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FlexMotion™
Hardware User Manual

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A Return Material Authorization (RMA) number must be obtained from the factory and clearly marked on the outside of the package before any equipment will be accepted for warranty work. National Instruments will pay the shipping costs of returning to the owner parts which are covered by warranty.

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About This Manual

This manual describes the electrical and mechanical aspects of each board in the FlexMotion family of motion control boards and contains information concerning their operation and programming. Unless otherwise noted, text applies to all boards in the FlexMotion family.

The FlexMotion family of motion control boards includes the following boards:

* PC-FlexMotion
* PCI-FlexMotion

The FlexMotion boards are high-performance motion control boards for ISA and PCI bus computers.

Organization of This Manual

The *FlexMotion Hardware User Manual* is organized as follows:

* Chapter 1, *Introduction*, describes the FlexMotion boards and their operation.

* Chapter 2, *Configuration and Installation*, describes how to configure and install your FlexMotion board.

* Chapter 3, *Hardware Overview*, presents an overview of the hardware functionality on the FlexMotion board.

* Chapter 4, *Functional Overview*, presents an overview of the motion control algorithms and software functionality on the FlexMotion board.

* Chapter 5, *Signal Connections*, describes how to make input and output signal connections directly to the FlexMotion board and briefly describes the associated FlexMotion I/O circuitry.

* Appendix A, *Specifications*, lists the hardware and software performance specifications of the FlexMotion boards.

* Appendix B, *Cable Connector Descriptions*, describes the connector pinout for the cables that connect to your FlexMotion boards.

* Appendix C, *Customer Communication*, contains forms you can use to request help from National Instruments or to comment on our products and documentation.

- The Glossary contains an alphabetical list and description of terms used in this manual, including abbreviations, acronyms, metric prefixes, mnemonics, and symbols.
- The Index contains an alphabetical list of key terms and topics in this manual, including the page where you can find each one.

Conventions Used in This Manual

The following conventions are used in this manual:

< >	Angle brackets containing numbers separated by an ellipsis represent a range of values associated with a bit or signal name—for example, DBIO<3..0>.
☞	This icon to the left of bold italicized text denotes a note, which alerts you to important information.
⚠	This icon to the left of bold italicized text denotes a caution, which advises you of precautions to take to avoid injury, data loss, or a system crash.
⚠	This icon to the left of bold italicized text denotes a warning, which advises you of precautions to take to avoid being electrically shocked.
bold	Bold text denotes the names of menus, menu items, parameters, dialog boxes, dialog box buttons or options, icons, windows, Windows 95 tabs, or LEDs.
bold italic	Bold italic text denotes an activity objective, note, caution, or warning.
FlexMotion CPU	This term refers to the processor on the FlexMotion board.
Host CPU	This term refers to the processor in your host computer.
FlexMotion Software Reference	Unless otherwise noted, this title refers to both the *FlexMotion Software Reference Manual* and the *FlexMotion Software Reference Online Help.*
italic	Italic text denotes variables, emphasis, a cross reference, or an introduction to a key concept. This font also denotes text from which you supply the appropriate word or value, as in Windows 3.*x*.

Related Documentation

The following documents contain information you may find helpful as you read this manual:

- *FlexMotion Software Reference Manual*
- *FlexMotion Software Reference Online Help*
- *PCI Local Bus Specification*, Revision 2.1
- *FlexMotion VI Online Help*
- Your computer's technical reference manual

Customer Communication

National Instruments wants to receive your comments on our products and manuals. We are interested in the applications you develop with our products, and we want to help if you have problems with them. To make it easy for you to contact us, this manual contains comment and configuration forms for you to complete. These forms are in Appendix C, *Customer Communication*, at the end of this manual.

1

Introduction

This chapter describes the FlexMotion boards and their operation.

About the FlexMotion Boards

Thank you for purchasing a FlexMotion motion control board. FlexMotion provides you with advanced motion control performance along with easy-to-use software tools and add-on motion VI libraries for use with LabVIEW and BridgeVIEW.

The FlexMotion line of motion control boards are a combination of servo and stepper motor controllers for ISA and PCI bus computers. These boards provide fully programmable motion control for up to six independent or coordinated axes of motion, with dedicated motion I/O for limit and home switches and additional I/O for general-purpose functions. You can configure up to two of the axes for stepper motor control. You can use these boards for all position and velocity control applications including the following:

- Point-to-point positioning
- Velocity profiling
- 3-D Linear interpolation
- Electronic gearing
- Circular, helical, and spherical interpolation
- Time-based motion integration
- Vector space motion

Servo axes can control servo motors, servo hydraulics, servo valves, and other servo devices. Servo axes always operate in closed-loop mode. These axes use quadrature encoders or analog inputs for position and velocity feedback and provide analog command outputs with an industry-standard range of ±10 V. FlexMotion can also be configured for up to two stepper axes to control stepper motors. These axes can operate in open or closed-loop mode. They use quadrature encoders for position and velocity feedback (closed-loop only), and provide step/direction or clockwise

(CW)/counter-clockwise (CCW) digital command outputs. All stepper axes support full-, half-, and microstepping applications.

FlexMotion's high-performance capabilities are the result of an advanced dual-processor architecture using a Motorola MC68331 real-time 32-bit CPU combined with an Analog Devices ADSP-2111 digital signal processor (DSP) and custom field programmable gate arrays (FPGA). Its first-in-first-out (FIFO) bus interface and powerful function set provide high-speed communications while off-loading complex motion functions from the host PC for optimum command throughput and system performance.

You can use FlexMotion's full onboard programming to execute up to 10 simultaneous motion programs in a preemptive, real-time multitasking operating system environment.

Motion profiles are controlled with enhanced PID/PIVff servo updates at 62 μs per axis and encoder feedback rates up to 16 MHz. Each axis has optoisolated motion I/O for end-of-travel limit and home switch inputs, breakpoint output, and high-speed position capture input. FlexMotion also has non-dedicated user I/O including 24 bits of digital I/O and eight analog inputs for ±10 V signals, providing motion PID feedback for loop closure, joystick inputs, or coarse monitoring of analog sensors.

What You Need to Get Started

To set up and use your FlexMotion board, you will need the following:

❑   One of the FlexMotion boards:
   • PC-FlexMotion
   • PCI-FlexMotion

❑   *FlexMotion Hardware User Manual*

❑   *FlexMotion Software Reference Manual*

❑   One of the following software packages and documentation:
   • LabVIEW
   • LabWindows/CVI
   • BridgeVIEW
   • FlexMotion Software (includes FlexCommander)

❑   Your computer with an available ISA or PCI slot as appropriate.

Software Programming Choices

You have several options to choose from when programming your National Instruments FlexMotion board. You can use National Instruments application software, FlexMotion VIs for LabVIEW and BridgeVIEW, or the FlexMotion software.

Programming the FlexMotion controller board is straightforward using a simple but powerful high-level function set application programming environment (API). All setup and motion control functions are easily executed by calling into either a static or dynamically linked library (DLL). These libraries are callable from C, Visual Basic, and other high-level languages. Full function set implementations are available for LabVIEW, LabWindows/CVI, BridgeVIEW, and other industry-standard software programs.

National Instruments Application Software

LabVIEW and BridgeVIEW, based on the graphical programming language G, feature interactive graphics and a state-of-the-art user interface. In LabVIEW and BridgeVIEW, you can create 32-bit compiled programs and stand-alone executables for custom automation, data acquisition, test, measurement, and control solutions. National Instruments offers the FlexMotion VI Library, a series of virtual instruments (VIs) for using LabVIEW and BridgeVIEW with National Instruments motion control hardware. The Motion VI library implements the full function set API and a powerful set of demo functions, example programs, and fully operational, high-level application routines.

ANSI C-based LabWindows/CVI also features interactive graphics and a state-of-the-art user interface. Using LabWindows/CVI, you can generate C code for custom data acquisition, test, and all measurement and automation solutions. The FlexMotion software includes a series of sample programs for using LabWindows/CVI with National Instruments motion control hardware.

Optional Equipment

National Instruments offers a variety of products to use with FlexMotion boards, including cables, Universal Motion Interfaces (UMIs), nuDrive power amplifier units, and other accessories, as follows:

- Cables and cable assemblies
- UMI wiring connectivity blocks with integrated motion signal conditioning and motion inhibit functionality
- nuDrive, servo motor compatible driver amplifier units with integrated power supply and wiring connectivity
- Connector blocks, shielded and unshielded 50-pin screw terminal wiring aids.

Refer to Appendix C, *Customer Communication*, or visit our online catalog at www.natinst.com for information on how to contact National Instruments for specific information about these products.

Motion Signal and Motion I/O Connections

The external motion I/O connector on the FlexMotion boards is a 100-pin male, right-angle, metal shell-type connector.

The auxiliary 24-bit digital I/O connector is a 50-pin male, box-header connector.

You can use any compatible female mating connector. Mating connector types include insulation displacement ribbon cable connectors and discrete wire female mating connectors.

2

Configuration and Installation

This chapter describes how to configure and install your FlexMotion board.

Host PC Software Installation

Install your FlexMotion software, along with your Motion VI libraries (if appropriate) before you install the FlexMotion board. Refer to the release notes included with your FlexMotion board for specific instructions on the software installation sequence for your host PC.

Board Configuration

There are two types of required configuration to be performed on the FlexMotion boards before they are installed in the host computer—bus-related configuration and motion I/O-related configuration.

The motion I/O-related configuration consists of setting the isolated voltage supply jumpers to configure the optoisolated I/O for internal (non-isolated +5 V) or external isolated (+ISO) supply.

FlexMotion has full optoisolation on the motion I/O signals, but you can forgo the isolation and the need for an external supply by using the computer's internal +5 V supply, to power the I/O circuits. Refer to Chapter 3, *Hardware Overview*, for information on setting the isolated voltage supply jumpers.

The bus-related configuration is different for each bus type (ISA or PCI) of FlexMotion board.

PC-FlexMotion Boards

The PC-FlexMotion boards may occupy any available 16-bit ISA slot in the host computer. The bus communication address of the FlexMotion board is set with a DIP switch located on the board. See Chapter 3, *Hardware Overview*, for more information on setting the address DIP switch. You can

install multiple PC-FlexMotion boards, with different address selections
for each, in the host computer

PCI-FlexMotion Boards

The PCI-FlexMotion board is fully compatible with the *PCI Local Bus
Specification*, Revision 2.1. This compatibility allows the computer to
automatically perform all bus-related configuration and requires no user
interaction. There are no jumpers to configure for bus-related
configuration.

☞ **Note**   *For Windows Users: You can use the Board Configuration Utility to assign a
Board ID and verify the bus address. Use of this utility depends upon the version
of Windows you are using. Refer to the release notes included with your board for
more information.*

Hardware Installation

You can install the FlexMotion board in any open compatible ISA or PCI
expansion slot in your computer. Consider the power available for
expansion boards. Check your system power supply capability to determine
the per slot power budget and the power that each board presently installed
in the system requires. The typical power required for each FlexMotion
board is given in Appendix A, *Specifications*.

The following are general installation instructions, but consult your
computer user manual or technical reference manual for specific
instructions and warnings.

⚠ **Caution**   *FlexMotion boards are sensitive electronic devices shipped in an antistatic bag.
Open only at an approved workstation and observe precautions for handling
electrostatic-sensitive devices.*

1. Write down the FlexMotion board serial number in the *FlexMotion
   Hardware and Software Configuration Form* in Appendix C,
   Customer Communication, of this manual.

2. Turn off and unplug your computer.

3. Remove the top cover or access port to the ISA or PCI expansion slots
   in your computer.

4. Remove the expansion slot connector port cover on the back panel of
   the computer if installed.

5. Insert the FlexMotion board into a +5 V ISA or PCI slot as appropriate. Gently rock the board to ease it into place. It may be a tight fit, but *do not force* the board into place.

6. If available, screw the mounting bracket of the FlexMotion board to the back panel rail of the computer.

7. Replace the cover.

8. Plug in the 100-pin cable for motion I/O to the FlexMotion board.

9. Plug in and turn on your computer.

Your PC/PCI-FlexMotion board is installed.

3

Hardware Overview

This chapter presents an overview of the hardware functionality on the FlexMotion board. The FlexMotion board comes in two versions:

• PC-FlexMotion for ISA bus computers

• PCI-FlexMotion for PCI bus computers

Figures 3-1 and 3-2 show the PC-FlexMotion and PCI-FlexMotion parts locator diagrams.
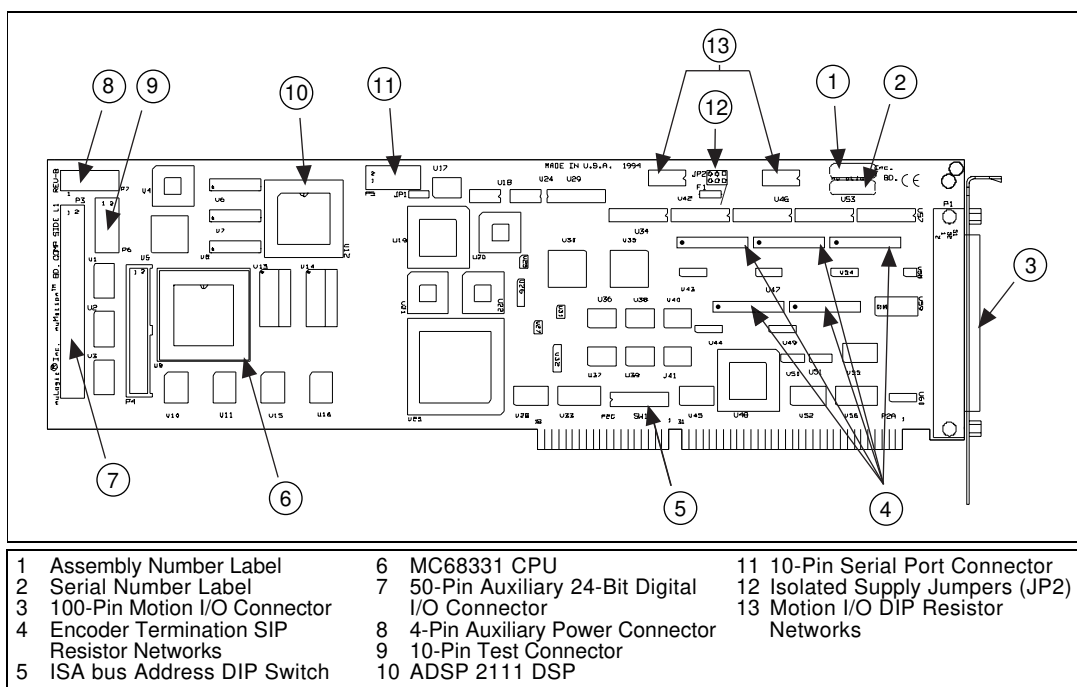

1 Assembly Number Label	6 MC68331 CPU	11 10-Pin Serial Port Connector
2 Serial Number Label	7 50-Pin Auxiliary 24-Bit Digital	12 Isolated Supply Jumpers (JP2)
3 100-Pin Motion I/O Connector	I/O Connector	13 Motion I/O DIP Resistor
4 Encoder Termination SIP	8 4-Pin Auxiliary Power Connector	Networks
Resistor Networks	9 10-Pin Test Connector	
5 ISA bus Address DIP Switch	10 ADSP 2111 DSP	

Figure 3-1. PC-FlexMotion Parts Locator Diagram

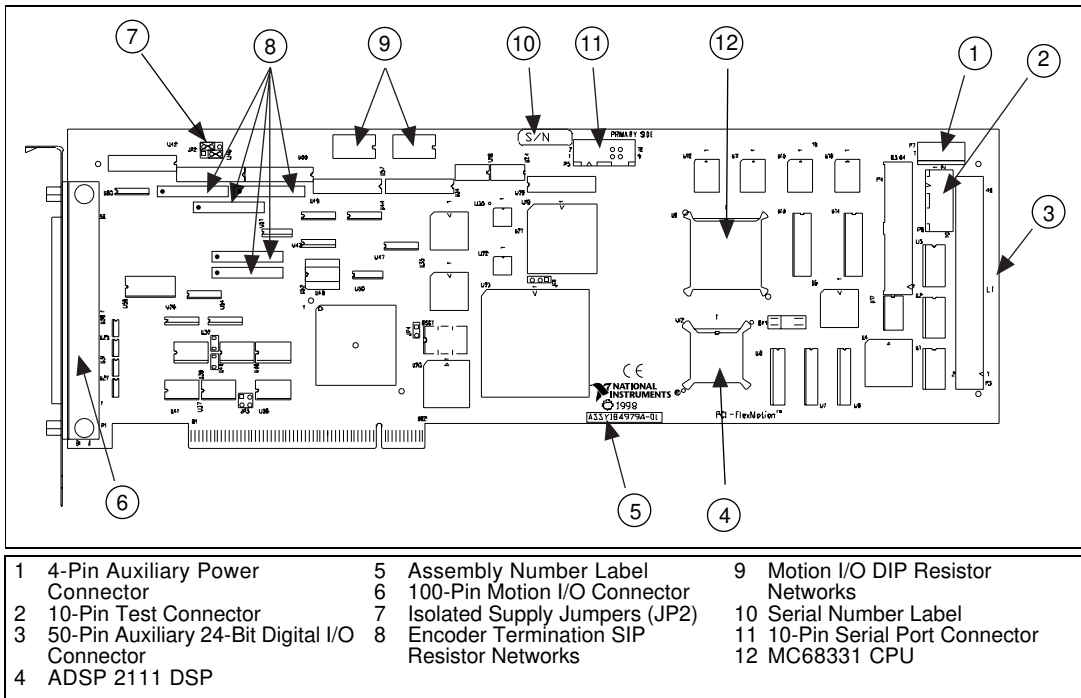|					
1	4-Pin Auxiliary Power Connector	5	Assembly Number Label	9	Motion I/O DIP Resistor Networks
2	10-Pin Test Connector	6	100-Pin Motion I/O Connector	10	Serial Number Label
3	50-Pin Auxiliary 24-Bit Digital I/O Connector	7	Isolated Supply Jumpers (JP2)	11	10-Pin Serial Port Connector
4	ADSP 2111 DSP	8	Encoder Termination SIP Resistor Networks	12	MC68331 CPU

Figure 3-2. PCI-FlexMotion Parts Locator Diagram

User Connectors

The 100-pin motion I/O connector provides all of the signals for the six axes of closed-loop motion control including encoder feedback, limit and home inputs, breakpoint outputs, high-speed capture inputs and A/D converter signals. Refer to Chapter 5, *Signal Connections*, for the complete details of the signals in the motion I/O connector.

The 50-pin auxiliary 24-bit digital I/O connector provides an Opto 22-compatible interface to 24 bits of user-configured digital I/O. Refer to Chapter 5, *Signal Connections*, for the complete details of the signals in the auxiliary 24-bit digital I/O connector.

Reserved Connectors

The 10-pin test connector is a proprietary interface for production testing and troubleshooting. Do not plug anything into this connector.

☞ **Note**   *Misuse of these reserved connectors may seriously damage the FlexMotion board. Unauthorized use of the connectors will void any warranty coverage for the product.*

With the FlexMotion board properly installed, only two connectors are typically used—the 100-pin motion I/O connector and the 50-pin auxiliary 24-bit digital I/O connector. Cables and accessories provide connections to your motion system.

Interface accessories for the FlexMotion family vary from the enhanced Universal Motion Interface (UMI) units with signal conditioning and pluggable screw terminal connectors to simple screw terminal blocks. Available FlexMotion nuDrive units provide pluggable connectors, power supplies, amplifier/drivers, and direct motion system interfacing capabilities.

ISA Bus Address Table (PC-FlexMotion Only)

For backward compatibility with non-Plug-and-Play computers, the PC-FlexMotion board has an onboard DIP switch-selectable address setting. You must set the desired address for all communications with the FlexMotion board prior to inserting the board into the computer.

The ISA bus is designed to support many peripheral device boards as long as all of the boards have different, distinct ISA bus addresses. You must use an address that is not currently used by another board to avoid conflict during host communications and the potential for faulty operation. Set the board address using the DIP switch as shown in Figure 3-1.

Table 3-1 provides a listing of possible base addresses for the PC-FlexMotion, along with the corresponding settings for the address selector DIP switch. All addresses in this table are hexadecimal. Positions 1 through 6 are used for setting the base address. Positions 7 and 8 are used for internal test and must be left off.

Write down the base I/O address that you select and the DIP switch configuration on the FlexMotion Hardware and Software Configuration form in Appendix C, *Customer Communication*. This information will be used for further configuration, board ID verification, and for future reference of this address from software.

⚠ **Caution**   *DIP switch positions 7 and 8 must be off for the PC-FlexMotion to function properly.*

The factory-default base address for your board is 0x3E0, as shown in Figure 3-3.
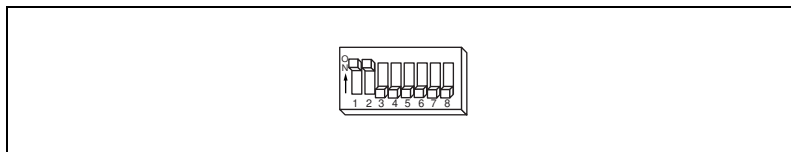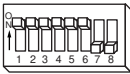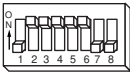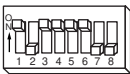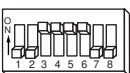

Figure 3-3. Factory-Default DIP Switch Setting

☞ **Notes**   *For Windows 3.1 and DOS Users: Certain addresses that are typically used for host computer functions such as serial and parallel I/O ports and display adapters are indicated in the following list. However, since not all manufacturers use these standards, please verify that an address is truly available and not used before setting the PC-FlexMotion DIP switch to that address.*

For Windows 95 and NT Users: Board address selection is determined by registry control within the operating system. Refer to the release notes included with your FlexMotion board for step-by-step instructions for installing under these operating systems.

Table 3-1. ISA Bus Address Map

Base Address	DIP Switch Address	Typical Use[1]	Base Address	DIP Switch Address	Typical Use[1]
200		Game I/O	258		
208			260		
210			268		
218			270		
220			278		Parallel Port 2
228			280		
230			288		
238			290		
240			298		
248			2A0		
250			2A8		
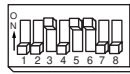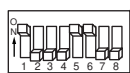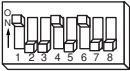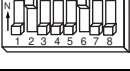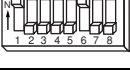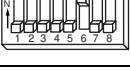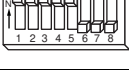
Table 3-1. ISA Bus Address Map (Continued)

Base Address	DIP Switch Address	Typical Use[1]	Base Address	DIP Switch Address	Typical Use[1]
2B0			308		Prototype Card
2B8			310		Prototype Card
2C0			318		Prototype Card
2C8			320		
2D0			328		
2D8			330		
2E0			338		
2E8		Serial Port 4	340		
2F0			348		
2F8		Serial Port 2	350		
300		Prototype Card	358		

Table 3-1. ISA Bus Address Map (Continued)
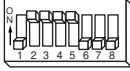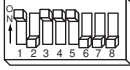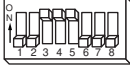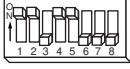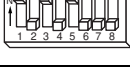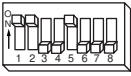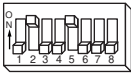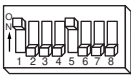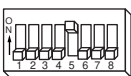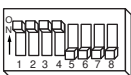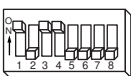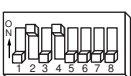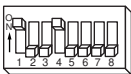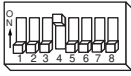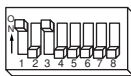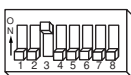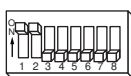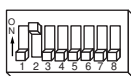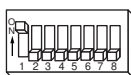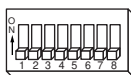
Base Address	DIP Switch Address	Typical Use[1]	Base Address	DIP Switch Address	Typical Use[1]
360		PC Network	3B8		Monochrome/ Printer
368		PC Network	3C0		EGA/VGA Adapter
370			3C8		EGA/VGA Adapter
378		Parallel Port 1	3D0		CGA/MCGA Adapter
380		SDLC/ Bisynchronous	3D8		CGA/MCGA Adapter
388		SDLC/ Bisynchronous	3E0		**Factory Default**
390			3E8		Serial Port 3
398			3F0		Diskette Controller
3A0		Bisynchronous 1	3F8		Serial Port 1
3A8		Bisynchronous 1			
3B0		Monochrome/ Printer			

[1] Blank table cells indicate this base address is typically available for plug-in boards.

Motion I/O Configuration

The FlexMotion board has a number of user-configurable components shown previously in Figures 3-1 and 3-2. You can use these components to tailor and optimize the motion I/O circuits to satisfy specific application requirements. All of these user-configurable components are mounted in sockets for easy replacement in the field. The FlexMotion board ships with an accessory pack that includes an appropriate assortment of single inline package (SIP) and dual inline package (DIP) resistor networks and jumpers.

Selecting an Isolated External/Internal Voltage Supply Configuration

The FlexMotion board provides optoisolation on the motion I/O signals. Isolated I/O reduces noise sensitivity by breaking ground loops and isolating the FlexMotion and host PC's ground from field sensors and external device ground wiring. These optocoupled signals include forward, reverse, and home limit inputs, high-speed capture inputs, breakpoint outputs, and E-Stop input.

Optocoupled signals require a power supply to power the isolation circuits. If your motion system uses optoisolation for limits and/or other motion I/O, it is necessary to supply an external isolated voltage source (+ISO), on the 100-pin connector to power these isolated I/O circuits. Alternatively, you can forgo the optoisolation and set onboard jumpers to use the computer's internal +5 V supply to power the motion I/O circuits. In this case, the motion I/O signals will be non-isolated.

Locating the Isolated Supply Jumper Block JP2

Refer to Figures 3-1 and 3-2 for the location of the isolated supply jumper block (JP). This six-pin jumper block allows you to select between the computer's internal +5 V supply or an external isolated (+ISO) power source for the FlexMotion optocoupled circuitry.

☞ **Note**   *The FlexMotion isolated supply jumpers are factory configured for external isolated voltage source, and motion I/O will not function properly until a +ISO voltage is supplied, or the jumpers are re-configured to use the internal +5 V supply.*

How to Set the Isolated Supply Jumpers (JP2) for Internal +5 V Supply

To use the internal +5 V supply for isolated (+ISO) and isolated return (ISORTN), place the jumpers on jumper block JP2 as shown in Figure 3-4. You must also change DIP resistor networks RP3 and RP10 from 2.2 kΩ to 470 Ω. The appropriate DIP resistor networks are included in the FlexMotion accessory pack that ships with the board.

When changing networks, be careful to install the resistor network with the correct pin 1 orientation. You can then connect your limit and home switches between the limit or home input and the ISORTN (ground-referenced) signals on the 100-pin motion I/O connector.
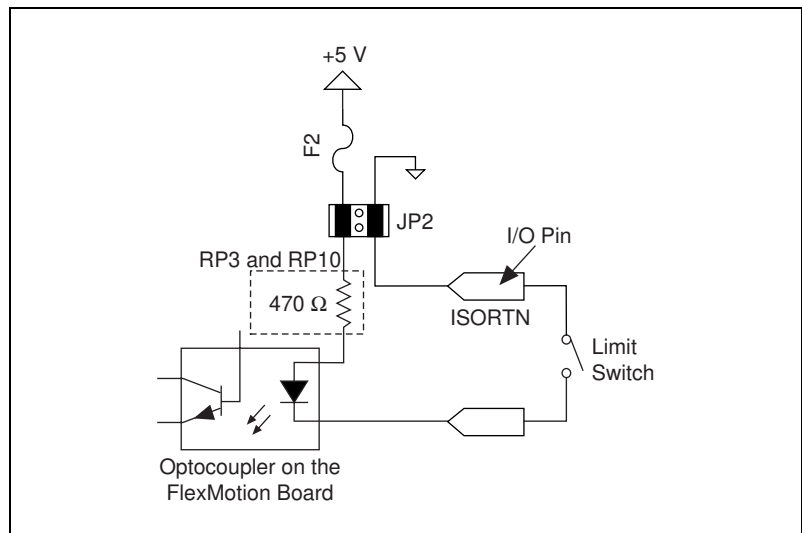
Figure 3-4. Internal +5 V Supply Configuration, Limit Switch Connection Example

⚠ **Caution**   *Do not connect an external voltage source to the +ISO or ISORTN signals on the 100-pin motion I/O connector if you have the jumpers set for internal +5 V supply. When the jumpers are set for internal +5 V, the I/O circuitry uses voltages already present on the FlexMotion board. Improper signal connections can damage the FlexMotion board and void the warranty.*

How to Set the Isolated Supply Jumpers (JP2) for External Isolated Supply (+ISO)

To configure the motion I/O circuits to use an external voltage source for +ISO and ISORTN, place the jumpers on jumper block JP2, as shown in Figure 3-5. The FlexMotion board comes factory configured for +18 to +24 V external isolated supply with DIP resistor networks RP3 and RP10 set at 2.2 kΩ (refer to the following section, *RP3 and RP10 DIP Resistor Networks*, for more information on DIP resistor value and +ISO voltage range selection). Apply a positive voltage (+24V max.) from an external supply to the +ISO input, connect the ISORTN to the external isolated supply return (ground) and connect the limit or home switch between the limit or home input and the ISORTN ground on the 100-pin motion I/O connector.
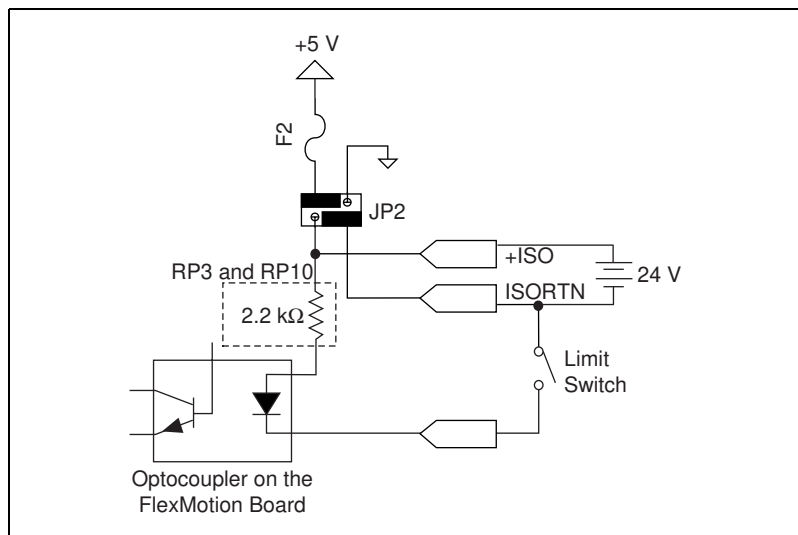
Figure 3-5. External Voltage Supply Configuration, Limit Switch Connection Example

RP3 and RP10 DIP Resistor Networks

The DIP resistor networks RP3 and RP10 provide the current source for the optocoupled inputs and the pull-ups for the optocoupled outputs, as shown in Figure 3-6. One end of these resistors is connected to the +ISO voltage source and the other end is connected to the individual input or output signal, via the optocoupler component.

The correct operating value of these resistor networks depends upon the external isolated supply voltage used. The FlexMotion board ships with

2.2 kΩ networks installed in RP3 and RP10 for use with +24 V external isolated supplies. If a different value is needed, you can change these networks by removing them from their sockets and replacing them with the appropriate value network.

☞ **Note**   *When changing networks, be careful to install the correct resistor network value, for the +ISO voltage supplied, with the correct pin 1 orientation in the socket.*
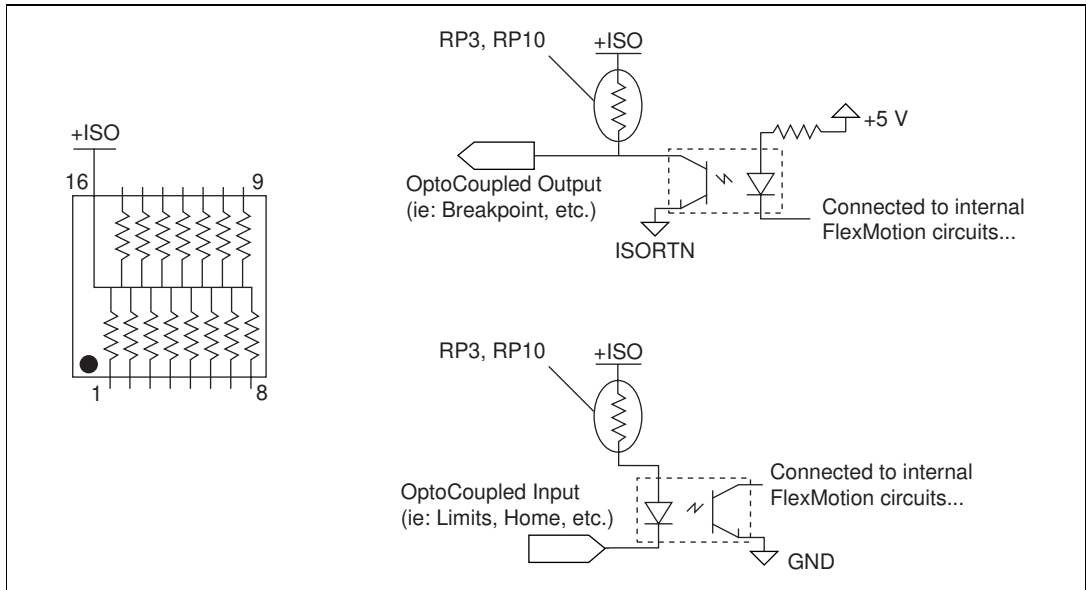
Figure 3-6. Optocoupled Motion I/O DIP Resistor Networks

Table 3-2 shows the correct DIP resistor values for each range of external (and internal) isolated supply voltage.

Table 3-2. Motion I/O Resistor Values

Isolated Supply Voltage	DIP Resistor Network
5 V, Internal	470 Ω
5 to 12 V, External	470 Ω
10 to 18 V, External	1 K Ω
18 to 24 V, External	2.2 kΩ (Factory Default)

☞ **Note**   *The resistor networks used for RP3 and RP10 are 16-pin DIP packages with 15 resistor, bused pull-up networks, Bourns part number 4116R-002-RRR or equivalent (RRR = resistor value).*

Selecting Encoder Termination Networks

FlexMotion offers high-speed differential or single-ended encoder inputs with user-configurable termination for optimum encoder signal performance. The termination is provided by SIP resistor networks RP6, RP8, RP11, RP13, and RP15. These networks are dual-termination networks. The terminated encoder signals are pulled up to +5 V and pulled down to GND through appropriate resistance values, as shown in Figure 3-7.

The recommended values for these terminator resistor SIP networks is dependent upon two primary factors: the maximum frequency of the encoder input signals, and the presence or lack of a differential line driver at the encoder source end. The FlexMotion accessory pack shipped with the board includes appropriate SIP resistor networks.

☞ **Note**   *When changing networks, be careful to install the correct resistor network with the correct pin 1 orientation in the socket.*
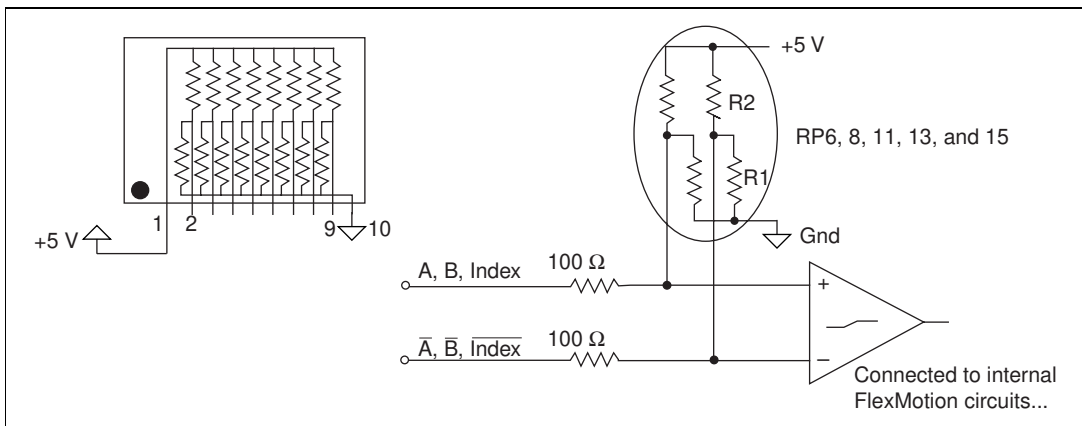
Figure 3-7. Encoder Input Termination SIP Resistor Networks

Table 3-3 lists the recommended termination networks for various encoder types.

Table 3-3. Encoder Termination Resistor Values

Encoder Type	SIP Termination Resistor Network R1/R2
Differential, $\geq$ 1 MHz	180/390 Ω (Factory Default)
Differential, < 1 MHz	1.5/3.3 kΩ
Single Ended	1.5/3.3 kΩ

☞ **Note**   *The resistor networks used for RP6, RP8, RP11, RP13, and RP15 are 10-pin SIP packages with eight channel, dual-termination resistor networks, Bourns part number 4610X-104-RRR/RRR or equivalent (R1/R2 = resistor values).*

4

Functional Overview

This chapter presents an overview of the motion control algorithms and embedded firmware functionality on the FlexMotion board.

Dual Processor Architecture

The FlexMotion board allows you to perform up to six axes of simultaneous, coordinated motion control in a preemptive multitasking, real-time environment.

FlexMotion's high-performance capabilities result from an advanced dual-processor architecture using a Motorola MC68331 real-time 32-bit CPU combined with an Analog Devices ADSP 2111 DSP and custom FPGAs. Its FIFO bus interface and powerful function set provide high-speed communications while off-loading complex motion functions from the host PC for optimized system performance.

FlexMotion uses the digital signal processor for all closed-loop control including position tracking, PID control closed-loop computation, and motion trajectory generation. The DSP chip is supported by custom FPGAs and I/O processors that perform the high-speed encoder interfacing, position capture and breakpoint functions, motion I/O processing, and stepper pulse generation for hard real-time functionality.

The embedded, multitasking real-time CPU handles host communications, command processing, multi-axis interpolation, onboard program execution, error handling, general-purpose digital I/O, and overall motion system integration functions.

Embedded Real Time Operating System (RTOS)

The embedded firmware is based upon the RTXC embedded RTOS kernel for optimum system performance in varying motion applications. Motion tasks are prioritized. Task execution order depends upon its priority, the state of the entire motion system, I/O or other system events, and the real-time clock.

The DSP chip, being a separate processor, operates independently from the CPU but is closely synchronized by an internal packet-based command, data, and messaging event structure. FlexMotion is truly a multiprocessing as well as a multitasking embedded controller.

Enhanced PID Functions

The DSP chip implements an enhanced PID/PIVff closed-loop servo control algorithm. PID update rates are user-programmable and can be as fast as 62 µs per axis. The trajectory generators calculate the instantanous desired position in each PID update period for unsurpassed trajectory control and smoothness. On stepper axes, the DSP chip services the stepper pulse generators each update period, resulting in accurate step pulse frequency outputs.

In addition to the standard PID loop control terms, FlexMotion adds:

- An integration limit value to minimize the effects of integrator windup, by limiting the contribution on the integral sum.
- A derivative sample time multiplier to minimize quantization induced torque noise, and control the effect of the derivative gain.
- Velocity and acceleration feedforward for following error minimization.
- A velocity estimator and feedback gain for improved low-speed smoothness.

FlexMotion also supports dual-loop feedback configurations where the primary sensor is used for position feedback and the secondary feedback is used for velocity estimation and feedback damping.

Note   *Refer to the* Axis and Resource Configuration *section of the* FlexMotion Software Reference*, for more information on enhanced PID and dual-loop feedback functions.*

Trajectory Generators

FlexMotion trajectory generators are responsible for calculating the instantaneous position command that controls acceleration and velocity while it moves the axis to its target position. This command is then sent to the PID servo loop or stepper pulse generator, depending on axis configuration.

To implement infinite trajectory control, FlexMotion has 12 trajectory generators implemented in the DSP chip, two per axis. Each generator calculates an instantaneous position each PID update period. While simple

point-to-point moves require only one trajectory generator, two simultaneous generators are required for unsurpassed blended move and infinite trajectory control processing.

The following sections describe the five primary trajectory types supported by the FlexMotion board.

Trapezoidal Point-to-Point Position Control

Like virtually all motion controllers, FlexMotion implements trapezoidal profile control for point-to-point moves. FlexMotion has enhanced the trapezoidal profile to offer independent acceleration and deceleration value programming and S-curve smoothing (jerk control) of the acceleration/deceleration inflection points.

Motion occurs first with a programmable acceleration (smoothed by the S-curve value), then for a period at a constant velocity (if required) and then with a programmed deceleration, stopping at the desired target position. You can interrupt motion by executing a stop or kill motion function. Motion is automatically halt-stopped if an enabled limit or home input signal becomes active during the move.

☞ **Note**   *Refer to the FlexMotion Software Reference for more information on the programming of trapezoidal trajectory control parameters.*

Velocity Control

Velocity control is a simple variation of trapezoidal position control. The same trajectory generator implements a continuous velocity control mode. If you select this mode, the target position is effectively set to infinity and the axis moves at the programmed constant velocity. You can change velocity on the fly and all existing acceleration, deceleration, and S-curve limits are in effect during the velocity transition. You can interrupt motion by executing a stop or kill function. Motion is automatically halt-stopped if an enabled limit or home input signal becomes active. This mode is useful for jogging moves, simple speed control, and continuous contouring motion applications.

Move Blending

You can use the FlexMotion board to blend moves together with a programmable blend factor. Using the user-defined blend factor, the FlexMotion DSP chip starts a second trajectory generator with the second move on an axis while the first trajectory generator is still decelerating from the previous trajectory move. The two position command outputs are

combined digitally by superposition. You can use FlexMotion's infinite trajectory control processing to automatically and smoothly blend any move type into any other move without stopping the axis or axes involved.

☞ **Note**   *Refer to the* FlexMotion Function Reference *for more information on blending and blend factors.*

Electronic Gearing

With electronic gearing, you can slave both position and velocity on one or more axes to a master position/velocity source for synchronous ratio-based motion. The master can be the feedback of an axis, an independent encoder input or ADC channel, or even the trajectory generator output of another axis.

A slave axis operates in a special mode that calculates an instantaneous position command value that is a ratio of the master position. Since this calculation is completed every PID update, the axis accurately tracks the ratio of the master position velocity. For example, setting a gear ratio of 3:2 results in the slave axis rotating three revolutions for every two revolutions of the master. Each slave axis can have its own gear ratio independent and relative to the master axis.

You can also superimpose any move type on top of the geared slave because its trajectory generators are not used for gearing. Again, the target position command values are combined digitally using superpositon. This very powerful feature allows registration moves in an electronically geared, master/slave system.

☞ **Note**   *Refer to the* FlexMotion Software Reference *for more information on electronic master/slave gearing.*

Linear and Circular Interpolation

You can synchronize and control multiple axes to perform 2D and 3D linear interpolation, 2D circular interpolation, and 3D helical and spherical interpolation.

FlexMotion generates linear interpolated moves by scaling the velocity, acceleration, deceleration, and S-curve values appropriately so that the axes assigned to the 2D/3D move will travel in a straight line in 2D or 3D space and arrive at their target positions simultaneously.

For circular, helical, and spherical arcs, the FlexMotion embedded CPU calculates points along the arc segment, and the DSP performs a cubic

spline algorithm that interpolates between these points. The resulting arc is extremely smooth and accurate with none of the chordal error associated with blended straight line segment approaches.

You can use FlexMotion's infinite trajectory control processing to blend any arc move into another 2D or 3D arc or 2D or 3D vector straight line segment without stopping the axes involved.

☞ **Note**   *Refer to the* FlexMotion Software Reference *for more information on circular, helical, and spherical arcs.*

Analog Feedback

The FlexMotion board provides an eight channel multiplexed, 12-bit ADC. The converted analog values are broadcast to both the DSP and CPU via a dedicated internal high-speed serial bus. The multiplexer scan rates is approximately 50 μs per enabled ADC channel. This provides the high sampling rates required for PID feedback loop closure, joystick inputs, or monitoring analog sensors.

Flash Memory

Non-volatile memory on the FlexMotion board is implemented with Flash ROM. This means that the FlexMotion board can electrically erase and reprogram its own ROM. Since all of the FlexMotion board's embedded firmware, including the RTOS and DSP code, is stored in Flash, you can upgrade the onboard firmware contents in the field for support and new feature enhancement.

Flash memory also allows objects such as programs and data arrays to be stored in non-volatile memory. It is possible to save the entire parameter state of the board with the Save Default Parameters function. On the next power cycle, the FlexMotion board will automatically load and return the configuration to these new saved default values.

The FPGA configuration program is also stored in the Flash ROM. Upon power-up, the encoder FPGA is booted with this program. This means that updates to the FPGA program can be performed in the field.

A Flash memory download utility is included with the FlexMotion software, that ships with the board.

Axes, Motion Resources, and Vector Spaces

FlexMotion can control up to six axes of motion. The axes can be completely independent, simultaneously coordinated, or mapped in multidimensional groups called vector spaces. You can also synchronize vector spaces for multi-vector space coordinated motion control.

Axes

At a minimum, an axis consists of a trajectory generator, a PID or stepper control block, and at least one output resource, either a DAC output or a stepper pulse generator output. Servo axes must have either an encoder or ADC channel feedback resource. Closed-loop stepper axes also require a feedback resource, open-loop stepper axes do not. These axis configurations are shown in Figures 4-1 and 4-2.

With FlexMotion, you configure an axis with the Configure Axis Resources function. This action will map one or two feedback resources and one or two output resources to the axis. An axis with its primary output resource a stepper output is by definition a stepper axis. An axis with its primary output resource a DAC is by definition a servo axis.
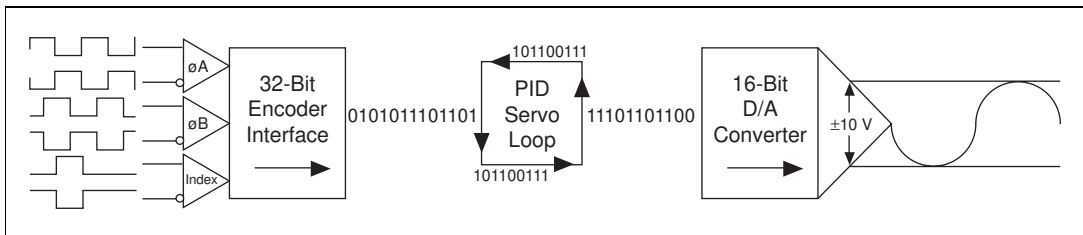
Figure 4-1. Servo Axis Resources
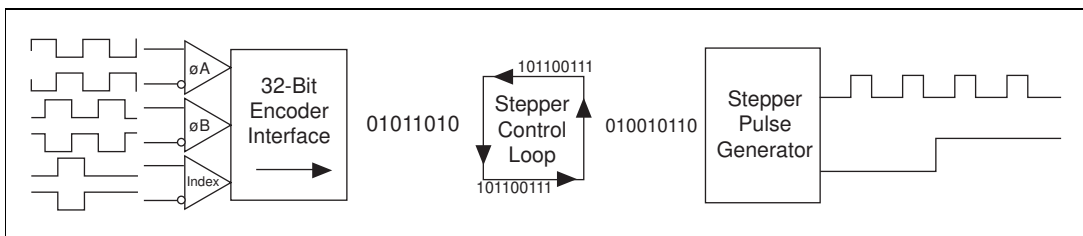
Figure 4-2. Stepper Axis Resources

In its default configuration, FlexMotion comes preconfigured as six servo axes with Encoder 1 and DAC 1 mapped to Axis 1, Encoder 2 and DAC 2

mapped to Axis 2, and so on through axis 6. However, it is simple for advanced users to map any feedback and output resource to any axis. This flexibility allows you to tailor each axis to accommodate your specific motion system requirements.

☞ **Note**   *For many servo applications, the factory-default mapping of encoders and DACs to axes will meet your typical system requirement.*

Available feedback resources are Encoder <1..6> and ADC <1..8>. Available output resources are DAC <1..6> and Stepper <5..6>.

Axes use the dedicated motion I/O signal lines assigned to them. A forward and reverse limit input, a home input, and an inhibit output are dedicated to each axis. Since there are six identical sets of these motion I/O signals, mapping is not required. If the motion I/O is not needed by the axis, you can reuse the signals as general-purpose I/O by disabling their indicated function.

FlexMotion supports axes with optional secondary feedback resources (encoders or ADCs) and/or secondary output resources (DACs or stepper outputs). Two feedback resources are used when implementing dual-loop control. Defining two output resources is useful when controlling axes with multiple motors, such as gantry systems where two DAC outputs can be configured with different torque limits and/or offsets.

☞ **Note**   *Refer to the* Axis and Resource Configuration *section of the* FlexMotion Software Reference*, for more information on configuring axes.*

Motion Resources

Encoder, DAC, and ADC resources that are not used by an axis are available for non-axis or non-motion specific applications. You can directly control an unmapped DAC as a general-purpose analog output (±10 V). Similarly, you can use any ADC channel to measure potentiometers or other analog sensors.

If an encoder resource is not needed for axis control, you can use it for any number of other functions including, position or velocity monitoring, as a digital potentiometer encoder input or as a master encoder input for master/slave, and electronic gearing applications.

Four of the six encoders feature high-speed capture inputs and breakpoint outputs. These features are implemented in the encoder processor FPGA and are fully functional when an encoder is used as feedback to an axis, or as an independent input resource.

👉 **Note**   *Once mapped to an axis, all features and functions of a resource are available as part of the axis. It is not necessary to remember or use the resource number directly when accessing these features. Resources are referenced by axis number once assigned to that axis.*

Vector Spaces

Vector spaces are logical, multidimensional groups of axes. They can be either single-dimensional, two dimensional with x and y axes, or three dimensional with x, y, and z axes. FlexMotion supports up to three, separate one or two-axis vector spaces (or two, three-axis vector spaces) defined at the same time.

Figure 4-3 shows a single three-axis vector space.
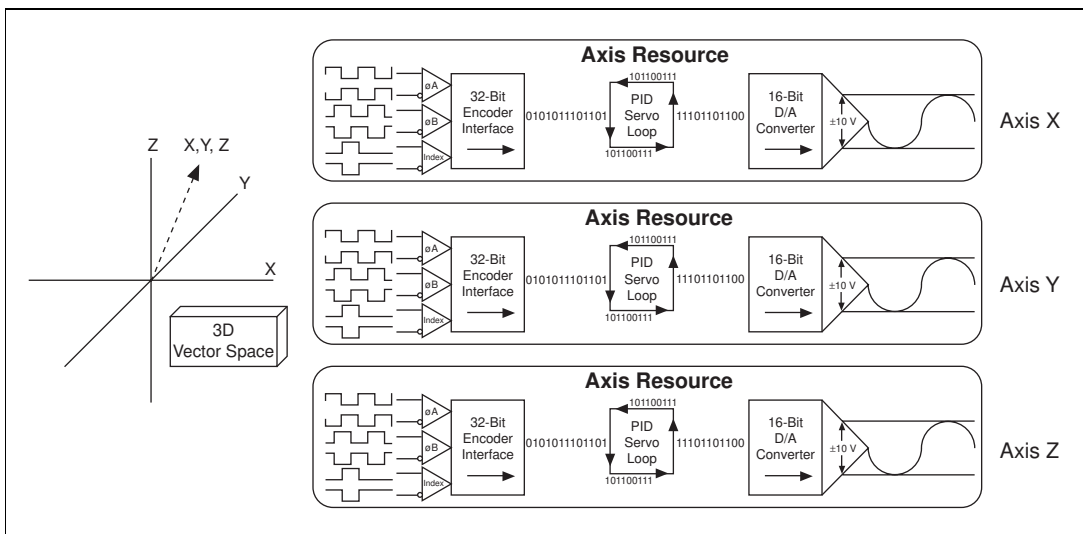
Figure 4-3. 3D Vector Space

Vector spaces facilitate 2D and 3D interpolation: linear, circular, helical and spherical. You can send many FlexMotion commands to a vector space to define vector position, vector velocity, vector acceleration, and so on.

Vector spaces are configured by mapping axes to the vector space. Vector spaces are logical, not physical, and do not require motion resources other than those used by the axes themselves.

👉 **Note**   *Refer to the* Axis and Resource Configuration *section of the* FlexMotion Software Reference*, for more information on configuring vector spaces.*

Onboard Programs

FlexMotion has full onboard programmability with the capability of executing up to 10 simultaneous motion programs in a real-time preemptive multitasking environment.

This extremely powerful feature is designed for real-time applications that need tight synchronization and/or minimum latency from a motion or other I/O event and fast command execution.

You can execute the entire FlexMotion function set from onboard programs. In addition, the onboard programs support basic math and data operation functions on up to 120 general-purpose variables.

Onboard programs also offer high-level, event-based functions such as Jump to Label on Condition and Wait on Condition, which allow you to sequence and make decisions in your programs. Onboard programs can even start and stop other onboard programs.

Implementing part or all of your motion application as an onboard program or programs offloads the host PC from handling these real-time tasks and events. This leaves the host PC more available for the other integrated tasks, such as data acquisition, image processing, user interface, data analysis, and/or overall measurement and automation system control.

Onboard programs can also isolate your application from the host PC's non-real-time operating system. Only the bus power is required to correctly execute an onboard FlexMotion program once it is started, and this program continues to run even if the host PC hangs, assuming the host power supply remains.

You can run onboard programs from RAM or optionally save them to Flash ROM. FlexMotion has 32 KB of each type of memory for program object storage. With an average command size of 10 bytes, a single program (which can be entirely stored in either RAM or ROM, but not split between both) can be as large as 3,200 commands. Conversely, FlexMotion can simultaneously execute 10 programs, five from RAM and five from ROM, each up to 640 commands long.

☞ **Note**   ***Refer to the*** *Onboard Programming Functions* ***section of the*** *FlexMotion Software Reference****, for detailed information on all of these onboard programming features.***

Find Home and Find Index

FlexMotion features two built-in programs to aid in initializing your system and establishing a repeatable zero position reference for system wide operation and control.

Find Home

You use the Find Home function to search for a home switch, stop on a specific edge of the switch, or optionally, go past and approach the home switch edge from a programmed direction. You can specify the initial search direction and are guaranteed to find the home switch (if one exists) because end-of-travel limit conditions are handled by reversing the home search direction.

☞ **Note**   *Refer to the* Find Home and Index Functions *section of the* FlexMotion Software Reference*, for more information on the Find Home function.*

Find Index

You can use the Find Index function to search one revolution for the Index mark of the feedback encoder. The program records the index position and returns the axis to the captured position, plus or minus an optional programmable offset. The encoder index mark is accurate to one quadrature count and provides a much more repeatable reference than a typical home switch.

☞ **Notes**   *The Find Index function is only available on closed-loop axes with quadrature encoder feedback. The encoder must provide a valid, properly phased index signal. See Figure 5-3,* Quadrature Encoder Phasing Diagram*, for more information.*

Refer to the Find Home & Index Functions *section of the* FlexMotion Software Reference *for more information on the Find Index function.*

Host Communications

The host computer communicates with a FlexMotion board through a number of I/O port addresses on the host bus. The host bus can be any of the supported bus standards—ISA or PCI.

The primary bidirectional data transfer port is at the board's base address. This port supports FIFO data passing in both send and readback directions. The FlexMotion board has both a command buffer for incoming commands and a return data buffer (RDB) for readback data.

At address offsets from the board's base address are two read-only status registers. The communications status register (CSR) provides bits for communications handshaking as well as real-time error reporting and general status feedback to the host PC. The motion complete status (MCS) register provides instantaneous motion status of all axes.

Packets, Handshaking, and FIFO Buffers

This section briefly describes how commands and data are passed between the host computer and the FlexMotion board. This information is provided for reference purposes. The FlexMotion software that ships with the board provides drivers, DLLs, and C function libraries that handle the host to board communications automatically, with built-in error reporting.

Data passed to or from the FlexMotion board is handled in a packet format. A packet consists of a packet identifier word, command and data content, and a packet terminator word. This approach to communications enhances the accuracy of data communications, speeds the processing of the transferred command and data, and organizes operation into powerful, high-level motion functions.

Each word in a packet is sent over the host PC bus after checking the Ready-to-Receive (RTR) handshaking bit in the CSR. Refer to the Read Communication Status (`read_csr`) function in the *FlexMotion Software Reference* for the Status bitmap and more information on the status reported in the CSR.

Command and data packets are checked for packet format errors as they are received by the board. If a packet error is detected, it is immediately reported by setting an error bit in the CSR. Once the packet is received without error, the command and data is stored in a FIFO buffer.

This FIFO can hold up to 16 commands. The FlexMotion RTOS will process commands whenever it is not busy with higher priority tasks. In the unlikely occurrence that the FIFO fills up before any commands can be processed, the host detects a Not-Ready-to-Receive condition and waits for available room in the FIFO before sending additional packets.

Each command is processed and a determination is made whether to execute the command immediately, or store it away in an onboard program to be executed later. Commands are also checked for data and modal (sequence) errors at this time. A modal error is flagged by setting the error message bit in the CSR. A modal error is functionally different from the packet communication error described above. See, *Error Stack*, of this chapter for additional information on modal errors.

Return Data Buffer

Data or status requested by the host with a command is buffered in the return data FIFO buffer (RDB). The RDB is 26 WORDs deep and is large enough to hold the biggest return data packet or many smaller return data packets.

When data exists in the RDB, the Ready-to-Send bit in the CSR is set. The host can then perform a bus read to get the return data from the board.

You can use the RDB in two ways—as a temporary buffer holding a single data return packet, or as a small FIFO buffer. Typically, once the requested data is available in the RDB, it is read back by the host. It is possible however, to request a number of pieces of data and leave them in the buffer (RDB) for retrieval at a later time. The FlexMotion Software supports both ways of using the RDB.

If the RDB fills up and there is no place to put requested return data, FlexMotion will generate an error and set the error message bit in the CSR

☞ **Note**   *Refer to the* FlexMotion Software Reference *for more information on RDB buffering and readback.*

Error Stack

To handle run-time or modal errors, FlexMotion maintains an error stack. If an error is detected during command execution, the Command ID, Resource ID, and Error Code are placed on a last-in-first-out (LIFO) stack and the error message bit in the CSR is set.

Since commands can be buffered in the command FIFO, errors detected at command execution time are delayed and are not reported as packet errors. They are pushed on the error stack to be read back by the host at a later time. This error handling structure also correctly detects errors generated by incorrectly sequenced programs and other modal errors.

The error stack is organized as a LIFO buffer so that old errors can be ignored and the most recent error is readily available to be read with the Read Error Message function just like any other status or data value. Older errors can then be read back in the inverse order to which they were generated, and reviewed for their relevance.

The error stack can hold up to 30 errors. If the error stack fills up before any error message is read back (an unlikely event), additional error messages are thrown away.

☞ **Notes**   ***Refer to the*** *Error Codes section* ***of the*** *FlexMotion Software Reference* ***for additional information on types of errors and possible reasons for their occurrence.***

If the host or onboard program is correctly written, you should not see any packet or modal errors. These error-handling structures are used mostly during application development and debugging.

5

Signal Connections

This chapter describes how to make input and output signal connections directly to the FlexMotion board and briefly describes the associated FlexMotion I/O circuitry.

FlexMotion has two connectors that handle all signals to and from the external motion system:

- 100-pin motion I/O connector
- 50-pin auxiliary 24-bit digital I/O connector

Connections to your motion system is provided by cables and accessories, varying from simple screw terminal blocks to enhanced UMI units and FlexMotion nuDrives.

⚠ **Caution** *Turn off power to all devices when connecting or disconnecting FlexMotion motion I/O and auxiliary digital I/O cables. Failure to do so may damage the FlexMotion board.*

Motion I/O Connector

The motion I/O connector contains all of the signals required to control up to six axes of servo and stepper motion including—motor command DAC and stepper outputs, encoder feedback inputs, forward, home and reverse limit inputs, breakpoint outputs, high-speed capture inputs and inhibit outputs. This connector also contains eight channels of 12-bit A/D inputs for analog feedback or general-purpose analog input.

Figure 5-1 shows the pin assignments for the 100-pin motion I/O connector on the PC-FlexMotion and PCI-FlexMotion boards. A signal description follows the connector pinout. In this chapter, lines above signal names indicate that signal is active-low.

+ISO	1	51	+ISO
Axis 1 Forward Limit Input	2	52	Axis 3 Forward Limit Input
Axis 1 Home Input	3	53	Axis 3 Home Input
Axis 1 Reverse Limit Input	4	54	Axis 3 Reverse Limit Input
Encoder 1 High-Speed Input	5	55	Encoder 3 High-Speed Input
Encoder 1 Breakpoint Output	6	56	Encoder 3 Breakpoint Output
Axis 2 Home Input	7	57	Axis 4 Home Input
Axis 2 Forward Limit Input	8	58	Axis 4 Forward Limit Input
Encoder 2 High-Speed Input	9	59	Encoder 4 High-Speed Input
Axis 2 Reverse Limit Input	10	60	Axis 4 Reverse Limit Input
Axis 5 Forward Limit Input	11	61	ISORTN
Encoder 2 Breakpoint Output	12	62	Encoder 4 Breakpoint Output
Axis 5 Home Input	13	63	Analog Reference
Axis 5 Reverse Limit Input	14	64	A/D Channel 1
Axis 6 Forward Limit Input	15	65	A/D Channel 2
Axis 6 Reverse Limit Input	16	66	A/D Channel 3
Axis 6 Home Input	17	67	A/D Channel 4
E-Stop	18	68	A/D Channel 5
ISORTN	19	69	A/D Channel 6
Encoder 1 Phase $\overline{A}$	20	70	A/D Channel 7
Encoder 1 Phase A	21	71	A/D Channel 8
Encoder 1 Phase $\overline{B}$	22	72	Reference Ground
Encoder 1 Phase B	23	73	DAC 3 Vout
Encoder 1 $\overline{Index}$	24	74	Analog Ground
Encoder 1 Index	25	75	DAC 4 Vout
Encoder 2 Phase $\overline{A}$	26	76	Encoder 3 Phase $\overline{A}$
Encoder 2 Phase A	27	77	Encoder 3 Phase A
Encoder 2 Phase $\overline{B}$	28	78	Encoder 3 Phase $\overline{B}$
Encoder 2 Phase B	29	79	Encoder 3 Phase B
Encoder 2 $\overline{Index}$	30	80	Encoder 3 $\overline{Index}$
Encoder 2 Index	31	81	Encoder 3 Index
Common	32	82	Encoder 4 Phase $\overline{A}$
Encoder 5 Phase A	33	83	Encoder 4 Phase A
Encoder 5 Phase $\overline{A}$	34	84	Encoder 4 Phase $\overline{B}$
Encoder 5 Phase B	35	85	Encoder 4 Phase B
Encoder 5 Phase $\overline{B}$	36	86	Encoder 4 $\overline{Index}$
Encoder 5 Index	37	87	Encoder 4 Index
Encoder 5 $\overline{Index}$	38	88	Common
Encoder 6 Phase A	39	89	Stepper 5 Step/CW
Encoder 6 Phase $\overline{A}$	40	90	Stepper 5 Dir/CCW
Encoder 6 Phase B	41	91	Axis 3 $\overline{Inhibit}$
Encoder 6 Phase $\overline{B}$	42	92	Host +5 V
Encoder 6 Index	43	93	Stepper 6 Step/CW
Encoder 6 $\overline{Index}$	44	94	Stepper 6 Dir/CCW
Common	45	95	Axis 4 $\overline{Inhibit}$
Analog Ground	46	96	Common
DAC 1 Vout	47	97	Axis 1 $\overline{Inhibit}$
DAC 2 Vout	48	98	Axis 2 $\overline{Inhibit}$
DAC 5 Vout	49	99	Axis 5 $\overline{Inhibit}$
DAC 6 Vout	50	100	Axis 6 $\overline{Inhibit}$

Figure 5-1. 100-Pin Motion I/O Connector Pin Assignment

Table 5-1 describes the signals on the motion I/O connector.

Table 5-1. Motion I/O Signal Connections

Signal Name	Reference	Direction	Description
DAC <1..6> Vout	Analog Ground	Output	Analog motor command
Analog Ground	—	—	Reference for Vout
Stepper <5..6> Step/CW	Common	Output	Stepper only—motor step or clockwise control
Stepper <5..6> Dir/CCW	Common	Output	Stepper only—motor direction or counter-clockwise control
Axis <1..6> Inhibit*	Common	Output	Amplifier/drive inhibit
Encoder <1..6> Phase A	Common	Input	Phase A encoder input
Encoder <1..6> Phase A*	Common	Input	Phase A* differential encoder input
Encoder <1..6> Phase B	Common	Input	Phase B encoder input
Encoder <1..6> Phase B*	Common	Input	Phase B* differential encoder input
Encoder <1..6> Index	Common	Input	Index or marker input
Encoder <1..6> Index*	Common	Input	Index* or marker differential input
Common	—	—	Reference for digital I/O
Host +5 V	Common	Output	+5 V— bus power interlock
+ISO	ISORTN	Input	Isolated voltage supply
Encoder <1..4> High-Speed Input	ISORTN	Input	High-speed capture input
Encoder <1..4> Breakpoint Output	ISORTN	Output	Breakpoint output
Axis <1..6> Forward Limit Input	ISORTN	Input	Forward/clockwise limit input
Axis <1..6> Home Input	ISORTN	Input	Home input
Axis <1..6> Reverse Limit Input	ISORTN	Input	Reverse/counter-clockwise limit input
E-Stop	ISORTN	Input	Emergency Stop input
ISORTN	—	—	Reference for isolated signals

Table 5-1. Motion I/O Signal Connections

Signal Name	Reference	Direction	Description
Analog Reference	Reference Ground	Output	7.5 V (nom.) output
A/D Channel <1..8>	Reference Ground	Input	12-bit analog ADC input
Reference Ground	—	—	Reference for analog inputs
*Indicates that the signal is active-low.			

Motion Axis Signals

The following signals control the servo amplifier or stepper driver.

- DAC <1..6> Vout—These 16-bit DAC outputs are typically the servo command outputs for each axis. They can drive the industry-standard ±10 V output, and can be software limited to any ±V range desired. They also feature a software programmable voltage offset.

  Although typically used as the command output of an axis control loop, unused DACs can also function as independent analog outputs for general-purpose control.

- Analog Ground—To help keep digital noise separate from the analog DAC outputs, a separate return connection is provided. You should use this analog ground connection and not Common (digital I/O reference) as the reference for the DAC outputs when connecting to servo amplifiers.

- Stepper <5..6> Step/CW and Dir/CCW—These open-collector signals are the stepper command outputs for each axis. FlexMotion supports both major industry standards for stepper command signals—step and direction, or independent CW and CCW pulse outputs.

  The output configuration and signal polarity is software programmable for compatibility with various third party drives.

  When step and direction mode is configured, each commanded step (or microstep) produces a pulse on the step output. The direction output signal level indicates the command direction of motion, either forward or reverse.

  CW and CCW mode produces pulses (steps) on the CW output for forward commanded motion and pulses on the CCW output for reverse commanded motion.

  In either case, you can set the active polarity of both outputs to active-low (inverting) or active-high (non-inverting). For example, with step and direction, you can make a logic high correspond to either forward or reverse direction.

The Step/CW and Dir/CCW outputs are driven by high-speed open-collector TTL buffers that feature high sink current capability.

⚠️ **Caution**   *Do not connect these outputs to anything other than a +5 V circuit. The output buffers will fail if subjected to voltages in excess of +5.5 V.*

- Axis <1..6> Inhibit*—Use the inhibit output signals to control the enable/inhibit function of a servo amplifier or stepper driver. When properly connected and configured, the inhibit function causes the connected motor to be de-energized and its shaft turns freely. These open-collector inhibit signals feature high current sink capability and can directly drive most driver/amplifier inhibit input circuits. They are protected from excessive pull-up voltage with a diode clamp to internal +12 V.

  While the industry standard for inhibits is active-low (inverting), these outputs have programmable polarity and can be set to active-high (non-inverting) for increased flexibility and unique drive compatibility.

  Inhibit output signals are activated automatically upon a Kill Motion command or any motion error that causes a kill motion condition (for example, following error trip). You can also directly control the inhibit output signals to enable or disable a driver or amplifier.

Limit and Home Inputs

The following signals control limit and home inputs:

- Axis <1..6> Forward Limit Input
- Axis <1..6> Home Input
- Axis <1..6> Reverse Limit Input

These optoisolated inputs are typically connected to limit switches located at physical ends of travel and/or at a specific home position. Limit and home inputs may be software enabled and disabled at any time. When enabled, an active transition on a limit or home input causes a full torque halt stop of the associated motor axis. In addition, an active forward or reverse limit input will impede future commanded motion in that direction for as long as the signal is active.

☞ **Note**   *While limit and home transitions are edge-detected and always stop motion, active signals should remain active to prevent motion from proceeding further into the limit. Pulsed limit signals will stop motion but they do not prevent further motion in that direction.*

The input polarity of these signals is software programmable for active-low (inverting) or active-high (non-inverting).

You can use software disabled limit and home inputs as general-purpose inputs. You can read the status of these inputs at any time and set and change their polarity as required.

Limit and home inputs are a per axis enhancement on the FlexMotion boards and are not required for basic motion control. These inputs are part of a system solution for complete motion control. All motion control functions may be operated without limit switches except the Find Home function, which requires enabled limit and home inputs for operations.

☞ **Note**   *Both limits and home inputs must be enabled to use the Find Home function.*

During Find Home function execution, the first active limit signal in the search direction will not simply stop the motor, but will cause motion to turn around and travel in the opposite direction and continue to search for the home switch.

Similarly, during Find Home, you can use a home switch to either stop motion or to begin a predetermined sequence of homing moves to find the correct edge of the home switch and to approach it from the desired direction.

☞ **Note**   *After a Find Home sequence is complete, the home input should be disabled since it is no longer required assuming you do not want to stop on it the next time the system moves past it.*

Wiring Concerns

⚠ **Cautions**   *For the end of travel limits to function correctly, the forward limit must be located at the forward or positive end of travel and the reverse limit at the negative end of travel. Failure to do so may result in motion that stops at, but then travels through, a limit, potentially damaging the motion system. Miswired limits may prevent motion from occurring at all.*

Keep limit and home switch signals and their ground connections wired separately from the motor driver/amplifier signal and encoder signal connections. Wiring these signals near each other can cause faulty motion system operation.

Limit and Home Input Circuit

Figure 5-2 shows a simplified schematic diagram of the circuit used by the limit and home switch inputs for input signal isolation.
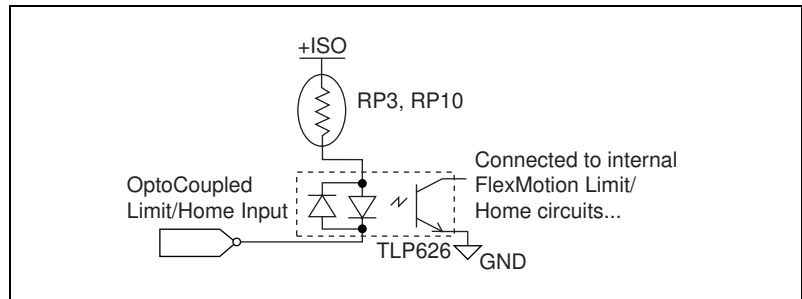
Figure 5-2. Limit and Home Input Circuit

☞ **Note**   *See* Selecting an Isolated External/Internal Voltage Supply Configuration *in* **Chapter 3,** Hardware Overview**, for information on selecting appropriate DIP resistor values.**

⚠ **Caution**   *Excessive input voltages can cause erroneous operation and/or component failure. Verify that your input voltage is within the specification range.*

Encoder Signals

FlexMotion offers six channels of differential or single-ended quadrature encoder inputs:

- Encoder <1..6> Phase A
- Encoder <1..6> Phase A*
- Encoder <1..6> Phase B
- Encoder <1..6> Phase B*

The encoder inputs provide position and velocity feedback for absolute and relative positioning of axes in any motion system configuration.

If an encoder resource is not needed for axis control, it is available for other functions including: position or velocity monitoring, digital potentiometer encoder inputs, or as a master encoder input for master/slave, or electronic gearing applications.

The first four encoder channels (Encoder <1..4>) are implemented in a FPGA and are high performance with extended input frequency response

and advanced features such as high-speed capture inputs and breakpoint outputs. Encoders one and two have a maximum count frequency of 16 MHz while Encoders three and four are limited to 1 MHz.

Encoders five and six have a maximum count frequency of 2 MHz, but do not offer the high-speed capture or breakpoint functionality.

Since you can map any encoder to any axis, this variation of performance and features across the six encoder channels results in a extremely flexible architecture that can be tailored to any motion application requirement.

An encoder input channel converts quadrature signals on Phase A and Phase B into 32-bit up/down counter values. Quadrature signals are generated by optical, magnetic, laser, or electronic devices that provide two signals, Phase A and Phase B, that are 90° out of phase. The leading phase, A or B, determines the direction of motion. The four transition states of the relative signal phases provide distinct pulse edges that cause count up or count down pulses in the direction determined by the leading phase.

A typical encoder with a specification of N (N = number) lines per unit of measure (revolutions or linear distance) will produce $4 \times N$ quadrature counts per unit of measure. The count is the basic increment of position in FlexMotion systems.

☞ **Note** *Determine quadrature counts by multiplying the encoder resolution in encoder lines by 4. The encoder resolution is the number of encoder lines between consecutive encoder indexes (marker or Z-bit). If the encoder does not have an index output, the resolution would be referred to as lines per revolution, or lines per unit of measure (inch, centimeter, millimeter, and so on).*

- Encoder <1..6> Index
- Encoder <1..6> Index*

The Index input is primarily used with the Find Index function. This function uses the number of counts per revolution (or linear distance) to initiate a search move that locates the index position. When a valid index signal transition occurs during a Find Index sequence, the position of the index signal is captured very accurately. You then use this captured position to establish a reference zero position for absolute position control or any other motion system position reference required. Figure 5-3 shows the quadrature encoder phasing diagram.
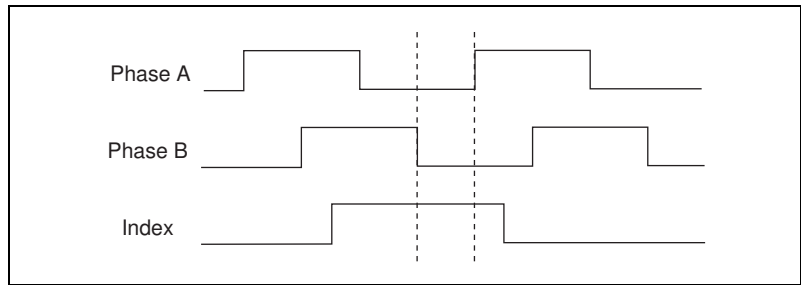
Figure 5-3. Quadrature Encoder Phasing Diagram

Wiring Concerns

The encoder inputs are connected to quadrature decoder/counter circuits. It is very important to minimize noise at this interface. Excessive noise may overwhelm the digital filters on these encoder input signals resulting in loss of counts or extra counts and erroneous closed-loop motion operation. Verify the encoder connections before powering up the system.

⚠ **Caution**   *Wire encoder signals and their ground connections separately from all other connections. Wiring these signals near the motor drive/amplifier or other signals can cause positioning errors and faulty operation.*

Encoders with differential line driver outputs are strongly recommended for all applications and must be used if the encoder cable length is longer than 10 feet. Shielded, 24 AWG wire is the minimum recommended size for the encoder cable. Cables with twisted pairs and an overall shield are recommended for optimized noise immunity.

⚠ **Caution**   *Use of an unshielded cable can permit noise to corrupt the encoder signals resulting in lost counts and reduced motion system accuracy.*

Encoder Input Circuit

Figure 5-4 shows a simplified schematic diagram of the circuit used for the Phase A, Phase B, and Index encoder inputs. FlexMotion supports both single-ended (A, B, Index) and differential (A, A*, B, B*, Index, Index*) encoder input configurations. Both phases A and B are required for proper encoder counter operation, and the signals must support the 90° phase difference within system tolerance. The Index signal is optional but highly recommended and required for initialization functionality with the Find Index function.
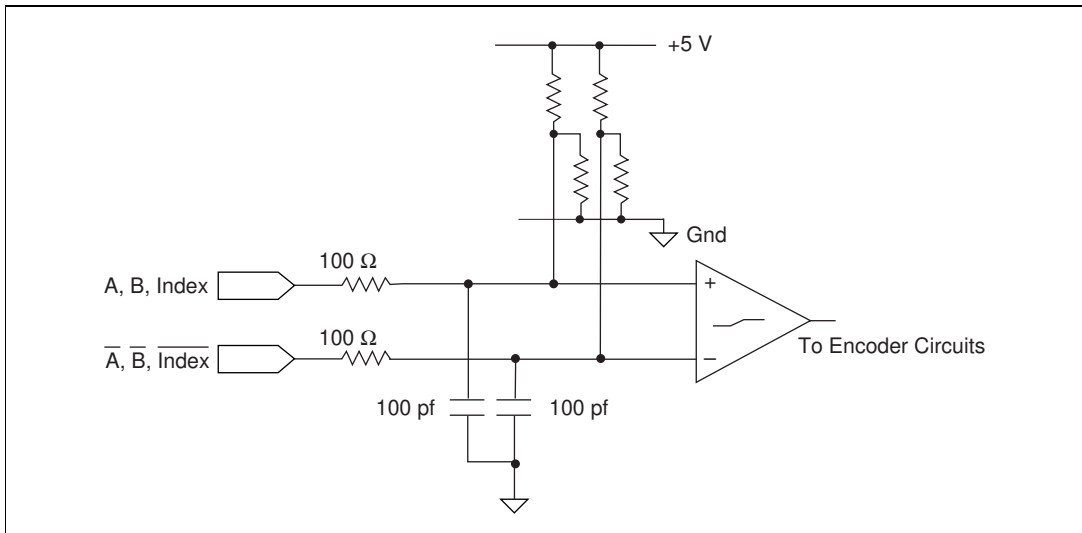
Figure 5-4. Encoder Input Circuit

👉 **Notes**   *See* Selecting Encoder Termination Networks *section in Chapter 3,* Hardware Overview*, for information on selecting the appropriate SIP resistor values.*

When connecting to single-ended encoder inputs, the unused differential input must be left unconnected. Connecting unused inputs to +5 V or Common will not damage the encoder input circuit but will cause faulty operation of the encoder channel.

Single-ended encoders must have TTL-compatible output drivers. Encoders with open-collector outputs can be interfaced but require you to add external 2.2 K Ω pull-up resistors to +5 V, from the encoder Phase A, B, and Index signals.

The differential nature of the encoder inputs also allows any encoder to satisfy the phasing requirements shown in Figure 5-4. Phases A and B can be swapped and/or the polarity of an individual phase can be inverted by swapping connectors from the non-inverting (A or B) to the inverting (A* or B*) signals, or vice versa. Similarly, single-ended signals can be inverted by simply connecting them to the inverting (A* or B*) input.

High-Speed Capture Inputs and Breakpoint Outputs

FlexMotion offers additional high-performance features in the encoder FPGA. The first four encoder channels have high-speed capture inputs and breakpoint outputs. These optoisolated signals are useful for high-speed

synchronization of motion with actuators, sensors, and other parts of the complete motion system:

- Encoder <1..4> High-Speed Input—When enabled, an active transition on a high-speed capture input causes instantaneous position capture (<100 ns latency) of the corresponding encoder count value. You can use this high-speed capture functionality for applications ranging from simple position tagging of sensor data to complex camming systems with advance/retard positioning and registration. An available FlexMotion position mode is: move an axis Relative to Captured Position.

  The polarity of the high-speed input is programmable in software as active-low (inverting) or active-high (non-inverting). You can also use a disabled high-speed capture input as a general-purpose digital input. You can read the logical status of all high-speed inputs at any time, independent of their enable/disable state.

- Encoder <1..4> Breakpoint Output—A breakpoint output can be programmed to transition when the associated encoder value equals the breakpoint position. You can use a breakpoint output to directly control actuators or as a trigger to synchronize data acquisition or other functions in the motion control system.

  You can program breakpoints as either Absolute or Relative position. Breakpoints are one-shot and must be enabled and re-enabled each time they occur to function properly. The Enable Breakpoint function also allows you to preset the breakpoint output to a known state so that the transition when the breakpoint occurs can be low to high, high to low, or toggle.

  You can read the status of the breakpoint function at any time. When a breakpoint is enabled, its corresponding status bit is reset to FALSE and its status goes TRUE when the breakpoint occurs.

☞ **Note**   *The Read Breakpoint Status function does not return the digital I/O value of the breakpoint outputs; it returns the enabled/occurred status instead.*

You can directly set and reset breakpoint outputs so you can use them as general-purpose digital outputs.

Wiring Concerns

⚠️ **Cautions** *Keep high-speed capture input and breakpoint output signals and their ground connections wired separately from the motor driver/amplifier signal and encoder signal connections. Wiring these signals near each other can cause faulty operation.*

Excessive input voltages can cause erroneous operation and/or component failure.

High-Speed Capture Input and Breakpoint Output Circuits

Figures 5-5 and 5-6 show a simplified schematic diagram of the circuits used by the high-speed capture inputs and breakpoint outputs for signal isolation. The high-speed capture inputs use optocouplers rated in excess of 10 MHz to provide minimum latency on these signals.
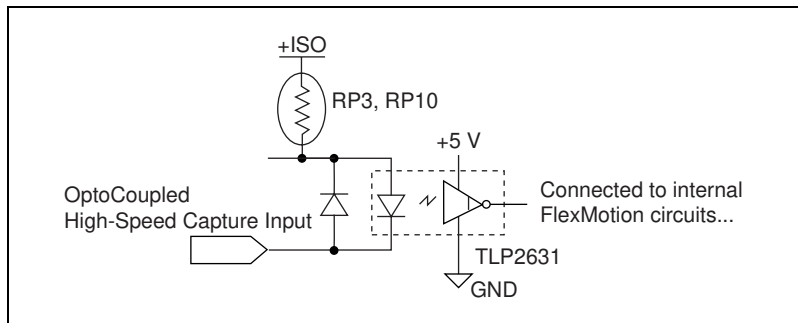

Figure 5-5. High-Speed Capture Input Circuit

Figure 5-6. Breakpoint Output Circuit

☞ **Note**   *See* Selecting an Isolated External/Internal Voltage Supply Configuration **in**
Chapter 3, Hardware Overview**, for information on selecting the appropriate DIP**
resistor value.

ADC Inputs

FlexMotion has the following ADC input signals:

- A/D Channel <1..8>—FlexMotion includes an eight channel
  multiplexed, 12-bit ADC capable of measuring ± 10 V inputs. You can
  configure each ADC channel for motion feedback, simple A/D
  conversion or both.

  You can read back the digital value of analog voltage on any of the
  board's eight ADC channels by using the Read ADC function. The
  values read back will be in the range of –2048 to 2047 (± 11 bits) with
  a voltage resolution of 0.0049 V per LSB (least significant bit).

  When configured as analog feedback, an analog sensor acts like a
  limited range absolute position device with a full scale position range
  of ± 2048 counts. You can map any ADC channel as feedback to any
  axis.

  You can enable and disable individual ADC channels in software. You
  should disable unused ADC channels for the highest multiplexer scan
  rate performance. Properly enabled, the scan rate is high enough to
  support analog feedback at the highest PID sample rate.

- Analog Reference—For convenience, 7.5 V (nominal) analog
  reference voltage is made available. You can use this output as a low
  current supply to sensors that require a stable reference.

- Reference Ground—To help keep digital noise out of the analog input,
  a separate return connection is provided. You should use this reference
  ground connection and not Common (digital I/O reference) or Analog
  Ground as the reference for the ADC inputs.

Wiring Concerns

For proper use of each ADC input channel, the analog signal to be
measured should be connected to the channel input and its ground reference
connected to the Reference Ground connection.

☞ **Note**   *If an external reference voltage is used, it must not be connected to the analog*
reference output, since this is an output signal only. You should, however, connect
the external reference's common to the reference ground pin for proper A/D
reference and improved voltage measurement.

Other Motion I/O Connections

FlexMotion provides other motion I/O connections as follows:

- +ISO—This is the external isolated voltage supply input used to power all of the optoisolated I/O circuitry when an external isolated voltage supply is selected.

  When the internal +5 V supply is selected, this signal is connected to the host computer's +5 V supply through a thermally resetable fuse. In this configuration, the I/O circuits are non-isolated and up to 0.5 A is available at this connection to power external sensors and devices.

- ISORTN—This is the current return connection for the external isolated voltage supply. All optoisolated circuitry is referenced to this signal connection.
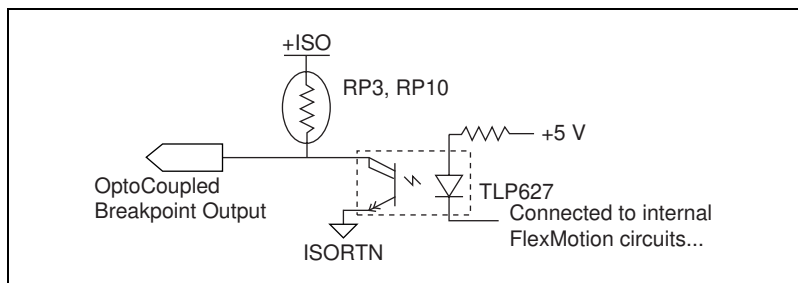
☞ **Note**   *See Selecting an Isolated External/Internal Voltage Supply Configuration in Chapter 3, Hardware Overview, for further information on how to use the +ISO and ISORTN connections.*

- Host + 5 V—This is the host computer's internal +5 V supply. It is used to detect when the host computer is powered and as an interlock to shut down external motion system components when the host computer is turned off.

⚠ **Caution**   *The host +5 V signal is limited to <100 mA and should not be used to power any external devices, except those intended in the host bus monitor circuits on the UMI and nuDrive products.*

- E-Stop—The optoisolated Emergency Stop input signal, when enabled in software, can be used to kill all motion by zeroing the DAC outputs and freezing the stepper pulse and/or direction outputs. You can program other command sequences and store them for automatic execution when an active input on this connection occurs.

☞ **Note**   *The E-Stop feature is not presently supported in software.*

Auxiliary 24-Bit Digital I/O Connector

All of FlexMotion's general-purpose digital I/O lines are available on a separate 50-pin box header connector. The pinout of the connector and electrical characteristics of the I/O signals follow the OPTO 22 type standard. Each output circuit can sink 24 mA and source –3 mA. Through a standard 50-pin ribbon cable, the 24-bits of digital I/O can be directly interfaced to industry-standard signal conditioning racks with relays,

optoisolated I/O, or special function modules, including the
National Instruments 6B Series signal conditioning devices.

Figure 5-7 gives the pinout of the auxiliary 24-bit digital I/O connector.

Port 3:bit 7	1	2	Common
Port 3:bit 6	3	4	Common
Port 3:bit 5	5	6	Common
Port 3:bit 4	7	8	Common
Port 3:bit 3	9	10	Common
Port 3:bit 2	11	12	Common
Port 3:bit 1	13	14	Common
Port 3:bit 0	15	16	Common
Port 2:bit 7	17	18	Common
Port 2:bit 6	19	20	Common
Port 2:bit 5	21	22	Common
Port 2:bit 4	23	24	Common
Port 2:bit 3	25	26	Common
Port 2:bit 2	27	28	Common
Port 2:bit 1	29	30	Common
Port 2:bit 0	31	32	Common
Port 1:bit 7	33	34	Common
Port 1:bit 6	35	36	Common
Port 1:bit 5	37	38	Common
Port 1:bit 4	39	40	Common
Port 1:bit 3	41	42	Common
Port 1:bit 2	43	44	Common
Port 1:bit 1	45	46	Common
Port 1:bit 0	47	48	Common
+5 V	49	50	Common

Figure 5-7. 50-Pin Auxiliary I/O Connector Pin Assignments

The 24-bit digital I/O port is configured in hardware as three 8-bit digital
I/O ports, as shown in Figure 5-8. The bits in a port are typically controlled
and read with byte-wide bitmapped commands.
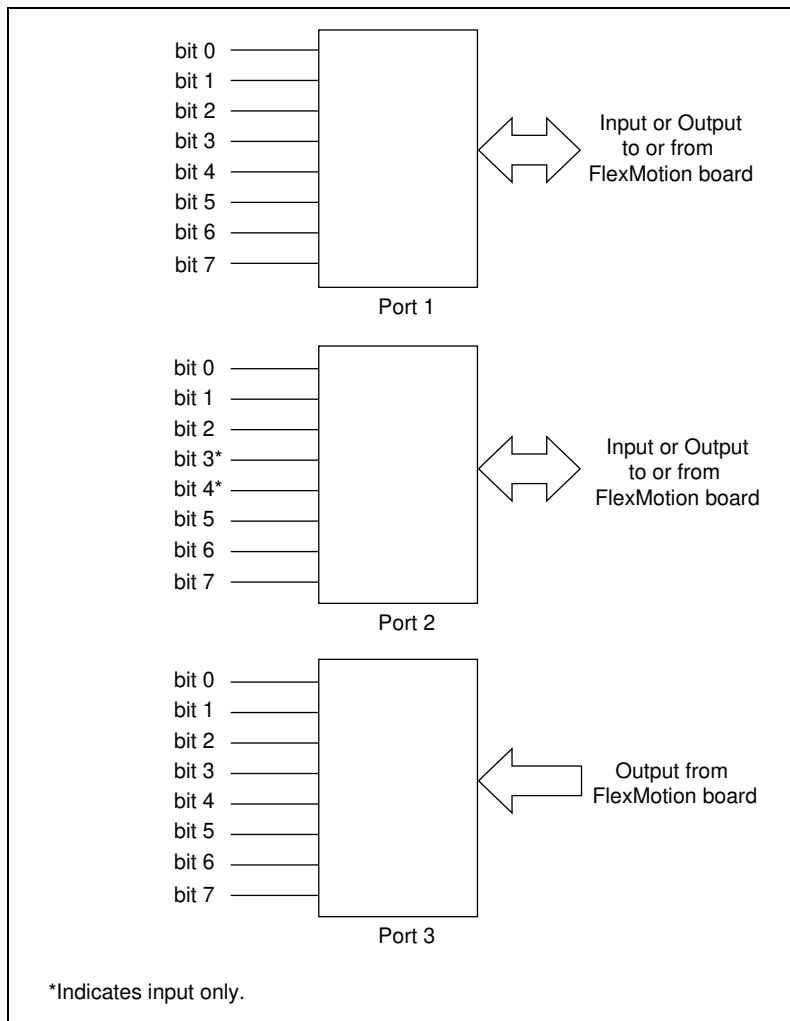
Figure 5-8. Auxiliary 24-Bit Digital I/O Port Configuration

Each port has different characteristics and features that you can configure and access through software. Port 1 is bidirectional and can be configured as a byte wide (8-bit) input or output port. All bits in the port follow this directional configuration.

Port 2 is also bidirectional, but I/O bits 3 and 4 are input only. If port 2 is configured as outputs, you cannot use bits 3 and 4.

Port 3 is a dedicated output port and the bits in it cannot be used as inputs.

With all three ports configured as outputs, you have 22 output bits. I/O bits 3 and 4 in port 2 are input only and are not usable. Conversely, it is possible to configure the ports for a maximum of 16 inputs and eight outputs.

All ports have bitwise programmable polarity and you can configure each bit as active-low (inverting) or active-high (non-inverting). Software commands that read and write the port use logical values (TRUE/FALSE) for each bit. Depending upon the programmed polarity for a bit, a TRUE value may correspond to a high voltage (active-high) or low voltage (active-low) on the physical pin.

Reads from input ports always return the logic value of the input bits. Writes to input ports do nothing. Writes to output ports set/reset the logic levels of the output bits. Reads from output ports return the logic levels last written to the port.

FlexMotion software supports the MustOn/MustOff (MOMO) protocol for setting and resetting the output bits in a port. The MOMO approach allows you to define which bits must be On (active), which bits must be Off (non-active), and which bits you want to stay in the same state. In this way, an individual bit or bits can be set or reset without worrying about the values of the other bits in the port. Of course, the entire port can also be set or reset at any time.

PWM and Counter Features

☞ **Note**   *PWM and counter features are not presently supported in software.*

FlexMotion offers a couple of special features on the 24-bit digital I/O connector. You can configure the input only I/O bits 3 and 4 of port 2 as counter function inputs and the output only I/O bits 0 and 1 of port 3 as PWM outputs. When configured for their alternate functions, you cannot use these bits general-purpose digital I/O. Table 5-2 lists these alternative functions.

Table 5-2. Enhanced I/O Features

I/O Bit	Port	Direction	Feature
I/O Bit 3	2	Input only	General-Purpose input (or) Counter clock input
I/O Bit 4	2	Input only	General-Purpose input (or) counter input

Table 5-2. Enhanced I/O Features (Continued)

I/O Bit	Port	Direction	Feature
I/O Bit 0	3	Output only	General-purpose output (or) PWM Output B
I/O Bit 1	3	Output only	General-purpose output (or) PWM Output A

The two PWM outputs generate periodic waveforms whose period and duty cycles may be independently controlled through software commands. You can think of PWM as a digital representation of an analog value because the duty cycle is directly proportional to the desired output value. PWM outputs are typically used for transmitting an analog value through a optocoupler. A simple low-pass filter will turn a PWM signal back into its corresponding analog value.

You can use the counter input to simply count events (active transitions) at the input or as a gate of the counter clock input. In this latter mode, you can measure the duty cycle of the counter input signal.

The programmable polarity of these bits is in effect whether or not you are using them for their alternative features or as general-purpose digital I/O.

A

Specifications

This appendix lists the hardware and software performance specifications for the FlexMotion board.

Servo Performance

PID update rate range............................ 62.5 to 500 μs/sample

    Max PID update rate .... 62.5 μs/axis

    6 axis PID update rate .... 375 μs total

Trajectory update rate .... Same as PID update rate

Multi-axis synchronization .... < 1 update sample

Position accuracy

    Encoder feedback........................... ±1 quadrature count

    Analog feedback .... ±1 LSB

Long-term velocity accuracy .... Oscillator based, 0.002%

    Drift.. 0.4 ppm/°C

Double-buffered trajectory parameters

    Absolute position range .... $\pm 2^{31}$ counts

    Max relative move size .... $\pm 2^{31}$ counts

    Velocity range............................... 1 to ±16,000,000 counts/s

    RPM range .... 10^{-5} to 10^{6} revolutions/minute

    Acceleration/deceleration .... 4,000 to 128,000,000 counts/s^2

    RPS/s range................................... 10^{-1} to 10^{8} revolutions/s^2

    S-Curve time range .... 1 to 32,767 samples

    Following error range .... 0 to 32,767 counts

    Gear ratio .... ±32,767:1 to 1:32,767

Servo control loop modes .... PID, PIVff, S-Curve, Dual Loop

    PID (Kp, Ki and Kd) gains .... 0 to 32,767

    Integration limit (Ilim)....................0 to 32,767

    Derivative sample period (Td).........1 to 63 samples

    Feedforward (Aff, Vff) gains ....0 to 32,767

    Velocity feedback (Kv) gain ....0 to 32,767

Servo command DAC outputs

    Voltage range...................................±10 V

    Resolution.......................................16 bits (0.000305 V/ LSB)

    Programmable torque (velocity) limits

      Positive limit ....±10 V (–32,768 to + 32,767)

      Negative limit..........................±10 V (–32,768 to + 32,767)

    Programmable offset ....±10 V (–32,768 to + 32,767)

Stepper Performance

Trajectory update rate range ....125 to 500 μs/sample

    Max update rate ....125 μs/axis

Multi-axis synchronization ....< 1 update sample

Position accuracy

    Open-loop stepper ....1 full, half, or microstep

    Encoder feedback ....±1 quadrature count

    Analog feedback.............................±1 LSB

Long-term velocity accuracy ....Oscillator based, 0.002%

    Drift ....0.4 ppm/°C

Double-buffered trajectory parameters

    Position range ....$\pm 2^{31}$ steps

    Max relative move size....................$\pm 2^{31}$ steps

    Velocity range ....1 to 1,500,000 steps/s

    RPM range.....................................10^{-5} to 10^{6} revolutions/minute

    Acceleration/deceleration ....4,000 to 128,000,000 steps/s^2

    RPS/s range ....10^{-1} to 10^{8} revolutions/s^2

    S-curve time range..........................1 to 32,767 samples

    Following error range ....0 to 32,767 counts

    Gear ratio ....±32,767:1 to 1:32,767

Stepper outputs

    Max pulse rate .... 1.5 MHz (full, half, and microstep)

    Min pulse width .... 300 ns at 1.5 MHz

    Step output mode .... Step and direction or CW/CCW

    Stepper outputs .... Open-collector TTL

        Voltage range .... 0 to 5 V

        Output low voltage .... < 0.6 V at 64 mA sink

    Polarity .... Programmable, active-high or active-low

System Safety

Watchdog timer function .... Resets board to startup state

    Watchdog timeout .... 63 ms

E- Stop input .... Optocoupled

    Voltage range .... 0 to 24 V

    Optocoupler .... TLP626 or equivalent

    Max input current .... 10 mA (built-in current limiting resistor)

    Control .... Disable all axes and command outputs (not yet implemented)

Motion I/O

Encoder inputs .... Quadrature, incremental

    Max count rate

        Encoders 1 and 2 .... 16 MHz

        Encoders 3 and 4 .... 1 MHz

        Encoders 5 and 6 .... 2 MHz

    Encoder signal options .... Differential or single-ended: A, A*, B, B*, Index, Index* per axis

    Differential Input Threshold .... ± 0.3 V (typical)

    Differential line receiver .... MC3486 or equivalent

    Voltage range .... 0 to 5 V

    Min index pulse width .... 83 ns

Forward, reverse, and home inputs.........Optocoupled

    Number of inputs.............................18 (3 per axis)

    Voltage range...................................0 to 24 V

    Optocoupler ....TLP626 or equivalent

    Max input current ....10 mA (built-in current limiting resistor)

    Polarity ....Programmable, active-high or active-low

    Control...Individual enable/disable, stop on input, prevent motion, Find Home

High-speed capture inputs ....Optocoupled

    Number of inputs.............................4 (Encoders 1 through 4)

    Voltage range...................................0 to 24 V

    Optocoupler ....TLP2631 or equivalent

    Max input current ....10 mA (built-in current limiting resistor)

    Polarity ....Programmable, active-high or active-low

    Min pulse width..............................83 ns

    Capture latency...............................<100 ns

    Capture accuracy ....1 count

    Max repetitive capture rate.............1 kHz

Breakpoint outputs..................................Optocoupled

    Number of outputs..........................4 (Encoders 1 through 4)

    Voltage range...................................0 to 24 V

        Output low voltage ....< 1.2 V at 50 mA sink

        Output high voltage.................open collector with built-in pull-up to +ISO (See Table 3-2)

    Optocoupler ....TLP627 or equivalent

    Polarity ....Programmable, active-high or active-low

Inhibit/enable output...............................Open collector

    Number of outputs..........................6 (1 per-axis)

    Voltage range...................................0 to 12 V

    Output low voltage ....<1.1 V at 100 mA sink

Buffer .... MC1413 or equivalent

Polarity... Programmable, active-high or active-low

Control .... MustOn/mustOff or automatic when axis off

A/D converter inputs

Number of inputs .... 8, multiplexed

Voltage range .... ±10 V

Input resistance .... 20 kΩ min

Resolution .... 12-bit (0.0049 V/LSB)

Analog reference output.................. 7.5 V (nominal)

Reference drift .... 25 ppm/°C type

Error

Positive full-scale error............ ±2.5 LSB max

Bipolar zero error..................... ±4 LSB max

Negative full-scale error .... ±2 LSB max

Relative accuracy .... ±1 LSB

Conversion time .... 10 μs

Multiplexor scan rate .... 50 μs/enabled channel

Converter .... AD7890-10 or equivalent

DAC outputs

Number of outputs 6

Voltage range .... ±10 V

Output current .... ±10 mA

Resolution .... 16 bits (0.000305 V/ LSB)

Settling time .... 1 μs (1 LSB step)

Gain accuracy .... ±2%

Drift.. 25 ppm/°C type

24-Bit Digital I/O

Ports .... 3, 8-bit ports

Port direction.................................. programmable

Max number of input ports 2

Max number of output ports 3

Inputs

    Voltage range...................................0 to 5 V

        Input low voltage......................0.8 V

        Input high voltage.....................2.0 V

    Polarity ....Programmable, active-high or active-low

    Counter function inputs

        Number of counter inputs.........2

        Max input frequency ....4 MHz

Outputs

    Voltage range...................................0 to 5 V

        Output low voltage ....< 0.5 V at 24 mA

        Output high voltage ....> 2.4 V at 3 mA

    Polarity ....Programmable, active-high or active-low

    PWM outputs

        Number of PWM outputs 2

        Max PWM frequency ....32 kHz

        Resolution................................8-bit

        Duty cycle range......................0 to (255/256)%

        Clock Sources..........................Internal or external counter input

Power Requirements (Max)

Device	+5 V (±3%)	+12 V (±3%)	-12 V (±3%)	Power Consumption
PC-FlexMotion	2.0 A	150 mA	200 mA	14.2 W
PCI-FlexMotion	2.0 A	150 mA	200 mA	14.2 W

Physical

Dimensions (Not Including Connectors)

PC-FlexMotion ....33.8 by 9.9 cm (13.3 by 3.9 in.)

PCI-FlexMotion.....................................31.2 by 9.9 cm (12.3 by 3.9 in.)

Connectors

Motion I/O connector............................ 100-pin female high density metal
shell D-type

Auxiliary 24-bit digital I/O connector
PC-Flexmotion and PCI-FlexMotion..... 50-pin male box header

Serial port connector
PC-FlexMotion and PCI-FlexMotion .... 10-pin male box header

Environment

Operating temperature............................ 0 to 55 °C

Storage temperature .... −20 to 70 °C

Relative humidity range .... 10 to 90% (non-condensing)

B

Cable Connector Descriptions

This appendix describes the connector pinout for the cables that connect to your FlexMotion boards.

Figures B-1 and B-2 show the pin assignment for the two 50 pin connectors on the R1005050 cables. This cable splits the 100-pin motion I/O signals into two 50-pin groups for easy interfacing to industry-standard 50-pin terminal blocks.

Notice that the first 50-pin group is a complete 4-axis subsystem with all of the required inputs and outputs for motion control. In many applications, you do not need any of the signals in the second 50-pin group and only one 50-pin screw terminal block is required. For more information on signal features and capabilities, please refer to Chapter 5, *Signal Connections*.

+ISO	1	2	Axis 1 Forward Limit Input
Axis 1 Home Input	3	4	Axis 1 Reverse Limit Input
Encoder 1 High-Speed Input	5	6	Encoder 1 Breakpoint Output
Axis 2 Home Input	7	8	Axis 2 Forward Limit Input
Encoder 2 High-Speed Input	9	10	Axis 2 Reverse Limit Input
Axis 5 Forward Limit Input	11	12	Encoder 2 Breakpoint Output
Axis 5 Home Input	13	14	Axis 5 Reverse Limit Input
Axis 6 Forward Limit Input	15	16	Axis 6 Reverse Limit Input
Axis 6 Home Input	17	18	E-Stop
ISORTN	19	20	Encoder 1 Phase $\overline{A}$
Encoder 1 Phase A	21	22	Encoder 1 Phase $\overline{B}$
Encoder 1 Phase B	23	24	Encoder 1 $\overline{Index}$
Encoder 1 Index	25	26	Encoder 2 Phase $\overline{A}$
Encoder 2 Phase A	27	28	Encoder 2 Phase $\overline{B}$
Encoder 2 Phase B	29	30	Encoder 2 $\overline{Index}$
Encoder 2 Index	31	32	Common
Encoder 5 Phase A	33	34	Encoder 5 Phase $\overline{A}$
Encoder 5 Phase B	35	36	Encoder 5 Phase $\overline{B}$
Encoder 5 Index	37	38	Encoder 5 $\overline{Index}$
Encoder 6 Phase A	39	40	Encoder 6 Phase $\overline{A}$
Encoder 6 Phase B	41	42	Encoder 6 Phase $\overline{B}$
Encoder 6 Index	43	44	Encoder 6 $\overline{Index}$
Common	45	46	Analog Ground
DAC 1 Vout	47	48	DAC 2 Vout
DAC 5 Vout	49	50	DAC 6 Vout

Figure B-1. First 50-Pin Motion I/O Connector Pin Assignment

+ISO	51	52	Axis 3 Forward Limit Input
Axis 3 Home Input	53	54	Axis 3 Reverse Limit Input
Encoder 3 High-Speed Input	55	56	Encoder 3 Breakpoint Output
Axis 4 Home Input	57	58	Axis 4 Forward Limit Input
Encoder 4 High-Speed Input	59	60	Axis 4 Reverse Limit Input
ISORTN	61	62	Encoder 4 Breakpoint Output
Analog Reference	63	64	A/D Channel 1
A/D Channel 2	65	66	A/D Channel 3
A/D Channel 4	67	68	A/D Channel 5
A/D Channel 6	69	70	A/D Channel 7
A/D Channel 8	71	72	Reference Ground
DAC 3 Vout	73	74	Analog Ground
DAC 4 Vout	75	76	Encoder 3 Phase $\overline{A}$
Encoder 3 Phase A	77	78	Encoder 3 Phase B
Encoder 3 Phase $\overline{B}$	79	80	Encoder 3 $\overline{Index}$
Encoder 3 Index	81	82	Encoder 4 Phase $\overline{A}$
Encoder 4 Phase A	83	84	Encoder 4 Phase $\overline{B}$
Encoder 4 Phase $\overline{B}$	85	86	Encoder 4 $\overline{Index}$
Encoder 4 Index	87	88	Common
Stepper 5 Step/CW	89	90	Stepper 5 Dir/CCW
Axis 3 $\overline{Inhibit}$	91	92	Host +5 V
Stepper 6 Step/CW	93	94	Stepper 6 Dir/CCW
Axis 4 $\overline{Inhibit}$	95	96	Common
Axis 1 $\overline{Inhibit}$	97	98	Axis 2 $\overline{Inhibit}$
Axis 5 $\overline{Inhibit}$	99	100	Axis 6 $\overline{Inhibit}$

Figure B-2. Second 50-Pin Motion I/O Connector Pin Assignment

C

Customer Communication

For your convenience, this appendix contains forms to help you gather the information necessary to help us solve your technical problems and a form you can use to comment on the product documentation. When you contact us, we need the information on the Technical Support Form and the configuration form, if your manual contains one, about your system configuration to answer your questions as quickly as possible.

National Instruments has technical assistance through electronic, fax, and telephone systems to quickly provide the information you need. Our electronic services include a bulletin board service, an FTP site, a fax-on-demand system, and e-mail support. If you have a hardware or software problem, first try the electronic support systems. If the information available on these systems does not answer your questions, we offer fax and telephone support through our technical support centers, which are staffed by applications engineers.

Electronic Services

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National Instruments has BBS and FTP sites dedicated for 24-hour support with a collection of files and documents to answer most common customer questions. From these sites, you can also download the latest instrument drivers, updates, and example programs. For recorded instructions on how to use the bulletin board and FTP services and for BBS automated information, call 512 795 6990. You can access these services at:

United States: 512 794 5422
Up to 14,400 baud, 8 data bits, 1 stop bit, no parity

United Kingdom: 01635 551422
Up to 9,600 baud, 8 data bits, 1 stop bit, no parity

France: 01 48 65 15 59
Up to 9,600 baud, 8 data bits, 1 stop bit, no parity

FTP Support

To access our FTP site, log on to our Internet host, `ftp.natinst.com`, as `anonymous` and use your Internet address, such as `joesmith@anywhere.com`, as your password. The support files and documents are located in the `/support` directories.

Fax-on-Demand Support

Fax-on-Demand is a 24-hour information retrieval system containing a library of documents on a wide range of technical information. You can access Fax-on-Demand from a touch-tone telephone at 512 418 1111.

E-Mail Support (Currently USA Only)

You can submit technical support questions to the applications engineering team through e-mail at the Internet address listed below. Remember to include your name, address, and phone number so we can contact you with solutions and suggestions.

`support@natinst.com`

Telephone and Fax Support

National Instruments has branch offices all over the world. Use the list below to find the technical support number for your country. If there is no National Instruments office in your country, contact the source from which you purchased your software to obtain support.

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Australia	03 9879 5166	03 9879 6277
Austria	0662 45 79 90 0	0662 45 79 90 19
Belgium	02 757 00 20	02 757 03 11
Brazil	011 288 3336	011 288 8528
Canada (Ontario)	905 785 0085	905 785 0086
Canada (Québec)	514 694 8521	514 694 4399
Denmark	45 76 26 00	45 76 26 02
Finland	09 725 725 11	09 725 725 55
France	01 48 14 24 24	01 48 14 24 14
Germany	089 741 31 30	089 714 60 35
Hong Kong	2645 3186	2686 8505
Israel	03 6120092	03 6120095
Italy	02 413091	02 41309215
Japan	03 5472 2970	03 5472 2977
Korea	02 596 7456	02 596 7455
Mexico	5 520 2635	5 520 3282
Netherlands	0348 433466	0348 430673
Norway	32 84 84 00	32 84 86 00
Singapore	2265886	2265887
Spain	91 640 0085	91 640 0533
Sweden	08 730 49 70	08 730 43 70
Switzerland	056 200 51 51	056 200 51 55
Taiwan	02 377 1200	02 737 4644
United Kingdom	01635 523545	01635 523154
United States	512 795 8248	512 794 5678

Technical Support Form

Photocopy this form and update it each time you make changes to your software or hardware, and use the completed copy of this form as a reference for your current configuration. Completing this form accurately before contacting National Instruments for technical support helps our applications engineers answer your questions more efficiently.

If you are using any National Instruments hardware or software products related to this problem, include the configuration forms from their user manuals. Include additional pages if necessary.

Name _____

Company _____

Address _____

_____

Fax (___) _____Phone (___) _____

Computer brand_____ Model _____Processor_____

Operating system (include version number) _____

Clock speed _____MHz RAM _____MB   Display adapter _____

Mouse ___yes ___no   Other adapters installed_____

Hard disk capacity _____MB Brand_____

Instruments used _____

_____

National Instruments hardware product model _____ Revision _____

Configuration _____

National Instruments software product _____ Version _____

Configuration _____

The problem is: _____

_____

_____

_____

_____

List any error messages: _____

_____

_____

The following steps reproduce the problem: _____

_____

_____

_____

_____

FlexMotion Hardware and Software Configuration Form

Record the settings and revisions of your hardware and software on the line to the right of each item. Complete a new copy of this form each time you revise your software or hardware configuration, and use this form as a reference for your current configuration. Completing this form accurately before contacting National Instruments for technical support helps our applications engineers answer your questions more efficiently.

National Instruments Products

Hardware revision _____

Interrupt level of hardware _____

Base I/O address of hardware _____

Programming choice _____

National Instruments software _____

Other boards in system _____

Base I/O address of other boards _____

DMA channels of other boards _____

Interrupt level of other boards _____

Other Products

Computer make and model _____

Microprocessor _____

Clock frequency or speed _____

Type of video board installed _____

Operating system version _____

Operating system mode _____

Programming language _____

Programming language version _____

Other boards in system _____

Base I/O address of other boards _____

DMA channels of other boards _____

Interrupt level of other boards _____

Documentation Comment Form

National Instruments encourages you to comment on the documentation supplied with our products. This information helps us provide quality products to meet your needs.

Title: *FlexMotion™ Hardware User Manual*

Edition Date: November 1998

Part Number: 321944A-01

Please comment on the completeness, clarity, and organization of the manual.

_____

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If you find errors in the manual, please record the page numbers and describe the errors.

_____

_____

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Thank you for your help.

Name _____

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Glossary

Prefix	Meanings	Value
p-	pico-	10^{-12}
n-	nano-	10^{-9}
μ-	micro-	10^{-6}
m-	milli-	10^{-3}
c-	centi	10^{-2}
k-	kilo-	10^{3}
M-	mega-	10^{6}

Numbers/Symbols

°	degrees
%	percent
±	plus or minus
+	positive of, or plus
−	negative of, or minus
/	per
Ω	ohm
%	percent
+5 V	+5 VDC source signal

A

A	amperes

absolute mode	treat the target position loaded as position relative to zero (0) while making a move
absolute position	position relative to zero
acceleration/ deceleration	A measurement of the change in velocity as a function of time. Acceleration and deceleration describes the period when velocity is changing from one value to another.
active-high	a signal is active when its value goes high (1)
active-low	a signal is active when its value goes low (0)
A/D	analog-to-digital
A/D Channel <1..8>	12-bit analog ADC input
address	character code that identifies a specific location (or series of locations) in memory or on a host PC bus system
amplifier	the drive that delivers power to operate the motor in response to low level control signals. In general, the amplifier is designed to operate with a particular motor type—you cannot use a stepper drive to operate a DC brush motor, for instance
API	application programming interface
axis	unit that controls a motor or any similar motion or control device
Axis <1..6> Inhibit*	axis 1 through 6 inhibit output
Axis <1..6> Forward Limit Input	axis 1 through 6 forward/clockwise limit switch
Axis <1..6> Home Input	axis 1 through 6 home input
Axis <1..6> Reverse Limit Input	axis 1 through 6 reverse/counter-clockwise limit input

B

b	bit—one binary digit, either 0 or 1

base address	memory address that serves as the starting address for programmable or I/O bus registers. All other addresses are located by adding to the base address.
binary	a number system with a base of 2
buffer	temporary storage for acquired or generated data (software)
bus	the group of conductors that interconnect individual circuitry in a computer. Typically, a bus is the expansion vehicle to which I/O or other devices are connected.
byte	eight related bits of data, an eight-bit binary number. Also used to denote the amount of memory required to store one byte of data.

C

CCW	counter-clockwise—implies direction of rotation of the motor
closed-loop	a motion system that uses a feedback device to provide position and velocity data for status reporting and accurately controlling position and velocity
common	reference signal for digital I/O
CPU	central processing unit
crosstalk	an unwanted signal on one channel due to an input on a different channel
CW	clockwise—implies direction of motor rotation

D

DAC <1..6> Vout	DAC voltage output
DC	direct current
dedicated	assigned to a particular function
DGND	digital ground signal
digital I/O port	a group of digital input/output signals
DIP	dual inline package

DLL	dynamic link library—provides the API for the motion control boards
drivers	software that communicates commands to control a specific motion control board

E

encoder	device that translates mechanical motion into electrical signals; used for monitoring position or velocity in a closed-loop system
encoder resolution	the number of encoder lines between consecutive encoder indexes (marker or Z-bit). If the encoder does not have an index output the encoder resolution can be referred to as lines per revolution.

F

f	farad
filtering	a type of signal conditioning that filters unwanted signals from the signal being measured
filter parameters	indicates the control loop parameter gains (PID gains) for a given axis
following error trip point	the difference between the instantaneous commanded trajectory position and the feedback position
freewheel	the condition of a motor when power is de-energized and the motor shaft is free to turn with only frictional forces to impede it
full-step	full-step mode of a stepper motor—for a two phase motor this is done by energizing both windings or phases simultaneously

G

Gnd	ground
GND	ground

H

half-step	mode of a stepper motor—for a two phase motor this is done by alternately energizing two windings and then only one. In half step mode, alternate steps are strong and weak but there is significant improvement in low-speed smoothness over the full-step mode.
hex	hexadecimal
home switch (input)	A physical position determined by the mechanical system or designer as the reference location for system initialization. Frequently, the home position is also regarded as the zero position in an absolute position frame of reference.
host computer	computer into which the motion control board is plugged

I

ID	identification
in.	inches
index	marker between consecutive encoder revolutions
I/O	input/output—the transfer of data to and from a computer system involving communications channels, operator interface devices, and/or motion control interfaces
interlock	5 volts bus interlock voltage
inverting	the polarity of a switch (limit switch, home switch, etc.) in *active* state. If these switches are active-low they are said to have inverting polarity.
IRQ	interrupt request
ISA	industry standard architecture, 16-bit (AT-bus) interface standard

K

k	kilo—the standard metric prefix for 1,000, or 10^3, used with units of measure such as volts, hertz, and meters
K	kilo—the prefix for 1,024, or 2^{10}, used with B in quantifying data or computer memory

L

limit switch/end-of-travel position(input)	sensors that alert the control electronics that physical end of travel is being approached and that the motion should stop

M

m	meters
microstep	The proportional control of energy in the coils of a Stepper Motor that allow the motor to move to or stop at locations other than the fixed magnetic / mechanical pole positions determined by the motor specifications. This capability facilitates the subdivision of full mechanical steps on a stepper motor into finer microstep locations that greatly smooth motor running operation and increase the resolution or number of discrete positions that a stepper motor can attain in each revolution.
modulo position	treat the target position as within the range of total quadrature counts per revolution for an axis

N

noise	an undesirable electrical signal—noise comes from external sources such as the AC power line, motors, generators, transformers, fluorescent lights, soldering irons, CRT displays, computers, electrical storms, welders, radio transmitters, and internal sources such as semiconductors, resistors, and capacitors. Noise corrupts signals you are trying to send or receive.
noninverting	the polarity of a switch (limit switch, home switch, etc.) in *active* state. If these switches are active-high, they are said to have non-inverting polarity.

O

open-loop	refers to a motion control system where no external sensors (feedback devices) are used to provide position or velocity correction signals

P

PID	proportional-integral-derivative control loop

PIVff	proportional-integral-velocity feed forward
port	(1) a communications connection on a computer or a remote controller (2) a digital port, consisting eight lines of digital input and/or output
position breakpoint	position breakpoint for an encoder can be set in absolute or relative quadrature counts. When the encoder reaches a position breakpoint, the associated breakpoint output immediately transitions.
power cycling	turning the host computer off and then back on, which causes a reset of a the motion control board
PWM	Pulse Width Modulation—a method of controlling the average current in a motors phase windings by varying the on-time (duty cycle) of transistor switches

Q

quadrature counts	the encoder line resolution times four

R

RAM	random-access memory
relative breakpoint	sets the position breakpoint for an encoder in relative quadrature counts
relative position	The destination or target position for motion specified with respect to the current location regardless of its value.
relative position mode	position relative to current position
ribbon cable	a flat cable in which the conductors are side by side
RPM	revolutions per minute—units for velocity.
RPSPS or RPS/S	revolutions per second squared—units for acceleration and deceleration.

S

s	seconds
servo	specifies an axis that controls a servo motor

stepper	specifies an axis that controls a stepper motor
stepper <5..6> Dir/CCW	direction output or counter-clockwise direction control
stepper <5..6> Step/CW	stepper pulse output or clockwise direction control

T

toggle	changing state from high to low, back to high, and so on
torque	force tending to produce rotation
trapezoidal profile	a typical motion trajectory, where a motor accelerates up to the programmed velocity using the programmed acceleration, traverses at the programmed velocity, then decelerates at the programmed acceleration to the target position
trigger	any event that causes or starts some form of data capture
TTL	transistor-transistor logic

V

V	volts
V_{CC}	positive voltage supply
velocity mode	move the axis continuously at the specified velocity

W

watchdog	a timer task that shuts down (resets) the motion control board if any serious error occurs
word	the standard number of bits that a processor or memory manipulates at one time, typically 8-, 16-, or 32-bit

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