

Leveraging the High Speed Averaging Mode in Ocean SR2 Spectrometers with OceanDirect

Technical Note

1.1



VERSION HISTORY

| Version # | Implemented | Description | Change |
|-----------|-------------|-------------|--------|
| 1.1 | xxxxxxxx | AUG-2022 | xxxxx |
| | | | |
| | | | |

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1 Signal To Noise Ratio Performance

1.1 Introduction

In spectroscopy, signal to noise ratio (SNR) performance is a key figure of merit, which in part, determines the final spectra quality and accuracy of a measurement. The SNR metric computes the ratio of the mean signal level to the rms noise level. The higher the SNR, the less the spectra will be degraded by unwanted noise -- reducing uncertainty and providing more accurate results.

Essentially, there are two considerations in modern spectrometers that limit the achievable SNR performance. One concern is the maximum permissible signal level (light intensity), beyond which, saturation occurs. However, the primary consideration in achieving good SNR performance is the unwanted noise generated in the detection process, which effectively limits the “noise floor” of your measurement. Noise is an unavoidable physical phenomenon that can be minimized but not eliminated. Measurements of signal spectra very close to the noise floor, i.e. low SNR, are degraded in accuracy, as a result of the random nature of noise being superimposed on the small signal of interest. The closer the relative magnitude of the noise is to the magnitude of the signal spectra, the larger the noise contribution and its impact.

As a spectrometer’s noise performance improves (lower noise), the ratio of signal to noise is increased, yielding better quality spectra results. Obtaining optimal SNR is especially key to making measurements in applications that require high accuracy, particularly when the level of incident light on the detector is low as a result of low reflectivity, low transmission, or other similar factors that limit incident light or integration time.

A well-known signal processing technique to improve SNR involves taking many spectra captures in time and then averaging the results. However, for time-sensitive applications, this brings up the question, “How long does it take to achieve a good SNR?”

Previous generation spectrometers increased the SNR by means of averaging spectra in software on the host computer. This traditional method requires significantly more time to do the equivalent number of averages compared to the hardware accelerated capability debuting in the new Ocean SR2 devices. In a given period

of time the Ocean SR2, when used with OceanDirect, will perform significantly more spectra averages yielding a far superior SNR per unit time. This is especially important for time-critical or real-time applications, where decisions must be made very quickly and with high accuracy.

The powerful hardware capability of High Speed Averaging Mode not only provides opportunities for new applications, but also can considerably enhance existing applications that require high SNR, on demand. This technical note will equip the user with all the details necessary to utilize the High Speed Averaging Mode feature.

1.2 COMPARATIVE PERFORMANCE

To appreciate the benefits of High Speed Averaging Mode, it is important to first compare the performance of an Ocean SR2 spectrometer to a hypothetical SR2, in which the feature is not present.

| Metric | Single Scans | High Speed Mode | Ratio |
|------------|--------------|-----------------|-------|
| Frame rate | 484 | 4,558 | 9.4 |

The table above shows a hypothetical SR2 value for Single spectra reads versus High Speed Averaging Mode with the lowest integration time. With the new hardware acceleration coupled with OceanDirect, a substantial speed increase can be accomplished.

This rate difference unlocks significant SNR per second improvement as shown below.

$$SNR\ improvement = \sqrt{9.4} \approx 3x$$

Before presenting measured data, it is important to note some considerations when attempting to make measurements of this caliber. Accurate measurements require a high-power, continuous light source. Moreover, it is important that the fiber optic have an even distribution of light filling all modes so that the variability of the light source does not impact the performance of the test. To accomplish this, an appropriate diffuser should be placed in-line with the

light source. Additionally, mechanical vibrations should be limited during testing to reduce the impact of the light distribution shifting throughout the test.

For the experimental data presented below, a glass diffuser was chosen with the Ocean SR2 instrument. A longer integration time was selected to compensate for the attenuation of light that is inherent with a diffuser. Alternatively, a brighter, diffuse light source may be chosen, and the integration time set to the minimum of 218 μs. Nevertheless, Table 1 shows the results using the High Speed Averaging Mode.

| Table 1 | | | |
|------------------|-----------|-------------|---------|
| Feature | Spectra/s | Integration | SNR |
| Integration time | 295 | 3,350 μs | 5,680:1 |

As **Figure 1** below indicates, this yields SNR of 5,680:1.

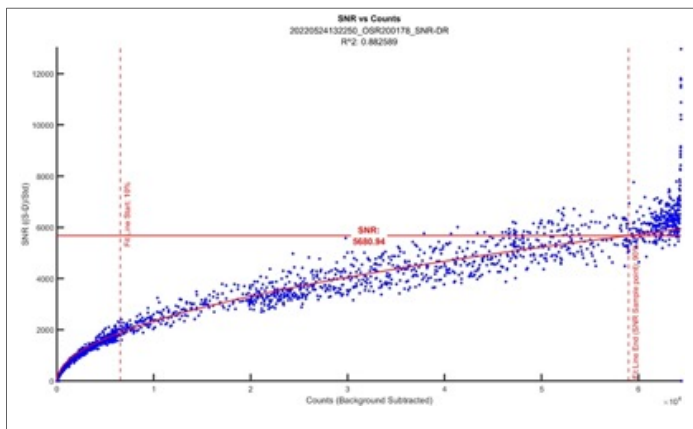


Figure 1 – SNR at 295 averages using High Speed Averaging Mode

Please refer to the section entitled “Appendix – SNR Test Procedure” for the equipment and test procedure used to obtain this data.

With the help of **Equation 1**, below, one may determine the maximum SNR achievable using the minimum integration time of 218 μs. The result is an incredible SNR

in 1 second of 22,338:1 using hardware acceleration! Incidentally, one could directly measure the maximum SNR/sec achievable, given an appropriate high intensity, diffuse light source so that integration time can be set at the minimum of 218 μs.

Equation 1

$$SNR_{MAX} = SNR_{Actual} \times \sqrt{S_{MAX} / S_{Actual}}$$

where:

SNR_{MAX} = Correlated maximum signal-to-noise ratio at 218 μs, with a diffuser

SNR_{Actual} = Actual signal-to-noise ratio

S_{MAX} = Maximum number of scans per second (4558 scans at 218 μs)

S_{Actual} = Actual number of scans used to calculate SNRActual

Extending these measured results to generate a plot of SNR versus time yields the plot shown in **Figure 2** below. This plot provides a dramatic illustration of how SNR improves over time for High Speed Averaging Mode versus the hypothetical Ocean SR2 that doesn’t have this feature.

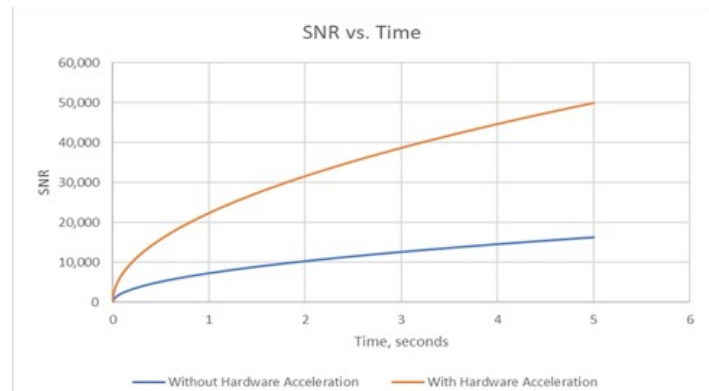


Figure 2 – Comparative SNR vs. Time

2 TECHNICAL DETAILS

2.1 High Speed Averaging Mode

Before getting into a discussion of High Speed Averaging Mode timing details, we need to first review some of the basic concepts related to Ocean Insight spectrometer timing. Specifically, it is important to understand spectrometer triggering and the spectrometer strobe outputs for synchronization. These concepts will be covered in the next two subsections. Following a review of these concepts, a detailed timing diagram will be presented that details trigger and strobe timing, specifically for High Speed Averaging Mode operation.

2.1.1 Triggering

A trigger is an action that causes the Spectrometer to start an acquisition cycle, after a user-defined Acquisition Delay has elapsed. A trigger event can be a command from software or a signal located on the auxiliary access connector of the spectrometer. In the context of this Technical Note, we are interested in the Software Triggering mode, since this supports High Speed Averaging Mode, enabling high SNR/sec performance.

As specified in the Ocean SR2 Installation and Operation Manual, the Ocean SR2 supports three triggering modes, which are set with the Trigger Mode command. As a review, the 3 trigger modes are as follows:

Software Triggering: A trigger is initiated internal to the Spectrometer with a command from Ocean Insight approved software. The integration period is set by software configuration. Specific to Software triggering only, there are 2 acquisition modes: **Single Spectra Capture** and **High Speed Averaging Mode**. *The Software Triggering mode is the only triggering mode that supports High Speed Averaging Mode.*

External Edge Triggering: A trigger is initiated by the rising edge of the external trigger signal on the auxiliary connector. The integration period is set by software configuration.

External Level Triggering: A trigger is initiated by the rising edge of the external trigger signal on the auxiliary connector. The integration time is determined by how long the trigger pulse is held high.

The default triggering mode is for a Software Trigger. A Software Trigger may be initiated by either OceanView, OmniDriver, or OceanDirect software. *However, use of High Speed Averaging Mode is only supported in OceanDirect software.* Once a command is sent to the Spectrometer, an internal trigger is generated that begins an integration cycle.

There are 2 acquisition modes for the Software Trigger with the default being the Single Spectra Capture. For the Single Spectra Capture mode, a software trigger will initiate a single acquisition cycle with the spectral data made available after the integration period and a specific busy time. The second acquisition mode, High Speed Averaging Mode, will generate n integration periods with the spectral data being an average of the spectral values for each of the n integration cycles. The spectral data is available after the last integration period and a specific busy time.

2.1.2 Strobes

Synchronization of external devices to the spectrometer's integration period can be accomplished with the use of either the Single Strobe Output or the Continuous Strobe Output, located on the auxiliary connector of the spectrometer.

Single Strobe Output

The Single Strobe Output is an active-high, 3.3V CMOS programmable pulse that occurs at a user-defined time during each acquisition cycle. This pulse has a user-defined delay (t_{SSDLV}) and a user-defined width (t_{SSW}). Both values are programmable in 1 μ s increments for the range of 0 to 65,535 μ s.

The timing of the Single Strobe signal output is referenced from a Trigger Event. The Single Strobe Delay defines the time from the Trigger Event until the rising edge of the Single Strobe output. Note that a user-defined Acquisition Delay for the Trigger can cause the Single Strobe to pulse before the start of integration. After the Single Strobe Delay has elapsed and the Single Strobe Output has gone high, it will remain active for a duration equal to the Single Strobe Width. The Single Strobe Output will return to a low or inactive state at the end of the Single Strobe Width.

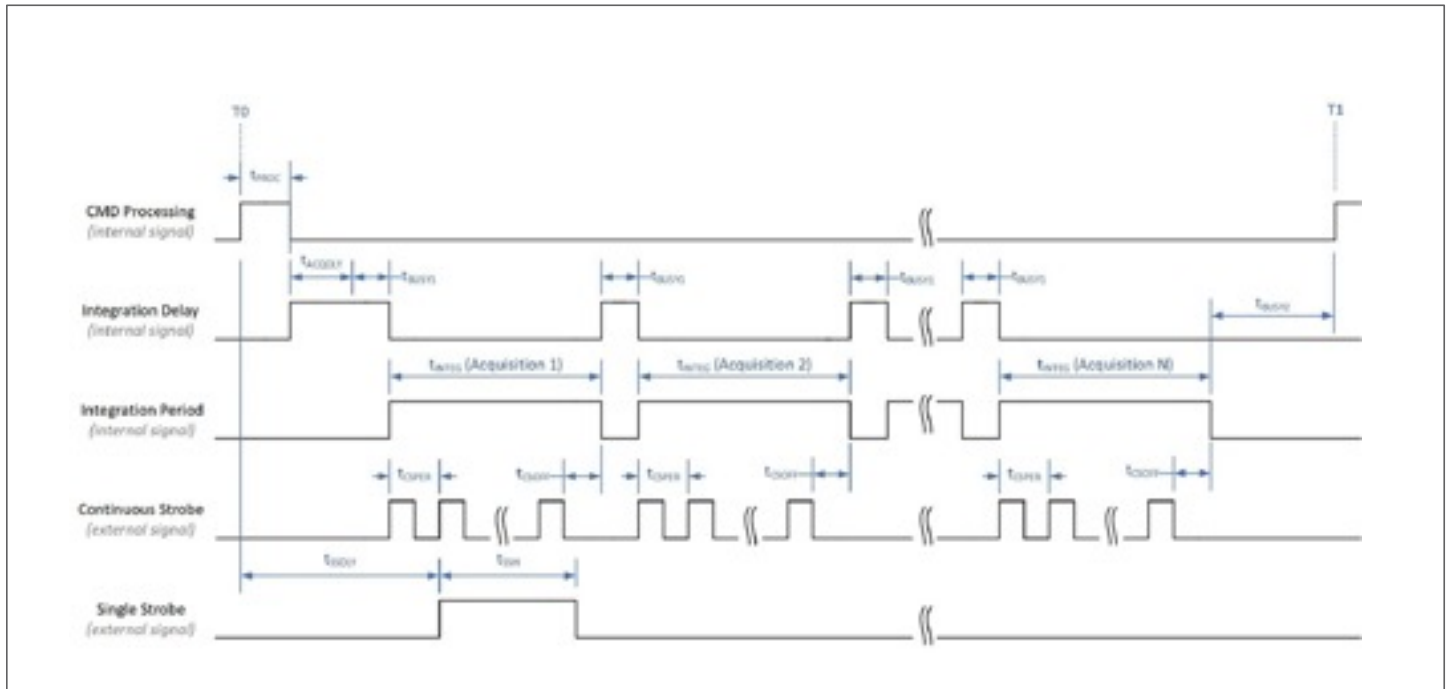
If the Single Strobe Output is programmed for a longer period than the integration time, it will reset to its inactive state at the end of the integration period.

Continuous Strobe Output

The Continuous Strobe output signal is an active-high, 3.3V CMOS programmable pulse that occurs at a user-defined time during each acquisition cycle. The

2.1.3 Timing Details

The following timing diagram in **Figure 3** specifies the timing relationship between triggering, integration cycles, and the spectrometer's strobe outputs for High Speed Averaging Mode. The values of the timing parameters annotated in the diagram may be found at the end of this section.



Continuous Strobe is a series of pulses defined by a user-defined period with a 50% duty cycle. The Continuous Strobe Period (t_{CSPER}) has a resolution of 1 μ s.

The Continuous Strobe signal is only valid during the integration period (t_{INTEG}). The Continuous Strobe period has a resolution of 1 μ s for a range of 0 to 65,535 μ s. However, the Continuous Strobe signal is only exercised if it can complete a full period within the integration period. If there are multiple Continuous Strobe periods within an integration period, only full periods are realized. This means the time between the last Continuous Strobe period and the end of integration time is between 0 and t_{CSPER} .

For the continuous Strobe signal to be fully realized for at least one period, the integration time must be greater than or equal to the Continuous Strobe Period.

Figure 3 – High Speed Averaging Mode Timing Diagram

High Speed Averaging Mode can be thought of as N Single Spectra Capture acquisitions back-to-back. The total time for a High Speed Averaging Mode acquisition with N integrations, t_{CISN} , can be defined as,

$$t_{CISN} = t_{PROC} + t_{ACQDLY} + N(t_{BUSY1} + t_{INTEG}) + t_{BUSY2}$$

If a start time of T_0 is defined as the moment a software command is entered into OceanDirect software requesting an acquisition, then there is a latency time of t_{PROC} , which is the Software Command Processing time from T_0 to when the “integration delay” starts. The integration delay starts after t_{PROC} and ends before the start of the first integration time, t_{INTEG} . As shown in the diagram, the integration delay is the sum of the user defined acquisition delay, t_{ACQDLY} and t_{BUSY1} , where t_{BUSY1} is a constant equal to 1 μ s.

Following the last integration period, the detector is busy to finish the acquisition cycle and that time is t_{BUSY2} . After this time, the detector is ready for another trigger.

Notice in the diagram above, that the single strobe is a single active-high pulse defined by an initial delay (t_{SSDLY}) from the start of the acquisition delay (t_{ACQDLY}) and a pulse width (t_{SSH}). The values for the single strobe delay and pulse high width are set by the user in OceanDirect software. Even though there are N integration cycles, there is still only one single strobe signal.

Alternatively, as can be seen in the diagram, the continuous strobe signal is a series of pulses with a user

specified period that starts with the beginning of each integration time, t_{INTEG} . The pulses have a 50% duty cycle and only full periods are exercised during an integration period. If a subsequent continuous strobe period cannot be completed before the end of the integration cycle, the continuous strobe signal is turned off and set to 0 for the remainder of the integration period.

Timing parameters for High Speed Averaging Mode are described below. It should be noted that the integration period, t_{INTEG} , is user-defined but has a minimum value of 218 μs .

| Symbol | Description | Time | | | Notes |
|---------------------|----------------------------|-------------------|-------------------|--------------------|--|
| | | MIN | TYP | MAX | |
| T_0 | Software Trigger Command | | | | Start of Acquisition Cycle |
| t_{PROC} | Trigger Command Processing | | | | System dependent (e.g., computer hardware, software, driver) |
| t_{ACQDLY} | Acquisition Delay | 0 μs | -- | 21.47 s | User specified, 1 μs resolution |
| t_{BUSY1} | Busy | -- | 1 μs | -- | 1 μs constant |
| t_{INTEG} | Integration Period | 218 μs | -- | 1.19 | User specified, 1 μs resolution |
| t_{BUSY2} | Busy | -- | 218 μs | hours | Constant at 218 μs |
| t_{SSDLY} | Single Strobe Delay | 0 μs | -- | -- | User specified, 1 μs resolution |
| t_{SSH} | Single Strobe High Time | 0 μs | -- | 1.19 | User specified, 1 μs resolution |
| t_{CSPER} | Continuous Strobe Period | 0 μs | -- | hours | User specified, 1 μs resolution |
| t_{CSOFF} | Continuous Strobe Off Time | 0 μs | -- | t_{CSPER} | |

2.2 Implementation In OceanDirect

OceanDirect is a powerful Software Developer's Kit (SDK) that allows you to easily write custom software solutions for your Ocean Insight spectrometers.

You may develop your application in any environment of your choosing such as C, C#, C++, LabVIEW, MATLAB, etc. A wrapper is provided specifically for developing applications in Python.

```
"""
@author: Ocean Insight Inc.
"""
from oceandirect.od_logger import od_logger
from oceandirect.OceanDirectAPI import OceanDirectAPI, OceanDirectError

# create stream logger
logger = od_logger()

def get_spectra_accelerate(device, num_spectra):

    try:
        device.set_scans_to_average(num_spectra)

        numb_pixel = len(device.get_formatted_spectrum())
        spectra_m = [0 for x in range(numb_pixel)]
        spectra_m = device.get_formatted_spectrum()

    except OceanDirectError as e:
        logger.error(e.get_error_details())

def get_spectra_single(device, numb_spectra):

    try:
        device.set_scans_to_average(1)

        numb_pixel = len(device.get_formatted_spectrum())
        spectra_m = [[0 for x in range(numb_pixel)] for y in
range(numb_spectra)]

        for i in range(numb_spectra):
            spectra_m[i] = device.get_formatted_spectrum()

    except OceanDirectError as e:
        logger.error(e.get_error_details())
```

```
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        spectra_m = device.get_formatted_spectrum()

    except OceanDirectError as e:
        logger.error(e.get_error_details())

def get_spectra_single(device, numb_spectra):

    try:
        device.set_scans_to_average(1)

        numb_pixel = len(device.get_formatted_spectrum())
        spectra_m = [[0 for x in range(numb_pixel)] for y in
range(numb_spectra)]

        for i in range(numb_spectra):
            spectra_m[i] = device.get_formatted_spectrum()

    except OceanDirectError as e:
        logger.error(e.get_error_details())
```

Figure 4 – Python Implementation Example

We are going to focus on **Python** examples (see **Figure 4**) due to its availability and cross-platform capabilities. The example above should be straightforward to translate to other development environments with minimal effort.

It is assumed that OceanDirect has been installed and the spectrometer is attached to the PC. We start with the `find_usb_devices()`, which returns a tracked handle to a list of Devices objects containing metadata for all detected/known devices on USB. A spectrometer may be opened with the `open_device()`, which then allows operations to be performed on it. The spectrometer should not be opened again until it is first closed using `close_device()`.

Once the device is open, several methods are available to configure and query the spectrometer. The serial number is displayed with `get_serial_number()` for verification purposes.

For this experiment, the electric dark correction is disabled, and the non-linearity is enabled. The desired integration time is passed to the spectrometer using the `set_integration_time()` method.

Two methods are available to retrieve spectra, `get_spectra_single()` and `get_spectra_accelerate()`. As the name suggests, each method demonstrates the software capabilities to collect one spectra sample at a time or the accelerated version.

```
$ py test_get_spectra_minimal.py
Serial Number: OSR200123
Integration time: 218 us

Single Capture: 4560 scans
Accelerated Capture: 4560 scans
Closing device!

**** exiting program ****
```

Figure 5 – Console Output for Python Implementation Example

Figure 5 shows the console output of the sample Python code. End users are going to notice a significant speed increase on the data processing when using the accelerated version.

3 Supported Models And Software

High Speed Averaging Mode is supported as follows:

Software

- OceanDirect versions 1.30 and higher

Spectrometers

- Ocean SR2

4 Appendix – Example SNR Test Procedure

4.1 Equipment List

- Spectrometer: OCEAN-SR2
 - o Microprocessor Firmware version: 1.1.2
 - o FPGA Firmware version: 1.3.2
- Ocean Insight OceanDirect
 - o Version: 1.30.1 rc4
- Light Source: HL-2000-FHSA-LL
- Optical Fiber 1: QP1000-2-SR
- Optical Fiber 2: QP1000-2-VIS-NIR
- MATLAB 2021b
- Ocean Insight SNR/DR Test Application
 - o Version: 3.1.0
- In-Line Diffuser

4.2 Procedure

1. Connect Fiber 1 to Light Source and Fiber 2 to Spectrometer. Connect In-Line Diffuser between Fiber 1 and Fiber 2.
2. Turn on Spectrometer and Light Source and let warm up 30 minutes.
3. Follow standard SNR testing procedures, setting the integration time so the spectrum is slightly saturated, with 5-10 pixels saturated. Standard SNR testing procedure is as follows:
 - a. 100 spectra taken at the same integration time with a lamp on
 - b. 100 spectra taken at the same integration time with lamp off
 - c. Spectra must reach at least 95% full scale, preferably go to saturation
 - d. Spectra should cover a range of counts down and below 10% full scale
 - e. The data must have linearity correction on
4. Adjust scans to average so the total averaging time is 1 ± 0.01 seconds.
5. Follow directions on Ocean Insight SNR/DR Test Application.

4.3 SNR Calculation

The following equation describes SNR for a given pixel p :

$$\text{SNR}_p = (S_p - D_p) / \sigma_p$$

where:

\underline{S} = signal to noise ratio

\underline{S} = mean intensity of the samples (with light)

\underline{D} = mean of dark (no light)

σ = standard deviation of samples (with light)

p = pixel number