OtO Photonics

SmartEngine™ Series

Product Sheet

Introduction

The SmartEngine™ (SE) Series spectrometer provides optimized spectrum analysis with an elegant architecture consisting of a CCD image sensor plus a 32-bit RISC microcontroller. Its optical bench delivers robust and reliable spectral measurement performance, with minimal resolution and wavelength drift under the influence of humidity, vibration, and shock. The miniature design provides additional flexibility for integrations with a wide range of systems.

The SE series employs a Czerny-Turner optical bench that delivers high optical resolution, high sensitivity, low dispersion, and high-speed spectrum response.

The SE series is powered by USB via the USB connection with a computer. In addition, it provides an interface with six I/O pins for connecting external devices.

This document provides detailed information about the SE Series and how to work with it.

The SE series spectrometer module uses Hamamatsu's high-sensitivity linear image sensor.

With RISC microcontrollers, the SE Series spectrometers can be operated using the software provided by OtO Photonics.

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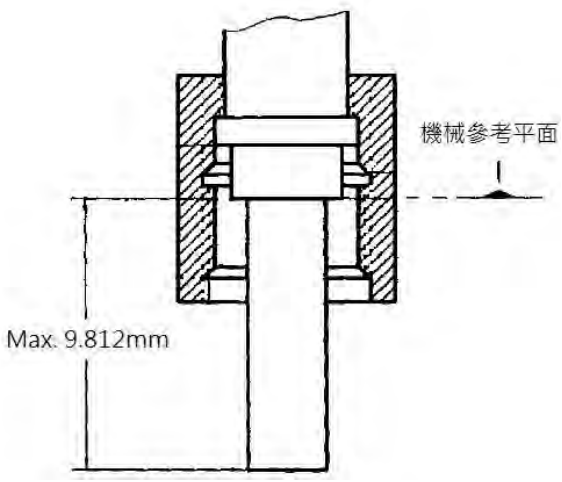
www.aptechnologies.co.uk
AP Technologies Ltd. 21A Charles Street Bath BA1 1HX
T: +44 (0) 1225 780400 E: info@aptechnologies.co.uk

Precautions

Illustration	Description
	Screw in the fiber optic connector with fingers. Do not use any tool to tighten it. Using tools such as wrenches to tighten the connector may cause the connector to press against and damage the inlet slit of the spectrometer. Such damage is not covered by the warranty. In cases where the connector needs to be firmly in place for long-term use, it is advised to apply a little glue to where the SMA905 connector is connected to the spectrometer.
	The SMA 905 connectors on all spectrometers made by OtO Photonics are manufactured in accordance with international standards. Customers should ensure that the ferrule length of the fiber used is not longer than 9.812mm to avoid damaging the slid in the SMA905 connector. Such damage is not covered by the warranty.

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Overview

▶ 1.1 SE Series Products

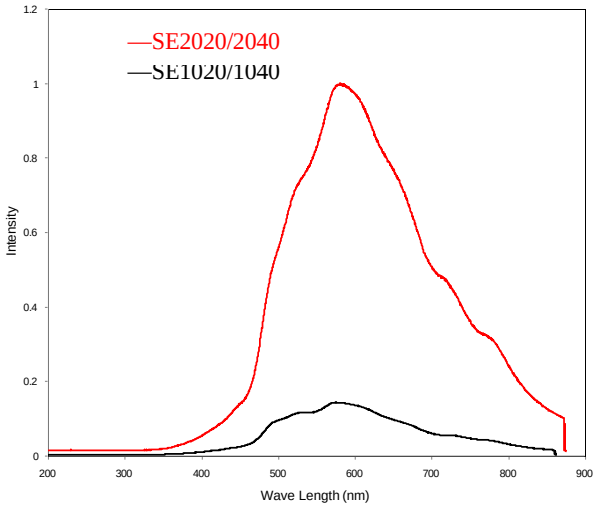
Model	Wavelength range					SNR*1	Dynamic range*2	Stray Light	A/D	Thermal Stability Test
	DUVN	FUV	FUVN	VNIR	NIR1					
	200 ~ 1025	180 ~ 850	180 ~ 1100	350 ~ 1020	790 ~ 1010					
SE1010 SE2010				√		200	2200	0.2%	16 bits	<0.04nm/℃
SE1020 SE2020	√	√	√	√	√	250	1700	0.2%		
SE1030 SE2030	√	√	√	√	√	350	4300(2.5MHz) 3000(10MHz)	0.2%		
SE1040 SE2040	√*3			√		200	2200	0.2%		
SE1050 SE2050				√	√	500	4600	0.45%		
SE1070 SE2070	√			√	√	350	2200	0.2%		
SE1080 SE2080	√			√	√	350	3200	0.2%		
SE1090 SE2090		√	√	√		500	6000	0.45%		
SE5090 SE6090 SE5190 SE6190		√	√	√						
SE1120 SE2120	√	√	√	√	√	350	4300(2.5MHz)	0.2%		

*1: Single measurement results
*2: The DUVN wavelength range of SE2040 starts at 275nm

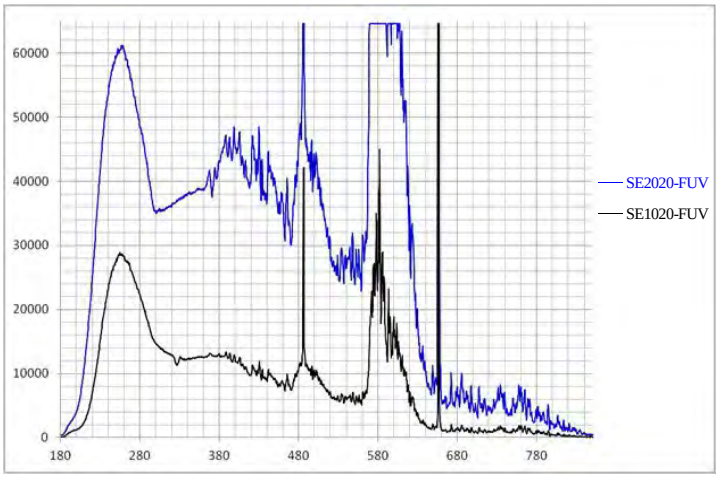
- The SE2xxx/4xxx spectrometers are sensitivity-enhanced.
- SE1020/SE2020 spectrometers feature CCDs coated with Lumogen E (a fluorescent pigment) to enhance the CCDs' sensitivity in the ultraviolet (UV) region. This improves the performance of ILX511B front-illuminated CCD by reducing the effect of thin-film interference on the spectral measurements.

► 1.2 Efficiency Comparison Experiment

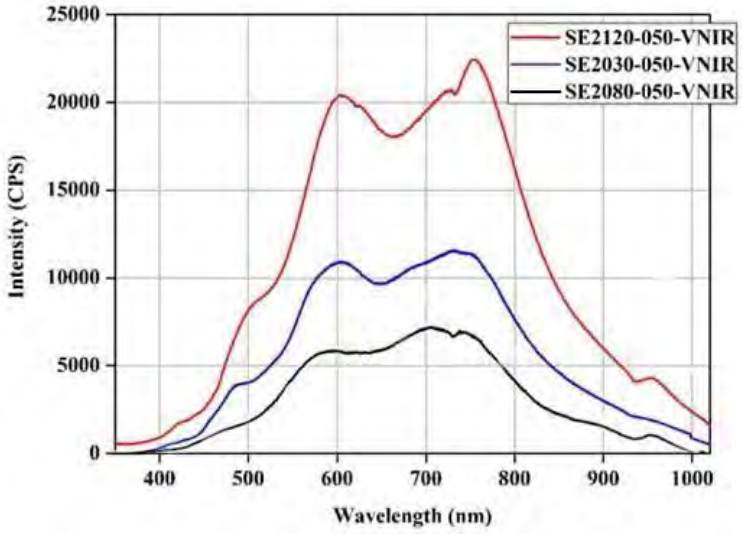
Comparing SE1020/1040 and SE2020/2040



Comparing SE1020-FUV and SE2020-FUV

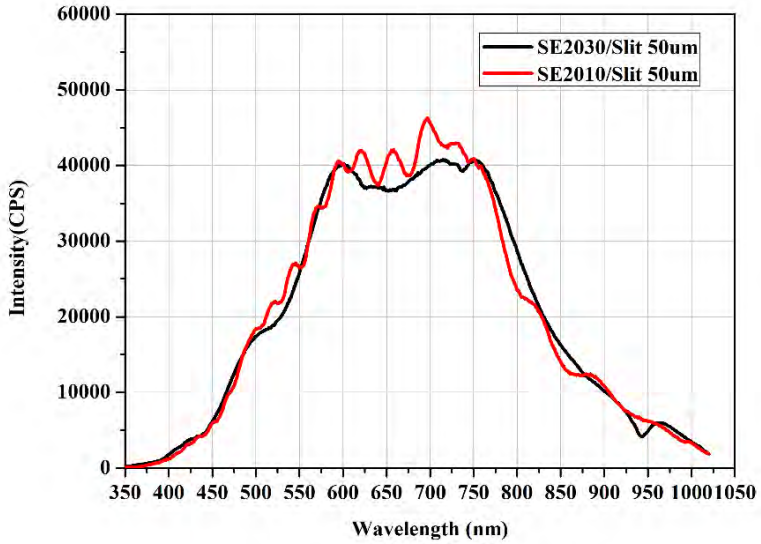


- As the results in the upper-left chart show, SE2020/2040 (with newer optical design) is 7.5 times more photosensitive-efficient than SE1020/1040 (with the standard design) at 570nm.
- As the results in the upper-right chart show, SE2020-FUV is 3 times more sensitive than SE1020-FUV in the UV region.

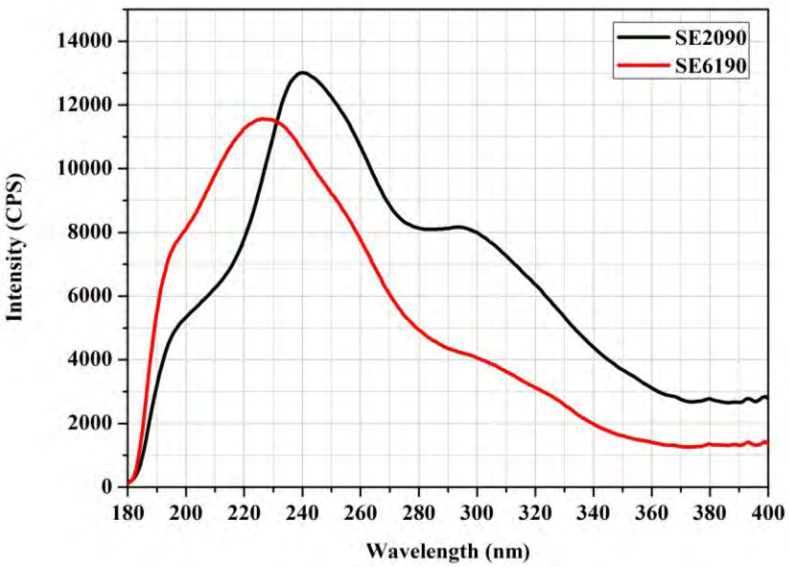


	SE2120	SE2030	SE2080
Pixels	1024	2048	4096
Pixel size (W x H, um)	28x200	14x200	7x200

- As the results show, while SE2120 has fewer pixels than SE2030, its pixel size is twice as large than SE2030, making it almost 2 times more efficient than SE2030, hence the greatly improved sensitivity.



- The results of the sensitivity comparison between SE2010 and SE2030 indicate that both exhibit similar spectral response capabilities



- SE6190 shows higher UV sensitivity than SE2090(or SE6090) below 230 nm

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Key Features

2.1 Characteristics

- Wavelength range: 180 ~1100 nm
- Optical resolution: 0.2 - 10.5 nm, depending on the inlet slit width and the concave grating
- Available in various types of image sensors for different applications:
  - High-sensitivity 2048-pixel CCD linear image sensor
  - Back-illuminated 2048-pixel CCD linear image sensor
  - High-speed 2048-pixel CMOS image sensor
  - High-speed 1024-pixel CMOS image sensor
  - High-resolution 3648-pixel CCD linear image sensor
  - High-speed 4096-pixel CMOS image sensor
- Customizable modular components: grating, image sensor, and inlet slit width
- Integration time range: 0.1 ms -65 second, depending on the type of the image sensor
- 16 bit, 15MHz A/D converter
- USB 2.0 @ 480 Mbps (High Speed)
- An 8-pin external I/O port for connecting external devices
  - 6 pins for digital I/O data acquisition
- Plug-n-Play computer application support
- Ultra-precise continuous exposure, holding up to 4,000 records of spectrum data in memory
- Different sensor clock speeds are available for customers to choose from, depending on their requirements for reproducibility or high speed processing
- Flash ROM storage
  - Wavelength calibration parameters
  - Linearity correction parameters
  - Intensity correction parameters
- The inlet slit can be moved to the left side of the spectrometer (SE2052, perpendicular to the original position) for better flexibility to integrate with other devices

► 2.2 Specifications

Features	Specifications								
	SE 2010	SE 2020	SE 2030	SE 2040	SE 2050	SE 2070	SE 2080	SE 2090 / 6190	SE 2120
Image Sensor	3000 Pixel	2048 pixels	2048 pixels	2048 pixels	2048 pixels	3648 pixels	4096 pixels	2048 pixels	1024 pixels
	Front-illuminated CCD	UV-enhanced front-illuminated CCD	Fast-exposure CMOS	Front-illuminated CCD	NIR-enhanced back-illuminated CCD	High pixel-resolution CCD	Fast-exposure CMOS	Fast-exposure back-illuminated CCD	Fast-exposure CMOS
Dark noise (Average)	30	38	15*1 21*2	30	14	30	21	11	15
Dynamic Range*3	2200	1700	4300*1 3000*2	2200	4600	2200	3200	6000	4300
SNR*4	200	250	350	200	500	350	350	500	350
Optical system characteristics	f/#: 5, NA: 0.1, Focal Length (R1-R2): 60-60 Recommendation: the inlet numerical aperture (NA) of the user's design should be higher than that of the spectrometer								
Spectrometer	SE Series, Czerny-Turner optical bench, 2nd and 3rd harmonics removed								
Dimensions	Type I version: 110 (L) x 86 (W) x 32.4 (H) mm Type II version: 110 (L) x 86 (W) x 35.4 (H) mm Double-layer version: 110 (L) x 86 (W) x 53.9 (H) mm (This version is available only with SE2030P-FUV2 & NIR1, SE2050P-NIR1, SE2060P-FUV2, FUV2:180-500nm, and NIR1:790-1010nm)								
Grating	15 types to choose from, wavelength range from UV to NIR								
Wavelength	From 180 nm to 1100 nm, various ranges to choose from								
Inlet slit width	10, 25, 50, 100, 200, 300 um								
Integration Time	0.1 ms – 65 sec, depending on the selected type of the image sensor								
Wavelength reproducibility	+/- 0.05 nm, 100 consecutive measurements (mercury-argon lamp)								

*1: Results for image sensor clock speed set at 2.5MHz
*2: Results for image sensor clock speed set at 10MHz
*3: Single measurement results

Features		Specifications
Wavelength Accuracy		± 0.3 nm (The testing environment is designed for the specifications of SE1020-050-VNIR. Actual results in real world may vary within ±1nm, depending on usage environments, such as high/low temperatures or prolonged vibrations. OtO can provide wavelength calibration software for customers who have such calibration needs
Resolution (FWHM)		0.2 nm - 10.5 nm, depending on configurations
Thermal Stability		<0.04 nm/°C
Environmental requirements	Storage temperature	-30°C to +70°C
	Operating temperature	0°C to +50°C
	Relative Humidity	0% - 90% non-condensing
Data transfer interface	SE2xxx	USB 2.0 @ 480 Mbps (High Speed)
	SE6xxx	USB 2.0 @ 480 Mbps (High Speed), Ethernet @100Mbps
Spectrometer fiber optic interface		SMA905: Φ3.18±0.005 mm
		SMA905: Φ3.20±0.01 mm
Recommend torque for screws to secure the system		0.3 Nm (onto 5 mm-thick aluminum sheet, flatness within 0.1 mm)
Power specifications		Power supply: 300mA at +5 VDC Voltage: 4.75-5.25 Boot up time: < 4s USB maximum input Vcc : +5.25VDC I/O signal voltage: +5.5VDC

- OtO also provides customized specifications for OEM customers. Aside from the spectrometer configurations listed above, higher sensitivities, wavelength resolutions, special wavelength ranges and gratings, or even customized software or hardware designs (such as integration time) can all be discussed and tailored to customers' requirements for their targeted markets.

Mechanical Designs

► 3.1 Outlines and Dimensions

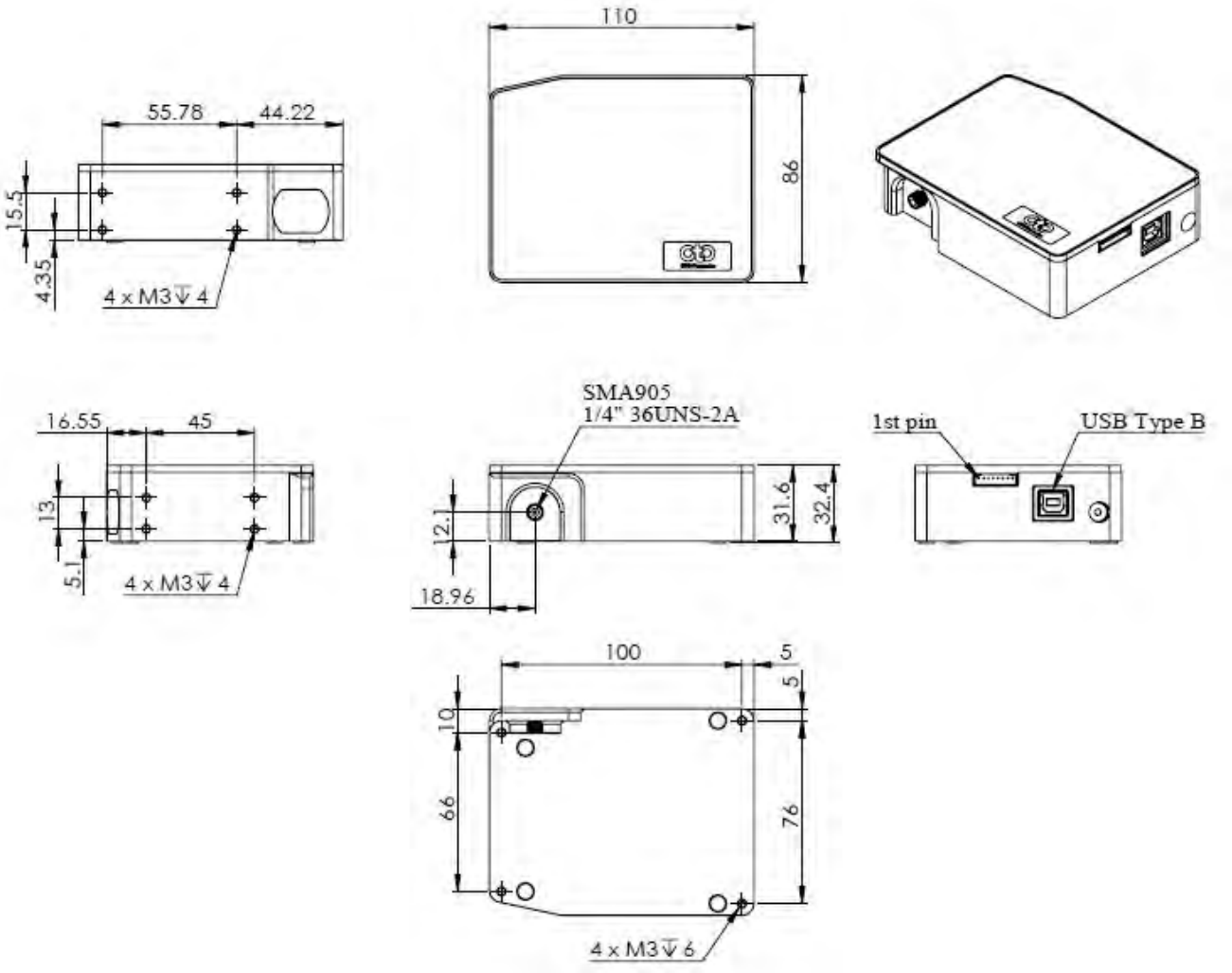

Figure 1. SE Series mechanical drawing (Type I)

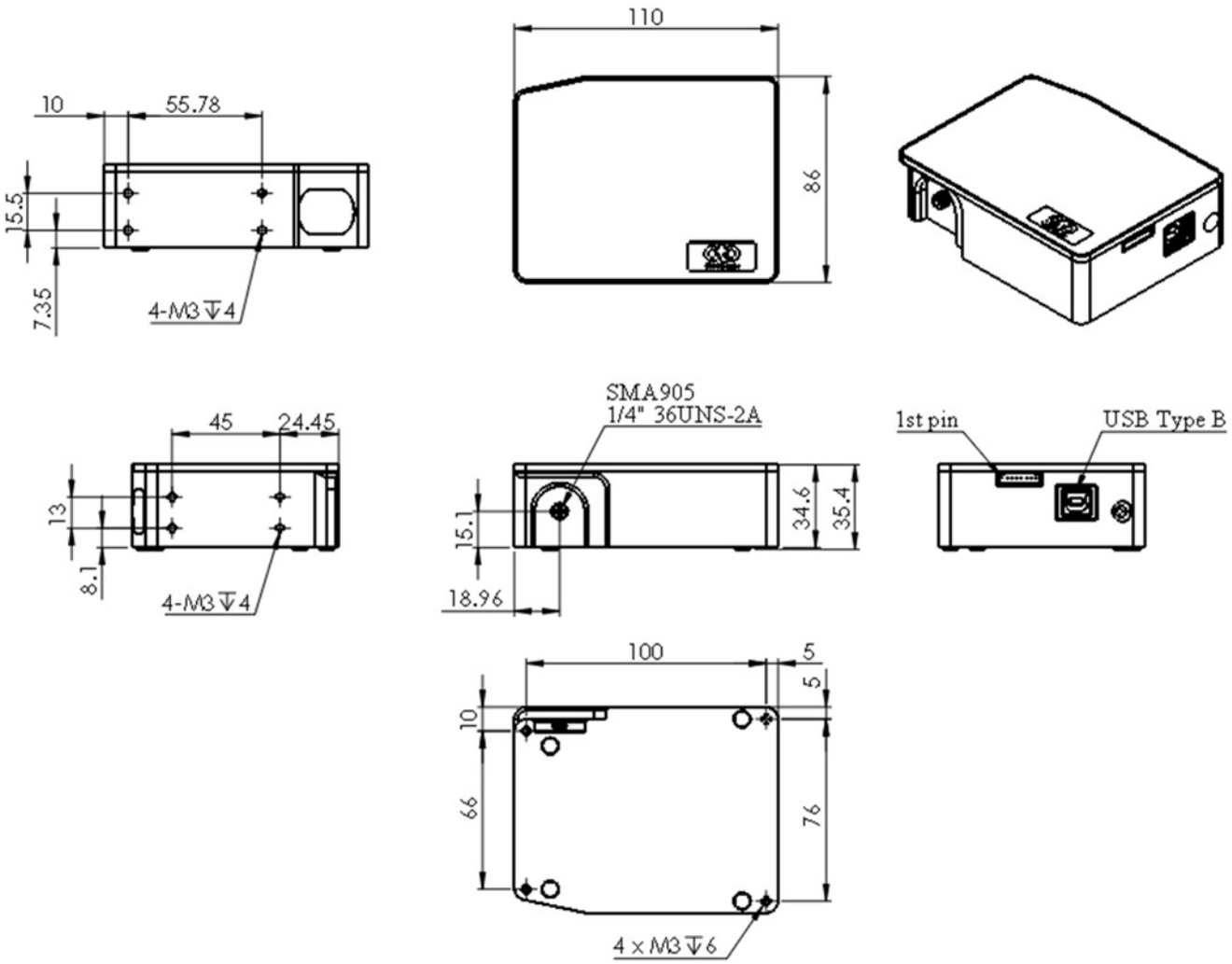

Figure 2. SE Series mechanical drawing (Type II)

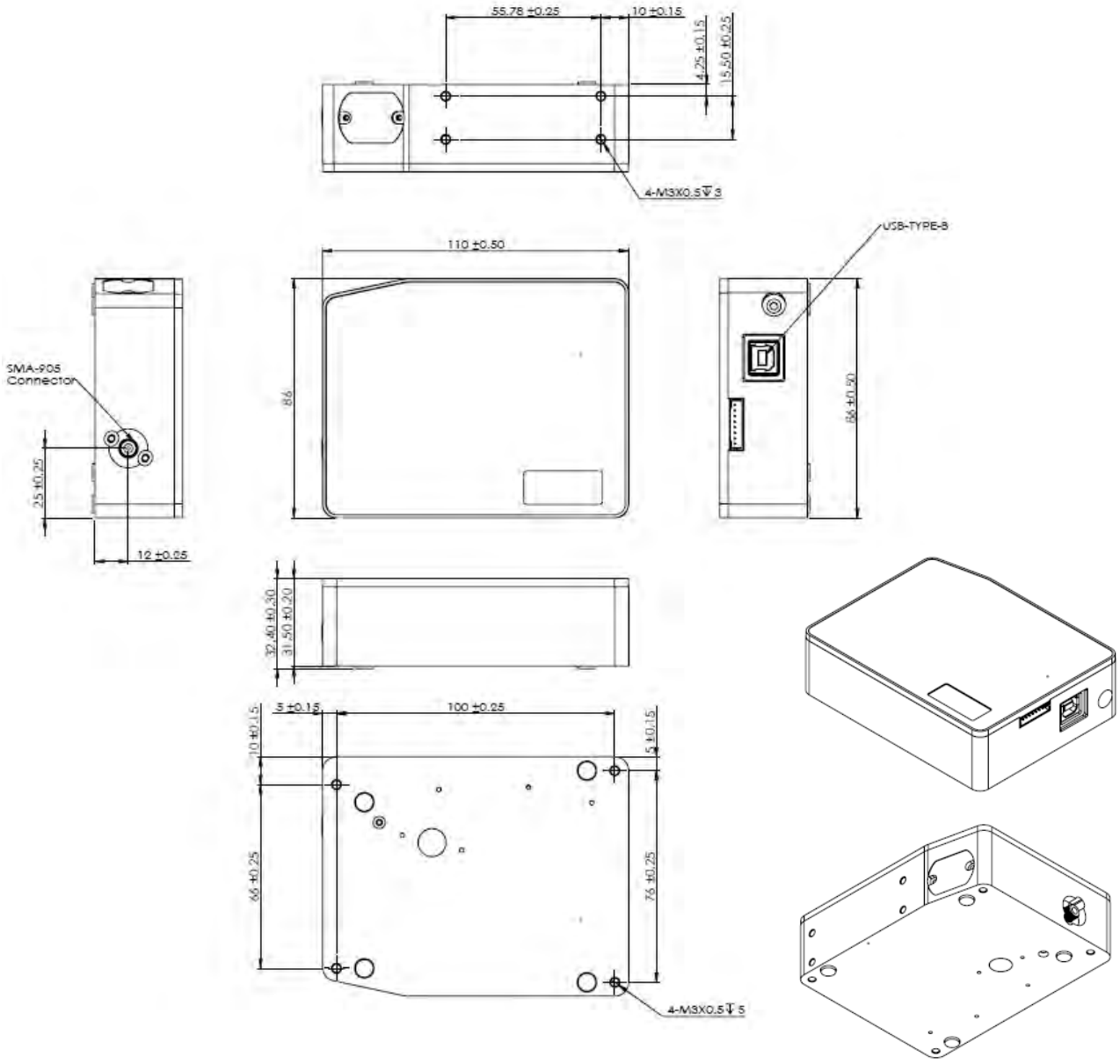

Figure 3. SE2052 mechanical drawing (inlet slit on the left-hand side)

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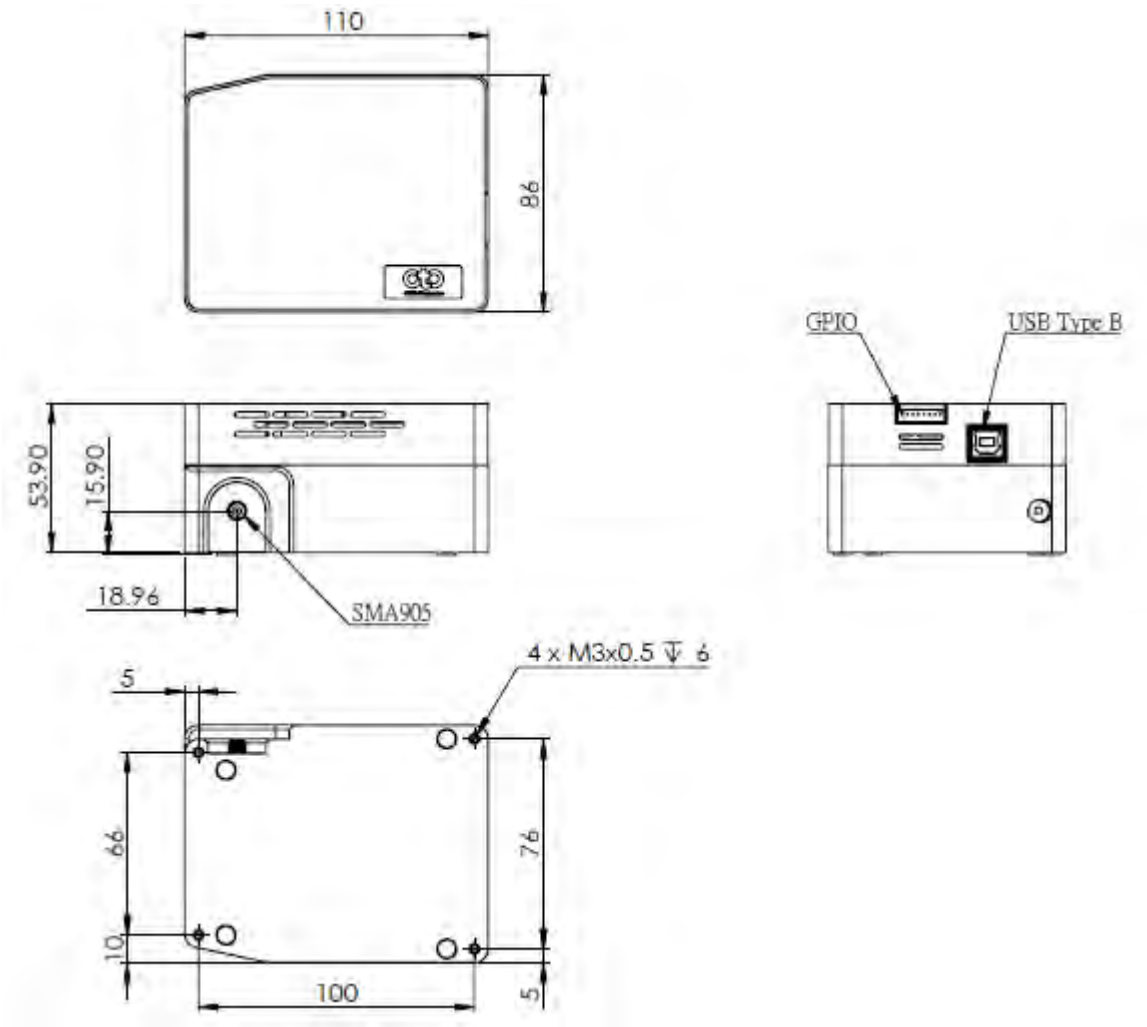

Figure 4. SE Series Double-layer version mechanical drawing (This version is only available with SE-3xxx, -5xxx, and -6xxx models supporting FUV2, FUVN2, NIR1, and NIR4 wavelength regions.)

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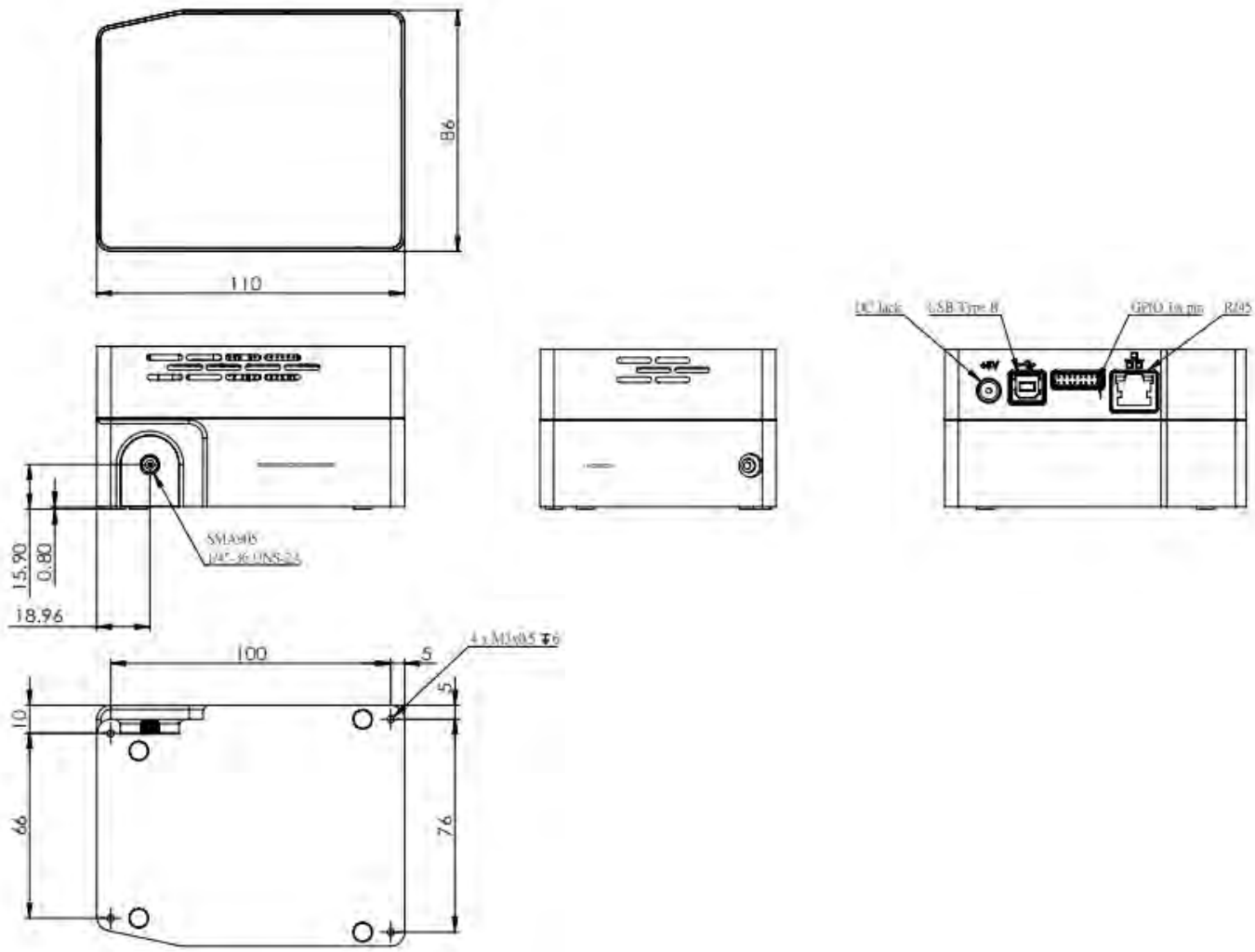

Figure 5. SE6xxx version mechanical drawing

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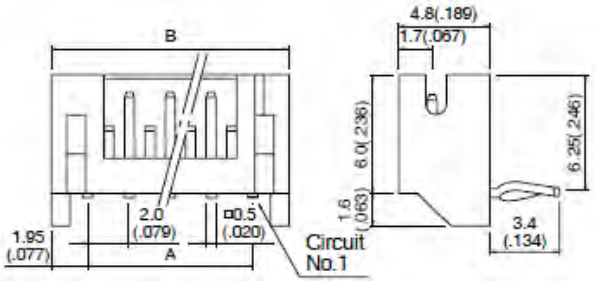
► 3.2 Electronic Output Pin Assignments

The SE Series provides an 8-pin 2.0 mm rear external I/O port.

Side entry type



Cir-cuits	Model No.		Dimensions mm(in.)		Q'ty / box	
	Top entry type	Side entry type	A	B	Top entry type	Side entry type
8	B 8B-PH-K-S	S 8B-PH-K-S	14.0(.551)	17.9(.705)	500	250

Figure 6. The 8-pin 2.0 mm rear external I/O port

Pin Assignments on the External I/O Port

*All I/Os are TTL-Level input/output.

Pin #	Type	Name	Description
1	Power	5V Input/Output	When the spectrometer is connected via USB to a computer, this pin connects to the VBUS so that the spectrometer can provide 0.1A of power to the external device
2	Output	TX	UART TX. TX is the output from the RISC microcontroller
3	Input	RX	UART RX. RX is the input to the RISC microcontroller
4	Output	GPIO0	General purpose output #0
5	Output	GPIO1	General purpose output #1
6	Output	LS_ON	Lamp on
7	Input	Trigger_IN	External trigger signal
8	GND	GND	Ground

External Ports

The following figure shows the external ports on the SE Series. From left to right: the rear external I/O port and the PC USB port.

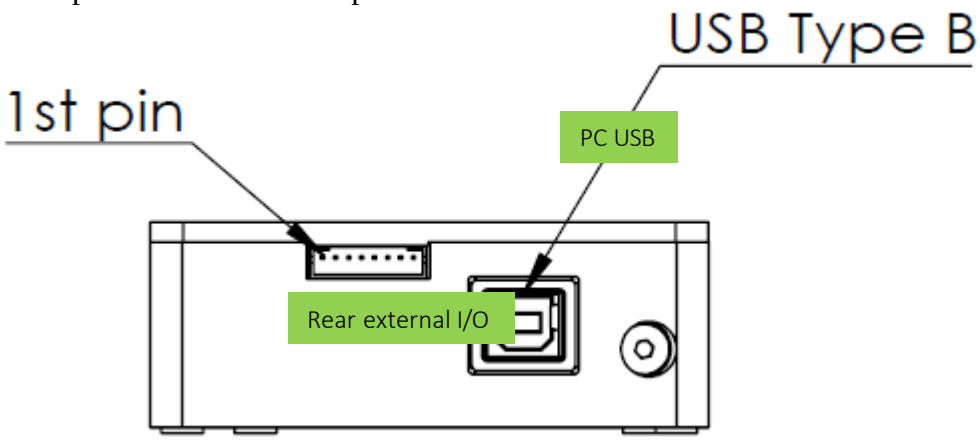


Figure 7. External ports on the SE Series

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► 3.3 CCD Overview

● CCD Image Sensor

The Sony ILX511B/ILX554B is a rectangular CCD linear image sensor specifically designed for use in optical measurements. With built-in timing generator and clock-drivers, it requires only a single 5V power supply to operate.

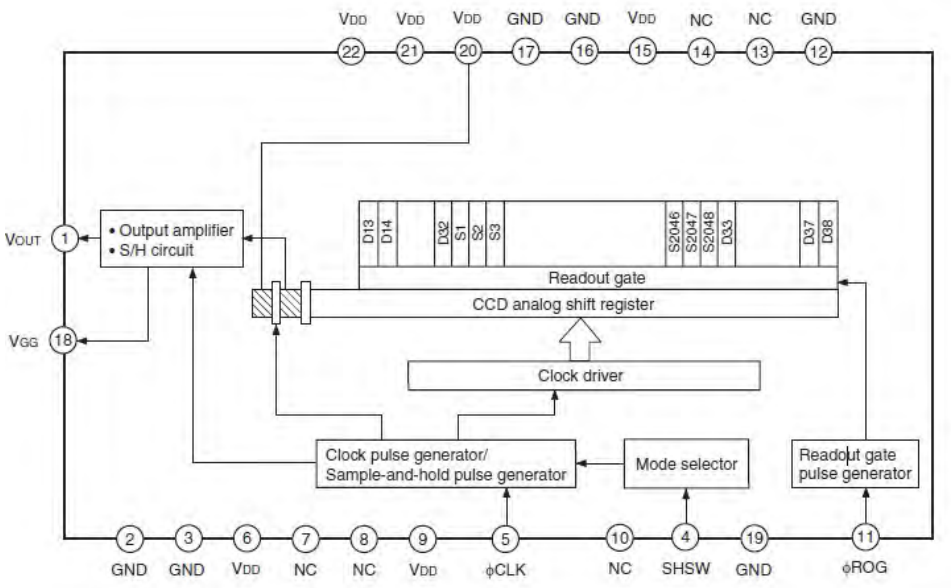


Figure 8. ILX511B CCD block diagram

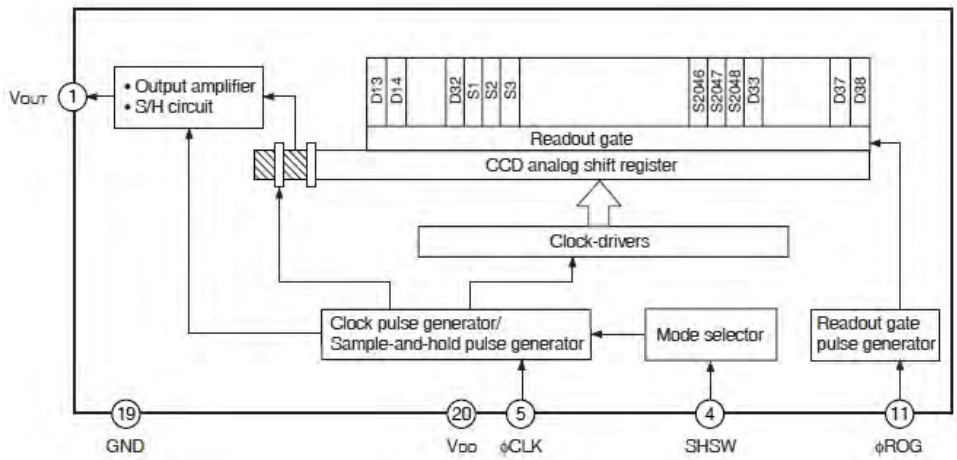


Figure 9. ILX554B CCD block diagram

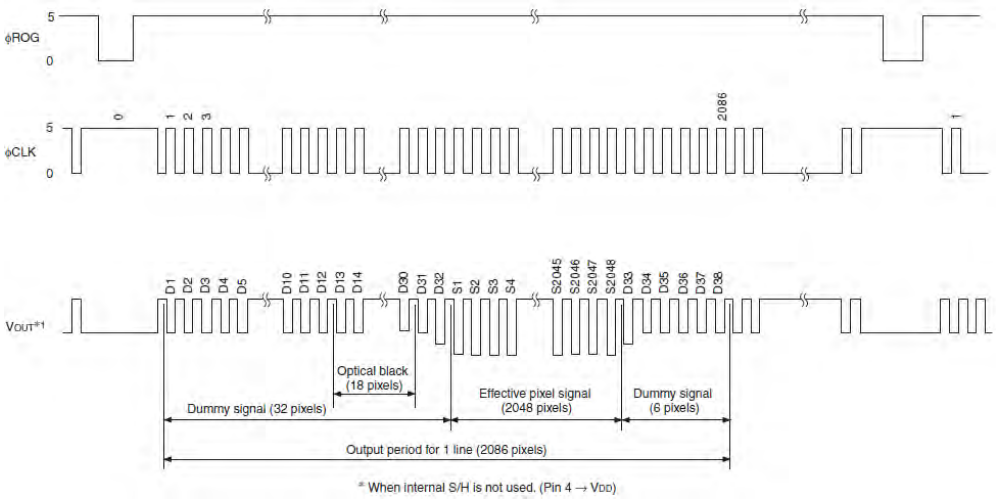


Figure 10. CCD SH clock timing diagram

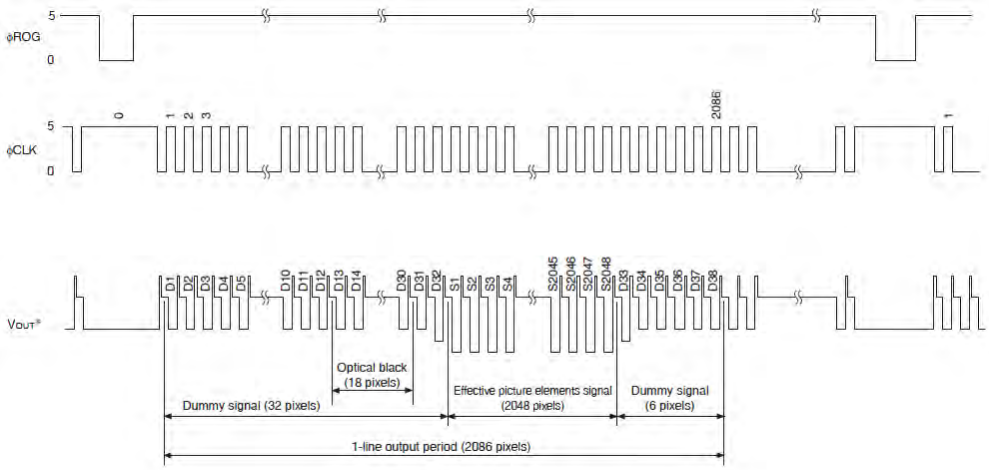


Figure 11. CCD CDS clock timing diagram

Sony's CCDs can work in two modes: One is called "sample/hold" mode, and the other is called "CDS" mode. Figure 9 shows its clock timing diagram in CDS mode. In this mode, the sensor resets after each timing cycle. The SE Series uses the CCD in this mode. Its AFE (analog front-end) needs to be set in the CDS mode to work.

The CCD operates in a “charge-transfer-readout sequence.” First, the CCD executes the integration period. Then, the readout is taken from Vout in the next cycle. The process works like a pipeline. The wavelength value represented by the Vout signal is actually the result of the last charge cycle. The output signal intensity is virtually proportional to the integration time. When too much light is received or the integration time is too long, causing the pixels to be fully charged, the output from the CCD will be an over-saturated signal. Depending on the characteristics of the CCD image sensor, the over-saturated signal may cause the signal to be reverted (such as ILX554B).

CCD/System Noise

The three key factors that affect the noise level of the output signal are: stability of the light source, electronic noise, and the sensor noise. Excluding the effect of the external light source, the first thing to check is the dark noise of the measurement system. Dark noise is defined as the voltage output (Vout RMS) over a period of 1 ms integration time in a completely dark environment. So the dark noise level is solely determined by the electronic noise in the readout and the CCD sensor itself.

Another way to determine the quality of the signal is signal-to-noise ratio (SNR). SNR is defined as the maximum signal level (65535) divided by RMS. Higher SNR means the signal is cleaner, and differences between signals are more discernible when signal levels are low.

Signal Averaging

In general, there are two ways to obtain a smooth curve for a signal: signal averaging and boxcar filter. Signal averaging can reduce the influence of noise on individual pixels. It is natural that increasing the number of samples taken for averaging creates a better averaged curve, but then it takes more time get the final spectrum. On the time-based curve, the signal-to-noise ratio (SNR) increases in proportion to the square root of the number of samples taken. For example, if the number of samples taken is 100, the SNR is increased 10 times.

The second method, boxcar filter, uses neighboring pixels for averaging to get a smooth curve for the signal, but it negatively impacts the optical resolution. This method is not recommended if you need to find the peak values of the signal. These two methods can be combined together in a single measurement if required.

Operations

► 4.1 Pixel Signal Intensity

The spectrometer is shipped with a baseline signal intensity at 1,000 counts. In cases where the user needs to modify this baseline intensity, it can be done using control commands. There is a command for the user to adjust the AFE OFFSET. Another way to change the baseline signal intensity is to use the "background removal" feature in the software. Which one to use depends on the way the user wants to use the baseline signal intensity.

- Pixel Definitions:

Pixel	Description
1-12	Unused pixels
13-30	Optical black pixels
31-32	Unused pixels
33-2080	Active pixels
2081-2086	Unused pixels

► 4.2 Digital Input/Output

General purpose input/output (GPIO)

The SE Series comes with six 3.3V digital input/output pins that can be used for data acquisition on the 8-pin external I/O port. Using software, these I/O pins can be defined for different application purposes. To support some OEM customization needs, the SE Series provides the flexibility to use a special clock generator (such as single pulse or PWM).

GPIO recommended voltages:

VIL(max) = 0.8V

VIH(min) = 2.0V

GPIO maximum/minimum Voltages:

VIN(min) = -0.3V

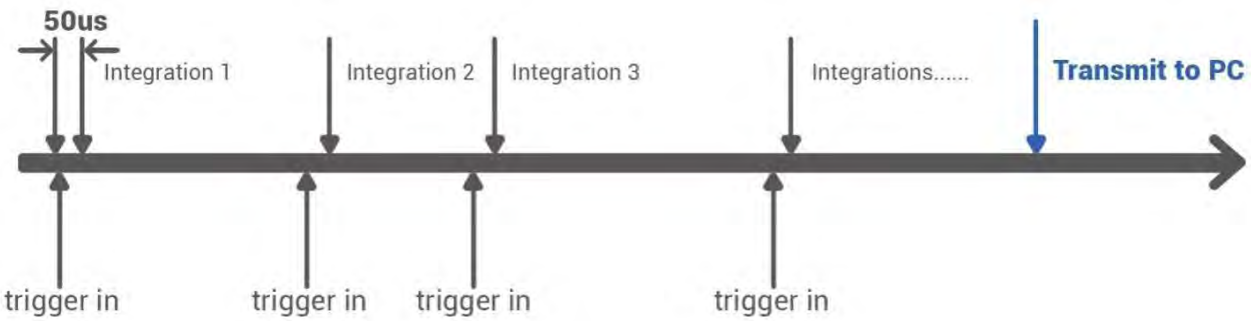
VIN(max) = 5.5V

- **Data transfer interface**

USB 2.0

The 480Mbit/s USB (Universal Serial Bus) is a widely used data transfer standard for computers. The spectrometer control software provided by OtO Photonics uses USB to connect to multiple SE Series spectrometers. The energy-saving SE Series can be powered via a USB cable over its VBUS line.

- **Ultra-precise continuous exposure**

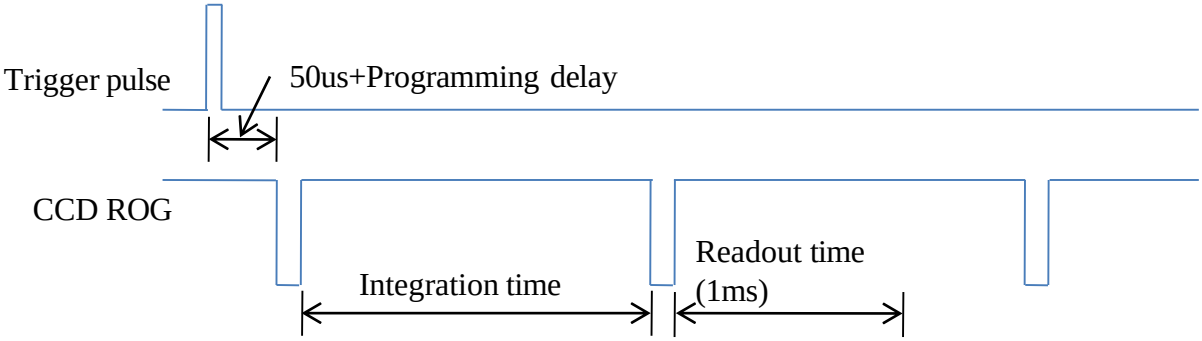


- Configurable arbitrary integration time
- The spectrum being captured is stored in the memory. The memory can hold up to 4,000 records of spectrum data
- The captured spectrum data is transferred to the host computer all at once when the measure is complete

► 4.3 Trigger Modes

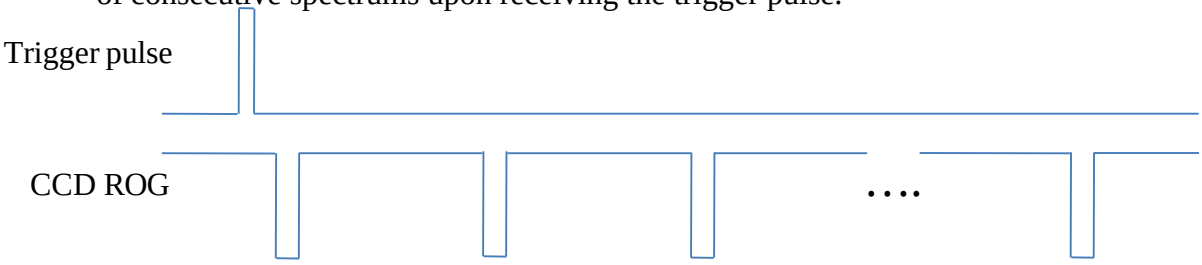
- **Single trigger/single capture**

In the single trigger/single capture mode (with preconfigured integration time), the spectrometer waits for a trigger pulse and captures the spectrum once upon receiving the trigger pulse. It can be triggered on a rising edge or a falling edge. An integration time programming delay can also be configured.



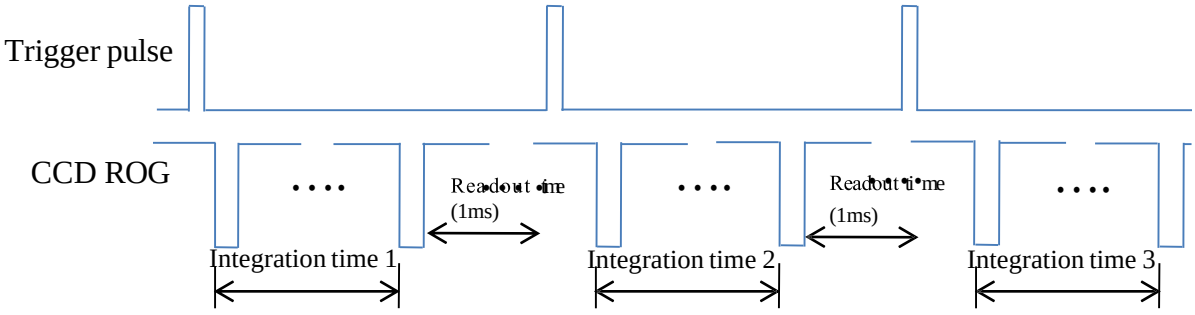
- **Single trigger/multiple capture**

In the single trigger/multiple capture mode (with preconfigured integration time and the number of captures to be made), the spectrometer captures the specified number of consecutive spectrums upon receiving the trigger pulse.



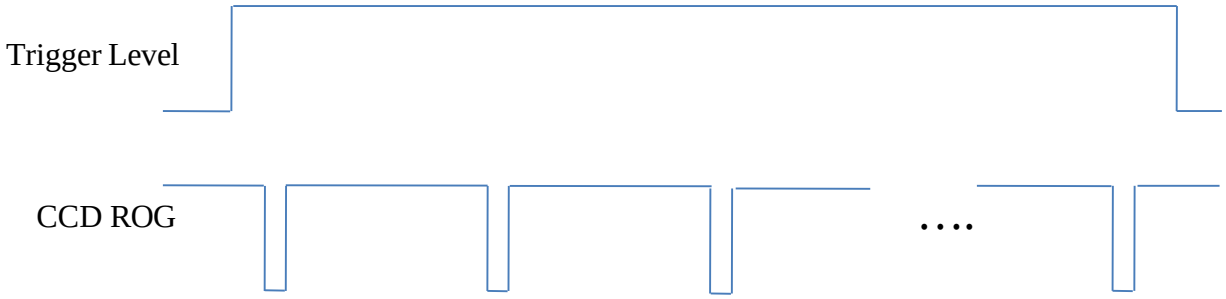
- **Multiple trigger/multiple capture**

In the multiple trigger/multiple capture mode (with preconfigured number of triggers and integration time for each trigger), the spectrometer captures a spectrum upon each trigger with the specified integration time for that trigger.



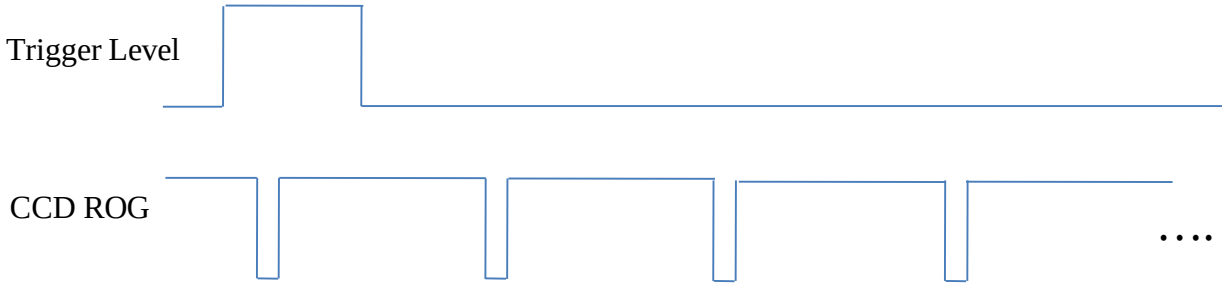
- **Software trigger**

  In the software trigger mode (with preconfigured integration time), the spectrometer waits for the external trigger signal level to go up then starts and continues to capture the spectrum using preconfigured integration time till the signal level drops.



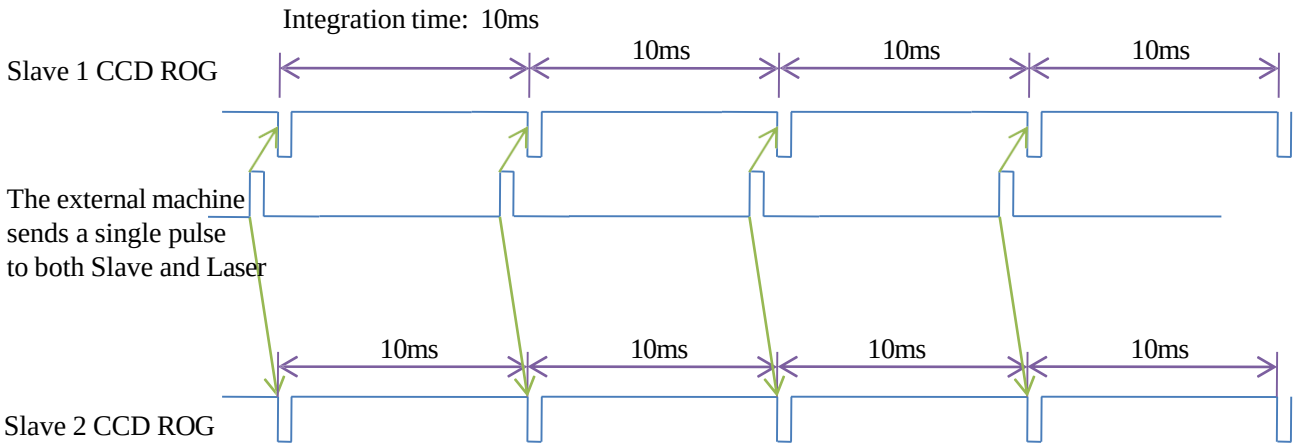
- **Software trigger/multiple capture**

  In the software trigger/multiple capture mode (with preconfigured integration time and software commands to capture the spectrum), the spectrometer continues to capture the spectrum with the preconfigured integration time even when the trigger pulse drops.



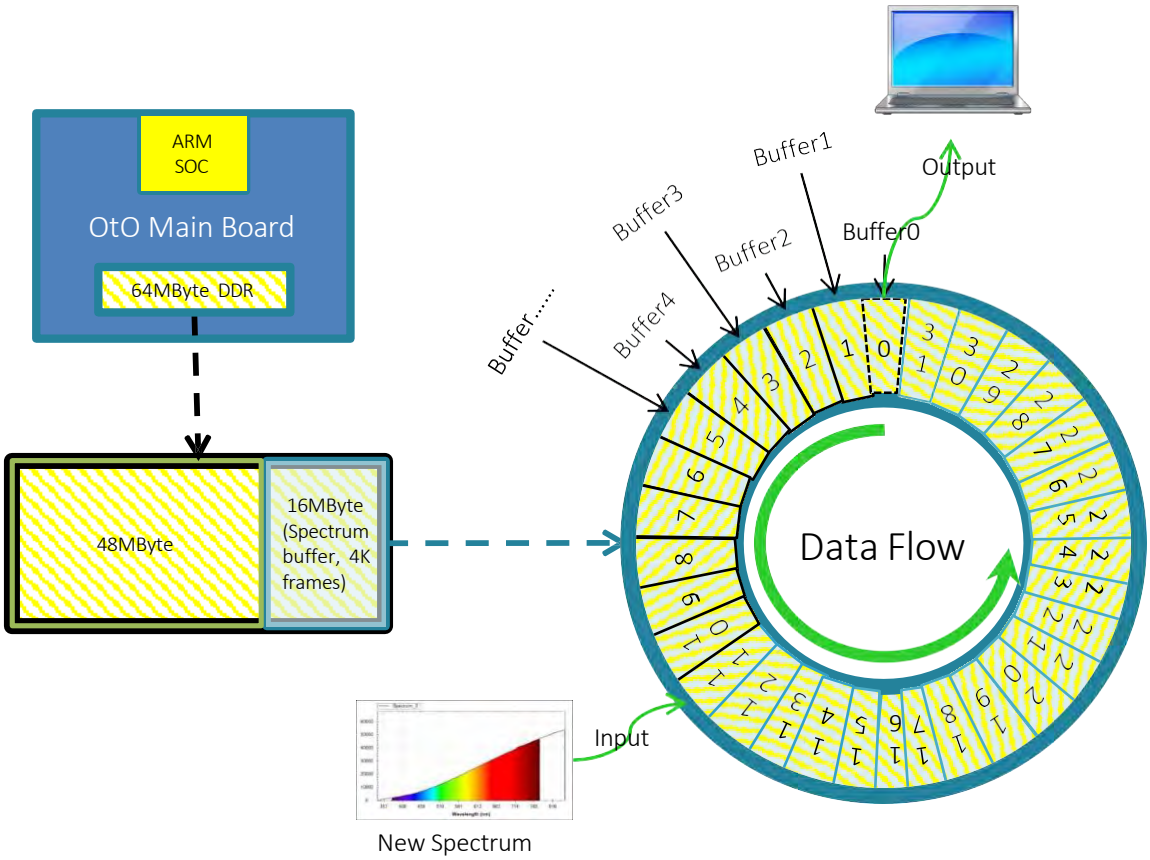
- **External trigger full control**

Inthe external trigger full control mode, the SE Series allows the external trigger signal to control the integration time. As show in the following picture, the integration time ends upon the rising edge of the external trigger signal. In other words, each individual integration time is totally up to the control of the external signal. This feature is provided by OtO per customer request. (SE1030/2020 already supports this feature.) When using a spectrometer supporting this mode, the user can configure the spectrometer via the USB connection. In this mode, the integration time equals to the interval between two triggers.



► 4.4 Ring Buffer

The SE Series supports a ring buffer mode for continuous spectrum capture. This feature is provided by OtO Photonics per customer request. (SE1030/2020 already supports this feature.) The ring buffer enables the user to record continuous spectrum data. For example, a computer can be set up to receive 360,000 records of spectrum data within 1 hour (with an integration time at 10 ms). In the ring buffer mode, the computer can control the size of each data transfer for efficient use of USB bandwidth. The ring buffer helps mitigate data congestion when the USB is busy. It also improves the data transfer efficiency. In the ring buffer mode, the shortest supported integration time is 1ms.



Ring buffer: 512KByte; Bulk transfer <1 sec;
16MByte stores up to 40 seconds of captured data (scanning at 100Hz)

USB Data Transfer and Controls

Overview

The SE Series is a compact spectrometer with an embedded microcontroller and supports USB data transfer. This section provides the computer programming details on how to control the SE Series vial USB. This information is intended only for those who intend to develop their own software instead of using the standard software provided by OtO Photonics (SpectraSmart).

Hardware Description

The SE Series leverages the built-in 32-bit RISC microcontroller in the USB 2.0 chip. The program codes and data are store in the SPI Flash. This RISC microcontroller provides 64MByte of DDR and 64Mbits of Flash.

USB Information

SE Series USB Vendor ID: 0x0638; Product ID: 0x0AAC The SE Series supports USB 2.0 connection and uses USB bulk streams for data transfer between the spectrometer and the computer. For more information on USB, please visit the USBIF website:http://www.usb.org.

Programming Guide

Application Programming Interface (API)

The following section provides a list of APIs and their functions.

Open SE Series Spectrometer

Description: Connecting the computer to an SE Series spectrometer.

a. **Function name:** UAI_SpectrometerOpen

b. **Parameters:**

dev: Since one computer can connect up to eight SE Series spectrometers simultaneously, the 'dev' parameter specifies which device to connect to.

handle: A unique identifier returned by the API to identify the connected spectrometer. Each connected device is assigned a different handle. This handle is used by the API to identify which device to control in subsequent operations.

☐ Get Frame Size

Description: Getting the frame size of the CCD in the spectrometer.
a.Function name: UAI_SpectromoduleGetFrameSize
b.Parameters:

device_handle: The unique identifier for the spectrometer to be controlled.
size: Returning the frame size in 16-bit format.

☐ Acquire Wavelengths

Description: Starting to acquire wavelengths. The SE Series can acquire the complete distribution of wavelengths.
a.Function name: UAI_SpectrometerWavelengthAcquire
b.Parameters:

device_handle: The unique identifier for the spectrometer to be controlled.
buffer: The buffer to receive the data acquired.

APTechnologies www.aptechnologies.co.uk
AP Technologies Limited | 21A Charles Street | Bath | BA1 1HX
Telephone: +44 (0) 1225 780400 | Email: info@aptechnologies.co.uk

☐ Acquire Spectrum

Description: Starting to acquire the spectrum. The SE Series can acquire the complete spectrum corresponding to the data acquired by the "UAI_SpectrometerWavelengthAcquire" function.

a. Function name: UAI_SpectrometerDataAcquire

b. Parameters:

device_handle: The unique identifier for the spectrometer to be controlled.

integration_time_us: Specifying the integration time in 32-bit format (μs).

buffer: The buffer to receive the data acquired.

average: The number of samples to take for signal averaging to reduce noise.

☐ Get Wavelength Range

Description: Getting the supported maximum and minimum wavelengths.

a. Function name: UAI_SpectromoduleGetWavelengthStart

UAI_SpectromoduleGetWavelengthEnd

b. Parameters:

device_handle: The unique identifier for the spectrometer to be controlled.

lambda: Returning the maximum/minimum wavelength (nm) supported by the SE Series in 32-bit format.

☐ Get Integration Time Range

Description: Getting the maximum/minimum integration time.

a. Function name: UAI_SpectromoduleGetMaximumIntegrationTime
UAI_SpectromoduleGetMinimumIntegrationTime

b. Parameters:

device_handle: The unique identifier for the spectrometer to be controlled.

Integration Time: Returning the maximum/minimum integration time supported by the SE Series in 16-bit format. Note: The minimum integration time is specified in microseconds (μs). The maximum integration time is specified in thousand seconds (ks).

☐ Close MR Series Spectrometer

Description: Disconnect the computer from the SE Series spectrometer.

a. Function name: UAI_SpectrometerClose

b. Parameters:

handle: The unique identifier for the spectrometer to be disconnected. The disconnected spectrometer will stop all of its operations when this command is executed.