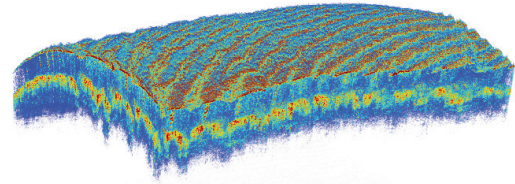# ATS-GPU-OCT
## OCT Signal Processing Library

- Very high-speed floating-point FFT for k-clocked data
- Dispersion compensation and windowing functions
- Requires ATS-GPU-BASE
- Transfer A/D data to GPU at high speed
- Up to 6.9 GB/s transfer rate for PCIe Gen 3 digitizer boards
- Optional ATS-GPU-NUFFT extension for non-uniform FFTs
- Supports CUDA®-enabled GPUs with compute capability 3.0 to 8.6‡
- Designed to work with AlazarTech® PCI Express waveform digitizers
- Compatible with Windows® & Linux®



> (!) You will need ATS-SDK (sold separately) to use ATS-GPU-OCT.

| Product | GPU Compatibility | Operating System | Throughput to GPU | FFT Length | Max. FFTs Per Second |
|---|---|---|---|---|---|
| ATS-GPU-OCT version 4.2 | CUDA compute capability 3.0 to 8.6‡ | 64-bit Windows & 64-bit Linux | Up to 6.9 GB/s | Up to 8 M Points | 1,900,000 (2048-pt FFTs, see benchmark table below for more details) |

## Overview

ATS-GPU-OCT is an OCT Signal Processing Library developed by AlazarTech that provides very high-speed floating-point FFT capability for data acquired by AlazarTech's PCI Express waveform digitizers. ATS-GPU-OCT must be used with ATS-GPU-BASE.

ATS-GPU-BASE allows users to do real-time data transfer from AlazarTech PCI Express waveform digitizers to a CUDA-enabled Graphical Processing Unit (GPU) at rates up to 6.9 GB/s.

Interfacing waveform digitizers to GPUs involves creating a software mechanism to move data from one to the other and back to user buffers. The standard techniques used most often can get the job done, but feature very low data throughput due to software overheads.

AlazarTech designed ATS-GPU-BASE so this software bottleneck is eliminated and data can be moved from AlazarTech digitizers to GPUs and from GPUs to user buffers at full PCIe bus speeds.

Once the data is available in GPU memory, many types of digital signal processing (DSP) can be done on this data at near-hardware speeds.

ATS-GPU-OCT contains floating-point FFT routines that have been optimized to provide the maximum number of FFTs per second. Kernel code running on the GPU can apply a windowing function, do a floating-point FFT, calculate the amplitude and convert the result to a log scale. It is also possible to output phase information.

ATS-GPU-OCT is intended to be used with data that is non-uniformly sampled in time domain, i.e. data that is sampled using a k-clock. Using a k-clock allows data to be sampled uniformly in k-space, which is required for ATS-GPU-OCT. If OCT data is acquired using a fixed sampling rate, this will result in data non-uniformly sampled in k-space. If this is the case, the ATS-GPU-NUFFT library extension is also required.

## Latency

ATS-GPU-BASE uses multiple CUDA streams to move data between the digitizer and GPU. This means there is a latency between data being acquired by the digitizer board and GPU receiving this data. The exact latency is determined by the buffer size used as well as the transfer rate of the PCIe link, but typical values are in in the range of several milliseconds.

## Benchmarks

An AlazarTech ATS®9373 in an Intel i9-7900X 10-Core @ 3.3 GHz system with an ASUS® x299 motherboard, 32 GB DDR4, and NVIDIA® Quadro® P5000 GPU had the following benchmarks:

| GPU Buffer Size (MB) | FFT Length | FFTs per second |
|---|---|---|
| 1 | 2048 | 1,900,000 |
| | 4096 | 950,000 |
| | 8192 | 485,000 |
| | 65536 | 45,000 |
| 4 | 2048 | 1,900,000 |
| | 4096 | 950,000 |
| | 8192 | 485,000 |
| | 65536 | 50,000 |
| | 1048576 | 2,500 |
| 16 | 2048 | 1,900,000 |
| | 4096 | 950,000 |
| | 8192 | 485,000 |
| | 65536 | 55,000 |
| | 1048576 | 2,600 |

Tests in an Intel i7 5930k 6-core @ 3.5 GHz system with an ASUS x99 Deluxe motherboard, 64 GB DDR4, and the same NVIDIA Quadro P5000 GPU produced very similar results.

## Modular API

ATS-GPU-OCT has a unique, modular API that allows users to easily customize their signal processing algorithms. The modularity provides many hooks into the GPU data path, where customers can add their own signal processing code.

**OCT Signal Processing Block Diagram**

*Data can come from multiple channels
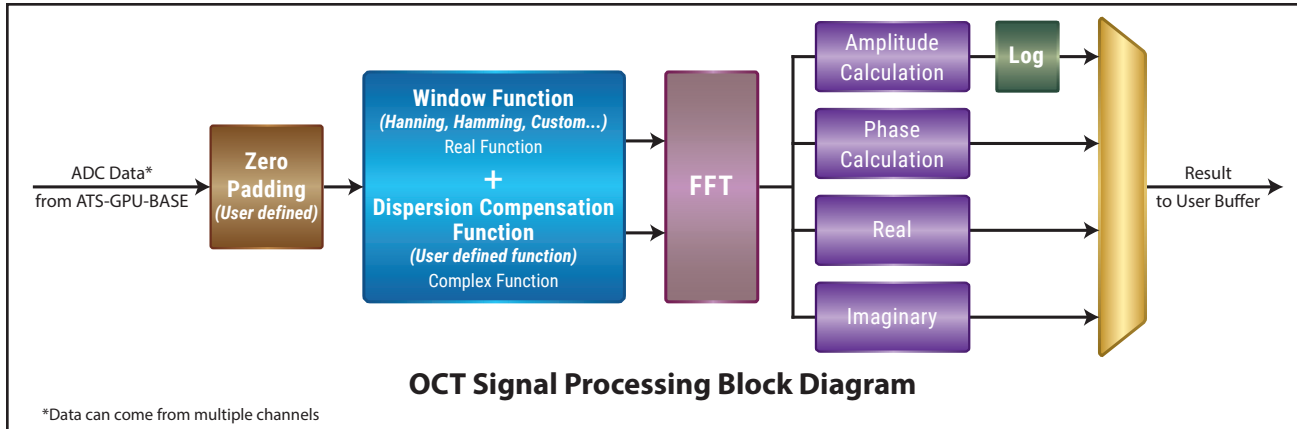
## ATS-GPU and CUDA Runtime Library

ATS-GPU is shipped with a specific version of CUDA runtime library and links statically to it.

Programmers are allowed to use a different version of CUDA runtime library for their custom kernel code. NVIDIA guarantees that the two versions of CUDA runtime libraries will be interoperable.

Note: ATS-GPU only supports Windows versions and Linux distributions that are supported by NVIDIA's CUDA Toolkit. 32-bit operating system support is also similarly limited by NVIDIA. In particular, the ATS-GPU-OCT cannot be built as a 32-bit library. We currently use CUDA toolkit 10.2, older versions are untested.

## ATS-GPU Data Flow



**ATS-GPU Data Flow**
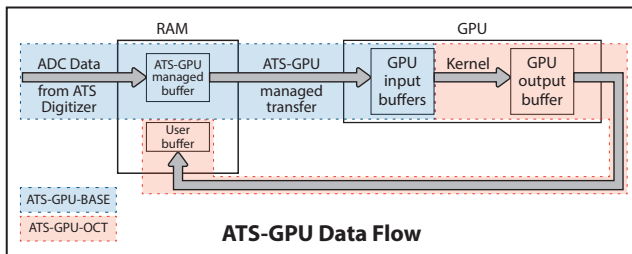
ATS-GPU-BASE is supplied with an example user application in source code. The application includes GPU kernels that use ATS-GPU-BASE to receive data, do very simple signal processing (data inversion), and copy the processed (inverted) data back to a user buffer. All this is done at the highest possible data transfer rate.

ATS-GPU-OCT is supplied with example programs in C/C++, Python, LabVIEW, and MATLAB that allows users to set-up the waveform digitizer parameters, set-up FFT parameters in the GPU, do the acquisition, and receive the FFT result buffer.

## Programming with ATS-GPU-OCT

Please note: You will need ATS-SDK (sold separately) to use ATS-GPU-OCT.

C/C++ example programs are provided with Visual Studio projects and CMake build files.

Python code is tested under Python 2.7 and 3.6. 64-bit LabVIEW 2016 or newer is necessary to use LabVIEW example code (LabVIEW NXG is not supported). MATLAB code is developed under MATLAB 2017A, but is expected to work with most 64-bit MATLAB versions.

Waveform digitizer data is transferred to the GPU in a buffer that may contain many records. This number, RecordsPerBuffer, is specified by the user. Users should make sure that they choose this number such that the buffer size is in the order of 1 to 16 Megabytes. Smaller buffers can reduce overall data throughput.

ATS-GPU-OCT supports zero-padding, if required, and it will apply a complex windowing function to each record. It will then do a single-precision floating-point FFT, calculate the amplitude and phase, and convert the amplitude to logarithmic values.

## Very Long FFTs

For some applications, it is necessary to perform very long FFTs (e.g. one million points).

Even if a waveform digitizer has an on-board FPGA, such very long FFTs do not fit inside an FPGA due to resource limitations of the FPGA.

With the ATS-GPU-OCT Signal Processing Library, ATS-GPU is fully capable of calculating such very long FFTs. Our benchmarks using an Intel i9-7900X 10-Core @ 3.3 GHz system with an ASUS x299 motherboard, and NVIDIA Quadro P5000 GPU have shown that ATS-GPU is capable of doing 2600 one-million-point FFTs per second in single channel mode (keep up with sample rate of up to 2600 MS/s).

Even longer FFTs are possible. We have measured 8-million-point ($2^{23}$) FFTs but we have not fully tested the limits of FFT length with ATS-GPU.

## Zero Padding

If the number of samples per record (A-scan) is not a power of 2, the user should perform zero-padding before doing further signal processing. Although users can zero pad A-scans to any given length, for performance reasons, we recommend zero-padding A-lines to the next power of two. Code samples to do this zero padding is provided.

## Dispersion Compensation Function

Dispersion compensation is an essential part of any OCT signal processing system. ATS-GPU-OCT Signal Processing Library allows users to multiply the zero-padded data with a user-specified Dispersion Compensation Function (DCF). The DCF is a complex function.

## Windowing Function

The windowing function in the ATS-GPU-OCT Signal Processing Library is used to ensure that there are no discontinuities in the FFT. Note that the length of the window function should be the same as the length of the A-Scan, e.g. if the A-scan

is 1536 points long, the window function should also be 1536 points long, even though the FFT length will be 2048.

## Amplitude and Phase Output
The FFT algorithm implemented in the OCT Signal Processing Library is capable of calculating both amplitude and phase outputs. All outputs are provided as single-precision floating-point data (32 bits per data point).

## Compatible Waveform Digitizers
All AlazarTech PCI Express and Thunderbolt 3 waveform digitizers are compatible with ATS-GPU. Only single-board configurations are supported at this time.

AlazarTech's PCI bus waveform digitizers are not supported, as the host CPU is more than capable of handling data rates generated by PCI bus boards.

ATS-GPU cannot directly be interfaced with non-AlazarTech waveform digitizers.

## User-Supplied Data
For validation purposes, user-supplied data can be used when an AlazarTech PCIe digitizer is installed in the system. This data path has significant performance penalties and should only be used for validation purposes.

## Data Throughput to GPU
The data transfer rate to GPU is dependent on the generation of PCI Express digitizer board used or Thunderbolt 3 system configuration:

| PCIe Link Speed | Transfer Rate |
|---|---|
| Gen 3x8: ATS9373, ATS9371, ATS9637, ATS9437 | Up to 6.9 GB/s |
| Gen 2x8: ATS9360, ATS9416 | Up to 3.5 GB/s |
| Gen 3x4: ATS9364 | Up to 3 GB/s |
| Gen 2x4: ATS9872, ATS9352, ATS9353, ATS9628, ATS9428<br>Gen 1x8: ATS9870, ATS9350, ATS9351, ATS9625, ATS9626, ATS9440 | Up to 1.6 GB/s |
| Gen 1x4: ATS9462 | Up to 720 MB/s |
| Gen 1x1: ATS9146, ATS9182, ATS9130, ATS9120 | Up to 200 MB/s |
| Thunderbolt 3: ATST364, ATST146, ATST352<br>*dependent on system configuration | Up to *2.6 GB/s |

## Electronic Delivery
As of June 2020, AlazarTech software products are only available as a digital download. Customers who purchase ATS-GPU-OCT must provide a valid email address to receive their serial number, download link, and required license key.

## Software Licensing Policy
Users are allowed to freely distribute the ATS-GPU-OCT library as long as there is an AlazarTech PCI Express waveform digitizer present in the same computer.

Users must purchase a separate license for each computer on which ATS-GPU-OCT is installed.

In no case is the user allowed to distribute or share the source code of ATS-GPU-OCT with other users.

## Annual Subscriptions
The purchase of an ATS-GPU-OCT license includes a subscription that allows users to download ATS-GPU-OCT updates from the AlazarTech website for a period of 12 months from the date of purchase.

Customers who want to download new releases beyond this 12-month period must purchase extended maintenance.

## Extended Maintenance
Customers can extend their ATS-GPU-OCT subscription by ordering the 1 year extended maintenance for ATS-GPU-OCT (order number ATSGPU-102).

This must be purchased before expiration of the standard subscription (or before expiration of an extended subscription).

If the subscription lapses, renewal at a later date will incur reinstatement fees for the forward service period and any applicable subscription extension to cover the lapsed period. The reinstatement fee is 15% of the cost of subscription extension.

Get your subscription end date by registering your product at: www.alazartech.com/en/my-account/my-products/. You will need the product serial number, which can be found in the email you received with your download link and password. In the case of older purchases, the serial number can be found on the CD envelope.

Subscription extensions will not be offered for discontinued products.

## Technical Support
AlazarTech is known for its world-class technical support. Customers receive free technical support on hardware products that are under warranty.

AlazarTech digitizers come with a standard one (1) year parts and labor warranty. This warranty can be extended for a fee (more information can be found in the Extended Warranty section of each digitizer datasheet).

If your waveform digitizer is out of warranty, you will not be eligible for free technical support on AlazarTech hardware or software products and you will need to purchase technical support hours (order number SUPPORT-HR5) to obtain assistance.

In addition, any necessary repairs to your out-of-warranty hardware products will carry a minimum bench charge.

Note that support is provided for product bugs, and not for writing custom GPU kernels or for learning GPU programming.

## Use with Out-of-Warranty Waveform Digitizers
In order to avoid possible disappointment in product functionality, customers purchasing ATS-GPU-NUFFT for use with an out-of-warranty waveform digitizer must first confirm that the digitizer is in working order by running a series of tests provided by AlazarTech: https://www.alazartech.com/en/support/faq/?faq=[1067].

AlazarTech reserves the right to refuse orders of ATS-GPU for use with an inadequately functioning digitizer.

‡ Version 4.1 or higher of ATS-GPU-BASE is required for support of GPUs with CUDA-compute capability 3.0 to 8.6.

Version 4.0.1 provides support for compute capability 3.0 to 7.5.

## ATS-GPU-OCT main API functions

```
ATS_GPU_OCT_AbortCapture
ATS_GPU_OCT_AllocBuffer
ATS_GPU_OCT_EnableVerificationMode
ATS_GPU_OCT_FreeBuffer
ATS_GPU_OCT_GenerateWindowFunction
ATS_GPU_OCT_GetBuffer
ATS_GPU_OCT_PostBuffer
ATS_GPU_OCT_SetBuffer
ATS_GPU_OCT_Setup
ATS_GPU_OCT_SetWindowFunction
ATS_GPU_OCT_StartCapture
```

## ORDERING INFORMATION

| | |
|---|---|
| ATS-GPU-BASE: GPU Streaming Library License + 1 Year Subscription | ATSGPU-001 |
| ATS-GPU-BASE-1YR: 1 year extended maintenance for ATS-GPU-BASE | ATSGPU-002 |
| ATS-GPU-OCT: Signal Processing Library License + 1 Year Subscription (requires ATSGPU-001; also requires ATS-SDK for use with Python, MATLAB, & LabVIEW) | ATSGPU-101 |
| ATS-GPU-OCT-1YR: 1 year extended maintenance for ATS-GPU-OCT | ATSGPU-102 |
| ATS-GPU-NUFFT: ATS-GPU-OCT Extension for fixed-frequency sampled data License + 1 Year Subscription (requires ATSGPU-001 and ATSGPU-101) | ATSGPU-201 |
| ATS-GPU-NUFFT-1YR: 1 year extended maintenance for ATS-GPU-NUFFT | ATSGPU-202 |
| ATS-SDK purchased with a digitizer board or ATS-GPU: License + 1 Year Subscription (Supports C/C++, Python, MATLAB, and LabVIEW) | ATS-SDK |
| ATS-SDK purchased separately: License + 1 Year Subscription + 5 hours of technical support (Supports C/C++, Python, MATLAB, and LabVIEW) | ATS-SDK-WOD |
| 5 Hours of technical support | SUPPORT-HR5 |

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# DATASHEET REVISION HISTORY

## Changes from version 4.2.2 (Nov 2022) to version 23.1 — Section, Page

| | |
|---|---|
| Added new products to table | Data Throughput to GPU,  pg.  3 |
| Replaced password with license key | Electronic Delivery,  pg.  3 |
| Modified to include new subscription reinstatement policy | Extended Maintenance,  pg.  3 |

## Changes from version 4.2 (Aug 2022) to version 4.2.2 — Section, Page

| | |
|---|---|
| Updated CUDA Compute Capability: ATS-GPU-BASE now supports compute capability 3.0 to 8.6 | Global change |
| Added ATS9364, ATS9182, and ATST364 | Data Throughput to GPU,  pg.  3 |
| Updated ATS-GPU licensing policy: a separate license is required for each computer | Software Licensing Policy,  pg.  3 |

## Changes from version 4.1b (Nov 2021) to version 4.2 — Section, Page

| | |
|---|---|
| Updated ATS-GPU-OCT version number | Feature Table,  pg.  1 |
| Added Thunderbolt 3 digitizers | Compatible Waveform Digitizers,  pg.  3 |
| Moved text about user-supplied data from Overview to its own new section | User-Supplied Data,  pg.  3 |
| Added ATS9872, ATS9353, and Thunderbolt 3 digitizers | Data Throughput to GPU,  pg.  3 |
| Updated section to remove technical support from list of subscription benefits | Annual Subscriptions,  pg.  3 |
| Updated section to remove technical support from maintenance extension | Extended Maintenance,  pg.  3 |
| Added new section to specify how AlazarTech handles technical support: Customers receive free technical support on hardware products that are under warranty. Out-of-warranty support requires the purchase of support hours. | Technical Support,  pg.  3 |
| Added new section to specify that customers who wish to use ATS-GPU-OCT with an out-of-warranty digitizer card are required to complete a series of tests to validate that the dgitizer is in working order prior to purchase. | Use with Out-of-Warranty,  pg.  3 Waveform Digitizers |
| Updated name for product *Software Development Kit* Now called: *ATS-SDK purchased with a digitizer board or ATS-GPU* | Ordering Information,  pg.  4 |
| Updated descriptions for maintenance items *ATSGPU-002, ATSGPU-102 & ATSGPU-202:* Removed technical support from maintenance extension | Ordering Information,  pg.  4 |
| Added products ATS-SDK-WOD and SUPPORT-HR5 | Ordering Information,  pg.  4 |

## Changes from version 4.1a (Aug 2020) to version 4.1b — Section, Page

| | |
|---|---|
| Modified note: ATS-SDK (sold separately) is required for using ATS-GPU-OCT | pg.  1 |
| Modified note: ATS-SDK (sold separately) is required for using ATS-GPU-OCT | Programming with ATS-GPU-OCT  pg.  2 |
| Updated product registration URL | Extended Support & Maintenance,  pg.  3 |

## Changes from version 4.1 (June 2020) to version 4.1a — Section, Page

| | |
|---|---|
| Added note that ATS-SDK (sold separately) is required for using ATS-GPU-OCT with Python, MATLAB, and LabVIEW. | pg.  1 |
| Added note that ATS-SDK (sold separately) is required for using ATS-GPU-OCT with Python, MATLAB, and LabVIEW. | Programming with ATS-GPU-OCT  pg.  2 |
| Added ATS-SDK to order information | Ordering Information,  pg.  4 |

## Changes from version 4.0c (Jan 2020) to version 4.1 — Section, Page

| | |
|---|---|
| Updated CUDA Compute Capability: ATS-GPU-BASE 4.1 supports compute capability 3.0 or higher | Global change |
| Added detail for high-speed floating-point FFT: for k-clocked data Added new optional ATS-GPU-NUFFT extention for non-uniform FFTs | Feature list,  pg.  1 |
| Added ATS-GPU-OCT version number | Feature table,  pg.  1 |
| Specified that AlazarTech PCIe digitizer must be installed for using user-supplied data Updated introductory text Removed zero-padding from list of signal processing done by kernel code Added paragraph about ATS-GPU-OCT use for data that is non-uniformly sampled in time domain and the new ATS-GPU-NUFFT for data non-uniformly sampled in frequency domain. | Overview,  pg.  1 |
| Added section on Latency | Latency,  pg.  1 |
| Updated CUDA toolkit in use to version 10.2 | ATS-GPU and CUDA Runtime Library,  pg.  2 |

# DATASHEET REVISION HISTORY

## Changes from version 4.0c (Jan 2020) to version 4.1 (continued)                    Section, Page

Removed repeated paragraph about provided sample programs.                    Programming with ATS-GPU-OCT,  pg.  2
  Updated LabVIEW compatibility: 64-bit LabVIEW 2016 or newer is required,
  Added note that LabVIEW NXG is not supported,
  Specified 64-bit MATLAB,
  Updated buffer size for RecordsPerBuffer to 1 to 16 Megabytes,
  Updated description to reflect that zero-padding is the responsibility of the user.

Updated to reflect that zero-padding is the responsibility of the user                    Zero Padding,  pg.  2

Added section Electronic Delivery                    Electronic Delivery,  pg.  3

Added ATS-GPU-NUFFT library extension order information                    Ordering Information,  pg.  4

## Changes from version 4.0b (May 2019) to version 4.0c                    Section, Page

Updated CUDA Compute Capability: ATS-GPU-BASE now supports compute capability 3.0 to 7.5                    Global change

Added new products (ATS9352, ATS9146) to data transfer rate table                    Data Throughput to GPU,  pg.  2

## Changes from version 4.0a (Feb 2019) to version 4.0b                    Section, Page

Added paragraph about support and updates beyond the included 12 months                    Annual Subscriptions,  pg.  3

Added section: *Extended Support & Maintenance*                    Extended Support & Maintenance,  pg.  3

## Changes from version 4.0 (Jan 2019) to version 4.0a                    Section, Page

Corrected operating systems support: removed 32-bit Windows                    Feature table,  pg.  1