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HR4000 Data Sheet

Description

The Ocean Optics HR4000 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 HR4000 spectrometer is a unique combination of technologies providing users with both an unusually high spectral response and high optical resolution in a single package. The electronics have been designed for considerable flexibility in connecting to various modules as well as external interfaces. The HR4000 interfaces to PC's, PLC's and other embedded controllers through USB 2.0 or RS-232 communications. The information included in this guide provides detailed instructions on the connection and operation of the HR4000.

The detector used in the HR4000 spectrometer is a high-sensitivity 3648-element CCD array from Toshiba, product number TCD1304AP. (For complete details on this detector, visit Toshiba's web site at **www.toshiba.com**. Ocean Optics applies a coating to all TCD1304AP detectors, so the optical sensitivity could vary from that specified in the Toshiba datasheet).

The HR4000 operates off of a single +5VDC supply and either a USB or RS-232 interface. The HR4000 is a microcontroller-controlled spectrometer, thus all operating parameters are implemented through software interfacing to the unit.

Features

- TCD1304AP Detector
  - High sensitivity detector
  - Readout Rate: 1MHz
  - Shutter mode
- Optics
  - An optical resolution of ~0.03nm (FWHM)
  - A wide variety of optics available
  - 14 gratings
  - 6 slit widths
  - 1 order sorting filter
- Electrical Performance
  - 14 bit, 5MHz A/D Converter
  - Integration times from 3.8ms to 10s
- 4 triggering modes
- Embedded microcontroller allows programmatic control of all operating parameters & Standalone operation
  - USB 2.0 480Mbps (High Speed) & 12Mbps (Full speed)
  - RS232 115Kbaud
  - Multiple Communication Standards for digital accessories (SPI, I^2C)
- 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 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}	+ 5.5 VDC
Voltage on any pin	Vcc
Physical Specifications:	
Physical Dimensions	148.6 mm x 104.8 mm x 45.1 mm
Weight	570 g
Power:	
Power requirement (master)	500 mA at +5 VDC
Supply voltage	4.5 – 5.5 V
Power-up time	~5s depending on code size
Spectrometer:	
Design	Asymmetric crossed Czerny-Turner
Focal length (input)	F/4 101mm
Focal length (output)	68 mm (75, 83 and 90 mm focal lengths also available)
Input Fiber Connector	SMA 905 to single-strand optical fiber (0.22 NA)
Gratings	14 different gratings
Entrance Slit	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.)
Detector	Toshiba TCD1304AP
Filters	2^{nd} & 3^{rd} order rejection, long pass (optional)
Spectroscopic:	
Integration Time	3.8 ms – 10sec
Dynamic Range	2500 single integration period, 2.5 x 10^9 over integration range
Signal-to-Noise	300:1 single acquisition
Readout Noise (single dark spectrum)	6 counts RMS, 20 counts peak-to-peak
Resolution	0.03 – 1.0 nm varies by configuration (see www.oceanoptics.com for configuration options)
Stray Light	<0.05% at 600 nm; <0.10% at 435 nm
Spectrometer Channels	One
Environmental Conditions:	
Temperature	-30° to +70° C Storage & -10° to +50° C Operation
Humidity	0% - 90% non-condensing
Interfaces:	
USB	USB 2.0, 480 Mbps
RS-232	2-wire RS-232
I^2C	**I**nter-**I**ntegrated **C**ircuit 2-Wire serial BUS

Mechanical Diagram

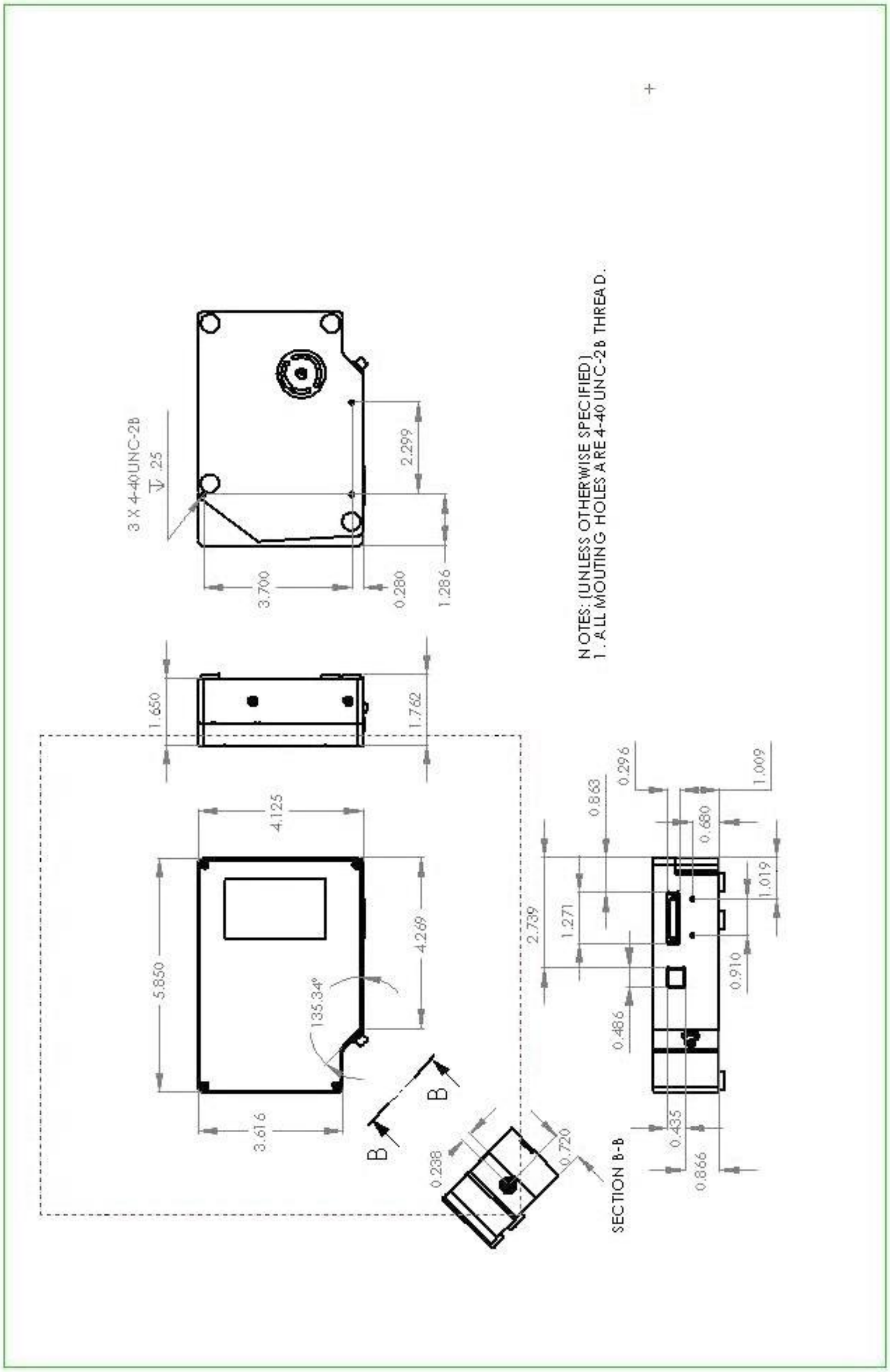
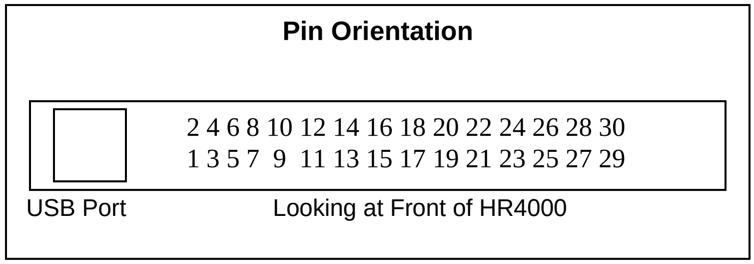


Figure 1. HR4000 Outer Dimensions

Electrical Pinout

Listed below is the pin description for the HR4000 Accessory Connector (J3) located on the front vertical wall of the unit. The connector is a Pak50$_{TM}$ model from 3M Corp. Headed Connector Part# P50-030P1-RR1-TG. Mates with Part # P50-030S-TGF (requires two: 1.27mm (50 mil) flat ribbon cable: Recommended 3M 3365 Series).

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



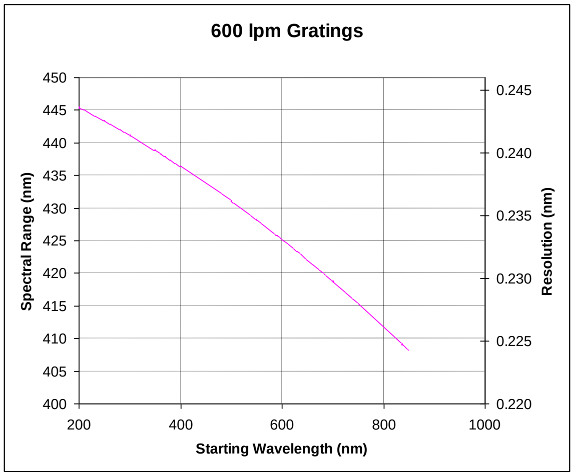
Pin #	Function	Input/Output	Description
1	RS232 Rx	Output	RS232 Receive signal – for communication with PC connect to DB9 pin 3
2	RS232 Tx	Input	RS232 Transmit signal – for communication with PC connect to DB9 pin 2
3	GPIO (2)	Input/Output	General purpose, software-programmable digital input/output (channel number)
4	V5_SW	Output	This is a regulated 5-Volt power pin out of the HR4000. It can supply 50mA (max).
5	Ground	Input/Output	Ground
6	I^2C 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^2C 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 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 HR4000. 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 HR4000. 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)

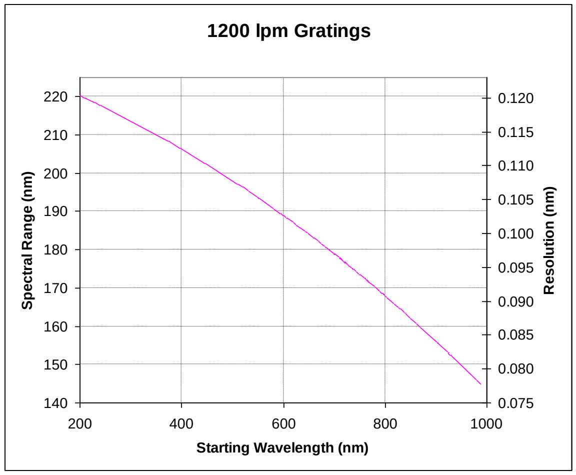
Pin Definition and Descriptions (Cont'd)

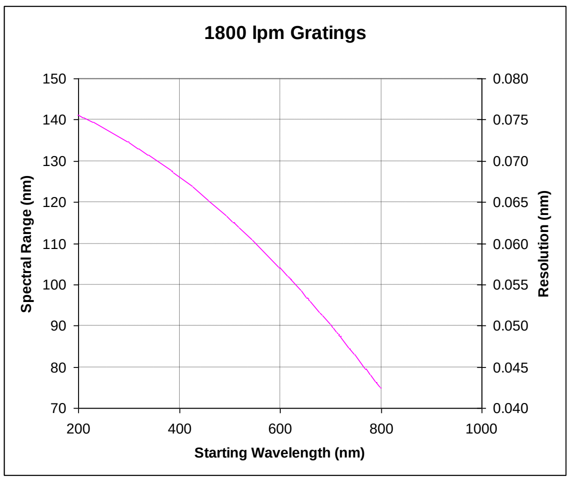
Pin #	Function	Input/Output	Description
19	Reserved	Output	
20	Continuous Strobe	Output	TTL output signal used to pulse a strobe that is divided down from the Master Clock signal
21	Reserved	Output	
22	GPIO (6)	Input/Output	General purpose, software-programmable digital input/output (channel number)
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 HR4000
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)

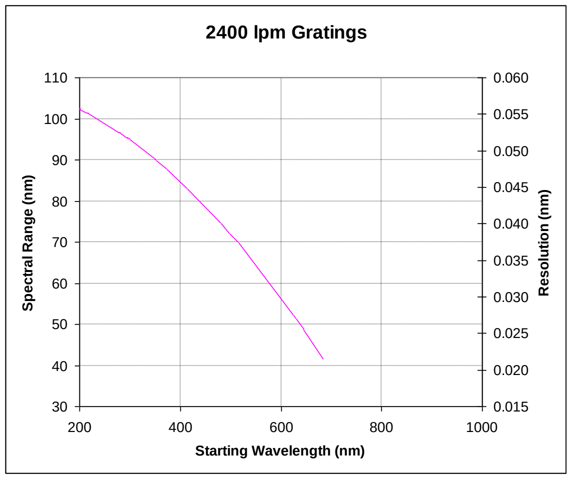
Optical Performance

Below are the graphs showing the range and resolution for the various gratings when configured with a 5um slit.









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 HR4000 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 high enough to allow for system drift. The following table is a description of all of the pixels:

Pixels	Description
1 – 5	Not usable
6 – 18	Optical black pixels
19 – 21	Transition pixels
22 – 3669	Optical active pixels
3670 – 3681	Not usable

CCD Detector Reset Operation

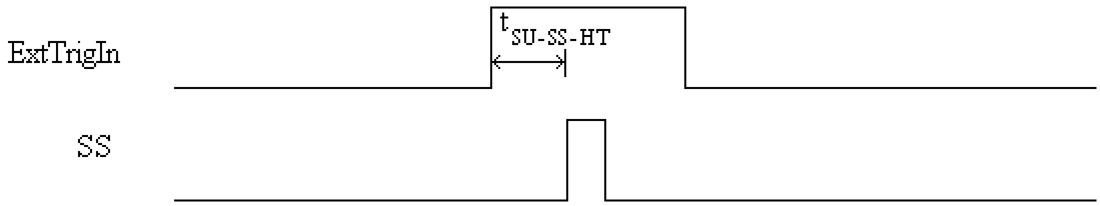
At the start of each integration period, the detector transfers the signal from each pixel to the readout registers and resets the pixels. The total amount of time required to perform this operation is ~12µs. The user needs to account for this time delay when the pixels are optically inactive, especially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

Timing Signals

Strobe Signals

Single Strobe

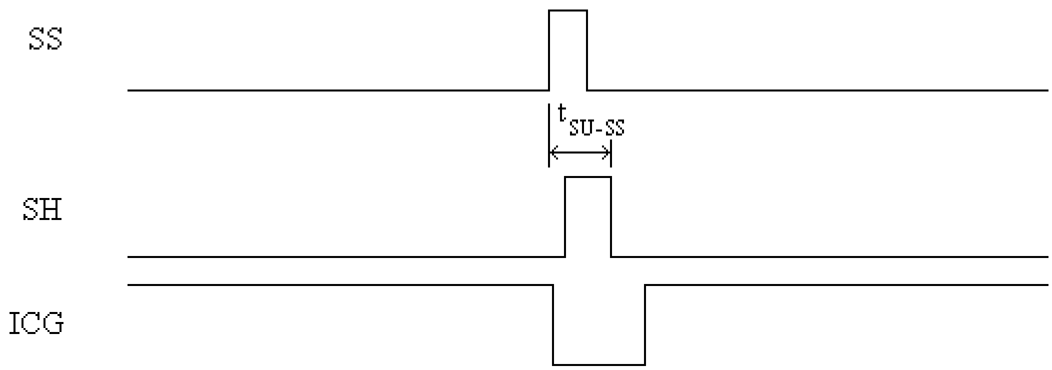
The Single Strobe (SS) signal is a programmable TTL pulse that occurs at a user-determined time during each integration period. This pulse has a user-defined delay and pulse width. The pulse is only active if the Lamp Enable command is active. This pulse allows for synchronization of external devices to the spectrometers integration period. The Strobe delay can range from 0 to 30 ms. In External Hardware Trigger mode, the timing of the Single Strobe is based on the External Trigger signal. In Normal (free running) and External Synchronization Trigger modes, the timing of the Single Strobe is based on the beginning of the integration period (the falling edge of SH that occurs during ICG). The timing diagram for the Single Strobe in External Hardware Trigger mode is shown below:



Single Strobe (External Hardware Trigger Mode)

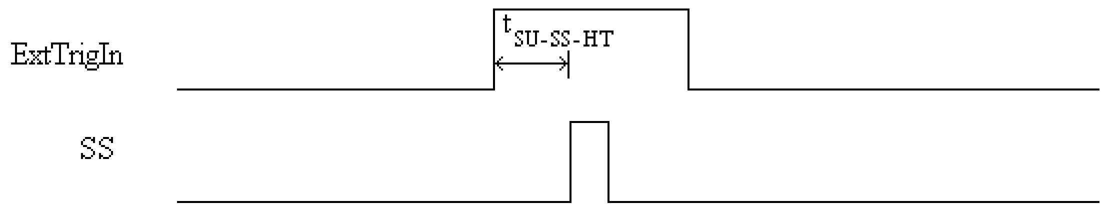
The width and delay of the Single Strobe can be adjusted in 500ns increments. If the delay is set to 0, there is still a setup time between when ExtTrigIn goes HIGH, and when SS goes HIGH. This setup time is defined as $0<t_{SU\_SS\_HT}<0.6\mu s$. If the delay is set to something larger than 0 (which can be controlled by the user through the software interface), then the actual delay is the set delay plus 0 – 0.6µs. So, for example, if the delay is set to 50µs, the SS will begin between 50µs and 50.6µs after ExtTrigIn goes high.

The timing diagram for the Single Strobe in Normal or External Synchronization Trigger mode is shown below:



Single Strobe (Normal or External Synchronization Trigger Mode)

Similar to the Single Strobe signal in External Hardware Trigger mode, the width and delay of the Single Strobe in Normal or External Synchronization mode can be adjusted in 500ns increments. If the delay is set to 0, there is still a setup time between when SH goes LOW, and when SS goes HIGH. This setup time is negative, and is defined as $(-7.5\mu s<t_{SU\_SS}<-9.5\mu s)$. If the delay is set to something larger than 0, then the actual delay is the set delay minus t_{SU_SS}. So, for example, if the delay is set to 50µs, the SS will begin between 40.5µs and 42.5µs after SH goes LOW.



Continuous Strobe

The Continuous Strobe signal is a programmable frequency pulse-train (50% duty cycle). The range of frequency is 100µs to 60s. The pulse 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.

Operational Modes

The HR4000 supports four triggering modes, which are set with the Trigger Mode command. A detailed description of each triggering mode follows.

Normal Mode

In the Normal (Free-run) mode, the spectrometer will acquire back-to-back spectra based on the integration period specified. After the Integration Cycle completes, the data is read out of the detector and written into an internal FIFO where it is available for reading. In parallel to this read/write operation, another integration is occurring. If the data from the FIFO is completely read before the parallel integration completes, a back-to-back operation will occur. If the data is not read (FIFO Empty) in this time period, the FPGA will generate an Idle Cycle which is equivalent to one integration period and the data from the detector is discarded. After the Idle Cycle has completed, the FIFO Empty status is checked. If the FIFO is empty and a new spectrum is requested by the software, a new acquisition will begin. If either condition is false, additional Idle Cycles will be generated until both conditions are true.

Shutter Mode

Shutter Mode is always invoked when the specified integration period is less than 3800 microseconds. Back-to-back operations are not permitted in this mode because the parallel use of the shutter operation would corrupt the detector data as it is being read. Once the data is retrieved and written into the FIFO, a complete Idle Cycle is executed. As in the Normal Mode, the FIFO Empty and the spectrum request are evaluated to determine what occurs next. Due to the steps required for each acquisition, the minimum time per acquisition will be approximately three times the minimum detector cycle time (3 x 3800 us).

Normal (Shutter) Mode

Normal (Shutter) Mode is a hybrid operation which combines the Normal Mode Integration Cycle with the Detector Reset Cycle that is used in all Trigger Modes. This combination allows the spectrometer to exhibit the same behavior in a Free-Run mode as it does in the Trigger Modes. In actuality, the Normal (Shutter) Mode is the equivalent of the External Hardware Level Trigger Mode with the trigger input stuck high (logic '1').

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 Cycle specified through the software interface. After the Integration Cycle completes, 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, continuous acquisitions will occur with the following exception. Each subsequent acquisition must wait until a minimum CCD Reset Cycle completes. This Reset Cycle insures that the CCD performance uniform on a scan-to-scan basis. The time duration for this reset cycle is relative to the Integration Cycle time and will change if the integration period is changed. So the timing sequence is Trigger, Trigger Delay, Integration Cycle, Read/Write Cycle, Reset Cycle, Idle Cycle(s), and Integration Cycle (if trigger is still high). The Idle Cycle will on last 2 µs if the trigger remains high and the FIFO is empty and a spectrum request is active, otherwise the Idle Cycle will continue until all 3 conditions are satisfied.

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 Cycle specified through the software interface. After the Integration Cycle completes, the spectrum is retrieved and written to the FIFO in the FPGA followed by a CCD Reset Cycle. Only one acquisition will be performed for each External Trigger pulse, no matter what the pulse's duration is. The Reset Cycle insures that the CCD performance uniform on a scan-to-scan basis. The time duration for this reset cycle is relative to the Integration Cycle time and will change if the integration period is changed. So the timing sequence is Trigger, Trigger Delay, Integration Cycle, Read/Write Cycle, Reset Cycle, and Idle Cycle(s). The Idle Cycle will until the next trigger occurs.

Analog Output

The HR4000 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 HR4000 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 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(min) = 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 **U**niversal **S**erial **B**us 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 HR4000 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 HR4000 to be a standalone device, which can output data to other logic devices/controllers such as a PLC or microcontroller. The HR4000 requires an external 5-Volt power source when operating in RS-232 mode.

I^2C

Inter-**I**ntegrated **C**ircuit 2-Wire serial BUS is widely used in embedded systems applications. With I^2C you can add peripherals to your system without using valuable resources like I/O ports.

HR4000 USB Port Interface Communications and Control Information

Overview

The HR4000 is a microcontroller-based Miniature Fiber Optic Spectrometer that can communicate via the Universal Serial Bus or RS-232. This section contains the necessary command information for controlling the HR4000 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 HR4000. Only experienced USB programmers should attempt to interface to the HR4000 via these methods.

Hardware Description

The HR4000 utilizes 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 E^2PROM that are loaded at boot-up via the I^2C 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 HR4000 can have 2 Product ID's depending upon the EEPROM configuration. In the case where the code is loaded from the EEPROM the PID is 0x1012. The microcontroller allows for the code to be loaded from the host processor (Re-numeration), in this case the PID is 0x1011.

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 HR4000 through End Point 1 Out (EP1). All spectra data is acquired through End Point 2 and 6 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

EP2 Command Byte Value	Description	Version
0x01	Initialize HR4000	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^2C Read	0.90.0
0x61	General I^2C 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

EP2 Command Byte Value	Description	Version
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 HR4000 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 HR4000

Initializes certain parameters on the HR4000 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 HR4000 integration time in microseconds. The value is a 32-bit value whose acceptable range is 10 – 65,535,000us. If the value is outside this range the value is unchanged. For integration times less than 655,000us, the integration counter has a resolution of 10us. 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 HR4000 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 HR4000 shutdown mode. When shutdown, 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 I^2C 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 – HR4000 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	…
0x05	Configuration Index	ASCII byte 0	ASCII byte 1	…

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 HR4000 will acquire a complete spectrum (3840 pixel values). The data is returned in bulk transfer mode through EP2 and EP6 depending on the USB Communication Speed. 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 (12Mbps) is shown below. All pixel values are 16 bit values which are organized in LSB | MSB order. There is an additional packet containing one value that is used as a flag to insure proper synchronization between the PC and HR4000.

USB High Speed (480Mbps) Packet Format

In this mode the first 2K worth of data is read from EP6In and the rest is read from EP2In. The packet format is described below.

Packet #	End Point	# Bytes	Pixels
0	EP6In	512	0-255
1	EP6In	512	256-511
2	EP6In	512	512-767
3	EP6In	512	768-1023
4	EP2In	512	1024-1279
5	EP2In	512	1280-1535
…	EP2In	512	
14	EP2In	512	3584–3840
15	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	
119	EP2In	64	3808–3839
120	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 HR4000 Trigger mode to one of three states. If an unacceptable value is passed then the trigger state is unchanged (Refer to the HR4000 manual for a description of the trigger modes).

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 I^2C addresses 2 through 7 respectively. The I^2C addresses are reserved for various categories of devices and the value for each category is shown below. I^2Caddresses 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^2C address 2	Value @ I^2C address 3	…	Value @ I^2C address 7	0x00

Detect Plug-ins

Reads all of the plug-in accessories that are plugged into the I^2C bus. No data values are returned.

Byte Format

Byte 0
0x0D

General I^2C Read

Performs a general purpose read on the I^2C 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 I^2C 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^2C Address	Bytes to Read

Return Byte Format

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

I^2C Result Value	Description
0	I^2C bus Idle
1	I^2C bus Sending Data
2	I^2C bus Receiving Data
3	I^2C bus Receiving first byte of string
5	I^2C bus in waiting for STOP condition
6	I^2C experienced Bit Error
7	I^2C experience a Not Acknowledge (NAK) Condition
8	I^2C experienced successful transfer
9	I^2C 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	I²C Address	Bytes to Write	Data Byte 0	…	Data byte N

Return Byte Format

Byte 0
I²C Results

Write Register Information

Most all of the controllable parameters for the HR4000 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 (i.e. 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
0x00*	Set Master Clock Counter Divisor. Master Clock freq = 48MHz/Divisor	12	1	0xFFFF
0x04	FPGA Firmware Version (Read Only)			
0x08	Continuous Strobe Timer Interval	10 (100 Hz)	0	0xFFFF
0x0C	Continuous Strobe Base Clock. Divisor operates from 48MHz Clock	48000 (1KHz)	0	0xFFFF
0x10*	Integration Period Base Clock Base Freq = 48MHz	480 (10us)	0	0x0FFF
0x18*	Integration Clock Timer	600 (6ms)	0	0xFFFF

Register	Description	Default Value	Min Value	Max Value
0x20*	Shutter Clock (contact OOI for info)	N/A	0	0x0FFF
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
0x2C&*	Trigger Mode 1 = External Synchronization 2 = External Hardware Trigger	0	0	2
0x30	Reserved			
0x38	Single Strobe High Clock Transition	1	0	0x0FFF
0x3C	Single Strobe Low Clock Transition	10	0	0x0FFF
0x40	Strobe Enable	0	0	0x0001
0x48	GPIO Mux Register (0 = pin is GPIO pin, 1 = pin is alternate function)	0	0	0x03FF
0x50	GPIO Output Enable (1 = pin is output, 0= pin is input)	0	0	0x03FF
0x54	GPIO Data Register For Ouput = Write value of signal For Input = Read current GPIO state	0	0	0x03FF
0x58	Reserved			
* - 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 HR4000 (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 HR4000 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:

Temperature (^{o}C) = .003906 * 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 used 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

Writes 60 bytes of data used 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
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 Mpbs)
15	Reserved	

Appendix A

HR4000 Serial Port Interface Communications and Control Information

Overview

The HR4000 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 HR4000 via the RS-232 interface.

Hardware Description

Overview

The HR4000 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 HR4000 can store up to 4 spectra in the spectral data section. The full spectra (3840 points) is stored. Spectra are organized in a stack formation (i.e. LIFO). Its important to realize that the spectral math (averaging and boxcarring) 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 commands is 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).

In the ASCII data value mode, the HR4000 "echoes" the command back out the RS-232 port. In binary mode alldata, 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
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 HR4000 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 HR4000 should be compressed to speed data transfer rates. For more information on HR4000 Data Compression, see Technical Note 1.

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 HR4000'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 HR4000'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 HR4000'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 HR4000's baud rate.

Command Syntax:	K{DATA WORD}
Value:	0=2400 1=4800 2=96003=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 3669 (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 HR4000'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. 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 in this mode and the data values are terminated with a carriage return (ASCII 13) or linefeed (ASCII 10). In this mode the HR4000 "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 HR4000 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 HR4000 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 – 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 – HR4000 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 second ASCII character corresponds to the command character which sets the parameter of interest (acceptable values are B, A, I, K, T, J, y). A special case of this command is ?x (lower case) which requires an additional data word bee 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 HR4000 may become out-of-synch with the controlling program. It is good practice to cycle power on the HR4000 when errors occur.
- If you question the state of the HR4000, you can transmit a space (or another non-command) using a terminal emulator. If you receive a NAK, the HR4000 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: HR4000 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 HR4000 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 HR4000 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 HR4000. 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

Pixel Value	Value Difference	Transmitted Bytes
383	262	0x80 0x01 0x7F
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: HR4000 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: HR4000 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.