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QE65000 Data Sheet

Description

The Ocean Optics QE65000 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 QE65000 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 QE65000 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 QE65000.

The detector used in the QE65000 spectrometer is a scientific-grade, back-thinned, TE Cooled (TEC), 1044x64 element CCD array from Hamamatsu (product number S7031-1006). For complete details on this detector, visit **www.Hamamatsu.com**.

The QE65000 operates from power provided through the USB (without TEC operation), or from a separate + 5VDC power supply. The QE65000 is a microcontroller-controlled spectrometer, thus all operating parameters are implemented through software interfacing to the unit.

Features

- ❑ Hamamatsu S7031-1006 Detector:
  - Peak QE: 90%
  - Back-thinned for good UV sensitivity
  - MPP operation for low noise operation
  - TE Cooled
- ❑ Spectrometer Design:
  - Symmetrical Crossed Czerny Turner
  - 101mm focal length
  - 14 gratings (H1 – H14)
  - 6 slit widths
- ❑ Electrical Performance:
  - 16 bit, 500KHz A/D Converter
  - Integration times from 8ms to ~10 minutes
- ❑ Embedded microcontroller allows programmatic control of all operating parameters and standalone operation:
  - USB 2.0 480Mbps (high-speed) and 12Mbps (full speed)
  - RS232 115Kbaud
  - Multiple Communication Standards for digital accessories (SPI, I2C)
- ❑ TE Cooler
  - Software-controlled set-point
  - Temperature stability: <0.1℃
  - Maximum cooling 40℃ below ambient
- ❑ 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
- ❑ 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
Physical Specifications:	
Physical Dimensions (LxWxH)	185 mm (7.28 in.) x 115 mm (4.53 in.) x 50 mm (1.97 in.)
Spectrometer Weight	1.18 kg (2.6 lbs.)
Power Supply Weight	0.45 kg (1 lb.)
Power:	
Power requirement	500 mA at +5 VDC (no TE Cooler) 3.5A at +5V (with TE Cooler)
Supply voltage	4.5 – 5.5 V
Power-up time	~2s depending on code size
Absolute Maximum Ratings:	
V_{CC}	+ 5.5 VDC
Voltage on any pin	Vcc
Spectrometer:	
Design	Symmetric crossed Czerny-Turner
Focal length (input)	F/4 101mm
Input Fiber Connector	SMA 905 to single-strand optical fiber (0.22 NA)
Gratings	14 different gratings (H1 – H14)
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	Hamamatsu S7031-1006
Pixels	1024 x 58 (total pixels 1044 x 64)
Pixel size	24.6µm square
Active area	24.576 x 1.392mm
Spectral range	200 – 1100nm with window (see etalon section). VUV option available (150nm). VUV option includes purge port & window removal (no TE Cooling)
Quantum efficiency	90% peak (see figure following this table)
Well Depth	Individual pixel: 300K electrons; Column summing well: ~1.5M electrons
Dark Current	4000 e/pixel/sec (typ) @ 25° C; 200 e/pixel/sec (typ) @ 0° C
Filters	6 OF Series available
Spectroscopic:	
Integration Time	8ms – 15 minutes
Dynamic Range	2500:1 single integration period, 7.5×10^9 over integration range
Signal-to-Noise	1000:1 single acquisition
Dark Noise (single dark spectrum)	2.5 counts RMS
Readout Noise	1.5 counts RMS (40 electrons)
Linearity	~1% max. nonlinearity (uncorrected); <0.5% nonlinearity (corrected)

| Specifications	Criteria

Environmental Conditions:
 	
  Temperature
 	
  Humidity
	
	–30° to +70° C Storage & –0° to +50° C Operation
	TE Cooler can only cool 40° C below ambient
	0% – 90% noncondensing

Interfaces:
  USB
  RS-232
	
	USB 2.0, 480 Mbps
	3-wire RS-232
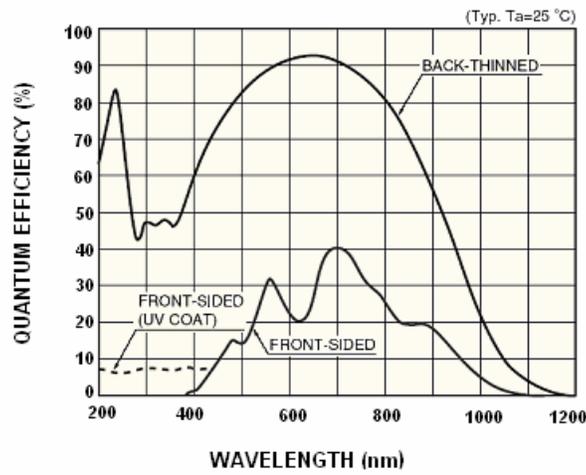
Quantum Efficiency of Detector

QE65000 Sensitivity

The QE65000 contains a back-thinned detector that has up to 90% peak UV Quantum Efficiency (QE). The graph in the following figure shows the overall sensitivity of the HR2000 & QE65000 for the UV & Visible range. The raw scope mode signals are normalized to the full-scale saturation level under the same acquisition settings. From this data it may appear that the HR2000 has better sensitivity than the QE65000. However, it's important to factor in the well depth differences.
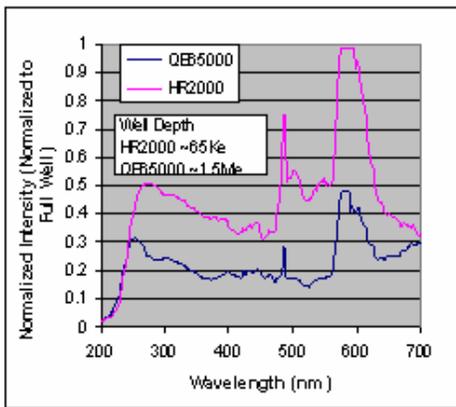
Normalized Scope mode comparison between
QE65000 and HR2000. Spectra is of a
DH2000 lamp taken at 5ms for the HR2000
and 10ms for the QE65000. This integration
time difference has been factored into the data.

The graph below shows the total charge collected by the CCD in terms of electrons. While at first this may seem like a strange way to compare the overall sensitivity, it provides a good comparison between the two detectors. Basically the QE65000 has the good S/N of a deep well device but the sensitivity of a shallow well device. The sum total is a 10-30X increase in total signal collected.
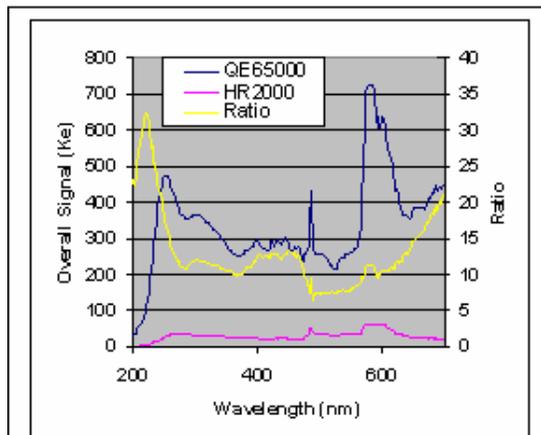
Sensitivity comparison between QE65000 and
HR2000 showing total signal collected. The
QE65000 has good S/N and great sensitivity. The
ratio of the two curves is plotted in yellow on the
left axis.

Optical Performance

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

QE65000 Optical Performance for 600 LPM Grating & 5nm Slit

QE65000 Optical Performance for 1200 LPM Grating and 5um Slit

QE65000 Optical Performance for 1800 LPM Grating and 5um Slit

QE65000 Optical Performance for 2400 LPM Grating and 5um Slit
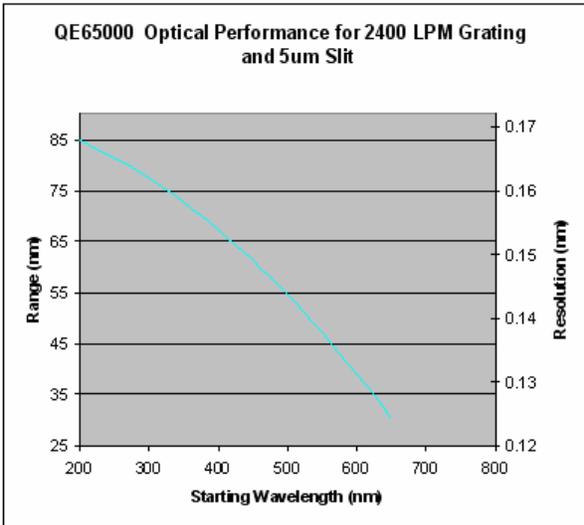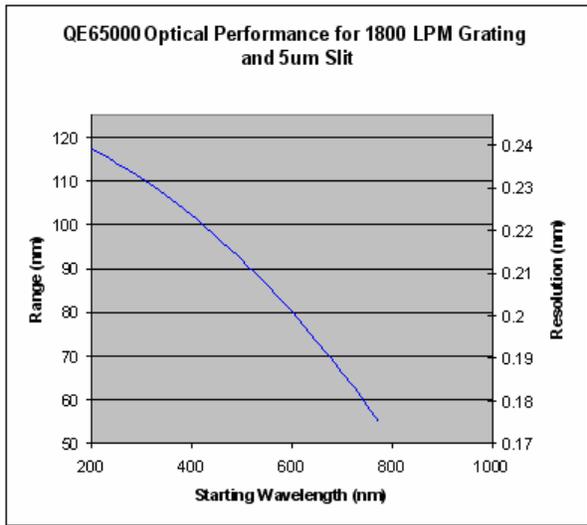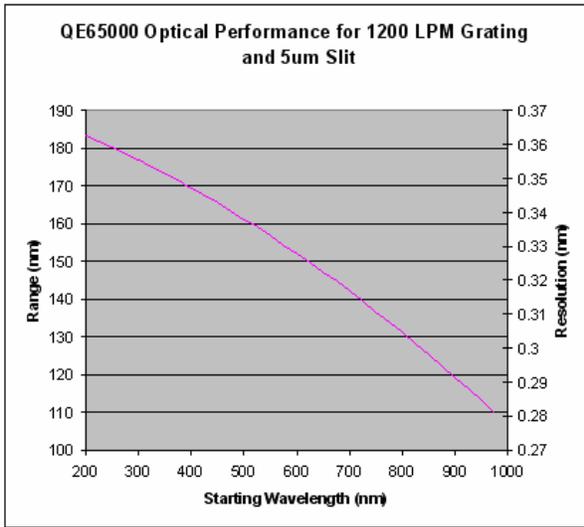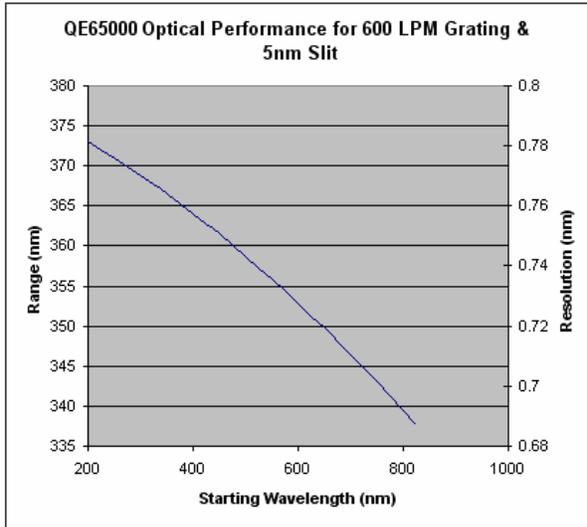
The following table shows the resolution for various slit sizes.

|		5	10	25	50	100	200
				Slit			
				Pixel Resolution Factor			
Grating	Avg Range	2	2.2	2.6	3.3	4.6	8.9
300	750	1.46	1.61	1.90	2.42	3.37	6.52
600	360	0.70	0.77	0.91	1.16	1.62	3.13
1200	150	0.29	0.32	0.38	0.48	0.67	1.30
1800	90	0.18	0.19	0.23	0.29	0.40	0.78
2400	70	0.14	0.15	0.18	0.23	0.31	0.61

QE65000 Resolution (nm)

QE65000 Etalon Effect

As with many detectors, the QE65000 has top layer passivations that create an etalon effect. This effect is most easily seen when broadband light is introduced into the optical bench as shown in the figure below. Due to tight process control at the detector manufacturer, the etalon effect occurs in the 800-1000nm range. This effect is stable and "normalizable" as long as the detector temperature is constant between the reference and sample spectra. To effectively eliminate this effect, the user must do the following:

- Run the TE Cooler to stabilize the detector temperature
- Use Absorbance, Transmission or Relative Irradiance modes in the software (not raw Scope mode)
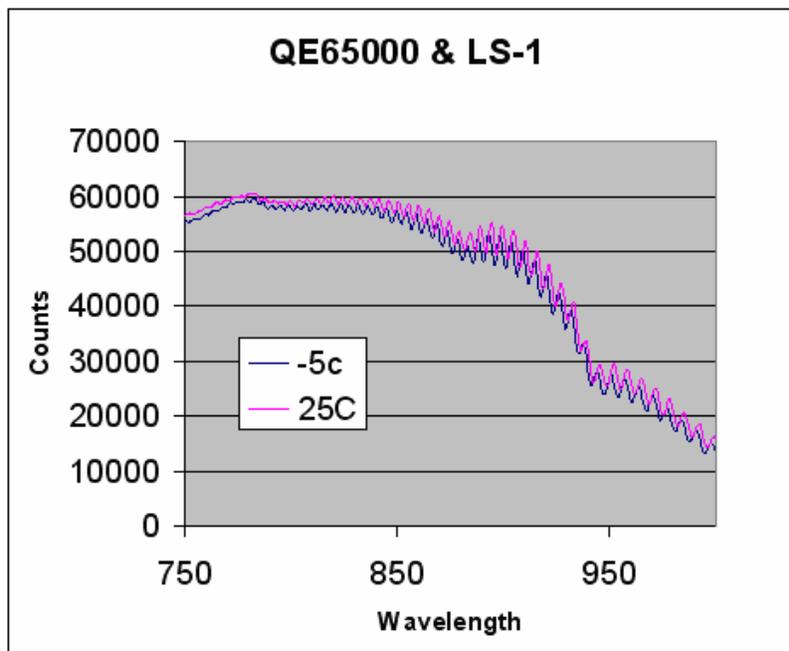
Electrical Pinout

Listed below is the pin description for the QE65000 Accessory Connector (J3) located on the front vertical wall of the unit. The connector is a Pak50TM 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 orientation

              2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
              1 3 5 7  9  11 13 15 17 19 21 23 25 27 29

         USB Port Looking at Front of QE65000
```
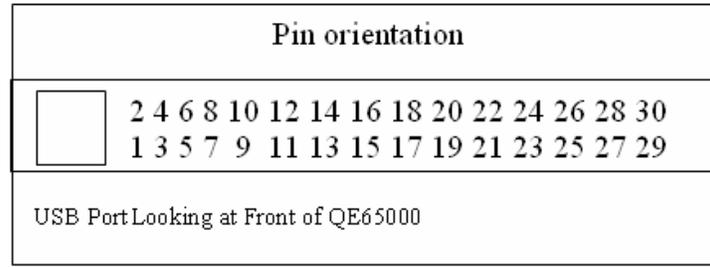
Pin #	Function	Input/Output	Description
1	RS232 Rx	Input	RS232 receive signal – Communicates with a PC over DB9 Pin 3
2	RS232 Tx	Output	RS232 transmit signal – Communicates with a PC over DB9 Pin 2
3	GPIO (2)	Input/Output	General purpose software-programmable, digital input/output (channel number)
4	N/A	N/A	Reserved
5	Ground	Input/Output	Ground
6	I2C SCL	Input/Output	I2C clock signal for communication to other I2C peripherals
7	GPIO (0)	Input/Output	General purpose software-programmable, digital input/output (channel number)
8	I2C SDA	Input/Output	I2C data signal for communication to other I2C peripherals
9	GPIO (1)	Input/Output	General purpose software-programmable, digital input/output (channel number)
10	Ext. Trigger In	Input	TTL input trigger signal
11	GPIO (3)	Input/Output	General purpose software-programmable, digital input/output (channel number)
12	VCC or 5VIN	Input or Output	Input power pin for QE65000 – When operating via USB, this pin can power other peripherals – Ensure that peripherals comply with USB specifications (no TEC power)
13	SPI Data Out	Output	SPI Master Out Slave In (MOSI) signal for communication to other SPI peripherals
14	VCC or 5VIN	Input or Output	Input power pin for QE65000 – When operating via USB, this pin can power other peripherals – Ensure that peripherals comply with USB specifications (no TEC power)

Pin #	Function	Input/Output	Description
15	SPI Data In	Input	SPI Master In Slave Out (MISO) signal for communication to other SPI peripherals
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 – 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)
19	SPI Clock	Output	SPI clock signal for communication to other SPI peripherals
20	Continuous Strobe	Output	TTL output signal used to pulse a strobe – Divided down from the master clock signal
21	SPI Chip Select	Output	SPI Chip/Device Select signal for communication to other SPI peripherals
22	GPIO (6)	Input/Output	General purpose software-programmable, digital input/output (channel number)
23	N/A	N/A	Reserved
24	N/A	N/A	Reserved
25	Lamp Enable	Output	TTL signal 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)

Mechanical Diagram

NOTES: (UNLESS OTHERWISE SPECIFIED)
1. ALL MOUTING HOLES ARE 4-40UNC-2B THREAD.
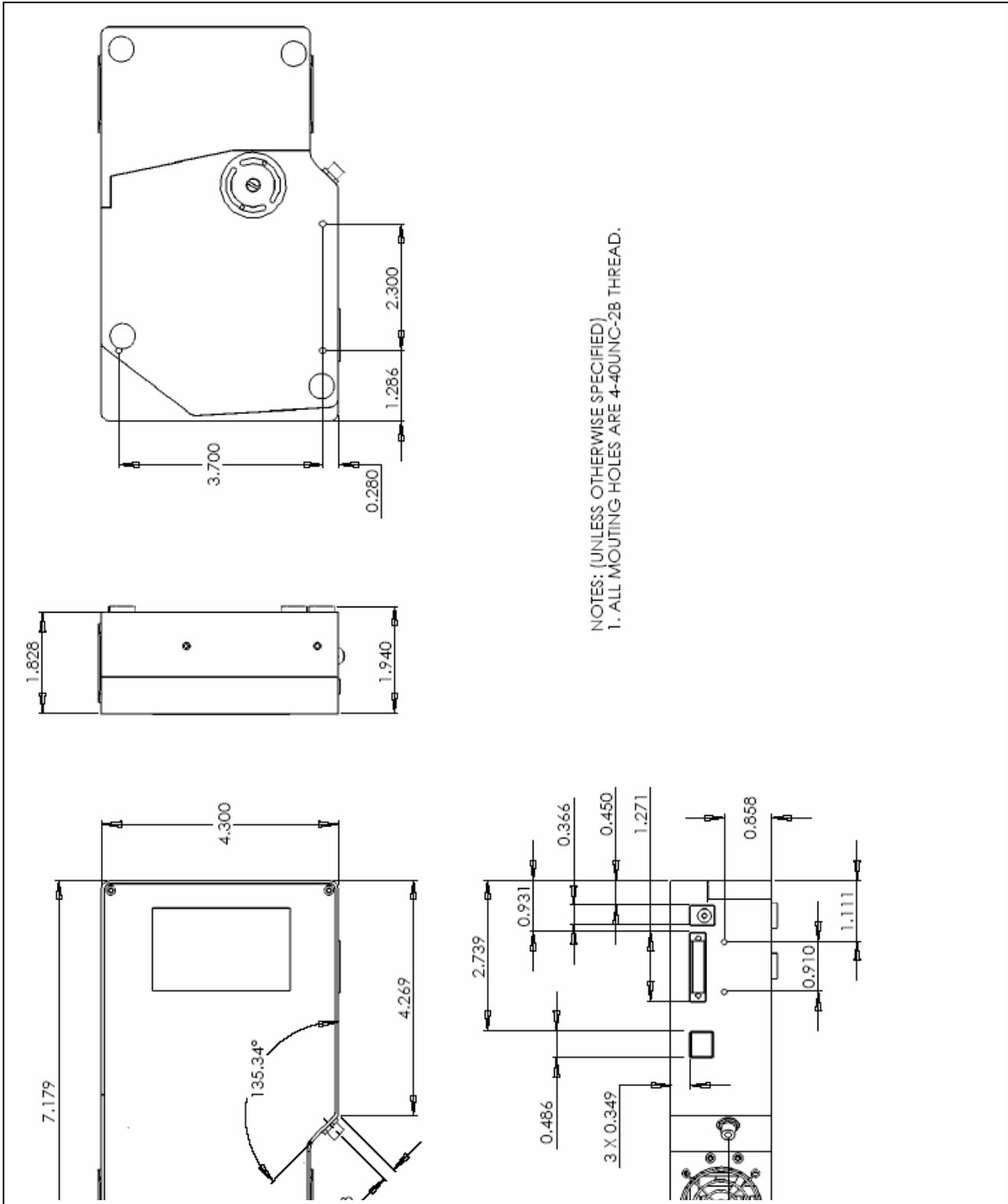
QE65000 Pixel Definition

The QE65000 contains a Hamamtsu S7031-1006 CCD which is a two dimensional CCD. The QE65000 electronics only support reading out the device as a 1-D array (e.g. all rows are summed together on chip). The structure of the S7031 CCD is shown in figure 9. The device has 1024 x 58 active pixels and a total of 1044 x 64 pixels. While the pixels are digitized in the order shown in the diagram, they are rearranged depending on the interface (USB or RS232). The pixel order is shown below.

	USB Interface	RS232 Interface
Total Transmitted Values	1280 WORDS which contains 1044 pixels followed by 0's	1044 Values which contain 1044 pixel value
Pixel order	10 Blank & Bevel Pixels (first 10) 1024 Active Pixels 10 Blank & Bevel Pixels (last 10)	1024 Active Pixels 10 Blank & Bevel Pixels (last 10) 10 Blank & Bevel Pixels (first 10)
Notes: Order is rearranged by OOI drivers to be: 1024 Active Pixels 10 Blank & Bevel Pixels (last 10) 10 Blank & Bevel Pixels (first 10)		
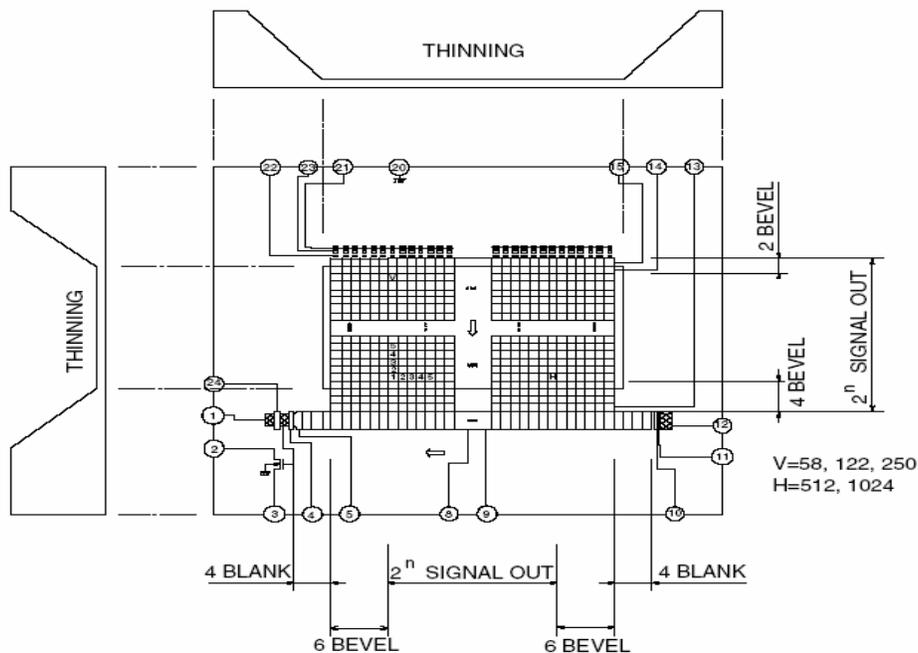
QE65000 CCD Device structure. The device has 58 active vertical pixels and 1024 active horizontal pixels.

QE65000 TEC Cooler

The QE65000 contains a TE cooled CCD and the electronics to driver it. The drive electronics were designed to only cool the device (no heating possible) and were optimized to generate the best cooling possible. The cooling range of the TE Cooler and electronics provides cooling for 30-43°C below ambient. Thus for an ambient temperature of 23°C, the cooling range is -7 to -20°C. The TE Cooler setpoint is user programmable in increments of 0.1^{o}C over this range.

QE65000 Trigger/Acquisition Modes

The QE65000 supports 4 Trigger/Acquisition modes including the standard free running mode. Unfortunately the CCD does not have any means to instantly reset all of the pixels in microseconds, so the typical external hardware and external synchronization modes are not supported. However since the external hardware trigger mode is widely utilized, a close equivalent has been implemented. This mode is called Quasi-External Hardware Trigger and is available in firmware versions from 2.20.0 and later. The various modes are described below.

- **Free Running Acquisition Mode**: In this mode, the CCD is constantly being driven at the user specified integration time. When a spectra is requested via software, the QE65000 electronics wait for the current integration period to expire. Then at the start of the next integration period, they readout the CCD which contains the data for photons which were collected by the CCD in the previous integration period.

- **Software Trigger Mode**: This mode is basically the same as the Free Running Mode, except that the on-board microcontroller waits for the External Trigger line to be HIGH before it start the acquisition process.

- **External Synchronization Mode**: Not Supported

- **Quasi-External Hardware Trigger Mode**: In this mode, the CCD is running as fast as possible at an integration time of 8ms. Once a spectra is requested, the QE65000 waits for the External Trigger Input to be HIGH. Once this is detected, it waits for the current integration period to expire, then switches to the desired integration period. Once this expires, it switches back to an integration period of 8ms and reads-out the CCD. In this mode the maximum integration time is 65,534ms. This mode is only supported in firmware versions 2.20.0 and later

- **Quasi-RealTime Acquisition Mode**: In this mode, the CCD is running at a moderately fast integration period of 150ms. When a spectra is requested, it waits for the current period to expire and then switches to the desired integration time. When that completes it switches back to 150ms and reads out the CCD. This mode is similar to the Quasi External Hardware Trigger mode except that no trigger signal is required and its maximum integration time is 1600sec.

QE65000 USB Port Interface Communications and Control Information

The QE65000 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 QE65000 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 QE65000. Only experienced USB programmers should attempt to interface to the QE65000 via these methods.

Hardware Description

The QE65000 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 Info

Ocean Optics Vendor ID number is 0x2457 and the Product ID is 0x1018.

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 QE65000 through End Point 1 Out (EP1). All spectra 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	Hi 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 QE65000	0.90.0
0x02	Set Integration Time	0.90.0
0x03	Set Strobe Enable Status	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
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 QE65000 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 QE65000

Description: Initializes certain parameters on the QE65000 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

Description: Sets the QE65000 integration time in milliseconds. The value is a 32-bit value whose acceptable range is 8 – 16,000,000ms (1600s or 26.67min). If the value is outside this range the value is unchanged. For integration times less than 655,000ms, the integration counter has a resolution of 1ms. For integration times greater than this the integration counter has a resolution of 25ms.

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

Description: Sets the QE65000 Lamp Enable line (J2 pin 25) 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 = !0 ➔ Lamp Enable HIGH/On

Byte Format

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

Query Information

Description: Query's 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. 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 info #1: gg fff sss
gg – Grating #, fff – filter wavelength, sss – slit size
16 –  QE65000 configuration info #2: Detector Serial Number
17 – Reserved
18 – Power up Baud Rate Value
19 – User Defined
```

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

Description: 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

Description: Initiates a spectra acquisition. The QE65000 will acquire a complete spectra (1280 data values). The data is returned in bulk transfer mode through EP2. The table below provides the pixel order for the two 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 QE65000.

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	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	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	
39	EP2In	64	1248-1279
20	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

Description: Sets the QE65000 Trigger mode to one of three states. If an unacceptable value is passed then the trigger state is unchanged (Refer to the QE65000 manual for a description of the trigger modes)

Data Value = 0 ➔ Normal (Free running) Mode
Data Value = 1 ➔ Software Trigger Mode
Data Value = 2 ➔ Not Supported
Data Value = 3 ➔ Quasi-External Hardware Trigger Mode
Data Value = 4 ➔ Quasi Real-time acquisition Mode

Byte Format

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

General I^{2}C Read

Description: Performs a general purpose read on the I^{2}C 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^{2}C 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

Description: 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

General SPI Input/Output

Description: Performs a general-purpose write and read on the SPI bus 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 SPI bus runs at ~25KHz Clock. The maximum number of bytes that can be written or read is 61. During this transfer the SPI Chip Select signal is driven to an active LOW TTL level. Data is transmitted out the MOSI (Master Out Slave In) line on the rising edge of the clock signal. Data is also latched in the from the MISO line on the falling edge of the clock signal.

Command Byte Format

Byte 0	Byte 1	Byte 2	Byte 3	…	Byte N+2
0x62	# of Bytes (N)	Write Byte 0	Write Byte 1	…	Write Byte N

Return Byte Format

Byte 0	Byte 1	Byte 2	Byte 3	…	Byte N+1
# of Bytes (N)	Read Byte 0	Read Byte 1	Read Byte 2	…	Read Byte N

TEC Controller

Description: All of the TEC controller commands are read and written using this command. The TEC controller is implemented using a separate microcontroller. 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 LSB | MSB order. Almost all temperature values are signed WORD values expressed in 10^{ths} of a degree C. Thus, -12.5°C would be represented by a value of -125. This command requires 200µs to complete; the calling program needs to delay for this length of time before issuing another command.

Command Byte Format

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

Register Value	Description	Default Value	Min Value	Max Value
0x02	Read current TEC temperature. Temperature in 10^{ths} of a degree C.	NA	−500	500
0x10	TEC Enabled/Disabled 0 = Disabled 1 = Enabled	0	0	1
0x40	Get TEC setpoint temperature in 10^{ths} of a degree C.	NA	−500	500
0x80	Write TEC setpoint temperature in 10^{ths} of a degree C.	−100	−500	300

To set the TEC setpoint to −9ºC (or -90 tenths is 0xFFA6), the following command by bytes would be issued 0x6a 0x80 0xFF 0xA6.

Write Register Information

Description: Most all of the controllable parameters for the QE65000 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 Address	Description	Default Value	Min Value	Max Value	Time Base
0x00[*]	Master Clock Counter Divisor	6	1	0xFFFF	48MHz

Register Address	Description	Default Value	Min Value	Max Value	Time Base
0x04	FPGA Firmware Version (Read Only)				
0x08	Continuous Strobe Timer Interval Divisor	48000	0	0xFFFF	Continuous Strobe Base Clock (see Register 0x0C)
0x0C	Continuous Strobe Base Clock Divisor	4800	0	0xFFFF	48MHz
0x10*	Integration Period Base Clock Divisor	1000	0	0xFFFF	1MHz
0x14	Set base_clk or base_clkx2 0: base_clk 1: base_clkx2	1	0	1	N/A
0x18*	Integration Clock Timer Divisor	10	0	0xFFFF	Integration Period Base Clock (see Register 0x10)
0x20*	Reserved				
0x28	Reserved				
0x2C&*	Reserved				
0x30	Reserved				
0x38	Single Strobe High Clock Transition Delay Count	1	0	0xFFFF	1MHz
0x3C	Single Strobe Low Clock Transition Delay Count	5	0	0xFFFF	1MHz
0x40	Lamp Enable	0	0	1	N/A
0x48	GPIO Mux Register 0: pin is GPIO pin 1: pin is alternate function	0	0	0x03FF	N/A
0x50	GPIO Output Enable 1: pin is output 0: pin is input	0	0	0x03FF	N/A
0x54	GPIO Data Register For Ouput: Write value of signal For Input: Read current GPIO state	0	0	0x03FF	N/A

Register Address	Description	Default Value	Min Value	Max Value	Time Base
0x58	Reserved				
0x60	Bit*(0) => Fan Enable 1: enables fan 0: disables fan	1	0	1	N/A
	Bit*(1) => Reserved DO NOT MODIFY	0	0	1	N/A
	Bit*(2) => Reserved DO NOT MODIFY	1	0	1	N/A
	Bit*(3) => Reserved DO NOT MODIFY	0	0	1	N/A
	Bit*(4) => Reserved DO NOT MODIFY	0	0	1	N/A

Notes: * - User should not change these values because spectrometer performance can be effected. This information is included just for completeness

& - These values are controlled by other command interfaces to the QE65000 (i.e Set integration time command).

Read Register Information

Description: 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

Description: Read the Printed Circuit Board Temperature and the heat sink temperature. The QE65000 contains two DS1721 temperature sensor chips—one of which is mounted to the main PCB and the other which is mounted close to the heat sink. This command is sent to End Point 1 Out and the data is retrieved through End Point 1 In. The values returned are two signed 16-bit A/D conversion value which is equated to temperature by:

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

Byte Format

Byte 0
0x6C

Return Format (EP1In)

Byte 0	Byte 1	Byte 2
Read Result for PCB Temperature	ADC Value LSB	ADC Value MSB
Byte 3	**Byte 4**	**Byte 5**
Read Result for Heatsink Temperature	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

Description: 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

Description: 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

Description: 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 Spectral Data Values – WORD(s)	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 !0 – Signal HIGH
7	Trigger Mode Value	
8	Spectral Acquisition Status	For internal use
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:

QE65000 Serial Port Interface Communications and Control Information

Overview

The QE65000 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 QE65000 via the RS-232 interface.

Hardware Description

The QE65000 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 E^2PROM, which are loaded at boot-up via the I^2C bus.

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 QE65000 "echoes" the command back out the RS-232 port. In ASCII data mode the device transmits a prompt ">" to show that is waiting for acommand. 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
B	Set Pixel Boxcar	2.00.0
C	Tec ON/OFF	2.00.0
D	Tec Setpoint	2.00.0
E		
F		
G	Set Data Compression	2.00.0
H		
I	Sets integration time(16-bit resolution)	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	Initialize Spectrometer	
R	Display Tec Current Temperature	2.00.0
S	Starts spectral acquisition with previously set parameters	2.00.0
T	Sets trigger mode	2.00.0
U		
V		
W	Write to FPGA Register	2.00.0
X		
Y		
Z		
a	Set ASCII mode for data values	2.00.0
b	Set binary mode for data values	2.00.0
i	Set integration time(32-bit resolution)	2.00.0
k	Sets Checksum mode	2.00.0
v	Provides microcode version #	2.00.0

Letter	Description	Version
x	Sets calibration coefficients	2.00.0
t	Reads the Board's temperature Degrees C	2.00.0
?	Queries parameter values	2.00.0

Command Descriptions

A detailed description of all QE65000 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

Description: Sets the number of discrete spectra to be summed together. The number of

Command Syntax:	A{DATA WORD}
Response:	ACK or NAK
Range:	1-65000
Default value:	1
Response:	ACK or NAK

Pixel Boxcar Width

Description: 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
Response:	ACK or NAK

Turn TEC Cooler ON/OFF

Turns TEC on or off. If turned on , the TEC is driven to the set point value.

Command Syntax:	C{DATA WORD}
Response:	ACK or NAK
Range:	0-1
Default value:	1
Response:	ACK or NAK

TEC Cooler Temperature Setpoint Degrees C°

Sets the TEC cooler temperature. The value passed is the temperature in tenths of a degree C.

Command Syntax:	D{DATA WORD}
Response:	ACK or NAK
Range:	-7 to –20 (Format is X10 e.g. –10C = -100)
Default value:	-10
Response:	ACK or NAK

Set Data Compression

Description: Specifies whether the data transmitted from the QE65000 should be compressed to speed data transfer rates. For more information on QE65000 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
Response:	ACK or NAK

Integration Time

Description: Sets the QE65000's integration time, in milliseconds, to the value specified. This command is limited to a 16 bit value. If a larger integration time is required, utilize the 32 bit version (lower case I command)

Command Syntax:	I{16 bit DATA WORD}
Response:	ACK or NAK
Range:	10 – 65,535
Default value:	10

Integration Time(32-Bit)

Same as above command(I) but uses 32-bit values.

Command Syntax:	i{DATA DWORD}
Value:	10 - 1600000000
Response:	ACK or NAK
Default value:	10

Lamp Enable

Description: Sets the QE65000's Lamp Enable line to the value specified

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

Baud Rate

Description: Sets the QE65000'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　　　7=230,400
Response:	See below
Default value:	2

When changing baud rates, the following 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

---

Notes

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

The power-up Baud rate can be set by setting the EEPROM Memory slot to the desired value (i.e., 6 for a value of 115,200 Baud)

Pixel Mode

Description: 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}	
Value:	Description 0 = all 1024 pixels 1 = every nth 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 1023 (denoted p1, p2, … p10)	Example P 0 (spaces for clarity only) P 1<Enter> N<Enter> P 2<Enter> N<Enter > 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	

Note

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.

Read TEC Cooler Temperature in Degrees C°

Description: Returns the current temperature of the TEC Cooler.

Command Syntax:	R
Response:	ACK followed by {DATA WORD}
Default value	If stable then should reflect Setpoint. If not repeated R commands will show progression to setpoint temperature.

Spectral Acquisition

Description: 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 16Bit or 32Bit Flag. If 1 then DWORDS transmitted for spectral data values

WORD Add Scans

DWORD integration time in Milliseconds

WORD ALWAYS 0

WORD pixel mode

WORDs if pixel mode not 0, indicates parameters passed to the Pixel Mode command (P)

WORDs/DWORDs spectral data

WORD 0xFFFD – end of spectrum

Trigger Mode

Description: Sets the QE65000's external trigger mode to the value specified.

Trigger Mode 4:   This mode is called "Quasi-Real Time Acquisition" mode. In this mode we run the integration clock at a quick rate (150ms in the case of the QE65000). Once an acquisition is requested by the controller, the hardware waits until the current integration period expires and changes it to the desired rate which is typically much longer (i.e. many seconds). Once this integration period has expired, the integration time is changed back to the default rate and the detector is readout. In this mode, no external signal is required.

Command Syntax:	T{DATA WORD}
Value:	0 = Normal – Continuously scanning 1 = Software trigger 2 = Not Supported 3 = Quasi External Hardware Trigger 4 = Quasi Real Time acquisition
Response:	ACK or NAK
Default value:	0

Write FPGA Register

Description: Writes a value to an FPGA Register. The register map is defined in the USB command set section.

Command Syntax:	W{Register Address: WORD}{Register Value: WORD}
Value:	
Response:	ACK or NAK
Default value	N/A

Note

To query a register value, issue ?W{Register Address}.

ASCII Data Mode

Description: 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 QE65000 "echos" the command and data values back ou the RS-232 port.

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

Notes

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 QE65000 is in the ASCII data mode.

Binary Data Mode

Description: 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

<div align="center">

Note

</div>

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

Description: Specifies whether the QE65000 will generate and transmit a 16-bit checksum of the spectral data. This checksum can be used to test the validity of the spectral dat, 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

Description: 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

Read Board Temperature

Returns the PCB temperature followed by the heatsink temperature in Degrees 100th's C. Response will x100 e.g. 25C = 2500

Command Syntax:	t
Value:	None
Response:	ACK followed by {DATA WORD}{DATA WORD}
Default value:	N/A

Calibration Constants

Description: 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 – QE65000 configuration: AWL V A – Array coating Mfg, W – Array wavelength (VIS, UV, OFLV), L – L2 lens installed, V – CPLD Version 17 – Reserved 18 – Startup Baud Rate value 19 – Reserved
Response:	ACK or NAK
Default value:	N/A

Note

To query the constants, use the ?x{DATA WORD} format to specify the desired constant. To query all coefficients issue ?x-1 command.

Query Variable

Description: 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 parenthesis. For clarity, the commands are shown in the ASCII mode (a command) instead of the default binary mode.

The desired operating conditions are: acquire every 4th pixel from the spectrometer with a 200ms integration time, set number of scan to add to 5 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)

A2<CR> (Add 5 spectra)

I200<CR> (Set integration time to 200ms)

P1<CR> (Pixel Mode 1...

4<CR> every 4 pixels)

> S (Acquire spectra)

… Repeat as necessary

Application Tips

- During the software development phase of a project, the operating parameters of the QE65000 may become out-of-synch with the controlling program. It is good practice to cycle power on the QE65000 when errors occur.

- If you question the state of the QE65000, you can transmit a space (or another non-command) using a terminal emulator. If you receive a NAK, the QE65000 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

     Click OK in Port Settings and in Properties dialog boxes.

Technical Note 1: QE65000 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 QE65000 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 QE65000 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.
3. If the byte is equal to 0x80, the next two bytes are taken as the pixel value (16-bit **unsigned** integer).
4. 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.
5. Repeat step 2 until all pixels have been read.

Using this data compression algorithm greatly increases the data transfer speed of the QE65000. 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: QE65000 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, 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

Data Value	Value Difference	Transmitted Bytes	Value added to Checksum
87	-2	0xFE	0x00FE
89	2	0x02	0x0002
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.