Technical Note

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

PRODUCT DESIGN SPECIFICATION TEMPLATE

Version 1.3
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VERSION HISTORY

Version #	Implemented By	Revision Date	Change
1	Greg S. / Alex F.	14-June-2022	Initial Draft
1.1	Brian M.	22-June-2022	Minor text edits
2.0	Greg S.	27-Sept-2022	Make product generic & simplified timing diag.
2.1	Steven F.	16-Nov-2022	Updated timing diagram. Add HR4 timing values.
2.2	Steven F.	01-Mar-2023	• Added more supported devices SR4, SR6, HR6, and ST. • Added timing details for newly supported devices • Updated Triggering section to indicate that External Edge Trigger mode supports High Speed Averaging Mode • Minor updates to wording in strobes section.

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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 latest series of Ocean devices.

In a given period of time the new Ocean spectrometers, 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 guide the use of the High Speed Averaging feature.

1.2 COMPARATIVE PERFORMANCE

To appreciate the benefits of High Speed Averaging Mode, we will compare the performance of an Ocean SR2 spectrometer using High Speed Averaging Mode to the SR2 not using the feature. Although a similar comparison could be done for any of the new Ocean spectrometers that support High Speed Averaging Mode, we will use the Ocean SR2 for the purpose of this example.

Metric	Single Scans	High Speed Mode	Ratio
Framerate	484	4,558	9.4

The table above compares the framerate for the SR2 performing 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.

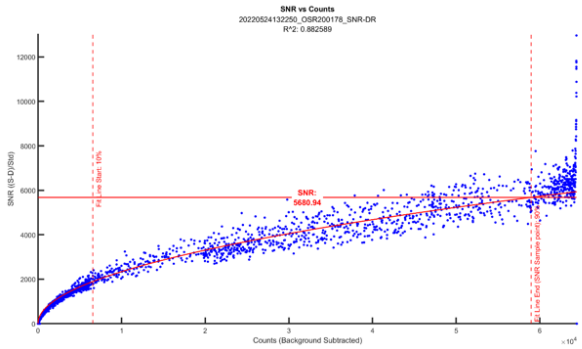

Figure 1 – SNR at 295 averages using High Speed Averaging Mode

Please refer to the section entitled “Appendix – Example 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

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

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 calculateSNR_{Actual}

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 Ocean SR2 not using this feature.

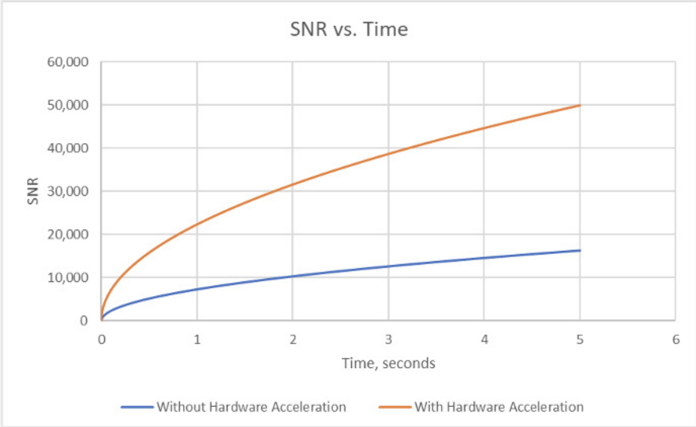

Figure 2 – Comparative SNR vs. Time

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 Installation and Operation Manual for each spectrometer, the devices support three triggering modes, which are set with the Trigger Mode command. As a review, the 3 trigger modes are as follows:

Software Trigger: A trigger is initiated internal to the Spectrometer with a command from Ocean Insight approved software. The integration period is set by software configuration. *Software Trigger mode supports High Speed Averaging Mode.*

External Edge Trigger: 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 Edge Trigger mode supports High Speed Averaging Mode.*

External Level Trigger: 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. *External Level Trigger mode does NOT support High Speed Averaging Mode.*

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 which 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 (tSSDLY) and a user-defined width (tSSH). Both values are programmable in 1 µs increments.

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. 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.

Note that there is a delay from the Trigger Event until the start of integration. So, if the Single Strobe Delay is less than the Integration Delay, then the Single Strobe will assert before the start of integration. If the Single Strobe Output is programmed for longer than the integration time, it will reset to its inactive state at the end of the first integration period.

Continuous Strobe Output

The Continuous Strobe output signal is an active-high, 3.3V CMOS periodic signal with a 50% duty cycle that occurs during the integration time during each acquisition cycle. The Continuous Strobe is defined by the Continuous Strobe Period (tCSPER) and has a resolution of 1 µs.

The Continuous Strobe signal is only valid during the integration period (tINTEG). Moreover, 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.

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

2.1.3 Timing Details

The timing diagram in Figure 3, below, illustrates the timing relationship between triggering, integration cycles, and strobe outputs for all spectrometers that support High Speed Averaging Mode. The values of the timing parameters annotated in the diagram, may be found in subsequent subsections for each specific series of spectrometer, as each series will have its own characteristic values.

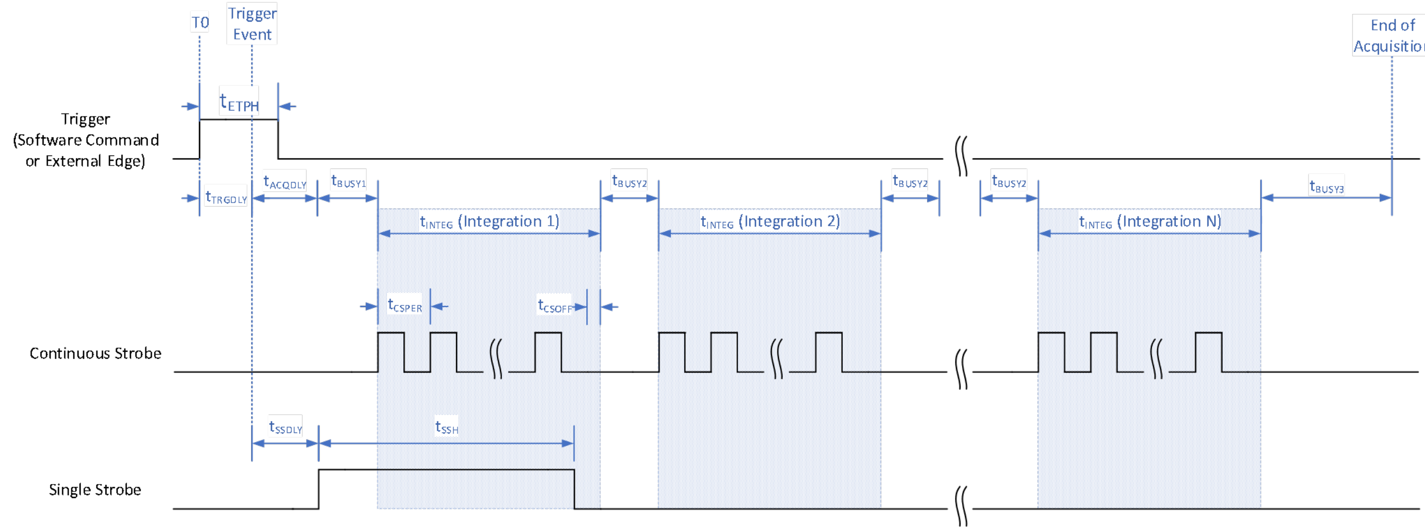

Figure 3 – High Speed Averaging Mode Timing Diagram

High Speed Averaging Mode can be thought of as N Single Spectra Capture acquisitions back-to-back. From the diagram, the total time for a High Speed Averaging Mode acquisition with N integrations, tN, can be defined as,

$$tN = tACQDLY + tBUSY1 + (N * tINTEG) + ((N-1) * tBUSY2) + tBUSY3$$

Following the last integration period, the detector is busy to finish the acquisition cycle and that time is tBUSY3. After this time, the data is transmitted back to the host and then 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 (tSSDLY) from the Trigger Event and a pulse width (tSSH). 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, tINTEG.

2.1.3.1 SR2/HR2 Series Timing Parameters

Symbol	Description	Time			Notes
		min	typ	max	
t_{ETPH}	External Edge Trigger Pulse Width	10 ns	--	--	
$t_{ETRGDLY}$	External Edge Trigger Delay	20 ns	--	30 ns	
t_{ACQDLY}	Acquisition Delay	0 µs	--	335,500 µs	User specified, 1µs resolution
t_{BUSY1}	Initial busy time	--	1 µs	--	Constant at 1 µs
t_{INTEG}	Integration Time	218 µs	--	6 s	User specified, 1 µs resolution
t_{BUSY2}	Busy time between integrations	--	0 µs	--	Constant at 0 µs. Integrations are back-to-back in High Speed Averaging Mode
t_{BUSY3}	Final busy time	--	218 µs	--	Constant at 218 µs
t_{SSDLY}	Single Strobe Delay	0 µs	--	--	User specified, 1 µs resolution. Single Strobe returns low at the end of the first integration time.
t_{SSH}	Single Strobe Width	0 µs	--	--	User specified, 1 µs resolution. Single Strobe returns low at the end of the first integration time.
t_{CSPER}	Continuous Strobe Period	0 µs	--	t_{INTEG}	User specified, 1 µs resolution. Should be less than Integration Time to activate.
t_{CSOFF}	Continuous Strobe Off Time	0 µs	--	t_{CSPER}	
N	Number of Integrations	2	--	65,535	User specified.

2.1.3.2 SR4/HR4 Series Timing Parameters

Symbol	Description	Time			Notes
		min	typ	max	
t_{ETPH}	External Edge Trigger Pulse Width	10 ns	--	--	
$t_{ETRGDLY}$	External Edge Trigger Delay	20 ns	--	30 ns	
t_{ACQDLY}	Acquisition Delay	0 µs	--	335,500 µs	User specified, 1µs resolution
t_{BUSY1}	Initial busy time	--	3706 µs	--	Constant at 3706 µs
t_{INTEG}	Integration Period	3800 µs	--	10 s	User specified, 1 µs resolution
t_{BUSY2}	Busy time between integrations	--	0 µs	--	Constant at 0 µs. Integrations are back-to-back in High Speed Averaging Mode
t_{BUSY3}	Final busy time	--	3706 µs	--	Constant at 3706 µs
t_{SSDLY}	Single Strobe Delay	0 µs	--	--	User specified, 1 µs resolution. Single Strobe returns low at the end of the first integration time.
t_{SSH}	Single Strobe Width	0 µs	--	--	User specified, 1 µs resolution. Single Strobe returns low at the end of the first integration time.
t_{CSPER}	Continuous Strobe Period	0 µs	--	t_{INTEG}	User specified, 1 µs resolution. Should be less than Integration Time to activate.
t_{CSOFF}	Continuous Strobe Off Time	0 µs	--	t_{CSPER}	
N	Number of Integrations	2	--	65,535	User specified.

2.1.3.3 SR6/HR6 Series Timing Parameters

Symbol	Description	Time			Notes
		min	typ	max	
t_{ETPH}	External Edge Trigger Pulse Width	10 ns	--	--	
$t_{ETRGDLY}$	External Edge Trigger Delay	20 ns	--	30 ns	
t_{ACQDLY}	Acquisition Delay	0 µs	--	335,500 µs	User specified, 1µs resolution
t_{BUSY1}	Initial busy time	--	15 ns	--	Constant at 15 ns
t_{BUSY2}	Busy time between integrations	--	835 µs	--	Constant at 835 µs
t_{INTEG}	Integration Period	7200 µs	--	5 s	User specified, 1 µs resolution
t_{BUSY3}	Final busy time	--	4977 µs	--	Constant at 4977 µs
t_{SSDLY}	Single Strobe Delay	0 µs	--	--	User specified, 1 µs resolution. Single Strobe returns low at the end of the first integration time.
t_{SSH}	Single Strobe Width	0 µs	--	--	User specified, 1 µs resolution. Single Strobe returns low at the end of the first integration time.
t_{CSPER}	Continuous Strobe Period	0 µs	--	t_{INTEG}	User specified, 1 µs resolution. Should be less than Integration Time to activate.
t_{CSOFF}	Continuous Strobe Off Time	0 µs	--	t_{CSPER}	
N	Number of Integrations	2	--	65,535	User specified.

2.1.3.4 ST Timing Parameters

Symbol	Description	Time			Notes
		min	typ	max	
t_{ETPH}	External Edge Trigger Pulse Width	10 ns	--	--	
$t_{ETRGDLY}$	External Edge Trigger Delay	20 ns	--	30 ns	
t_{ACQDLY}	Acquisition Delay	0 µs	--	335,500 µs	User specified, 1µs resolution
t_{BUSY1}	Initial busy time	--	1561 µs	--	Constant at 1561 µs
t_{INTEG}	Integration Period	3800 µs	--	6 s	User specified, 10 µs resolution
t_{BUSY2}	Busy time between integrations	--	0 µs	--	Constant at 0 µs. Integrations are back-to-back in High Speed Averaging Mode
t_{BUSY3}	Final busy time	--	1553 µs	--	Constant at 1553 µs
t_{SSDLY}	Single Strobe Delay	0 µs	--	--	User specified, 1 µs resolution. Single Strobe returns low at the end of the first integration time.
t_{SSH}	Single Strobe Width	0 µs	--	--	User specified, 1 µs resolution. Single Strobe returns low at the end of the first integration time.
t_{CSPER}	Continuous Strobe Period	0 µs	--	t_{INTEG}	User specified, 10 µs resolution. Should be less than Integration Time to activate.
t_{CSOFF}	Continuous Strobe Off Time	0 µs	--	t_{CSPER}	
N	Number of Integrations	2	--	65,535	User specified.

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.

```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())
```

```
if __name__ == '__main__':

    od = OceanDirectAPI()
    device_count = od.find_usb_devices()
    device_ids = od.get_device_ids()

    device_count = len(device_ids)

    if device_count:
        for id in device_ids:
            device       = od.open_device(id)
            serialNumber = device.get_serial_number()
            print("Serial Number: %s          " % serialNumber)

            int_time_us = 218
            numb_spectra = 4560

            print("Integration time: %d us \n" % int_time_us)

            device.set_electric_dark_correction_usage(False)
            device.set_nonlinearity_correction_usage(True)
            device.set_integration_time(int_time_us)

            print("Single Capture: %d scans" % numb_spectra)
            get_spectra_single(device, numb_spectra)

            print("Accelerated Capture: %d scans" % numb_spectra)
            get_spectra_accelerate(device, numb_spectra)

            print("Closing device!\n")
            od.close_device(id)

    print("**** exiting program ****")
```

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.

SUPPORTED MODELS AND SOFTWARE

High Speed Averaging Mode is supported as follows:

Software

- OceanDirect versions 1.30 and higher

Spectrometers

The following spectrometers support High Speed Averaging Mode with FPGA Firmware version 1.3.0 or higher.

- Ocean SR2
- Ocean HR2
- Ocean SR4
- Ocean HR4
- Ocean SR6
- Ocean HR6
- Ocean ST

APPENDIX – EXAMPLE SNR TEST PROCEDURE

High Speed Averaging Mode is supported as follows:

Software

- OceanDirect versions 1.30 and higher

Spectrometers

The following spectrometers support High Speed Averaging Mode with FPGA Firmware version 1.3.0 or higher.

- Ocean SR2
- Ocean HR2
- Ocean SR4
- Ocean HR4
- Ocean SR6
- Ocean HR6
- Ocean ST