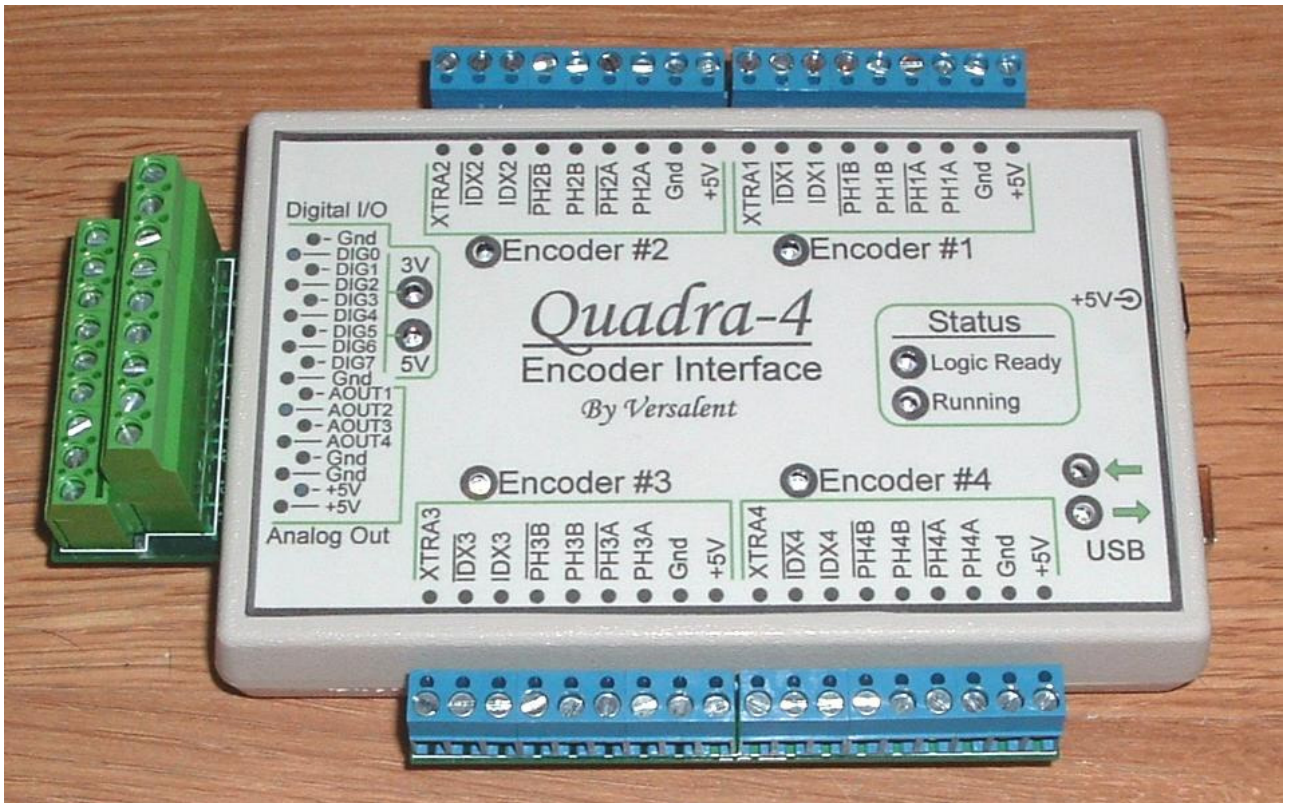


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## QUADRA-4 USB Quadrature Encoder Interface Manual

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## **General Description**

Quadra-4 provides a PC with USB feedback from 4 quadrature encoders, as well as 4 analog outputs to drive associated servos to provide the PC with 4 axes of servo control. This allows you to use the simple PID loop software provided by Versalent, or write your own to implement higher-order loops to optimize your servo system. Eight digital I/Os are included for use as motion limit switches, reference position markers or for other general use. Multiple Quadra-4s can be connected to the same PC to provide more servo axes.

This small module (6.5" x 4.5" x 1.7") connects to a host computer via a USB 1.1 or 2.0 compliant Full-Speed (12Mbps) connection. The encoders can be single-ended or differential phase signal types with an optional index signal. Each interface utilizes a 32-bit up/down counter which can be configured to reset upon receipt of an index pulse-edge, or to simply store the counter value when the index edge occurs. Analog hysteresis followed by digital filtering of the encoder signals prevents chatter from corrupting the position counters.

Quadra-4 also provides 4 analog output signals which are generated by 10-bit DACs that can be used to provide the motor/actuator drive signals in closed-loop servo systems. Each output can be software configured for 0 to 10V, -5V to +5V or -10 to +10V ranges to accommodate a variety of actuator drivers. Even with the widest output range 10-bits provides an output resolution of 20mv. The 8 digital I/Os can be individually configured as input or output.

Each encoder interface can be configured for X1, X2 or X4 multiplication (a count occurs on each edge of each encoder phase) and optional 100 ohm termination resistors may be enabled to terminate the typical impedance of a twisted-pair of differential encoder phase signals to minimize ringing from distant encoders.

External +5VDC power is required to operate the Quadra-4, and the encoders may operate from this 5V power input, or may be powered by an external voltage. (The encoder phase and index inputs will accept up to 12VDC input voltages). As soon as power is applied to the Quadra-4 and the encoders, the internal 32-bit counters begin tracking encoder position. The default encoder multiplication is X4 and all analog output voltages default to zero volts. Once the Quadra-4 enumerates (identifies itself to the USB host) it can be initialized and normal operation can begin – settings will be accepted and encoder positions can be read. The enumeration process takes a couple of seconds from when the Quadra-4 USB cable is connected or power-up.

## Installation

Quadra-4 is installed by simply plugging its cable into a USB host. As a USB HID device, no additional USB drivers are required. A Windows DLL is provided (Quad4.dll) for .NET as well as VB6 usage, and the source code is provided for a simple PID servo loop with independently controllable PID gain parameters. This DLL can be used as part of a production system license-free by referencing it in your own application, or using one of the provided applications. A Quadra-4 Diagnostic application is also provided -- this fully operational program allows you to connect some encoders and see the encoder positions on-screen as well as manually configure any of the Quadra-4's parameters without writing a single line of code. Multi-Axis Demonstration Servo applications are included in both C#.net and VB6 is provided so you can connect your system and see it manage positions, again without writing any code at all.

## Reliability Features

Quadra-4 implements an internal watchdog timer, and an internal brown-out detector. Should its microcontroller get disrupted through static discharge or other temporary interference, the watchdog will automatically reset the unit so that normal operation can resume. All analog output voltages go to zero volts on reset, all counters are reset to 0, encoder multiplication defaults to X4.

## Encoder Power

USB provides up to 500mA for use by attached USB devices, however 4 encoders plus the Quadra-4 typically require more power than this. The Quadra-4 itself requires 150mA for its own operation, and since many encoders require more than that, USB power is typically insufficient and an external power source is needed.

A +5VDC @1A power supply is provided with the Quadra-4 which offers 850mA for encoders (in addition to the 150mA needed by the Quadra-4). If your complement of 5V encoders requires more current than this, or they require a different supply voltage, the encoders should be powered externally (not from the +5V terminals in each group of Encoder 1-4 Interface terminals). To integrate the Quadra-4 into a system which already has 5 volts available, you can connect any of the 5V terminals to your external supply *instead* of using the 5V wall-brick provided. So the 5V terminals become the power-input terminal(s) instead of encoder-power-output terminals. This will power the Quadra-4 from your 5V supply. (There are 5V terminals within each of the Encoder sections, as well as the Digital/Analog I/O section. To supply the 150mA necessary for Quadra-4 operation, connecting your 5V supply to any one of these terminals is sufficient. DO NOT connect both the 5V wall-brick, and an external 5V source to the Quadra-4 – use one or the other).

One terminal in each Interface group is labeled XTRAx (x=1-4). This terminal is not electrically connected to any signals in the Quadra-4, and is provided as a convenient tie-point for non-5volt encoders. See Encoder Connections section below.

## Operational Description

Quadra-4 and its associated software is intended to bring easy servo-loop control to PCs. Once initialized, it transfers encoder position to the PC at the USB signaling rate (1kHz) and accepts analog output updates at this same rate allowing fairly fast servo system feedback/feed forward.

USB imposes some limits to the speed of feedback updates as well as analog drive signal updates. Quadra-4 data is transferred using USB Interrupt transactions, and typically a new 32-bit position will be reported for all encoders every 1 ms (the fastest USB Full-Speed messaging rate). And a new analog servo drive signal is sent at this same rate. This 1 ms rate will be maintained as long as the USB connection has enough bandwidth available, and to ensure that there is, it is recommended that the Quadra-4 not be connected to any USB hub which transfers large amounts of isochronous data. Large bulk transfers are alright since those transfers have the lowest priority and will not interfere with the transfer of position data however isochronous transfers may hog the available bandwidth and interfere with your servo. If you are unsure of what other types of transfers are occurring in your USB 'tree', it is recommended that the Quadra-4 be given a USB port of its own on the host and not be in a 'hubbed' connection sharing bandwidth with other devices. And be aware that many PC compatible computers have a single on-board USB port and provide multiple USB ports through the use of internal hubs on the motherboard.

The operating system (OS) may introduce additional latencies into the position feedback and (analog) feed forward as well. For instance, Windows does not guarantee any particular thread or application servicing time so faster hardware will allow the OS to perform all its required tasks faster and introduce less latency into your readout or servo system. So with a non-deterministic OS, keeping the number of tasks low can minimize this latency. Windows latencies can be fairly short (1ms or less typically) with few tasks running and few demanding devices connected. But servo errors due to these latencies must be considered. For instance, when performing velocity calculations the simplification of assuming that each servo loop takes the same amount of time can speed the calculations, but may not be appropriate to your application. (The Demo applications provided use this simplification).

Quadra-4 synchronizes itself to the USB messaging rate to maintain a consistent read-delay. That is, after a USB message transfer is detected, the Quadra-4 waits 750usec, then samples all encoder positions so that the data is available at 1000usec (1ms) -- when the next USB message-time arrives. So although there is some read-latency in the Quadra-4, it is controlled and fairly constant at 250usec. If the Quadra-4 did not synchronize to the USB messaging rate, there would be a variable 0 to 1ms latency in its readings.

# Physical/Environmental and Electrical Specifications

## Physical and Environmental

Size:	6.5" X 4.5" X 1.75"
Weight:	9 oz
USB Connector:	Standard B-type
Encoder, Digital/Analog I/O Connectors	Screw terminals
Case Color:	Ivory
Temperature Range	0C to +70C
Humidity	< 80% non condensing
AirFlow requirements	none

## Electrical

USB Voltage Input:	Currently not used
USB Current Input:	None – externally powered device
USB Signaling Speed:	12Mbit (Full speed)
External Voltage Input:	+5 VDC +/- 5%
External Current Input:	150mA for Quadra-4 ...(plus encoder current)
Digital Output Current	Source and sink typically 3mA/8mA
Max LOW digital input logic level	1.0V
Min HIGH digital logic level output	When 5 volt Logic Level selected: 4.5v @ 8 mA When 3 volt Logic Level selected: 2.6v @ 3mA
Max digital I/O input current	+/- 50uA (inputs have internal 100k ohm pullup)
Max LOW encoder input level	Applied to non-inverting phase/index inputs: 1.5V Applied to inverting phase/index inputs : 1.0V
Min HIGH encoder input level	Applied to non-inverting phase/index inputs: 2.0V Applied to inverting phase/index inputs: 1.5V
Encoder input impedance (inverting and non-inv inputs)	10k ohms (terminations OFF)
Maximum encoder input frequency	3MHz
Encoder Phase/Index Input Sensitivity	Differential +/- 50 mv ----- Single-Ended Non-Inverting Input: 50mv Above/Below 1.25v Threshold ----- Single-Ended Inverting Input: 50mv Above/Below 1.75v Threshold
Encoder Phase/Index Differential Terminations	ON: nominal 120 ohms (AC termination) OFF: 12pf typical

# Feature Details

## Encoder Counters

Each encoder interface contains a 32-bit up/down counter that increments or decrements as its encoder phases change state. If the counter is incremented when it is already at 0xFFFFFFFF (the maximum 32-bit count) it rolls to 0x0, and if decremented when at 0x0 it rolls to 0xFFFFFFFF. At power-up all counters are reset to 0, however depending on positional references etc, it may be more convenient to have the zero-count occur at some reference position, or have mid-count occur at a reference position so your software does not have to deal with the roll-over anywhere in its travel range. The 2's complement arithmetic will slow calculations and can be avoided with judicious selection of counter referencing. For this reason the counters can be pre-loaded to any value – at any time. So during system initialization you might send a small (open-loop) voltage to the servo driver which will slowly jog/move the servo towards a reference position. When the reference position is detected you could set the associated counter to a convenient mid-range value such that the 32-bit count will never roll-over throughout the travel range.

## Encoder Connections

Encoders are connected using the screw terminals located around the periphery of the module. Each encoder interface has a group of 9 terminals labeled as shown in the table below.

Terminal Position	Terminal Label	Terminal Description
1	+5V	If the encoder can be powered with +5VDC connect its power input here. Power will be supplied by the AC adapter, or an external +5VDC power applied to the I/O connector terminals 17&18
2	Gnd	Encoder Ground should be connected here.
3	PH1A	Encoder Phase A (single-ended or non-inverted differential)
4	/PH1A	Encoder Phase A (inverted differential)
5	PH1B	Encoder Phase B (single-ended or non-inverted differential)
6	/PH1B	Encoder Phase B (inverted differential)
7	INDX1	Encoder Index (single-ended or non-inverted differential)
8	/INDX1	Encoder Index (inverted differential)
9	EXT PWR	Unconnected terminal for use with non-5VDC encoders*

### Notes:

**Terminal Position #1 :** The Quadra-4 requires a 5VDC power source to operate its internal circuits. This is supplied by either connecting the included +5V AC wall-adaptor, or by supplying your system's +5VDC @ 150mA to the I/O terminals 17 & 18 labeled +5V. If the encoders also operate on 5V, and there is sufficient current available for both the Quadra-4 and the complement of encoders, then

connect the encoder power input to this terminal. Current requirement = 150mA + (Number\_Of\_Encoders \* Encoder\_Current).  
(Do not exceed 250mA per encoder when using the Quadra-4 to distribute 5V power to the encoders via Terminal #1).

**Terminal Position #3-8 :** These terminals are inputs to be connected to the encoder's phase and index outputs. For single-ended encoders (non-differential), connect the encoder phase outputs to the associated inverting or non-inverting differential input and leave the alternate input unconnected. (For non-differential encoders, the terminations should be set to OFF). Quadra-4 internally holds (lightly) the inverting inputs at appropriately 1.25 volts, and the non-inverting inputs at approximately 1.75 volts and single-ended encoders may be connected to either input. Choosing the alternate input reverses the apparent direction of the encoder movement. Since the two inputs are held at slightly different voltages, when both inputs are left open, the counters do not move – there is no apparent motion.

**Terminal Position #9:** This terminal is *not connected to the Quadra-4 electronics* and is provided as a convenient power distribution point for non-5V encoders. Example: To connect +15V to an encoder, connect an external +15V supply between Terminal #9 and Terminal #2 (GND), and also connect the encoder's power and ground signals to these same terminals. In this case the current available from the 15V supply must be sufficient for the encoders only since Quadra-4 itself does not use any power from this external supply. Note that a +5VDC supply (either the supplied wall brick, or your system 5VDC) is still required to power the Quadra-4 when using non-5V encoders operating with their own supply voltage.

## Encoder Index Signals

Many incremental encoders provide index signals which can be used as positional reference points. If index signals (single-ended or differential) are connected to the Quadra-4, a set of internal storage registers can be configured to capture the counter value when the index pulse occurs, or clear the associated encoder counter when the pulse occurs. In some motion systems there are external limit switches or optical beams which define a positional reference point. These may be connected to the index signals to cause the counters to be cleared or latched if desired. Alternatively these types of switches may be connected to digital I/O configured as inputs – and your software can pre-load the encoder counters with any desired 32-bit value when this signal occurs. The Index and /Index inputs can accept single-ended, or differential inputs and operate just like the encoder phase inputs. The non-inverting input 'floats' to a reference level of 1.75 volts .. and the inverting input 'floats' to a reference level of 1.25 volts when not driven.

## Encoder Differential Terminations

Differential-output encoders are often used when they are a significant distance away from the Quadra-4. Differential signals are more immune to noise injected from external sources and are typically connected using shielded, twisted-pair cable with an impedance of approximately 120 ohms. The Quadra-4 accommodates this by providing internal 120 ohm termination resistors which can be software enabled (default is OFF). There is only one enable control per encoder interface and when turned ON, it enables 3 termination resistors providing a termination of PhaseA to /PhaseA, PhaseB to /PhaseB and Index to /Index.

The termination used is an AC type which consists of a 120 ohm resistor in series with a 330 pf capacitor across each pair of differential signals. This AC termination has no effect on the DC steady-state signal output levels of the encoder and has no noticeable effect on signal frequencies below about 1 MHz. However it significantly dampens the higher frequency components occurring at the signal edges and reduces the ringing overshoot and undershoot caused by the reflections of an unmatched transmission line.

## Digital I/O Connections

Quadra-4 provides 8 general purpose 3 or 5 volt digital I/O signals for your use. They are individually programmed as input or output, but are programmed as a group to be compatible with either 3V logic, or 5V logic. When 3V is selected, the output high level does not exceed 3.3V and the inputs remain 5V tolerant. And similarly when 5V is selected the output level does not exceed 5V and the input levels remain 5V tolerant. Two LEDs annunciate the logic level selected. When configured as outputs these signals are active pull-up and pull-down (not open collector with passive pullup), and can sink 8mA and source 4mA at valid logic levels. They can sink/source up to 20mA for non-logic-level devices such as LEDs. When configured as inputs the individual bits provide a 'weak' 100k pullup resistor. If the driving source is an open collector type, you should add an external pullup resistor to reduce the signal rise time. Digital I/Os are also connected via the screw terminals provided

Terminal #	Terminal Label	Terminal Description
1	Gnd	Signal Ground
2	DIG0	Digital I/O Bit 0
3	DIG1	Digital I/O Bit 1
4	DIG2	Digital I/O Bit 2
5	DIG3	Digital I/O Bit 3
6	DIG4	Digital I/O Bit 4
7	DIG5	Digital I/O Bit 5
8	DIG6	Digital I/O Bit 6
9	DIG7	Digital I/O Bit 7
10	Gnd	Signal Ground
11	AOUT1	Analog Output #1
12	AOUT2	Analog Output #2
13	AOUT3	Analog Output #3
14	AOUT4	Analog Output #4
15	Gnd	Signal Ground
16	Gnd	Signal Ground
17	+5V	Alternate +5VDC input (instead of power brick), or 5 volt output if using power brick.
18	+5V	Alternate +5VDC input (instead of power brick), or 5 volt output if using power brick.

## Analog Outputs

The four analog outputs are intended to provide the drive signals to your servo system motors/actuators. The voltage range for each can be selected as 0 to +10v, -5v to +5v, or -10v to +10v. The outputs are short-circuit protected and capacitor isolated so they can drive capacitive loads of up to 0.47uf without oscillation. This accommodates shielded cables of moderate length. To maintain the full -10V to +10V output swing it is recommended that the analog outputs be loaded with 10k ohms or greater. The load resistance can be lowered when using the -5v to +5V range, but should never be lower than 2k ohms.

## LED Indicators

Several LED indicators provide some visual indication of the operating state of the Quadra-4. All indicators are green, and some should be ON continuously, or flash continuously, or flash intermittently as described below.

- 1) **Running** - During power-up, while the internal logic/FPGA is being configured, this LED flashes very quickly for ½ to 1 second during that configuration. The flashing then slows to approximately 2 flashes per second and is an indicator that the unit is powered, the internal logic has configured itself, and the Quadra-4 is in an operating state.
- 2) **Logic Ready** - This LED is initially off when the unit is powered-up, however within typically ½ to 1 second the internal logic configures itself and this LED comes on and stays on continuously.
- 3) **3V** - This LED lights to indicate that the Digital I/Os are in the 3V volt logic compatibility mode. It stays on continuously once set to 3V logic mode.
- 4) **5V** - This LED lights to indicate that the Digital I/Os are in the 5V volt logic compatibility mode. It stays on continuously once set to 5V logic mode.
- 5) **Encoder #X** (X=1-4) - This LED flashes briefly each time one of its encoder phase inputs changes state. So when the encoder is moving very slowly it will flash briefly and as the frequency of the encoder phase transitions increases its persistence and brightness increases. It does not depend on which way the encoder is moving, so these LEDs are simply visual indicators of servo/encoder movement, and also provide some indication of relative speed.
- 6) **USB ->** - This LED flashes briefly each time the Quadra-4 reads the encoder positions and makes them available for the host to read. Note that this is independent of the host actually reading the positions, and since this occurs about 1,000 times per second the LED appears to be on continuously.
- 7) **USB <** - This LED flashes briefly each time the host sends a command to the Quadra-4. While holding a servo loop the host will typically send a new servo drive setting at the maximum USB signaling rate (1,000 per second) so this LED will appear continuously ON. However when running the Versalent Diagnostic program it will only flash when the operator manually sends a new setting to the Quadra-4. So the LED will flash periodically.

**Document Revision Record:**

<b>Revision #</b>	<b>Revision Date</b>	<b>Description</b>
V1.00	June 1 , 2008	Initial Release
V1.01	Aug 1, 2009	Add more details.
V1.02	Nov 23, 2009	Change photo, add LED indicators, more operational detail, remove preliminary indicator.
V1.03	Jan 15, 2010	Change photo, add more descriptive detail
V1.04	Mar 12, 2010	Minor changes, add electrical details
V1.05	Apr 9, 2010	Add Table of Contents, minor text updates.