Limited Warranty

The AMUX-64T is warranted against defects in materials and workmanship for a period of one year from the date of shipment, as evidenced by receipts or other documentation. National Instruments will, at its option, repair or replace equipment that proves to be defective during the warranty period. This warranty includes parts and labor.

The media on which you receive National Instruments software are warranted not to fail to execute programming instructions, due to defects in materials and workmanship, for a period of 90 days from date of shipment, as evidenced by receipts or other documentation. National Instruments will, at its option, repair or replace software media that do not execute programming instructions if National Instruments receives notice of such defects during the warranty period. National Instruments does not warrant that the operation of the software shall be uninterrupted or error free.

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 mechanical and electrical aspects of the AMUX-64T and contains information about configuring, operating, and programming the AMUX-64T. The AMUX-64T is a front-end analog multiplexer that quadruples the number of analog input signals that can be digitized with a National Instruments MIO board (except the AT-MIO-64). The AMUX-64T also has an integrated circuit temperature sensor that can be connected as a differential input to two of the 64 input channels (jumper-selectable) for low-cost thermocouple cold junction compensation. The AMUX-64T also has signal conditioning positions available for all 64 input channels.

Organization of This Manual

The AMUX-64T User Manual is organized as follows:

• Chapter 1, *Introduction*, describes the AMUX-64T; lists what you need to get started with your AMUX-64T; describes the software programming choices and optional equipment; and explains how to unpack your AMUX-64T.

• Chapter 2, *Configuration and Installation*, describes the configuration and installation of your AMUX-64T. The topics discussed include switch and jumper configuration, connection of the AMUX-64T board to the MIO board, power, and signal connections.

• Chapter 3, *Signal Connections*, describes the AMUX-64T signal connections and has specifications and connection instructions for the AMUX-64T connector signals.

• Chapter 4, *Signal Conditioning*, discusses signal conditioning and describes how to build systems such as filters and attenuators for passive analog input signal conditioning.

• Chapter 5, *Theory of Operation and Register-Level Programming*, contains a functional overview of the AMUX-64T and explains the operation of each functional unit making up the AMUX-64T. This
chapter also contains register-level programming information for the MIO board.

- Appendix A, *Specifications*, lists the specifications for the AMUX-64T.

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

- 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:

**bold italic** Bold italic text denotes a note, caution, or warning.

*italic* Italic text denotes emphasis, a cross reference, or an introduction to a key concept.

**E Series** E Series refers to the AT-MIO-16E-2, AT-MIO-16E-10, AT-MIO-16DE-10, AT-MIO-16XE-10, and NEC-MIO-16E-4 boards.

**MC** MC refers to the Micro Channel Series computers.


**monospace** Text in this font denotes text or characters that are to be literally input from the keyboard, sections of code, programming examples, and syntax examples. This font is also used for the proper names of disk drives, paths, directories, programs, subprograms, subroutines, device names, functions, variables, filenames, and extensions, and for statements and comments taken from program code.

**NB** NB refers to the NuBus series computers.

**PC** PC refers to the IBM PC/XT, the IBM PC AT, and compatible computers.

Abbreviations, acronyms, metric prefixes, mnemonics, symbols, and terms are listed in the *Glossary*. 
National Instruments Documentation

The AMUX-64T User Manual is one piece of the documentation set for your system. You could have any of several types of manuals, depending on the hardware and software in your system. Use the different types of manuals you have as follows:

• Your DAQ hardware user manuals—These manuals have detailed information about the DAQ hardware that plugs into or is connected to your computer. Use these manuals for hardware installation and configuration instructions, specification information about your DAQ hardware, and application hints.

• Software manuals—Examples of software manuals you may have are the LabVIEW and LabWindows® manual sets and the NI-DAQ manuals. After you set up your hardware system, use either the application software (LabVIEW or LabWindows) manuals or the NI-DAQ manuals to help you write your application. If you have a large and complicated system, it is worthwhile to look through the software manuals before you configure your hardware.

• Accessory installation guides or manuals—if you are using accessory products, read the terminal block and cable assembly installation guides or accessory board user manuals. They explain how to physically connect the relevant pieces of the system. Consult these guides when you are making your connections.

Related Documentation

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

• NIST Monograph 175: Temperature-Electromotive Force Reference Functions and Tables for the Letter-Designated Thermocouple Types Based on the ITS-90, National Institute of Standards and Technology, 1993

The following document contains information you may find helpful as you read this manual and is available from National Instruments upon request:

• Application Note 043, Measuring Temperature with Thermocouples
In addition, the National Instruments DAQ board user manuals contain information you may find helpful as you read this 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 B, *Customer Communication*, at the end of this manual.
Chapter 1
Introduction

This chapter describes the AMUX-64T; lists what you need to get started with your AMUX-64T; describes the software programming choices and optional equipment; and explains how to unpack your AMUX-64T.

About the AMUX-64T

The AMUX-64T is a front-end analog multiplexer that quadruples the number of analog input signals that can be digitized with a National Instruments MIO board (except the AT-MIO-64). The AMUX-64T has 16 separate four-to-one analog multiplexer circuits. Four AMUX-64T boards can be cascaded to digitize up to 256 single-ended or 128 differential signals by one MIO board.

The AMUX-64T has an integrated circuit temperature sensor that can be connected as a differential input to two of the 64 input channels (jumper-selectable) for low-cost thermocouple cold-junction compensation. Cold-junction compensation is achieved by adding the temperature reading of the sensor to the temperature readings of thermocouples at the remaining 62 AMUX-64T input channels. You can cascade up to four AMUX-64T boards to increase the number of thermocouple inputs with cold-junction compensation to 248 in single-ended mode or 124 in differential mode.

The AMUX-64T also has open component positions on all 64 input channels. These positions are for building signal conditioning devices such as filters and attenuators.

Note: When an MIO board is referred to without an AT, MC, NB, NEC, or SB prefix, the reference applies to the AT, MC, NB, NEC, and SB versions of that board.

The AMUX-64T is a circuitboard assembly that is placed on a workbench or mounted in a 19-in. rack. You can configure the AMUX-64T to draw power from the MIO board or from an external +5 V supply. A red LED indicates when the board is powered on. Input signal leads are attached at screw terminals.

What You Need to Get Started

To set up and use your AMUX-64T, you will need the following:

- AMUX-64T board
- AMUX-64T User Manual
- 0.2, 0.5, 1.0, or 2.0 m cable
- MIO board

Detailed specifications of the AMUX-64T are listed in Appendix A, Specifications.
Software Programming Choices

There are four options to choose from when programming your National Instruments DAQ and SCXI hardware. You can use LabVIEW, LabWindows, NI-DAQ, or register-level programming software.

Your accessory hardware kit does not include software. The AMUX-64T works with LabVIEW for Windows, LabVIEW for Macintosh, LabWindows for DOS, and LabWindows/CVI for Windows, NI-DAQ for PC compatibles, and NI-DAQ for Macintosh.

LabVIEW and LabWindows Application Software

LabVIEW and LabWindows are innovative program development software packages for data acquisition and control applications. LabVIEW uses graphical programming, whereas LabWindows enhances traditional programming languages. Both packages include extensive libraries for data acquisition, instrument control, data analysis, and graphical data presentation.

LabVIEW currently runs on four different platforms—AT/MC/EISA computers running Microsoft Windows, NEC computers running Windows, the Macintosh platform, and the Sun SPARCstation platform. LabVIEW features interactive graphics, a state-of-the-art user interface, and a powerful graphical programming language. The LabVIEW Data Acquisition VI Library, a series of VIs for using LabVIEW with National Instruments DAQ hardware, is included with LabVIEW. The LabVIEW Data Acquisition VI Libraries are functionally equivalent to the NI-DAQ software, except that the SCXI functions are not included in the LabVIEW software for Sun.

LabWindows has two versions—LabWindows for DOS is for use on PCs running DOS, and LabWindows/CVI is for use on PCs running Windows and for Sun SPARCstations. LabWindows/CVI features interactive graphics, a state-of-the-art user interface, and uses the ANSI standard C programming language. The LabWindows Data Acquisition Library, a series of functions for using LabWindows with National Instruments DAQ hardware, is included with the NI-DAQ software kit. The LabWindows Data Acquisition libraries are functionally equivalent to the NI-DAQ software except that the SCXI functions are not included in the LabWindows/CVI software for Sun.

Using LabVIEW or LabWindows software will greatly reduce the development time for your data acquisition and control application.

NI-DAQ Driver Software

The NI-DAQ driver software is included at no charge with all National Instruments DAQ hardware. NI-DAQ is not packaged with SCXI or accessory products, except for the SCXI-1200. NI-DAQ has an extensive library of functions that you can call from your application programming environment. These functions include routines for analog input (A/D conversion), buffered data acquisition (high-speed A/D conversion), analog output (D/A conversion), waveform generation, digital I/O, counter/timer operations, SCXI, RTSI, self calibration, messaging, and acquiring data to extended memory.
NI-DAQ has both high-level DAQ I/O functions for maximum ease of use and low-level data acquisition I/O functions for maximum flexibility and performance. Examples of high-level functions are streaming data to disk or acquiring a certain number of data points. An example of a low-level function is writing directly to registers on the data acquisition device. NI-DAQ does not sacrifice the performance of National Instruments data acquisition devices because it lets multiple devices operate at their peak performance—up to 500 kS/s on ISA computers and up to 1 MS/s on EISA computers.

NI-DAQ includes a Buffer and Data Manager that uses sophisticated techniques for handling and managing data acquisition buffers so that you can simultaneously acquire and process data. NI-DAQ functions for the DAQCard-DIO-24 can transfer data using interrupts or software polling.

With the NI-DAQ Resource Manager, you can simultaneously use several functions and several DAQ devices. The Resource Manager prevents multiple-device contention over DMA channels, interrupt levels, and RTSI channels.

NI-DAQ can send event-driven messages to DOS, Windows, or Windows NT applications whenever a user-specified event occurs. Thus, polling is eliminated and you can develop event-driven data acquisition applications. An example of an NI-DAQ user event is when a specified digital I/O pattern is matched.

NI-DAQ also internally addresses many of the complex issues between the computer and the DAQ hardware such as programming the PC interrupt and DMA controllers. NI-DAQ maintains a consistent software interface among its different versions so that you can change platforms with minimal modifications to your code.

Figure 1-1 illustrates the relationship between NI-DAQ and LabVIEW and LabWindows. You can see that the data acquisition parts of LabVIEW and LabWindows are functionally equivalent to the NI-DAQ software.
The National Instruments PC, AT, MC, DAQCard, and DAQPad Series DAQ hardware is packaged with NI-DAQ software for PC compatibles. NI-DAQ software for PC compatibles comes with language interfaces for Professional BASIC, QuickBASIC, Visual Basic, Borland Turbo Pascal, Turbo C++, Borland C++, Microsoft Visual C++, and Microsoft C for DOS; and Visual Basic, Turbo Pascal, Microsoft C with SDK, and Borland C++ for Windows and Microsoft Visual C++ for Windows NT. You can use your AMUX-64T, together with other PC, AT, MC, EISA, DAQCard, and DAQPad Series DAQ and SCXI hardware, with NI-DAQ software for PC compatibles.

The National Instruments NB Series DAQ boards are packaged with NI-DAQ software for Macintosh. NI-DAQ software for Macintosh comes with language interfaces for MPW C, THINK C, Pascal, and Microsoft QuickBASIC. Any language that uses Device Manager Toolbox calls can access NI-DAQ software for Macintosh. You can use NB Series DAQ boards and SCXI hardware with NI-DAQ software for Macintosh.

The National Instruments SB Series DAQ boards are packaged with NI-DAQ software for Sun, which comes with a language interface for ANSI C.
Register-Level Programming

The final option for programming any National Instruments DAQ hardware is to write register-level software. Writing register-level programming software can be very time-consuming and inefficient, and is not recommended for most users. The *only* users who should consider writing register-level software should meet at least one of the following criteria:

- National Instruments does not support your operating system or programming language.

- You are an experienced register-level programmer who is more comfortable writing your own register-level software.

Even if you are an experienced register-level programmer, always consider using NI-DAQ, LabVIEW, or LabWindows to program your National Instruments DAQ hardware. Using the NI-DAQ, LabVIEW, or LabWindows software is easier than, and as flexible as, register-level programming, and can save you weeks of development time.

The *AMUX-64T User Manual* and your software manuals contain complete instructions for programming your AMUX-64T with NI-DAQ, LabVIEW, or LabWindows. For register-level programming information, see Chapter 5, *Theory of Operation and Register-Level Programming*. If you are using NI-DAQ with LabWindows, use this manual and your LabWindows software manual. If you are using LabVIEW, use your LabVIEW manual. If you are using NI-DAQ, LabVIEW, or LabWindows to control your board, you should not need the programming information in Chapter 5, *Theory of Operation and Register-Level Programming*.

Chapter 5, *Theory of Operation and Register-Level Programming*, contains low-level programming details, such as register maps, bit descriptions, and register programming hints, that you will need only for register-level programming.

Optional Equipment

Contact National Instruments to order any of the following optional equipment:

- CB-50 I/O connector (50-screw terminals) with 0.5 or 1.0 m cable
- SCB-68 I/O connector (68-screw terminals) with 0.5 or 1.0 m cable
- SH6868 shielded cable assembly with 1, 2, 5, or 10 m cable
- SH6850 shielded cable assembly with 1, 2, 5, or 10 m cable
- R6868 1 m ribbon cable assembly
- R6850 1 m ribbon cable assembly
- Rack-mount kit with acrylic plastic cover (single- or double-height)
- Rack-mount kit with metal wraparound cover (single- or double-height)
Introduction

For more information about optional equipment available from National Instruments, refer to your National Instruments catalog or call the office nearest you.

Unpacking

Your AMUX-64T board is shipped in an antistatic package to prevent electrostatic damage to the board. Electrostatic discharge can damage several components on the board. To avoid such damage in handling the board, take the following precautions:

- Ground yourself via a grounding strap or by holding a grounded objects.
- Touch the antistatic package to a metal part of your computer chassis before removing the board from the package.
- Remove the board from the package and inspect the board for loose components or any other sign of damage. Notify National Instruments if the board appears damaged in any way. Do not install or connect a damaged board in your computer or to your MIO board.
- Never touch the exposed pins of connectors.
Chapter 2
Configuration and Installation

This chapter describes the configuration and installation of your AMUX-64T. The topics discussed include switch and jumper configuration, connection of the AMUX-64T to the MIO board, power, and signal connections.

Board Configuration

The AMUX-64T contains two sets of switches and three jumpers to change the multiplexer settings and power connection configurations of the board. These jumpers and switches are shown in Figure 2-1.

The five-position switch at U12 configures the AMUX-64T for single-board or multiple-board operation. Switch SW1 selects either the internal +5 V power from the MIO board or an external +5 V power source for the AMUX-64T. Jumper W1 optionally connects the onboard temperature sensor to Channels 0 and 32 of the AMUX-64T. Jumper W2 connects the AMUX-64T analog ground to the shield of a rack-mounted chassis. Jumper W3 connects the AMUX-64T 68-pin connector shield to the shield of a rack-mounted chassis.

Power, Temperature Sensor, and Shield Configuration

To configure the AMUX-64T board, use the three user-configurable jumpers (W1–W3) shown in the parts locator diagram, Figure 2-1. Tables 2-1 to 2-3 list the description and configuration of the user-configurable jumpers.
Figure 2-1. AMUX-64T Parts Locator Diagram
### Table 2-1. Power Supply Selection

<table>
<thead>
<tr>
<th>Switch</th>
<th>Description</th>
<th>Configuration</th>
</tr>
</thead>
<tbody>
<tr>
<td>SW1</td>
<td>INT position—Use this setting to configure the AMUX-64T to draw +5 V power through the MIO board. (factory setting)</td>
<td>Internal Power Selected</td>
</tr>
<tr>
<td></td>
<td>EXT position—Use this setting to draw +5 V power from an external supply connected to connector J41.</td>
<td>External Power Selected</td>
</tr>
</tbody>
</table>

### Table 2-2. Temperature Sensor Selection

<table>
<thead>
<tr>
<th>Jumper</th>
<th>Description</th>
<th>Configuration</th>
</tr>
</thead>
<tbody>
<tr>
<td>W1</td>
<td>CH0 and CH32 position—Use this setting to select CH0 and CH32. (factory setting)</td>
<td>Channel 0 and 32 Selected (Factory Setting)</td>
</tr>
<tr>
<td></td>
<td>Temp position—Use this setting to select the temperature sensor.</td>
<td>Temperature Sensor Selected</td>
</tr>
</tbody>
</table>
Table 2-3. Shield Selection

<table>
<thead>
<tr>
<th>Jumper</th>
<th>Description</th>
<th>Configuration</th>
</tr>
</thead>
<tbody>
<tr>
<td>W2</td>
<td>No Connect position—Use this setting to disconnect the AMUX-64T analog ground from the shield of a rack-mounted chassis. (factory setting) AIGND position—Use this setting to connect the AMUX-64T analog ground to the shield of a rack-mounted chassis.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>![Diagram]</td>
</tr>
<tr>
<td>W3</td>
<td>No Connect position—Use this setting to disconnect the AMUX-64T 68-pin connector shield from the shield of a rack-mounted chassis. (factory setting) CABLE SHLD position—Use this setting to connect the AMUX-64T 68-pin connector shield to the shield of a rack-mounted chassis.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>![Diagram]</td>
</tr>
</tbody>
</table>

Note: *The shaded area indicates the position of the jumper.*

### Supplementary Configuration Information

#### Power Supply Selection

Switch SW1 selects internal or external +5 V power for the AMUX-64T. Set SW1 to the INT position to power the AMUX-64T by drawing power through the MIO board. Set SW1 to the EXT position to draw power from an external +5 V source connected to J41.

With the exception of the MC-MIO-16, all MIO boards are capable of powering up to four AMUX-64T boards. The MC-MIO-16 has enough remaining power to start up to two AMUX-64T boards. Each AMUX-64T board typically draws 78 mA. Table 2-4 shows the amount of power the MIO boards can supply to the AMUX-64T.
Table 2-4. MIO Board Power Budget

<table>
<thead>
<tr>
<th>Board</th>
<th>Power Allotted</th>
<th>Power Used</th>
<th>Power Remaining</th>
<th>Total Number of AMUX-64Ts That Can Be Powered through MIO Board</th>
</tr>
</thead>
<tbody>
<tr>
<td>AT-MIO-16</td>
<td>no restriction*</td>
<td>1.5 A</td>
<td>1.0 A (limited by a fuse)</td>
<td>4</td>
</tr>
<tr>
<td>AT-MIO-16D</td>
<td>no restriction*</td>
<td>1.75 A</td>
<td>1.0 A (limited by a fuse)</td>
<td>4</td>
</tr>
<tr>
<td>AT-MIO-16F-5</td>
<td>no restriction*</td>
<td>1.6 A</td>
<td>1.0 A (limited by a fuse)</td>
<td>4</td>
</tr>
<tr>
<td>AT-MIO-16X</td>
<td>no restriction*</td>
<td>1.6 A</td>
<td>1.0 A (limited by a fuse)</td>
<td>4</td>
</tr>
<tr>
<td>E Series</td>
<td>no restriction*</td>
<td>1.0 A</td>
<td>1.0 A (limited by a fuse)</td>
<td>4</td>
</tr>
<tr>
<td>MC-MIO-16</td>
<td>1.6 A</td>
<td>1.4 A</td>
<td>0.2 A</td>
<td>2</td>
</tr>
<tr>
<td>NB-MIO-16</td>
<td>2.0 A</td>
<td>1.5 A</td>
<td>0.5 A</td>
<td>4</td>
</tr>
<tr>
<td>NB-MIO-16X</td>
<td>2.0 A</td>
<td>1.4 A</td>
<td>0.6 A</td>
<td>4</td>
</tr>
<tr>
<td>SB-MIO-16E-4</td>
<td>2.0 A</td>
<td>1.5 A</td>
<td>0.5 A</td>
<td>4</td>
</tr>
</tbody>
</table>

* This value depends on the computer model and configuration of other boards in the system.

Temperature Sensor

Table 2-2 shows the positions for jumper W1.

The AMUX-64T is equipped with an onboard temperature sensor for use with thermocouple cold-junction compensation. This sensor is a National Semiconductor LM-35CZ that provides a voltage output of 10 mV/°C, with an accuracy of ±1° C. The sensor is jumper-selected on differential input channel 0.

Configure the host MIO board for differential inputs if you plan to use this temperature sensor. Use jumper W1 to select either the temperature sensor or the external screw terminals as the input source for differential channel 0. The AMUX-64T is shipped from the factory with the jumpers set so that CH0 and CH32 are connected to the terminal block (the temperature sensor is not selected).

Shield Selection

The AMUX-64T is shipped from the factory with the jumpers set so that AIGND and CABLE SHLD are disconnected from CHASSIS. Table 2-3 shows the jumper W2 and jumper W3 settings.

The AMUX-64T has two optional connections that are relevant when using a rack-mount kit to mount the AMUX-64T, jumpers W2 and W3. Jumper W2 connects the analog input ground (AIGND) to the rack-mount kit. Setting this jumper to the AIGND position connects the AIGND signal to the metal standoff in the lower left corner of the board. Setting this jumper to the NC position keeps the AMUX-64T AIGND isolated from the rack.
Jumper W3 connects the shield of the 68-position connector to the rack-mount kit. Setting this jumper to the CABLE SHLD position connects the shield of the 68-position connector to the metal standoff in the lower left corner of the board. Setting this jumper to the NC position keeps the computer chassis isolated from the rack.

Both jumpers’ ground configurations may or may not be desired for your application. For most applications, you should not connect the grounds together with these jumpers. Connecting jumper W3 may cause ground currents to flow between the computer chassis and the rack-mount chassis. These currents are likely to couple noise into the analog signals in the cabling. Connecting jumper W2 may cause ground currents to flow between the MIO board AIGND signal (measurement ground) and the rack-mount chassis. These currents directly interfere with measurements made with the analog signals, especially when the MIO board is in RSE mode.

If the rack-mount chassis is floating (that is, not earth-grounded) then you should ground it. Ground the rack should via a ground strap or other recommended ways. You may ground it using jumper W3. In general, you will get the best results if all grounds and shields have exactly one conduction path to earth ground.
Single-Board and Multiple-Board Configurations

The AMUX-64T is designed so that up to four AMUX-64T boards can be daisy-chained and connected to a single MIO board, as shown in Figure 2-2. You can configure the five-position switch labeled U12 according to the number of boards daisy-chained together. This switch is also used to assign distinct channel addresses to different AMUX-64T boards. Table 2-5 lists the description and configuration of the switches.

Note: In all of the following dual in-line package (DIP) switch illustrations, the dark-shaded end of the switch is the end that you press down.

Table 2-5. Single- and Multiple-Board Configuration

<table>
<thead>
<tr>
<th>Switch</th>
<th>Description</th>
<th>Configuration</th>
</tr>
</thead>
<tbody>
<tr>
<td>U12</td>
<td>U12—Set for single-board configuration. (factory setting).</td>
<td>U12 SW1 SW2 SW3 SW4 SW5 OFF OFF OFF OFF</td>
</tr>
<tr>
<td>U12</td>
<td>U12—Set for two-board configuration.</td>
<td>U12 Board A U12 Board B</td>
</tr>
<tr>
<td>U12</td>
<td>U12—Set for four-board configuration.</td>
<td>U12 Board A U12 Board B U12 Board C U12 Board D</td>
</tr>
</tbody>
</table>
When you connect two or more AMUX-64T boards together, the multiplexers on different boards must be enabled at different times. Therefore, each board is assigned a different channel address range determined by the configuration of switch U12. The switch settings for each board configuration are given in the following sections.

### Table 2-6. Channel Ranges for Multiple AMUX-64T Boards

<table>
<thead>
<tr>
<th>Number of External Multiplexer Boards</th>
<th>Channel Range Single-Ended</th>
<th>Channel Range Differential</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>64</td>
<td>32</td>
</tr>
<tr>
<td>2</td>
<td>128</td>
<td>64</td>
</tr>
<tr>
<td>4</td>
<td>256</td>
<td>128</td>
</tr>
</tbody>
</table>

When you connect two or more AMUX-64T boards together, the multiplexers on different boards must be enabled at different times. Therefore, each board is assigned a different channel address range determined by the configuration of switch U12. The switch settings for each board configuration are given in the following sections.
Single-Board Configuration

The AMUX-64T is shipped from the factory with U12 set for single-board configuration as shown in Table 2-5.

Two-Board Configuration

For the two-board single-ended configuration, assign one board channel addresses from 0 to 63, and assign the other board channel addresses from 64 to 127. For differential operation, assign one board channel addresses 0 through 31 and assign the other board channel addresses 32 through 63. The board that you assign addresses 0 through 63 (or 0 through 31) is referred to as board A, and the board that you assign addresses 64 through 127 (or 32 through 63) is referred to as board B. You can configure any board as board A or board B, as shown in Table 2-7.

<table>
<thead>
<tr>
<th>Board</th>
<th>Channel Address Range</th>
<th>Single-Ended</th>
<th>Differential</th>
<th>SW1</th>
<th>SW2</th>
<th>SW3</th>
<th>SW4</th>
<th>SW5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Board A</td>
<td>0–63</td>
<td>0–31</td>
<td>ON</td>
<td>OFF</td>
<td>OFF</td>
<td>ON</td>
<td>OFF</td>
<td>OFF</td>
</tr>
<tr>
<td>Board B</td>
<td>64–127</td>
<td>64–95</td>
<td>OFF</td>
<td>OFF</td>
<td>ON</td>
<td>OFF</td>
<td>OFF</td>
<td>OFF</td>
</tr>
</tbody>
</table>

The switch settings for board A and board B in a two-board configuration are shown in Table 2-5.

Four-Board Configuration

For the four-board configuration, each board has a different switch setting. You assign the first board channel addresses from 0 to 63, the second board channel addresses from 64 to 127, the third board channel addresses from 128 to 191, and the fourth board channel addresses from 192 to 255. For differential operation, assign the first board channel addresses 0 through 31, the second board channel addresses 32 through 63, the third board channel addresses 64 through 95, and the fourth board channel addresses 96 through 127. The board that you assign addresses 0 through 63 (or 0 through 31) is referred to as board A; the board that you assign addresses 64 through 127 (or 32 through 63) is referred to as board B; the board that you assign addresses 128 to 191 (or 64 through 95) is referred to as board C; and the board that you assign addresses 192 through 255 (or 96 through 127) is referred to as board D. You can configure any board as board A, board B, board C, or board D, as shown in Table 2-8.
Table 2-8. U12 Switch Settings for Four-Board Configuration

<table>
<thead>
<tr>
<th>Board</th>
<th>Channel Address Range</th>
<th>Switches</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Single-Ended</td>
<td>Differential</td>
</tr>
<tr>
<td>Board A</td>
<td>0–63</td>
<td>0–31</td>
</tr>
<tr>
<td>Board B</td>
<td>64–127</td>
<td>64–95</td>
</tr>
<tr>
<td>Board C</td>
<td>128–191</td>
<td>128–159</td>
</tr>
<tr>
<td>Board D</td>
<td>192–255</td>
<td>192–223</td>
</tr>
</tbody>
</table>

The switch settings for boards A, B, C, and D in a four-board configuration are shown in Table 2-5.

Installation

Warning: *Power off all units connected to your computer before you install the AMUX-64T.*

If you have a 50-pin MIO board, connect a 50-pin ribbon cable from the 50-pin MIO board I/O connector to either connector J1 or J2 on the AMUX-64T. If you have a 68-pin MIO board, connect a 68-pin shielded or ribbon cable from the 68-pin MIO board I/O connector to J42 on the AMUX-64T.

If you use more than one AMUX-64T, you can daisy-chain the boards by connecting J1 or J2 on one AMUX-64T to J1 or J2 on another AMUX-64T, and so on (see Figure 2-2).

You can install the AMUX-64T into a 19-in. rack-mount kit as shown in Figure 2-3. If you use a round 68-pin shielded cable, route the cable as shown, leaving passage for the ribbon cable (if you use it for daisy-chaining) in the other direction.

Figure 2-3. Cable Positioning for the AMUX-64T
Power-On Sequence

If the AMUX-64T is powered by an external power source, you must turn on power to the AMUX-64T before turning on the computer. Similarly, you must turn off power to the AMUX-64T after turning off the computer. The red LED, labeled D2, indicates when power is applied to the board.
Chapter 3
Signal Connections

This chapter describes the AMUX-64T signal connections and has specifications and connection instructions for the AMUX-64T connector signals.

The following warnings contain important safety information concerning hazardous voltages.

**Warning:** Connections that exceed any of the maximum ratings of input signals on the AMUX-64T board can damage the AMUX-64T, the MIO board, or the computer. This includes connecting any power signals to ground and vice versa. Maximum input ratings are given in Appendix A, Specifications. National Instruments is NOT liable for any damages resulting from signal connections that exceed these ratings.

DO NOT OPERATE DAMAGED EQUIPMENT. The safety-protection features built into this board can become impaired if the board becomes damaged in any way. If it is damaged, disconnect power and do not use the board until service-trained personnel can check its safety. If necessary, return the board to National Instruments for service and repair to ensure that its safety is not compromised.

DO NOT SUBSTITUTE PARTS OR MODIFY EQUIPMENT. Because of the danger of introducing additional hazards, do not install unauthorized parts or modify the board. Return the board to National Instruments for service and repair to ensure that its safety features are not compromised.

**Caution:** NEVER connect a signal to screw terminals CH0–CH63 that violates their overvoltage protection limits. When the AMUX-64T is powered on, the screw terminals CH0–CH63 overvoltage protection is ±35 V; when the AMUX-64T is powered off, overvoltage protection is ±20 V.

**I/O Connector**

Connectors J1 and J2 are connected together pin by pin and have exactly the same pinout as the 50-pin MIO board I/O connector. J42 has the exact same pinout as the 68-pin MIO board I/O connector. Table 3-1 shows the pin mapping between J1, J2, and J42.
Table 3-1. Pin Mapping for I/O Connectors J1, J2, and J42

<table>
<thead>
<tr>
<th>50-Pin Connector (J1 and J2) Pin Numbers</th>
<th>68-Pin Connector (J42) Pin Numbers</th>
</tr>
</thead>
<tbody>
<tr>
<td>1, 2</td>
<td>24, 27, 29, 32, 56, 59, 64, 67</td>
</tr>
<tr>
<td>3</td>
<td>68</td>
</tr>
<tr>
<td>4</td>
<td>34</td>
</tr>
<tr>
<td>5</td>
<td>33</td>
</tr>
<tr>
<td>6</td>
<td>66</td>
</tr>
<tr>
<td>7</td>
<td>65</td>
</tr>
<tr>
<td>8</td>
<td>31</td>
</tr>
<tr>
<td>9</td>
<td>30</td>
</tr>
<tr>
<td>10</td>
<td>63</td>
</tr>
<tr>
<td>11</td>
<td>28</td>
</tr>
<tr>
<td>12</td>
<td>61</td>
</tr>
<tr>
<td>13</td>
<td>60</td>
</tr>
<tr>
<td>14</td>
<td>26</td>
</tr>
<tr>
<td>15</td>
<td>25</td>
</tr>
<tr>
<td>16</td>
<td>58</td>
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<tr>
<td>17</td>
<td>57</td>
</tr>
<tr>
<td>18</td>
<td>23</td>
</tr>
<tr>
<td>19</td>
<td>62</td>
</tr>
<tr>
<td>20</td>
<td>22</td>
</tr>
<tr>
<td>21</td>
<td>21</td>
</tr>
<tr>
<td>22</td>
<td>20</td>
</tr>
<tr>
<td>23</td>
<td>54, 55</td>
</tr>
<tr>
<td>24, 33</td>
<td>4, 7, 9, 12, 13, 15, 18, 35, 36, 39, 44, 50, 53</td>
</tr>
<tr>
<td>25</td>
<td>52</td>
</tr>
<tr>
<td>26</td>
<td>19</td>
</tr>
<tr>
<td>27</td>
<td>17</td>
</tr>
<tr>
<td>28</td>
<td>51</td>
</tr>
<tr>
<td>29</td>
<td>49</td>
</tr>
<tr>
<td>30</td>
<td>16</td>
</tr>
<tr>
<td>31</td>
<td>47</td>
</tr>
<tr>
<td>32</td>
<td>48</td>
</tr>
<tr>
<td>34, 35</td>
<td>8, 14</td>
</tr>
<tr>
<td>36</td>
<td>46</td>
</tr>
<tr>
<td>37</td>
<td>45</td>
</tr>
<tr>
<td>38</td>
<td>11</td>
</tr>
<tr>
<td>39</td>
<td>10</td>
</tr>
<tr>
<td>40</td>
<td>43</td>
</tr>
<tr>
<td>41</td>
<td>42</td>
</tr>
<tr>
<td>42</td>
<td>41</td>
</tr>
<tr>
<td>43</td>
<td>40</td>
</tr>
<tr>
<td>44</td>
<td>6</td>
</tr>
<tr>
<td>45</td>
<td>5</td>
</tr>
<tr>
<td>46</td>
<td>38</td>
</tr>
<tr>
<td>47</td>
<td>37</td>
</tr>
<tr>
<td>48</td>
<td>3</td>
</tr>
<tr>
<td>49</td>
<td>2</td>
</tr>
<tr>
<td>50</td>
<td>1</td>
</tr>
</tbody>
</table>
The signals from the AMUX-64T input connector screw terminals are connected to the MIO board via J1, J2, or J42 as shown in Figure 3-1. Observe that AISENSE is connected directly to the MIO board AISENSE pin and that AIGND on the AMUX-64T is connected to the AIGND signal of the MIO board.

Figure 3-1. AMUX-64T Signal Routing
Differential Connections

On the AMUX-64T, channels 0 through 31 are connected to channels 0 through 7 of the MIO board. AMUX-64T channels 32 through 63 are connected to channels 8 through 15 of the MIO board. If the MIO board is configured for differential mode, the AMUX-64T input channels are automatically used in differential mode. The input screw terminals on the AMUX-64T are grouped together such that for differential mode, all input signals (SIG+) and the corresponding signal return path (SIG-) input appear directly next to each other. For example, signal return path for channel 0 is channel 32, and the signal return path for channel 31 is channel 63.

Using the AMUX-64T for Thermocouple Measurements

The AMUX-64T is equipped with a temperature sensor for thermocouple cold-junction compensation. Because thermocouple output voltages are typically a few millivolts, you must use a high-gain board (any speed) for best resolution. Thermocouples may be measured in either differential or single-ended configurations. Differential connection tends to yield the best results, but single-ended connection allows twice as many thermocouples to be used on each AMUX-64T.

The cold-junction compensation is accurate only if the temperature sensor reading is close to the temperature of the screw terminals. Therefore, when thermocouples are being read, you should keep the AMUX-64T away from drafts or other temperature gradients such as those caused by heaters, radiators, fans, very warm equipment, and so on.

Selecting the Gain and Input Ranges

Since thermocouple output voltages are very low, a gain of 500 or 100 is usually necessary for best resolution. You should set the input range on the MIO board to ±5 V to improve resolution. You can use these settings in all but a few cases, such as a fairly high-output thermocouple type that is being used at elevated temperatures. Table 3-2 lists the voltage extremes from several popular thermocouple types. Use it as a guide for determining the best gain and input range settings to use. If you are using the thermocouples in a known temperature range, consult a book of thermocouple tables to determine the approximate millivolt output and the best gain and input range settings.

Caution: NEVER connect a signal to screw terminals CH0–CH63 that violates their overvoltage protection limits. When the AMUX-64T is powered on, the screw terminals CH0–CH63 overvoltage protection is ±35 V; when the AMUX-64T is powered off, overvoltage protection is ±20 V.
Table 3-2. Thermocouple Voltage Output Extremes (mV)\(^1\)

<table>
<thead>
<tr>
<th>Thermocouple</th>
<th>Low</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>J</td>
<td>-8.095 at -210° C(^2)</td>
<td>69.553 at 1,200° C(^2)</td>
</tr>
<tr>
<td>K</td>
<td>-6.458 at -270° C</td>
<td>54.886 at 1,372° C</td>
</tr>
<tr>
<td>E</td>
<td>-9.835 at -270° C</td>
<td>76.373 at 1,000° C</td>
</tr>
<tr>
<td>T</td>
<td>-6.258 at -270° C</td>
<td>20.872 at 400° C</td>
</tr>
<tr>
<td>S</td>
<td>-0.236 at -50° C</td>
<td>18.693 at 1,768° C</td>
</tr>
<tr>
<td>R</td>
<td>-0.226 at -50° C</td>
<td>21.101 at 1,768° C</td>
</tr>
<tr>
<td>B</td>
<td>-0.000 at 0° C</td>
<td>13.820 at 1,820° C</td>
</tr>
</tbody>
</table>


\(^2\) All temperatures are the difference between the measuring end and the cold junction, or AMUX-64T screw terminals in this case.

## Linearizing the Data

Thermocouple output voltages are highly nonlinear. The *Seebeck coefficient*, or voltage change per degree of temperature change, can vary by a factor of three or more over the operating temperature range of some thermocouples. For this reason, the temperature from thermocouple voltages must either be approximated by often complex polynomials or matched against a look-up table. The polynomial approach is easier to use, but it trades measurement time for memory usage. The polynomials are in the following form:

\[
T = a_0 + a_1 x + a_2 x^2 + ... + a_n x^n
\]

where \(x\) is the thermocouple voltage in volts, \(T\) is the temperature difference between the measuring end and the AMUX-64T screw terminals in degrees Celsius, and \(a_0\) through \(a_n\) are coefficients that are specific to each thermocouple type. To speed computation time, a polynomial should be computed in nested form. Consider the following fourth order polynomial:

\[
T = a_0 + a_1 x + a_2 x^2 + a_3 x^3 + a_4 x^4
\]

If this polynomial is evaluated as it is written, then several extra multiplications will be performed to raise \(x\) to the various powers. If the polynomial is instead written as follows:

\[
T = a_0 + x(a_1 + x(a_2 + x(a_3 + xa_4)))
\]

and evaluated this way, then no powers are computed, and execution proceeds much faster. Table 3-3 lists the National Institute of Standards and Technology (NIST) polynomial coefficients for several popular thermocouples.
### Table 3-3. NIST Polynomial Coefficients

<table>
<thead>
<tr>
<th>Type</th>
<th>E</th>
<th>E</th>
<th>J</th>
<th>J</th>
<th>T</th>
<th>T</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temp. Range</td>
<td>-200°C to 0°C</td>
<td>0°C to 1000°C</td>
<td>-210°C to 0°C</td>
<td>0°C to 760°C</td>
<td>-200°C to 0°C</td>
<td>0°C to 400°C</td>
</tr>
<tr>
<td></td>
<td>±0.03°C to -0.01°C</td>
<td>±0.02°C</td>
<td>±0.03°C to -0.05°C</td>
<td>±0.04°C</td>
<td>±0.03°C to -0.02°C</td>
<td>±0.03°C</td>
</tr>
<tr>
<td>c0</td>
<td>0.0000000</td>
<td>0.0000000</td>
<td>0.0000000</td>
<td>0.0000000</td>
<td>0.0000000</td>
<td>0.0000000</td>
</tr>
<tr>
<td>c1</td>
<td>1.6977288E-2</td>
<td>1.7057035E-2</td>
<td>1.9528628E-2</td>
<td>1.7978425E-2</td>
<td>2.5949192E-2</td>
<td>2.592800E-2</td>
</tr>
<tr>
<td>c2</td>
<td>-4.3514970E-7</td>
<td>-2.3301759E-7</td>
<td>-1.2281638E-6</td>
<td>-2.001204E-7</td>
<td>-2.1316967E-7</td>
<td>-7.602961E-7</td>
</tr>
<tr>
<td>c3</td>
<td>-1.585967E-10</td>
<td>6.5435585E-12</td>
<td>-1.0752178E-9</td>
<td>1.036969E-11</td>
<td>7.9018692E-10</td>
<td>6.437791E-11</td>
</tr>
<tr>
<td>c5</td>
<td>-2.6084314E-17</td>
<td>-1.789601E-21</td>
<td>-1.7256713E-16</td>
<td>3.585153E-21</td>
<td>1.3304473E-16</td>
<td>6.084144E-20</td>
</tr>
<tr>
<td>c6</td>
<td>-1.3601999E-21</td>
<td>8.403639E-26</td>
<td>-1.7567136E-16</td>
<td>2.5949192E-21</td>
<td>2.024144E-16</td>
<td>-7.293422E-25</td>
</tr>
<tr>
<td>c9</td>
<td>1.0000000</td>
<td>1.334584505E + 1</td>
<td>0.0000000</td>
<td>1.334584505E + 1</td>
<td>0.0000000</td>
<td>0.0000000</td>
</tr>
<tr>
<td>c10</td>
<td>1.8891380E-1</td>
<td>1.472644573E - 1</td>
<td>1.84949460E - 1</td>
<td>1.466298863E - 1</td>
<td>2.5173462E - 2</td>
<td>2.508355E - 2</td>
</tr>
<tr>
<td>c11</td>
<td>-9.3835290E - 5</td>
<td>-1.844024844E - 5</td>
<td>-8.00504062E - 5</td>
<td>-1.534713402E - 5</td>
<td>-1.1662878E - 6</td>
<td>-7.293422E - 25</td>
</tr>
<tr>
<td>c12</td>
<td>1.0368619E - 7</td>
<td>1.0237343E - 7</td>
<td>3.145949573E - 9</td>
<td>1.0833638E - 9</td>
<td>1.268171E - 14</td>
<td>-2.793422E - 25</td>
</tr>
<tr>
<td>c15</td>
<td>-3.8953900E - 16</td>
<td>-4.58750426E - 21</td>
<td>-1.59085941E - 16</td>
<td>-1.291637500E - 21</td>
<td>-8.6632643E - 20</td>
<td>1.057734E - 20</td>
</tr>
<tr>
<td>c16</td>
<td>2.8239471E - 19</td>
<td>8.2302788E - 20</td>
<td>2.183475087E - 26</td>
<td>-1.0450598E - 23</td>
<td>-4.413030E - 26</td>
<td>1.057734E - 20</td>
</tr>
<tr>
<td>c17</td>
<td>-1.2607281E - 22</td>
<td>-5.313401790E - 30</td>
<td>-2.34181944E - 23</td>
<td>-1.44739515E - 31</td>
<td>-5.1920577E - 28</td>
<td>-1.052755E - 35</td>
</tr>
</tbody>
</table>

These polynomials are accurate only within the temperature ranges specified. Also, all terms must be included to achieve the specified accuracy.

To avoid the long computation time required for these high-order polynomials, the operating range of a thermocouple can be subdivided into several smaller ranges. Each of the smaller ranges can then be approximated by a much lower order polynomial (i.e., third or fourth degree). Further examples of polynomials, including lower order polynomials for subdivided temperature ranges, can be found in *NIST Monograph 175: Temperature-Electromotive Force Reference Functions and Tables for the Letter-Designated Thermocouple Types Based on the ITS-90*.

### Differential Measurements

Connect the temperature sensor to channel 0 and channel 32 (differential channel 0) by configuring jumper W1 as shown in Table 2-2. Connect the thermocouples to the appropriate pairs of input channel screw terminals (for example, CH1 and CH33, CH2 and CH34, and so on). Notice that some thermocouples, such as those from Omega Engineering, have red insulation on the negative terminal. Check with the vendor to determine the output polarity of any particular
thermocouple. Since thermocouples are floating signal sources, you must attach a bias return resistor between the negative channel and ground, which is connected to the MIO board AIGND (analog input ground) pin. The signal path of each channel has component locations for such resistors. Refer to the Connecting Nonreferenced or Floating Signal Sources section of Chapter 4, Signal Conditioning, for the resistor component locations. For more information about signal sources and their connections, see the configuration chapter of the user manual that came with your MIO board.

An Example of Using Thermocouples (Differential or Single-Ended)

For this example, assume that a J-type thermocouple is connected to differential channel 1 and is being used to measure a high-pressure boiler system. The maximum temperature that can be reached is 300° C. Before taking readings, it is necessary that you configure the MIO board for the maximum resolution possible. A thermocouple table shows that the output voltage will never exceed 16 to 17 mV (recall that the exact voltage measured is a function of the AMUX-64T temperature as well as the temperature being measured). Therefore, you could select either a ±5 V input range with a gain of 100 (±50 mV maximum signal) or a ±10 V input range with a gain of 500 (±20 mV maximum signal). In this case, the ±10 V input range with a gain of 500 gives the best resolution. Set the jumpers on the MIO board for differential input, ±10 V input range.

Note: Set jumper W1 on the AMUX-64T to select the temperature sensor, and connect the thermocouple to CH1 and CH33. Connect a resistor between CH33 and GND for the bias current return path.

Set the jumpers on the MIO board for single-ended input, ±10 V input range. Set jumper W1 on the AMUX-64T to select the temperature sensor, and connect the thermocouple to CH1.

Two software compensation procedures for this example follow. Procedure 1 is more accurate, but procedure 2 is faster and requires less computation.

Procedure 1

1. Read the voltage from the temperature sensor (channel 0). If you are using NI-DAQ, you can use the AI_Read and AI_Scale functions to do the reading. This voltage is 10 mV/°C, so the gain should be either 1 or 10 (10 for the best resolution). Multiply the voltage by 100 to get the AMUX-64T temperature in degrees Celsius. For example, if the reading is 0.25 V, then the AMUX-64T is at 25° C.
2. Translate the reading into the voltage for a J-type thermocouple at that temperature using either a look-up table or an NIST polynomial. Notice that the polynomials required here are the *inverses* of those given in Table 3-3. For your reading of 25°C, you would have 1.277 mV.

3. Read the voltages on any thermocouple channels. If you are using NI-DAQ, you can use the `AI_Read` and `AI_Scale` functions to read each channel. For the example given, assume that you get a reading of 9.39 mV on channel 1.

4. Add the voltage from step 2 to the voltage measured in step 3. You then have:

   \[ 1.277 + 9.39 = 10.667 \text{ mV} \]

5. Translate the result into a temperature using either a look-up table or a polynomial such as one from Table 3-3. For example, assume that the reading from the J-type thermocouple is 10.667 mV. By applying the third formula in the *Linearizing the Data* section and using the coefficients from Table 3-3, you can calculate that the temperature is 198°C.

### Procedure 2

1. Read the voltage from the temperature sensor (channel 0). If you are using NI-DAQ, you can use the `AI_Read` and `AI_Scale` functions to do the reading. This voltage is 10 mV/°C, so the gain should be either 1 or 10 (10 for the best resolution). Multiply the voltage by 100 to get the AMUX-64T temperature in degrees Celsius. For example, if the reading is 0.25 V, then the AMUX-64T is at 25°C.

2. Read the voltages on any thermocouple channels. If you are using NI-DAQ, you can use the `AI_Read` and `AI_Scale` functions to read each channel, or you can use the `SCAN` functions to scan all the channels at once. If you use the `SCAN` functions, use a sample interval of 100 μs between channels. For the example given, the gain is at 500 for channel 1. Other thermocouple types may require other gains.

3. Translate the reading into a temperature using either a look-up table or a polynomial such as one from Table 3-3. For example, when reading 9.39 mV from a type J thermocouple, the temperature is 175°C.

4. Add the cold-junction temperature from step 1 to the temperature obtained in the previous step. This result is the temperature at the measuring end of the thermocouple. For the example given, the temperature is 175°C + 25°C = 200°C.

### Comments

Procedure 1 is more accurate, but it requires two temperature-voltage conversions. Procedure 2 is faster, but introduces an error of 2°C. To determine if the error from procedure 2 is acceptable or not in your application, you can work through some examples both ways. Use a thermocouple reference table and consider voltages and temperatures close to those in your application.
Single-Ended Measurement

Connect the temperature sensor to channels 0 and 32 by configuring jumper W1 as shown in Table 2-2. Connect the positive leads of the thermocouples to any AMUX-64T input channels except CH0 and CH32. Connect the negative leads to GND. Notice that some thermocouples, such as those from Omega Engineering, have red insulation on the negative terminal. Check with the vendor to determine the output polarity of any particular thermocouple. Configure the MIO board for ground-referenced, single-ended inputs. For more information about signal sources and their connections, see the Signal Connections chapter of the user manual that came with your MIO board.

Using More Than One AMUX-64T

Two cold-junction compensation options are possible when thermocouples are being used with two or more AMUX-64T boards connected to one MIO board. If all AMUX-64T boards are at approximately the same temperature, then only one needs to have the temperature sensor connected to channels 0 and 32. These two channels on the other boards are then free for more thermocouples. If the AMUX-64T boards are not at approximately the same temperature, then you should use the temperature sensor on each AMUX-64T. Using the temperature sensors on each board reduces the chance of cold-junction compensation error, but it does increase software overhead and reduce the number of channels available for general use.

If you use two AMUX-64T boards, the sensors will appear at channel 0 for board A and channel 64 for board B. If you use four AMUX-64T boards, the sensors will appear at channel 0 for board A, channel 64 for board B, channel 128 for board C, and channel 192 for board D (see the Single-Board and Multiple-Board Configurations section earlier in this chapter).

Sources of Error

There are several major sources of error when making thermocouple measurements with the AMUX-64T and an MIO board. These sources of error are compensation, linearization, measurement, and thermocouple wire errors.

Compensation error can arise from two sources, inaccuracy of the temperature sensor and temperature differences between the sensor and the screw terminals. The sensor on the AMUX-64T is specified to be accurate to ±1° C. You can minimize temperature differences between the sensor and the screw terminals by keeping the AMUX-64T away from drafts, heaters, warm equipment, and so on. Linearization error is a consequence of the fact that the polynomials are by nature approximations of the true thermocouple output. The linearization error is dependent on the degree of polynomial used. Table 3-3 lists the linearization errors for the NIST polynomials.
Measurement error is the result of inaccuracies in the MIO board. These include gain and offset errors. If the board is properly calibrated, the offset error should be zeroed out. The only remaining error is a gain error of ±0.08% of full range (see the MIO board specifications). If the input range is ±10 V and the gain is 500, then gain error will contribute 0.0008 x 20 mV, or 16 µV of error. If the Seebeck coefficient of a thermocouple is 32 µV/°C, then this measurement error will add 0.5° C of uncertainty to the measurement. For best results, use a well-calibrated MIO board so that you can ignore offsets.

You can eliminate offset error, however, by grounding one channel on the AMUX-64T and measuring it. This value is the offset of the MIO board, and it can then be subtracted in software from all other readings. For the best results, you should use an average of many readings (about 100 or so). When you take these measures, typical accuracies are about ±2° C.

Finally, thermocouple wire error is caused by inhomogeneities in the thermocouple manufacturing process. These errors vary widely depending on the thermocouple type and even the gauge of wire used, but a value of ±2° C is typical. For more information on thermocouple wire errors and more specific data, see Application Note 043, Measuring Temperature with Thermocouples.

**Thermocouple Measurement Accuracies**

Table 3-4 lists the expected thermocouple accuracies in degrees Celsius, subject to the following conditions:

- The MIO board must be correctly calibrated.
- The temperature of the screw terminals equals the temperature of the board (no gradients on the board).

The uncertainties listed apply at either 0° C (Type J, K, E, T) or 600° C (Type S, R). The linearization errors of the NIST polynomials in Table 3-2, measurement error of a calibrated MIO board, and the ±1° C cold-junction sensor error are included. Thermocouple wire error is neglected because of dependence on several factors as listed above. Finally, these uncertainties are for the gains listed with a ±10 V input range.

<table>
<thead>
<tr>
<th>Gain</th>
<th>J</th>
<th>K</th>
<th>E</th>
<th>T</th>
<th>S</th>
<th>R</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>±2.7° C</td>
<td>±3.7° C</td>
<td>±2.9° C</td>
<td>±3.6° C</td>
<td>±9.8° C</td>
<td>±8.5° C</td>
</tr>
<tr>
<td>500</td>
<td>±1.4° C</td>
<td>±2.1° C</td>
<td>±1.8° C</td>
<td>±1.9° C</td>
<td>±3.6° C</td>
<td>±2.9° C</td>
</tr>
</tbody>
</table>

**Other Connection Considerations**

Refer to the sections titled Analog Input Signal Connections and Cabling and Field Wiring in the Signal Connections chapter of the user manual that came with your MIO board for additional signal connection information.
Chapter 4
Signal Conditioning

This chapter discusses signal conditioning and describes how to build systems such as filters and attenuators for passive analog input signal conditioning.

Analog Input

Each differential analog input has seven open positions for signal conditioning components. Six of these positions are designated as resistors, and one is designated as a capacitor. The board is shipped with jumpers in two positions for each input. The equivalent circuit of one input is shown in Figure 4-1. You can use the board when the MIO board is configured for both 16 single-ended inputs and eight differential inputs. For thermocouple and other low-level applications, you can obtain best results when using differential inputs. For specific applications illustrating signal conditioning with both single-ended and differential inputs, refer to Application Notes later in this chapter.

Figure 4-1. Onboard Equivalent Circuit
The components are numbered differently for each channel. Table 4-1 lists the components in each channel and their correspondence to the circuit shown in Figure 4-1.

Table 4-1. Component Positions in Each Channel

<table>
<thead>
<tr>
<th>Channel</th>
<th>Differential (Positions in Figure 4-1)</th>
<th>(Positions in Figure 4-1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>(0, 32)</td>
<td>R1 R2 R3 R4 R65 R66 C3</td>
</tr>
<tr>
<td>1</td>
<td>(1, 33)</td>
<td>R5 R6 R7 R8 R67 R68 C4</td>
</tr>
<tr>
<td>2</td>
<td>(2, 34)</td>
<td>R9 R10 R11 R12 R69 R70 C5</td>
</tr>
<tr>
<td>3</td>
<td>(3, 35)</td>
<td>R13 R14 R15 R16 R71 R72 C6</td>
</tr>
<tr>
<td>4</td>
<td>(4, 36)</td>
<td>R17 R18 R19 R20 R73 R74 C7</td>
</tr>
<tr>
<td>5</td>
<td>(5, 37)</td>
<td>R21 R22 R23 R24 R75 R76 C8</td>
</tr>
<tr>
<td>6</td>
<td>(6, 38)</td>
<td>R25 R26 R27 R28 R77 R78 C9</td>
</tr>
<tr>
<td>7</td>
<td>(7, 39)</td>
<td>R29 R30 R31 R32 R79 R80 C10</td>
</tr>
<tr>
<td>8</td>
<td>(8, 40)</td>
<td>R33 R34 R35 R36 R81 R82 C11</td>
</tr>
<tr>
<td>9</td>
<td>(9, 41)</td>
<td>R37 R38 R39 R40 R83 R84 C12</td>
</tr>
<tr>
<td>10</td>
<td>(10, 42)</td>
<td>R41 R42 R43 R44 R85 R86 C13</td>
</tr>
<tr>
<td>11</td>
<td>(11, 43)</td>
<td>R45 R46 R47 R48 R87 R88 C14</td>
</tr>
<tr>
<td>12</td>
<td>(12, 44)</td>
<td>R49 R50 R51 R52 R89 R90 C15</td>
</tr>
<tr>
<td>13</td>
<td>(13, 45)</td>
<td>R53 R54 R55 R56 R91 R92 C16</td>
</tr>
<tr>
<td>14</td>
<td>(14, 46)</td>
<td>R57 R58 R59 R60 R93 R94 C17</td>
</tr>
<tr>
<td>15</td>
<td>(15, 47)</td>
<td>R61 R62 R63 R64 R95 R96 C18</td>
</tr>
<tr>
<td>16</td>
<td>(16, 48)</td>
<td>R129 R130 R131 R132 R97 R98 C37</td>
</tr>
<tr>
<td>17</td>
<td>(17, 49)</td>
<td>R133 R134 R135 R136 R99 R100 C38</td>
</tr>
<tr>
<td>18</td>
<td>(18, 50)</td>
<td>R137 R138 R139 R140 R101 R102 C39</td>
</tr>
<tr>
<td>19</td>
<td>(19, 51)</td>
<td>R141 R142 R143 R144 R103 R104 C40</td>
</tr>
<tr>
<td>20</td>
<td>(20, 52)</td>
<td>R145 R146 R147 R148 R105 R106 C41</td>
</tr>
<tr>
<td>21</td>
<td>(21, 53)</td>
<td>R149 R150 R151 R152 R107 R108 C42</td>
</tr>
<tr>
<td>22</td>
<td>(22, 54)</td>
<td>R153 R154 R155 R156 R109 R110 C43</td>
</tr>
<tr>
<td>23</td>
<td>(23, 55)</td>
<td>R157 R158 R159 R160 R111 R112 C44</td>
</tr>
<tr>
<td>24</td>
<td>(24, 56)</td>
<td>R161 R162 R163 R164 R113 R114 C45</td>
</tr>
<tr>
<td>25</td>
<td>(25, 57)</td>
<td>R165 R166 R167 R168 R115 R116 C46</td>
</tr>
<tr>
<td>26</td>
<td>(26, 58)</td>
<td>R169 R170 R171 R172 R117 R118 C47</td>
</tr>
<tr>
<td>27</td>
<td>(27, 59)</td>
<td>R173 R174 R175 R176 R119 R120 C48</td>
</tr>
<tr>
<td>28</td>
<td>(28, 60)</td>
<td>R177 R178 R179 R180 R121 R122 C49</td>
</tr>
<tr>
<td>29</td>
<td>(29, 61)</td>
<td>R181 R182 R183 R184 R123 R124 C50</td>
</tr>
<tr>
<td>30</td>
<td>(30, 62)</td>
<td>R185 R186 R187 R188 R125 R126 C51</td>
</tr>
<tr>
<td>31</td>
<td>(31, 63)</td>
<td>R189 R190 R191 R192 R127 R128 C52</td>
</tr>
</tbody>
</table>
When the board is shipped, jumpers are inserted in the E and F positions of the input network (see Figure 4-1). You can easily remove these jumpers to build analog input signal conditioning circuits. Several applications showing the use of these open component positions are discussed in the next section, Application Notes.

Application Notes

The open component positions on the AMUX-64T board make adding signal conditioning components to the analog input signals easier. Several applications are covered in this section, including filtering and attenuation.

The figures in this section give examples on a specific input channel. If you want to install the circuit on a different channel, consult Table 4-1 to determine the equivalent component positions for the other channels.

Soldering and Desoldering on the AMUX-64T Board

The following applications require you to make modifications to the printed circuit board, usually in the form of removing jumpers and adding components. The AMUX-64T board is shipped with wire jumpers in the E and F positions (see Table 4-1 and Figure 4-1).

**Note:** Remove the plastic insulator on the bottom of the AMUX-64T before removing wire jumpers or adding components to the board. To remove the insulator, unscrew the standoffs from the top of the board; the insulator and standoffs should fall off. Replace the insulator and standoffs after completing your modifications to the board.

Use a low-wattage soldering iron (20 to 30 W) when soldering to the board. To desolder on the AMUX-64T, use vacuum-type tools for best results. Use care when desoldering to avoid damaging component pads. You should use only rosin-core electronic-grade solder. Acid-core solder damages the printed circuit board and components.

Channel Configurations

You can configure the analog input channels of an MIO DAQ board for one of three input modes: differential input, referenced single-ended input, or nonreferenced single-ended. These modes may be referred to as DIFF, RSE, and NRSE input modes, respectively.

As described in Chapter 2, Configuration and Installation, of your MIO user manual, the input configuration of the MIO board depends on the type of signal source. There are two types of signal sources: nonreferenced or floating signals and ground-referenced signals. To measure floating signal sources, configure the MIO board for referenced single-ended input or differential input with bias resistors. To measure ground-referenced signal sources, configure the MIO board for non-referenced single-ended input or differential input. Both types of signal sources and the recommended methods for MIO board connection are discussed as follows.
Connecting Nonreferenced or Floating Signal Sources

A floating signal source is a signal source that is not connected in any way to the building ground system, but has an isolated ground-reference point. If an instrument or device has an isolated output, that instrument or device falls into the floating signal source category. Some examples of floating signal sources are outputs for the following: thermocouples, transformers, battery-powered devices, optical isolators, and isolation amplifiers. You must tie the ground reference of a floating source to the ground of the DAQ board to establish a local or onboard reference for the signal.

Differential Inputs

To provide a return path for the instrumentation amplifier bias currents, floating sources must have a resistor connected to AIGND on one input if the signal is DC-coupled, or both inputs if the signal is AC-coupled. For more detailed information on connections to floating signal sources and differential inputs, refer to the configuration chapter in the user manual that came with your MIO board.

You can install these bias resistors in positions B and D (Table 4-1 and Figure 4-1) of the AMUX-64T board. Figure 4-2 shows both the schematic and the component placement for a single 100-kΩ bias return resistor on the negative input from a floating source connected to channel 1 (the D position in Table 4-1). You can build additional signal conditioning circuitry, such as filters and attenuators (described in Building Lowpass Filters, Building Highpass Filters, and Building Attenuators later in this chapter), in the open component positions.

![Bias Return Resistor for DC-Coupled Floating Source on Channel 1](image-url)
Single-Ended Inputs

When measuring floating signal sources, you should configure the MIO board to supply a ground reference. Therefore, you should configure the MIO board for referenced single-ended input. In this configuration, the negative input of the MIO board instrumentation amplifier is tied to the analog ground. Therefore, you should use the AMUX-64T board in its factory configuration. In the factory configuration, jumpers are in the two series positions, E and F (see Table 4-1). In this configuration, you should tie all of the signal grounds to AIGND. You can build signal conditioning circuitry such as filters and attenuators (described in Building Lowpass Filters, Building Highpass Filters, and Building Attenuators later in this chapter) in the open component positions.

Connecting Ground-Referenced Signal Sources

A grounded signal source is connected in some way to the building system ground; therefore, the signal source is already connected to a common ground point with respect to the DAQ board (assuming the host computer is plugged into the same power system). Nonisolated outputs of instruments and devices that plug into the building power system fall into this category.

Differential Inputs

If the MIO DAQ board is configured for differential inputs, ground-referenced signal sources connected to the AMUX-64T board need no special components added to the AMUX-64T board. You can leave the inputs of the AMUX-64T board in the factory-original condition, that is, with only jumpers in the two series positions, E and F (see Table 4-1). You can build signal conditioning circuitry, such as filters and attenuators (described in Building Lowpass Filters, Building Highpass Filters, and Building Attenuators later in this chapter), in the open component positions.

Single-Ended Inputs

When measuring ground-referenced signals, the external signal supplies its own reference ground point and the MIO board should not supply one. Therefore, you should configure the MIO board for nonreferenced single-ended input mode. In this configuration, you should tie all of the signal grounds to AISENSE, which connects to the negative input of the instrumentation amplifier on the MIO board. You can leave the inputs of the AMUX-64T board in the factory-default condition, that is, with jumpers in the series position (E or F, depending on the channel). You should not use the open positions that connect the input to AIGND, B and D (see Table 4-1 and Figure 4-1) in this configuration. Therefore, you should not build signal conditioning circuitry requiring a ground reference in the open component positions. Referencing the signal to AIGND can cause inaccurate measurements resulting from an incorrect ground reference.

Caution: NEVER connect a signal to screw terminals CH0–CH63 that violates their overvoltage protection limits. When the AMUX-64T is powered on, the screw terminals CH0–CH63 overvoltage protection is ±35 V; when the AMUX-64T is powered off, overvoltage protection is ±20 V.
Building Lowpass Filters

You can easily install simple resistance-capacitance (RC) lowpass filters in the AMUX-64T board on any differential input channel. The filters are useful for accurate measurement and noise rejection. By substituting resistance and capacitance values into the following formula (hereafter referred to as Formula 4-1), you can calculate a simple, one-pole RC filter to have a -3 dB point \( f_c \) or cutoff frequency:

\[
f_c = \frac{1}{(2\pi RC)}
\]  
(Formula 4-1)

The frequency response rolls off at a rate of -20 dB per decade of increase thereafter. A Bode plot of the amplitude versus normalized frequency is shown in Figure 4-3.

![Figure 4-3. Normalized Frequency Response of Lowpass Filter](image)

When measuring low-frequency signals (about 4 Hz), if you have 400-Hz noise on your inputs, you can add a lowpass filter with a cutoff frequency of 4 Hz. The 400 Hz noise then attenuates by 40 dB. Notice that your 4-Hz signal also attenuates, but by only 3 dB. Do not neglect any potential attenuation of signals of interest by this low-order filter.

You must also choose the filter component values. You can select the resistance or the capacitance arbitrarily; one value determines the other. Picking the capacitor first and letting its value determine the resistance required is preferable because more standard resistor values are available.

If a capacitance of 1 \( \mu \)F is available, the resistance is (by substitution into the formula) 39,789 \( \Omega \), or about 39.8 k\( \Omega \). This resistance must be divided by two to get the resistor value on each input of a differential channel. Therefore, in this example, each input has a 19.89-k\( \Omega \) resistor (or closest standard value) in its series positions, \( E \) and \( F \).

The closest standard 5% tolerance resistors are 20 k\( \Omega \). The closest standard 0.5% resistors are 19.8 k\( \Omega \). National Instruments recommends using 1% or better tolerance resistors in this application because differences between the resistor values degrade the common-mode rejection ratio. Figure 4-4 shows both the schematic and the component placement for a 4-Hz lowpass
filter placed on differential input channel 1. If the input signal source is floating, you must place a bias return resistor in the \( D \) position (\( R8 \) in this case).

Do not install RC lowpass filters on the AMUX-64T board open component locations when the MIO board is configured for single-ended inputs.

![Input Schematic](image.png)

**Figure 4-4. Lowpass Filter on Differential Channel 1**

### Building Highpass Filters

You can easily install simple RC highpass filters in the AMUX-64T board on any differential input channel. The filters are useful for accurate high-frequency measurement and low-frequency noise rejection. By substituting resistance and capacitance values into the following formula, (hereafter referred to as Formula 4-2), you can calculate a simple, one-pole R-C filter to have a -3 dB point (\( f_c \) or cutoff frequency):

\[
 f_c = \frac{1}{2\pi RC} \quad \text{(Formula 4-2)}
\]
The frequency response rolls off at a rate of -20 dB per decade decrease thereafter. A Bode plot of the amplitude versus normalized frequency is shown in Figure 4-5.

![Figure 4-5. Normalized Frequency Response of Highpass Filter](image)

When measuring high-frequency signals (about 50 kHz), if you have 50-Hz noise on your inputs, you can add a highpass filter with a cutoff frequency of 50 kHz. The 50-Hz noise then attenuates by 60 dB. Notice that your 50-kHz signal also attenuates, but by only 3 dB. Do not neglect any potential attenuation of signals of interest if you add a low-order filter.

You must also choose the filter component values. You can select the resistance or the capacitance arbitrarily; one value determines the other. Picking the capacitor first and letting its value determine the resistance required is preferable because more standard resistor values are available.

The filter circuit has one series capacitor on each input of the differential channel. Because the two capacitors are in series, the capacitance value that must be substituted into Formula 4-2 is the series capacitance of the two capacitors in series. For two capacitors in series, the net capacitance is the reciprocal of the sum of the reciprocals of the two capacitances. For example, two 0.001 μF capacitors in series have a net capacitance of 0.0005 μF. The two capacitors should be the same value, or the common-mode rejection is degraded. If capacitors of 0.001 μF are available, the resistance is (by substitution into Formula 4-2) 6,366 Ω, or about 6.4 kΩ. Therefore, in this example, the input channel has a 6.37-kΩ resistor (or closest standard value) in its capacitor position, G.

The closest standard 5% tolerance resistors are 6.2 kΩ. The closest standard 1% resistors are 6.34 kΩ. Figure 4-6 shows both the schematic and the component placement for a 50-kHz highpass filter placed on differential input channel 1. If the input signal source is floating, you must place a bias return resistor in the D position (R8 in this case).
Note: Highpass filters generally exhibit poorer common-mode rejection characteristics than lowpass filters because capacitors are in the series input paths. Capacitors have poorer tolerances than resistors, and matching of the input impedances is crucial for good common-mode rejection.

Do not install RC highpass filters on the AMUX-64T board open component locations when the MIO board is configured for single-ended inputs.

![Highpass Filter on Differential Channel 1](image)

**Building Attenuators (Voltage Dividers)**

You can connect attenuators (voltage dividers) to the analog inputs of the AMUX-64T board when the inputs from its DAQ board are in differential mode. Do not install voltage dividers on the AMUX-64T board open component locations when the MIO board is configured for single-ended inputs. You can use attenuators to reduce a signal that is outside the normal input range of the DAQ board (±10 V max).

Warning: The AMUX-64T board is not designed for any input voltages greater than 42 V, even if a user-installed voltage divider reduces the voltage to within the input range of the DAQ board. Input voltages greater than 42 V can result in damage to the AMUX-64T board, any and all boards connected to it, and the host.
computer. Overvoltage can also cause an electric shock hazard for the operator. National Instruments is NOT liable for damage or injury resulting from such misuse.

A three-resistor circuit for attenuating voltages at the differential inputs of the AMUX-64T board is shown in Figure 4-7. The figure also shows the placement of the resistors on the open component positions for differential Channel 1. The gain $G$ of this attenuator is given by the following formula:

$$G = \frac{R_G}{(R_E + R_F + R_G)}$$  \hspace{1cm} (Formula 4-3)

Therefore, the input to the MIO board ($V_{MIO}$) is

$$V_{MIO} = V_{SC} \cdot G$$

where $V_{SC}$ is the voltage applied to the screw terminals of the AMUX-64T. The accuracy of this gain equation depends on the tolerances of the resistors used.

![Input Schematic](image)

Figure 4-7. Attenuator for Use with Differential Inputs
Example:

Using the values in Figure 4-7,

\[
G = \frac{10 \, k\Omega}{(10 \, k\Omega + 10 \, k\Omega + 10 \, k\Omega)} = \frac{1}{3}
\]

Therefore,

\[
V_{\text{MIO}} = \frac{1}{3} V_{\text{SC}}
\]

When the MIO board is configured for ±10 V inputs, the board can acquire ±30 V signals with this attenuator circuit.
Chapter 5
Theory of Operation and
Register-Level Programming

This chapter contains a functional overview of the AMUX-64T and explains the operation of each functional unit making up the AMUX-64T. This chapter also contains register-level programming information for the MIO board.

Note: If you plan to use a software package such as LabWindows, NI-DAQ, or LabVIEW with your MIO board, you need not read this chapter.

Functional Overview

Figure 5-1 shows the block diagram of the AMUX-64T. The AMUX-64T contains 16 CMOS four-to-one analog multiplexers for a total of 64 channels. Each analog multiplexer expands a single MIO analog input channel to four AMUX-64T analog input channels.
The AMUX-64T multiplexers are controlled by a 4-bit scanning counter that is loaded via the 4-bit digital I/O port A of the MIO board. The MIO signal EXTSTROBE* loads the value at digital I/O port A into the AMUX-64T scanning counter. The MIO signal SCANCLK, which is active during scanned data acquisition, switches the input channels automatically on the AMUX-64T after each A/D conversion.
The DIP switch attached to the scanning counter configures the AMUX-64T for one-board, two-board, or four-board operation. Individual AMUX-64T boards are selected depending on the higher-order two bits of the scanning counter.

The AMUX-64T contains an onboard switch to either power the AMUX-64T from the MIO board or to supply +5 V externally. From the +5V power, an onboard DC-to-DC converter generates a ±15 V source, which is used to power the multiplexers. The MIO board can supply enough +5 V power to drive up to four AMUX-64T boards except the MC-MIO-16, which can power only two boards.

**How to Address AMUX-64T Analog Input Channels**

**A/D Conversions on a Single AMUX-64T Analog Input Channel**

Before an AMUX-64T channel can be selected, digital I/O port A must be enabled as a digital output port. You can enable this port by setting the DOUTEN0 bit in the MIO Command Register 2 (this bit has different names depending on your MIO board). This bit needs to be set only once after initializing the MIO board.

The scanning counter is used to select individual multiplexer inputs and individual AMUX-64T boards. The bit assignment for the scanning counter and MIO board digital I/O port A is shown in Figure 5-2.

![Figure 5-2. Scanning Counter Control Bits](image)

These Digital Output Register bits are loaded into the Scanning Counter and used to select AMUX-64T channels.

Channel Select

Board Select

© National Instruments Corporation 5-3 AMUX-64T User Manual
Bits ADO0 and ADO1 address each four-to-one multiplexer on the AMUX-64T and work in combination with the MIO Mux-Gain Register (the Mux-Mem Register in the AT-MIO-16F-5) to select the analog input channel. An address map for selecting analog input channels on a single AMUX-64T is shown in Table 5-1.

Table 5-1. AMUX-64T Channel Selection

<table>
<thead>
<tr>
<th>Channel Number</th>
<th>Mux-Gain Register MA&lt;3..0&gt;</th>
<th>Digital Port A Bits ADO&lt;1..0&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0000</td>
<td>00</td>
</tr>
<tr>
<td>1</td>
<td>0000</td>
<td>01</td>
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<td>0001</td>
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<td>62</td>
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<td>11</td>
</tr>
<tr>
<td>63</td>
<td>1111</td>
<td>11</td>
</tr>
</tbody>
</table>

Bits ADO2 and ADO3 select each individual AMUX-64T board in a multiple-board configuration. If you use only one AMUX-64T board, ADO2 and ADO3 are ignored. If you use two AMUX-64T boards, only ADO2 is used. An address map for the different channel groups is shown in Table 5-2.
Table 5-2. Multiple AMUX-64T Board Addressing

<table>
<thead>
<tr>
<th>Digital Port A Bits ADO&lt;3..2&gt;</th>
<th>Board Selected</th>
<th>Channels Selected</th>
</tr>
</thead>
<tbody>
<tr>
<td>00</td>
<td>A</td>
<td>0–63</td>
</tr>
<tr>
<td>01</td>
<td>B</td>
<td>64–127</td>
</tr>
<tr>
<td>10</td>
<td>C</td>
<td>128–191</td>
</tr>
<tr>
<td>11</td>
<td>D</td>
<td>192–255</td>
</tr>
</tbody>
</table>

Observe that channels on a single AMUX-64T are labeled 0 through 63. If you use more than one AMUX-64T board, however, channel numbering changes (see Table 5-2).

When you use four AMUX-64T boards with channel addresses ranging from 0 to 255, eight bits are required to address any single channel. This 8-bit address must be split and written to the Digital Output Register and the Mux-Gain Register (the Mux-Mem Register in the AT-MIO-16F-5). Figure 5-3 shows the mapping of the 8-bit channel address to the Digital Output and Mux-Gain Registers. To select a given channel, write the two least significant bits to bits ADO0 and ADO1 of digital I/O port A, the four middle bits to bits MA<3..0> of the Mux-Gain Register, and the two most significant bits to bits ADO3 and ADO2 of digital I/O port A. Notice that for differential operation, bit MA3, which corresponds to bit 5 of the channel address, becomes a don't care bit. This occurs because only eight multiplexers are used for differential operation.

Figure 5-3. AMUX-64T Channel Address Mapping
To perform an A/D conversion on a single AMUX-64T channel, perform the following programming steps:

1. Select an analog input channel on the AMUX-64T by writing the appropriate channel address bits to digital I/O port A (bits 0 through 3 of the Digital Output Register).

2. Write to the External Strobe Register to load the channel address into the AMUX-64T scanning counter.

3. Write to the MA<3..0> bits in the Mux-Gain Register to select the four-to-one multiplexer on the AMUX-64T you want to address.

Now follow the normal procedure for performing a single A/D conversion or multiple A/D conversions on a single input channel of the MIO board with one exception—the bits MA<3..0> of the Mux-Gain Register must correspond to the middle four bits of your channel address shown in Figure 5-3.

**Automatic Channel Scanning with the AMUX-64T**

Automatic scanning of the AMUX-64T analog input channels is performed by the scanning counters on the AMUX-64T and the MIO board. Scanning operations on the MIO board are controlled by the mux-gain memory, which holds a sequence of multiplexer addresses. After each A/D conversion, the mux-gain memory switches to the next multiplexer input in the sequence. When the MIO board is used alone, a single-level multiplexer switches the 16 input channels to the analog-to-digital converter (ADC). A two-level multiplexer must be controlled when an AMUX-64T board is connected to the MIO board. The AMUX-64T switches 64 inputs down to 16 outputs, and the MIO board switches 16 inputs down to 1 output going to the ADC, as shown in Figure 5-4.
When operating stand-alone, the MIO board selects a new input channel after each A/D conversion. A clock signal, SCANCLK, is generated by the MIO board and starts each A/D conversion on the rising edge of the signal. This clock also increments the onboard scanning counter. When a single AMUX-64T board is connected to the MIO board, four AMUX-64T input channels must be scanned for every MIO board channel. SCANCLK increments the AMUX-64T scanning counter on every A/D conversion, and Counter 1 on the MIO board must be used to divide the onboard scanning counter clock by 4. The *Single-Board Configuration* section of Figure 5-5 shows the scanning order for the four AMUX-64T channels multiplexed to MIO board channel 0.

If two AMUX-64T boards are attached to the MIO board, then eight AMUX-64T channels must be scanned for every MIO board input channel. For example, channels 0 through 3 on AMUX-64T board A and channels 64 through 67 on AMUX-64T board B are multiplexed together into MIO board channel 0. The *Two-Board Configuration* section of Figure 5-5 shows the order in which these eight AMUX-64T channels are scanned. Observe that the first four channels on board A are scanned first, followed by the first four channels on board B.

If four AMUX-64T boards are attached to the MIO board, then 16 AMUX-64T channels must be scanned for every MIO board input channel. For example, channels 0 through 3 on AMUX-64T board A, channels 64 through 67 on AMUX-64T board B, channels 128 through 131 on AMUX-64T board C, and channels 192 through 195 on board D are multiplexed together into MIO board channel 0. The *Four-Board Configuration* section of Figure 5-5 shows the order in which these 16 AMUX-64T channels are scanned: the first four channels on board A are...
scanned first, followed by the first four channels on board B, the first four channels on board C, and finally the first four channels on board D.

Figure 5-5. Scanning Order for Different AMUX-64T Board Configurations
Scanning Order

The order in which channels are scanned depends on the contents of the mux-gain memory. The mux-gain memory on the MIO board can be loaded with a sequence to scan the MIO onboard channels in any order. Figure 5-5 shows the scanning order on the AMUX-64T. Table 5-3 shows the order in which the AMUX-64T channels are scanned for every MIO board input channel for different AMUX-64T configurations. Observe that channels 0 through 15 of the MIO board are used for a single-ended input configuration, but only channels 0 through 7 are used for a differential input configuration.

Table 5-3. AMUX-64T Scanning Order for Each MIO Board Input Channel

<table>
<thead>
<tr>
<th>MIO Board</th>
<th>One Board</th>
<th>Two Boards</th>
<th>Four Boards</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Board A</td>
<td>Board B</td>
<td>Board A</td>
</tr>
<tr>
<td>0</td>
<td>0–3</td>
<td>0–3</td>
<td>64–67</td>
</tr>
<tr>
<td>2</td>
<td>8–11</td>
<td>8–11</td>
<td>72–75</td>
</tr>
<tr>
<td>3</td>
<td>12–15</td>
<td>12–15</td>
<td>76–79</td>
</tr>
<tr>
<td>5</td>
<td>20–23</td>
<td>20–23</td>
<td>84–87</td>
</tr>
</tbody>
</table>

For example, if one AMUX-64T board is used, channels 0 through 3 on the AMUX-64T are automatically scanned whenever channel 0 on the MIO board is selected in the scan sequence. If two AMUX-64T boards are used, channels 0 through 3 (board A) and channels 64 through 67 (board B) are automatically scanned. If four AMUX-64T boards are used, channels 0 through 3 (board A), channels 64 through 67 (board B), channels 128 through 131 (board C), and channels 192 through 195 (board D) are automatically scanned.
If the MIO board is programmed with a sequential channel scan sequence (0 through 7 or 0 through 15) the AMUX-64T channels are scanned from top to bottom in the order given in Table 5-3.

If only one AMUX-64T board is used, the channels are scanned in the order 0 through 63 for single-ended configuration. The scanning order becomes complex only when more than one AMUX-64T board is used.

During interval scanning, the number of channels scanned during an interval is four times the channel scan sequence for one AMUX-64T board, eight times for two AMUX-64T boards, and sixteen times for four AMUX-64T boards.

### Programming Channel Scanning with the AMUX-64T

To program the MIO board to conduct a scanning operation with the AMUX-64T, the following steps must be added to the instructions for programming multiple A/D conversions with channel scanning given in Chapter 4 of the user manual that came with your MIO board. These steps can be added any time before initiating the A/D conversions.

#### Initialize the AMUX-64T Scanning Counter

The DOUTEN0 bit in the MIO board Command Register 2 (this bit has different names depending on your MIO board) must be set in order to load the AMUX-64T scanning counter.

To initialize the AMUX-64T scanning counter, use the following programming sequence:

1. Write 0 to digital I/O port A.
2. Write to the External Strobe Register to load 0 into the AMUX-64T scanning counter.

#### Configure Counter 1 to Control the MIO Board Scanning Clock

Counter 1 on the MIO board is used to divide the onboard scanning clock controlling the scanning counter so that the onboard multiplexers switch at a slower rate than the AMUX-64T multiplexers. To program counter 1, use the following programming sequence. All operations are 16-bit write operations. All values given are hexadecimal.

- Write FF01 to the Am9513 Command Register to select the Counter 1 Mode Register.
- Write 0325 (hex) to the Am9513 Data Register to store the Counter 1 mode value.
- Write FF09 to the Am9513 Command Register to select the Counter 1 Load Register.
• Write the divide-down value to the Am9513 Data Register to load counter 4. The divide-down values are as follows:
  – One AMUX-64T board: 4 (hex)
  – Two AMUX-64T boards: 8 (hex)
  – Four AMUX-64T boards: 10 (hex)

• Write FF41 to the Am9513 Command Register to load counter 1.

• Write FFF1 to the Am9513 Command Register to step counter 1.

• Write FF21 to the Am9513 Command Register to arm counter 1.

After you apply this programming sequence, counter 1 is configured to divide-down SCANCLK during A/D conversions.

Set the SCANDIV Bit in MIO Command Register 1

To enable SCANCLK division, set the SCANDIV bit in Command Register 1.

After this programming sequence, the analog inputs on the AMUX-64T are automatically scanned during MIO-scanned A/D conversion operations.
Appendix A
Specifications

This appendix lists the specifications of the AMUX-64T. These specifications are typical at 25°C unless otherwise noted.

Analog Input

Input Characteristics

Number of channels
- Single board ..........................................................64 single-ended or 32 differential
- Two boards............................................................128 single-ended or 64 differential
- Four boards connected ..........................................256 single-ended or 128 differential

Input signal ranges ...................................................... .
- Differential analog ................................................
  - ±10 V, ±5 V, 0 to 10 V (selectable on MIO board)

Max working voltage
- (signal + common mode) ......................................Each input should remain within ±12 V of ground
  - ±20 V powered on
  - ±35 V powered off

On resistance ..........................................................2 kΩ

AMUX-64T Settling Times to 12-Bit Precision

Settling time to ±0.5 LSB, 12-bit precision in μs

<table>
<thead>
<tr>
<th>Gain</th>
<th>One AMUX-64T Board</th>
<th>Two AMUX-64T Boards</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>AT-MIO-16E-2</td>
<td>AT-MIO-16E-10</td>
</tr>
<tr>
<td>±FS</td>
<td>0 to +FS</td>
<td>±FS</td>
</tr>
<tr>
<td>.5</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>1</td>
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<td>3</td>
</tr>
<tr>
<td>2</td>
<td>5</td>
<td>3</td>
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<tr>
<td>5</td>
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<td>20</td>
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</tr>
<tr>
<td>100</td>
<td>9</td>
<td>8</td>
</tr>
<tr>
<td>500</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Gain</th>
<th>AT-MIO-16E-2</th>
<th>AT-MIO-16E-10</th>
<th>NB-MIO-16</th>
</tr>
</thead>
<tbody>
<tr>
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<td>±FS</td>
<td>0 to +FS</td>
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<tr>
<td>.5</td>
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</tbody>
</table>
### Four AMUX-64T Boards

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<thead>
<tr>
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<th>AT-MIO-16E-2</th>
<th>AT-MIO-16E-10</th>
<th>NB-MIO-16</th>
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<tr>
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<td>—</td>
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<tr>
<td>500</td>
<td>—</td>
<td>—</td>
<td>110</td>
</tr>
</tbody>
</table>

### Cold-Junction Sensor

Jumper selectable on differential channel 0
- **Output** ................................................................. 10 mV/°C
- **Accuracy** .............................................................. ±1.0° C from 0 to 110° C

### Power Requirement

From computer through MIO board or external power
- +5 VDC (±5%) ............................................................... 78 mA typ

### Physical

- **Dimensions** .......................................................... 12.75 by 3.80 in (32.43 by 9.65 cm)
- **I/O connector** ...................................................... Two 50-pin male ribbon-cable connectors, one 68-pin male shielded or ribbon-cable connector
  - 78-screw terminals

### Environment

- **Operating temperature** ............................................ 0° to 70° C
- **Storage temperature** ................................................ -55° to 150° C
- **Relative humidity** .................................................. 5% to 90% noncondensing
Appendix B
Customer Communication

For your convenience, this appendix contains forms to help you gather the information necessary to help us solve technical problems you might have as well as a form you can use to comment on the product documentation. Filling out a copy of the Technical Support Form before contacting National Instruments helps us help you better and faster.

National Instruments provides comprehensive technical assistance around the world. In the U.S. and Canada, applications engineers are available Monday through Friday from 8:00 a.m. to 6:00 p.m. (central time). In other countries, contact the nearest branch office. You may fax questions to us at any time.

Corporate Headquarters
(512) 795-8248
Technical support fax: (800) 328-2203
(512) 794-5678

<table>
<thead>
<tr>
<th>Branch Offices</th>
<th>Phone Number</th>
<th>Fax Number</th>
</tr>
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<tr>
<td>Australia</td>
<td>(03) 879 9422</td>
<td>(03) 879 9179</td>
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<tr>
<td>Austria</td>
<td>(0662) 435986</td>
<td>(0662) 437010-19</td>
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<td>02/757.03.11</td>
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<td>32-848400</td>
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<td>08-730 43 70</td>
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<td>056/20 51 55</td>
</tr>
<tr>
<td>U.K.</td>
<td>0635 523545</td>
<td>0635 523154</td>
</tr>
</tbody>
</table>
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  
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 will reproduce the problem  

AMUX-64T 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

- DAQ Hardware
- Number of Boards
- Power source

### Other Products

- MIO Board
- Computer Make and Model
- Programming Language
- Programming Language Version
- Other Boards in System
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Part Number: 320253B-01

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## Glossary

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<th>Prefix</th>
<th>Meaning</th>
<th>Value</th>
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<tr>
<td>p-</td>
<td>pico-</td>
<td>$10^{-12}$</td>
</tr>
<tr>
<td>n-</td>
<td>nano-</td>
<td>$10^{-9}$</td>
</tr>
<tr>
<td>µ-</td>
<td>micro-</td>
<td>$10^{-6}$</td>
</tr>
<tr>
<td>m-</td>
<td>milli-</td>
<td>$10^{-3}$</td>
</tr>
<tr>
<td>k-</td>
<td>kilo-</td>
<td>$10^3$</td>
</tr>
<tr>
<td>M-</td>
<td>mega-</td>
<td>$10^6$</td>
</tr>
</tbody>
</table>

° degrees
> greater than
≥ greater than or equal to
< less than
- negative of, or minus
Ω ohms
% percent
± plus or minus
+ positive of, or plus
+5 V +5 Volts signal
A amperes
ACH <0..7> Analog Channel 0 through 7 signals
ACK* Acknowledge Input signal
A/D analog-to-digital
ADC analog-to-digital converter
AGND Analog Ground signal
AISENSE/AIGND Analog Input Sense/Analog Input Ground signal
ANSI American National Standards Institute
AWG American Wire Gauge
C Celsius
CLKB1, CLKB2 Counter B1, B2 Clock signals
cm centimeters
CMOS complementary metallic oxide semiconductor
CNTINT Counter Interrupt signal
D/A digital-to-analog
D*/A Data/Address signal
DAC digital-to-analog converter
DAC OUTPUT UPDATE DAC output update signal
DACWRT DAC Write signal
DAQ data acquisition
DAQD*/A Data Acquisition Board Data/Address Line signal
DAC0OUT, DAC1OUT Digital-to-Analog Converter 0, 1 Output signals
DATA Data Lines at the Specified Port signal
dB decibels
<table>
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<th>Description</th>
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</thead>
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<td>DC</td>
<td>direct current</td>
</tr>
<tr>
<td>DGND</td>
<td>Digital Ground signal</td>
</tr>
<tr>
<td>DIFF</td>
<td>differential</td>
</tr>
<tr>
<td>DIN</td>
<td>Deutsche Industrie Norme</td>
</tr>
<tr>
<td>DIP</td>
<td>dual-inline package</td>
</tr>
<tr>
<td>DMA</td>
<td>direct memory access</td>
</tr>
<tr>
<td>EEPROM</td>
<td>electrically erased programmable read-only memory</td>
</tr>
<tr>
<td>EPP</td>
<td>Enhanced Parallel Port</td>
</tr>
<tr>
<td>EXTCONV*</td>
<td>External Convert signal</td>
</tr>
<tr>
<td>EXTTRIG</td>
<td>External Trigger signal</td>
</tr>
<tr>
<td>EXTUPDATE*</td>
<td>External Update signal</td>
</tr>
<tr>
<td>ft</td>
<td>feet</td>
</tr>
<tr>
<td>GATB &lt;0..2&gt;</td>
<td>Counter B0, B1, B2 Gate signals</td>
</tr>
<tr>
<td>hex</td>
<td>hexadecimal</td>
</tr>
<tr>
<td>IBF</td>
<td>Input Buffer Full signal</td>
</tr>
<tr>
<td>in.</td>
<td>inches</td>
</tr>
<tr>
<td>INTR</td>
<td>Interrupt Request signal</td>
</tr>
<tr>
<td>I/O</td>
<td>input/output</td>
</tr>
<tr>
<td>LED</td>
<td>light-emitting diode</td>
</tr>
<tr>
<td>LSB</td>
<td>least significant bit</td>
</tr>
<tr>
<td>m</td>
<td>meters</td>
</tr>
<tr>
<td>max</td>
<td>maximum</td>
</tr>
<tr>
<td>MB</td>
<td>megabytes of memory</td>
</tr>
<tr>
<td>min</td>
<td>minutes</td>
</tr>
<tr>
<td>MIO</td>
<td>multifunction I/O</td>
</tr>
<tr>
<td>MSB</td>
<td>most significant bit</td>
</tr>
<tr>
<td>NRSE</td>
<td>nonreferenced single-ended</td>
</tr>
<tr>
<td>OBF*</td>
<td>Output Buffer Full signal</td>
</tr>
<tr>
<td>OUTB0, OUTB1</td>
<td>Counter B0, B1 Output signals</td>
</tr>
<tr>
<td>PA, PB, PC &lt;0..7&gt;</td>
<td>Port A, B, or C 0 through 7 signals</td>
</tr>
<tr>
<td>POSTTRIG</td>
<td>Posttrigger mode</td>
</tr>
<tr>
<td>PRETRIG</td>
<td>Pretrigger mode</td>
</tr>
<tr>
<td>RC</td>
<td>resistance-capacitance</td>
</tr>
<tr>
<td>RD*</td>
<td>Read signal</td>
</tr>
<tr>
<td>R&lt;sub&gt;EXT&lt;/sub&gt;</td>
<td>external resistance</td>
</tr>
<tr>
<td>RSE</td>
<td>referenced single-ended</td>
</tr>
<tr>
<td>RTSI</td>
<td>Real-Time System Integration</td>
</tr>
<tr>
<td>s</td>
<td>seconds</td>
</tr>
<tr>
<td>SCXI</td>
<td>Signal Conditioning eXtensions for Instrumentation (bus)</td>
</tr>
<tr>
<td>SDK</td>
<td>Software Developer's Kit</td>
</tr>
<tr>
<td>SERCLK</td>
<td>Serial Clock signal</td>
</tr>
<tr>
<td>SERDATIN</td>
<td>Serial Data In signal</td>
</tr>
<tr>
<td>SERDATOUT</td>
<td>Serial Data Out signal</td>
</tr>
<tr>
<td>SLOT0SEL*</td>
<td>Slot 0 Select signal</td>
</tr>
<tr>
<td>SPICLK</td>
<td>Serial Peripheral Interface Clock signal</td>
</tr>
<tr>
<td>SS*</td>
<td>Slot-select signal</td>
</tr>
<tr>
<td>STB</td>
<td>Strobe Input signal</td>
</tr>
<tr>
<td>TTL</td>
<td>transistor-transistor logic</td>
</tr>
<tr>
<td>typ</td>
<td>typical</td>
</tr>
<tr>
<td>Symbol</td>
<td>Definition</td>
</tr>
<tr>
<td>---------</td>
<td>-----------------------------------------------------</td>
</tr>
<tr>
<td>UP/BP*</td>
<td>Unipolar/bipolar bit</td>
</tr>
<tr>
<td>V</td>
<td>volts</td>
</tr>
<tr>
<td>V±_in</td>
<td>positive/negative input voltage</td>
</tr>
<tr>
<td>V_cm</td>
<td>common-mode noise</td>
</tr>
<tr>
<td>V_diff</td>
<td>differential input voltage</td>
</tr>
<tr>
<td>V_DC</td>
<td>volts direct current</td>
</tr>
<tr>
<td>V_EXT</td>
<td>external voltage</td>
</tr>
<tr>
<td>VI</td>
<td>virtual instrument</td>
</tr>
<tr>
<td>V_m</td>
<td>measured voltage</td>
</tr>
<tr>
<td>V_rms</td>
<td>volts, root-mean-square</td>
</tr>
<tr>
<td>V_s</td>
<td>signal source</td>
</tr>
<tr>
<td>W</td>
<td>watts</td>
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