

HR2000+ Data Sheet

Description

The Ocean Optics HR2000+ Spectrometer includes the linear CCD-array optical bench, plus all the circuits necessary for spectrometer operation. The result is a compact, flexible system, with no moving parts, that's easily integrated as an OEM component.



The HR2000+ spectrometer is a unique combination of technologies providing users with both an unusually high spectral response and high optical resolution in a small footprint. The electronics have been designed for considerable flexibility in connecting to various modules as well as external interfaces. The HR2000+ interfaces to PCs, PLCs and other embedded controllers through USB 2.0 or RS-232 communications. The information included in this data sheet provides detailed instructions on the connection and operation of the HR2000+.

The detector used in the HR2000+ spectrometer is a high-sensitivity 2048-element CCD array from Sony, product number ILX511B. (For complete details on this detector, visit Sony's web site at www.sony.com. Ocean Optics applies a coating to all ILX511 detectors, so the optical sensitivity could vary from that specified in the Sony datasheet).

The HR2000+ operates from the +5V power, provided through the USB, or from a separate power supply and either a USB or RS-232 interface. The HR2000+ is a microcontroller-controlled spectrometer, thus all operating parameters are implemented through software interfacing to the unit.

The HR4000 Breakout Box (HR4-BREAKOUT) is available from Ocean Optics for use with the HR2000+ Spectrometer. The HR4000 Breakout Box is a passive module that separates the signals from their 30-pin port to an array of standard features found on the HR2000+ Spectrometer.

Features

- ❑ An optical resolution of ~0.035 to 6.8 nm (FWHM)
- ❑ A wide variety of optics available
 - 14 gratings
 - 6 slit widths
 - 6 optical filters, 1 order-sorting filter
- ❑ Electrical Performance
 - 14 bit, 5MHz A/D Converter
 - Integration times from 10 ms to 65 s
- ❑ 3 or 4 triggering modes (depending on firmware)
- ❑ Embedded microcontroller allows programmatic control of all operating parameters and Standalone operation
 - USB 2.0 480Mbps (High-speed) & 12 Mbps (Full speed)
 - RS232 115Kbaud
 - Communication Standard for digital accessories (I²C)
- ❑ Onboard Pulse Generator
 - 2 programmable strobe signals for triggering other devices
 - Software control of nearly all pulse parameters
- ❑ Onboard GPIO
 - 10 user programmable digital I/O
- ❑ Onboard Analog Interface
 - Analog Input: 13bit, 0-5V
 - Analog Output: 9bit, 0-5V
- ❑ EEPROM storage for
 - Wavelength Calibration Coefficients
 - Linearity Correction Coefficients
 - Absolute Irradiance Calibration (optional)
- ❑ Plug-n-Play Interface for PC applications
- ❑ 30-pin connector for interfacing to external products
- ❑ CE Certification

Specifications

Specifications	Criteria
Absolute Maximum Ratings: V_{CC} Voltage on any pin	+ 5.5 VDC V_{CC}
Physical Specifications: Physical Dimensions Weight	148.6 mm x 104.8 mm x 45.1 mm 570 g
Power: Power requirement (master) Supply voltage Power-up time	220 mA at +5 VDC 4.5 – 5.5 V ~5s depending on code size
Spectrometer: Design Focal length (input and output) Input Fiber Connector Gratings Entrance Slit Detector Filters	Asymmetric crossed Czerny-Turner F/4, 101 mm SMA 905 to single-strand optical fiber (0.22 NA) 14 different gratings 5, 10, 25, 50, 100, or 200 μm slits. (Slits are optional. In the absence of a slit, the fiber acts as the entrance slit.) Sony ILX511B CCD 2nd & 3rd order rejection, long pass (optional)
Spectroscopic: Integration Time Dynamic Range Signal-to-Noise Readout Noise (single dark spectrum) Resolution Stray Light Spectrometer Channels	1 millisecond – 65 seconds 2×10^8 (system), 1300:1 (single acquisition) 250:1 (single acquisition) 12 counts RMS, 20 counts peak-to-peak ~0.035 to 6.8 nm (FWHM), varies by configuration (see www.oceanoptics.com for configuration options) <0.05% at 600 nm; <0.10% at 435 nm One
Environmental Conditions: Temperature Humidity	-30° to +70° C Storage & -10° to +50° C Operation 0% - 90% non-condensing
Interfaces: USB RS-232 I ² C	USB 2.0, 480 Mbps 2-wire RS-232 Inter-Integrated Circuit 2-Wire serial BUS

Mechanical Diagram

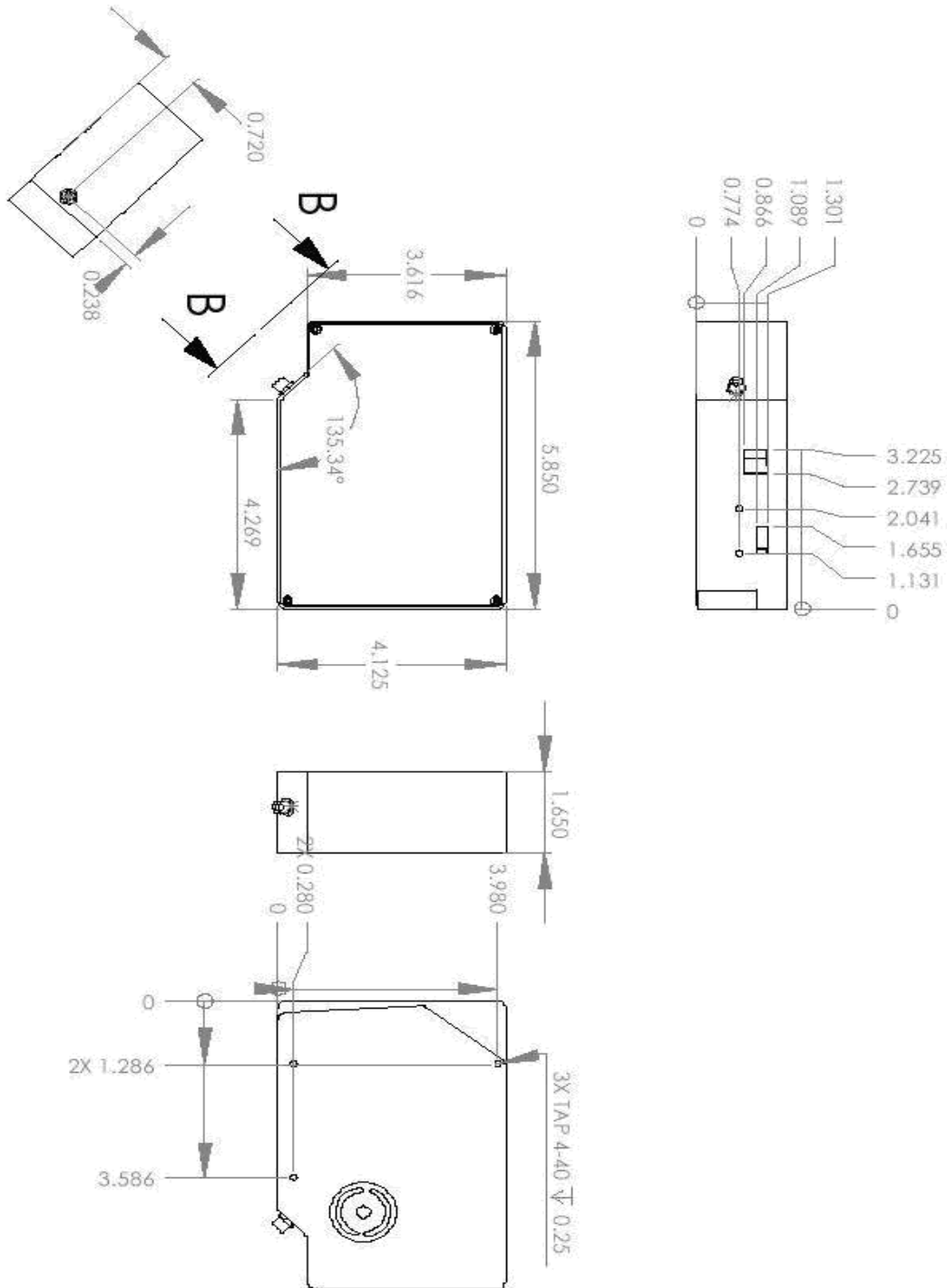
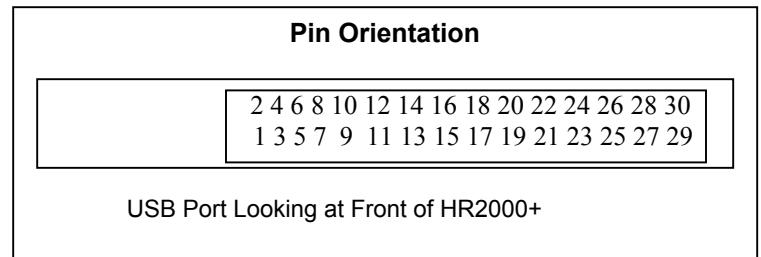


Figure 1. HR2000+ Outer Dimensions

Electrical Pinout

Listed below is the pin description for the HR2000+ Accessory Connector (J3) located on the front vertical wall of the unit. The connector is a Pak50™ model from 3M Corp. Headed Connector Part# P50-030P1-RR1-TG. It mates with Part # P50-030S-TGF (requires two: 1.27mm (50 mil) flat ribbon cable: Recommended 3M 3365 Series).

Pin#	Description	Alt Function
1	RS232 Rx	
2	RS232 Tx	
3	GPIO(2)	Reserved
4	V5_SW	
5	Ground	
6	I2C SCL	
7	GPIO(0)	Reserved
8	I2C SDA	
9	GPIO(1)	Reserved
10	External Trigger In	
11	GPIO(3)	Reserved
12	VCC, VUSB or 5Vin	
13	Reserved	
14	VCC, VUSB or 5Vin	
15	Reserved	
16	GPIO(4)	Reserved
17	Single Strobe	
18	GPIO(5)	Reserved
19	Reserved	
20	Continuous Strobe	
21	SPI Chip Select	
22	GPIO(6)	Reserved
23	Analog In (0-5V)	For future use
24	Analog Out (0-5V)	
25	Lamp Enable	
26	GPIO(7)	Reserved
27	Ground	
28	GPIO(8)	Reserved
29	Ground	
30	GPIO(9)	Reserved



Pin Definition and Descriptions

Pin #	Function	Input/Output	Description
1	RS232 Tx	Output	RS232 Transmit signal – for communication with PC connect to DB9 pin 2
2	RS232 Rx	Input	RS232 Receive signal – for communication with PC connect to DB9 pin 3
3	GPIO (2)	Input/Output	General purpose, software-programmable digital input/output (channel number)
4	V5_SW	Output	This is a regulated 5-Volt power pin out of the HR2000+. It can supply 50mA (max).
5	Ground	Input/Output	Ground
6	I ² C SCL	Input/Output	The I2C Clock signal for communications to other I2C peripherals
7	GPIO (0)	Input/Output	General purpose, software-programmable digital input/output (channel number)
8	I ² C SDA	Input/Output	The I2C Data signal for communications to other I2C peripherals
9	GPIO (1)	Input/Output	General purpose, software-programmable digital input/output (channel number)
10	External Trigger In	Input	The TTL input trigger signal. In External Hardware Trigger mode this is a rising edge trigger input. In Software Trigger Mode this is an Active HIGH Level signal. In External Synchronization Mode (or External Hardware Level Trigger Mode) this is a clock input, which defines the integration period of the spectrometer.
11	GPIO (3)	Input/Output	General purpose, software-programmable digital input/output (channel number)
12	V _{CC} , V _{USB} or 5V _{in}	Input or Output	This is the input power pin to the HR2000+. Additionally when operating via a Universal Serial Bus (USB) this is the USB power connection (+5V) which can be used to power other peripherals (Care must be taken to insure that the peripheral complies with USB Specifications).
13	Reserved	Output	
14	V _{CC} , V _{USB} or 5V _{in}	Input or Output	This is the input power pin to the HR2000+. Additionally when operating via a Universal Serial Bus (USB) this is the USB power connection (+5V) which can be used to power other peripherals (Care must be taken to insure that the peripheral complies with USB Specifications).
15	Reserved	Input	
16	GPIO (4)	Input/Output	General purpose, software-programmable digital input/output (channel number)
17	Single Strobe	Output	TTL output pulse used as a strobe signal, which has a programmable delay relative to the beginning of the spectrometer integration period.
18	GPIO (5)	Input/Output	General purpose, software-programmable digital input/output (channel number)

Pin Definition and Descriptions (Cont'd)

Pin #	Function	Input/Output	Description
19	Reserved	Output	
20	Continuous Strobe	Output	TTL output signal used to pulse a strobe that is divided down from the Master Clock signal
21	Reserved	Output	
22	GPIO (6)	Input/Output	General purpose, software-programmable digital input/output (channel number)
23	Reserved	Input	
24	Analog Out (0-5V)	Output	The Analog Out is a 9-bit programmable output voltage with a 0-5 Volt range.
25	Lamp Enable	Output	A TTL signal that is driven Active HIGH when the Lamp Enable command is sent to the spectrometer
26	GPIO (7)	Input/Output	General purpose, software-programmable digital input/output (channel number)
27	Ground	Input/Output	Ground
28	GPIO (8)	Input/Output	General purpose, software-programmable digital input/output (channel number)
29	Ground	Input/Output	Ground
30	GPIO (9)	Input/Output	General purpose, software-programmable digital input/output (channel number)

Internal Operation

Pixel Definition

A series of pixels in the beginning of the scan have been covered with an opaque material to compensate for thermal induced drift of the baseline signal. As the HR2000+ warms up, the baseline signal will shift slowly downward a few counts depending on the external environment. The baseline signal is set between 90 and 140 counts at the time of manufacture. If the baseline signal is manually adjusted, it should be left low enough to allow for system drift. The following is a description of all of the pixels, both as they exist on the hardware device and as they are actually read from the device via USB (note that the HR2000+ only digitizes the first 2048 pixels):

Pixels on the Device

Pixel	Description
0–11	Not usable
12–29	Optical black pixels
30–31	Not usable
32–2079	Optical active pixels
2080–2085	Not usable

Pixels Read from the Device via USB

Pixel	Description
0–17	Optical black pixels
18–19	Not usable
20-2047	Optical active pixels

CCD Detector Reset Operation

At the start of each integration period, the detector transfers the signal from each pixel to the readout registers and resets the pixels. The total amount of time required to perform this reset operation is $\sim 12\mu\text{s}$. The user needs to account for this time delay when the pixels are optically inactive, especially in the external triggering modes.

Timing Signals

Strobe Signals

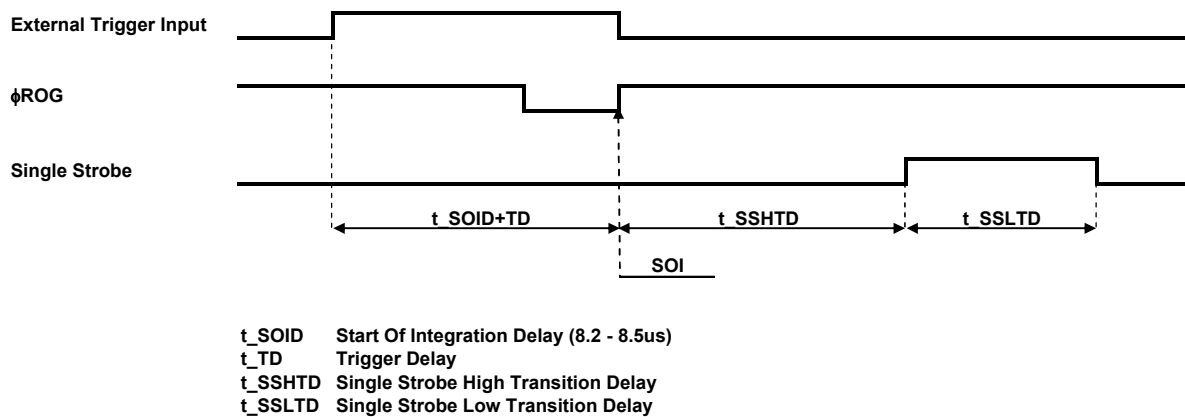
Single Strobe

The Single Strobe signal is a programmable TTL pulse that occurs at a user-determined time during each integration period. This pulse has a user-defined High Transition Delay and Low Transition Delay. The pulse width of the Single Strobe is the difference between these delays. It is only active if the Lamp Enable command is active.

Synchronization of external devices to the spectrometer's integration period is accomplished with this pulse. The Strobe Delay is specified by the Single Strobe High Transition Delay (SSHTD) and the Pulse Width is specified by the Single Strobe Low Transition Delay (SSLTD) minus the Single Strobe High Transition Delay ($PW = SSLTD - SSHTD$). Both values are programmable in 500ns increments for the range of 0 to 65,535 (32.7675ms).

The timing of the Single Strobe is based on the Start of Integration (SOI). SOI occurs on the rising edge of ϕ ROG which is used to reset the Sony ILX511 detector. In all trigger modes using an External Trigger, there is a fixed relationship between the trigger and the SOI. In the Normal mode and Software Trigger mode, the SOI still marks the beginning of the Single Strobe, but due to the nondeterministic timing of the software and computer operating system, this timing will change over time and is not periodic. That is, at a constant integration time, the Single Strobe will not be periodic, but it will indicate the start of the integration.

The timing diagram for the Single Strobe in External Hardware Trigger mode is shown below:



Single Strobe (External Hardware Trigger/External Synchronous Trigger Mode)

The Trigger Delay (TD) is another user programmable delay which specifies the time in 500ns increments that the SOI will be delayed beyond the normal Start of Integration Delay (SOID).

An example calculation of the Single Strobe timing follows:

If the TD = 1ms, SSHTD = 50ms, and SSLTD = 70ms then, the rising edge of the Single Strobe will occur approximately 51.82ms (1ms + 50ms + 8.2us) after the External Trigger Input goes high and the Pulse Width will be 20ms (70ms – 50ms).

Continuous Strobe

The Continuous Strobe signal is a programmable frequency pulse-train with a 50% duty cycle. It is programmed by specifying the desired period whose range is 2us to 60s. This signal is continuous once enabled, but is not synchronized to the Start of Integration or External Trigger Input. The Continuous Strobe is only active if the Lamp Enable command is active.

Synchronizing Strobe Events

If the application requires more than one pulse per integration period, the user needs to insure the continuous strobe and integration period are synchronized. The integration time must be set so that an equal number of strobe events occurs during any given integration period. This synchronization only occurs when the integration period is a multiple of a power of 2.

Triggering Modes

The HR2000+ supports four triggering modes (plus Normal mode), which are set with the Trigger Mode command. Detailed information of each triggering mode follows. Also refer to the External Triggering Options document for HR2000+ Firmware versions 3.0 and above located on our website at <http://www.oceanoptics.com/technical/External-Triggering2.pdf>. The following paragraphs describe these modes. For firmware version below 3.0, see <http://www.oceanoptics.com/technical/External-Triggering.pdf>.

Normal

In the Normal (Free-Run) mode, the spectrometer continuously acquires spectra. This data is made available for reading as soon as all the data is stored in the FIFO. This is also referred to as the nonbuffering mode because only one spectrum is stored within the FPGA and not multiple spectra. In this scenario, ReadEnable is generated by the software/firmware to initiate each new acquisition. Since only one spectrum is stored at a time in the FPGA, a new integration may be started but cannot be stored until the FIFO data has been fully retrieved by the software.

External Software Trigger

In this mode, the HR2000+ uses the user-defined integration clock; however, the A/D converter is required to wait until the Trigger Input Signal goes HIGH before it acquires the data at the start of the next integration period. This is an asynchronous trigger mode that allows the user to define an integration period through the software. The time between scans is dependent on PC speed.

External Synchronous Trigger Mode

In the External Synchronous Trigger mode, two external triggers are required to complete a data acquisition. The first rising edge starts the integration period and the second rising edge stops the integration and starts the next. Thus the integration time is the period between the two external trigger pulses. After the integration period, the spectrum is retrieved and written to the FIFO in the FPGA. As in all nonbuffered modes, no further spectra are acquired until the software has read the entire contents of the FIFO.

External Hardware Level Trigger Mode

In the External Hardware Level Trigger mode, a rising edge detected by the FPGA from the External Trigger input starts the integration period specified through the software interface. After the integration period, the spectrum is retrieved and written to the FIFO in the FPGA. As long as the trigger level remains active in a logic one state, back-to-back acquisitions will occur, as in the Normal mode, until the trigger transitions to an inactive level. As in all nonbuffered modes, no further spectra are acquired until the software has read the entire contents of the FIFO.

External Hardware Edge Trigger Mode

In the External Hardware Edge Trigger mode, a rising edge detected by the FPGA from the External Trigger input starts the integration period specified through the software interface. After the integration period, the spectrum is retrieved and written to the FIFO in the FPGA. Only one acquisition will be performed for each External Trigger pulse, no matter what the pulse's duration is. As in all nonbuffered modes, no further spectra are acquired until the software has read the entire contents of the FIFO.

Analog Input & Output

Analog Input

The analog input option of the HR2000+ is a dedicated 13-bit Analog to Digital converter, which has an input range of 0 to 5 Volts. The analog input is accessed through the HR2000+'s 30-pin accessory connector. The spectrometer provides a software-programmable Gain and D.C. offset adjustment for the input signal. The digitized output is passed into software and can be used for various applications such as temperature or pressure transducers.

Analog Output

The HR2000+ provides a user programmable Analog output, which is accessed through its 30-pin accessory connector. This analog out is a 9-bit, low power, digital to analog converter with a range of 0-5 Volts. The analog output can be used for multiple applications such as single pixel intensity analysis or programmable reference/dimmer to light sources.

Digital Inputs & Outputs

General Purpose Inputs/Outputs (GPIO)

The HR2000+ will have 10 user programmable digital Input/Output pins, which can be accessed at the 30-pin accessory connector. Through software, the state of these I/O pins can be independently defined and used for multi-purpose applications such as communications buses, sending digital values to an LCD/LED display, or even implementing complex feedback systems.

The GPIO input and output levels are as follows:

VIL (min)	= - 0.5V
VIL (max)	= 0.8V
VIH (min)	= 2.0V
VIH (max)	= 3.6V
VOL (max)	= 0.4V
VOH (max)	= 2.4V
IOL	= 24mA
IOH	= - 24mA

GPIO absolute maximum ratings are as follows:

VIN (min)	= - 0.5V
VIN (max)	= 4.0V

Communication and Interface

USB 2.0

480-Mbit Universal Serial Bus allows for ultra fast data transfer. This is the main communication standard for PC users. The USB BUS also provides power as well as communications over a single cord, thereby allowing the HR2000+ to operate anywhere you can take a laptop computer without any bulky external power supplies.

RS-232

Also known as serial port communication, RS232 is a standard in PC and industrial device communications. Using transmit and receive signals this option allows the HR2000+ to be a standalone device, which can output data to other logic devices/controllers such as a PLC or microcontroller. The HR2000+ requires an external 5-Volt power source when operating in RS-232 mode.

HR2000+ USB Port Interface Communications and Control Information

Overview

The HR2000+ is a microcontroller-based Miniature Fiber Optic Spectrometer that can communicate to a host PC via the Universal Serial Bus or RS-232. This section contains the necessary command information for controlling the HR2000+ via the USB interface. This information is only pertinent to users who wish to not utilize Ocean Optics 32 bit driver to interface to the HR2000+. Only experienced USB programmers should attempt to interface to the HR2000+ via these methods.

Hardware Description

The HR2000+ uses a Cypress CY7C68013 microcontroller that has a high speed 8051 combined with an USB2.0 ASIC. Program code and data coefficients are stored in external E²PROM that are loaded at boot-up via the I²C bus. The microcontroller has 8K of internal SRAM and 64K of external SRAM. Maximum throughput for spectral data is achieved when data flows directly from the external FIFO's directly across the USB bus. In this mode the 8051 does not have access to the data and thus no manipulation of the data is possible.

USB Information

Ocean Optics Vendor ID number is 2457. The HR2000+ can have 2 Product IDs, depending upon the EEPROM configuration. In the case where the code is loaded from the EEPROM the PID is 0x1012.

Instruction Set

Command Syntax

The list of the commands is shown in the following table followed by a detailed description of each command. The length of the data depends on the command. All commands are sent to the HR2000+ through End Point 1 Out (EP1). All spectral data is acquired through End Point 2 In and all other queries are retrieved through End Point 1 In (EP1). The endpoints enabled and their order is:

Pipe #	Description	Type	High-speed Size (Bytes)	Full-speed Size (Bytes)	Endpoint Address
0	End Point 1 Out	Bulk	64	64	0x01
1	End Point 2 In	Bulk	512	64	0x82
2	End Point 6 In	Bulk	512	64	0x86
3	End Point 1 In	Bulk	64	64	0x81

USB Command Summary

EP1 Command Byte Value	Description	Version
0x01	Initialize HR2000+	0.90.0
0x02	Set Integration Time	0.90.0
0x03	Set Strobe Enable Status	0.90.0
0x04	Set Shutdown Mode	0.90.0
0x05	Query Information	0.90.0
0x06	Write Information	0.90.0
0x09	Request Spectra	0.90.0
0x0A	Set Trigger Mode	0.90.0
0x0B	Query number of Plug-in Accessories Present	0.90.0
0x0C	Query Plug-in Identifiers	0.90.0
0x0D	Detect Plug-ins	0.90.0
0x60	General I ² C Read	0.90.0
0x61	General I ² C Write	0.90.0
0x62	General SPI I/O	0.90.0
0x68	PSOC Read	0.90.0
0x69	PSOC Write	0.90.0
0x6A	Write Register Information	0.90.0
0x6B	Read Register Information	0.90.0
0x6C	Read PCB Temperature	0.90.0
0x6D	Read Irradiance Calibration Factors	0.90.0
0x6E	Write Irradiance Calibration Factors	0.90.0
0xFE	Query Information	0.90.0

USB Command Descriptions

A detailed description of all HR2000+ commands follows. While all commands are sent to EP1 over the USB port, the byte sequence is command dependent. The general format is the first byte is the command value and the additional bytes are command specific values.

Byte 0	Byte 1	Byte 2	...	Byte n-1
Command Byte	Command Specific	Command Specific	...	Command Specific

Initialize HR2000+

Initializes certain parameters on the HR2000+ and sets internal variables based on the USB communication speed the device is operating at. This command should be called at the start of every session however if the user does not call it, it will be executed on the first Request Scan command. The default values are set as follows:

Parameter	Default Value
Trigger Mode	0 – Normal Trigger

Byte Format

Byte 0
0x01

Set Integration Time

Sets the HR2000+ integration time in microseconds. The value is a 32-bit value whose acceptable range is 1,000 μ s – 65,535,000 μ s. If the value is outside this range the value is unchanged. For integration times less than 655,000 μ s, the integration counter has a resolution of 10 μ s. For integration times greater than this the integration counter has a resolution of 1ms.

Byte Format

Byte 0	Byte 1	Byte 2	Byte 3	Byte 4
0x02	LSW-LSB	LSW-MSB	MSW-LSB	MSW-LSB

MSW & LSW: Most/Least Significant Word

MSB & LSB: Most/Least Significant Byte

Set Strobe Enable Status

Sets the HR2000+ Lamp Enable line (J2 pin 4) as follows. The Single Strobe and Continuous Strobe signals are enabled/disabled by this Lamp Enable Signal.

Data Byte = 0 → Lamp Enable Low/Off
 Data Byte = 1 → Lamp Enable HIGH/On

Byte Format

Byte 0	Byte 1	Byte 2
0x03	Data byte LSB	Data Byte MSB

Set Shutdown Mode

Sets the HR2000+ shutdown mode. When shut down, the internal FX2 microcontroller is continuously running however all other functionality is disabled. In this power down mode the current consumption is reduced to 250mA (operating current for the FX2 microcontroller). When shutdown is active (active low), the external 5V signal (V5_Switched pin 3) is disabled in addition to all other signals except I²C lines.

Data Byte = 0 → Shutdown everything but the FX2
 Data Byte = !0 → Power up entire Spectrometer

Byte Format

Byte 0	Byte 1	Byte 2
0x04	Data Byte LSB	Data Byte MSB

Query Information

Queries any of the 20 stored spectrometer configuration variables. The Query command is sent to End Point 1 Out and the data is retrieved through End Point 1 In. When using Query Information to read EEPROM slots, data is returned as ASCII text. However, everything after the first byte that is equal to numerical zero will be returned as garbage and should be ignored.

The 20 configuration variables are indexed as follows:

Data Byte - Description

- 0 – Serial Number
- 1 – 0th order Wavelength Calibration Coefficient
- 2 – 1st order Wavelength Calibration Coefficient
- 3 – 2nd order Wavelength Calibration Coefficient
- 4 – 3rd order Wavelength Calibration Coefficient
- 5 – Stray light constant
- 6 – 0th order non-linearity correction coefficient
- 7 – 1st order non-linearity correction coefficient
- 8 – 2nd order non-linearity correction coefficient
- 9 – 3rd order non-linearity correction coefficient
- 10 – 4th order non-linearity correction coefficient
- 11 – 5th order non-linearity correction coefficient
- 12 – 6th order non-linearity correction coefficient
- 13 – 7th order non-linearity correction coefficient
- 14 – Polynomial order of non-linearity calibration
- 15 – Optical bench configuration: gg fff sss
gg – Grating #, fff – filter wavelength, sss – slit size
- 16 – HR2000+ configuration: AWL V
A – Array coating Mfg, W – Array wavelength (VIS, UV, OFLV), L – L2 lens installed, V – CPLD Version
- 17 – Reserved
- 18 – Reserved
- 19 – Reserved

Byte Format

Byte 0	Byte 1
0x05	Data byte

Return Format (EP7)

The data is returned in ASCII format and read in by the host through End Point 7.

Byte 0	Byte 1	Byte 2	Byte 3	...	Byte 17
0x05	Configuration Index	ASCII byte 0	ASCII byte 1	...	ASCII byte 15

Write Information

Writes any of the 19 stored spectrometer configuration variables to EEPROM. The 19 configuration variables are indexed as described in the Query Information. The information to be written is transferred as ASCII information.

Byte Format

Byte 0	Byte 1	Byte 2	Byte 3	...	Byte 17
0x06	Configuration Index	ASCII byte 0	ASCII byte 1	...	ASCII byte 15

Request Spectra

Initiates a spectra acquisition. The HR2000+ will acquire a complete spectrum (2048 pixel values). The data is returned in bulk transfer mode through EP2. The table below provides the pixel order overview for the 2 different speeds. The pixel values are decoded as described below.

Byte Format

Byte 0
0x09

Return Format

The format for the returned spectral data is dependant upon the USB communication speed. The format for both High Speed (480 Mbps) and Full Speed (12 Mbps) is shown below. All pixel values are 16-bit values organized in LSB | MSB order. Bit 13 has to be flipped for every pixel before converting to an integer. This is equivalent to performing a xor 0x20 with MSB. There is an additional packet containing one value that is used as a flag to insure proper synchronization between the PC and HR2000+.

USB High Speed (480Mbps) Packet Format

Packet #	End Point	# Bytes	Pixels
0	EP2In	512	0-255
1	EP2In	512	256-511
2	EP2In	512	512-767
3	EP2In	512	768-1023
4	EP2In	512	1024-1279
5	EP2In	512	1280-1535
...	EP2In	512	
7	EP2In	512	1792-2047
8	EP2In	1	Sync Packet

The format for the first packet is as follows (all other packets except the synch packet has a similar format except the pixel numbers are incremented by 256 pixels for each packet).

Packet 0

Byte 0	Byte 1	Byte 2	Byte 3
Pixel 0 LSB	Pixel 0 MSB	Pixel 1 LSB	Pixel 2 MSB
...			
		Byte 510	Byte 511
		Pixel 255 LSB	Pixel 255 MSB

Packet 15 – Synchronization Packet (1 byte)

Byte 0
0x69

USB Full Speed (12Mbps) Packet Format

In this mode all data is read from EP2In. The pixel and packet format is shown below.

Packet #	End Point	# Bytes	Pixels
0	EP2In	64	0-31
1	EP2In	64	32-63
2	EP2In	64	64-95
...	EP2In	64	
63	EP2In	64	2016–2047
64	EP2In	1	Sync Packet

Packet 0

Byte 0	Byte 1	Byte 2	Byte 3
Pixel 0 LSB	Pixel 0 MSB	Pixel 1 LSB	Pixel 2 MSB
...			
		Byte 62	Byte 63
		Pixel 31 LSB	Pixel 31 MSB

Packet 120 – Synchronization Packet (1 byte)

Byte 0
0x69

Set Trigger Mode

Sets the HR2000+ Trigger mode to one of three states. If an unacceptable value is passed then the trigger state is unchanged Also refer to the External Triggering Options document located on our web site at <http://www.oceanoptics.com/technical/operatinginstructions.asp> under **Other Spectrometer Documents** for more information.

Data Value = 0 → Normal (Free running) Mode
Data Value = 1 → Software Trigger Mode
Data Value = 2 → External Synchronization Trigger Mode
Data Value = 3 → External Hardware Trigger Mode

Byte Format

Byte 0	Byte 1	Byte 2
0x0A	Data Value LSB	Data Value MSB

Query Number of Plug-in Accessories

Queries the number of Plug-in accessories preset. This is determined at power up and whenever the Plug-in Detect command is issued

Byte Format

Byte 0
0x0B

Return Format

The data is returned in Binary format and read in by the host through End Point 7.

Byte 0
Value (BYTE)

Query Plug-in Identifiers

Queries the Plug-in accessories identifiers. This command returns 7 bytes with the last byte always being zero at this point. Each of the first 6 bytes correspond to Ocean Optics compatible devices which responded appropriately for I²C addresses 2 through 7 respectively. The I²C address are reserved for various categories of devices and the value for each category is shown below. I²C addresses 0-1 are reserved for loading program code from EEPROMS.

Byte Format

Byte 0
0x0C

Return Format

The data is returned in Binary format and read in by the host through End Point 7.

Byte 0	Byte 1	...	Byte 5	Byte 6
Value @ I ² C address 2	Value @ I ² C address 3	...	Value @ I ² C address 7	0x00

Detect Plug-ins

Reads all of the plug-in accessories that are plugged into the I²C bus. No data values are returned.

Byte Format

Byte 0
0x0D

General I²C Read

Performs a general purpose read on the I²C pins for interfacing to attached peripherals. The time to complete the command is determined by the amount of data transferred and the response time of the peripheral. The I²C bus runs at 400KHz. The maximum number of bytes that can be read is 61.

Command Byte Format

Byte 0	Byte 1	Byte 2
0x60	I ² C Address	Bytes to Read

Return Byte Format

Byte 0	Byte 1	Byte 2	Byte 3	...	Byte N+3
I ² C Results	I ² C Address	Bytes to Read	Data Byte 0	...	Data Byte N

I ² C Result Value	Description
0	I ² C bus Idle
1	I ² C bus Sending Data
2	I ² C bus Receiving Data
3	I ² C bus Receiving first byte of string
5	I ² C bus in waiting for STOP condition
6	I ² C experienced Bit Error
7	I ² C experience a Not Acknowledge (NAK) Condition
8	I ² C experienced successful transfer
9	I ² C bus timed out

General I²C Write

Performs a general-purpose write on the I²C pins for interfacing to attached peripherals. The time to complete the command is determined by the amount of data transferred and the response time of the peripheral. The I²C bus runs at 400KHz. The results codes are described above.

Command Byte Format

Byte 0	Byte 1	Byte 2	Byte 3	...	Byte N+3
0x61	I ² C Address	Bytes to Write	Data Byte 0	...	Data byte N

Return Byte Format

Byte 0
I ² C Results

Write Register Information

Most all of the controllable parameters for the HR2000+ are accessible through this command (e.g., GPIO, strobe parameters, etc). A complete list of these parameters with the associate register information is shown in the table below. Commands are written to End Point 1 Out typically with 4 bytes (some commands may require more data bytes). All data values are 16 bit values transferred in MSB | LSB order. This command requires 100us to complete; the calling program needs to delay for this length of time before issuing another command. In some instances, other commands will also write to these registers (e.g., integration time), in these cases the user has the options of setting the parameters through 2 different methods.

Byte Format

Byte 0	Byte 1	Byte 2	Byte 3
0x6A	Register Value	Data Byte LSB	Data Byte MSB

Register	Description	Default Value	Min Value	Max Value	Time Base	Version
0x00*	Set Master Clock Counter Divisor. Master Clock freq = 48MHz/Divisor	12	1	0xFFFF	48MHz	1.00.0
0x04	FPGA Firmware Version (Read Only)					1.00.0
0x08	Continuous Strobe Timer Interval Divisor	10 (100 Hz)	0	0xFFFF	Continuous Strobe Base Clock (see Register 0x0C)	1.00.0

Register	Description	Default Value	Min Value	Max Value	Time Base	Version
0x0C	Continuous Strobe Base Clock. Divisor operates from 48MHz Clock	4800 (1KHz)	0	0xFFFF	48MHz	1.00.0
0x10*	Integration Period Base Clock Base Freq = 48MHz	480 (10us)	0	0xFFFF	48MHz	1.00.0
0x14	Set base_clk or base-clkx2 0: base_clk 1:base_clkx2	0	0	1	N/A	1.00.0
0x18*	Integration Clock Timer Divisor	600 (6ms)	0	0xFFFF	Integration Period Base Clock (see Register 0x10)	1.00.0
0x20*	Reserved					1.00.0
0x28	Hardware Trigger Delay – Number of Master Clock cycles to delay when in External Hardware Trigger mode before the start of the integration period	0	0	0xFFFF		1.00.0
0x2C&*	Trigger Mode 0 = Free Running 1 = External Synchronization 2 = External Hardware Trigger	0	0	2		1.00.0
0x30	Reserved					1.00.0
0x38	Single Strobe High Clock Transition Delay Count	1	0	0xFFFF		1.00.0
0x3C	Single Strobe Low Clock Transition Delay Count	5	0	0xFFFF		1.00.0
0x40	Lamp Enable	0	0	1		1.00.0
0x48	GPIO Mux Register (0 = pin is GPIO pin, 1 = pin is alternate function)	0	0	0x03FF		1.00.0
0x50	GPIO Output Enable (1 = pin is output, 0= pin is input)	0	0	0x03FF		1.00.0
0x54	GPIO Data Register For Output = Write value of signal For Input = Read current GPIO state	0	0	0x03FF		1.00.0
0x58	Reserved					1.00.0
0x5C	Enable External Master Clock – For LIBS	0	0	1	N/A	1.10.0

* - These values affect spectrometer performance and should not be changed. This information is included just for completeness.

& - These values are controlled by other command interfaces to the HR2000+ (i.e, Set Integration Time command).

Read Register Information

Read the values from any of the registers above. This command is sent to End Point 1 Out and the data is retrieved through End Point 1 In.

Byte Format

Byte 0	Byte 1
0x6B	Register Value

Return Format (EP1In)

Byte 0	Byte 1	Byte 2
Register Value	Value MSB	Value LSB

Read PCB Temperature

Read the Printed Circuit Board Temperature. The HR2000+ contains an DS1721 temperature sensor chip which is mounted to the under side of the PCB. This command is sent to End Point 1 Out and the data is retrieved through End Point 1 In. The value returned is a signed 16-bit A/D conversion value which is equated to temperature by:

$$\text{Temperature (}^{\circ}\text{C)} = .003906 * \text{ADC Value}$$

Byte Format

Byte 0
0x6C

Return Format (EP1In)

Byte 0	Byte 1	Byte 2
Read Result	ADC Value LSB	ADC Value MSB

If the operation was successful, the Read Result byte value will be 0x08. All other values indicate the operation was unsuccessful.

Read Irradiance Factors

Reads 60 bytes of data, which is utilized for Irradiance Calibration information from the desired EEPROM memory address.

Byte Format

Byte 0	Byte 1	Byte 2
0x6D	EEPROM Address LSB	EEPROM Address MSB

Return Byte Format

Byte 0	Byte 1	...	Byte 59
Byte 0	Byte 1	...	Byte 59

Write Irradiance Factors

Write 60 bytes of data, which is utilized for Irradiance Calibration information to the desired EEPROM memory address.

Byte Format

Byte 0	Byte 1	Byte 2	Byte 3	...	Byte 62
0x6E	EEPROM Address LSB	EEPROM Address MSB	Byte 0	...	Byte 59

Query Status

Returns a packet of information, which contains the current operating information. The structure of the status packet is given below.

Byte Format

Byte 0
0xFE

Return Format

The data is returned in Binary format and read in by the host through End Point 1 In. The structure for the return information is as follows.

Byte	Description	Comments
0-1	Number of Pixels - WORD	LSB MSB order
2-5	Integration Time - WORD	Integration time in μs – LSW MSW. Within each word order is LSB MSB

HR2000+ Data Sheet

Byte	Description	Comments
6	Lamp Enable	0 – Signal LOW 1 – Signal HIGH
7	Trigger Mode Value	
8	Spectral Acquisition Status	
9	Packets In Spectra	Returns the number of packets in a Request Spectra Command.
10	Power Down Flag	0 – Circuit is powered down 1 – Circuit is powered up
11	Packet Count	Number of packets that have been loaded into End Point Memory
12	Reserved	
13	Reserved	
14	USB Communications Speed	0 – Full Speed (12Mbs) 0x80 – High Speed (480 Mbps)
15	Reserved	

Appendix A

HR2000+ Serial Port Interface Communications and Control Information

Overview

The HR2000+ is a microcontroller-based Miniature Fiber Optic which can communicate via the Universal Serial Bus or RS-232. This document contains the necessary command information for controlling the HR2000+ via the RS-232 interface.

Hardware Description

Overview

The HR2000+ utilizes a Cypress FX2 microcontroller, which has a high speed 8051, combined with an USB ASIC. Program code and data coefficients are stored in external E₂PROM which are loaded at boot-up via the I²C bus.

Spectral Memory Storage

The HR2000+ can store up to 4 spectra in the spectral data section. The full spectra (2048 points) is stored. Spectra are organized in a stack formation (i.e., LIFO). It's important to realize that the spectral math (averaging and boxcar smoothing) is performed when the data is transmitted out and not when the spectra is acquired. This allows up to 4 scans to be acquired with one command (set A=4 and send the S command) and then read out on scan at a time (set A=1 and use Z1 command).

Instruction Set

Command Syntax

The list of the command are shown in the following table along with the microcode version number they were introduced with. All commands consist of an ASCII character passed over the serial port, followed by some data. The length of the data depends on the command. The format for the data is either ASCII or binary (default). The ASCII mode is set with the “a” command and the binary mode with the “b” command. To insure accurate communications, all commands respond with an ACK (ASCII 6) for an acceptable command or a NAK (ASCII 21) for an unacceptable command (i.e., data value specified out of range).

HR2000+ Data Sheet

In the ASCII data value mode, the HR2000+ “echoes” the command back out the RS-232 port. In binary mode all data, except where noted, passes as 16-bit unsigned integers (WORDS) with the MSB followed by the LSB. By issuing the “v command” (Version number query), the data mode can be determined by viewing the response (ASCII or binary).

In a typical data acquisition session, the user sends commands to implement the desired spectral acquisition parameters (integration time, etc.). Then the user sends commands to acquire spectra (S command) with the previously set parameters. If necessary, the baud rate can be changed at the beginning of this sequence to speed up the data transmission process.

Command Summary

Letter	Description	Version
A	Adds scans 2.00.0	2.00.0
B	Set Pixel Boxcar	2.00.0
C		
D		
E		
F		
G	Set Data Compression	2.00.0
H		
I	Sets integration time (16 bit value in milliseconds)	2.00.0
J	Sets Lamp Enable Line	2.00.0
K	Changes baud rate	2.00.0
L	Clear Memory	
M		
N		
O		
P	Partial Pixel Mode	2.00.0
Q		
R		
S	Starts spectral acquisition with previously set parameters	2.00.0
T	Sets trigger mode	2.00.0
U		
V		
W	Set FPGA Register Values	2.10.0
X		
Y		

Letter	Description	Version
Z		
A	Set ASCII mode for data values	2.00.0
B	Set binary mode for data values	2.00.0
K	Sets Checksum mode	2.00.0
I	Set Integration Time (32 bit value in microseconds)	2.10.0
V	Provides microcode version #	2.00.0
X	Sets calibration coefficients	2.00.0
?	Queries parameter values	2.00.0
+	Reads the plugged-in accessories	2.00.0

Command Descriptions

A detailed description of all HR2000+ commands follows. The {} indicates a data value which is interpreted as either ASCII or binary (default). The default value indicates the value of the parameter upon power up.

Add Scans

Sets the number of discrete spectra to be summed together. Since this routine can add up to 4 spectra, each with a maximum intensity of 16383, the maximum returned intensity is 65535.

Command Syntax:	A{DATA WORD}
Response:	ACK or NAK
Range:	1-4
Default value:	1

Pixel Boxcar Width

Sets the number of pixels to be averaged together. A value of n specifies the averaging of n pixels to the right and n pixels to the left. This routine uses 32-bit integers so that intermediate overflow will not occur; however, the result is truncated to a 16-bit integer prior to transmission of the data. This math is performed just prior to each pixel value being transmitted out. Values greater than ~ 3 will exceed the idle time between values and slow down the overall transfer process.

Command Syntax:	B{DATA WORD}
Response:	ACK or NAK
Range:	0-15
Default value:	0

Set Data Compression

Specifies whether the data transmitted from the HR2000+ should be compressed to speed data transfer rates. For more information on HR2000+ Data Compression, see Technical Note 1.

HR2000+ Data Sheet

Command Syntax:	G{DATA WORD}
Response:	ACK or NAK
Range:	0 – Compression off !0 – Compression on
Default value:	0

Integration Time (16 Bit Value)

Sets the HR2000+'s integration time, in milliseconds, to the value specified.

Command Syntax:	I{16 bit DATA WORD}
Response:	ACK or NAK
Range:	1 – 65,000
Default value:	6

Note

The 32-bit version of the Set Integration Command is reserved for future use.

Integration Time (32 Bit Value)

Sets the HR2000+'s integration time, in microseconds, to the value specified.

Command Syntax:	i {32 bit DATA WORD}
Response:	ACK or NAK
Range:	10 – 65,000,000
Default value:	6,000

Lamp Enable

Sets the HR2000+'s Lamp Enable line to the value specified

Command Syntax:	J{DATA WORD}
Value:	0 = Light source/strobe off—Lamp Enable low 1 = Light source/strobe on—Lamp Enable high
Response:	ACK or NAK
Default value:	0

Baud Rate

Sets the HR2000+'s baud rate.

Command Syntax:	K{DATA WORD}
Value:	0=2400 1=4800 2=9600 3=19200 4=38400 5=Not Supported 6=115,200
Response:	See below
Default value:	6

When changing baud rates, this sequence must be followed:

1. Controlling program sends K with desired baud rate, communicating at the old baud rate.
2. A/D responds with ACK at old baud rate, otherwise it responds with NAK and the process is aborted.
3. Controlling program waits longer than 50 milliseconds.
4. Controlling program sends K with desired baud rate, communicating at the new baud rate.
5. A/D responds with ACK at new baud rate, otherwise it responds with NAK and old baud rate is used.

If a deviation occurs at any step, the previous baud rate is used.

Clear Memory

Clears spectral data memory based upon the value specified. Clearing memory is immediate since only pointer values are reinitialized.

Command Syntax:	L{DATA WORD}
Value:	0 = Clear Spectral memory 1 = Clear Spectral memory
Response:	ACK or NAK
Default value:	N/A

Pixel Mode

Specifies which pixels are transmitted. While all pixels are acquired on every scan, this parameter determines which pixels will be transmitted out the serial port.

Command Syntax:	P{DATA WORD}{other optional data words possible required}	
Value:	Description 0 = all 3840 pixels 1 = every n^{th} pixel with no averaging 2 = N/A 3 = pixel x through y every n pixels 4 = up to 10 randomly selected pixels between 0 and 2047 (denoted p1, p2, ... p10)	P 0 (spaces for clarity only) P 1<Enter> N<Enter> P 2 N/A P3<Enter> x<Enter> y<Enter> n<Enter> P 4<Enter> n<Enter> p1<Enter> p2<Enter> p3<Enter> ... p10<Enter>
Response:	ACK or NAK	
Default value:	0	

Since most applications only require a subset of the spectrum, this mode can greatly reduce the amount of time required to transmit a spectrum while still providing all of the desired data. This mode is helpful when interfacing to PLCs or other processing equipment.

Spectral Acquisition

Acquires spectra with the current set of operating parameters. When executed, this command determines the amount of memory required. If sufficient memory does not exist, an ETX (ASCII 3) is immediately returned and no spectra are acquired. An STX (ASCII 2) is sent once the data is acquired and stored. If the Data Storage Mode value is 0, then the data is transmitted immediately.

Command Syntax:	S
Response:	If successful, STX followed by data If unsuccessful, ETX

The format of returned spectra includes a header to indicate scan number, channel number, pixel mode, etc. The format is as follows:

- WORD 0xFFFF – start of spectrum
- WORD Spectral Data Size Flag (0 → Data is WORD's, 1 → Data is DWORD's)
- WORD scan number ALWAYS 0
- WORD Number of scans accumulated together
- DWORD integration time in microseconds (LSW followed by MSW)
- WORD pixel mode
- WORDS if pixel mode not 0, indicates parameters passed to the Pixel Mode command (P)
- (D)WORDS spectral data – see Data Size Flag for variable size
- WORD 0xFFFD – end of spectrum

Trigger Mode

Sets the HR2000+'s external trigger mode to the value specified.

Command Syntax:	T{DATA WORD}
Value:	0 = Normal – Continuously scanning 1 = Software trigger 2 = External Synchronization 3 = External Hardware Trigger
Response:	ACK or NAK
Default value:	0

Set FPGA Register Value

Sets the appropriate register within the FPGA. The list of register setting is in the USB command set information. This command requires two data values, one to specify the register and the next to specify the value.

Command Syntax:	W{DATA WORD 1}{DATA WORD 2}
Value:	Data Word 1 – FPGA Register address Data Word 2 – FPGA Register Value
Response:	ACK or NAK

ASCII Data Mode

Sets the mode in which data values are interpreted to be ASCII. Only unsigned integer values (0 – 65535) are allowed and the data values are terminated with a carriage return (ASCII 13) or linefeed (ASCII 10). In this mode the HR2000+ echoes the command and data values back to the RS-232 port.

Command Syntax:	aA
Response:	ACK or NAK
Default value	N/A

The command requires that the string “aA” be sent without any CR or LF. This is an attempt to insure that this mode is not entered inadvertently. A legible response to the Version number query (v command) indicates the HR2000+ is in the ASCII data mode.

Binary Data Mode

Sets the mode in which data values are interpreted to be binary. Only 16 bit unsigned integer values (0– 65535) are allowed in this mode with the MSB followed by the LSB

Command Syntax:	bB
Response:	ACK or NAK
Default value	Default at power up – not changed by Q command

The command requires that the string “bB” be sent without any CR or LF. This is an attempt to insure that this mode is not entered inadvertently.

Checksum Mode

Specifies whether the HR2000+ will generate and transmit a 16-bit checksum of the spectral data. This checksum can be used to test the validity of the spectral data, and its use is recommended when reliable data scans are required. See Technical Note 2 for more information on checksum calculation.

Command Syntax:	k{DATA WORD}
Value:	0 = Do not transmit checksum value !0 = transmit checksum value at end of scan
Response:	ACK or NAK
Default value:	0

Version Number Query

Returns the version number of the code running on the microcontroller. A returned value of 1000 is interpreted as 1.00.0.

Command Syntax:	v
Response:	ACK followed by {DATA WORD}
Default value	N/A

Calibration Constants

Writes one of the 16 possible calibration constant to EEPROM. The calibration constant is specified by the first DATA WORD which follows the x. The calibration constant is stored as an ASCII string with a max length of 15 characters. The string is not check to see if it makes sense.

Command Syntax:	x{DATA WORD}{ASCII STRING}
Value:	DATA WORD Index description 0 – Serial Number 1 – 0 th order Wavelength Calibration Coefficient 2 – 1 st order Wavelength Calibration Coefficient 3 – 2 nd order Wavelength Calibration Coefficient 4 – 3 rd order Wavelength Calibration Coefficient 5 – Stray light constant 6 – 0 th order non-linearity correction coefficient 7 – 1 st order non-linearity correction coefficient 8 – 2 nd order non-linearity correction coefficient 9 – 3 rd order non-linearity correction coefficient 10 – 4 th order non-linearity correction coefficient 11 – 5 th order non-linearity correction coefficient 12 – 6 th order non-linearity correction coefficient 13 – 7 th order non-linearity correction coefficient 14 – Polynomial order of non-linearity calibration 15 – Optical bench configuration: gg fff sss gg – Grating #, fff – filter wavelength, sss – slit size 16 – HR2000+ configuration: AWL V A – Array coating Mfg, W – Array wavelength (VIS, UV, OFLV), L – L2 lens installed, V – CPLD Version 17 – Reserved 18 – Reserved 19 – Reserved
Response:	ACK or NAK
Default value:	N/A

To query the constants, use the ?x{DATA WORD} format to specify the desired constant

Query Variable

Returns the current value of the parameter specified. The syntax of this command requires two ASCII characters, the 2nd of which corresponds to the command character that sets the parameter of interest (acceptable values: B, A, I, K, T, J, y). A special case of this command is ?x (lower case), which requires an additional data word be passed to indicate which calibration constant is to be queried.

Command Syntax:	?{ASCII character}
Response:	ACK followed by {DATA WORD}
Default value:	N/A

Examples

Below are examples on how to use some of the commands. Commands are in **BOLD** and descriptions are in parentheses. For clarity, the commands are shown in the ASCII mode (a command) instead of the default binary mode. The prompt ">" is also shown since the example is in ASCII mode.

The desired operating conditions are: acquire spectra from the spectrometer with a 200ms integration time, set number of scan to add to 3 and operate at 115,200 Baud.

```

aA          (Set ASCII Data Mode)
> K6<CR>    (Start baud rate change to 115,200)
                Wait for ACK, change to 115200, wait for 20ms
K6<CR>    (Verify command, communicate at 115200)
> A3<CR>    (Add 3 spectra)
> I200<CR>  (Set integration time to 200ms)
> S        (Acquire spectra)
...          Repeat as necessary
  
```

Application Tips

- During the software development phase of a project, the operating parameters of the HR2000+ may become out-of-synch with the controlling program. It is good practice to cycle power on the HR2000+ when errors occur.
- If you question the state of the HR2000+, you can transmit a space (or another non-command) using a terminal emulator. If you receive a NAK, the HR2000+ is awaiting a command; otherwise, it is still completing the previous command.
- For Windows users, use HyperTerminal as a terminal emulator after selecting the following:
 1. Select **File | Properties**.
 2. Under **Connect using**, select **Direct to Com x**.
 3. Click **Configure** and match the following **Port Settings**:
 - Bits per second (Baud rate): Set to desired rate
 - Data bits: 8
 - Parity: None
 - Stop bits: 1
 - Flow control: None
 4. Click **OK** in **Port Settings** and in **Properties** dialog boxes.

Technical Note 1:

HR2000+ Data Compression

Transmission of spectral data over the serial port is a relatively slow process. Even at 115,200 baud, the transmission of a complete 3840 point spectrum takes around 600 msec. The HR2000+ implements a data compression routine that minimizes the amount of data that needs to be transferred over the RS-232 connection. Using the “G” command (Compressed Mode) and passing it a parameter of 1 enables the data compression. Every scan transmitted by the HR2000+ will then be compressed. The compression algorithm is as follows:

1. The first pixel (a 16-bit unsigned integer) is always transmitted uncompressed.
2. The next byte is compared to 0x80.
 - If the byte is equal to 0x80, the next two bytes are taken as the pixel value (16-bit **unsigned** integer).
 - If the byte is not equal to 0x80, the value of this byte is taken as the difference in intensity from the previous pixel. This difference is interpreted as an 8-bit **signed** integer.
3. Repeat Step 2 until all pixels have been read.

Using this data compression algorithm greatly increases the data transfer speed of the HR2000+. Compression rates of 35-48% can easily be achieved with this algorithm.

The following shows a section of a spectral line source spectrum and the results of the data compression algorithm.

Pixel Value	Value Difference	Transmitted Bytes
185	0	0x80 0x00 0xB9
2151	1966	0x80 0x08 0x67
836	-1315	0x80 0x03 0x44
453	-383	0x80 0x01 0xC5
210	-243	0x80 0x00 0xD2
118	-92	0xA4
90	-28	0xE4
89	-1	0xFF
87	-2	0xFE
89	2	0x02
86	-3	0xFD
88	2	0x02
98	10	0x0A
121	23	0x17
383	262	0x80 0x01 0x7F

Pixel Value	Value Difference	Transmitted Bytes
1162	779	0x80 0x04 0x8A
634	-528	0x80 0x02 0x7A
356	-278	0x80 0x01 0x64
211	-145	0x80 0x00 0xD3
132	-79	0xB1
88	-44	0xD4
83	-5	0xFB
86	3	0x03
82	-4	0xFC
91	9	0x09
92	1	0x01
81	-11	0xF5
80	-1	0xFF
84	4	0x04
84	0	0x00
85	1	0x01
83	-2	0xFE
80	-3	0xFD
80	0	0x00
88	8	0x08
94	6	0x06
90	-4	0xFC
103	13	0x0D
111	8	0x08
138	27	0x1B

In this example, spectral data for 40 pixels is transmitted using only 60 bytes. If the same data set were transmitted using uncompressed data, it would require 80 bytes.

Technical Note 2: HR2000+ Checksum Calculation

For all uncompressed pixel modes, the checksum is simply the unsigned 16-bit sum (ignoring overflows) of all transmitted spectral points. For example, if the following 10 pixels are transferred, the calculation of the checksum would be as follows:

Pixel Number	Data (decimal)	Data (hex)
0	15	0x000F
1	23	0x0017
2	46	0x002E
3	98	0x0062
4	231	0x00E7
5	509	0x01FD
6	1023	0x03FF
7	2432	0x0980
8	3245	0x0CAD
9	1984	0x07C0

Checksum value: 0x2586

When using a data compression mode, the checksum becomes a bit more complicated. A compressed pixel is treated as a 16-bit **unsigned** integer, with the most significant byte set to 0. Using the same data set used in [Technical Note 1:](#)

[HR2000+ Data Compression](#), the following shows a section of a spectral line source spectrum and the results of the data compression algorithm.

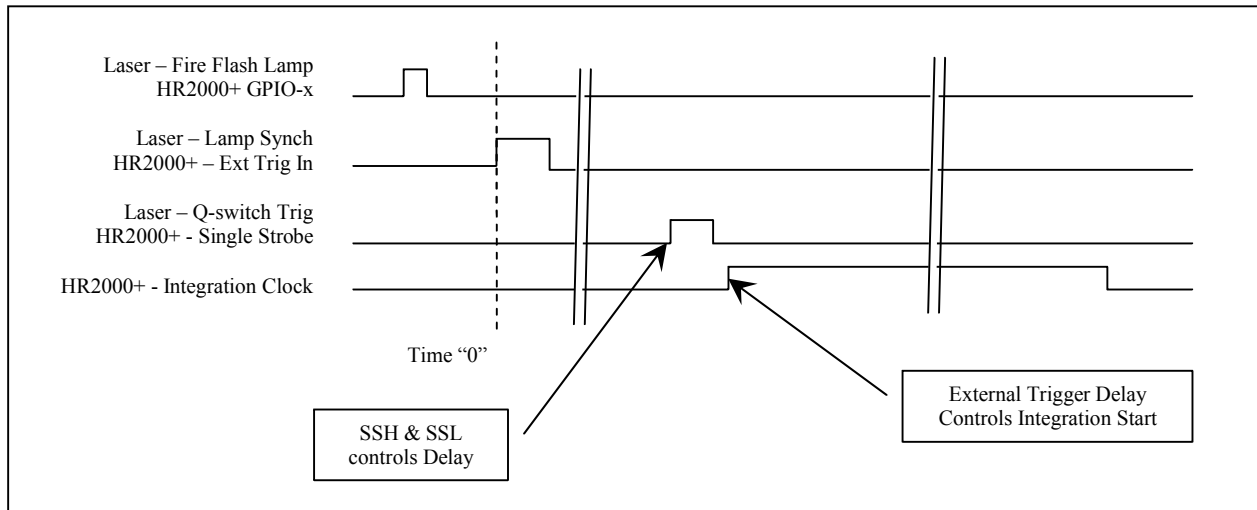
Data Value	Value Difference	Transmitted Bytes	Value added to Checksum
185	0	0x80 0x00 0xB9	0x0139
2151	1966	0x80 0x08 0x67	0x08E7
836	-1315	0x80 0x03 0x44	0x03C4
453	-383	0x80 0x01 0xC5	0x0245
210	-243	0x80 0x00 0xD2	0x0152
118	-92	0xA4	0x00A4
90	-28	0xE4	0x00E4
89	-1	0xFF	0x00FF
87	-2	0xFE	0x00FE
89	2	0x02	0x0002

Data Value	Value Difference	Transmitted Bytes	Value added to Checksum
86	-3	0xFD	0x00FD
88	2	0x02	0x0002
98	10	0x0A	0x000A
121	23	0x17	0x0017
383	262	0x80 0x01 0x7F	0x01FF
1162	779	0x80 0x04 0x8A	0x050A
634	-528	0x80 0x02 0x7A	0x02FA
356	-278	0x80 0x01 0x64	0x01E4
211	-145	0x80 0x00 0xD3	0x0153
132	-79	0xB1	0x00B1
88	-44	0xD4	0x00D4
83	-5	0xFB	0x00FB
86	3	0x03	0x0003
82	-4	0xFC	0x00FC
91	9	0x09	0x0009
92	1	0x01	0x0001
81	-11	0xF5	0x00F5
80	-1	0xFF	0x00FF
84	4	0x04	0x0004
84	0	0x00	0x0000
85	1	0x01	0x0001
83	-2	0xFE	0x00FE
80	-3	0xFD	0x00FD
80	0	0x00	0x0000
88	8	0x08	0x0008
94	6	0x06	0x0006
90	-4	0xFC	0x00FC
103	13	0x0D	0x000D
111	8	0x08	0x0008
138	27	0x1B	0x001B

The checksum value is simply the sum of all entries in the last column, and evaluates to 0x2C13.

Technical Note 3: LIBS Specifics

The standard firmware in the HR2000+ was designed to support LIBS applications; this technical note describes those details. Typically in these applications, there will be a group of HR2000+ spectrometers operating synchronously, each measuring a different wavelength range. Typically in these applications, one of the HR2000+'s will be selected as a Master device. This selection is arbitrary since all the HR2000+'s are the same, however one device will be required to drive the common clock and trigger the laser. The figure below shows a typical timing diagram for a LIBS application. Below that are the firmware and hardware configurations required for most common LIBS applications.



Common Clock: In order to reduce the jitter between the HR2000+'s, it is necessary to operate these on a common Clock. This is done by having the Master HR2000+ drive its Maser Clock Signal (default 2.4MHz – FPGA Register address 0), and having the other HR2000+'s use this Master Clock. This is done by configuring the master clock to drive the MCLK signal out the GPIO-1 pin (alternate function) and have the other spectrometers use this signal.

Master HR2000+:

Signal	Description	Command Bytes (hex)
GPIO-1	Set Output Enable of GPIO-1	0x6A 0x50 0x02 0x0
GPIO-1	Set Alternate Function of GPIO-1	0x6A 0x48 0x02 0x0

Other HR2000+'s:

Signal	Description	Command Bytes (hex)
GPIO-1	Utilize External Master Clock	0x5C 0x1 0x0

Hardware Trigger Delay: The trigger input signal is routed to all of the HR2000+'s. Each spectrometer should be programmed with the same Hardware Trigger Delay setting. The value entered is the number of Master Clock intervals (2.4MHz default = 416.67ns) that is delayed between the rising edge of the External Trigger input signal and the start of the integration time.

HR2000+ (All):

Description	Command Bytes (hex)
Hardware Trigger Delay	0x6A 0x28 LSB MSB

Q-Switch Fire (Single Strobe): The Single Strobe signal has the ability to be delayed independently from the External Trigger Input event and thus it is recommended that it is used to fire the Q Switch signal. The user can program the number of Master Clock Increments (default = 416.67ns) after the trigger input before the Single Strobe transitions from TTL Low to TTL High (SSH transition). The user can also program when the Single Strobe will transition from TTL High to TTL Low (SSL transition). Additionally the Single Strobe signal is gated by the Strobe Enable command, thus it is easily enabled/disabled for laser firing.

Master HR2000+:

Description	Command Bytes (hex)
Single Strobe High Transition (SSH)	0x6A 0x38 LSB MSB
Single Strobe Low Transition (SSL)	0x6A 0x3C LSB MSB
Strobe Enable	0x03 (1/0 for Enable/Disable)

HR2000+ Hardware Configuration: The following figure shows a 3-channel LIBS setup using HR2000+'s. The right-most HR2000+ is designated as the Master unit. This figure shows the PCBs included in Ocean Optics' LIBS25000plus for reference.



Laser: Laser Trigger In
HR2000+: GPIO-5

Laser: Lamp Synch
Out

HR2000+: Ext Trig In

Laser: Q-Switch
Trigger

HR2000+: Single
Strobe

3-channel HR2000+ LIBS setup

