Acqiris Swept-Source OCT Solutions

Since 2014, Acqiris has developed swept-source OCT signal acquisition solutions for medical and industrial applications. Our solutions support A-scan rates from 100 kHz up to 2 MHz. They combine state-of-the-art hardware based on high-speed DAQ modules, dedicated firmware for real-time processing, and a friendly software environment.

Thanks to the on-board FPGA, we provide a complete and flexible real-time OCT engine, allowing the acquisition of both OCT and K-clock signals and delivering in output high image quality and clarity.

Overview

Instrument Info	
Description	IVI-C Driver for AqSsoct [Compiled for 64-bit]
Revision	1.6.4.0
Manufacturer	Acqiris
Model	SA220P
Serial	AQ00070736
Firmware Rev	Stage1 Version 3.6.152.0, FPGA Firmware Version 3.6.152.67
Options	CH2,MEA,EXA,SS4
Resource Descriptor	PXI10::0::0::INSTR
Channels	
Channel1	
Full Scale Range	0.5 V
Offset	0 V
Channel2	
Full Scale Range	0.5 V
Offset	0 V
A-scan	
Acquisition size	3904
Decimation Ratio	1
Primary Sweep Sync	Edge Negative
Secondary Sweep Enabled	☐
Trigger Delay Primary Sweep	0
Trigger Delay Secondary Sweep	0
Trigger Level	0 V
K-clock	
Delay Primary Sweep	-4
Delay Secondary Sweep	-4
Filter Mode	Default
Hilbert Gain	1
Hilbert Offset	0
Image	
Data Format	Raw
A-scan size	3904
B-scan size	2000
B-scan Trigger Mode	Free Running
C-scan size	1
C-scan Trigger Mode	Free Running
Image Processing	
A-scan nbr of average	1
FFT Window Type	None
Advanced	
FFT Readout	Full Spectrum
Header Enabled	☐
Control IO	
Control IO 1 Signal	Disabled
Control IO 2 Signal	Disabled
Control IO 3 Signal	Disabled
Scanner Control	
Mode	Unidirectional Sweep
Analog Out X	
Enabled	☐
Range	1 V
Offset	-500 mV
Settling Delay	0
Analog Out Y	

Loaded A-scans: 2000

Key features:

- A-scan rate: from 100 kHz to 2 MHz
- 1 or 2 OCT channels, simultaneously
- Resolution from 8-bit to 14-bit ADC, enabling better contrast
- Deeper analysis thanks to high sampling rate up to 4GS/s
- Real-time processing in the FPGA
  - Digital K-clock resampling
  - Programmable analysis depth
  - Flexible real-time OCT Engine
  - Up and down sweep support
- Excellent image quality and clarity
  - Minimal artifacts and noise
  - Increased contrast and stability

Easy integration:

- Integrated XY Galvo control in real-time, allowing full synchronization with the A-scan and reducing the system footprint
- 2 additional analog inputs for feedback control
- 2 form factors available: PCIe or Thunderbolt 3 module
- Light source independent
- Dedicated OCT Graphical user interface & Software Development Kit (SDK)
- Custom options available

1. DAQ module hardware

Acqiris SS-OCT solutions are based on our 8-bit, 12-bit or 14- bit ADC technology with exclusive proprietary ICs and IPs enabling excellent signal performances, image details, depth, contrast, and acquisition speed.

Our front-end has been designed to minimize noise, signal distortion and enable stable signal performances over the full bandwidth.

With a high dynamic range, accurate triggering, and specific low jitter clock distribution, our DAQ module provides better image clarity and pixel contrast, addressing the most demanding phase-sensitive OCT applications.

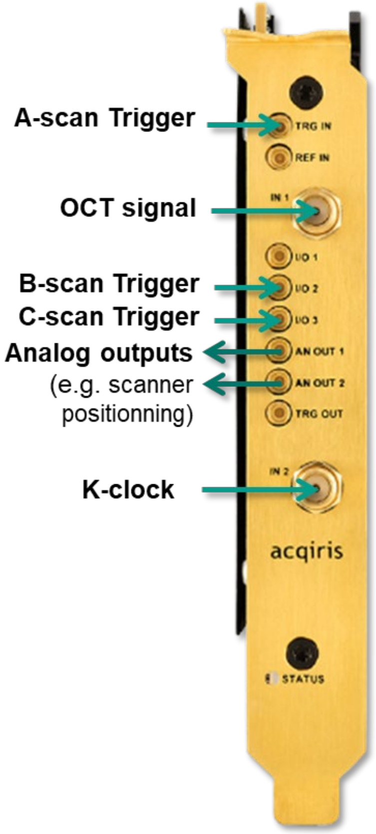

Fig 1. SA220P/SA240P DAQ module connection with OCT system.

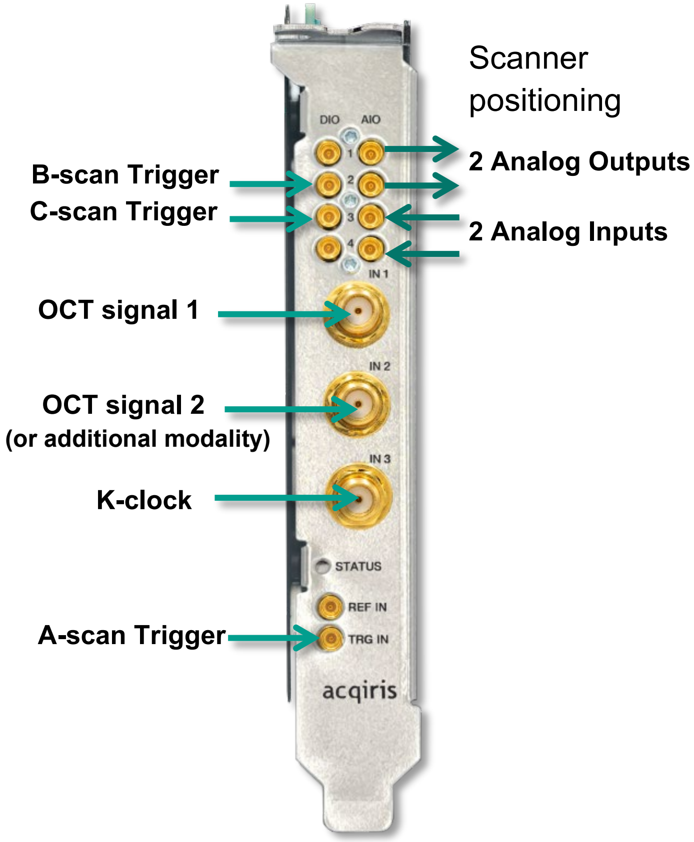

Fig 2. SA331 DAQ module connection with OCT system.

2. Real-time Processing

The OCT processing steps are implemented in real-time in the module’s FPGA.

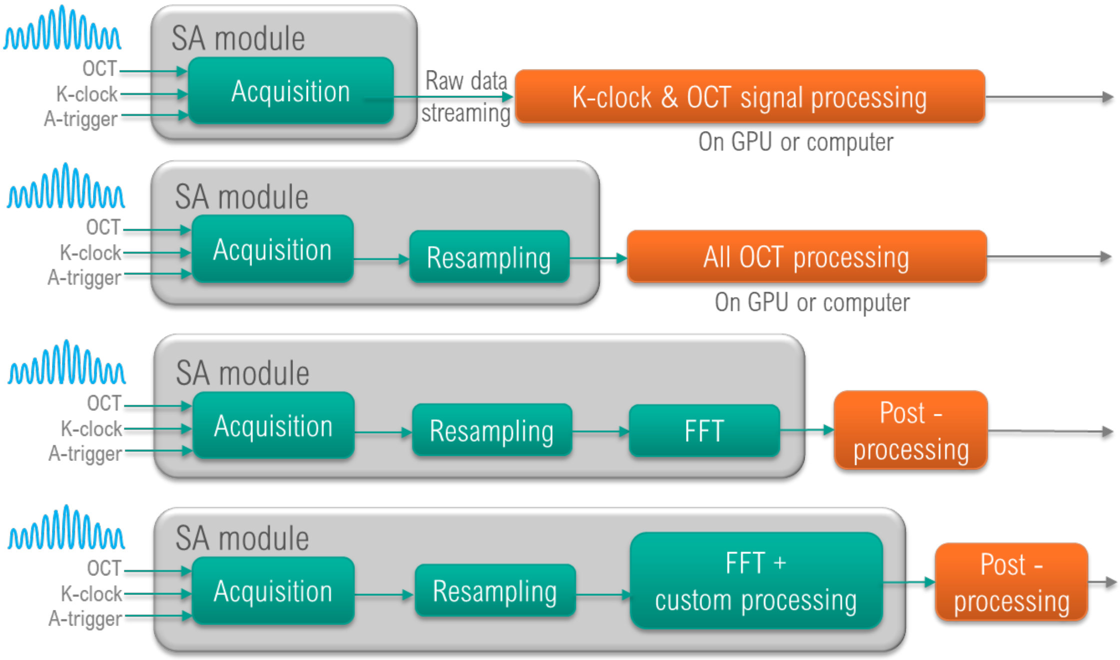

Fig 3. SS-OCT firmware and processing flexibility.

The following processing blocks are available and can be bypassed/switched on-off programmatically by the user:

1. Programmable FIR on both channels
2. Fractional re-sampler for K-space remapping
3. Background subtraction
4. Programmable Windowing/Dispersion compensation
5. FFT with complex/magnitude/phase output[1]
6. A-scans averaging

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[1] Note: Depending on DAQ Module, some processing may not be supported in the FPGA.

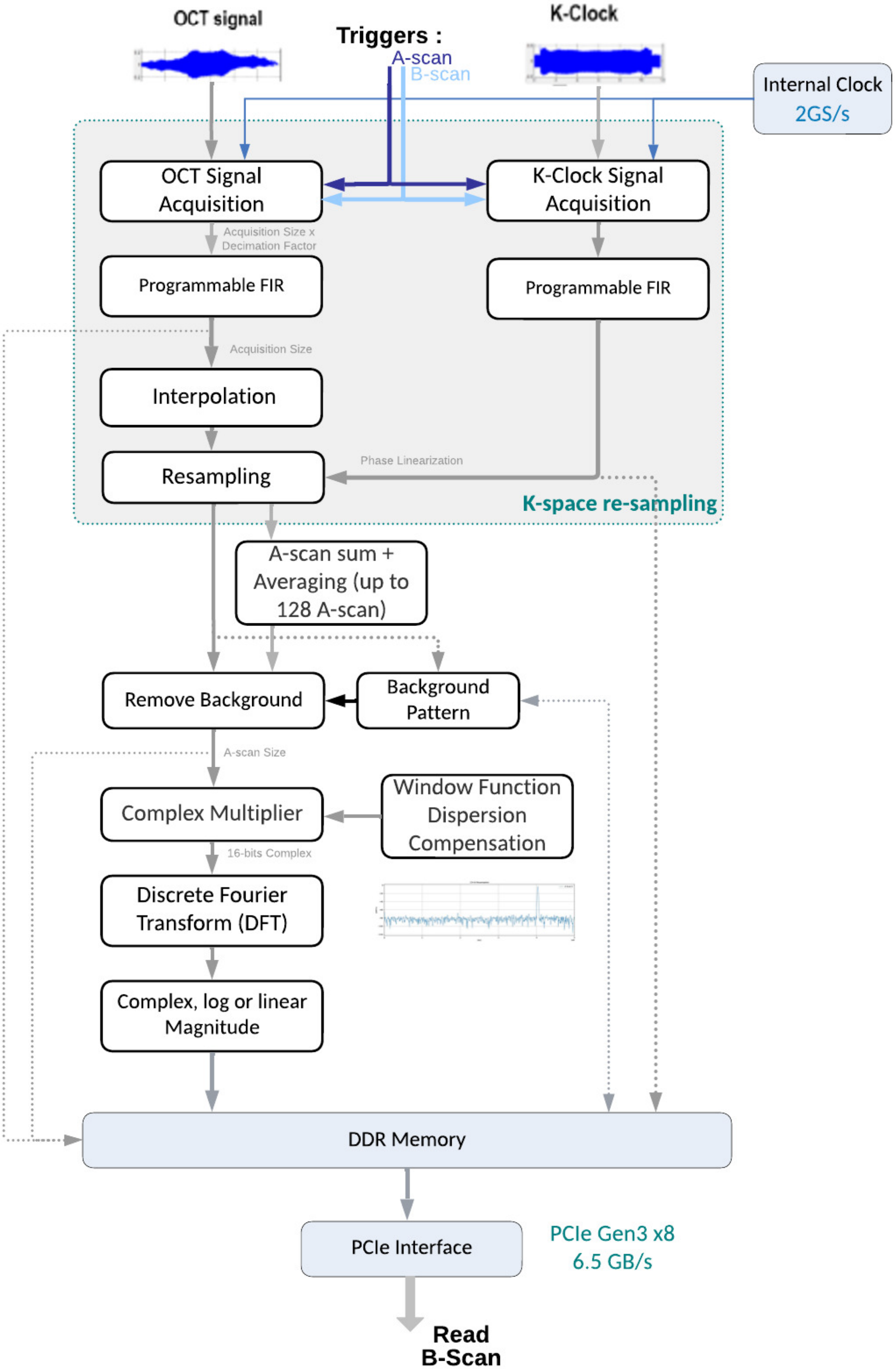


Fig 4. SS-OCT processing successive steps (SA220P-SS6).

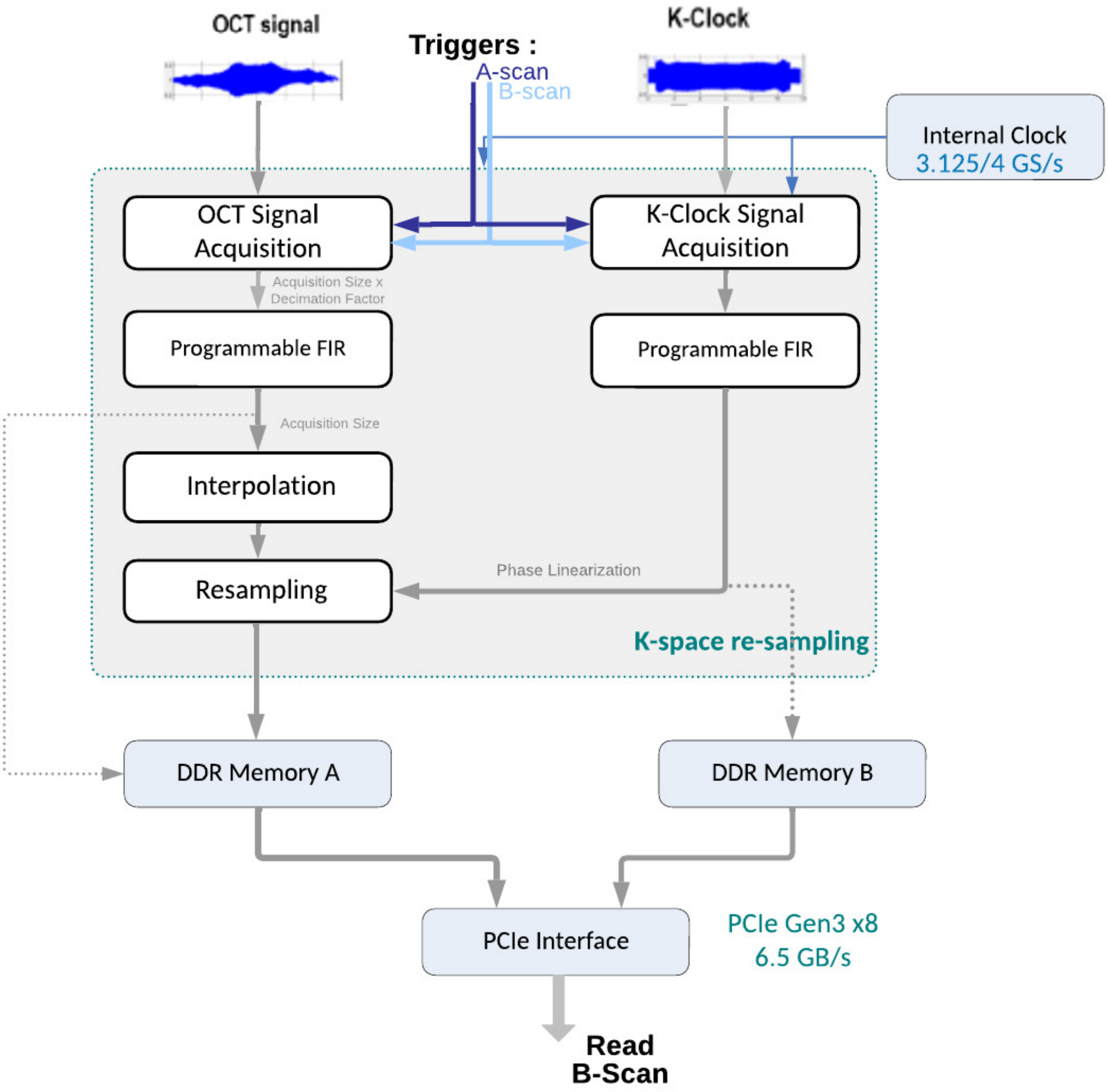


Fig 5. SS-OCT processing successive steps (SA240P-SS6 and SA3-SS6).

2.1. Output DATA

The output data format can be selected programmatically:

- Raw data
- Re-mapped data
- FFT data

2.2. Programmable FIR

The programmable Finite Impulse Response (FIR) filters on both the OCT (IN1) and K-clock (IN2) channels is designed to serve multiple purposes:

1. **Noise Reduction**: They significantly reduce in-band noise, leading to a cleaner signal.
2. **Signal-to-Noise Ratio (SNR) Improvement**: By reducing noise, they enhance the SNR, which is vital for image quality and accurate measurements.
3. **Frequency Control:** The independent configurability of the filters allows precise control over the frequency response. This contributes to:
    - Avoid Aliasing: Prevent unwanted frequencies from folding back into the desired frequency range (an effect called aliasing).
    - K-clock Optimization: Smooth out noise or irregularities in the K-clock signal, ensuring accurate and stable data acquisition.

2.3. Digital K-space remapping

Both OCT-signal and K-clock waveforms are sampled by an independent low-jitter and stable fast clock synthesized on the ADC module. The digital K-space resampling allows to remap the digitized OCT signal in K-space, based on the K-clock phase.

Compared with the direct clock solution, there are multiple interests in this approach:

- **Configurable analysis depth**: The analysis depth (imaging range) can be adjusted digitally, independently of the k-clock from the laser. This provides more flexibility in tailoring the system to specific applications.
- **Artifact Minimization:** Direct clocking can introduce artifacts into the OCT image. Digital remapping eliminates these artifacts, resulting in cleaner, more accurate images.
- **Elimination of Dummy Clock:** Direct clocking often requires a dummy clock signal, which is not needed with digital remapping
- **Higher Sampling Rates:** Digital remapping allows for higher sampling rates, enabling deeper analysis and potentially improving image resolution.
- **Independent Sampling:** The ADC sampling rate is constant and independent of the K-clock frequency, simplifying system design and ensuring stable and accurate data acquisition.
- **Light Source Flexibility:** The system is adaptable to a wider range of light sources, as it doesn't rely on specific clocking requirements.
- **Enhanced Control:** Digital remapping offers greater control over signal processing, including the ability to compensate for optical path differences between the K-clock and OCT signal.

2.3.1. Fractional Re-sampler

At the heart of the k-space remapping block there is a fractional re-sampler that allows for changing the sampling rate of a signal by a non-integer factor. In the context of SS-OCT and k-space remapping, it plays a pivotal role:

- **K-clock Driven Remapping:** The k-clock signal, which carries information about the instantaneous wavelength of the swept laser source, is used as the reference for remapping. The fractional re-sampler adjusts the sampling rate of the acquired OCT signal to align it precisely with the k-clock phase.
- **Interpolation and Decimation:** To achieve this alignment, the fractional re-sampler performs a combination of interpolation (increasing the sample rate) and decimation (decreasing the sample rate). This ensures that each sample of the OCT signal corresponds to a specific k-value, effectively remapping the signal from the time domain to the k-space domain.

2.3.2. Decimation with the re-sampler

While the primary goal in k-space remapping is to adjust the sampling rate to match the k-clock, a fractional re-sampler can also be used for decimation. By configuring it to output only every Nth sample it effectively reduces the sample rate by a factor of N. This is known as down-sampling or decimation. To prevent aliasing (unwanted high-frequency components folding back into the lower frequency range), an anti-aliasing filter can be applied using the programmable FIR filters described in section 2.1. By configuring the Acquisition size (before resampling) and A-scan size parameters (after resampling) the decimation factor can be fine-tuned.

2.3.3. Phase-Based Resampling

The resampling mode leverages the inherent relationship between the K-clock and the optical frequency sweep of the light source. By a precise calibration the ADVANCED mode can ensure high accuracy while preserving the phase stability of the overall system.

2.3.4. K-clock conditioning

To have an effective **resampling** the K-clock needs conditioning and precise real-time calibration that is performed continuously on an A-scan bases on Acqiris DAQs.

2.4. Background subtraction

Background subtraction is a crucial technique for removing unwanted background artifacts in SS-OCT images, resulting in improved image clarity and signal-to-noise ratio (SNR). The process involves capturing and averaging multiple A-scans (depth profiles) without the sample present, creating a reference background noise profile. This averaged background is then subtracted from each acquired A-scan containing sample information. To further enhance flexibility and streamline workflows, the captured background noise samples can be saved and stored externally. This operation is performed in real time pre-resampling in the SS4/SS5 solutions and post-resampling in the SS6/SS7 solutions.

2.5. Programmable windowing & Dispersion compensation

The application of programmable windowing and dispersion compensation techniques significantly improves image definition and overall quality. These operations are made easier by a complex multiplier block, between the resampling phase and the Fast Fourier Transform (FFT) block.

2.5.1. Windowing:

- **Purpose:** Windowing involves applying a weighted function to the resampled A-scan data. This reduces spectral leakage, a phenomenon where energy from one frequency bin spreads into adjacent bins, leading to blurring and decreased resolution in the OCT image.
- **Types:** Various window functions can be uploaded from the host computer to the SS-OCT system, including common options like Hann, Hamming, Blackman, or custom-designed windows tailored to specific applications.
- **Benefits:** Proper windowing significantly sharpens image features, improves contrast, and enhances the overall visual quality of the OCT image

2.5.2. Dispersion Compensation:

- **Purpose:** Dispersion compensation corrects for the broadening of optical pulses as they travel through different media. This broadening can cause distortions and reduce the axial resolution of the OCT image.
- **Implementation:** Dispersion compensation is implemented by applying a phase correction to the A-scan data using complex coefficients uploaded from the host computer. The coefficients are calculated based on the known dispersion characteristics of the system and sample.
- **Benefits:** By mitigating dispersion effects, this technique restores axial resolution, enhances image sharpness, and enables more accurate depth measurements.

2.6. FFT with complex/magnitude/phase output

Acqiris SS-OCT solutions leverage onboard, real-time Fast Fourier Transform (FFT) processing to achieve great image resolution with up to 32k samples. This powerful capability enables fine-grained analysis of spectral information, leading to detailed and accurate OCT images.

Offloading the computationally demanding FFT calculations to the FPGA, brings multiple benefits for the final system:

- **Reducing Host Requirements:** Minimizes the processing power needed for the host computer, enabling the use of less expensive and more readily available hardware.
- **Accelerating Imaging:** Enables real-time OCT imaging, providing immediate visual feedback and streamlining workflows.
- **Simplifying Software:** Reduces the complexity of host software, as the heavy lifting is handled by the FPGA.

2.6.1. Direct B-scan Output

A unique advantage of Acqiris solutions is the ability to directly output B-scan data. This means that the OCT image can be visualized and analyzed directly without additional software processing, further enhancing real-time capabilities and making easier the implementation.

2.6.2. Flexible Output Formats and Scaling

Acqiris SS-OCT systems offer a high degree of flexibility in terms of FFT output:

- **Complex Samples:** Provides access to the raw complex FFT output, enabling advanced signal processing and analysis techniques.
- **Magnitude and Phase:** Separates the FFT output into magnitude (representing signal intensity) and phase (encoding depth information) components, facilitating targeted visualization and analysis.
- **Full or Half FFT:** Offers both full FFT (covering the entire frequency range) and half FFT (focusing on positive frequencies) options, depending on the specific application requirements.
- **Logarithmic or Linear Scale:** Allows for flexible scaling of the output data, either in logarithmic or linear format, to optimize visualization and analysis depending on signal characteristics.

2.6.3. Seamless Zero Padding

To ensure optimal FFT performance, the system automatically implements zero padding when the A-scan size is not equal to a power of two. This padding enhances spectral resolution and minimizes artifacts in the FFT output without requiring any user intervention.

2.7. A-scans averaging

A-scan averaging is a powerful technique employed in SS-OCT to enhance signal quality and reduce noise, ultimately leading to clearer and more accurate images. Acqiris SS-OCT solutions offer two distinct averaging modes to cater to different application needs:

2.7.1. Standard Averaging:

- **Mechanism:** In standard averaging, a fixed number of consecutive A-scans (up to 128) are acquired and accumulated in real-time. The corresponding data points from each A-scan are summed and then divided by the total number of A-scans to obtain an averaged A-scan.
- **Benefits:** This method effectively reduces asynchronous noise, which is noise that varies randomly between A-scans. By averaging multiple A-scans, the random fluctuations tend to cancel out, resulting in a smoother and more reliable signal. This directly translates to improved signal-to-noise ratio (SNR) and enhanced image clarity.

2.7.2. Moving Averaging:

- **Mechanism:** Moving averaging involves calculating the average of a fixed number of A-scans (up to 128) within a sliding window. As each new A-scan is acquired, the oldest A-scan in the window is discarded, and the average is recalculated.
- **Benefits:** This approach offers a continuous, real-time averaging process. It is particularly useful for dynamic imaging scenarios where the sample or imaging conditions may change over time. Moving averaging adapts to these changes and provides a continuously updated, smoothed representation of the OCT signal.

2.1. Phase stabilization

Phase jitter, a fluctuation in the timing of A-scans, can lead to distortions and artifacts in OCT images. Phase stabilization aims to correct these timing errors, resulting in clearer and more reliable images. A correction algorithm is implemented on Acqiris DAQ to adjust the timing of subsequent A-scans to compensate for these phase errors.

3. Scanner control

3.1.1. Integrated Scanner Control: Streamlining SS-OCT Systems

Acqiris SS-OCT Solution also offers scanner control, as an option, to get a more compact, efficient, and cost-effective system design. The DAQ card/module can directly generate the signal to manage the X and Y positioning of the scanner or galvo mirrors, reducing the need for external electronics.

3.1.2. Synchronized Control:

The analog outputs from the Acqiris DAQ card enable precise synchronization of multiple critical components within the SS-OCT system:

- **Scanner/Galvo Mirror Positioning:** The DAQ card generates analog voltages to precisely control the X and Y positions of the scanner or galvo mirrors, directing the OCT beam across the sample.
- **OCT Source Laser:** The card can trigger the OCT source laser to emit light pulses in sync with the scanner movements, ensuring optimal data acquisition.
- **OCT Processing:** The card coordinates the timing of OCT signal processing steps, such as A-scan acquisition, k-space remapping, and FFT calculations, in alignment with the scanning pattern.

3.1.3. Flexible Control Signals:

The system allows for the configuration of control signals to define various scanning patterns:

- **XY Sweeps:** Linear sweeps across the X and Y axes to acquire 2D OCT images (B-scans).
- **Galvo Positioning:** Arbitrary positioning of the galvo mirrors to achieve specific scanning trajectories or patterns.
- **Predefined and Custom Patterns:** Users can choose from a set of predefined scanning patterns or create custom patterns to suit specific imaging needs.

3.1.4. Real-time Position Feedback:

The analog inputs of the DAQ provide real-time feedback on the current position of the scanner or galvo mirrors. This information can be used for closed-loop control, ensuring accurate and precise positioning throughout the imaging process.

3.1.5. Benefits of Integrated Scanner Control:

- **Simplified System Design:** Eliminates the need for external scanner control electronics, reducing system complexity and cost.
- **Improved Synchronization:** Ensures tight synchronization between the scanner, laser source, and OCT processing, leading to more reliable and accurate data acquisition.

- **Enhanced Flexibility:** Offers a wide range of scanning modes and customizable patterns to accommodate diverse imaging requirements.
- **Real-time Feedback:** Enables closed-loop control for precise and stable scanner positioning.

Analog outputs Specifications	
Output Ranges (Selectable by Software)	+/- 10V +/- 5V +/- 2.5V
Resolution	12-bit
Data rate (or refresh rate)	+/- 2.5V
Coupling	DC, with 300 ohm source resistor
Rise Time / Fall Time	12.5 ns / V (typ on 1Mohm termination)

Table 1: Specification of the analog outputs dedicated to scanner position control.

4. Software and Development Environment

The Software Development Kit includes a dedicated API, code examples and a user-friendly Graphical User Interface.

4.1. AQOCT API

The API dedicated to SS-OCT, allows to control all programmable features of the ADC module and the dedicated real-time OCT processing. It is provided with:

- Project and example
- Debug features, e.g., providing at output raw data + FFT

Supported OS	Windows 10/11 Linux (Debian, Ubuntu)
API	C++ API Python API Labview API
FPGA Firmware	Real-time processing: • K-space re-mapping • FFT, log scaling • fast readout of B-scan to the host computer
Graphical user interface	• General purpose soft Front panel • SS-OCT GUI

Table 2: SS-OCT dedicated Software Development Kit.

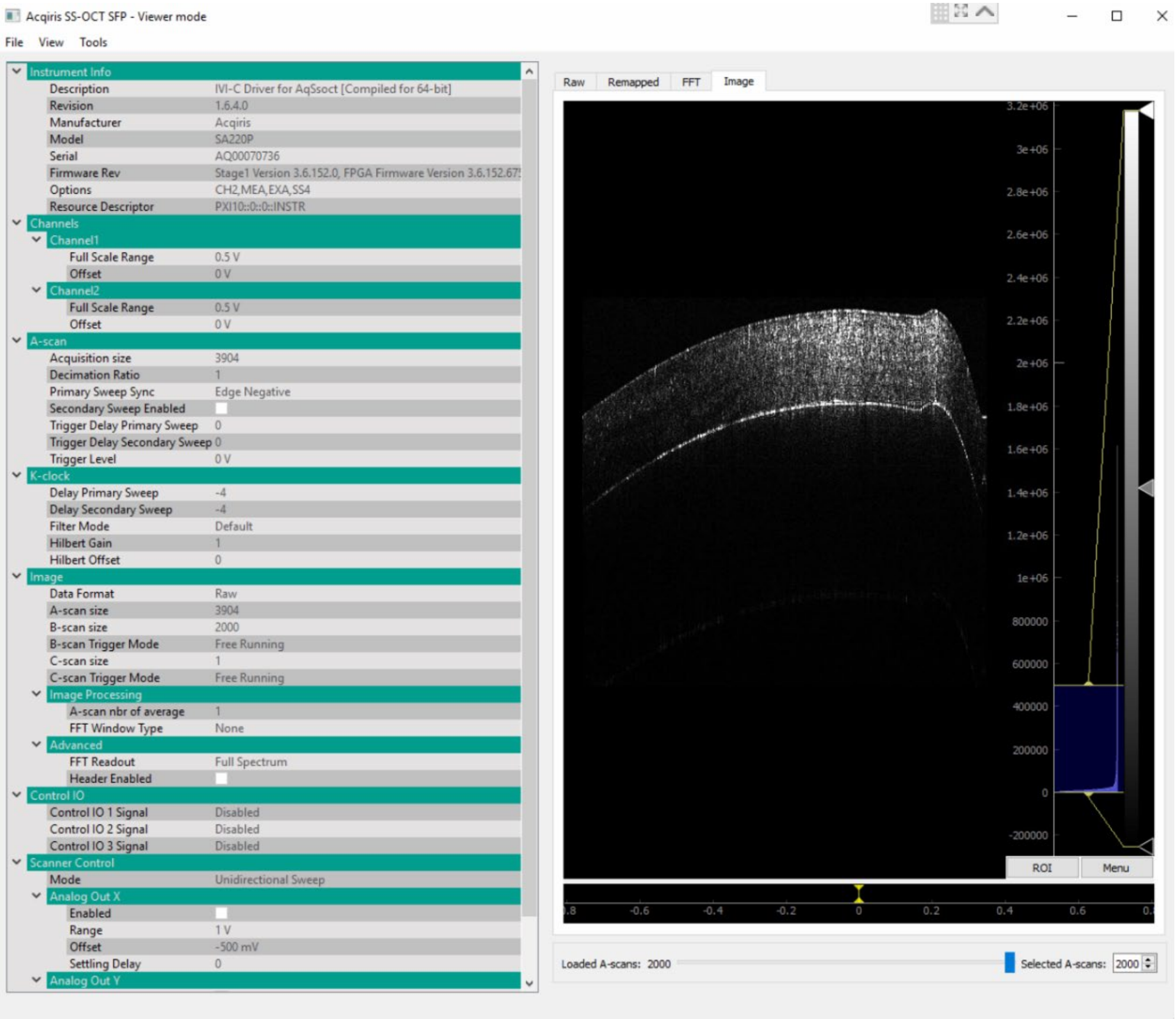
4.1. SS-OCT dedicated graphical user interface

The SS-OCT dedicated Graphical User Interface allows quick get started with the DAQ module and get OCT images live. All the key parameters can be defined by user.

It supports 3 modes:

1. **Viewer mode**
    - Data visualization with SW OCT Processing
    - Import saved data directly from CPP example
    - Save processed data for analysis
2. **Live mode**
    - Directly control the DAQ OCT firmware
    - Easy tuning of the parameters
    - Save and export the data
    - Save and export the configuration
3. **Simulation mode**
    - Makes easy the SW application development
    - Uses emulated K-clock and OCT signals

This interface allows to display the raw data, the data after k-space remapping, the OCT signal after FFT, and the SS-OCT image.
Once the setup parameters are fine-tuned, it is possible to save or export the parameter configuration.



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Channels	
Channel1	
Full Scale Range	0.5 V
Offset	0 V
Channel2	
Full Scale Range	0.5 V
Offset	0 V
A-scan	
Acquisition size	3904
Decimation Ratio	1
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Secondary Sweep Enabled	☐
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Trigger Delay Secondary Sweep	0
Trigger Level	0 V
K-clock	
Delay Primary Sweep	-4
Delay Secondary Sweep	-4
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Image	
Data Format	Raw
A-scan size	3904
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B-scan Trigger Mode	Free Running
C-scan size	1
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Image Processing	
A-scan nbr of average	1
FFT Window Type	None
Advanced	
FFT Readout	Full Spectrum
Header Enabled	☐
Control IO	
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Control IO 3 Signal	Disabled
Scanner Control	
Mode	Unidirectional Sweep
Analog Out X	
Enabled	☐
Range	1 V
Offset	-500 mV
Settling Delay	0
Analog Out Y	

Loaded A-scans: 2000

Selected A-scans: 2000

Fig 5. Dedicated SS-OCT Graphical user interface.

5. Solution specifications

5.1. Key specifications

SS-OCT Solutions and key features

Technology	SA240	SA331		SA220
Resolution	14-bit	12-bit		14-bit
Firmware solution	SS6	SS6	SS7	SS6 (1)
A-scan rate	up to 2 MHz	up to 2 MHz		up to 2 MHz
Channels	1 OCT signal + k-clock	1 OCT signals + k-clock	**2 OCT signals** + k-clock	1 OCT signal + 1 k-clock
Sampling rate	up to 4 GS/s	up to 3.125 GS/s	up to 1.5625 GS/s	up to 2 GS/s
UP/DOWN Sweep support	Up or down only	Both		Both

(1) With former Solutions based on SA220P with SS4 and SS5 firmware are still supported, however SS6 firmware is recommended for new designs The SS6 firmware covers the specifications of SS4 and SS5 firmware. It is also possible to migrate from SS4 or SS5 to SS6 firmware. Please contact us for more details at support@acqiris.com.

5.2. Real-time processing features

SS-OCT Solutions and Real-time Processing

Technology	SA240	SA331		SA220
Output data	• Data after k-space remapping • Raw data	• Data after k-space remapping • Raw data	• Data after k-space remapping • Data after FFT • Raw data	• Data after k-space remapping • Data after FFT • Raw data
Fractional re-sampler	☑	☑	☑	☑
Maximum Acquisition size	64k	64k		64k
Maximum A-scan size	64k	64k		64k
Acquisition and A-scan size increment	32 samples	32 samples		64 samples
Resampling mode	Advanced	Advanced		Advanced
Channel FIR (OCT and k-clock channels)	15/15 or 15/47(1) taps	25/25 taps		48/48 taps
K-Clock filtering	NA(2)	☑	☑	☑
K-Clock calibration	☑	☑	☑	☑
Background Subtraction	NA	After remapping		After remapping
Dispersion compensation			☑	☑
FFT with zero padding and windowing			8 Ksamples	32 Ksamples
Standard average	NA(2)	Up to 64 ksample (K-space)		
Moving average		Up to 64 ksamples		Up to 64 ksamples
Sample conversion	12/10 bits	12/10 bits		12/10 bits
Real-time phase stabilization	☑	☑	☑	☑
Direct-DMA to GPU	☑(3)	☑(3)	☑(3)	☑(3)

(1) If K-clock frequency < 500 MHz.

(2) Available upon request.

(3) Linux only.

5.3. Galvo position driving

SS-OCT Solutions and Galvo position driving				
Technology	**SA240**	**SA331**		**SA220**
Resolution	**14-bit**	**12-bit**		**14-bit**
Channel version	1 OCT signal + k-clock	1 OCT signals + k-clock	**2 OCT signals** + k-clock	1 OCT signal + 1 k-clock
Analog output basic	☑	☑	☑	☑
Analog output advanced	NA	☑	☑	☑
Analog inputs		☑	☑	

5.4. Software

Software				
Technology	**SA240**	**SA331**		**SA220**
Resolution	**14-bit**	**12-bit**		**14-bit**
Channel version	1 OCT signal + k-clock	1 OCT signals + k-clock	**2 OCT signals** + k-clock	1 OCT signal + 1 k-clock
Windows	☑	☑	☑	☑
Linux	☑	☑	☑	☑
C++ driver/API	☑	☑	☑	☑
Labview driver/API	☑(2)	☑	☑	☑(2)
Python driver/API	☑	☑	☑	☑
Application Driver	AqSSoct or Aq4SSoct	Aq4SSoct		Aq4SSoct

(2) Available upon request.

5.5. Form factor

Two factors are available:

- PCIe card x8, to be plugged in your host computer
- Module with a Thunderbolt 3 interface (USB-c connector) which can be connected to a laptop, mini-PC or standard workstation for a compact and plug and play solution.

Software				
Technology	**SA240**	**SA331**		**SA220**
Resolution	**14-bit**	**12-bit**		**14-bit**
Channel version	1 OCT signal + k-clock	1 OCT signals + k-clock	**2 OCT signals** + k-clock	1 OCT signal + 1 k-clock
PCIe x8	☑	☑	☑	☑
Module with Thunderbolt 3 interface		☑	☑	☑

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