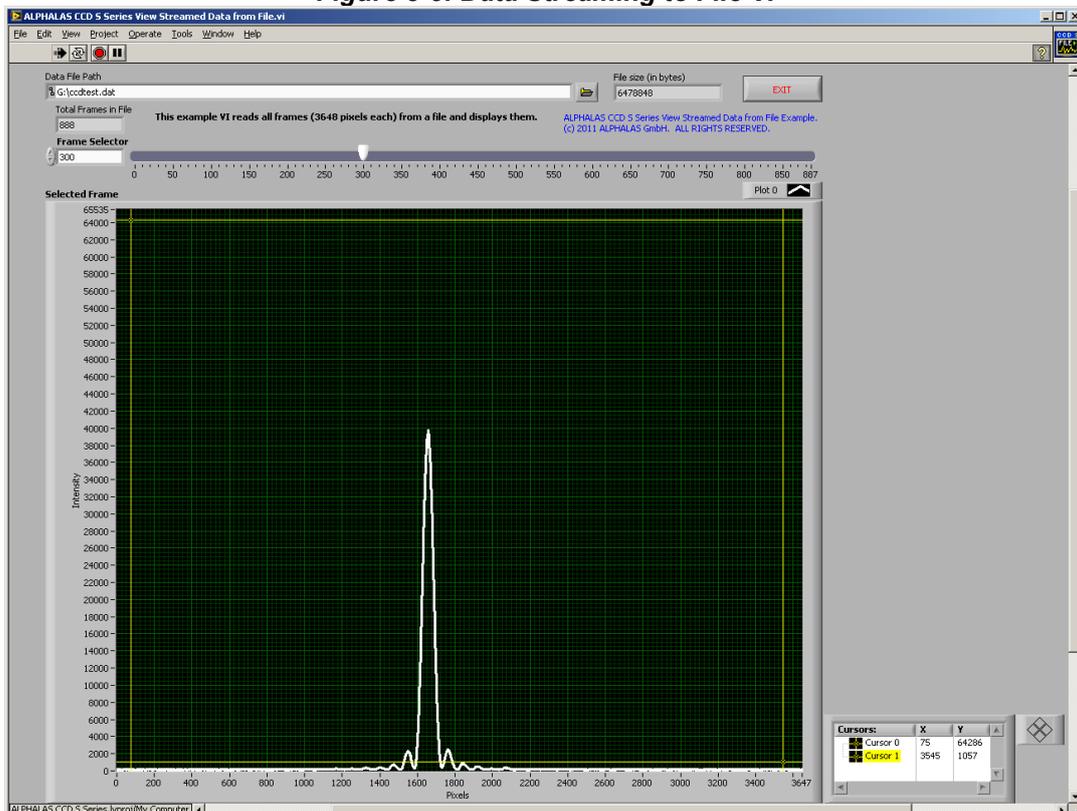
Figure 8-6: View Streamed Data from File VI

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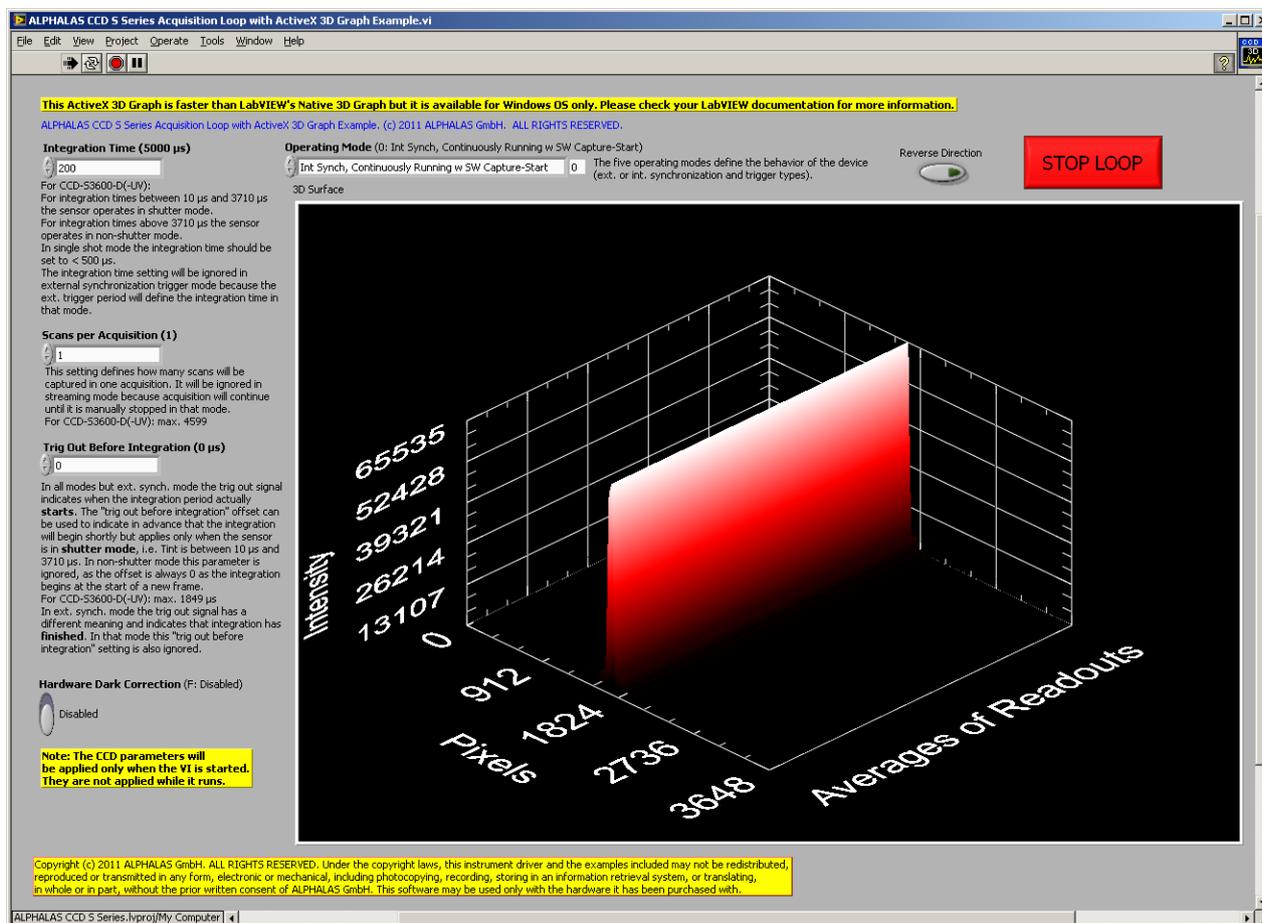
Figure 8-7: Acquisition Loop with 3D Graph VI

Please note that the Active X version of this example can be run on Windows OS only, as other OS do not support Active X.

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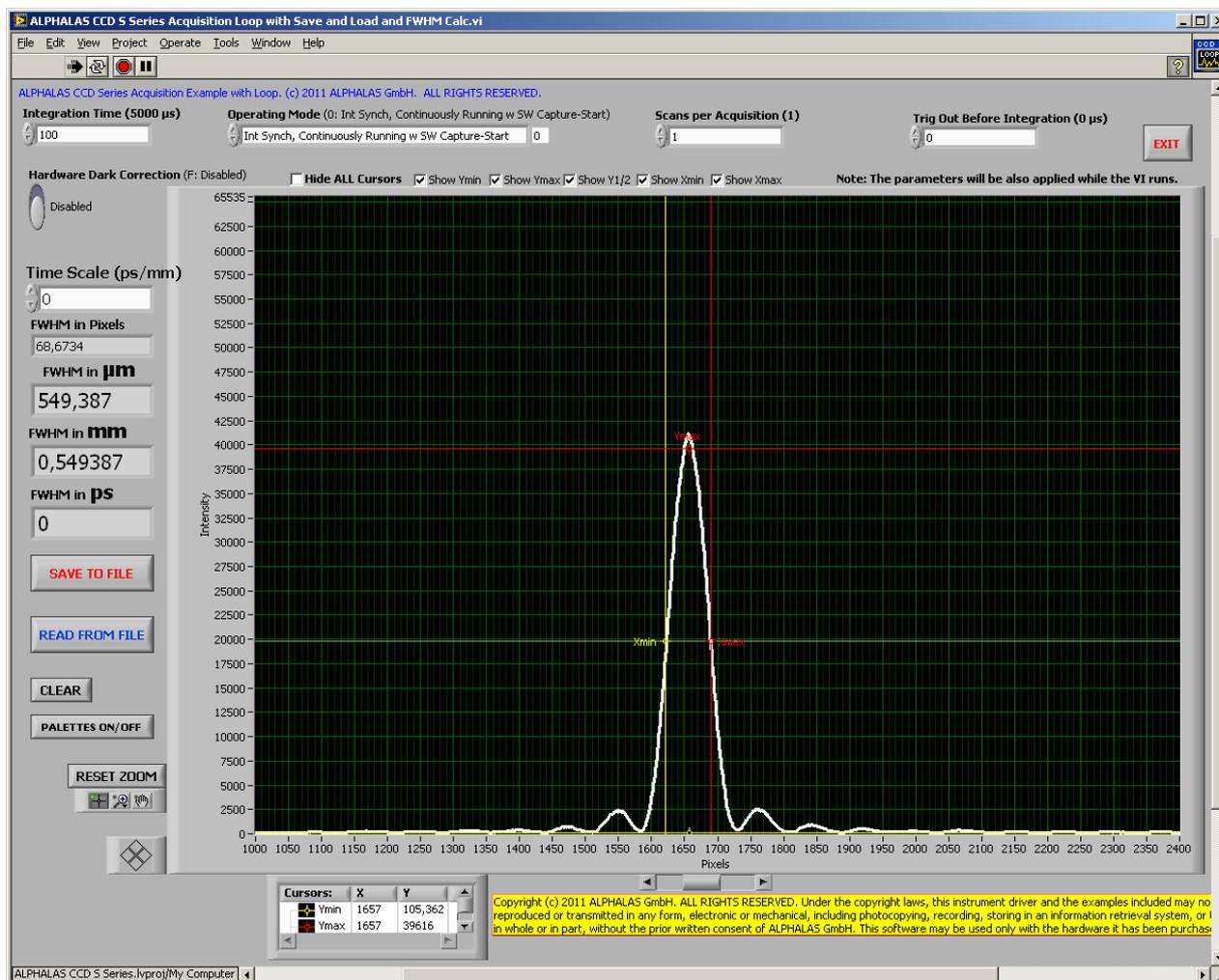
Figure 8-8: Acquisition Loop with Save and Load and FWHM Calculation VI

9. C++ Examples

The included C++ examples demonstrate how to interface and use the CCD-S3600-D-(UV) device from C++. The well-commented cross-platform console application code will initialize & configure the device with the user-specified parameters; then it will acquire and fetch the data and will finally print the values on the screen and write them into a comma-separated text file (CSV) as well as a binary file (big-endian).

All examples are located in the "**C++ Examples**" folder provided to the customer via e-mail, on a USB stick or in a similar way. The subfolders include:

- A **Visual C++** project for Microsoft **Windows**. This project is also compatible with the free Express edition of Visual C++. The project also contains the built executable (.exe) example for Windows.
- A **GCC C++** project for **Linux**, **Mac OS X** and other OS.

The source code is actually *the same* for Visual C++ and for GCC C++ and can be compiled under Windows, Linux, Mac OS X, etc. This is a good example that cross-platform development and access to the CCD camera is possible.

## 9.1. Microsoft Visual C++ for Windows
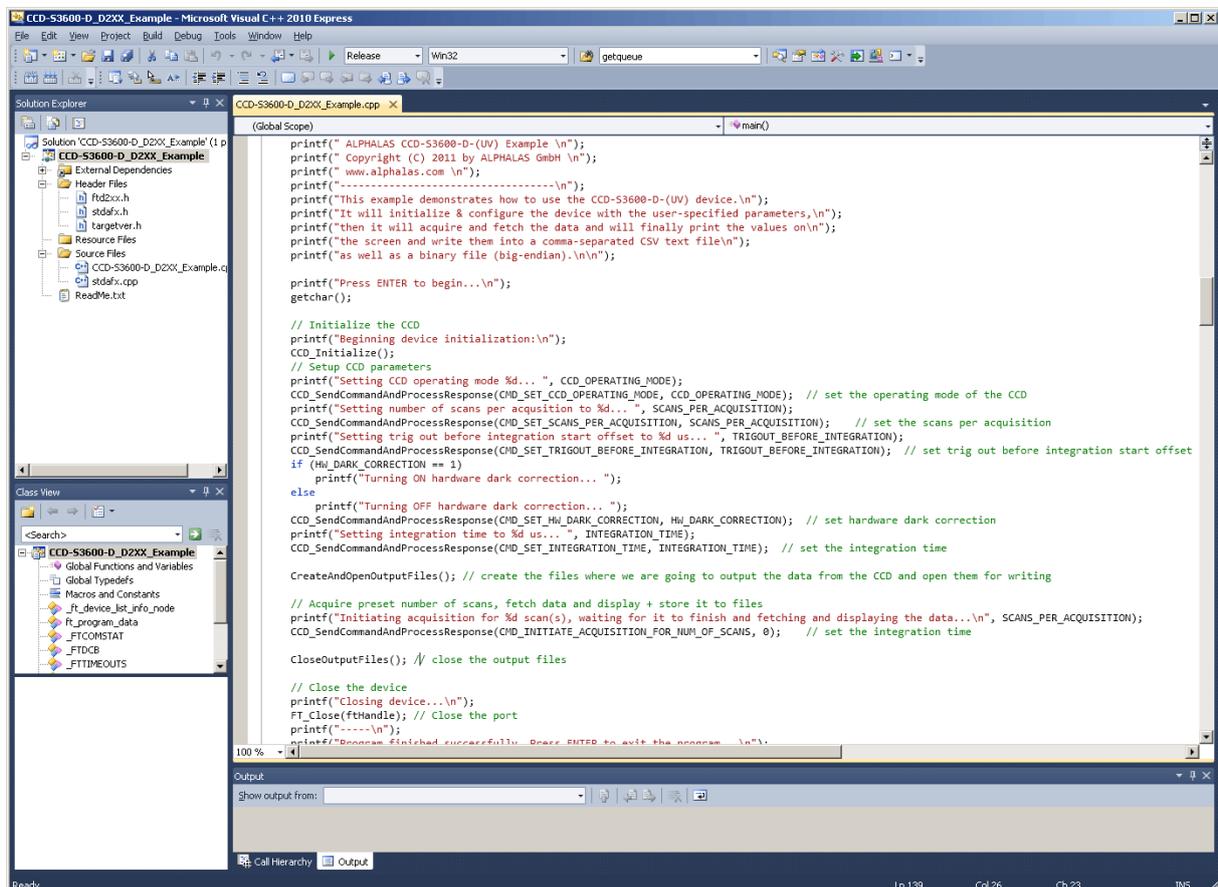
Figure 9-1: The Included Microsoft Visual C++ Project

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These instructions have been written for Microsoft Visual C++ 2010 Express but should apply in a similar way to other versions of the software.

The VC++ project requires **ftd2xx.dll** which should have been already installed with the FTDI D2XX driver into the Windows system folder. This project also requires **ftd2xx.lib** and **ftd2xx.h** which are included with the FTDI D2XX driver available on the FTDI website. Both files must be made available in the same folder as the source code CCD-S3600-D_D2XX_Example.cpp file.

ftd2xx.lib must be also added to the Visual C++ project through Project > CCD-S3600-D_D2XX_Example Properties... > Configuration Properties > Linker > Input > **Additional Dependencies**.

Make sure that ftd2xx.lib is added to that additional dependencies **list of .lib files separated by a semicolon and for all configurations** (Debug and Release).

For further information please refer to the files in the project directory.

9.2.   GCC C++ for Linux, Mac OS X, etc.

Make sure that the FTDI D2XX Driver for Linux / Mac OS X has been installed from http://www.ftdichip.com/Drivers/D2XX.htm.

Make sure that the GNU Compiler Collection GCC C++ compiler is installed correctly. In order to install GCC for Mac OS X you should install Apple's Xcode development environment.

Make sure that the **ftd2xx.h** and **WinTypes.h** files from the Linux / Mac OS X driver are accessible from the main C++ program (e.g. place them in the same folder).

To build the example, use the following GCC statement (assuming you have the D2XX library installed in the /usr/local/lib directory):
g++ -o CCD-S3600-D_D2XX_Example CCD-S3600-D_D2XX_Example.cpp -L. -lftd2xx -Wl,-rpath /usr/local/lib

<u>**Notes for Linux:**</u>

As described in chapter 6.2.1, because the example uses the D2XX driver you need to first unload any VCP drivers loaded by the kernel by running **sudo rmmod ftdi_sio** and **sudo rmmod usbserial**.

Another important thing is that the FTDI library makes use of libusb. In order to get access to a USB device you have to **run all programs that access the USB device**

as a root user using **sudo**. For the compiled example code this means starting it like this: **sudo ./CCD-S3600-D_D2XX_Example**.

Instead of using sudo as described above, you may also change the permissions by a udev rule like described here:

http://code.google.com/p/picusb/wiki/libusb_and_udev

The device's VID is 0x0403 and the PID is 0x6010.

For further information please refer to the files in the source code directory.

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10. Maintenance

The device is **not** water resistant. Do not expose the device to spray, liquids or solvents.

Also when disconnected, the CCD device must be protected from electrostatic charges. Keep the device and the cables in a clean, dry and dust-free place.

⚠	**FOR CLEANING THE DETECTOR WINDOW PLEASE USE ISOPROPYL ALCOHOL. AVOID SCRATCHING THE WINDOW. ALWAYS DISCONNECT THE DEVICE BEFORE CLEANING.**

In case of malfunction, please contact ALPHALAS. Do not try to open or repair the device. Doing so will void any warranty. There are no parts in the device that can be repaired by the customer himself.

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11. Troubleshooting

The device is not recognized by the computer

- Make sure that the FTDI D2XX driver is installed correctly and the FTDI USB device shows up correctly in the device manager of your operating system. The latest Microsoft Windows operating systems should be able install the driver automatically.
  For detailed information, also refer to www.ftdichip.com and the driver installation instructions listed there.
- Make sure that you have administrator privileges on the computer.
- Restart the computer and see if the problem persists.
- Make sure that your computer (especially if using a notebook) can supply 500 mA to the USB port as required by the USB standard.
- Try to attach the device to a different USB port.
- Try to install the device on a different computer to make sure that there is no installation problem or conflict related to a specific computer.

The device does not return from acquisition, it appears frozen

- If using CCD operating modes that require the external trigger input signal, make sure that this signal is applied correctly and actually triggers the device.
- Make sure that the acquisition has actually completed; especially if you have set a long integration time or multiple scans per acquisition. Also make sure that the external trigger has triggered the requested number of scans. If using data streaming mode, make sure that the acquisition has been stopped and the last frames have been triggered.
- To reset the device and abort the acquisition in progress, disconnect and reconnect the device.

Acquisition starts but after some time it is interrupted

- If you are acquiring data for a longer time make sure that the computer does **not** enter any standby or sleep modes. If this happens, the USB ports will be disabled and the acquisition will be interrupted. This is expected behavior.

Document Change List

Revision	Changes / Notes
2011-11-14	Initial release.
2012-06-07	Added trigger output control for firmware A1.10. Added dual-triggering example for pulsed lasers and application example. Other minor changes, additions and improvements.
2013-12-07	Included Acquisition & Viewer Software for Windows Minor changes, additions and improvements.
2014-05-20	Updates regarding Windows 8.x and LabVIEW 2013 SP1. Minor changes, additions and improvements.
2016-01-25	Updates regarding sensor noise and signal-to-noise ratio. LabVIEW Run-Time is now included in standalone Acquisition & Viewer Software installer. Minor changes, additions and improvements.
2022-11-22	Added driver support for the 64 bit version of LabVIEW for Windows (LabVIEW 2017 and later). Minor changes, updates and improvements.